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THE ROYAL SOCIETY OF NEW SOUTH WALES

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Some Mesozoic Igneous Rocks from Northeastern New South Wales and their Tectonic Setting

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ABSTRACT. K-Ar ages, mineralogy and petrology of a group of volcanic and subvolcanic rocks from northeastern New South Wales is reported. They range in age from Late Permian (250 ±10 million years, or Ma) to Early Cretaceous (108 ±4 Ma) and comprise a basanite, a variety of basalts and two nepheline normative microsyenites. To develop a model that can account for their origin and evolution, the Permian and Mesozoic magmatic history of eastern Australia is evaluated. From the Early Permian to the end of the Early Cretaceous the magmatic history of New South Wales was frequently interlinked with the evolution of the linear tectonic feature that become the Sydney-Gunnedah- Bowen Basin System. During the Late Cretaceous the magmatic and tectonic history of New South Wales was dominated by the processes of rifting and drifting that led to sea-floor spreading in the Tasman Basin.

For most of the Early Permian a magmatic focus was located beneath the proto- Sydney- Gunnedah-Bowen Basin System. It produced an extensive belt of volcanoes that extruded a diverse range of products. The next major magmatic epoch was active during the Late Permian and Early Triassic. It produced extensive silicic magmatism in New England and northwards into Queensland. In the Sydney and Gunnedah basins high-K basanitic, basaltic, trachybasaltic, shoshonitic and latitic materials erupted. Throughout the Mid to Late Triassic large volumes of andesitic, dacitic and rhyolitic rocks were extruded in southeastern Queensland. During the Early to Mid Jurassic more alkaline magma was introduced into the Sydney- Gunnedah- Bowen Basin System and elsewhere in eastern Australia. This magmatic epoch includes the eruption of the Garrawilla Volcanics in the Gunnedah Basin, and a variety of alkaline diatremes and intrusives in the central and northwestern parts of the Sydney Basin. Throughout the Jurassic and Cretaceous small volumes of basanitic/basaltic magma erupted in the Sydney Basin. In the Early Cretaceous there was renewed calc-alkali activity along a volcanic chain that extended from Bowen via Rockhampton and then on to the Lord Howe Rise. At the beginning of the Late Cretaceous the rifting and separation of the Lord Howe Rise / New Zealand plate from eastern Australia shifted the major magmatic focus to beneath the zone of active spreading. Rifting triggered the eruption of the alkaline volcanic and plutonic rocks in the Mt Dromedary cluster of ring complexes and led to changes in the pattern of sublithospheric convection. These processes gave rise to the Eastern Highlands which became a new locus for widespread intraplate volcanism.

INTRODUCTION

In an earlier paper the authors (Dulhunty et al., 1987) examined and discussed the age, geochemistry and petrology of twelve Mesozoic igneous rocks from northeastern New South Wales. The present paper augments this earlier study and uses these data to evaluate Mesozoic magmatism in the state. Eastern New South Wales contains many outcrops of Mesozoic igneous rocks, however most are small, and the rocks themselves usually lack petrographic characteristics that are distinctive enough to tie them to a specific magmatic epoch. These observations are readily substantiated if one examines the igneous rocks of the Coonabarabran- Mullaley area. Their petrography is similar (Wilshire and Standard, 1963, p. 123), yet they range in age from Early Jurassic to Miocene (Bean, 1974; Dulhunty, 1967). Two of the rocks examined in the present study (Samples K49 & K51) show that the magmatic history of this area is even more ravelled than previously recognised. Embleton et al. (1985, p. 62) have described sporadic igneous activity in New South Wales from the Late Permian to the middle of the Miocene, with activity maxima at 255-240 Ma, 200-170 Ma and 60-30 Ma. These data indicate that both the upper (65 Ma) and lower (245 Ma) boundaries (Harland et al., 1990, p. 12) of the Mesozoic occur in the middle of epochs of enhanced magmatic activity. Many more radiometric age determinations are required if the many, scattered, outcrops of Mesozoic igneous rocks are to be identified and grouped into comagmatic suites. This need is eloquently demonstrated in Henley's (1991, pp. 12-17) paper on the lamprophyres of New England. He reveals that only two of the many rocks he describes have been dated, and both of them are Mesozoic in age. To assign the various post- Carboniferous igneous rocks of eastern New South Wales to specific magmatic epochs, and develop models that chronicle their origin and evolution, one has not only to determine their age and petrographic characteristics, one has also to consider their petrogenesis in relation to a broader tectonic framework. At the beginning of the Mesozoic Era Australia was enclosed within the supercontinent of Pangaea, yet by the end of this era Australia had drifted from (a) Greater India, (b) the Lord Howe Rise / New Zealand and (c) Antarctica; and there was also active sea-floor spreading in the Coral Sea.

METHODS

Field investigations were carried out by Dulhunty. Petrological research and electron microprobe studies were undertaken by Middlemost using the equipment of the Electron Microscope Unit in the University of Sydney. Whole-rock major element analyses were carried out for Beck in the XRF laboratory in the Department of Applied Geology at the University of New South Wales using a Siemens SRS300 sequential XRF with a rhodium end window tube. Sample preparation and analysis followed the methods of Norrish and Hutton (1969). Potassium- argon dating was performed by Geochron Laboratories, Cambridge, U.S.A. Table 1 gives the

Table 1 : K-Ar analytical data and calculated rock ages

Spec. No	Wt.% K	Ave.% K	40K, ppm	40*Ar, ppm	40*Ar/ Tot.40Ar	Ave. 40*Ar, ppm	40*Ar/40K	Age in Ma
K46	0.941 0.875 0.898	0.905	1.079	0.014750 0.147000	0.654 0.873	0.014730	0.013640	221±9
K47	0.387 0.457 0.411	0.418	0.499	0.003265 0.003358	0.257 0.457	0.003312	0.006635	111±5
K49	5.721 5.832	5.777	6.891	0.048470 0.049270	0.850 0.845	0.048870	0.007091	118±4
K51	5.822 5.704	5.763	6.875	0.044130 0.045070	0.835 0.868	0.044600	0.006487	108±4
K52	1.275 1.411 1.333	1.340	1.598	0.025240 0.024630	0.901 0.816	0.024940	0.015600	250±10
K53	0.549 0.565	0.557	0.665	0.009793 0.102900	0.657 0.630	0.010041	0.015110	243±10
K55	0.779 0.760	0.770	0.918	0.010350 0.010980	0.526 0.807	0.010670	0.011620	190±8

Constants used: $\lambda_\beta = 4.962 \times 10^{-10}$/ year : $(\lambda_e + \lambda_{e'}) = 0.581 \times 10^{-10}$/ year : $^{40}K/K = 1.193 \times 10^{-4}$g/g. $^{40*}Ar$ refers to radiogenic ^{40}Ar.

potassium- argon analytical data and calculated rock ages; whereas Tables 2 and 3 give the major element compositions and CIPW norms of the rocks. Tables 4 to 6 show electron microprobe analyses of the essential minerals.

PETROGRAPHY AND MINERALOGY

As there is only a limited amount of quantitative geochemical mineralogical and petrographic data available on the Mesozoic volcanic and subvolcanic rocks of northeastern New South Wales, the aim of the following section is to help to rectify this deficiency. According to the TAS chemical classification of volcanic rocks the samples examined consist of one basanite (K47) that contains 14.3 % normative olivine and 13.5 % normative nepheline; an alkali basalt (K53) that contain 8.1 % normative nepheline and 20.1 % normative olivine; three olivine tholeiitic basalts (K46, K52 & K55) that contain both normative olivine and normative hypersthene; and two microsyenites (K49 and K51) that contain small amounts of normative nepheline, that is, 2.8 % and 4.0 %, respectively (Figure 1).

SAMPLE K46 is an olivine and hypersthene normative basalt that was collected 9 km southeast of Gilgandra

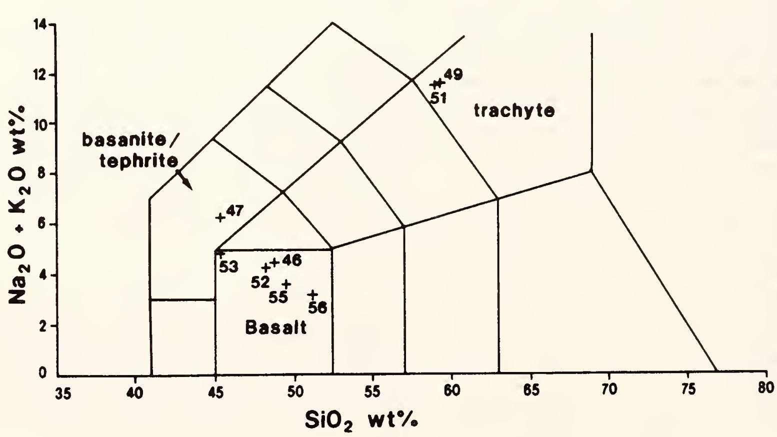

Figure 1 A total alkali - silica diagram used to classify the rocks studied (after Le Maitre et al. 1989, p. 28)

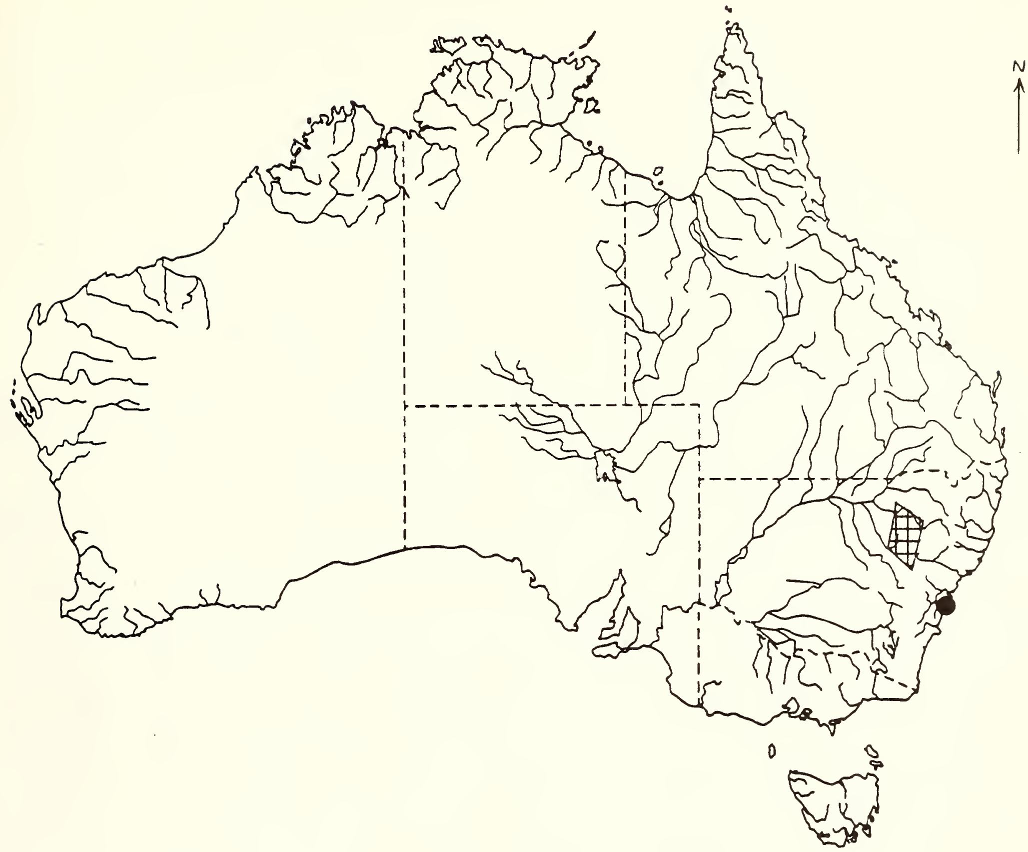

Figure 2 All samples were collected within the cross-hatched area of New South Wales

on the Gilgandra- Mendooran road (Latitude 31.75° South, Longitude 148.77° East; Gilgandra 1: 250 000 Sheet). This Late Triassic (221 ± 9 Ma: See Table 1) rock is medium grained holocrystalline and all the essential phases are approximately the same size. Essential minerals are plagioclase, which usually occurs in elongate crystals (~50 vol.%), clinopyroxene, slightly smaller in size and pink in colour (~25 vol.%), and olivine that is usually euhedral but partly altered to goethite, haematite, chlorite and antigorite (~15 vol.%). The accessory minerals include opaque oxides (titanomagnetite and ilmenite) and/or sulphides (~5 vol.%) and occasional small aggregate of irregular shaped alkali feldspars (~5 vol.%). The mean composition of the olivine crystals is $Fo_{67.9}$, and they ranged in composition from $Fo_{63.5}$ to $Fo_{70.3}$. Generally the cores of the larger crystals are enriched in magnesium. Table 4 shows that the mean MnO composition of these olivines is 0.46%, their mean NiO content is ~0.15%, whereas their mean Cr_2O_3 content is ~0.03%. The pyroxene is diopside. It has a mean composition of $En_{40.3}$ $Fs_{12.9}$ $Wo_{46.8}$ and a range of $En_{41.6}$ $Fs_{11.2}$ $Wo_{47.2}$ to $En_{37.4}$ $Fs_{15.7}$ $Wo_{46.9}$. The non-quadrilateral components have the following mean abundances: TiO_2 = 4.65%, Al_2O_3 = 3.52%, Na_2O = 0.57% and Cr_2O_3 = 0.14%. The mean composition of the plagioclase is $An_{58.8}$ $Ab_{39.3}$ $Or_{1.9}$, and its range is from labradorite $An_{64.7}$ $Ab_{33.7}$ $Or_{1.6}$ to andesine $An_{47.8}$ $Ab_{48.9}$ $Or_{3.3}$. These plagioclases have a mean Fe_2O_3 content of 0.64% and no BaO was detected.

SAMPLE K47 is a basanite that contains 14.3 % normative olivine and 13.5 % normative nepheline. It is an Early Cretaceous (111 ± 5 Ma: See Table 1) rock that was collected from Mullamuddy Creek near Queen's Pinch, 20 km south of Mudgee (Latitude 32.72° South, Longitude 149.63° East; Dubbo 1: 250 000 Sheet). It has a porphyritic to vitrophyric texture as it contains many large euhedral and/or zoned olivine phenocrysts (~15 vol.%), with a few purplish-pink, zoned clinopyroxene phenocrysts set in a groundmass of fine-grained clinopyroxene (~25 vol.% cpx), plagioclase (~25 vol.%), opaque oxides (~8 vol.%) and irregular patches of fine-grained alkali feldspar and brownish-pink glass (~27 vol.%). The mean composition of the olivine crystals is $Fo_{81.7}$, and they ranged in composition from $Fo_{78.1}$ to $Fo_{83.2}$. Table 4 shows that the mean MnO composition of these olivines is 0.27%, their mean NiO content is ~0.24%, and their mean Cr_2O_3 content is ~0.05%. The

Table 2 Chemical Composition of Mesozoic Rocks of N.E. New South Wales

No	K.46	K.46*	K.47	K.47*	K.49	K.49*	K.51	K.51*
SiO_2	46.82	48.73	41.48	45.37	56.89	59.19	55.66	58.95
TiO_2	2.02	2.10	2.31	2.53	0.64	0.67	0.61	0.65
Al_2O_3	14.68	15.28	12.73	13.92	17.55	18.26	17.41	18.44
Fe_2O_3	1.82	1.89	2.69	2.94	2.25	2.34	2.25	2.38
FeO	9.11	9.48	8.98	9.82	4.49	4.67	4.49	4.76
MnO	0.16	0.17	0.22	0.24	0.18	0.19	0.18	0.19
MgO	8.55	8.90	7.32	8.01	0.53	0.55	0.45	0.48
CaO	8.21	8.54	9.17	10.03	2.34	2.43	2.39	2.53
Na_2O	2.98	3.10	4.09	4.47	5.73	5.96	6.03	6.39
K_2O	1.27	1.32	1.58	1.73	5.28	5.49	4.72	5.00
P_2O_5	0.47	0.49	0.86	0.94	0.24	0.25	0.23	0.24
LOI	(1.65)		(5.65)		(2.90)		(3.23)	
Total	96.09	100.00	91.43	100.00	96.12	100.00	94.42	100.00

No	K.52	K.52*	K.53	K.53*	K.55	K.55*	K.56	K.56*
SiO_2	46.03	48.25	43.56	45.39	46.15	49.43	49.35	51.22
TiO^2	2.18	2.29	2.57	2.68	2.01	2.15	1.43	1.48
Al_2O_3	12.99	13.62	12.89	13.43	13.45	14.41	14.38	14.92
Fe_2O_3	1.83	1.92	2.16	2.25	1.82	1.95	1.81	1.88
FeO	9.17	9.61	10.82	11.28	9.11	9.76	9.02	9.36
MnO	0.16	0.17	0.18	0.19	0.17	0.18	0.16	0.17
MgO	10.08	10.57	9.09	9.47	9.52	10.20	7.93	8.23
CaO	8.33	8.73	9.39	9.79	7.79	8.34	9.06	9.40
Na_2O	2.49	2.61	3.60	3.75	2.39	2.56	2.71	2.81
K_2O	1.50	1.57	1.01	1.05	0.91	0.97	0.31	0.32
P_2O_5	0.64	0.67	0.69	0.72	0.04	0.04	0.19	0.20
LOI	(1.76)		(0.87)		(3.65)		(1.07)	
Total	95.40	100.00	95.96	100.00	93.36	100.00	96.35	100.00

pyroxene is diopside. It has a mean composition of $En_{37.2}$ $Fs_{15.0}$ $Wo_{47.8}$ and a range of $En_{38.9}$ $Fs_{13.0}$ $Wo_{48.1}$ to $En_{34.5}$ $Fs_{16.7}$ $Wo_{48.8}$. The non-quadrilateral components have the following mean abundances: TiO_2 = 3.24%, Al_2O_3 = 6.00%, Na_2O = 0.88% and Cr_2O_3 = ~0.11%.

SAMPLE K49 is a nepheline normative microsyenite, with a granular to trachytoid texture. It was collected from the summit of Mullaley Mountain, 4 km south of Mullaley Village (Latitude 31.13° South, Longitude 149.88° East; Gilgandra 1: 250 000 Sheet). It is Early Cretaceous (118 ± 4 Ma: See Table 1) in age. Rocks from this general area have previously been described by Bean (1974), Dulhunty (1967) and Wilshire and Standard (1963). Most of the rock is composed of aligned, elongate alkali feldspars (~85 vol.%). These feldspars have a brown clouded appearance and some of the larger crystals display perthitic intergrowths. The most abundant mafic phase is a green, pleochroic clinopyroxene that has a 10°-30° extinction angle (~7 vol.%). Opaque oxides (titanomagnetite ~5 vol.%) and small, subhedral grains of nepheline (~3 vol.%) occur between the essential minerals. All the nephelines are mediopotassic and contain more than four Si ions per formula unit. A few euhedral crystals of apatite were also discovered. The pyroxenes are variable in composition and range from the diopsides to hedenbergites. Their mean composition is $En_{24.2}$ $Fs_{28.4}$ $Wo_{47.4}$ and they range from $En_{29.2}$ $Fs_{24.7}$ $Wo_{46.1}$ to $En_{19.5}$ $Fs_{32.1}$ $Wo_{48.4}$. The non-quadrilateral components have the following mean abundances: TiO_2 = 0.82%, Al_2O_3 = 2.22%, Na_2O = 0.72% and Cr_2O_3 = ~0.01%.

SAMPLE K51 is another nepheline normative microsyenite but it was collected from the base of Mullaley Mountain (Same locality as Sample 49). It is Early Cretaceous (108 ±4 Ma: See Table 1) in age, with a granular to trachytoid

Table 3 CIPW Norms of Mesozoic Rocks of N.E. New South Wales

No	K.46	K.47	K.49	K.51	K.52	K.53	K.55	K.56
Or	7.80	10.21	32.45	29.54	9.28	6.21	5.75	1.89
Ab	26.23	12.86	45.26	46.68	22.08	16.71	21.66	23.80
An	23.87	12.81	6.85	6.88	20.80	16.71	24.96	27.16
Ne	0.00	13.52	2.81	3.99	0.00	8.14	0.00	0.00
Di	12.43	25.05	3.10	3.56	14.65	22.10	13.08	14.84
Hy	3.08	0.00	0.00	0.00	5.24	0.00	15.35	25.13
Ol	18.70	14.28	4.29	4.11	19.25	20.09	12.18	1.17
Mt	2.74	4.26	3.39	3.45	2.78	3.26	2.83	2.73
Il	4.00	4.81	1.27	1.23	4.35	5.09	4.09	2.82
Ap	1.15	2.20	0.58	0.56	1.57	1.69	0.10	0.46
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

texture. The dominant phase is a medium grained alkali feldspar (~76 vol.%). Most crystals have a stubby lath shape. They are brownish-pink, slightly clouded perthites, that are probably after sanidine. The second most abundant phase is a pleochroic green to colourless clinopyroxene (~12 vol.%). A few of the larger clinopyroxene crystals have pale cores and darker green rims. Extinction is usually in the range 10° to 25°. Opaque oxides (titanomagnetite ~5 vol.%) are relatively abundant and some have square outlines in thin section. Analcime (~4 vol.%) occurs as a clear colourless phase that is interstitial to the essential phases. Small nepheline crystals were also found. The thin-section also contains a few green patches that are composed of an aggregate of small crystals of chlorite, amphibole and clays (~2 vol.%). These patches were produced by the alteration of an unknown ferromagnesian phase. Euhedral apatite (~1 vol.%) crystals were also observed. The pyroxene is mainly hedenbergite. It has a mean composition of $En_{24.5}$ $Fs_{28.9}$ $Wo_{46.6}$ and ranges from $En_{26.4}$ $Fs_{26.9}$ $Wo_{46.7}$ to $En_{22.2}$ $Fs_{31.6}$ $Wo_{46.2}$. The non-quadrilateral components have the following mean abundances: TiO_2 = 0.57%, Al_2O_3 = 1.73%, Na_2O = 0.74% and no Cr_2O_3 was detected.

SAMPLE K52 is an olivine and hypersthene normative basalt with a porphyritic to intergranular texture. It was collected from Couradda South, 19 km east of Edgeroi Village on the Narrabri - Terry Hie Hie road (Latitude 30.04° South, Longitude 149.97° East; Narrabri 1: 250 000 Sheet). This rock is Late Permian (250 ±10 Ma: See Table 1) in age. It contains elongate plagioclase (~50 vol.%) laths arranged in a network with clinopyroxenes (~23 vol.%) and other smaller phases filling the triangular spaces between the feldspars.There are a limited number of large olivine (~15 vol.%) phenocrysts. Some of these phenocrysts are partly or completely altered to a green aggregate composed of smectite and chlorite. The clinopyroxene is pinkish-grey in colour with an extinction angle of between 50° and 60°. Within the thin-section there are interstitial orange patches (~6 vol.%) that appear to contain zeolites, smectite and haematite. Opaque oxides (titanomagnetite ~6 vol.%) are moderately common. The mean composition of the olivine crystals is $Fo_{82.3}$, and they ranged in composition from $Fo_{75.6}$ to $Fo_{89.0}$. Table 4 shows that the mean MnO composition of these olivines is 0.23%. Their mean NiO content is 0.30%, whereas their mean Cr_2O_3 content is ~0.06%. The

Table 4 : Mean Compositions of the Olivines

No	K. 46	K. 47	K. 52	K. 53	K. 55	K.56
SiO_2	36.03	38.9	38.88	37.91	38.07	38.15
TiO_2	~0.04	~0.01	0.00	0.00	0.00	0.00
Al_2O_3	~0.05	~0.14	0.00	~0.08	~0.08	~0.10
FeO	28.70	17.38	16.63	19.28	21.09	17.39
MnO	0.46	0.27	~0.23	0.28	0.34	~0.24
MgO	34.12	43.46	43.90	41.89	40.05	42.84
CaO	0.42	0.36	0.00	0.36	~0.10	0.92
Cr_2O_3	~0.03	0.05	0.06	~0.04	0.05	0.05
NiO	~0.15	0.24	0.29	0.17	0.23	0.31
BaO	~0.01	0.00	0.00	0.00	0.00	0.00
Fa	32.11	18.33	17.68	20.53	22.92	18.54
Fo	67.89	81.67	82.32	79.47	77.08	81.46

Table 5 : Mean Compositions of the Pyroxenes

No	K.46	K.47	K.49	K.51	K.52	K.53	K.55
SiO_2	47.89	46.32	49.01	49.45	47.61	50.19	50.98
TiO_2	4.65	3.24	0.84	0.57	3.04	2.20	0.81
Al_2O_3	3.52	6.00	2.26	1.73	5.16	4.94	2.30
FeO	7.68	9.13	16.16	17.10	8.56	8.06	8.93
MnO	0.15	0.23	0.51	0.65	0.18	0.15	0.18
MgO	13.50	11.93	8.39	8.16	12.77	13.41	14.50
CaO	21.81	21.96	22.04	21.58	21.90	22.70	21.81
Na_2O	0.57	0.88	0.73	0.74	0.78	0.50	~0.39
Cr_2O_3	~0.14	~0.11	~0.01	0.00	0.00	0.00	~0.06
NiO	0.06	0.01	0.00	0.00	0.00	0.00	0.03
BaO	~0.03	0.19	~0.05	0.00	0.00	~0.05	0.00
Wo	46.81	47.84	47.36	46.62	47.27	47.65	44.56
En	40.32	37.15	24.23	24.52	38.31	39.15	41.18
Fs	12.88	15.00	28.41	28.86	14.42	13.20	14.26

pyroxene is diopside. It has a mean composition of $En_{38.6}$ $Fs_{17.94}$ $Wo_{43.8}$ and ranges from $En_{40.1}$ $Fs_{12.4}$ $Wo_{47.5}$ to $En_{34.5}$ $Fs_{16.0}$ $Wo_{49.5}$. Non-quadrilateral components have the following mean abundances: TiO_2 = 3.04%, Al_2O_3 = 5.16%, Na_2O = 0.78% and no Cr_2O_3 was detected. The mean composition of the plagioclases is $An_{57.6}$ $Ab_{40.1}$ $Or_{2.3}$, and their range lies within the labradorite field from $An_{59.8}$ $Ab_{38.4}$ $Or_{1.8}$ to $An_{54.9}$ $Ab_{42.4}$ $Or_{2.7}$. These plagioclases have a mean Fe_2O_3 content of 0.87% and a mean BaO abundance of ~0.11%.

A volcanic bomb of hypersthene and olivine normative basaltic composition was collected from a tuff bed that cropped out to the north of sample site K52. This rock (Sample K56) has a vitrophyric texture. Olivine phenocrysts occur in clusters (~10 vol.% ; with a mean composition of $Fo_{81.5}$) set in a yellowish-brown glassy groundmass. Set in the glass are small elongate laths of plagioclase (~48 vol.%) with small, pale, purplish-pink, anhedral crystals of clinopyroxene (~34 vol.%). In the field this rock was presumed to be of the same age as sample K52; however, a radiometric age determination established that it was of Late Oligocene age (30.5 ± 2.5 Ma).

SAMPLE K53 is an alkali basalt that contains 8.1 % normative nepheline. It was collected from Red Hill, 4 km west of Boggabri (Latitude 30.70° South, Longitude 149.98° East; Narrabri 1: 250 000 Sheet). This sample is Late Permian (243 ± 10: See Table 1) Ma in age and has a porphyritic texture, with large, often resorbed, olivine (~18 vol.%) crystals set in a fine-grained groundmass. The olivine phenocrysts often occur in clusters giving the rock a glomerophyric texture. Typically the groundmass is composed of a reddish pink clinopyroxene (~25 vol.%) with an extinction angle of between 50° and 60°, and plagioclase (~40 vol.%) that occur as small laths. Opaque oxides (~7 vol.%), nepheline (~7 vol.%), aegirine augite (~3 vol.%) and zeolites also appear in the groundmass. All the nephelines are mediopotassic with more than four Si ions per formula unit. The mean composition of the olivine crystals is $Fo_{79.5}$, and they range from $Fo_{77.2}$ to $Fo_{81.2}$. Table 4 shows that the mean MnO composition of these olivines is 0.28%, their mean NiO content is ~0.17%, and their mean Cr_2O_3 content is ~0.04%. Most of the pyroxene is diopside with a mean composition of $En_{39.1}$ $Fs_{13.2}$ $Wo_{47.7}$, but some small green, pleochroic crystals of aegirine augite occur in the groundmass. The non-quadrilateral components have the following mean abundances: TiO_2 = 2.20%, Al_2O_3 = 4.94%, Na_2O = ~0.50% and no Cr_2O_3 was detected.

SAMPLE K55 is a hypersthene and olivine normative basalt collected from Delwood Sheep Station, 24 km west of Boggabri (Latitude 30.66° South, Longitude 149.84° East; Narrabri 1: 250 000 Sheet). It is Early Jurassic (190 ± 8 Ma: See Table 1) in age and probably part of the Garrawilla Volcanics. The rock is porphyritic with large olivine crystals set in a medium grained groundmass. Some of the olivine (~12 vol.%) phenocrysts are partly altered to a homogeneous-looking green aggregate that contains a mixture of chlorite and smectite. The groundmass is composed of elongate plagioclase (~53 vol.%) laths and a pink clinopyroxene (~25 vol.%) with an extinction angle of between 50° and 60°. Opaque oxides (titanomagnetites and ilmenites ~6 vol.%) also occur in the groundmass. They are sometimes associated with red fine-grained interstitial patches that appear to be aggregates of haematite and smectite (~4 vol.%). The mean composition of the olivine crystals is $Fo_{77.1}$, and they ranged in composition from $Fo_{68.6}$ to $Fo_{80.9}$. Table 4 shows that the mean MnO composition of these olivines is 0.34%, their mean NiO content is 0.23%, and their mean Cr_2O_3 content is ~0.05%. The pyroxene ranges in composition between augite and diopside. Their mean composition is $En_{41.2}$ Fs14.3 Wo44.5 with a range from $En_{43.2}$ $Fs_{12.1}$ $Wo_{44.7}$ to $En_{38.8}$ $Fs_{16.0}$ $Wo_{45.2}$. The non-quadrilateral components have the following mean abundances: TiO_2 = 0.81%, Al_2O_3 = 2.30%, Na_2O = ~0.40% and Cr_2O_3 = ~0.06%. The mean composition of the plagioclase is $An_{58.3}$ $Ab_{39.6}$ $Or_{2.1}$, with a range from $An_{61.7}$ $Ab_{36.4}$ $Or_{1.9}$ to $An_{52.3}$ $Ab_{45.1}$ $Or_{2.6}$. They have a mean Fe_2O_3

Table 6 : Mean Compositions of some Feldspars

No	K.46	K.51	K.52	K.53	K.55	K.56
SiO_2	53.30	66.53	53.12	64.41	53.03	52.01
TiO_2	0.04	0.00	0.00	0.00	0.00	0.00
Al_2O_3	29.14	18.81	28.57	21.64	28.70	29.28
Fe_2O_3	0.65	0.25	0.87	0.24	0.78	0.90
CaO	12.09	0.41	12.23	2.94	12.40	11.28
Na_2O	4.45	5.17	4.71	4.56	4.70	4.26
K_2O	0.34	8.64	0.40	5.67	0.38	2.26
BaO	0.00	0.18	0.11	0.54	0.01	0.00
Or	1.89	51.30	2.25	37.78	2.11	11.91
Ab	39.30	46.63	40.11	45.76	39.63	35.88
An	58.81	2.07	57.64	16.46	58.26	52.21

content of 0.78% and a mean BaO abundance of ~0.01%.

MESOZOIC MAGMATISM IN EASTERN AUSTRALIA

During most of the Early Permian a chain of active volcanoes stretched for over 2 000 km from Sydney to Cairns (BMR Palaeogeog. Group,. 1990, pp. 48-50). The rocks that issued from these volcanoes ranged in composition from basalt to trachyte and rhyolite (Leitch & Skilbeck, 1991; Vickers, 1991). This magmatic epoch was probably related to the inception of rifting in the proto- Sydney- Gunnedah- Bowen Basin System (cf. Vickers, 1991). The various magmas that evolved during this epoch were probably derived from the blending of; (a) residual calc-alkali magma that developed in response to subduction in the Carboniferous, (b) transitional basaltic magma that segregated in the asthenosphere, and (c) silicic magmas that evolved as the result of anatexis. The later Gympie Terrane collision (BMR Palaeogeog. Group, 1990, pp. 51-52) produced extensive thrusting and shortening of the lithosphere. In the south much of the displacement concentrated along the Hunter- Mooki- Burunga- Leichhardt tectonic line. The shortening and concomitant thickening of the lithosphere thrust a linear body of rocks from the base of the lithosphere into the hotter and less dense asthenosphere. At first the root, aided by the downwelling convection currents responsible for convergence, dragged itself and the overlying rocks downwards. Mafic lower crustal rocks transported to depths greater than 50 km were transform into eclogites (Kay & Mahlburg-Kay, 1991). Part of the root of dense rocks (e.g. harzburgite, lherzolite and eclogite) is likely to detach from the lithosphere. Gradually, as the geotherms at the base of the new lithosphere reverted to their normal configuration, local partial melting occurred. When the downwelling convection currents started to wane the gravitational potential energy stored in the root forced it to rise. This facilitated lithospheric extension, and reactivated and expanded the system of graben and half graben that marked out the Sydney- Gunnedah- Bowen Basin System. While the rift system was being reactivated the detached slabs cast into the asthenosphere were being heated, deformed and eroded. Reaction between the foundered slabs and the asthenosphere is likely to transfer incompatible elements from the slabs into the fluid phase in the surrounding asthenosphere. Once segregated from the solid phases this fluid is likely to move upwards and assist in generating a singular K-rich basanitic magma. Most of this magma would vein and pervasively metasomatised the rocks at the base of the lithosphere thus providing a ready source for producing high-K magmas. This special magma is characteristic of the the Mesozoic igneous rocks of the Sydney and Gunnedah basins. Another geochemical characteristic of many Mesozoic rocks from the northern Sydney and Gunnedah basins is that they plot in the "within- plate" field on the Ti/100 - Zr - Y*3 tectonic discriminant diagram as shown by Dulhunty et al. (1978, p. 80).

There was extensive magmatic activity in eastern New South Wales and southeastern Queensland during the Late Permian and Early Triassic. The granitic and granodioritic rocks of the New England Batholith and its northern extensions were emplaced between 253 and 222 Ma (Day et al., 1983, p. 117; Shaw et al., 1991, p. 45; Shaw & Flood, 1981). This Greater New England Batholith is bounded by the Demon and Peel fault systems, and these fault zones contain a variety of tectonic enclaves of mafic to ultramafic composition, including serpentinites (Voisey, 1969, p.228; and Wilkinson, 1953, p. 305). It is postulated that during the latest Permian subduction was oblique to the Lord Howe Rise / New Zealand margin of Gondwana, and part of the convergent movement was taken up by strike-slip movement. Such faulting produced local pull-apart structures at the divergent bends in the transcurrent faults thus facilitating the movement of large bodies of viscous, silicic magma into the upper crust (Glazner, 1991). Whereas some of this magma crystallised to form the various granitic and granodioritic rocks of the Greater New England Batholith, another large volume of magma breached the surface. The resulting explosive volcanism spread large volumes of pyroclastic materials over adjoining areas of New England and into the Sydney- Gunnedah- Bowen Basin System. Tephra of this type is preserved in the Late Permian Singleton Supergroup. Barnes et al. (1991, p. 3) have called these pyroclastic rocks the Wandsworth Volcanic group and they are typically ash-flow crystal tuffs that range in composition from basaltic andesite to rhyolite. Most are dacites or rhyolites.

Many other magmatic rocks, with a variety of "tectonic signatures", were erupted during the Late Permian and Early Triassic. They include high-K basalts (Samples K52 &

K53) in the Boggabri- Narrabri area; K-rich basanitic to latitic magmas in the Hunter Valley section of the Sydney Basin (Gamble, 1984, p. 180; Schön, 1978); and rocks of the trachybasalt- shoshonite- latite association (i.e. the Gerringong Magmatic Suite) in a volcanic belt that extends from east of Sydney via Wollongong to Bawley Point (Carr, 1981; Carr, 1985; Facer & Carr, 1979, p. 76; Middlemost, 1976). During the Late Triassic high-K basalts (Sample K46) were extruded in the Gilgandra area of N.S.W. In northeaster Victoria the Benambra monzonite- syenite complex (circa 211 Ma) was intruded (Crohn, 1950; McDougall & Wellman, 1976, p.4). In southeastern Queensland there was prolific calc-alkali magmatic activity in the Mid and Late Triassic. Great thicknesses of andesitic, dacitic and rhyolitic materials accumulated in the Esk and Abercorn fault troughs (Day et al., 1983, p. 118). The Late Permian and Triassic was thus a magmatic epoch during which large volumes of silicic magma erupted in the general area of the Greater New England Batholith, prolific calc-alkali magmatic activity occurred in southeastern Queensland, and a variety of K-rich (sensu Le Maitre et al., 1989, p. 29) magmas erupted in the general area of the Sydney- Gunnedah- Bowen Basin System. At present most of the rocks of the Gerringong Magmatic Suite crop out on, or just off, the coast of New South Wales. They appear to mark the edge of the Sydney Basin. As the various basins and sub-basins of the Sydney- Gunnedah- Bowen Basin System are likely to be separated by transfer faults, it is postulated that the potassic parental magma of this suite was possibly intruded into the area along a major fault zone of unknown type that terminated the Sydney Basin on its eastern side.

In the Early to Mid Jurassic the alkaline volcanics of the Garrawilla rock association (Sample K55; Bean, 1974; Dulhunty, 1965, 1967, 1986; Kenny, 1929; Dulhunty & McDougal, 1966; Wilshire and Standard, 1963), the magmatic rocks of the Bowral- Mittagong area (Gobert, 1976; McDougall & Wellman, 1976; Middlemost, 1976; Stevens, 1957), the Mt Dangar tephrite from west of Muswellbrook (Dulhunty et al., 1987), and the micrograndiorites of the Lorne Basin (McDougall & Wellman, 1976), were all erupted. Duggan et al. (1989, p. 151) have also described rocks of the same age as the Garrawilla Volcanics from a wide area that extends from Mullaley southeast to Muswellbroek. It is difficult to asses the original extent of these volcanic rocks because erosion has removed all evidence of them to the east of Mullaley, and they are covered by Jurassic rocks to the immediate south and west of Mullaley. The rocks in the type area consist of lavas and tephra of the alkali basalt - trachyte rock association. Many diatremes from the central and northwestern parts of the Sydney Basin are of Early Jurassic age (Helby & Morgan, 1979, p. 1) and their juvenile ejecta shows that these volcanic vents developed during the explosive emplacement of high-K basanitic to trachybasaltic magmas (Crawford et al., 1980, p. 321; Wilshire, 1961).

During the Mid Jurassic (circa 175 Ma) vast quantities of tholeiitic flood basalt and basaltic andesite erupted in the Ferrar comagmatic region (Hergt et al., 1991, p.137). This comagmatic region includes tholeiitic rocks from southwestern Victoria, southern South Australia and Tasmania (Schmidt & McDougall, 1977). While these tholeiitic lavas, dykes and sills were being erupted, smaller volumes of hypersthene normative basalts and nepheline normative trachybasalts were being extruded near Coleraine in western Victoria (Hergt et al., 1991, p.134). In the Sydney Basin the Ferrar magmatic epoch was a time of widespread magmatic activity (Embleton et al., 1985: McDougall & Wellman, 1976; Rickwood, 1985). This was when the Prospect Layered Intrusion was emplaced in the centre of the basin (Wilshire, 1967), and a variety of alkaline rocks, particularly phonolites, were intruded in the in the Botobolar area on its western rim (Day, 1961; Dulhunty, 1976; Langley, 1976). In the Southern Highlands Fold Belts the Myall Road Syenite and trachybasaltic dykes were emplaced (McDougall & Wellman, 1976, p. 3), and in the Wellington area northwest of Sydney the Mt Bodangora phonotephrite was extruded (Dulhunty et al., 1987).

During the Permian, Triassic and Jurassic most of New Zealand lay in a deep water, trench that collected large amounts of material from adjacent calc-alkali volcanic chains on the Lord Howe Rise / New Zealand margin of Gondwana. In the Early Cretaceous this active volcanic arc appears to have moved closer to the Australian craton resulting in renewed calc-alkali magmatic activity in the coastal areas between Rockhampton and Bowen in eastern Queensland (Day et al., 1983; Evernden & Richards, 1962; Webb & McDougall, 1968). During this epoch rift valleys developed along the southern margin of what was soon to be Australia. In Victoria phonolites erupted at Gallows Hill northeast of Mansfield, and monchiquitic lamprophyres were intruded in the Bendigo area (158 Ma and 149 Ma respectively; McDougall & Wellman, 1976, p.4). Simultaneously in the area that became Bass Strait three east-west aligned intracratonic, fault bounded basins began to form. They filled with sediments and mildly alkalic volcanic materials (Duggan et al., 1989, p. 151; Etheridge et al., 1987). On shore in Victoria the first group of "Older Volcanics" erupted in the Poowong and Bacchus Marsh areas. The compositions of these rocks ranged from basanite to hawaiite (Johnson et al., 1989, p. 134).

In New South Wales southwest of Boggabri alkali basalts and basanites were intruded between 148- 145 Ma (Dulhunty et al., 1987, p. 85). These dates lie astride the Jurassic- Cretaceous boundary. Later there was renewed alkali magmatic activity in the Mullaley area with the intrusion of a suite of nepheline normative microsyenites (Samples K49 & K51). South of this area in the Mudgee district a basanitic plug (Sample K47) was emplaced. In the middle of the Cretaceous (circa 90-111 Ma) basaltic dykes were intruded in the Hunter Valley. South in the Central Tilba area, the Mt Dromedary cluster of ring complexes (circa 96 Ma) was emplaced both on shore and on what is now the mid continental slope (Boesen & Joplin, 1972, p. 346; Brown, 1930; Jenkins, 1991, p.98). The rocks that comprise these complexes belong to the shoshonite- latite-trachyte rock association. They erupted during the initial rifting stage immediately prior to spreading in the Tasman Basin.

In New Zealand the Rangitata Orogeny reached its peak in the middle of the Cretaceous producing widespread folding, regional metamorphism and magmatism. Circa 94 Ma rhyolite samples have been obtained from near the southern end of the Lord Howe Rise, and at the time of eruption this area was attached to the northeast coast of Tasmania (McDougal & Van der Lingen, 1974). Simultaneously silicic volcanoes were active in the Whitsunday area of Queensland. It is thus likely that an extensive calc- alkali volcanic chain stretched from the Whitsunday area to the east of Tasmania. These magmatic events all coincide with the birth of the Lord Howe / New Zealand plate. During the Late Cretaceous (circa 74-70 Ma) a variety of alkali basaltic rocks erupted along the eastern margin of Australia (Carr

& Facer, 1980; Duggan et al., 1989, p. 149). With the separation of the Lord Howe Rise / New Zealand from eastern Australia (circa 96 Ma: Veevers et al., 1991) isostasy required the centres of gravity of the new lithospheric blocks to adjust to the new structural setting. This adjustment was complex because before drift a broad belt of lithosphere that formed the eastern margin of the supercontinent had been coupled to an active subduction system. Whilst active this subduction system had pulled down the overlying lithosphere. This process is similar to the one operating in parts of Indonesia at present. Sea-floor spreading requires an active upwelling convection system. It is postulated that the Eastern Highlands of Australia rose as the new continental margin became decoupled from the old subduction- driven convection system that pulled it down, and it was briefly coupled to the new system of upwelling. During the Cenozoic the Eastern Highlands became the locus of extensive intraplate continental volcanism. Fission track analysis has revealed that uplift along the continental margins of southeastern Australia is of the order of 1.5 to 3 km (Dumitru et al., 1991, p. 141).

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Health Hazards Associated with Extremely Low Frequency Electromagnetic Fields from Power Lines and Home Appliances

J.K. BROWN

Life on earth has evolved in the presence of a continuous flux of electromagnetic waves. The electromagnetic spectrum consists of bands of different wavelength and frequency ranging from gamma rays and X-rays, ultra violet, visible light, infra-red, microwaves to radiowaves. Gamma rays have an extremely short wavelength (10^{-14} metre) and very high frequency (10^{24} cycles per second or Hz) whereas at the other end of the spectrum the radio waves have an extremely long wavelength ($>10^4$m) and low frequency ($<10^4$Hz).

The most energetic waves, gamma rays and X-rays, are referred to as ionising radiation because of their ability to break chemical bonds holding together the atoms of molecules. Ionising radiation is dangerous to man by virtue of its capacity to damage nuclear DNA in cells. This results in cell death or sometimes in mutations in surviving cells which can lead to cancer in the individual or, through mutations in the germ cells, lead to defective offspring. The non-ionising portion of the electromagnetic spectrum includes the longer wavelengths of infra-red, microwaves and radiowaves. These wavelengths can produce thermal effects and be injurious to cells if large amounts of energy are delivered in short periods of time.

In the extremely low frequency (ELF) part of the electromagnetic spectrum (0-300Hz), the electromagnetic waves are extremely weak and are incapable of ionisation or thermal heating. Consequently, when the first reports were presented in the mass media purporting to show that electromagnetic fields (EMFs)- such as those emitted by high voltage power lines (HVPLs) and electrical equipment - were harmful they were viewed by many scientists as quite incredible. No plausible mechanism could be proposed to account for the supposed effects. However, it has now been established that biological effects can be induced in cells by ELF EMFs.

In Australia, electric power is generated and transmitted with an alternating current at a frequency of 50Hz. High voltage (220,300 & 500kV) is broken down, via substations and transformers, to the distribution lines (22,66, & 132kV) and then to low voltage (240,415V) for consumer use.

Both electric and magnetic fields are present around wires carrying electricity. The strength of the electric and magnetic fields depends on the voltage in the case of electric fields and the size of the current (amps) carried in the case of magnetic fields. Both decrease rapidly with distance from the wire. Electric field strengths are measured in kilovolts per metre (kV/m). Magnetic fields are measured in units of amps per metre (A/m) or alternatively are expressed in terms of the quantity magnetic flux density measured in units of tesla (T) which is proportionally related to the magnetic field strength. Magnetic fields are of two types: static where direct current is flowing and time varying where alternating current is flowing, as in the case of HVPs. Magnetic fields near HVPLs fluctuate widely day to day and with the season as the power flow rises and falls.

Natural sources of ELF EMFs are galactic, solar and terrestrial and include sunspots, thunderstorms and the earth's magnetic field. Most electrical and electronic equipment produces two kinds of emissions: electric and magnetic which are emitted as electromagnetic energy fields. Time-varying magnetic fields originating from man-made sources - such as HVPLs, home appliances and other electrical equipment - generally have higher intensities than the natural occurring fields, particularly for the 50-60Hz power frequency range. ELF EMF with the characteristics of 50Hz frequency, AC current and sinusoidal wave form will subsequently be referred to as power frequency EMF.

Residents of a house will generally be shielded from about 90% of the electric fields from an overhead power line. On the other hand, magnetic fields are difficult to shield and readily penetrate materials, including the body. This is the main reason for believing that the biological effects of EMFs are largely or wholly due to magnetic field origin rather than due to electric fields.

There are four sources of EMFs in the home: appliances, currents flowing in the home (depending on wiring and consumption), magnetic fields in loops due to imbalance in current flowing through plumbing and underground paths and proximity to overhead HVPLs etc. The contribution from HVPLs has been exaggerated by the mass media; a more important source in homes is domestic wiring. Background magnetic fields in homes are highly variable (range 0.05-1μT but are usually between 0.1-0.2 Tμwith home appliances showing magnetic fields of 0.03-30μT at 30cm. The highest readings are from can openers, hair dryers, stoves, drills, saws, vacuum cleaners, mixers, fluorescent desk lamps and electric blankets. Although magnetic field intensity emitted buy such appliances is often high, usage is usually brief and intermittent so that their cumulative contribution to EMF exposure is relatively low.

Since 1983 it has been accepted that the biological effects of EMFs are attributable to magnetic rather than electric fields but it is not certain whether short periods of high exposure, long periods of lower exposure or even "windows" of wavelengths at particular frequencies in the ELF range (0-300Hz) are the most significant.

Within cells are internal electric fields and currents that play an essential role in normal cellular function. Both electric and magnetic fields can induce currents in the body. In particular, magnetic ELF-induced currents in tissue and the electric fields thus created have been shown to act in the cells. The types of currents and fields which are induced in the body by exposure to power frequency EMFs are much less than those which occur naturally in the body. For example, natural currents arising from muscular or nerve activity are in the region of 10-100 milliamps per square metre (mA/m^2) compared with the whole body induced currents of about 3 mA/m^2 experienced while standing in an electric field of 10kV/m, the highest that would normally be encountered by a member of the public. On this basis a mechanism for the alleged health hazards of EMFs seems inexplicable. However, it has been claimed that currents induced by ELF EMF may produce, through amplification of weak electrochemical events in the cell membrane, aberrant internal signals which can affect the nucleus of the cell. This mechanism has been proposed as a possible means by which cancer promotion might be induced but there is little evidence, as yet, to support this hypothesis.

Numerous studies have been undertaken of the effects of EMFs from molecular and cellular investigations in the laboratory, animal studies to epidemiological and laboratory studies in humans. The principal health hazards alleged to be produced by chronic exposure to low level power frequency EMFs are cancer in children and adults (leukemia, brain and nervous system tumours) and birth defects and miscarriages derived from an exposed mother or father. Since 1979 several studies have been published in the scientific literature which suggest that children living in homes near overhead HVPLs or other electric transmission equipment or in homes with elevated magnetic fields have an increased risk of cancer. Other childhood investigations have not demonstrated any increased effect. Some studies in adults have also shown a positive association, although less convincingly. Of 23 studies of occupationally exposed groups, 19 have reported an increase in some form of cancer in workers in electrical occupations or electronics. Occupational environments can expose workers to magnetic field strengths which are 100 to 1000 times higher than household fields but in some particular electrical occupations it is not certain whether higher than average exposures to EMFs are involved. In such studies it is unclear whether EMFs are the most likely active agent in cancer induction as many of these workers are also exposed to chemicals, solvents, fluxes etc. which are known or suspected to be capable of causing cancer. The chief criticism of most studies of electrical workers has been the lack of precise measurements of the actual levels of exposure. In occupational studies job classification is generally used as a surrogate for EMF exposure but it is not certain whether such work involves higher than average exposure to EMFs. For example, in the case of electronic assemblers an 810 times difference in exposure was measured between individual workers; welders exposed to some of the highest levels of magnetic fields (100-200μT) have only a small risk of leukemia and magnetic field exposures are sometimes very high for so-called non-electrical jobs.

The most serious defect, casting doubt on the validity of the findings in epidemiological studies, is the lack of direct measurement of electric and magnetic fields in the actual subjects in the study groups. Additionally, none of even the better studies have tried to assess magnetic field exposure from all sources. In residential studies magnetic field exposure is invariably estimated indirectly from the wiring configuration in individual homes, proximity to HVPLs and other electrical installations or from records of current loadings. Spot or 24 hour measurement of magnetic fields, undertaken in a few studies but not in all homes, are not thought to necessarily reflect the extent and intensity of past exposure as the levels and duration of exposure are quite unknown. No suitable devices for continuous monitoring of the electric and magnetic fields in individuals have been available for use in past studies but pocket-size battery powered dosimeters have recently been developed. Other important defects, minimising the significance of the results, are that epidemiological studies have been based on previously exposed persons. Information has been derived from death certificates or cancer registries, often without personal interview (retrospective type of study). Of more value is the prospective type of study where both the so-called exposed and non-exposed groups are followed repeatedly as they develop disease and accumulate exposure to magnetic fields. Other major faults are the small sample size of the groups investigated limiting the statistical power of the study and the low number of homes with high magnetic field exposures.

Electric blankets have the potential to be responsible for the highest and most prolonged exposure to magnetic fields in the home because of the relatively high intensity of emission, prolonged exposure and intimate contact with the body. EMF levels are commonly up to 10 times the exposure contributed by the background magnetic field. Most of the limited number of studies, conducted in the U.S., have failed to establish an association between electric blankets and cancer but a direct adverse effect on foetal development and abortion rates during pregnancy has been suggested. If such an effect does exist it is not evident whether it is due to EMF exposure or excessive heat. In any case a substantial exposure can only be reached by very heavy use of electric blankets such as eight hours per day, eight months a year on the high setting. Further, in Australia, EMF exposure is less than in the U.S. where a higher exposure results from the routine use of overblankets compared with underblankets used here. A recent questionnaire conducted in Victoria indicated that about 30% used the blanket only to heat the bed before retiring, 40% for partial overnight use and the remainder left the blanket on all night but only 1.6% on the highest setting. Thus it seems unlikely that the usage of electric blankets in Australia contributes significantly to EMF exposure.

Since the late 1960s there has been widespread controversy and public alarm over the alleged health hazards of power frequency EMFs. Unfortunately, reports emanating from the mass media and pseudo-scientific writers are usually based on incomplete scientific knowledge and contradictory results of existing studies. The apparent lack of agreement between scientists has also contributed to public misconceptions and panic over powerlines. Sensational newspaper headlines have included unfounded conclusions such as "cot deaths being due to strong electric fields in homes" and that "up to 40% of childhood cancers are due to HVPLs and electrical home appliances". In Australia, rural and urban citizen groups have been active in protesting against the introduction of new HVPLs claiming the likelihood of increased risk of cancer, reduction in livestock production and lower crop yields. As a result there have been two recent government investigations. In Victoria, the Advisory Committee on Non-ionising Radiation commissioned a report from the University of Melbourne. Report 242, "Epidemiological Studies of Cancer and Powerline Frequency Electromagnetic Fields : A Meta-Analysis" by I.Gordon et al.,1990. In N.S.W. the Department of Minerals and Energy commissioned a report "Inquiry Into Community Needs and High Voltage Transmission Line Development" by H.Gibbs, 1991. In the Victoria report an attempt was made to improve the statistical accuracy of the possible association between the induction of cancer and exposure to EMFs in residential (children and adults) and occupational studies by combining the results of previous studies. Due to the types of faults previously described it was only feasible to combine the data from three childhood studies out of the 11 studies published. Although an elevated risk of childhood cancer was found, providing the magnetic exposure exceeded 0.3μT, one of the conclusions of the report was that the evidence was not convincing. In the N.S.W. inquiry Gibbs concluded, after a survey of the latest literature and consultation with leading experts in the world, that an association between exposure to EMF and cancer was not proven.

The scientific evidence of whether or not power frequency EMFs poses a cancer risk remains unresolved. No conclusion can be reached on the basis of current data due to serious deficiencies in all the studies. However, there is consensus opinion that the present results indicate the need for further epidemiological studies of highly exposed populations with the use of personal dosimeters and daily diary records monitoring EMF exposure over long periods, preferably years.

The Electricity Commission of New South Wales actively supports research into the effects of EMFs. Two projects are currently being supported. The first involves the effects of EMFs on the human body and measurements in the vicinity of electrical equipment conducted by the School of Safety Science at the University of N.S.W. The Commission is also sponsoring the first stage of a multinational epidemiological study with a total cost of $1.6 million.

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Delivered by Dr.J.K.Brown (former Head of the Radiation Biology Group at the Australian Nuclear Science and Technology Organisation) before the Royal Society of New South Wales at the General Monthly Meeting 1.5.91.

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Doctoral Thesis Abstract: Alluvial Sapphire and Diamond Deposits of the New England Gem Fields, New South Wales, Australia.

ROBERT R. COENRAADS

The Central Volcanic Province in northern New South Wales, also known as the New England Gem Field is one of Australias most important sapphire producing areas. Large-scale mechanized mining and restoration techniques are the most effective means of utilizing this resource.

The Central Volcanic Province has been divided into three prospective target regions. These comprise a western region with potential for Tertiary deep-lead alluvial diamond deposits, a central belt with Eocene-Oligocene deep-lead sapphire deposits, and an eastern division with Holocene alluvial sapphire deposits.

A detailed palaeotopographic reconstruction technique had not been applied previously to the search for economic deposits of diamond or sapphire in the Central Volcanic Province. This method has proven to be a valuable exploration tool for delineating palaeochannels containing the above-mentioned deposits.

ORIGIN OF CORUNDUM ASSOCIATED WITH VOLCANIC PROVINCES

Sapphire Inclusion studies

Uranium-lead isotope dating of two zircon inclusions in sapphires from the Central Province, New South Wales gave ages of 35.9 ± 1.9 and 33.7 ± 2.1 million years (Ma). These ages fall within the range of basalt potassium-argon ages (19 to 38 Ma) and zircon fission track ages (2 to 49 Ma) for the timing of volcanism in the Central Province. These data, combined with the observation that corundum is found associated with many alkali basaltic provinces, indicate a genetic link between the growth of large corundum crystals and contemporaneous processes involved in alkali basaltic magma generation.

The abundance of incompatible elements such as U, Th, Zr, Nb and Ta in inclusion minerals, indicate that the melting/crystallization process is not simple. Corundum, and other minerals (such as zircon, columbite, thorite, uranium pyrochlore, alkali feldspar etc.) found as inclusions in corundum, could not have crystallized from most basaltic compositions. A more complex process must occur in which crystallization of coarse aggregates takes place when high proportions of incompatible elements and volatiles are present in early melt fractions. These unusual crystallization products are subsequently transported to the surface by voluminous basaltic magmas. The extent to which this process occurs, and the rate of transport to the surface, presumably determine whether a particular basaltic province carries sufficient corundum to be worked into economic concentrations of sapphire.

Sapphire surface features

The majority of surface features observed on rubies and sapphires of volcanic origin reflect their trigonal crystal structure and are the result of layer dissolution or etching that occurred while the crystals were exposed to the hostile melt environment whilst en route to the surface. Such features generated by magmatic resorption include trigonal prismatic hillocks, trigonal pyramids, inverted trigonal pyramids, flat floored trigonal and hexagonal depressions, and "brick-like" stacks of trigonal prisms. The style of features observed on a given surface is dependent both on the angle of the surface to the c-axis of the corundum crystal and the degree of etching.

There is often little evidence of abrasion of the corundum due to fluvial transport and the pitting and etching on associated heavy minerals is commonly the result of surface biodegradation. This, coupled with the spatial variability in the character of the corundum, and the differences in proportions of heavy minerals in placer deposits, indicates minimal amount of fluvial transport, and minimal degree of downstream reworking and mixing. Such observations indicate that the corundum is derived from local multiple sources.

DIVISION OF THE NEW ENGLAND GEM FIELDS INTO THREE EXPLORATION REGIONS

Key areas for diamond and sapphire exploration may be defined within the New England Gem Fields through an understanding of the geologic and geomorphic processes that operated within the Tertiary Central Volcanic Province.

At least two distinct periods of volcanic activity - one at 32-38 Ma and the other at 19-23 Ma - were controlled by SSE/NNW trending fracture sets revealed by landsat data. The locus of volcanism stepped westwards with time from the Glen Innes-Ben Lomond-Guyra area (the East Central Province) to the area west of Inverell and Armidale (the West Central Province).

Drainage and pre-volcanic topography indicate a radial pattern of drainage associated with East Central Province uplift and volcanism (32 - 38 Ma). This was modified by the later West Central Province volcanism (19 - 23 Ma) which established its own radial pattern. This geologic development of the Central Volcanic Province has resulted in broad areas suitable for sapphire and diamond exploration. The three prospective target regions comprise a western region with a potential for "palaeo-Gwydir type" alluvial diamond deposits, a central belt with "Braemar type" deep-lead sapphire deposits, and an eastern division with "Kings Plains-Reddestone type" alluvial sapphire deposits.

1. Diamond-bearing deep-leads of the West Central Volcanic Province

The Palaeo-Gwydir River system was buried by 19-23 Ma volcanism of the West Central Province. Prospectivity for diamond-bearing deep-lead alluvium is considered to be favorable in two major palaeodrainage systems that extend northward from the present Gwydir River in the vicinity of Copeton Dam. These are the palaeo-Hobbs and palaeo-Gwydir systems. The palaeotopographic reconstruction indicates at least 3 separate systems of diamond bearing alluvials and therefore, local, multiple sources for the diamonds.

2. Braemar-type deep-lead deposits in the zone-of-overlap

Exploration areas for deep-lead sapphire deposits, such as those found at Braemar were defined via mapping of palaeochannels in which the deposits are situated. The potential sapphire-bearing palaeochannels have been delineated within the zone in which the 19-23 million year old volcanics forming the West Central Province overlap onto 32-38 million year old sapphire bearing volcanics forming the East Central Province. In this zone, the 19-23 Ma basaltic lavas flooded a number of major palaeodrainage systems already containing 32-38 Ma basalt flows and alluvial deposits reworked from them.

The extent of these "deep-lead" deposits to the east of Braemar, in palaeochannels that drained the sapphire-bearing East Central Province, is related to the easternmost incursions of the lavas of the West Central Province.

3. Holocene alluvial sapphire deposits of the East Central Volcanic Province

In the East Central Province the post-eruptive fluvial history was vital in controlling the concentration of economic sapphire deposits from lower grade source rocks.

Two major sapphire deposits are situated in the Kings Plains and Reddestone Creeks of the East Central Province. There is a clear association between these deposits which have developed since the filling of the palaeovalleys with basalt, and the present drainage. The sapphire-bearing placer deposits occur as "shoestring" type accumulations occupying channels within broad, flat, basalt-filled valleys. Higher grades generally correspond to areas where channels are deepest, and sapphire grades in excess of 500 grams per cubic metre have been recorded. The heavy minerals have moved vertically downwards, rather than downstream, and become concentrated with time.

Palaeotopographic reconstruction highlights potential abandonned channel deposits which may no longer show any obvious association with the present day drainage. Such sapphire deposits may occur along abandoned palaeovalleys which continue below the points of capture by the present drainage.

HEAVY MINERAL SUITES IN THE NEW ENGLAND GEM FIELDS

Sapphire associates of the East Central Volcanic Province

Heavy minerals associated with sapphire in the alluvial gravels are pleonaste, ilmenite, chromium-spinel, titanium-magnetite, magnetite, corundum, zircon and minor chrysoberyl. Additional minerals found in nearby *in situ* basaltic soils comprise olivine, clinopyroxene, enstatite and amphibole, with zircon and sapphire being extremely rare.

Mineral species present vary within and between particular drainage catchments as well as visual characteristics of the sapphires. This implies that sources are 'local' to the placer deposits. The similarity in composition of minerals from soil and placer sites indicates that the sapphire-bearing placers have formed through extensive reworking of the immediately surrounding alkali basaltic and volcaniclastic rocks. Concentration was largely through vertical movement, with fine or light material being winnowed downstream leaving behind a heavy gem-bearing residue, within low gradient, low energy drainage systems.

Ilmenite-mantled rutile crystals of the Uralla area

Ilmenite-mantled rutile crystals of enigmatic origin, found in Late Tertiary conglomeratic arkoses and Quaternary alluvium in the vicinity of Uralla, may have formed as late-stage or cavity crystallizations from fractionated felsic magmas before eruption. They are an unlikely to be an indicator for diamond source rocks.

Pyrope-almandine garnets from Horse Gully

Deep red to purplish, gem quality pyrope-almandine intermediate series garnets have been recovered from sapphire-bearing river gravels at Horse Gully. They are believed to be derived from a local, probably mafic, source situated within the catchment area of Horse Gully.

INVESTIGATION OF SAPPHIRE SOURCE ROCKS AND POTENTIAL SOURCE STRUCTURES IN THE CENTRAL VOLCANIC PROVINCE

The basalts of the Central Province

Only four major catchments in the New England Gem Fields contain rich sapphire deposits. These are the Frazers, Kings Plains, Reddestone and Marowan catchments and are the most likely targets for sapphire source rocks.

Within the Central Province, variation diagrams show no significant difference between the 32-38 Ma sapphire-associated eastern basalts and the 19-23 Ma sapphire-barren western alkali-basalts. The compositional fields also overlap the Atherton, McBride and Chudleigh provinces in north Queensland, known to contain sapphire, as well as those of the sapphire-barren northeastern Australian volcanic provinces. These Australian compositional fields also overlap the corundum-bearing and corundum-barren fields for the southeast Asian volcanic provinces. Therefore major and minor element chemistry of basaltic rocks is not considered to be a useful exploration tool for discriminating sapphire-bearing from sapphire-barren volcanic provinces, nor for recognizing potentially high-grade areas within a sapphire-bearing province.

The lagoons of the Central Province

Lagoons located in the basalts of the Central Province were investigated to determine whether they could be maars and therefore potential sources of sapphire-bearing volcaniclastic rocks. Based on drilling, geophysical modelling and geological mapping, this was found not to be the case and the lagoons are interpreted to have formed within wind blown lunettes occupying the wide, flat floors of basalt filled valleys. Bulk testing at Kings Plains and Dunvegan lagoons indicates that these features do not constitute economic targets.

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ANNUAL REPORT OF COUNCIL

for the Year Ended 31 March, 1992

PATRON

The Council wishes to express its gratitude to his Excellency Rear Admiral Peter Sinclair, AO, Governor of New South Wales, for his continuing support as Patron of the Society.

MEETINGS

Eight General Monthly Meetings and the 124th Annual General Meeting were held during the year. The average attendance was 27 (range 16 to 44). Abstracts of all addresses were published in the Newsletter. The Annual General Meeting and seven of the General Monthly Meetings were held at the Australian Museum. A summary of proceedings is set out in a report attached.

The 46th Clarke Memorial Lecture was held on 23 October 1991 in the Hallstrom Theatre, Australian Museum. Associate Professor Barry Webby of the Department of Geology and Geophysics at the University of Sydney delivered the lecture before 25 members and visitors. The title of the lecture was "Ordovician Island Arc Biotas".

The Society was co-sponsor of a joint meeting held on 11 February 1992, with the Institution of Engineers (Australia) Sydney Division, the Australian Nuclear Association and the Australian Institute of Energy. The meeting was addressed by Dr. C.J.Hardy, formerly of the Australian Atomic Energy Commission, who spoke on "AUSTATOM - 34 years of the Australian Atomic Energy Commission (1953-1987)".

An Annual Dinner was held on 18 March 1992, at the Royal Exchange of Sydney, Gresham Street. The guests of honour were His Excellency Rear Admiral Peter Sinclair, AO, Governor of New South Wales, and Mrs. Sinclair. The President, Dr.E.C.Potter, welcomed the guests of honour and introduced His Excellency who delivered the Occasional Address. His Excellency then presented the Society's Awards for 1991. He presented the Cook Medal to Professor Graeme Clark, the Society's Medal to Associate Professor Denis Winch (Vice-President), the Clarke Medal to Dr.Shirley Jeffrey and the Edgeworth David Medal to Dr. Mark Harvey. Each recipient delivered a few words of thanks to the Society. Dr.Dalwood Swaine, a former President, then proposed a vote of thanks to His Excellency. A total of 59 members and their guests attended.

Eleven meetings of the council were held at the Society's Office, at North Ryde. The average attendance was 15.

PUBLICATIONS

Volume 123 Parts 3 and 4, and Volume 124 Parts 1-4 of the "Journal and Proceedings of the Society of New South Wales" were published during the year. They incorporated eight papers and the Occasional Address by the Hon.Mr. Justice Gleeson, AO, Lieutenant-Governor of New South Wales at the Annual Dinner in March 1991, together with the Annual Report of Council for 1990-1991. The Presidential Address for 1991 was also included. Council is again grateful to the voluntary independant referees who assessed papers offered for publication.

Ten issues of the Newsletter were published during the year and Council thanks the authors of short articles for their contributions.

Several requests to reproduce material from the "Journal and Proceedings of the Royal Society of New South Wales" were approved by Council.

MEMBERSHIP

The membership of the Society as at 31 March 1992 was:

Patron	1
Honorary Members	13
Life Members	21
Ordinary Members	210
Absentee Members	17
Associate Members	7
Retired Members	20
Spouse Members	12
Total	301

The following ten new Members were elected and welcomed into the Society.

Melena Amanda VALIS
Stephen Damian LYONS
John Arthur ROSS
Caroline GROVER

Edmund James MINTY,Jnr.
Margaret Ann HANLON
Keith HANLON
Marguerita Tracanelli MILLIKAN
John Andrew SHAW
James Butler STONEY

With great regret, the Council received news during the year of the deaths of the following members:

Mr.Francis George Arnot MORT
Dr.Alan HARPER, AO

Awards

The following awards were made for 1991:

Cook Medal:
Professor Graeme Clark, Director of the Institute of Otolaryngology, Melbourne.

Clarke Medal (in Botany)
Dr.Shirley Jeffrey, Chief Research Scientist, CSIRO Division of Fisheries, Hobart.

Edgeworth David Medal (research under the age of 35 years):
Dr.Mark Harvey, Curator of Arachnids at the Museum of Western Australia.

Royal Society of New South Wales' Medal:
Associate Professor Denis Winch, School of Mathematics and Statistics, University of Sydney.

The Olle Prize and the Walter Burfitt Prize was not awarded this year.

SUMMER SCHOOL

This year's Summer School on "Communications" attracted some 41 senior high school students from public and private schools statewide. It was held from 13 to 17 January 1992 at Macquarie University. Sixteen voluntary speakers from universities, government and industry addressed the students. Half-day excursions were held to the OTC Research facility in Sydney and to the Pymble Telephone Exchange.

The Honourable Ross Free, Minister for Science and Technology, officially opened the Summer School. This very successful Summer School was organised by Mrs.M.Krysko on behalf of the Society.

The Council wishes to extend its thanks to Telecom Australia for its generous sponsorship of the Summer School and to Mrs.Krysko, Mrs.W.Swaine and Mrs.M.Potter for their generous donations of time and energy. Council also thanks the speakers for giving generously of their time. Telecom are also thanked for allowing the Summer School students access to OTC's research facility and to the Pymble Telephone Exchange.

OFFICE

The Society continued during the year to lease for its office and library a half share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of Macquarie University campus. The Council is grateful to the University for allowing it to continue leasing the premises.

During 1991 the Society announced with regret the retirement of Mrs Judy Day as Assistant Secretary after 15 years' service. The Council wishes to thank Mrs.Day for her long and loyal service to the Society.

Mrs.Margaret Evans accepted the position of Assistant Secretary in Mrs.Day's stead.

LIBRARY

Acquisitions by gift and exchange continued as heretofore, the overseas and most Australian material being lodged in the Royal Society of New South Wales' Collection in the Dixson Library, University of New England. The remainder of the Australian material was lodged in the Society's office at North Ryde. The Council thanks Mr. Karl Schmude, University of New England, for his continuing care and concern in ensuring the smooth operation of the Royal Society Collection and associated inter-library photocopy loans.

An accession list for all material lodged at the Society's office has been programmed for each calendar half-year and tabled at Council meetings.

Accommodation for the Society's holdings remains limited. Nevertheless, the large historical collection housed in glass-fronted cabinets is in reasonably good condition, however, several monographs require some restoration.

A donation of bound Volumes 32-89 of the "Journal and Proceedings of the Royal Society of New South Wales", together with single unbound issues of Volumes 90-100, was received from the Burfitt family. These have been added to the store of back issues of the Journal held at the Society's office.

The Council thanks members of the family of Mrs. Barbara MacNamara for this gift.

NEW ENGLAND BRANCH REPORT

The Branch held six very successful meetings during the year, the 30th anniversary of its existence:

Tuesday 23 April 1991:
Associate Professor G.A.Woolsey, Department of Physics, University of New England, spoke on "Keeping in touch in the 1990's - the story of optical fibre communications".

Tuesday 14 May 1991:
Professor S.K.Runcorn, FRS, of the University of Newcastle-upon-Tyne, U.K. spoke on: "Continental drift and planetary interiors".

Tuesday 11 June 1991:
Dr.B.C.McKelvey of the Department of Geology and Geophysics, University of New England, spoke on "New botanical evidence of a recent climatic change in Antarctica".

Wednesday 31 July 1991:
Professor B.A.Hills of the Department of Physiology at the University of New England spoke on "The digestive system and why the stomach does not digest itself".

Wednesday 28 August 1991:
Professor R.J.Arculus of the Department of Geology and Geophysics at the University of New England spoke on "Island Arcs".

Wednesday 18 September 1991:
Dr.Marte Kiley-Worthington of the University of Sussex spoke on: "Animal welfare: towards symbiosis in the 21st century".

ABSTRACT OF PROCEEDINGS

APRIL 3, 1991
(a) The 1016th General Monthly Meeting. Location: The Peppermint Room, at the Australian Museum, Sydney. The President, Mr.G.W.K.Ford, was in the Chair and 37 members and visitors were present.

Stephen Damian Lyons, Milena Amanda Valis, and John Arthur Ross were elected to membership.

Dr.John Paul Wild was elected an Honorary Member by Council at its meeting on 28 November 1990. Dr.Wils is Chairman of the VFT Joint Project and was formerly Chairman of the CSIRO.

James Butler Stoney was elected an Associate Member at the Council Meeting of 6 February 1992.

(b) The 123rd Annual General Meeting. The Annual Report of Council for 1990/1991 and the Financial Report for 1990 were adopted, and Messrs Wylie and Puttock were re-elected as Auditors for 1991.

The following Awards for 1990 were announced:
Clarke Medal(Zoology):
Barry Gillean Molyneux Jamieson
Society Medal:
Dr.Frederick Linstead Sutherland
Edgeworth David Medal:
Dr.Timothy Fridtjof Flannery

The Cook Medal, the Olle and Walter Burfitt Prizes were not awarded this year.

The following Office-bearers and Council were elected for 1991-1992:

President:	Dr.E.C.Potter
Vice-Presidents:	Mr.G.W.K.Ford
	Mr.H.S.Hancock
	Assoc.Prof.Denis E.Winch
	Dr.F.L.Sutherland
	Emer.Prof.R.L.Stanton
Honorary Secretaries:	Dr.R.S.Bhathal
	Mrs.M.Krysko v.Tryst (Editorial)
Honorary Treasurer:	Dr.A.A.Day
Honorary Librarian:	Miss P.M.Callaghan
Members of Council:	Mr.C.V.Alexander
	Mr.J.R.Hardie
	Prof.J.H.Loxton
	Mr.E.D.O'Keeffe
	Mr.T.J.Sinclair
	Assoc.Prof.W.E.Smith
	Dr.D.J.Swaine

The retiring President, Mr.G.W.Ford, delivered his Presidential Address entitled "Fire from Heaven, or, P5 (Proton Power: Past, Present and Prospective)". ^A vote of thanks was proposed by Dr.Edmund C.Potter.

MAY 1, 1991
1017th General Monthly Meeting. Location: The Peppermint Room, the Australian Museum, Sydney. The President, Dr.E.C.Potter, was in the Chair, and 33 members and visitors were present.

Dr.Keith Brown, former Head of the Radiation Biology Group at ANSTO gave an address on "Health Hazards Associated with Extremely Low Frequency Electromagnetic Fields from Power Lines and Home Appliances".

JUNE 5, 1991
1018th General Monthly Meeting. Location: The Peppermint Room, at the Australian Museum, Sydney. The President, Dr.E.C.Potter, was in the Chair, and 16 members and visitors were present.

Edmund James Minty, jnr. was elected to membership.

An address was given by Mr.Colin Pitchfork, Head of Division of Chemical and Food Technology, NSW TAFE Commission, entitled " Learning from Coins".

JULY 3, 1991

1019th General Monthly Meeting. Location: The Peppermint Room, at the Australian Museum, Sydney. The President, Dr.E.C.Potter, was in the Chair, and 26 members and visitors were present.

Dr.T.F.Flannery, Head of the Mammal Section, Division of Vertebrate Sciences, at the Australian Museum, Sydney, gave an address on "The Impact of Humans upon the Biota of Australasia".

AUGUST 7, 1991

1020th General Monthly Meeting. Location: The Peppermint Room, at the Australian Museum, Sydney. The President, Dr.E.C.Potter, was in the Chair, and 27 members and visitors were present.

It was announced, with regret, the death of Mr.Francis George Arnot Mort on 16th July 1991. Mr.Mort joined the Society in 1934, and was elected Life Member on 29th September 1976.

The address, given by Mr. Sol Lebovic, Managing Director of Newspoll Research, was entitled " Opinion Polling - Art or Science?".

SEPTEMBER 4, 1991

1021st General Monthly Meeting. Location: The Peppermint Room, at the Australian Museum, Sydney. The President, Dr.E.C.Potter was in the Chair, and 22 members and visitors were present.

Dr.Alison Rodger of U.K. was elected Spouse Member.

Dr.Helene A.Martin, who has been a member since 1976, resigned from the Society.

The address was given by Dr.David Rees, of Division of Radiophysics, CSIRO, on "Chaos in Brain Function".

OCTOBER 2, 1991

1022nd General Monthly Meeting. Location: The Peppermint Room, at the Australian Museum, Sydney. The President, Dr.E.C.Potter, was in the Chair, and 18 members and visitors were present.

Dr.Margaret Ann Hanlon was elected member of the Society.

The address was given by Dr.Michael Dean of the State Pollution Control Commission, and was entitled " Incinerator Technology Overseas".

NOVEMBER 6,1991

1023rd General Monthly Meeting. Location: University of Western Sydney (Nepean). The President, Dr.E.C.Potter, was in the Chair, and 44 members and visitors were present.

Keith Harper, John Andrew Shaw, and Marguerita Tracanelli Millikan, were elected to membership.

The address was given by Dr.Graeme White of the Department of Physics, University of Western Sydney (Nepean), and was entitled "Astronomy from the Ground and from Space".

EERRATUM: Vol.124, p 85:

3.para, line 20-21 should read:

"...., with whom he served (in the South West Pacific) until 1945."

FINANCIAL STATEMENTS FOR THE YEAR ENDED 31ST DECEMBER

AUDITORS REPORT TO THE MEMBERS

We have audited the accounts set out on pages 2 to 9 in accordance with Australian Auditing Standards.

In our opinion, the accounts are properly drawn up in accordance with the Rules of the Society and so as to give a true and fair view of the state of affairs of the Society as at 31 December 1991 and of the results of the Society for the year ended on that date and are in accordance with Statements of Accounting Concepts, and Applicable Accounting Standards.

The accounting records and other records, and the registers required by the Rules to be kept by the Society have been properly kept in accordance with the provisions of those Rules.

WYLIE & PUTTOCK
Chartered Accountants

ALAN M. PUTTOCK

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET as at 31st December 1991

	CURRENT ASSETS			
192.05	Petty Cash Imprest		249.23	
1175.83	Debtors for Subscriptions	1701.57		
	Less Provision For Doubtful			
1175.83	Debts	1701.57		
10294.06	Other Debtors & Prepayments		4834.68	
10788.46	Cash at Bank		7537.78	
----------			----------	
21274.57	TOTAL CURRENT ASSETS			12621.69
	NON-CURRENT ASSETS			
	Property, Plant & Equipment			
	Office Equipment - at 1991			
0.00	valuation less Depreciation		5883.00	
	Furniture, Office Equipment, etc.- at cost less			
955.37	Depreciation		975.37	
	Library - 1936 Valuation			
13600.00	(note 4)		13600.00	
	Pictures - at cost less			
10.00	Depreciation		10.00	
----------			----------	
14565.37			20468.37	
	Investments			
	Commonwealth Bonds &			
2500.00	Inscribed Stock	0.00		
100000.00	Loans on Mortgage	0.00		
40422.11	Interest Bearing Deposits	149198.81		
----------		----------		
142922.11			149198.81	
----------			----------	
157487.48	TOTAL NON-CURRENT ASSETS			169667.18
----------				----------
178762.05	TOTAL ASSETS			182288.87
----------				----------
	CURRENT LIABILITIES			
20637.96	Sundry Creditors & Accruals		6359.00	
	Life Members Subscriptions -			
23.67	Current Portion		23.67	
	Membership Subscriptions			
176.21	Paid in Advance		88.45	
	Subcriptions to Journal Paid			
1500.00	in Advance		1418.22	
----------			----------	
22337.84	TOTAL CURRENT LIABILITIES			7889.34
	NON-CURRENT LIABILITIES			
	Life Members Subscriptions -			
159.41	Non-Current Portion		135.74	
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	TOTAL NON-CURRENT			
159.41	LIABILITIES			135.74
----------				----------
22497.25	TOTAL LIABILITIES			8025.08
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BALANCE SHEET as at 31st December 1991

156264.80	NET ASSETS	174263.79
==========		==========
	RESERVES	
7310.57	Library Reserve (note 2(a))	7310.57
6715.18	LIBRARY FUND (note 2(b))	9364.03
23078.43	TRUST FUNDS (note 3)	24910.28
119160.62	ACCUMULATED FUNDS	132678.91
----------		----------
156264.80	TOTAL RESERVES AND FUNDS	174263.79
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E.C. POTTER President

A.A. DAY Honorary Treasurer

ACCUMULATED FUNDS ACCOUNT
For the Year Ended 31st December 1991

(2861.53)	OPERATING SURPLUS for year (note 5)		6550.99
924.08	Donations & Interest to Library Fund		2689.15
0.00	Equipment Donations (note 6)		6927.00
2028.25	Transfer from Library Fund		40.30
119993.90	Accumulated Funds - Beginning of Year		119160.62
120084.70	AVAILABLE FOR APPROPRIATION		135368.06
924.08	Transfer to Library Fund	2689.15	
924.08			2689.15
119160.62	ACCUMULATED FUNDS - End of Year		132678.91

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1991

1. SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES

The accounts have been prepared in accordance with applicable approved accounting standards.
Set out hereunder are the significant accounting policies adopted by the Society in the preparation of its accounts for the year ended 31st December, 1991. Unless otherwise stated, such accounting policies were also adopted in the preceding year

(a) Basis of Accounting

The accounts have been prepared on the basis of historical costs and do not take into account changing money values or, except where stated, current valuations of non-current assets.

(b) Depreciation

Depreciation is calculated on a written down value basis so as to allow for anticipated repair costs in later years.

The principal annual rates in use are:

Furniture	7.50%
Office Equipment	15.00%

2. MOVEMENTS IN PROVISIONS AND RESERVES

(a) Library Reserve

7310.57	Balance at 1st January	7310.57
7310.57	Balance at 31st December	7310.57

(b) Library Fund

7819.35	Balance at 1st January		6715.18
924.08	Add Donations and bank interest		2689.15
8743.43			9404.33
28.25	Less Library purchases and expenses	40.30	
2000.00	Transfer to general fund re costs exchange jnls for library	0.00	
2028.25			40.30
6715.18	Balance at 31st December		9364.03

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1991

3. TRUST FUNDS

	Clarke Memorial Fund - Capital			
5000.00	Balance at 1st January	5000.00		
5000.00	Balance at 31st December		5000.00	
	Clarke Memorial Fund - Revenue			
965.70	Revenue Income for Period	661.37		
85.89	Less Expenditure for Period	146.86		
879.81		514.51		
43.63	Balance at 1st January	923.44		
923.44	Balance at 31st December		1437.95	
5923.44				6437.95
	Walter Burfitt Prize Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Walter Burfitt Prize Fund - Revenue			
459.40	Revenue Income for Period	396.82		
459.40		396.82		
3480.43	Balance at 1st January	3939.83		
3939.83	Balance at 31st December		4336.65	
6939.83				7336.65

	Liversidge Bequest Fund - Capital			
3000.00	Balance at 1st January	3000.00		
3000.00	Balance at 31st December		3000.00	
	Liversidge Bequest Fund - Revenue			
834.40	Revenue Income for Period	396.82		
1040.00	Less Expenditure for Period	5.40		
(205.60)		391.42		
825.44	Balance at 1st January	619.84		
619.84	Balance at 31st December		1011.26	
3619.84				4011.26

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31st December 1991

	Olle Bequest Fund - Capital			
4000.00	Balance at 1st January	4000.00		
4000.00	Balance at 31st December		4000.00	
	Olle Bequest Fund - Revenue			
612.60	Revenue Income for Period	529.10		
612.60		529.10		
1982.72	Balance at 1st January	2595.32		
2595.32	Balance at 31st December		3124.42	
6595.32				7124.42
23078.43	Total Trust Funds			24910.28

4. LIBRARY

During the 1983 year the Society gifted the serials collection component of the library to the University of New England. The Society has retained that section of the library which is of historical significance. At the 31st December, 1991 a current valuation of the library had not been obtained.

5. OPERATING SURPLUS

The operating surplus this year includes the benefit resulting from an overestimation of journal publication and distribution costs to be incurred in 1991 but expensed in 1990 and subsequent achievement of significant cost savings in 1991. The effect of this on the operating surplus is shown below:

(2861.53)	OPERATING SURPLUS for year (note 5)	6550.99
4605.34	Overestimated costs re J & P Vol. 123	(4605.34)
1999.35	Underestimated costs re J & P Vol. 122	0.00
3743.16	Adjusted operating surplus	1945.65

6. EQUIPMENT DONATION

Equipment donation includes a model PS/2#30 computer donated by IBM Australia Ltd to the Society at a value of $6927 in April 1991.

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1991

	INCOME			
7288.50	Membership Subscriptions - Ordinary			7806.75
25.77	Membership Subscriptions - Life Members			23.67
57.00	Application Fees			43.00
7371.27				7873.42
8137.74	Subscriptions and Contributions to Journal Publication Costs			4718.14
15509.01	Total Membership and Journal Income			12591.56
18404.80	Interest Received			16393.12
37.70	Sale of Reprints			30.00
266.20	Sale of Back Numbers			63.00
10.00	Sale of Other Publications			20.00
27.50	Photocopying Refunds			9.18
0.00	Research Fees			10.00
0.00	Summer School Surplus			58.59
34255.21				29175.45
	Less:EXPENSES			
1933.00	Accountancy Fees		2050.00	
116.86	Annual Dinner Deficit		23.10	
967.00	Audit Fees		1025.00	
30.70	Bank Charges & Government Duties		103.18	
0.00	Branches of the Society		150.00	
0.00	Computer Software		465.00	
121.00	Depreciation		1154.00	
271.80	Entertainment Expenses		443.00	
80.80	Insurance		541.28	
	Journal Publication and Distribution Costs			
14294.85	Printing	(178.43)		
4046.99	Wrapping & Postage	1523.57		
18341.84			1345.14	
28.25	Library Expenses		40.30	
0.00	Long Service Leave		1507.11	
2727.43	Miscellaneous Expenses		792.14	

100.00	Monthly Meeting Expenses	410.00	
	Newsletter Printing &		
1982.39	Distribution	2111.66	
305.36	Postage	704.55	
	Printing & Stationery -		
226.97	General	849.17	
(68.67)	Provision for Doubtful Debts	923.74	
2000.00	Rent	2000.00	
400.00	Repairs & Maintenance	88.00	
6435.83	Salaries	5642.69	
845.90	Summer School Deficit	0.00	
270.28	Telephone	255.40	
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37116.74			22624.46
----------			----------
(2861.53)	SURPLUS for the year		6550.99
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FUNDS STATEMENT
For the Year Ended 31 December 1991

SOURCE OF FUNDS		
Funds from operations		19678.73
Reduction in assets		
Current assets		8127.14

Total source of funds		27805.87
		==========
APPLICATION OF FUNDS		
Increase in non-current assets		
Property, plant & equipment	7057.00	
Investments	6276.70	

		13333.70
Reduction in liabilities		
Current liabilities	14448.50	
Non-current liabilities	23.67	

		14472.17

Total application of funds		27805.87
		==========

RECONCILIATION OF FUNDS FROM
OPERATIONS WITH OPERATING SURPLUS:

Operating surplus	6550.99
Add	
Depreciation	1154.00
Provision for doubtful debts	525.74
Library Fund movement	2689.15
Trust Fund movement	1831.85
Equipment donation	6927.00

Funds from operations	19678.73
	==========

COOK MEDAL FOR 1991

The James Cook Medal is awarded for "outstanding contributions to science and human welfare in and for the Southern Continent". The Cook Medal for 1991 is awarded to Professor Graeme Milbourne Clark, Foundation Professor of Otolaryngology at the University of Melbourne.

After graduating from the University of Sydney, he was a resident medical officer at two Sydney hospitals and a registrar at two English hospitals. He then returned to the University of Sydney where he completed two higher degrees, a Master of Surgery and Doctor of Philosophy. Around this time Professor Clark started studying the ear and problems of deafness.

Fundamental research on brain cells led to behavioural studies on experimental animals and eventually to considerations of the possibility of developing a device to overcome deafness in humans. An important question had to be answered, namely "could the inner ear be invaded surgically without damaging the very nerves that would need to be electrically stimulated?" During the past 20 years Professor Clark and his team have carried out painstaking studies involving multi-disciplinary research in physiology, biology, surgery, engineering, speech science and related fields. Eventually a complete receiver-stimulator unit was implanted in a patient and a mini device was developed for use with children. The production of the multi-electrode cochlear implant or bionic ear means that many hundreds of totally deaf people are now able to hear.

Clearly Professor Clark has carried out fundamental research and difficult developmental work of the highest order. He is the leader in his field and he and his team are recognised world-wide for their pioneering work. It is significant that this work is the basis of an Australian industry for the production of aids for the deaf which are exported to more than twenty countries.

In view of his outstanding research and many achievements, not the least being nearly 400 publications, it is most fitting that Professor Graeme Clark joins the list of illustrious Cook medallists.

CLARKE MEDAL FOR 1991

The Society's Clarke Memorial medal for 1991 is awarded to Dr Shirley Winifred Jeffrey, Chief Research Scientist, CSIRO Division of Fisheries, Marine Laboratories, Hobart.

Shirley Jeffrey developed her biological studies at the University of Sydney in Australia. She graduated in biochemistry and microbiology in 1952 and continued her studies at that institution, gaining an M. Sc in 1954 for a thesis on the metabolism of oyster spermatozoa. From Sydney she went to Kings College, University of London and was awarded a Ph D in 1958 for her work on the effects of salicylate on carbohydrate metabolism of isolated tissues.

Since then Dr Jeffrey has explored the breadth and depths of marine botany. Her international renown was established in her work on chlorophylls C1 and C2 and the elucidation of their structures. The consequences of her recent discoveries of a new family of chlorophyll C haveenormous implications for the classification of the algae and an understanding of the evolutionary relationships between groups. She was not just content to discover and characterise the pigments but also rigorously explored the potential of a basic understanding of pigments for both theoretical and applied science. Her early work on pigments is now used in the standard equations used to measure pigments in the oceans and hence to estimate ocean productivity. Later work on more critical pigment analyses allowed for accurate quantitative analysis of the phytoplankton.

As head of the 'Algal Physiology and Ecology ' section of the CSIRO Division of Fisheries, Dr Jeffrey and her team study all aspects of marine micro-algae, physiology and biochemistry, ecology, taxonomy, cell biology and ultrastructure, and algal culture. Dr Jeffrey, recently extended her interests to field hatcheries and nurseries with axenic microalgae, for use as food for early stages of cultured animal species. She also initiated a series of "Microalgae for Mariculture" workshops. This proved a highly successful move to orient research to the needs of industry and establish a process of technology transfer. With her co-workers, Dr Jeffrey has helped identify the causative organisms in paralytic shell fish poisoning and bitter taste contamination due to toxic algae. The group is presently tackling factors causing blooms of toxic species.

Dr Jeffrey has published extensively maintaining a prodigious research output while undertaking major administrative roles for her organisation. She has made many contributions to education of marine science through her writings, editorial work, workshops, UNESCO activities and provision of laboratory materials. In 1988, she was awarded the inaugural Jubilee Award for Excellence in Marine Science by the Australian Marine Sciences Association. In May 1991 she was elected a Fellow of the Australian Academy of Science for outstanding contributions to science and marine research. Dr Jeffrey is an admirable choice to be the recipient of the Clarke Medal for 1991.

EDGEWORTH DAVID MEDAL FOR 1991

The Edgeworth David Medal, for distinguished contributions to Australian science by a young scientist under the age of 35, is awarded to Dr Mark Stephen Harvey, BSc, PhD *Monash.*

Mark Harvey is Curator of Arachnids at the Museum of Western Australia, a post he has held since 1989. His appointment to the curatorship testifies to his international standing and outstanding scientific achievements.

His work has centred on the systematic survey of pseudoscorpions of the Australasian region. He has written a detailed catalogue of all species of pseudoscorpions which stands as the definitive work on these species. Amongst his 44 research papers, he has described new species of water mites and revised the description of micro-whip scorpions, revealing 25 species in 5 new genera for which he has proposed a novel naming system. His work on arachnid biogeography shows close relationships between Australia, India, southern Africa and Madagascar and indicates an ancient faunal assemblage in Australia. He has received support from the prestigious Australian Biological Resources Study for studies of three quite separate orders of arachnids.

Mark has a reputation as an excellent speaker, noted for the clarity and humour of his presentations. He has been successful in communicating science to both expert and general audiences and his book *Worms to Wasps*, written jointly with Alan Yen, brings the numerous wonders of Australian invertebrates to lay readers. He is Editor of the journal

Australasian Arachnology and a member of the Editorial Boards of several other journals in his field.

Mark Harvey's contributions to taxonomy and the study of invertebrates and to the application of science to environmental issues make him a very worthy recipient of the Edgeworth David Medal.

THE ROYAL SOCIETY OF NEW SOUTH WALES MEDAL FOR 1991

The Society's Medal for contributions to the progress of the Society and to Science is awarded to Associate Professor Denis Edwin Winch, MSc, PhD *Syd*, FRAS. Denis Winch joined the Society in 1968 and was elected to the Council in 1984. He became President in 1988 and has served as Vice-President since 1989.

Denis Winch has been Associate Professor in the Department of Applied Mathematics at the University of Sydney since 1973. He is known nationally and internationally for his research on the Earth's magnetic field and this was the subject of his Presidential Address in 1989. Geomagnetism, the mathematical analysis of spherical harmonic functions which underpins it, and the interpretation of magnetic variations and wobbles are the themes which have driven his work throughout a long career at the University of Sydney. He has for some years been a member of a Working Group of the International Association of Geomagnetism and Aeronomy concerned with defining the slowly-varying part of the Earth's magnetic field through the analysis of data contributed by observing stations around the world. In a recent joint project with Professor Keith Runcorn of the University of Newcastle-upon-Tyne and others, he is using voltage measurements on undersea cables to monitor variations in the magnetic field and to define the contributions from the solar and lunar cycles and those generated within the Earth. He has observed that changes in the variation of the Earth's magnetic field can be linked to changes in the structure of the upper atmosphere and to changes in global ocean circulation. His work is therefore relevant to the understanding of ozone levels in the stratosphere and perhaps also to the interpretation of the so-called Greenhouse Effect.

Denis is a most conscientious university teacher and a capable and patient administrator. He was the First Acting Head of the School of Mathematics and Statistics at the time of the historic merging of the separate Departments of Pure and Applied Mathematics at the University of Sydney into a single School. He then served as Deputy Head of the School throughout 1991, responsible for most of the administration and for setting the new enterprise on its feet.

He has brought the same qualities to his work in the Royal Society of New South Wales. He ran a very successful Summer School on Light in 1985 and played a major role in the Summer School on Computing and Science in 1986. He has agreed to take on the arduous duties of Honorary Treasurer for the Society in 1992.

Denis Winch's contributions to the Society and to science through his work in mathematics and magnetism make him a very worthy recipient of the Society's Medal.

ARTHUR FREDERICK ALAN HARPER, AO, MSc, F.Inst.P, FAIP (Hon.)

I first met Mr.Harper back in 1947. I was then a newly graduated physicist responsible for temperature standards at the Defence Research Laboratory, Maribyrnong, Victoria. Mr.Harper had agreed to accept me for a four-weeks training period in his Heat Section at the CSIRO National Standards Laboratory (NSL), as it was then called. It was my privilege to return to the NSL from mid-1956 to late 1958 to assist with research into the establishment of the International Temperature Scale. Mr.Harper not only taught me how to undertake scientific research, he also introduced me (as he did many others) to the Royal Society of New South Wales where I was admitted as a member while he was its President during 1959/60.

I apologise for these references to myself in this tribute to his memory. I want to emphasise that I do not write about Mr.Harper as a stranger but that I owe him a substantial debt of gratitude, and this in many more ways than for the incidents cited above. I have known many others in the same position as myself because Alan Harper was essentially a giver, someone whose inner resources could enrich the personalities of those around him.

Through hard thinking and hard working he had amassed an impressive wealth of high character traits and intellectual competence. These were the characteristics he brought to bear on whatever he did. The Royal Society of New South Wales, its members and its Council, were fortunate recipients of these gifts while Mr.Harper served on Council from 1955 to 1967 and continued to give his valuable support while no longer an office bearer. He was a highly deserving recipient of the Medal of the Society and was later elected a Life Member.

Mr.Harper's contributions to the physical sciences and to society at large are summarised on the attached list. The length of this list is an eloquent testimony to the abilities, the generosity and the public-spiritedness of the man. He was a devoted and conscientious husband and father, a competent colleague who stood by his undertakings through "thick and thin", and a thoughtul and considerate boss to those who worked under his direction.

Although he had his share of honours and recognition - needless to add, a much smaller share than due to his work on behalf of all of us - fate imposed upon him many heavy burdens which he bore with uncomplaining fortitude.

No-one who looks at his manifold achievements over some five decades and a very wide field of activities - notably his crowning achievements as Executive Member of the Australian Metric Conversion Board and Chairman of the National Standards Commission - would not feel pride and satisfaction to have been in some ways associated with him or regret not to have had the privilege of having met him in person. While there will be a Royal Society of New South Wales, its members will treasure the memory of Arthur Frederick Alan Harper.

G.C.L.

ARTHUR FREDERICK ALAN HARPER (1913-1991)
BIOGRAPHICAL SUMMARY
(relating to his scientific career)

1913	Born in Sydney
1924-8	Educated in England; First-class Honours in Oxford Senior Examinations 1928
1928	Returned to Australia and completed secondary schooling at Wolaroi College, Orange
1929	NSW Leaving Certificate
1930-4	BSc (Sydney University) with First-class Honours & University Medal (1934) in Physics
1933	Co-founder and President, Sydney University Physical Society
1935	MSc (Sydney University) in Physics for research on an

	accurate determination of the absolute velocity of beta particles from Radium (B+C)
	Appointed Physicist to Hospitals in NSW by the Cancer Research Committee of the University of Sydney
1936	President, Sydney University Science Association
	Member, Royal Society of NSW
1938	Elected to Associateship of the Institute of Physics (A.Inst.P)
1939	Awarded Studentship in Physics by the Council for Scientific and Industrial Research (CSIR) to be trained at the National Physical Laboratory (NPL), Teddington, in activities related to the newly established National Standards Laboratory of CSIR
1939-40	Training at NPL, Teddington
1941	Appointed Assistant Research Officer in the Physics Section, National Standards Laboratory, with responsibility for establishing pyrometric measurements for industry and, later, Commonwealth standards of measurement of temperature, viscometry, humidity and thermal conductivity
1943	Inaugural NSW Branch Chairman, CSIRO Officers Association (CSIROOA)
1943-5	Vice-President, CSIROOA
1945-6	President, CSIROOA
1945	Elected to Fellowship of the Institute of Physics (F.Inst.P)
1945-71	Leader, Heat Section of the CSIRO Division of Physics
1948-70	Chairman, NATA Registration Advisory Committee for Heat and Temperature Measurement
1950	Reclassified to Principal Research Officer, CSIRO
1950	W.R.G. Kemp and A.F.A.Harper first liquified helium in Australia in June 1950 in a liquifier constructed in the NSL workshop
1951	Australian representative on Technical Committee 48 (Volumetric Glassware and Thermometry) of the International Standards Organisation (ISO)
1951-60	Member and Convener, Constitution Committee, CSIROOA
1954	Harper (with R.G.Wylie and M.H.Cass) developed hypothermia equipment for heart surgery
1954-71	Member, Consultative Committee on Thermometry (CCT), International Bureau of Weight and Measures (BIPM)
1954	Assistant Secretary, National Standards Commission
1954	Australian Representative, International Institute of Refrigeration
1955-62	Honorary Secretary, Australian Branch of the Institute of Physics and the Physical Society
1957	Reclassified Senior Principal Research Officer
1963	Elected to Honorary Life Membership, CSIRO Officers Association
1963-6	Foundation Honorary Secretary, Australian Institute of Physics (AIP)
1967-8	Vice President, AIP
1967-8	Technical Consultant, Senate Select Committee on Metrication
1969-70	President, AIP
1970	Member of the S.A.A.Council
1971-81	Executive Member, Australian Metric Conversion Board
1975	Elected to Honorary Fellowship of the Australian Institute of Physics (Hon.FAIP)
1978-81	Chairman, National Standards Commission
1979-87	Executive Board Member of the S.A.A.Council

Speech by His Excellency Rear-Admiral Peter Sinclair, A.O., Governor of New South Wales, at Annual Dinner and Presentation of Medals, Royal Society of New South Wales, 18th March 1992

Dr.Edmund Potter - President Royal Society of NSW
Members of Council
Distinguished Guests
Members of the Royal Society

My wife and I are very pleased to be with you tonight for this Annual Dinner of the Society. I feel particularly honoured as Patron to have been asked to present the Royal Society Awards to worthy recipients, as I am aware of both the historical and scientific significance of these Awards.

Whilst I am very proud to be Patron of the Royal Society of New South Wales, I cannot claim to be a scientist, and I must confess that some of the papers that I read in the Society's Journal are a shade beyond my comprehension. However, I do take some comfort from the fact that my background as a Naval Officer over four decades gives me at least a tenuous link with sailors of the past who were prominent in many fields of science.

Captain Cook would have to be a classic example, and it might not be stretching credibility too far to claim that the genesis of this Society might be traced to the stimulus provided by Cook, Banks and Solander during the epic visit by "Endeavour" in 1770. Cook became a fellow of the Royal Society, as did the much and unfairly maligned Captain Bligh some years later, through his contribution to extending the frontiers of scientific discovery in his day.

Bligh also introduces my second personal link with this Society in that he was also the fourth Governor of New South Wales. Many of the early Governors made significant contributions to the advance of science in this country, but perhaps none more so than the sixth Governor, Sir Thomas Brisbane. He was an accomplished astronomer who brought the then state of the art equipment to establish an observatory at Parramatta when he first arrived in Sydney in 1821. He subsequently catalogued some 7,385 Southern Hemisphere stars. Governors clearly had more spare time in those days, or perhaps it was the absence of television!

Governor Brisbane also encouraged the formation in 1821 of the Philosophical Society of Australasia, with a view to enquiring into the various branchesof physical science of this vast continent and its adjacent regions. This later evolved into the Australian Philosophical Society in 1850, the Philosophical Society of New South Wales in 1855 and finally, due partly, I understand, to problems with the word "Philosophical", to the founding of the Royal Society of New South Wales in 1866.

The conflict between hilosophical and scientific emphasis in the name of the Society is interesting. I think it was Bertram Russell who once said that "Science is what we know and Philosophy is what we don't know".

That may be an over-simplification, and sciencific endeavour is, after all, stimulated by the unique human desire to explore and explain the unknown. However, it does seem to me that Philosophy and Science both fit well with the Society's past (and present) activities and achievements, and will continue to do so in the future.

In its two centuries of modern history, Australia can rightly claim to have made an outstanding contribution to the advancement of science; in almost every field of scientific endeavour – medicine, chemistry, geology, botany, agronomy, aviation, astronomy, to name but a few, Australians have made their mark in history; this in spite of limited resources and national support, which falls well short of that enjoyed by scientists overseas.

Our scientists are not just important - they are critical to our future in this ever competitive world, And yet, we do not seem to be able to give them the public recognition and status that their achievements deserve. Sports stars, singers, T.V. announcers, and even solid-hoofed, herbivorous quadrupeds, become national household names, but I doubt whether too many Australians could name one of the many Australian scientists of world standing.

This is sad for many reasons, and it says something about our level of maturity as a nation and our inability to identify national priorities or real substance. It is perhaps partly the reason why science subjects are not as popular as they should be in our secondary and tertiary education systems; why too many gifted Australians export their talents; and why Australian industry, with few exceptions, seems unable to properly capitalise on the extraordinary achievements of our scientific community.

We must lift the level of national recognition for science generally and leave our achievers in no doubt that they are genuine Australian heroes of whom this nation is immensely proud.

The Royal Society of New South Wales has a fundamental role to play in this process of recognition. Through the Summer School and other such initiatives, you are able to stimulate the curiosity and interest of the younger generations in science. You provide opportunities for publication of papers and debate on subjects of relevance, and through your annual awards of prizes and medals you recognise excellence in scientific achievement.

You cannot overstate the value of this contribution that the Royal Society is making to the Australian community.

I know that you will maintain the proud traditions begun so many years ago and in so doin will help to ensure that future generations will inherit an even better Australia. There could be no more noble objective.

Summer School on "Communication", January 13 - 17, 1991
Official Opening Address by the Honourable Ross Free, Minister for Science and Technology, and Minister Assisting the Prime Minister

I am pleased to be here to open the Royal Society of New South Wales 1992 Summer School.

The theme of this year's Summer School - Communication - is one of particular importance to a country as vast as Australia. It is an exciting and challenging field which is rapidly expanding and will offer many opportunities. The idea of this Summer School is to introduce young people to some of the many achievements and responsibilities of people working in this important field.

The Summer School helps increase awareness of the importance of science and technology to Australia and society in general. It also highlights to young people some of the benefits of pursuing a career in science or technology.These aims are of great interest to me, and I would like to take this opportunity to commend the hard work of all those who have been involved in making this Summer School possible.
Initiatives such as this, which capture, the imagination and stimulate an interest in science and technology are vital in promoting a positive future for Australia.

Over the last decade, the Government has done much to strengthen the role of science and technology in the life of the nation.
Commonwealth support for science and innovation has increased by 29 per cent in real terms since 1982-83. In this year's Budget, Commonwealth support rose from $2.4 billion to around $2.6 billion, an increase of 4.3%. Since then a further $30 million has been committed.Much of this support has been directed towards research and development that can be applied effectively to improving our national well-being.

We need to be able to generate income and benefits from our scientific developments. The communications field is one where Australia has been able to capture the benefits of research - the connection of remote areas of the country by solar telephones is a good example. The Government also has a strong commitment to raising awareness among young people of the importance of science and technology.

For Australia to maintain its place among the developed nations of the world, it must embrace a culture of which science and technology are vital elements.In the future, it is likely that many more Australians will become involved in technology-based employment. Expertise in the various fields of science and technology - such as communication - can give our industries a competitive edge. An excellent example is Telecom, which is now exporting its services.

Australian scientists, technologists and engineers are among the best in the world. Australian scientists have won the Nobel

Prize and an Australian, Professor Allen Kerr, was one of the winners of the first Australia Prize for outstanding contributions to science.
The winner of the second Australia Prize is to be announced in Sydney on Thursday week. The Prize this year will be given for contributions to mining science and there are many Australians among the nominations. In another outstanding achievement, a young Australian astronomer, Matthew Bailes, was one of the discoverers of the first planet found outside our solar system.

Younger Australians are acknowledged for their contributions to science and technology through the BHP Awards. For example, Gregory Fox, a 16 year old from Sydney, recently won one of the BHP Science Awards for his study of the effects of bushfires on germination of native plants.

Australians must value their scientists, technologists and engineers more highly. We make heroes of our sportsmen and women but not of our scientists. There are big-selling magazines devoted to our cricket and football stars, but I've never seen a magazine that has pin-ups of our scientists. Scientists, technologists and engineers produce real wealth for Australia - from disease free agricultural products to computer software packages. Trade in these goods and services creates jobs and helps to build a stronger, better future for Australia.

I am very pleased to see many young women here today. It cannot be overstressed how important it is that women as well as men know about and understand the importance of science and technology. Women can also have a strong influence on the attitudes of young people - as career scientists, as parents and as teachers. All young people should appreciate how science and technology affects their lives. You represent tomorrow's decision makers, workers, teachers, journalists and politicians. For the future of Australia, we need more smart, innovative, thoughtful citizens.

Young people are often uncertain about their options when making career choices, and often have mixed feelings towards possible careers in science, engineering and technology.
Yet a career in these areas does not mean being shut up in a remote laboratory. Science is a social activity. Modern scientists work as part of a team.

Communication between scientists, and with users of research results, is increasingly important. The general public are often a forgotten audience for scientific research.

The stereotype of the scientist as an awkward old man dressed in a white coat with a beard and thick horn-rimmed glasses is a myth we must put to rest.

Today, that scientist is just as likely to be a young man or woman and the white lab coat might be replaced by a business suit, a wet suit or a hard hat. Depending on one's personal interests, a career in science can lead to jobs in many fields. Many scientists work on important issues which affect us all in one way or another. Issues such as public health, the environment, agriculture and manufacturing. Skills learnt as scientists, such as the ability to research and draw conclusions based on methodical observations, can be readily applied to other areas of work.

You will discover scientists working in fields as diverse as politics, statistics, teaching and journalism. Of course, these skills can also be used effectively in managing our personal lives - in making informed consumer choices, for example.

I hope that the young people who come to this Summer School will consider careers in science or technology - the opportunities and challenges facing our nation are continually expanding. The scientists of tomorrow can and, I hope, will make the difference. I am sure you will all enjoy the coming week.

I have much pleasure in opening the Royal Society of New South Wales 1992 Summer School.

Participants in the Summer School on "Communication" , January 1992, at Macquarie University. Front row left: Dr. D.J.Swaine, Member of Council of the Society; front row right: Mrs.M.Krysko v. Tryst, Honorary Convener of the Summer School.
2nd row from front on left: Mrs.M.Potter and in centre: Mr. E.C.Potter, President of the Society.
Last row back on left: Mr.G.W.K.Ford, Vice-President of the Society.

From left to right: Mr.E.C.Potter, President of the Society, Mr.David Henry, National Manager Education, Telecom Australia, the Honourable Ross Free, Minister for Science and Technology, and Minister Assisting the Prime Minister, and Mr.Gary Lane, Regional Chief Engineer, Telecom Australia. Mr.D.Henry and Mr. G.Lane represented the sponsor of the Summer School:Telecom Australia.

The year of election to membership and the number of papers contributed to the Society's Journal are shown in brackets, thus: (1936: P6)

HONORARY MEMBERS

BIRCH, Emeritus Professor Arthur John, MSc,DPhil, FAA, CMG, FRS, AC, 14 Weatherburn Place, Bruce, ACT, 2617 (1973: P8)

CAREY, Emeritus Professor Samuel Warren, AO, DSc *Syd.*, Hon DSc. *PNG,* FNAI, FAA, "Ellimatta", 24 Richardson Avenue, Dynnyrne, Tasmania, 7000. (1938: P2)

CORNFORTH, Sir John Warcup, CBE, AC, FRS, DPhil. *Oxf.*, Nobel Prize, Royal Society Research Professor, University of Sussex, Sussex, BNI 9QJ, England. (1977: P6)

CRAIG, Professor David Parker, MSc. *Syd.*, DSc. (Hon.)*Syd.*, PhD, DSc. *London,* FRS Chem., FRACI, FAA, FRS, (1985: P7)

FIRTH, Raymond William, Emeritus Professor of Anthropology, DLitt., MA, PhD, 33 Southwood Avenue, London, N6, England. (1974)

HILL, Dorothy, Emeritus Professor of Geology & Mineralogy, CBE, PhD *Camb.*, DSc, Hon LLD(Q), FRS, FGS, FAA, c/- Dept. of Geology, University of Queensland, St.Lucia, Qld. 4067. (1970: P7)

Mc CARTHY, Frederick David, Dip.Anthr., Hon DSc *ANU*, FAHA, 10 Tycannah Road, Northbridge, 2063. (1974: P1; Pres.1956)

NOSSAL, Sir Gustav Joseph Victor, Kt, CBE, PhD FRCP, FAA, Director Walter & Eliza Hall Institute, P.O. Royal Melbourne Hospital, Melbourne, Vic. 3050. (1986)

OLIPHANT, Sir Marcus Elwin, AC, KBE, DSc, PhD, FTS, FRS, FAA, 28 Carstenz Street, Griffith, ACT, 2603. (1948)

PRICE, Sir Robert James, KBE, DSc *Adel.*, DPhil. *Oxf.*, FAA, 2 Ocean View Avenue, Red Hill South, Vic. 3937. (1976)

ROBERTSON, Emeritus Professor Sir Rutherford Ness, Kt, CMG, AC, PhD *Camb.*, DSc, FRS, FAA, P.O.Box 9, Binalong, N.S.W. 2584. (1985)

STANTON, Richard Limon, Emeritus Professor, MSc, PhD *Syd*, FAA, HonFIMM, Department of Geology, University of New England, Armidale, N.S.W. 2351 (1949;P2)

WHITE, Sir Frederick William George, KBE, CBE, DSc, PhD, FAA, FRS, 3/3 St.Ninians Road, Brighton Vic. 3186. (1973)

WILD, John Paul, AC, CBE, ScD *Camb.*, Hon DSc *ANU*, FTS, FAA, FRS, Chairman, VFT, GPO Box 2188 Canberra, ACT, 2601. (1990)

ORDINARY MEMBERS

ADRIAN, Jeanette, BSc., 18 Oxford Falls Road, Beacon Hill, N.S.W. 2106 (1970)

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ANDERSON, Geoffrey William, BSc, BE, P.O.Box 1210, Lane Cove, N.S.W. 2066 (1948)

ARCHER, Professor Michael, BA *Prin,* PhD *WA,* FRS *London,* FRZS *NSW,* School of Biological Science, University of N.S.W., P.O.Box 1, Kensington, N.S.W. 2033 (1985)

ARDITTO, Peter Andrew, BSc, MSc, Dip.Ed, BHP Petroleum, 35 Collins Street, Melbourne, Vic. 3000 (1981)

BADHAM, Dr.Charles David, MB, BS, DR *Syd,* FRACR, BSc *NSW,* "New Lodge", 96 Windsor Street, Paddington, N.S.W. 2021 (1962)

BAGGS, Dr.David Warwick, B.Arch (Hons) *NSWIT,* 9 Featherwood Way, Castle Hill, NSW. (1992)

BAGGS, Sydney Allison, BArch, DipArch, MArch, Land Des, PhD, 4 De Villiers Avenue, Chatswood, N.S.W. 2067 (1989)

BAKER, Stanley Charles, Msc, PhD, FRIP, 4 Aldyth Street, New Lambton, NSW 2305. (1934; P4)

BANFIELD, James Edmond, MSc, PhD *Melb,* Department of Botany, University of England, Armidale, N.S.W. 2351 (1963)

BANKS, Maxwell Robert, AM, BSc *Syd,* Dr (HC) *Lille,* DSc *Tas,* 38 View Street, Sandy Bay, TAS. 7000 (1951)

BARKAS, John Pallister, BSc, P.O.Box 281, Pymble, N.S.W. 2073 (1972)

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BASDEN, Helena, BSc, *Syd,* DipEd *Syd,* MAppSci *UTNSW,* 3 Norfolk Avenue, Collaroy Beach, NSW 2097 (1970)

BASDEN, Kenneth Spencer, BSc *UNSW,* PhD *UNSW,* ARACI MAusIMM, ASTC, CEng, FInstF, FAIE, MIEAust, P.O.Box 148, Lawson, N.S.W. 2783 (1951: P1)

BEADLE, Noel Charles William, Emeritus Professor, DSc *Syd,* P.O.Box 259, Armidale, N.S.W. 2350 (1964; 1983)

BEAN, Judith M., PhD,c/- Mrs.L.Hathaway, Yarrandoo, Mullaley, N.S.W. 2379 (1975; P1)

BEATTIE, David Raymond Hamilton, BSc (Hons) *Syd,* BE (ElecHons), MEngSc *UNSW,* 858 Henry Lawson Drive, Picnic Point, N.S.W. 2213 (1977)

BEAVIS, Francis Clifford, Emeritus Professor, MA *Camb*, BSc *Melb*, LLB *UNSW*, FGS, PhD *Melb*, 1 Lowan Place, Cowra, N.S.W. 2794 (1973; P1; Pres. 1978)

BENNETT, John Makepeace, Emeritus Professor, AO, BE (CIV), BE (Med & Elect), BSc *Qld*, PhD *Camb*, FACS, FBCS, FIEAust, FIMA, P.O.Box 22, Balgowlah, N.S.W. 2093 (1978)

BHATHAL, Ragbir, CertEd, BSc, PhD, FSAAS, 26 Lucinda Avenue, Georges Hall, N.S.W. 2198 (1982; P2, Pres.1984)

BILLS, Ross Maynard, MB,BS *Syd*, Shop 15B, Karaba Centre, Queenbar Road, Queanbeyan, N.S.W. 2620.(1982).

BINNS, Raymond Albert, BSc *Syd*, PhD *Camb*, C.S.I.R.O., Division of Exploration GeoScience, P.O.Box 136, North Ryde, N.S.W. 2113 (1964;P1)

BISHOP, Eldred George, 2/12 Muston Street, Mosman, N.S.W. 2088 (1920)

BLACK, David St.Clair, MSc *Syd*, PhD *Camb*, AMus A, FRACI, Professor of Organic Chemistry and Head of Dept of Organ nic Chemistry, University of NSW, P.O.Box 1, Kensington NSW 2033. (1983; P 1)

BLACK, Peter Laurence, 342 Cummins Street, Broken Hill, NSW 2880. (1975).

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BLAXLAND, David George, MB, BS *Syd*, FRCPA, "Coombe", Adaminaby, N.S.W. 2630 (1977)

BLAYDEN, Ian Douglas, BSc (Hons), PhD *Newc*, 14 Allison Street, Roseville, N.S.W. 2069 (1966)

BRAKEL, Albert T., BSc, PhD, c/- Bureau of Mineral Resources, P.O.Box 378, Canberra, A.C.T. 2601 (1968; P1)

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BROPHY, Joseph John, BSc, PhD *NSW*, DipEd *Monash* ARACI, c/- Department of Organic Chemistry, University of New South Wales, P.O.Box 1, Kensington, N.S.W. 2033 (1983; P5)

BROWN, Desmond Joseph, MSc *Syd*, DIC, PhD, DSc *Lond*, FRACI, 2 Hobbs Street, O'Connor, A.C.T. 2601 (1942)

BROWN, Henry Emanuel, MSc, 9 Watford Close, Epping, N.S.W. 2121 (1975)

BROWN, Kenneth John, ASTC, ARACI, 3 Karda Place, Gymea, N.S.W. 2227 (1963)

BRYAN, John Hamilton, BSc (Hons), PhD, Managing Director, Mc Elroy Bryan & Associates Pty. Ltd., P.O.Box 34, Willoughby, N.S.W. 2068 (1968)

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BURNS, Bruce Bertram, OBE, MDS, FICD, 3 Ocean Grove, Collaroy NSW 2097 (1961)

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CALLENDER, John Hardy, BSc *UNSW*, MSc (Hons) *Wollg*, 11 Lisa Valley Close, Wahroonga, N.S.W. 2076 (1969)

CAMPBELL, Ian Gavin Stuart, BSc, 10/6 Warwilla Avenue, Wahroonga, N.S.W. 2076 (1955)

CAMPBELL, Kenton Stewart Wall, MSc, PhD *Qld*, FAA, Professor and Head of Department of Geology, Australian National University, Canberra, A.C.T. 2600 (1975; P1)

CARRINGTON, Richard Hewitt Christopher, ThA, 3 Highlands Avenue, Gordon, N.S.W. 2072 (1983)

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CHAFFER, Edric Keith, 66 Victoria Avenue, Chatswood, N.S.W. 2067 (1954; P1; Pres.1975)

CHARMERS, Robert Oliver, c/- Australian Museum, College Street, Sydney, N.S.W. 2000 (1933; P1)

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COENRAADS, Robert Raymond, BA (Hons) *Macq*, MSc *Brit.Columbia*, PhD *Macq*, 8 Trigalana Place, Frenchs Forest, N.S.W. 2086 (1991;P2)

COHEN, Samuel Bernard, MSc, BEc, ARACI, Unit 1, "Torrington", 95 Darling Point Road, Darling Point, N.S.W. 2027 (1940)

COLE, Edward Ritchie, MSc *Syd*, PhD *UNSW*, FRACI, "Twickenham", 3/58 Vimiera Road, Eastwood, N.S.W. 2122 (1940; P2)

COLE, Joyce Marie, BSc, "Twickenham", 3/58 Vimiera Road, Eastwood, N.S.W. 2122 (1940;P1)

COLE, Trevor William, BE *WA*, PhD *Camb*, P.N.Russell Professor of Electrical Engineering University of Sydney, N.S.W. 2006 (1978;P1; Pres.1982)

COLLETT, Gordon, BSc, DipEd, ARACI, 16 Day Road, Cheltenham, N.S.W. 2119 (1940)

COLLINSON-SMITH, Phillis Ogilvie, P.O.Box 130A, Armidale, N.S.W. 2350 (1986)

COOK, James Lindsay, BSc, MSc, PhD *UNSW*, 17 Wallumatta Road, Caringbah, N.S.W. 2229 (1990;P1)

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CREELMAN, Robert Auchterlonie, BA, MSc, PhD, 108 Midson Road, Epping, N.S.W. 2121 (1973)

CROOK, Keith Alan Waterhouse, MSc *Syd*, PhD *NE*, BA *ANU*, Department of Geology, Australian National University, Canberra, A.C.T. 2600 (1954;P9)

DAVIES, George Frederick, AMIET *Lond*, 57 Eastern Avenue, Kingsford, N.S.W. 2032 (1952)

DAY, Alan Arthur, BSc *Syd*, PhD *Camb*, FRAS, P.O.Box 176, Lindfield, N.S.W. 2070 (1952;P3; Pres.1965)

DRAKE, Lawrence Arthur, BA (Hons), BSc *Melb*, MA, PhD *CALIF*, c/- Riverview College, Observatory, Riverview, N.S.W. 2066 (1962;P3)

DREW, Colleen Ann, BSc (Hons), PhD *Syd*, 40 Moreshead Drive, South Hurstville, N.S.W. 2221 (1987)

DULHUNTY, John Allan, DSc *Syd*, Department of Geology and Geophysics, University of Sydney, N.S.W. 2006 (1937; P28; Pres.1947)

ELLISON, Dorothy Jean, MSc, Unit 313, Northhaven Retirement Village, 1332 Pacific Highway, Turramurra, N.S.W. 2074 (1949)

ENGEL, Brian Adolph, MSc *NE*, PhD, Department of Geology, University of Newcastle, N.S.W. 2308 (1961;P1)

EVANS, Philip Richard,BA *Oxf*, PhD *Brist*, FGS, 14A Mallory Avenue, West Pymble, N.S.W. 2073 (1968; P2)

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FAYLE, Rex Dennis Harris, DipPharm, P.O.Box 261, Armidale, N.S.W. 2350 (1961)

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Contents

VOLUME 125 Parts 1 and 2

MIDDLEMOST, E.A.K., DULHUNTY, J.A., and BECK, R.W.:
Some Mesozoic Igneous Rocks from Northeastern New South Wales and their Tectonic Setting. 1

BROWN, J.K.:
Health Hazards associated with Extremely Low Frequency Electromagnetic Fields from Power Lines and Home Appliances. 13

BSTRACT OF THESIS:
COENRAADS, Robert R.: Alluvial Sapphire and Diamond Deposits of the New England Gem Fields, New South Wales, Australia. 19

RRATUM: Vol.124, p 85 26

ANNUAL REPORT OF COUNCIL 1991-1992:
- Report 23
- Abstract of Proceedings 25
- Financial Statements 27
- Awards 31
- Biographical Memoirs 34

ADDRESS BY HIS EXCELLENCY REAR-ADMIRAL PETER SINCLAIR, A.O., GOVERNOR OF NEW SOUTH WALES, ANNUAL DINNER 1992 36

SUMMER SCHOOL "COMMUNICATION" JANUARY 1992, OPENING ADDRESS BY THE HONOURABLE ROSS FREE, MINISTER FOR SCIENCE AND TECHNOLOGY 37

MEMBERSHIP LIST 41

DATE OF PUBLICATION, PARTS 1-2: JUNE 1992

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Ordovician island biotas: New South Wales record and global implications

B.D.WEBBY

Clarke Memorial Lecture, delivered to the Royal Society of New South Wales, 23rd October 1991, at the Australian Museum

ABSTRACT

The Ordovician period of earth history from about 500 to 430 Ma was characterized by significant phases of subduction-related volcanic activity and major evolutionary radiations of marine invertebrate taxa. Two important associations of Ordovician volcanics and sediments are preserved in fault-bounded remnants of the Lachlan Fold Belt in central New South Wales. The stratigraphy of both remnants (Molong High and Parkes Platform) is similar, with an early-mid Ordovician phase of volcanicity, then a quieter phase of island shelf-fringing to non-fringing bank-type shallow carbonate deposition, part drowning to form deeper island slope and basin conditions, and then resumption of volcanicity to the end of the Ordovician. A uniquely well-preserved record of low-latitude, offshore island shelf to slope biofacies assemblages of Gisbornian-Eastonian (Caradoc-early Ashgill) age has been documented. The terrigenous-fringing inner shelf includes three low-diversity associations, specifically, two transgressional, the lingulide and *Eodinobolus* biofacies of quiet water, intertidal aspect, and a third, the regressional, rhynchonellide biofacies, associated with rough water, on a sandy to pebbly substrate. The mid shelf has an open, shoal-type coral *(Tetradium cribriforme)* and stromatoporoid-dominated biofacies, and the outer shelf a richly diverse level-bottom strophomenide biofacies associated with a muddy substrate below wave base. Also recorded are shallow, quiet-water, terrigenous-free, "lagoonal" platform biofacies, and deeper, island slope periplatform ooze and graptolite basin biofacies. The periplatform oozes occur in allochthonous blocks, and exhibit a remarkably diverse siliceous sponge fauna.

The major Ordovician radiations have been attributed mainly to the global expansion of major invertebrate taxa, especially elements of the "Paleozoic" fauna of Sepkoski. Using the North American Platform as model, Sepkoski proposed that elements of the "Paleozoic" fauna, after originating onshore, were displaced progressively offshore through time. Inspection of the New South Wales onshore-offshore record of island biotas shows, on the contrary, the highest levels of productivity of new higher taxa and community types in the mid-outer shelf and slope habitats, not onshore. Moreover, there is no evidence of offshore displacement of stocks through the 10-15 Ma history of the island complex. A strong bias in the global Ordovician fossil record exists because continental platform biotas are much more widespread, accessible and well preserved than those of island habitats. The latter are often destroyed by subduction or much altered by metamorphism. Only by focussing on the few small remnants ("windows") of well preserved Ordovician island biotas like the New South Wales occurrences, given how significant modern islands are in explaining evolution and dispersal of organisms, can we expect to achieve a truly balanced global view of how the Early Palaeozoic diversification of metazoan life, including the Ordovician radiations, may have occurred.

INTRODUCTION

Mr President, Ladies and Gentlemen, we meet this evening to pay tribute to the memory of the late Rev. W.B Clarke, whose pioneering contributions on the geology of New South Wales during four decades from the early 1840s laid foundations for all future geological work in this state. His stratigraphic ordering of the New South Wales successions, especially in the Sydney Basin, and his observations on the distribution of coal and gold, may be singled out as particularly meritorious achievements.

Clarke made observations of extensive areas of what he called "Palaeozoic formations of the older class" (Clarke, 1860, p.197) during his tour of the Southern Highlands on goldfields work during

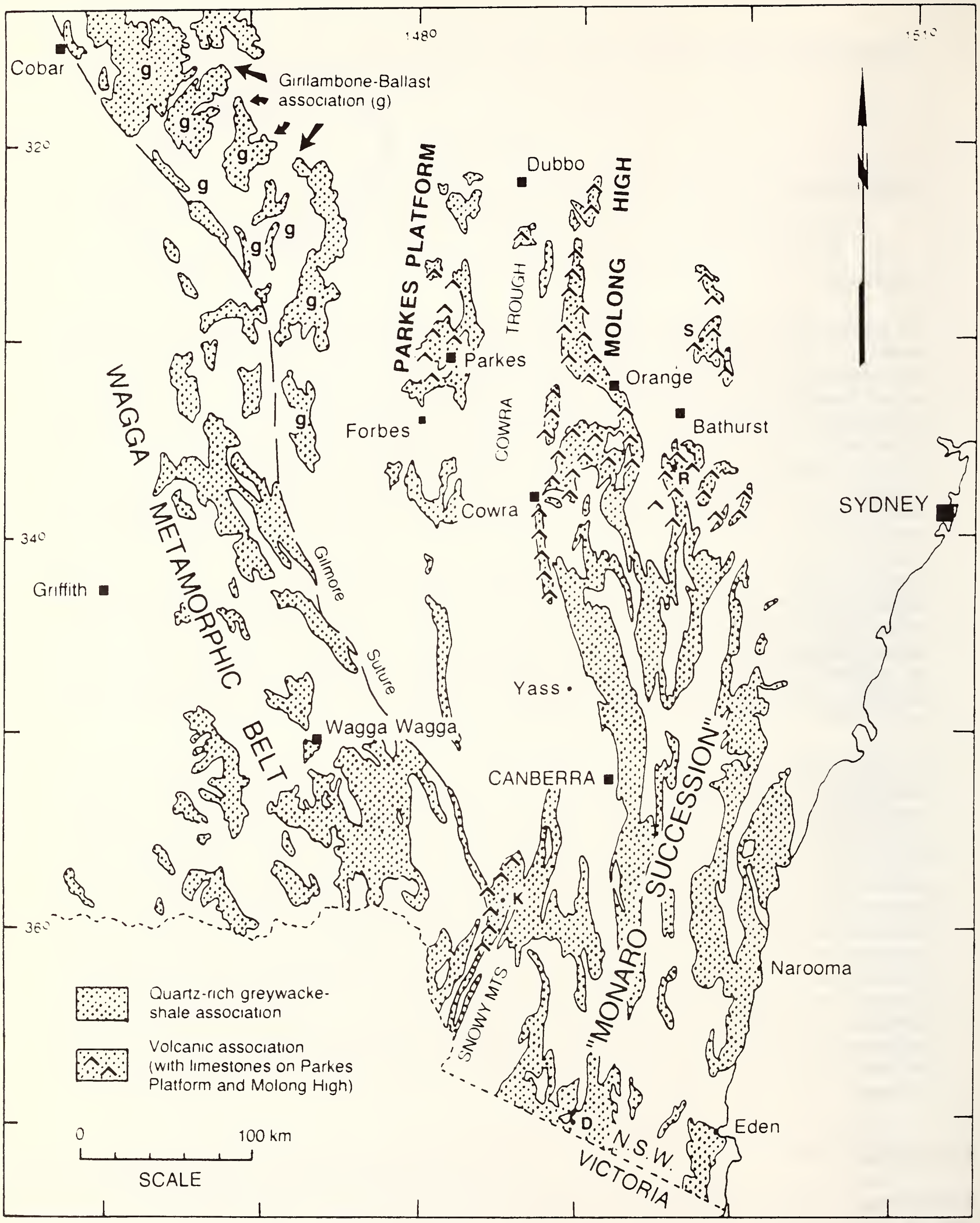


Figure 1. Map showing the distribution of Ordovician rocks in central and southern New South Wales, and the location of the four main volcanic areas in the Parkes Platform, the Molong High, the Sofala-Rockley belt near Bathurst, and the Kiandra belt in the Snowy Mountains. Key to abbreviations: S, Sofala; R, Rockley; K, Kiandra; and D, Delegate.

1851-52, but though he was able to establish a number of occurrences of Upper Silurian rocks, in areas near Delegate (Quidong), Canberra (Yarralumla), and Yass based on fossils he collected and sent to Salter and Lonsdale in England for identification (see Clarke, 1878, pp.12, 150-155), no graptolites or other fossils of Lower Silurian age were confirmed. There was little immediate follow-up work on these older rocks in central and southern New South Wales until the late 1890s and early 1900s when first graptolite fossils were found by Carne (1897; 1898) near the Victorian border. This and further discoveries were soon documented by Dun (1897; 1898) and Hall (1900; 1902), confirming the presence of extensive areas of Lower Silurian or, using the new terminology, **Ordovician,** rocks. Lapworth's (1879) stratigraphic subdivision Ordovician only became widely adopted in the early 1900s.

The slow progress towards establishing the age and distribution of New South Wales Ordovician rocks prior to the turn of the century was in marked contrast to what was happening in Victoria. Discoveries of gold in the Ordovician rocks of Victoria stimulated much exploration activity throughout the second half of the nineteenth century, and there were many finds of graptolites after A.R.C. Selwyn's initial discovery in 1856 (McCoy, 1875, p.5; Keble & Benson, 1939). Particularly important was the graptolite work of Hall (1895; 1899) on the succession of assemblages, which led to the establishment of an Ordovician graptolite zonal scheme for mapping and identifying the most auriferous parts of the Victorian successions.

The comparable New South Wales Ordovician graptolite zonal scheme was proposed more than a half century later (Sherrard, 1954; 1962). Similarly, most work on fossiliferous Ordovician successions of New South Wales, especially the limestones, only commenced in the 1950s and 1960s. The coral and stromatoporoid specimens described earlier by Etheridge (1895; 1909) were not initially recognized by him as Ordovician forms.

Stevens (1952) first established the presence of Ordovician limestones and shelly faunas in the Cliefden Caves area of the Molong High. Packham (1967) also recognized the limestones and faunas of the Billabong Creek area of the Parkes Platform as having an Ordovician age. A great deal of activity has followed, especially in documenting the biotas. Many new fossils have been described, and new interpretations of the sedimentological, palaeo-environmental and palaeotectonic relationships proposed, especially for the limestone successions of central New South Wales (Molong High and Parkes Platform). Appendix 1 lists with authors and dates all the taxonomic, palaeoecologic and palaeobiogeographic work.

REGIONAL SETTING

Extensive areas of Ordovician sedimentary and volcanic rocks occur in the Lachlan Fold Belt, and they mainly represent the oldest exposed basement rocks of the successions in central and southern New South Wales (Fig. 1). Mostly these occupy complexly folded and faulted, meridionally to NNW-trending belts. Packham (1969) emphasized the presence of two lithological associations - (i) a widely distributed quartz-rich greywacke-slate-chert association occurring in several distinct meridional belts from the South Coast near Narooma inland to Wagga Wagga, and (ii) an association of volcanics and limestones, which is far more restricted in distribution through the northern part of the Central Highlands between Mandurama and Wellington (within the Molong High), and near Parkes and Forbes (within the Parkes Platform), and other predominantly volcanic occurrrences of the Sofala-Rockley belt near Bathurst, and in the Kiandra belt of the Southern Highlands.

The association of volcanics and limestones occupies an intermediate position between the predominantly quartz-rich greywackes and slates of the Monaro "Trough" (Scheibner, 1972), here represented as the "Monaro succession" (Fig. 1), with its several belts inland from the south coast at Narooma to the Snowy Mountains, and the quartz-rich Wagga Trough succession, usually referred to as the Wagga Metamorphic Belt. This latter should also include the low grade metamorphics of the Girilambone Group and Ballast Beds, east of Cobar, or at least those occurrences with confirmed records of Ordovician microfossils (Stewart & Glen, 1986; Iwata *et al.*, 1992).

Most previous workers (Packham & Falvey, 1971; Scheibner, 1972; Webby, 1976; Cas, 1983; Powell, *in* Veevers, 1984) have interpreted the Ordovician quartz-rich turbidite successions of the Wagga Trough as having accumulated in a back-arc basin, or marginal sea like the present Sea of Japan. The deposits were subsequently uplifted, folded and regionally metamorphosed in the latest Ordovician-early Silurian Benambran Orogeny.

The Monaro Trough has been variously interpreted as (i) a fore-arc basin (Scheibner, 1972; Webby, 1976; Crook, 1980; Cas, 1983), (ii) as partly fore-arc basin (inland) and partly outer-arc slope along the present coast (Powell, 1983; Powell, *in*

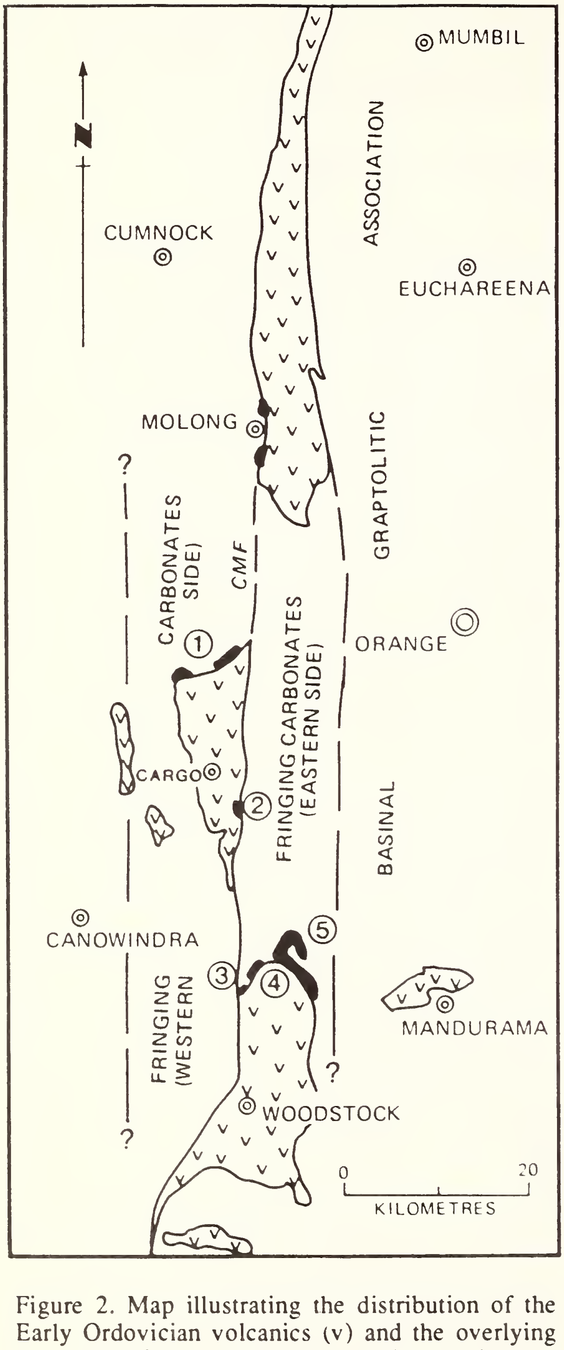


Figure 2. Map illustrating the distribution of the Early Ordovician volcanics (v) and the overlying Late Ordovician sedimentary, mainly carbonate, successions (in black) of the Molong High. Note the three-fold subdivision of the high into east and west-fringing carbonate belts, with a third, deeper basinal shale belt farther to the east. Circled numbers relate to the following areas: 1, Bowan Park; 2, Regan's Creek; 3, Licking Hole Creek; and 4-5, Cliefden Caves. CMF represents the present trace of the Columbine Mountain Fault. (Based on Webby & Percival, 1983, fig. 1B).

Veevers, 1984), and (iii) as including in part back-arc deposits displaced by large strike-slip faults from a more southerly extension of the Wagga Trough (inland) and partly fore-arc zone along the present coast (Packham, 1987).

In most of these plate tectonic reconstructions of the Lachlan Fold Belt the intervening volcanic arc with its Ordovician volcanic and sedimentary record (that is, including the Molong High and the Parkes Platform in central New South Wales) is interpreted as occupying a position between back-arc (Wagga Trough) and frontal arc basins (e.g., Powell, *in* Veevers, 1984). The volcanic arc has been interpreted as subduction related (Scheibner, 1989), and not necessarily part of an exotic (allochthonous) terrane.

However, Wyborn (*in* Wyborn *et al.*, 1991) has argued that the shoshonitic volcanism does not represent normal subduction-related island-arc magmatism. He also claims that the volcanic products are widely spread in a band 400 km across, not in a narrow curvilinear belt as in typical modern arc configurations. However the two volcanic areas with significant associations of shallow water carbonates, on the Molong High and the Parkes Platform, are presently only 100 km apart, and may have originated in closer proximity if the intervening Cowra Trough is taken to have formed by rifting in Early-Middle Silurian times (Pickett, 1982; Powell, *in* Veevers, 1984; Scheibner, 1989).

Suggestions that detachment and thrusting are important features of the deformation history of the Lachlan Fold Belt have led to the alternative proposition that the volcanic arc is an exotic terrane, an "allochthon thrust over the Ordovician craton-derived turbidite wedge", that is, over the otherwise unbroken, monotonous, quartz-rich Ordovician greywackes exposed elsewhere in the fold belt (Fergusson & VandenBerg, 1990; Fergusson, 1991; VandenBerg, 1991). These authors have argued that the "Wagga" and "Monaro" quartz-rich successions accumulated in an oceanic setting marginal to the Delamerian mountains of Gondwana. The "Monaro" successions, according to Glen *et al.*, (1990), comprise repetitions of thrusted Early Ordovician quartz-rich turbidites and Late Ordovician "starved" black graptolitic shales.

Parts of the volcanic arc like the Molong High and Parkes Platform exhibit little stratigraphic and/or structural evidence in support of an exotic origin. Indeed there are remarkably orderly patterns of lateral and vertical facies relationships within the associated sedimentary successions (Webby, 1974;

Webby & Packham, 1982; Webby & Percival, 1983). For example, it is possible to trace similar occurrences of the fringing island shelf *Tetradium cribriforme* biofacies between the Cliefden Caves area and Molong (Fig. 2), that is, over 70 km along strike, and approximately parallel with the meridional-trending shoreline (not north-westerly as suggested by Cas *et al.*, 1980, and Powell, *in* Veevers, 1984).

In contrast there are more rapid east-west facies changes across the Molong High (Fig. 3), between an eastern Cliefden Caves Limestone Group and equivalent successions, and a western Bowan Park Limestone Group and its equivalents, reflecting a consistent pattern of onshore to offshore relationships. The subdivision of the Molong High into eastern and western parts is based on the differences in the local Ordovician sedimentary successions (Fig. 2). The boundary more-or-less coincides with the present expression of the Columbine Mountain Fault (Stevens, 1950) and, as outlined below, this major N-S trending fault may have been in existence since Late Ordovician time.

In many areas of central New South Wales the quartz-rich greywacke-shale and volcanic associations seem to be isolated in separate fault-bounded blocks (or terranes). Erupting volcanogenic products should have been dispersed to neighbouring sedimentary basins, but presently only one good example of gradational facies relationships is known. More attention should be given to the field relationships between the two associations. VandenBerg's (1991) interpretation of the volcanic arc as an "exotic terrane" may have some credence, but his claim that "this exotic terrane came from the north, and was emplaced into its present position during the Silurian" remains to be substantiated.

ISLAND PALAEOENVIRONMENTS, BIOTAS, AND BIAS IN THE ORDOVICIAN FOSSIL RECORD

A substantial pile of basic and intermediate volcanics (Walli and Cargo volcanics and their equivalents) was erupted in Early Ordovician times to produce a partly emergent island (at least in part the Molong High). This then became planated to form the offshore sites for accumulation of Late Ordovician carbonates. These shallow-water carbonates developed first as terrigenous, fringing island shelf deposits, and subsequently as the sea transgressed entirely across the island, terrigenous-

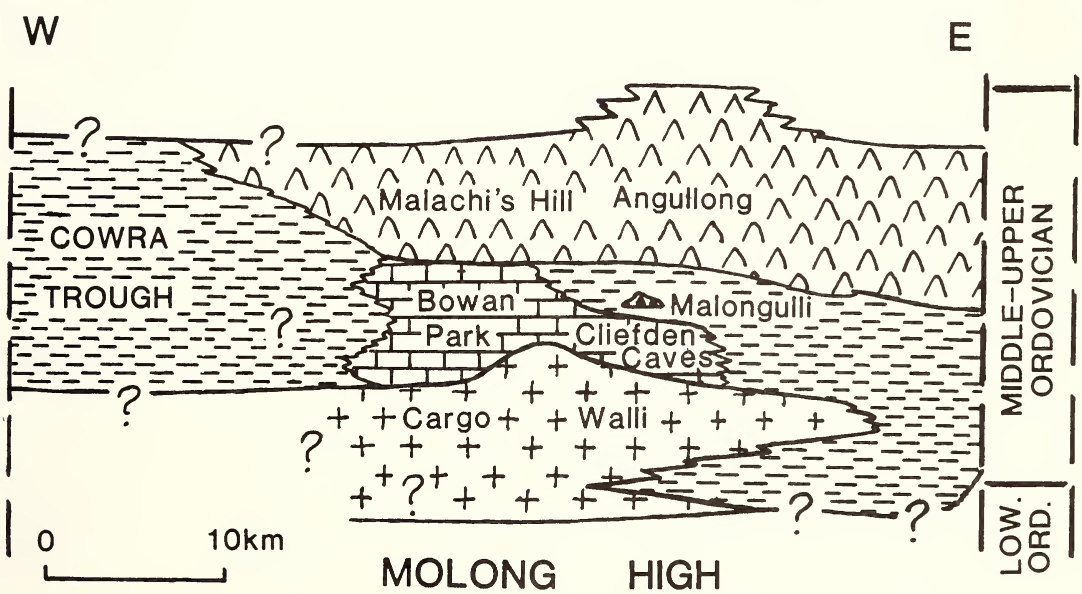


Figure 3. Diagram showing generalized Ordovician facies interrelationships across Molong High. Note the horizontal scale is shown. Vertical scale is exaggerated; it represents time not thickness. The Early-Mid Ordovician volcanics (shown by crosses) are succeeded by carbonates (brickwork symbol) and siltstones (horizontal dashes), and these are mantled by Late Ordovician volcanics (depicted by inverted v symbols). Lensoid limestone breccia deposit in the Malongulli Formation is also shown. (based in part on Webby, 1976, text-fig.8).

free bank-type (or mantling) deposits across both eastern, Cliefden Caves, and western, Bowan Park, sides of the Molong High (Figs. 2-3).

On the eastern side of the Molong High a depositional phase of basinal, deeper, spicule-rich and graptolitic Malongulli Formation replaced the shallow water Cliefden Caves carbonates. Possibly this comparatively sudden submergence event was the result of early movements on the Columbine Mountain Fault, with the debris flows in the Malongulli Formation being triggered by the successive displacements on this fault. The thick accumulation of the succeeding Angullong Tuff again resulted in the eastern side of the Molong High becoming a positive feature, and the site for shallow-water Silurian deposition. This contrasts with the history of events on the western side of the Molong High, which first remained a positive feature, with shallow-water carbonates being deposited contemporaneously with the slope-basinal Malongulli Formation, and then subsided to become a part of the Cowra Trough in Early-Middle Silurian times.

The Parkes Platform (Krynen *et al.*, 1990), like the eastern side of the Molong High, has a similar Late Ordovician shallow-water limestone succession (Billabong Creek Limestone), overlain by deeper water (slope to basinal) shales and siltstones (Gunningbland Shale Member of the Goonumbla Volcanics).

The Ordovician sedimentary succession in the Molong High is exceptional in providing the most complete and well preserved record of low-latitude, offshore island shelf to slope deposits known. This island shelf-slope succession is a unique "window" on an otherwise globally very patchy and incomplete record of Ordovician islands now preserved in Palaeozoic fold belts. Most Ordovician oceanic crust (with its associated volcanic islands and island chains) has either been subducted, or incorporated in suspect terranes of these fold belts, and often the deposits are metamorphosed or structurally deformed, retaining few details of depositional history or records of associated biotas. A few remnants like the exposures in the Molong High remain in a good state of preservation, though even they may now have relatively obscure palaeogeographic relationships.

In marked contrast are the Ordovician deposits of stable continental platform regions of the world, which are relatively easily placed in continental configurations of Gondwana or other lithospheric blocks (Scotese & McKerrow, 1990). These now have abundant and very widespread, well preserved occurrences, and a fossil record which remains substantially intact.

In consequence a very biased Ordovician fossil record exists, with a great deal known from the continental platforms, and comparatively little data available from offshore island settings. This has serious implications when it comes to achieving a balanced global view of how the major Ordovician radiations may have occurred. We know that the greatest sustained diversification of life occurred during the Ordovician Period, with the appearance (and/or dramatic expansion) of many higher taxa - the first vertebrates, the first plants, various echinoderm groups (cystoids, crinoids etc.), graptolites, articulate brachiopods, bryozoans, ostracods, cephalopods, gastropods, bivalves, corals and stromatoporoids. In all probability the island shelf and slope habitats of the Molong High, and those of a great many other Ordovician offshore islands played a very important role in promoting this diversification.

ISLAND BIOFACIES: ONSHORE-OFFSHORE PROFILE

The richly fossiliferous carbonate succession (Cliefden Caves Limestone Group) and the overlying graptolitic Malongulli Formation preserved on the eastern side of the Molong High provide a most complete record of onshore island shelf to offshore slope biofacies (Webby & Packham, 1982; Webby & Percival, 1983; Rigby & Webby, 1988). The Cliefden Caves shelf carbonates are about 460 m thick, and comprise: (1) fringing deposits with a variable terrigenous content derived from the exposed adjacent island, and (2) terrigenous free, mainly lagoonal bank-type platform deposits which accumulated after complete submergence of the island. The overlying slope-basinal Malongulli siltstones and shales are about 200 m thick. They contain significant slump-derived limestone deposits with clasts of mixed shelf and slope affinities.

Savage's (1990) conodont-based age determinations for the lowest part of the Cliefden Caves Limestone Group of about middle-late Caradoc (mid Shermanian-mid Edenian) time seem to be slightly in conflict with earlier indications by Barnes (*in* Webby & Kruse, 1984) that the conodonts from the lower part of the Cliefden Caves succession (Fossil Hill section) had a Blackriveran-Rocklandian aspect, that is, probable late early to earliest middle Caradoc age. The overlying Malongulli Formation, based on graptolite determinations of Moors (1970), Percival (1976) and Jenkins (1978), spans an interval from the late Eastonian (Ea3) to the Bolindian (Bo1), that is, from the late Caradoc to early-mid Ashgill (or in North American terminology, Edenian-Maysvillian, possibly to early Richmondian). Probably altogether the Cliefden

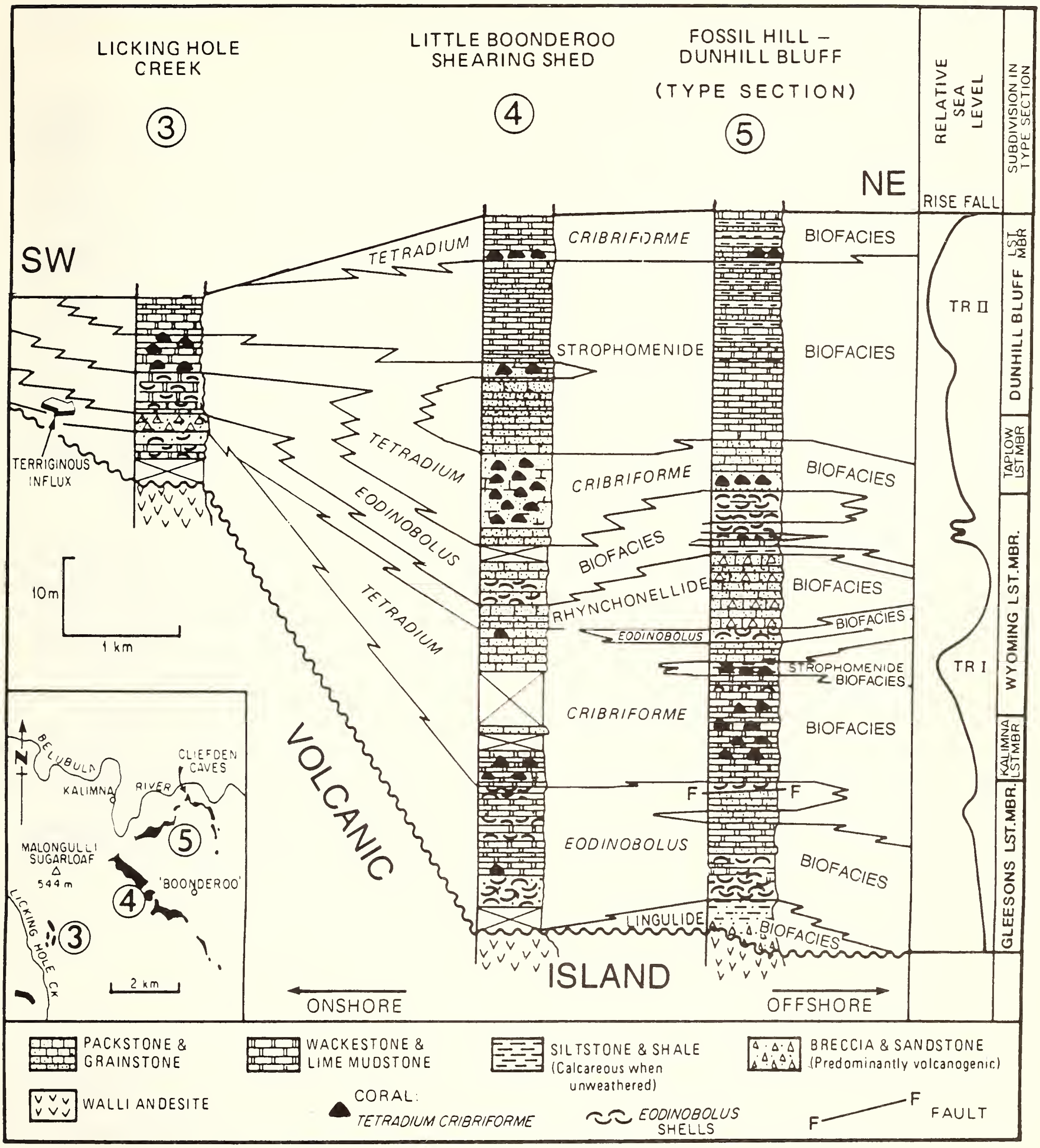


Figure 4. Key stratigraphic sections illustrating biofacies interrelationships in the lower two-thirds of the Fossil Hill Limestone, Licking Hole Creek and Cliefden Caves areas, eastern side of the Molong High. For location of inset map, see Fig. 2. This illustration depicts onshore-offshore biofacies patterns across the NE side of the fringing island shelf within two transgressive, and intervening regressive, depositional cycles (modified after Webby & Percival 1983, fig.3).

Caves-Malongulli succession represents a depositional period of about 10-15 Ma.

The lowest part of the Cliefden Caves succession (Fossil Hill Limestone) exhibits a number of repetitions of the main fringing shelf biofacies (Fig. 4). Four biofacies can be differentiated in the transgressional phases, and one biofacies in a regressional phase, of island shelf deposition. All five have some associated terrigenous influx from the adjacent island. The transgressional series (Fig. 5A), from onshore to offshore, comprise: (1) the relatively quiet bay-fill, low diversity **lingulide biofacies**, (2) the "big-shell" ***Eodinobolus* biofacies** with shell beds representing protected intertidal to shallow subtidal environments (Webby & Percival, 1983), (3) the coral-dominated ***Tetradium cribriforme* biofacies** which formed in shoals and bars of a well aerated, moderately high-energy zone above wave base, and (4) the high diversity **strophomenide biofacies** characterizing a quiet, level-bottom habitat below wave base.

Webby & Percival (1983) have summarized previously the main features of the low diversity shell-bed community dominated by large *Eodinobolus* shells. These sometimes form *in situ* banks, and have a few other associated elements (the alga *Hedstroemia, Tetradium variabile,* ?grazing gastropods and ostracods), an association rather like some modern nearshore oyster-bank accumulations. The overall diversity of this association is relatively low, usually from 4 to 8 but exceptionally up to 10 species being represented.

The *Tetradium cribriforme* biofacies is commonly composed of an asssociation of large domal colonies of *T. cribriforme* up to 1 m across in skeletal lime sands, but also at some levels is represented by biostromal or small biohermal developments, like the 1.5 m thick biostrome on Fossil Hill which exhibits boulder-like colonies of *T. cribriforme* (up to 90% by biovolume), with subordinate corals *(Nyctopora, Bajgolia, Hillophyllum)*, the stromatoporoid *Cystistroma*, the bryozoan *Batostoma* and the brachiopod *Rhynchotrema*. This biofacies has a comparatively higher diversity, with more than 35 species.

The strophomenide biofacies characterizes the outer shelf and is represented by a rich and varied fauna and flora (in excess of 55 species) which lived predominantly on lime muds of an open, quiet, level-bottom habitat below wave base. The thinly bedded sequences are dominated by occurrences of articulate brachiopods (*Sowerbyites, Wiradjuriella, Rhynchotrema, Plectorthis, Anoptambonites, Tylambonites)*, by trilobites *(Pseudobasilicus?, Eokosovopeltis, Pliomerina,* harpids), by bryozoans and by nautiloids (Webby & Packham, 1982; Percival, 1991). Two sub-biofacies, one dominated by small rugose and tabulate corals (especially heliolitines) and the other by calcified lithistid sponges and echinoderms *(Astrocystites)*, can also be recognized and probably represent slightly different outer shelf habitats.

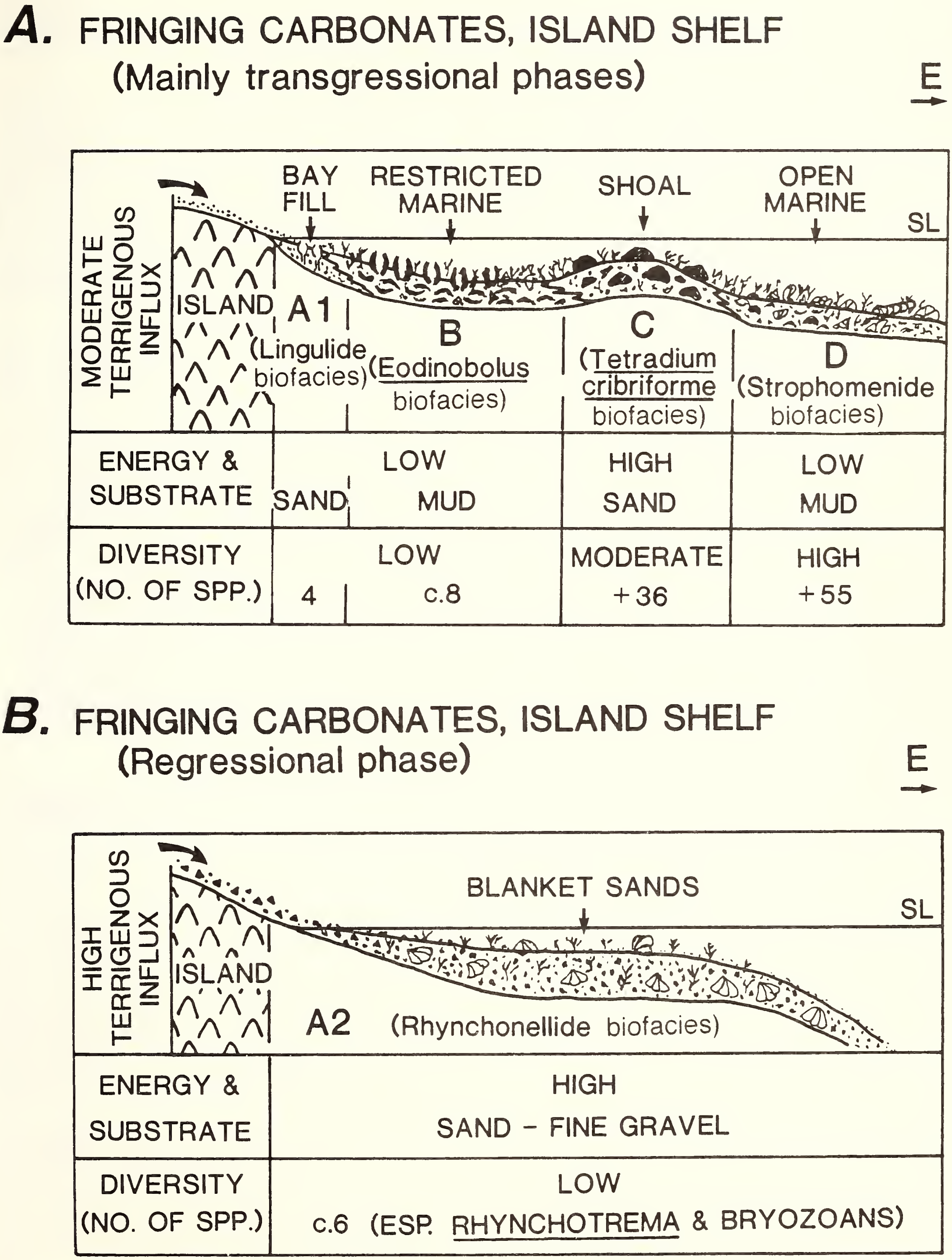
This onshore-offshore profile is similar to that proposed by Ziegler *et al.* (1968) for Silurian shelf communities, with a progressively higher species diversity offshore, and a similar pattern of onshore to offshore low-high-low energy zones, the high energy zone representing the mid shelf barrier or shoal.

The low diversity **rhynchonellide biofacies** is the fifth association (Fig. 5B), and represents a regressional phase which developed in response to a high level of terrigenous influx, of coarse sands blanketing the fringing island shelf. It is dominated by occurrences of articulate brachiopod *Rhynchotrema*.

A quiet water, terrigenous-free, low-diversity

Figure 5. ***A***. Diagrammatic representation of the faunal profile through the main fringing island shelf biofacies; composite based on two transgressional phases within the Fossil Hill Limestone. It shows the lingulide and *Eodinobolus* biofacies based on sections at Fossil Hill through lower-middle parts of the Gleesons Limestone Member, and the*Tetradium cribriforme* biofacies based on the Kalimna Limestone Member of the Fossil Hill Limestone. The strophomenide biofacies is based on the Dunhill Bluff Limestone Member of the Fossil Hill Limestone, in a section at Dunhill Bluff. Note the volcanic island and source of sediment (shown with inverted v symbols). Key to the cartoon representing the four biofacies A1 to D is as follows:*"Lingula"* is shown in vertical growth position of the bayfill sands of biofacies A1; *Eodinobolus* is represented by vertical *in situ,* and horizontally disarticulated, shells of biofacies B; large dome-like colonies of *Tetradium cribriforme* and other, smaller branching corals are shown in biofacies C; and a variety of articulate brachiopods and other shelly faunas are depicted in biofacies D. ***B***. Diagrammatic representation of the faunal profile across the fringing island shelf during a regressional phase, and development of the rhynchonellide biofacies in a section through the middle part of the Wyoming Limestone Member, Fossil Hill Limestone at Fossil Hill. Note the cartoon of the biofacies (A2) shows *Rhynchotrema* shells and bryozoans in the typical blanket sand and fine gravel deposit.

Figure 5.


A. FRINGING CARBONATES, ISLAND SHELF
(Mainly transgressional phases)
E
MODERATE TERRIGENOUS INFLUX
BAY FILL
RESTRICTED MARINE
SHOAL
OPEN MARINE
SL
ISLAND
A 1
(Lingulide biofacies)
B
(Eodinobolus biofacies)
C
(Tetradium cribriforme biofacies)
D
(Strophomenide biofacies)
ENERGY & SUBSTRATE
SAND
LOW
MUD
HIGH
SAND
LOW
MUD
DIVERSITY (NO. OF SPP.)
LOW
4
c.8
MODERATE
+36
HIGH
+55
B. FRINGING CARBONATES, ISLAND SHELF
(Regressional phase)
E
HIGH TERRIGENOUS INFLUX
BLANKET SANDS
SL
ISLAND
A2
(Rhynchonellide biofacies)
ENERGY & SUBSTRATE
HIGH
SAND - FINE GRAVEL
DIVERSITY (NO. OF SPP.)
LOW
c.6 (ESP. RHYNCHOTREMA & BRYOZOANS)

"lagoonal" biofacies is also developed at levels in the upper part of the Fossil Hill succession, a prelude to complete subsidence of the island, and development of the more continuous "lagoonal" offshore bank-type deposition of the succeeding 290 m thick Belubula Limestone. These massively bedded, poorly fossiliferous lime mudstones and wackestones show only a few traces of burrowing activity and rare shelly fragments, ossicles, corals (*Nyctopora* and heliolitines) and possible stromatoporoids. They probably formed in a protected environment like that exhibited in the shelf lagoon of the modern Great Bahamas Bank (Purdy, 1963).

Two other terrigenous-free, low-diversity shelf lagoon lime mudstone biofacies were developed, both in the Daylesford Limestone of the Bowan Park succession, western side of the Molong High (Semeniuk, 1973). These associations may have formed on the shelf platform on the lee side of a local barrier rim dominated by large colonies of *Tetradium compactum*. The first is characterized by an association of *Eodinobolus* shell beds and the cylindrical branching stromatoporoid *Alleynodictyon* (Webby & Percival, 1983), and the other, possibly occupied slightly deeper lagoonal waters. This latter was dominated by the anoxic indicator trace fossil *Chondrites*.

The subtidal level-bottom strophomenide biofacies is again well represented in the uppermost part of the Cliefden Caves succession (Vandon Limestone), also in the stratigraphically equivalent Quondong Limestone (middle of the Bowan Park Group) on the western side of the Molong High, and in the Billabong Creek Limestone of the Parkes Platform. This clearly represents an important widespread transgressive (?sea level) event.

The overlying contact between island shelf carbonates of the Cliefden Caves Limestone Group

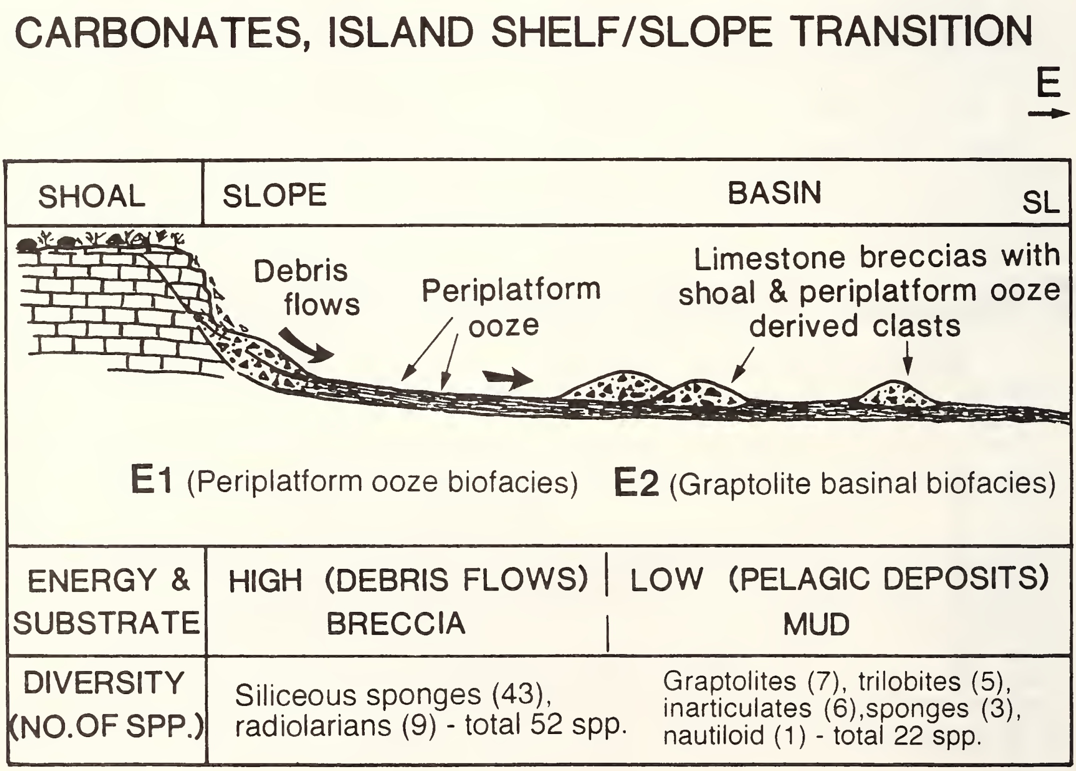


Figure 6. Diagrammatic representation of island slope to basin biofacies, based on sections in the lower part of the Malongulli Formation at Coppermine Creek and Trilobite Hill, Cliefden Caves area (see figure 2). Note the cartoon representing outer shelf to slope and basin environments, with (i) the brick-work symbols depicting the carbonate shelf at the margin of the slope, (ii) thin-bedded, fine-grained slope-basin sediment (depicted by the fine horizontal lines), and (iii) the associated lensoid bodies containing irregular clasts of mixed shoal and slope derivation.

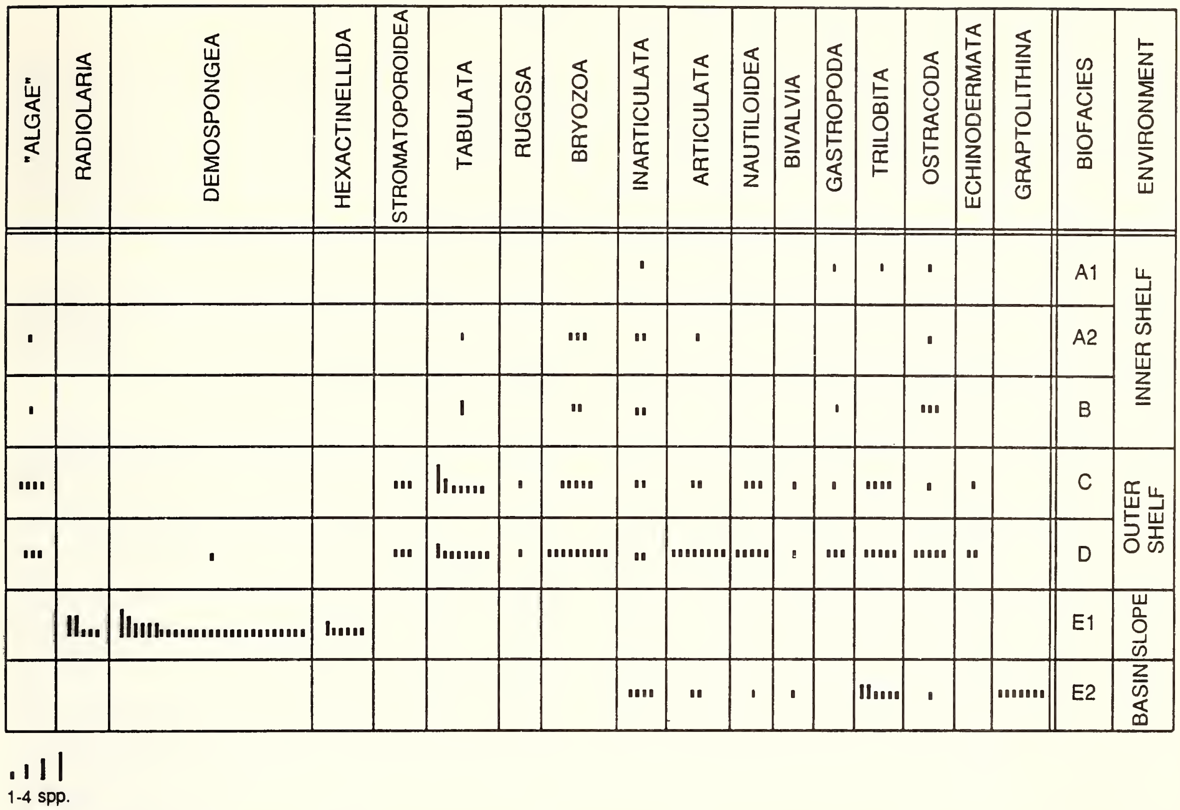


Figure 7. Plot summarizing the total diversity of species in the island shelf-slope-basin profile. Note that the "Algae" also include the Cyanobacteria. A number of discrete-element, problematical or minor groups are not included in the plot, for example, the conodonts, conulariids, hyolithids, sphinctozoans, discrete spicules (mainly of hexactinellid derivation) and trace fossils. Genera with more than one species are indicated by the longer bars; with up to four individual species (spp.), see key at bottom left corner of illustration.

and the island slope deposits of the overlying graptolitic Malongulli Formation is a marked unconformity surface. This sharp contact with evidence of scouring at the contact (Webby & Packham, 1982), has been interpreted as reflecting an episode of submarine scouring during subsidence, at or near the shelf-slope break. The period of subsidence (or drowning) affected the entire eastern part of the Molong High and is attributed to early displacements along the line of the Columbine Mountain Fault (Fig. 2). The slump breccia deposits in the Malongulli Formation also seem to reflect these tectonic movements.

The slump-derived breccia deposits in the Malongulli succession, contain two types of limestone clasts, some of island shelf, and others of island slope, derivation. The slope-derived blocks are distinctively laminated, tabular clasts representing a **periplatform ooze biofacies** (Fig. 6). These clasts were eroded from the floor of the slope probably just below the shelf-slope break (Rigby & Webby, 1988) as the debris flows travelled basinward. The allochthonous limestone blocks exhibit remarkably diverse sponge associations including in a wide variety of demosponges, hexactinellids and a few sphinctozoans, along with well preserved radiolarians. A total of 43 species of mainly siliceous sponges and 9 radiolarian species have been recorded (Webby & Blom, 1986; Rigby & Webby, 1988), as well as varied conodont assemblages currently being studied by J. Trotter. There is a great variety of growth form among the lithistid sponges, including domal, cylindrical and stick-like anthaspidellids *(Archaeosyphia, Aulocopodium, Perriscocoelia* and *Dunhillia)*, and sheet-like, branching and spherical hindiids *(Palmatohindia, Arborohindia, Hindia, Mamelohindia* and *Fenestrospongia)*. A number of more loosely aggregated hexactinellids *(Tiddalickia, Wongaspongia* and *Wareembaia)* also occur, and a wide range of distinctive, discrete sponge spicules, many being of hexactinellid derivation (Webby & Trotter, 1993).

The overlying deeper water Malongulli siltstones, shales and spiculite deposits exhibit a different set of associations comprising 6 species of brachiopods (Percival, 1978; 1979a), 5 trilobite species (Webby, 1973; 1974), 7 graptolite species (Moors 1970), one species of nautiloid (Glenister, 1952; Hewitt & Stait, 1985), a bivalve, numerous disarticulated, mainly hexactinellid, spicules and a few apparently *in situ* siliceous sponges *(Astylostroma, Gleesonia* and *?Hudsonospongia)*. These deposits include a total of more than 22 species, presumably mainly representing the **graptolite basinal biofacies** (Fig. 6).

To summarize, this low-latitude island shelf to slope profile exhibits the highest species diversities in the outer shelf and slope environments, with articulate brachiopods, corals, stromatoporoids and bryozoans the dominant elements in the outer shelf, and the siliceous sponges most important in the slope (Fig. 7). The high concentration of spicules, discrete sponges and radiolarians in the tabular clasts of the Malongulli breccias suggests a particularly favourable slope environment with ready supply of nutrients allowing biogenic silica to be produced in abundance, presumably as a result of upwelling at the equatorial divergence (Rigby & Webby, 1988).

The diversity of these Ordovician siliceous sponges is remarkable in terms of the overall Palaeozoic record. Moreover, probably only a small part of the hexactinellid component of the faunas has so far been described, given that they were mainly loosely aggregated forms. Only 7 species were included in the descriptions of Rigby & Webby (1988) which, relative to the more rigidly-fused demosponges (35 species), is a small proportion of the total fauna. Also, a large part of the isolated spicule material in the residues left after dissolving the allochthonous blocks is of hexactinellid origin. This high Ordovician diversity is puzzling given that no other comparable, similarly rich and abundant records of siliceous sponges are known until Permian time (Finks, 1960). The explanation is presently unclear but may be related to one or more of the following factors: (1) the biases mentioned earlier, namely, that the slope habitat was often subducted, or the record virtually lost in poorly preserved, metamorphosed and/or structurally deformed remnants of fold belts, (2) that submarine erosion mainly destroyed the sponge-bearing upper slope habitat, or (3) that the sponges only occurred in abundance early in their history in slope habitats associated with equatorial (and other nutrient-rich) upwelling sites.

It may be concluded that among these Molong High island biofacies assemblages only three represent distinctly new community types, the *Eodinobolus* shell beds of the inner shelf, the *Tetradium cribriforme* coral banks of the outer shelf, and the richly diverse siliceous sponge assemblages of the island slope.

EVOLUTIONARY AND BIOGEOGRAPHIC SIGNIFICANCE OF CERTAIN ISLAND BIOTAS

In terms of the evolutionary and biogeographic significance of the more important fossil groups, the **brachiopods**, based on Percival's (1978; 1979a; 1979b; 1991; 1992) work, from the Molong High and the Parkes Platform comprise 43 genera, and altogether 31% of these are endemic forms (Webby, 1985). At the species level almost all the 49 species have a restricted N.S.W distribution. Most are benthonic forms, and the articulates dominate in the outer shelf. In addition to the many new genera first appearing on the island shelf, there are a few new higher taxa, from superfamily to subfamily level (e.g., the Superfamily Trimerellacea, subfamily Rhynchotrematinae, and the atrypid subfamilies Septatrypinae and Spiriferininae). The inarticulates are relatively more common in the adjoining basin (four out of a total of seven genera) and at least one or two may have had an epiplanktonic mode of life (Percival, 1978). The deeper water association has a lower endemicity (1 in 7 genera).

Fifty per cent of the generic components of this brachiopod fauna were capable of dispersing from the New South Wales islands across the Wagga marginal sea to the Tasmanian Shelf (a part of the margin of Gondwana, or a separate microcontinent); the other half was limited by this barrier. Only one species of *Sowerbyites* is known to occur in the N.S.W. islands as well as on the Tasmanian Shelf. Notable among the forms which did not migrate to Tasmania was the large, thick-shelled trimerellid *Eodinobolus*. Longer range zoogeographical links are chiefly with the North American region and with Kazakhstan. Based on first appearances, at least 15 genera came from North America, and three apparently went in the opposite direction; and 8 genera migrated from Kazakhstan, with five seemingly going in the opposite direction.

The richly diverse siliceous **sponge** assemblage not only includes a great number of new genera (Rigby & Webby, 1988), but these exhibit a remarkable range of growth forms, especially among the anthaspidellid and hindiid demosponges. They occupied a slope habitat and exhibit a very high level of endemicity (84% of the 34 genera, and 93% of the 45 spp.). Higher level taxa, the families Haplistioniidae and possibly the Dictyospongiidae, may also have their origins in this island slope setting. Only a few immigrants (a total of 6 lithistids) are recognized in the assemblages as coming from North America or from Europe. One of these genera *(Hudsonospongia)* also occurs in Tasmania.

There are also a few calcareous sponges on the island shelf (new sphinctozoan families Cliefdenellidae and Angullongiidae), and a few endemics *(Angullongia, Belubulaia)*. The cliefdenellids have close zoogeographic links with Alaska *(Cliefdenella)* and California *(Rigbeyetia)* of the Palaeo-Pacific rim and, judging from occurrences of a related genus *(Khalfinaea)* in SW Siberia, NW and N China, slightly less close relationships with these regions (Webby & Lin, 1988).

The **nautiloids** have low diversity and abundance (10 species, three of them new) mainly occurring in the island shelf, and belonging to long-ranging conservative genera of the orders Michelinoceratida and the Tarphycerida. They were exclusively nektonic forms (Stait *et al.*, 1985). Only one of these genera is endemic. There is also one genus recorded from the adjoining basin; this is the ellesmeroceratid *(Bactroceras)*, which represents a generic holdover from the Early Ordovician. None of the highly endemic, nektobenthonic forms described by Stait (1982; 1984a; 1984b) from the Tasmanian Shelf were apparently capable of crossing the deep water barrier of the Wagga marginal sea.

The **trilobites** are a conservative and stable group of mainly immigrant genera, and they are recognized as occurring in three distinctively different habitats. The first, characterized by the presence of *Pliomerina* and *Amphilichas*, includes a moderately diverse assemblage of 11 genera (20 species) on the island carbonate shelf. A possible new undescibed harpid is the only possible endemic genus. A slightly less diverse fauna occurs in the adjoining basin with 7 genera (eleven species), and includes the short-lived endemics *Parkesolithus* and *Malongullia* (Webby *et al.*, 1970, Webby 1971b; 1973; 1974). Only the genera *Remopleurides, Eokosovopeltis, Illaenus (Parillaenus)?* and possibly *Encrinuraspis* occupied both shelf and adjoining basin habitats (and no species of these genera are common to the two habitats). The subfamily Scutellinae, with *Eokosovopeltis* as the earliest known member, may have evolved in the island shelf-basin setting. A third, local basinal facies, possibly of deeper water aspect, exhibit Cambrian holdover stocks *(Triarthrus*, blind *Shumardia* and *Geragnostus?)*.

The island shelf trilobite association has moderately close zoogeographic links with the Tasmanian Shelf in having common occurrences of *Pliomerina*, *Amphilichas*, *Remopleurides* and *Eokosovopeltis* but only one or two species (*A. encyrtos* and possibly *R. saenuros*) are known to be the same. Relationships are virtually as close with SE Asia and Kazakhstan, within the *Eokosovopeltis-Pliomerina* province of the world-wide equatorial Remopleuridid realm.

Stromatoporoids are restricted to the offshore island shelf and include representatives of two orders, the labechiids which are mainly immigrants from North America and Asia, and the clathrodictyids which appear to be a new group which first diversified on the central N.S.W. island shelves (Webby, 1969; 1971a; 1979; 1980; Webby & Morris, 1976). Links exist between contemporaneous Late Ordovician N.S.W. island shelf and the Tasmanian Shelf, but overall the N.S.W. fauna has stronger Asian, and the Tasmanian, more mixed North American-Asian, connections.

Some labechiids exhibit species-level links with Tasmania, North China and other localities in Asia, for example, *Rosenella woyuensis*, *Labechiella variabilis* and *L. regularis*, as well as generic level relationships (Webby, 1991). But other labechiids which occur in abundance in the Tasmanian fauna and show strong North American faunal ties, such as representatives of *Stylostroma*, *Pachystylostroma* and the cylindrical forms *Thamnobeatricea* and *Aulacera*, have no counterparts in New South Wales.

The two main clathrodictyid genera *Clathrodictyon* and *Ecclimadictyon*, also colonized the Tasmanian Shelf but none of the species occurring in N.S.W. is the same as those recorded from contemporaneous to slightly younger levels on the Tasmanian Shelf (Webby & Banks, 1976). Closer links with Asia are again suggested by the common occurrences of *E. amzassensis* in the N.S.W. island shelf and the Chinese and SW Siberian Altai mountain regions (Lin & Webby, 1989).

Corals are also restricted to the offshore island shelf, and include mainly tabulate and rugose immigrants *(Nyctopora, Tetradium, Palaeophyllum* and *Favistina)* from Asia and North America. The assemblages belong to the shallow, equatorial, warm-water American-Siberian provincial realm (Webby, 1992). So far all the rugosans and about half the tabulate faunal component have been fully documented; these comprise some 37 described species. In more detail the New South Wales island shelf fauna has closer Asian links than North American, especially with the SW Siberian Altai region, NW and N China, and Kazakhstan. Again relationships with contemporaneous Tasmanian assemblages suggest general biogeographical similarity but there are rarely species-level connections. *Tetradium cribriforme* which forms abundant bank-like occurrences on the N.S.W. island shelf does not seem to be represented in Tasmania and, on the other hand, the distinctive ramose *T. tasmaniense* of the Tasmanian Shelf (which has affinities to North American *Paleoalveolites)* does not appear on the N.S.W. island shelf.

Major diversification of new higher level taxa also occurred, including first appearances of the bajgoliids (family), the tubulose and cystose heliolitines (superfamilies), the halysitines (subfamily), the aulocystids (family) and the tryplasmatids (family), again groups which probably originated in the island shelf (Webby 1985; 1987; Webby & Kruse, 1984). The heliolitines exhibit a remarkable diversification in the island shelf, with the development of new designs, first tubulose coenosclerenchyme derived from bacular, producing the first members of the Superfamily Helioliticae, and secondly the appearance of cystose coenosclerenchyme in the first representatives of the Superfamily Proporicae. The coenosteoid halysitids (Subfamily Halysitinae) (Webby & Semeniuk, 1969), and the first rugosan with rhabdacanthine septa (the tryplasmatid *Rhabdelasma* McLean & Webby, 1976) also made their first appearances.

In summary, the brachiopods (especially the articulates), sponges, stromatoporoids and corals, show evidence of remarkable evolutionary productivity in the island shelf and slope. The trilobites and nautiloids in contrast were more conservative constituents of the faunas, but even these were able to diversify somewhat on the island shelf, to produce some new species and one or two endemic genera. The trilobites were also represented in adjoining basins, in shallower and deeper, biofacies associations, the deeper having the older (Cambrian) "holdover"stocks. The nautiloids were also represented by an occurrence of a relict Early Ordovician "holdover" in the adjoining basin.

GLOBAL SIGNIFICANCE OF ISLAND BIOTAS

Islands and archipelagos have long been recognized as having important roles in explaining patterns of evolution and dispersal of present day marine and terrestrial organisms (Darwin,1872; Wallace, 1895; Darlington, 1957; Ekman, 1967; MacArthur & Wilson, 1967). However, Ordovician islands and island groups have had less focus of attention as potential sites for evolution and disperal. Neuman (1972; 1984) was the first to emphasize their importance in providing: (1) a wider range of shallow-water habitats, (2) pathways for migration, (3) centres for evolution of new taxa, and (4) opportunities for the development of biogeographically distinct island populations (the Celtic brachiopod fauna) in the Iapetus Ocean (now preserved as remnants in the Appalachian and Caledonide orogens). He noted the volcanic islands as occupying mid-high latitudes between the adjacent low latitude shores of the North American (Laurentian) continent and mid-high latitude shores of the European (Armorican and Baltic) continental blocks. Fortey (1984) has added that such islands possibly acted as havens for organisms following the retreat of the seas from the major continental platform regions during worldwide regressional phases of the Ordovician.

Global extent of island-forming volcanism

Subduction-related volcanicity is known to have been widespread in Ordovician time, with remnants preserved in most major Palaeozoic fold belts of the world. Ross (1984) has already commented on the wide global spread of these occurrences, including areas of the Appalachians (Neuman, 1972; 1984), the Caledonides (Stillman, 1984; 1986; Bruton & Harper, 1985), large tracts of Kazakhstan and the Northern Tien Shan (Nikitin *et al.*, 1986; 1991), with extensions to the east into NW China, for example, in the Qilian Mountains (Zhang, 1984). In addition there are the developments within the Lachlan Fold Belt (Webby, 1976; Wyborn, 1988; 1992; Wyborn *et al.*, 1991, and described herein), and occurrences in the Andean regions of NW Argentina (Acenolaza & Toselli, 1984; Acenolaza & Baldis, 1987).

The most extensive development of Ordovician island-arc volcanism is preserved in Kazakhstan and Northern Tien Shan with two major *en echelon* arc systems up to 600 km apart (Nikitin *et al.*, 1991). As in the New South Wales succession, two major periods of volcanic activity are exhibited, an early-mid Ordovician phase, and a later Ordovician

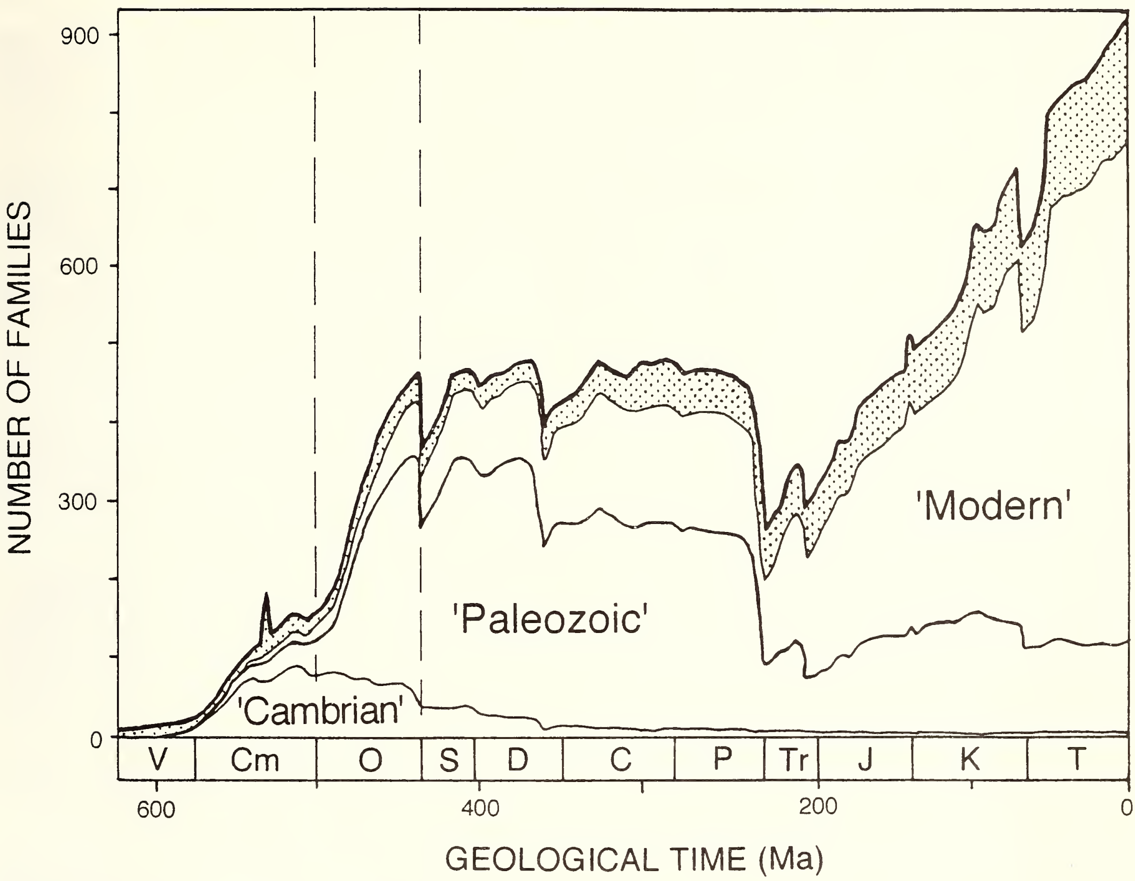


Figure 8. Diagram showing total diversity of Sepkoski's three great "evolutionary faunas" through time (after Sepkoski & Miller, 1985, fig.1). Major Ordovician radiation of new families is shown between vertical dashed lines. The fine stippled area includes an estimated contribution to diversity from the poorly preserved faunas. Also note that about 100 families of Lower-Middle Cambrian archaeocyaths are excluded by Sepkoski & Miller because they do not fit the "logistic pattern" (see Sepkoski 1979, fig. 4).

phase, with a quieter intervening period about Caradoc (Gisbornian-Eastonian) time. A system of small, elongated islands with associated narrow shelves formed within each arc. However, with the general shallowing towards the end of the Ordovician, some larger island areas emerged. The narrow island shelves were colonized by distinctive and diverse communities in the Middle Ordovician, and the larger Late Ordovician islands developed algal "reef" tracts with associated shelly and coralline faunas along their borders.

In central New South Wales, as already noted, the volcanic islands provided a wide range of onshore to offshore, shelf-slope habitats in low latitudes, and new community types became established in the inner shelf (*Eodinobolus* shell beds), the outer shelf (*Tetradium cribriforme* coral banks) and the upper slope (diverse siliceous sponge faunas), along with the evolutionary development of many new taxa (some of them endemics), and the dispersal of many other immigrant stocks.

Clearly a wide variety of patterns of Ordovician island arcs and oceanic islands must have existed in different latitudinal belts as in present day ocean settings, and they must have been, given the levels of evolutionary activity, fundamentally important in promoting this evolutionary activity and dispersal associated with the Ordovician radiations.

These radiations represent the greatest and most sustained burst of evolutionary activity in the fossil record (Fig. 8), with many of the present existing major taxa appearing, including the corals, stromatoporoids, bryozoans, various echinoderm groups, articulate brachiopods, most cephalopod groups, gastropods, graptolites and many other invertebrates, as well as the first vertebrates and the first primitive land plants. A tripling of the number of families occurred, with addition of a further 280 new families (Sepkoski & Sheehan, 1983).

Sepkoski's Model of Onshore-Offshore Faunal Change

Sepkoski (1981; 1991) has claimed that all Phanerozoic marine taxa may be partitioned into one or other of his three great ("Cambrian", "Paleozoic" and "Modern") evolutionary faunas (Fig. 8; Table 1). Each of these evolutionary faunas originated onshore, and displaced, successively through time, the earlier one to more offshore habitats. Both the "Paleozoic" and the "Modern" originated in the Ordovician. The focus of these surveys relies on patterns of onshore-offshore displacement (or replacement) of **benthonic** communities using the North American continental platform as model (see also Sepkoski & Sheehan, 1983). The Ordovician radiations are thought by Sepkoski & Sheehan (1983, p.706) to have been "produced by the great expansion of the Paleozoic fauna", though the mechanisms driving this faunal change remain unclear.

In outline Sepkoski explains the distinction between his "great" faunas as follows:-

(1) The "Cambrian" fauna includes such groups as the trilobites, inarticulate brachiopods, monoplacophorans and hyolithids. These were initially dominant on the shelf but retreated to more offshore positions as the "Paleozoic" evolutionary fauna diversified onshore during the period of major Ordovician radiation. The "Cambrian" fauna was characterized by low diversity and a high rate of taxonomic turnover (Sepkoski, 1991). The major Early Cambrian sponge-like archaeocyaths, which did not fit Sepkoski's (1979) family level analysis and model of patterns of diversity were excluded on the grounds that they were algae. Yet archaeocyathan specialists continue to confirm this group as non-spiculate calcified sponges (Debrenne & Vacelet, 1984; Zhuravlev, 1989; Kruse, 1990; Wood *et al.*, 1992).

(2) The "Paleozoic" fauna, which expanded dramatically during the Ordovician Period, remained dominant in the mid to outer shelf until the major extinction event at the end of the Palaeozoic Era. It was dominated by articulate brachiopods, bryozoans, crinoids, corals, cephalopods and others. The exact timing of the Ordovician diversification seems to have varied,

Table 1. Subdivisions of the three great "evolutionary" faunas of Sepkoski (1981). The data is based on figs.1-2 of Sepkoski & Sheehan (1983)

I."Cambrian Fauna":
Scyphozoa, Priapulida, Monoplacophora, Hyolitha, Trilobita, Inarticulata, Eocrinoidea, Pogonophora

II. "Paleozoic Fauna"
Calcarea, Sclerospongia, Anthozoa, Rostroconchia, Cephalopoda, Tentaculitoidea, Polychaeta, Merostomata, Ostracoda, Stenolaemata, Articulata, Crinoidea, Edrioblastoidea, Edriasteroidea, Blastoidea, Parablastoidea, Rhombifera, Diploporita, Paracrinoidea, Homoiostelea, Stylophora, Stelleroidea, Cyclocystoidea, Ophiocistoidea, Conodontophora, Graptolithina, Pterobranchia, marine Agnatha, marine Placodermi

III. "Modern (Mesozoic-Cenozoic) Fauna"
Rhizopodea, Radiolaria, Ciliata, Hexactinellida, Demospongia, Polyplacophora, Gastropoda, Scaphopoda, Bivalvia, Gymnolaemata, marine Malcostracea, Echinoidea, Holothuroidea, Chondrichthyes, marine Osteichthyes, marine Reptilia, marine Mammalia

with brachiopods and cephalopods expanding early, then crinoids and bryozoans in the middle of the period, and corals still later (Sepkoski & Sheehan 1983). Most of Sepkoski & Sheehan's (1983) documentation comes from the North American Platform where brachiopod-bryozoan-pelmatozoan communities expanded across the shelf effecting displacement of the Cambrian fauna to deeper off-shelf and basinal environments. The "Paleozoic" fauna has a moderate diversity and intermediate rate of taxonomic turnover (Sepkoski, 1991).

(3) The "Modern" fauna first arose during the Ordovician with such groups as the gastropods and bivalves appearing in onshore environments. Jablonski *et al.*, (1983) have noted mollusc-dominated communities as having developed in some onshore shelf situations of the Late Ordovician. However expansion was slow until the end-of-Permian extinction when the "Modern" fauna became dominant. Other members of the "Modern" fauna apparently included demosponges, bony fishes, crustaceans and echinoids (Sepkoski, 1984). The fauna had the highest level of diversity attained in post Palaeozoic time and the lowest rates of turnover.

The anomalous appearance of the "Modern" fauna in the offshore zone of the Devonian, having apparently "skipped" the "Paleozoic" fauna (Sepkoski, 1991, p.60) may merely represent change from a benthonic to nektonic mode of life for these particular molluscs. None of Sepkoski's analyses clearly differentiates between benthonic and other modes of life. Known nektonic forms (nautiloids and fish) and planktonic forms (radiolarians and graptolites) are included seemingly indiscriminantly with the benthonic community assemblages in the onshore-offshore faunal analyses (Sepkoski & Sheehan, 1983).

The broad patterns of Sepkoski's surveys are based on a summation of global data as well as reflecting local-regional biofacies patterns, such as seen in the Cambrian and Ordovician benthic community record of the North American Platform (Sepkoski & Sheehan, 1983). The analyses show the "great" evolutionary faunas to have originated successively in Cambrian to Ordovician nearshore environments, so that by the Late Ordovician (Fig. 9), they were arranged with the "Cambrian" fauna in deep water (slope and basin), the "Paleozoic" fauna on the mid to outer shelf, and the "Modern" fauna restricted to the inner shelf (Sepkoski, 1984).

Does the New South Wales onshore-offshore island faunal gradient support the Sepkoski model?

The low latitude island shelf to slope and basin setting of central New South Wales is only known to have existed for a relatively short period of Late Ordovician time (about 10 to 15 Ma), but might be expected to show a similar onshore-offshore faunal gradient to that found in comparable low-latitude positions of the North American Platform and margin. However the New South Wales onshore-offshore island shelf to slope-basin gradient is markedly different (Fig. 10).

(1) According to the Sepkoski & Sheehan (1983) model, hexactinellids, demosponges and radiolarians are a part of the "Modern" fauna and therefore should have occupied the inner shelf during the Late Ordovician. However, in central

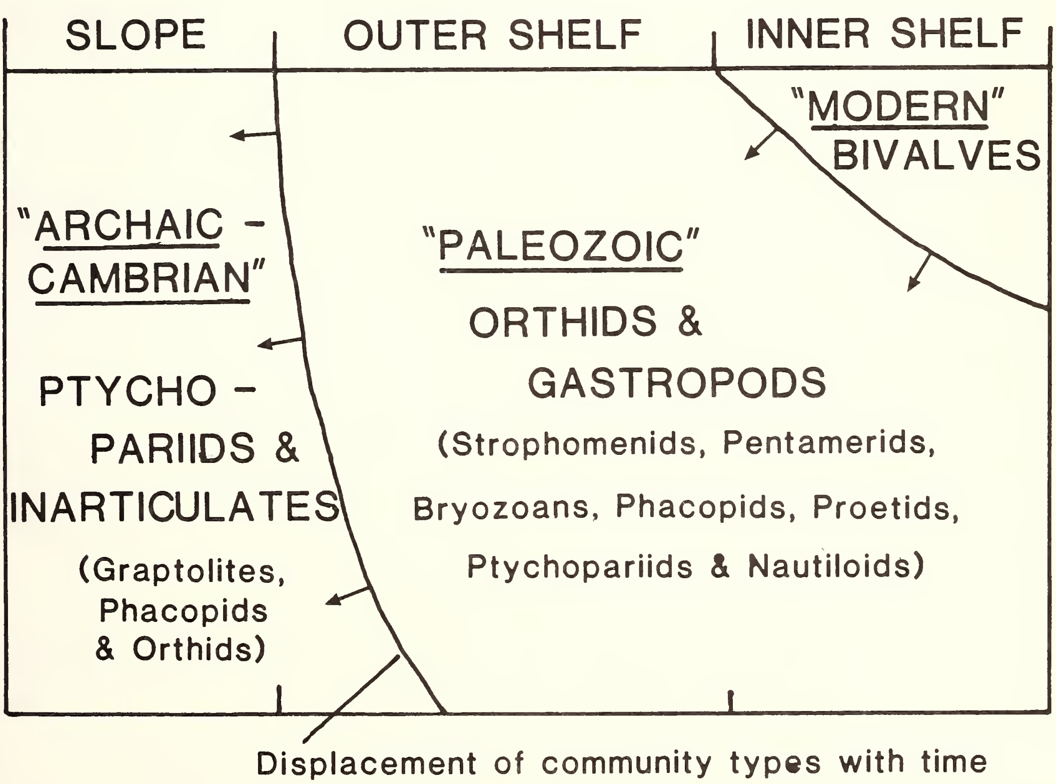


Figure 9. Time environment diagram showing the distribution of the Sepkoski "evolutionary faunas" based on the North American Platform for the Blackriveran-Maysvillian (Caradoc-earliest Ashgill) stratigraphical interval (based on Sepkoski & Sheehan, 1983, fig.7).

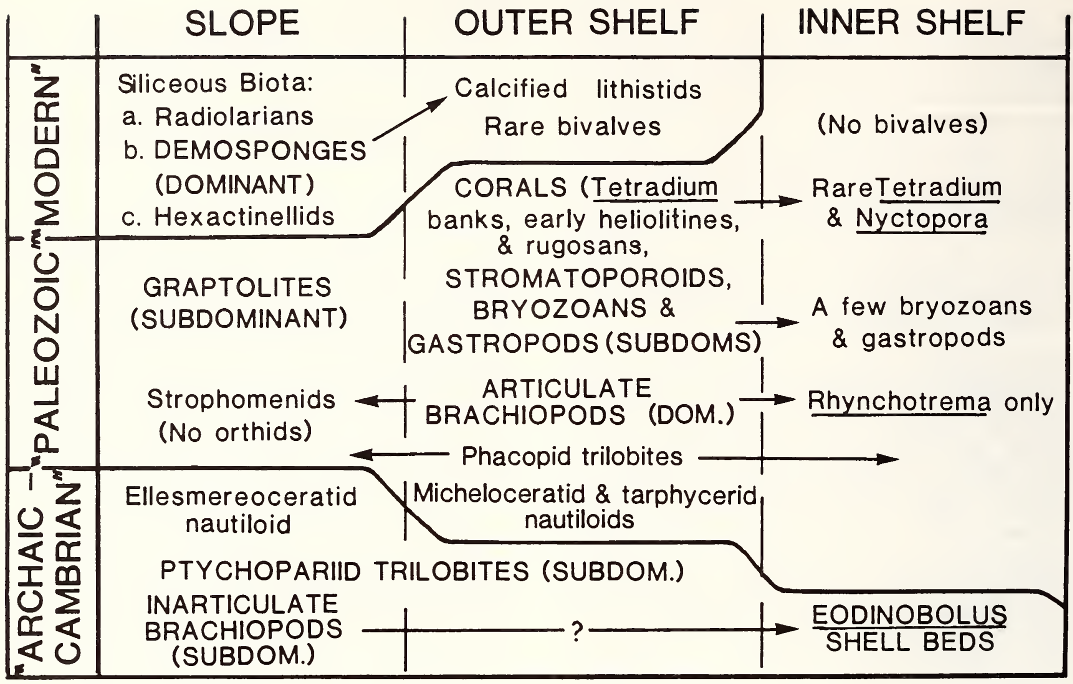


Figure 10. Time environment diagram illustrating the apparent relationship of the Sepkoski "evolutionary faunas" in the New South Wales island shelf to slope and basin profile during the same Blackriveran-Maysville stratigraphic interval (Caradoc-earliest Ashgill).

New South Wales, the siliceous hexactinellids and demosponges mainly occupied the slope habitat, as they continued to do from Cambrian times (Webby, 1984; Rigby, 1986). The sponges were probably benthonic but the radiolarians had a very different, probably planktonic, mode of life.

(2) Only a few bivalves have been found in the island setting (and these are currently being studied by J. Pojeta, Jr., U.S. Geological Survey, Washington D.C.). They mainly form relatively small and inconspicuous components of the middle-outer shelf, and the adjoining basin, not the inner shelf. This contrasts with bivalves on the North American Platform (Sepkoski & Sheehan, 1983) and on the Gondwana Platform, judging from the occurrences of large Early-Middle Ordovician bivalves (Pojeta & Gilbert-Tomlinson, 1977) in the Amadeus Basin, which occupied onshore sites.

(3) Organisms of the deeper graptolite basin biofacies have a mixed provenance, the graptolites a planktonic, the inarticulate brachiopods either epiplanktonic or benthonic (Percival, 1978), the trilobites probably benthonic, and the nautiloid a nektonic mode of life. In terms of the "great" evolutionary faunas, the assemblage is also mixed, with "archaic" Cambrian trilobites and inarticulate brachiopods, associated with more recently evolved "Paleozoic" graptolites and nautiloids, and a few "Modern" bivalves. The picture is further complicated by Sepkoski & Miller (1985) transferring the nautiloids from the "Paleozoic" to the "Modern" fauna. The particular nautiloid in the Malongulli assemblage is the ellesmeroceratid *Bactroceras* and, as already noted, this form represents a generic holdover from the Early Ordovician; it is not a "Modern" taxon. This again points to the arbitrariness of the subdivision by Sepkoski and co-workers of major taxonomic groups into the great "evolutionary" faunas, and to the inadequacies of their undertaking onshore-offshore community analyses without first discriminating the mode of life of the faunal elements.

(4) In terms of the New South Wales trilobite distribution, only about one in four genera are represented in both the outer shelf and the slope-basin settings, and no species occurs in common in both habitats (see Webby *et al.*, 1970; Webby, 1971b; 1973; 1974). Only one outer shelf species is known to extend onshore. No individual island shelf species invaded, or were displaced to, the deeper-water environments of the island slope and basin. Indeed, trilobite dispersal patterns seem mainly to

be in the opposite direction to that proposed by Sepkoski (1981; 1991). For example, in each cooling (or mass extinction) event recorded on the North American continental platform through the Middle-Upper Cambrian interval, trilobite stocks from the deeper slope environments invaded onshore platform sites (Palmer, 1965; 1979; Stitt, 1977).

(5) Similarly there is no evidence of outward shift of brachiopod associations across the island shelf. The inner shelf has very low diversity associations of inarticulates *(Eodinobolus, "Lingula")* and articulates *(Rhynchotrema)*, in about equal proportions. The outer shelf is dominated by diverse articulate assemblages (part of the "Paleozoic" fauna of Sepkoski, 1981; 1991). No evidence exists of endemic taxa, or their possible precursors, originating onshore, and then shifting through time to more outer shelf positions, as required by the Sepkoski model. The inarticulates, however, are well represented in the slope/basin setting, and seem appropriate to be a part of Sepkoski's (1981; 1991) more "archaic" Cambrian fauna.

Comparison between onshore-offshore faunal profiles of Late Ordovician low-latitude North American Platform and the New South Wales island setting

The onshore-offshore patterns of faunal change through an interval of the Late Ordovician (late Blackriveran to Maysvillian time) on the North American Platform (see Sepkoski & Sheehan, 1983, figs. 4 & 6-7), are represented as exhibiting the appearance of the "Modern" (mollusc-rich) fauna in the inner shelf towards the end of this period (though in other diagrams of Sepkoski & Miller, 1985, fig.6, and Sepkoski, 1991, fig.1, the "Modern" fauna is shown appearing onshore much earlier in the Ordovician). The "Paleozoic" fauna with its brachiopod-rich assemblages occupied the mid to outer shelf habitats (inner shelf as well in the early part of the period, according to Sepkoski & Sheehan, 1983), and the "Cambrian" fauna was mainly limited to the slope (Fig. 9).

Patterns in the contemporaneous New South Wales island inner shelf and slope habitats are markedly different (Fig.10). First, there are no records of the "Modern" fauna in the inner shelf; the elements are dominantly representatives of the "Paleozoic" fauna, and the only "new" community type is the low diversity inarticulate-dominated *Eodinobolus* shell beds, possibly derived from the "Cambrian" fauna. The low-latitude inner shelf island fringing habitats of central New South Wales, in contrast to equivalent inner shelf areas of the North American Platform, exhibit low diversities, a lack of significant evolutionary innovations, development of few new community types and no evidence of offshore displacement through time.

Secondly, though the outer island shelf shows diverse biotas of articulate brachiopods, bryozoans, corals and stromatoporoids, the development of the *Tetradium cribriforme* banks seems to represent the only particularly distinctive new community type.

Thirdly, in the island slope to basin setting, as previously stated, representatives of Sepkoski's three evolutionary faunas occur in association, or in near association, viz., the siliceous sponges and radiolarians of his "Modern" fauna, together with graptolites of the "Paleozoic" fauna, and trilobites and inarticulates of the "Cambrian" fauna. The siliceous sponges probably originated as benthonic organisms on the slope, and the radiolarians were part of the planktonic component of the ocean. Neither of these groups can be interpreted as having originated onshore, nor should they be classified as a part of Sepkoski's "Modern" fauna.

SUMMARY

(1) Sepkoski and co-workers have greatly oversimplified the picture of how the evolutionary radiations occurred during the Ordovician Period, using a mainly North American-based benthonic onshore-offshore model. In particular, they have failed to discriminate between the differing modes of life of Ordovician marine invertebrates and this has led to some rather misleading conclusions when applied globally.

(2) The existing global Ordovician fossil record is markedly biased, because data from continental platform deposits are relatively accessible and completely preserved, whereas information about deposits of oceanic and volcanic island-arc settings is rarely well preserved. Consequently the few sites with small fragmentary remnants of well preserved deposits and biotas within Palaeozoic fold belts, like those of the Molong High and the Parkes Platform, are uniquely important. We need to place greater emphasis on documenting these "windows" as a basis for providing a more balanced overall view of the nature of diversification of Early Palaeozoic marine life. The importance of patterns of present day islands has long been recognized as the basis for explaining the evolution and dispersal of organisms, following the pioneer nineteenth

century work on island biogeogeography by Charles Darwin and Alfred Wallace. More adequate focus on the existing remnants of Ordovician islands and their biotas may help elucidate aspects of how the Ordovician radiation events took place. Certainly they represented some of the most important evolutionary innovations of new groups of organisms in the history of life on earth.

(3) Sepkoski (1979) has claimed that the Palaeozoic taxa were more specialized with narrower ecological constraints than the more generalist, broad feeding and habitat Cambrian taxa they displaced. In terms of the Ordovician radiation events, Sepkoski & Sheehan (1983) point to most of the dramatic increase in diversity being associated with the expansion of the "Paleozoic" fauna with, at the community level, onshore origin followed by displacement of older community types to offshore sites, but the triggering mechanism for this onshore-offshore expansion at the beginning of the Ordovician is far from clear.

This may relate to the major physical changes which occurred in the world in late Cambrian through Ordovician time. These factors include: (i) increased continental fragmentation (Valentine & Moores, 1972), which provided a greater range of potential sites for diversification of shallow-water communities; (ii) subduction-related volcanicity which resulted in a greatly increased number of shallow, offshore island shelf-slope habitats within the oceans; and (iii) an increased global latitudinal gradient, accompanying the changes in the latest Ordovician towards a period of continental glaciation centred on North Africa (Beuf *et al.*, 1971), with a wider range of cool-water, nearshore habitats so becoming available for colonization.

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APPENDIX 1

List of authors and dates of Ordovician taxonomic, palaeoecologic and palaeobiogeographic studies in central New South Wales since the late 1950s

Algae (and/or **Cyanobacteria**) - Semeniuk & Byrnes, 1971; Webby, 1982; Webby & Trotter, 1992
Radiolaria - Webby & Blom, 1986
Stromatoporoidea - Webby, 1969; 1971a; 1979; Pickett, 1970; Webby & Morris, 1976
Sponges (Porifera) - Webby, 1969; Webby & Morris, 1976; Webby & Rigby, 1985; Rigby & Webby, 1988; Webby & Trotter, 1993
Corals (Tabulata) - Hill, 1957; Webby & Semeniuk, 1969; 1971; Webby, 1977; Webby & Kruse, 1984
Corals (Rugosa) - Webby, 1971c; 1972; 1988; McLean & Webby, 1976
Bryozoa - Ross, 1961
Brachiopoda - Percival, 1978; 1979a; 1979b; 1991; 1992
Nautiloidea - Glenister, 1952; Stait, Webby & Percival 1985; Hewitt & Stait, 1985
Trilobita - Campbell & Durham, 1970; Webby, Moors & McLean 1970; Webby, 1971b; 1973; 1974
Ostracoda - Schallreuter, 1988; Schallreuter & Siveter, 1988a; 1988b; 1988c
Echinodermata - Webby, 1968
Conodonta - Savage 1990
Graptolithina - Sherrard, 1962; Moors, 1970

Palaeoecology - Semeniuk, 1973; Webby & Percival 1983; Webby, 1987
Palaeobiogeography - Webby, 1974; 1985; 1987; Lin & Webby, 1989

APPENDIX 2

Faunal lists for Late Ordovician island shelf to island slope and basin biofacies, Cliefden Caves area, eastern part of the Molong High

A1. Lingulide biofacies, based on lower part of Gleesons Limestone Member, Fossil Hill.
Brachiopods: *"Lingula"*
Trilobites: *Pliomerina* (rare)
Ostracods and gastropods (rare)

A2. **Rhynchonellide biofacies**, based on the middle part of the Wyoming Limestone Member, Fossil Hill.
Brachiopods: *Rhynchotrema* (dominant), *"Lingula"*, *Eodinobolus* (fragmentary and sparse)
Bryozoans: *Stictopora* and two others (not determined)
Minor constituents include algae, ostracods and a possible coral *(Nyctopora)*

B. **Eodinobolus biofacies**, based on middle part of the Gleesons Limestone Member, Fossil Hill.
Brachiopod: *Eodinobolus* sp. nov.(dominant), *"Lingula"* (rare)
Alga: *Hedstroemia*
Corals: *Tetradium* (2 spp.)
Bryozoans: *Stictopora, Homotrypa*
Ostracods: *Trianguloschmidtella (Rempesgrinella), Elliptocyprites, Velapezoides?*
Gastropods: (common; not determined)

C. **Tetradium cribriforme biofacies**, based on the Kalimna Limestone Member, Fossil Hill.

(i) Dominant elements in biostrome:
Corals: *Tetradium cribriforme, Nyctopora, Bajgolia* (2 spp.), *Hillophyllum*
Stromatoporoid: *Cystistroma*
Cyanobacterium: *Cliefdenia*

(ii) Other less dominant representatives in biofacies:
Corals: *Billingsaria?, Bajgolia* (+2 spp.), *Eofletcheria, Coccoseris, Pragnellia, Tetradium* (+1 sp.)
Stromatoporoids: *Stratodictyon, Labechiella*
Algae: *Vermiporella, Girvanella, Solenopora*
Bryozoans: *Stictopora, Austraphylloporina, Homotrypa, Batostoma, Prasopora*
Brachiopods: *Eodinobolus* (rare), *"Lingula", Quondongia, Protozyga,*
Nautiloids: *Cliefdenoceras, Troedssonella, Gorbyoceras?*
Trilobites: *Eokosovopeltis, Pseudobasilicus?, Remopleurides, Pliomerina*
Other minor constituents include gastropods, ostracods, bivalves and echinoderm ossicles

D. **Strophomenide biofacies**, based on the Dunhill Bluff Limestone Member, Dunhill Bluff.
Brachiopods: *Sowerbyites, Wiradjuriella, Rhynchotrema, Plectorthis, Anoptambonites, Tylambonites, Webbyspira, Dinorthis, Eodinobolus* (rare), *"Lingula"*
Corals: *Hillophyllum, Tetradium cribriforme, Lichenaria, Nyctopora, Saffordophyllum, Bajgolia* (2 spp.), *Eofletcheria, Coccoseris, Acidolites*
Stromatoporoids: *Cystistroma, Labechiella, Rosenella*
Bryozoans: *Stictopora, Homotrypa, Batostoma, Monotrypella, Austraphylloporina, Fistulipora, Hallopora, Dyscotrypa, Prasopora*
Algae: *Solenopora, Hedstroemia* and others
Nautiloids: *Troedssonella, Gorbyoceras?, Trocholites, Paradiscoceras, Cliefdenoceras*
Gastropods: *Maclurites, Loxoplocus*, and several other forms
Bivalves: rare, and not yet determined
Trilobites: *Pliomerina, Remopleurides, Pseudobasilicus?, Eokosovopeltis*, harpid (indeterminate)
Ostracods: +5 genera (not determined)
Echinoderms: numerous ossicles
Conodonts: a rich assemblage but no specific list of identications yet available.

(i) The coralline-dominated, "biohermal" sub-biofacies is based on the roadside section west of the Boonderoo shearing shed and contains, in particular, the stromatoporoids *Cystistroma, Labechiella, Stratodictyon* and *Pseudostylodictyon*, the corals *Hillophyllum, Tetradium cribriforme T. cruciforme, Eofletcheria, Bajgolia, Nyctopora, Coccoseris*, other heliolitids, the cyanobacterium *Cliefdenia*, bryozoans, and the algae *Solenopora* and *Sphaerocodium*.

(ii) The echinoderm-dominated sub-biofacies is based on the Caves track section and differs mainly from the type biofacies association in exhibiting the edrioblastoid *Astrocystites*, much fragmentary echinoderm debris and calcified lithistid sponges.

(iii) A significantly more diverse articulate brachiopod biota is represented in the strophomenide biofacies of higher stratigraphic levels, for example, in the Quondong Limestone at Bowan Park, and in the Billabong Creek Limestone, between Forbes and Bogan Gate (Percival, 1991). The biofacies constitutents of the Quondong Limestone at Bowan Park comprise 19 articulates, including the genera *Australispira, Ptychopleurella, Molongcola, Trigrammaria, Phaceloorthis, Eridorthis, Christiania, Doleroides, Skenidioides, Dinorthis, Protozyga, Bowanorthis, Tylambonites, Hesperorthis* and *Zygospira*.

E1. Periplatform ooze biofacies, based on tabular clasts from the main debris flow in the lower part of the Malongulli Formation, Copper Mine Creek.

Demosponges: *Haplistion, Warrigalia* (2 spp.), *Taplowia, Lewinia* (2 spp.), *Boonderooia, Cliefdenospongia, Archaeoscyphia, Aulocopium, Perissocoelia, Hudsonospongia**, *Patellispongia, Psarodictyum, Amplaspongia* (2 spp.), *Malongullospongia**, *Pseudopalmatohindia, Dunhillia* (4 spp.), *Yarrowigahia**, *Gleesonia**, *Vandonia**, *Hindia, Belubulaspongia, Palmatohindia* (3 spp.), *Arborhindia* (2 spp.), *Mamelohindia, Fenestrospongia, Astylostroma**

Hexactinellids: *Tiddalickia**, *Wongaspongia, Walliospongia**, *Liscombispongia, Wareembaia, Kalimnospongia*, root tuft

Sponge spicules of hexactinellid and other problematical derivation: *Silicunuculus, Brachiospongia, Anomaloides* and other new form taxa (3 gen.)

Calcareans: *Nibiconia**, *Belubulaia**

Radiolarians: *Entactinia* (3 spp.), other entactiniids (3 different types), *Kalimnasphaera, Auliela*, rotasphaerids

Conodonts: (identifications courtesy of J. Trotter) *Bellodella, Bellodina* (several spp.), *Besselodus, Dapsilodus, Istorinus?, Oistodus, Oulodus, Ozarkodina, Panderodus* (several spp.), *Paroistodus?, Periodon, Phragmodus, Plectodina, Protopanderodus, Pseudobelodina* (several spp.), *Pseudooneotodus, Scabbardella, Spinodus?, Strachanognathus, Taoqupognathus, Walliserodus, Zanclodus* and other indeterminate elements

[*Taxa from other Malongulli breccia deposits, specifically the Sugarloaf Creek and Gleesons Creek localities]

E2. Graptolite basinal biofacies, based on basal Malongulli Formation, Trilobite Hill.

Graptolites: *Leptograptus, Climacograptus, Dicellograptus, Dicranograptus, Diplograptus, Orthograptus, Glyptograptus*

Hexactinellid sponges: numerous discrete spicules and a few indeterminate, loosely clustered skeletons

Trilobites: *Remopleurides, Eokosovopeltis, Parkesolithus, Malongullia* (2 spp.), *Encrinuraspis*

Brachiopods: (Inarticulates) *Anomaloglossa, Elliptoglossa, Paterula, Conotreta?;* (Articulates) *Durranella, Sericoidea*

Nautiloids: *Bactroceras*

Other minor constituents of the biofacies include bivalves, hyolithids, ostracods and conulariids

F. "Lagoonal" biofacies, based on massive grey lime mudstones and wackestones in the lower part of the Transmission Limestone Member and lower part of the Belubula Limestone, Dunhill Bluff.

A sparse biota including:

Algae: a possible dasyclad but others not determined

Stromatoporoids: possible *Cystostroma*

Corals: rare *Tetradium* and heliolitines

Trilobites: fragments only

Echinoderms: a few ossicles

Bryozoans: stictoporid (rare)

Gastropods: rare and indeterminate

Trace fossils: indeterminate burrowers; possible *Chondrites*

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ON BEING INTERESTED IN THE EXTREME

E.C. POTTER

Presidential Address delivered before the Royal Society of New South Wales on 1st April,1992

ABSTRACT. A listing of things in order of some characteristic generates an extreme at each end. Each extreme merits a superlative, such as highest or lowest, shortest or longest, and so on. More qualification and conditions must usually be applied before extremes are defined adequately, so that the supply of extremes is seemingly endless. As time progresses, discovery and attainment cause displacement of existing extremes by even more superlative ones. In this paper study and analysis are presented of selected familiar extremes of number, of human fleetness and strength, and of topology. Thus, the highest number expressible by three numerals is nine raised to the ninth power of nine, but this extreme is hugely surpassed if Roman numerals are used. In the field of human endeavour, analysis of trends in successive extremes of drug-free running indicates that the first woman to run a 4-minute mile will do so around the year 2025, about which time men will be attaining the ultimate extreme for the same distance of close to 222 seconds. Curiously, the extreme of human efficiency for lifting a mass above the head is exhibited by the male of the species weighing within about 2% of 60 kg. New extremes are continually being discovered. For example, all conventional 6-sided dice are not the same, and the extreme of 16 different has recently been proved to occur by chance in the ordinary market place.

INTRODUCTION

Everyone has some interest in extremes, that is those things which, when ranked in order of some common characteristic, appear at the head or the foot of the list. Some extremes never change, like zero and infinity, while others are unlikely to change, like the highest mountain or the deepest spot of the ocean; but a good proportion of extremes (those we often call records) are temporary and stand to be exceeded (or "broken" in the case of records). The new superlatives, on displacing the incumbents from their lofty (or lowly) perches, pad our newspapers and magazines for our fleeting enjoyment or secret disdain.

Most extremes are far from dull and a few are favourites for opening conversations (the weather, for instance, which is exceptional among extremes for always being extreme, even when it is average). There are curious and humorous extremes, and others that are decided subjectively (Miss World or Mr Universe). Others, again, must await recognition, such as the highest proven prime number or the longest human life. Anyone may successfully indulge in the pastime of inventing extremes, but it is far from easy to bring to light extremes that have wide appeal, enough to warrant inclusion in that ultimate resort of extremists, the Guinness Book of Records.

A few examples in catechetic form illustrate the variety that extremes offer, and the subtlety of conditions that sometimes apply.

Q. What stable (i.e. non-radioactive) compounds of only two different atoms have the extreme molecular masses?

A. The substance lithium hydride, LiH, prepared from the isotope ^{6}Li has a molecular mass of 7.023; at the other extreme lead telluride, PbTe, prepared from the isotopes ^{208}Pb and ^{130}Te has a molecular mass of 337.9.

Q. What is the longest Roman-numeral Anno Domini date so far?

A. The year 1888 was expressed by thirteen letters: MDCCCLXXXVIII, and this extreme will not be superseded before another 895 years from now.

Q. At what age on average does a human being cease to be the world's youngest person?

A. Since on average 264 human beings are born each minute, a baby is no longer the world's youngest person on reaching the age of approximately $^{1}/4$ second.

Q. What extremities of the biosphere can naturally support human life?

A. The air is too tenuous to support prolonged human life higher than about 5.5km above sea level, and is likewise too hot in a convection-ventilated shaft or cave more than about 2km below land at sea-level.

The author of this paper believes there is intellectual enchantment to be found in the study and analysis of selected alphas and omegas of the world around us and, accordingly, will examine some extremes of number, of human fleetness and strength, and of topology, aiming to estimate their future directions.

EXTREMES OF NUMBER

The author has difficulty appreciating high numbers, probably from a conviction that the amount of appreciation given ought to be in direct proportion to the magnitude of the number under consideration. For example, surely one's appreciation of one thousand of anything should be intensified 1000 times in order to do justice to a million of those same things. On the other hand, the act of appreciation (whether demanding wonder, humility, endorsement, or disapproval) does not seem capable of offering sufficient range and subdivision to make (say) the first million numbers fairly ranked and differentiated from each other. Making matters worse is the humdrum presentation to us of monstrous numbers like the present population of the world (over five thousand million) or the national debt of any of several countries (for example, one hundred thousand million monetary units). Such huge numbers lose their stature when given brief vocal rendering as "billion" and "trillion" or are otherwise disguised by exotic prefixes such as "giga" and "tera".

Daily confrontation with billions of this or that makes a million of something seem almost trivial. To regain a sense of proportion, consider a typical pad of sheets of graph paper each ruled in millimetre squares to cover a rectangle 27cm x 18cm. Twenty-one sheets (commonly about half the pad) will present to the eye slightly over one million squares, and thereby provide a fitting perspective of that number. In contrast, if every person now living were allotted a separate millimetre square, then this would require a pile of 50-sheet pads about 15m high, and visual assimilation would be too daunting to succeed. A new pad would need to be added most weeks to keep pace with the population growth, and a regular scanning of each new pad's squares should give a sobering impression of increments of millions at a time.

There is no highest number expressible in the figures (otherwise numerals, digits, or ciphers) we habitually use, although we do have a symbol for infinity, which is a number greater than any that can be counted to. There is no satisfaction in such an intangible extreme, but provided one applies conditions, extremes of number exist and some of these are fascinating in the extreme.

The Highest Number using just three Numerals

This century-old problem is solved using the familiar superscript notation for powers of numbers. However, before challenging the usual solution it is useful to clarify an ambiguity in the notation, and this will be done for simplicity using numeral 3.

Without question 3^3 is "three cubed", which equals 27. However, unless some convention is adopted the tower written 3^{3^3} may mean "three cubed cubed" i.e. $27^3 = 3^9$, which is less than twenty thousand, or it may mean "the three-cubed power of three", i.e. 3^{27}, which is nearly eight million. It seems the latter choice is tacitly adopted when the original problem is answered with the tower 9^{9^9}, that is nine raised to the ninth power of nine, or approximately, nine raised to a power somewhat greater than 387 million. Fully written out this number has (near enough) 370 million digits, (the last of which is 9), so that if each digit were made small enough to fit into a millimetre square, then 160 fifty-sheet pads of graph paper would be required. A scribe writing one digit per second and working 8-hour days (but taking normal holidays) would spend an entire career on the assignment. The tower notation using just three nines can comfortably be written in one second and is obviously a most effective shorthand for this notable extreme.

It is possible, however, to challenge the usual answer on the grounds that Roman numerals are an accepted and familiar alternative to Arabic ones for the expression of numbers. Roman numerals (we may remind ourselves) are based largely on a quinary system: I, V, X, L, C, D, M. The letter M is the largest single Roman numeral and equals one thousand; so that the highest three-numeral number is M^{M^M}, which is one thousand raised to the thousandth power of one thousand. In our usual decimal notation this is a number with one more than 3 x 10^{3000} digits (not just 4 x 10^8 digits, as was approximately the case for the answer based on the 3-high tower of nines). The universe we know has neither dimensional magnitudes nor subdivision and compression of matter to contemplate full scribal justice to the 3M-tower solution to the problem posed by the title of this section, although you could describe it as "1 followed by 3 x 10^{3000} zeros."

The Prime Extreme

The only divisors of a prime number are unity and itself. The lower extreme, the first prime, is 2 and it is the only even one. The only prime that ends in 5 is five itself; after that the scene is set and all the others must end in 1, 3, 7 or 9. If only because there is no upper extreme prime, a record exists for the highest known prime. In 1876 the record stood at $2^{127} - 1$, which is a 39-digit number beginning with 1 and ending in 7. This record, which stood little chance of being broken until electronic calculators came into being, was displaced in 1951 by a number with 41 digits. Since then the record has risen exponentially with date and a few days before this address was first delivered to the Society the record was again broken.

The highest known prime number is now 2^{756839}-1, which contains 227832 digits. This is still a minute number compared with the 3-nines tower (obviously not prime) discussed above, but assuming present rate of progress a prime exceeding this tower will be known less than 50 years from now. This leaves aside the problem of how the number would be written down with visual brevity but total precision.

It is logical to ask whether the present highest known prime is the number we know most precisely (assuming no-one has bothered to print out the 3-nines tower completely). The answer is "no".

The Extreme of Precision

The record for the most precise number is held by π, the first 1 011 196 691 decimal places of which have been known since 1989. In stating this, we exclude as spurious merely repetitive examples such as $^1/2$ (when expressed by $0.5\dot{0}$) and recurring decimals like $^1/3$ ($0.\dot{3}$).

The case of π as an extreme is worth examining. Anyone may take a rigid wheel, measure its diameter and then roll it one complete revolution to find its circumference. With some care the ratio of the larger to the smaller measurement (π) can be obtained to one part in three hundred, yielding π to 2 decimal places as 3.14. If, however, in order to fence a perfectly circular flat field (or paddock) exactly 300m across, precisely 942 metres of fence were obtained, there would be a gap of almost 48 cm unfenced. Clearly a more precise value of π would have avoided the problem, for which purpose existing mensuration techniques would soon establish its value to 5 decimal places as 3.14159

Regarding this 5-decimal π it is certain that all six figures (a rather lack-lustre cluster for something as all-pervading yet immutable as π) have to be what they are and in that order. Naturally the question arises (if only to seek a mnemonic for π) whether some pattern or code exists regulating the occurrence or succession of digits (in the first six only one is even). There is, for example, the conveniently remembered fraction 355/113, which calculates out to 3.14159 and encourages the enthusiast to see if its next decimal place is right for π. It is!

The typical so-called "scientific" hand calculator has a π button that displays 3.141592654 but invisibly operates with the more precise 36 in the 9th and 10th decimal places. Access to the 10th decimal place for π formally allows the equator (assumed circular) to be found with a precision of about 1mm, which seems adequate. The calculator also shows that 355/113 fails to follow π beyond the sixth decimal place, but its display fails to discredit the somewhat less memorable 103993/33102.

There are various series differing in convenience that may be used to calculate π to any desired precision. If the first 30 decimal places are obtained in this way, zero alone of the ten digits fails to appear, and suspicion arises that π eschews 0. If the succession of digits is random (which is compatible with each one being immutable), then three zeros are expected on average in any sequence of 30 successive decimal places, and the odds for no zeros are about 24 to 1 against. π's first zero turns up at the 32nd decimal place, and the second not until the 50th place - still three behind the norm. However, the suspicion dismisses itself, since in the first 200 decimal places there are 19 zeros when 20 is the expectation.

Perhaps, however, π won't abide 00 (the double zero), since this pair does not turn up in the first 200 decimal places, two being the expectation. Suffice it to say that any number of increasingly elaborate propositions can be set up challenging the randomness of digits in π, so that there is no limit to the number of digits required to test for veracity or otherwise as elaboration mounts. For example, on average in every 10^{10} successive decimal places of π the rising sequence 0, 1,....9 is expected to appear once. No reasonable statistician would test for appreciable divergence from expectation until this had reached 10 preferably, so that a minimum of 10^{11} decimal places are needed before we could harbour a fair suspicion that π has a real dearth or excess of 0 to 9 sequences. So far only just over 10^9 decimal places are available, and hence that particular question remains unanswered for the time being.

The discovery and construction of mnemonics is an art form in itself, and they have been devised for π. The author personally finds them difficult to remember and much prefers to memorize the numbers themselves (the record for this is held by a Japanese gentleman, who recited 40,000 decimal places from memory in under 17 hours). If the first 11 integers for π will do, the easiest mnemonic in English that the author has seen is: "May I have a large container of coffee beans now please". Provided one remembers where the decimal point is, this serves to check the batteries of one's scientific hand calculator.

EXTREMES OF HUMAN LOCOMOTION

The fastest form of unaided human locomotion across a firm level surface is the face-forward leaping from alternate feet called "running". Faster locomotion may be possible if some enthusiast perfects a style of running akin to the legs-and-arms gallop used by some monkeys. Not only would such a crouching gait make for a less-discontinuous application of the available force to the ground but wind-resistance would be significantly reduced. As it is, the only way that humans approach uniform force-application coupled with the lowered wind-resistance that crouching brings is with the aid of special footwear such as (friction-prone) roller skates or the near-frictionless ice skates. However, virtually continuous force-application with minimized friction and wind-resistance is achievable using the bicycle, a machine which, although itself powerless, allows the attainment of the greatest velocity with which the human being can progress solely by his own effort across level ground in the open air (currently 71 km/h sustained for 200 metres).

Nowadays the majority of able-bodied human beings of ordinary stature on reaching peak physical maturity can train themselves to run 100 metres in no more than 14.9 seconds, this being the pace which, if maintained for 1609.35 metres would suffice to achieve the four-minute mile, a feat which eluded human accomplishment until 1954. Even so, it is reasonable to assert that all fit and athletic young men and most similar young women would actually run a mile in four minutes provided they closely followed a large bus travelling downhill at a steady 15 miles per hour. This claim stands to be proved only if a new sport of motor-paced downhill running captures youthful imagination, but nevertheless it brings out the influence of two factors, namely gravity and wind-resistance, on the extremes of running attainment. There are other factors, which include distance run, starting skill, wind assistance, altitude, physical stature and fitness, drugs and (clearly) the sex and age of the athlete. It is instructive to examine and compare some of these factors in detail.

MAN versus WOMAN

At any selected running distance the fastest man has always outrun the fastest woman, although the records show that today's fastest women are the equal of the corresponding fastest men of around 70 years ago. While this belated `catch-up' by women is partly explained by their increased acceptance of training and competition this century, the principal reason (applicable to both sexes) is the continual general improvement in physical build, anatomical balance, nutrition and health that the human race has secured for itself by unprecedented medical and sociological advancement. However, for men at least there is evidence that the extreme limits of physical attainment are in sight, which implies dismissal of the idea that one day genetic alteration may produce humans capable of matching the speed of nimbler bipeds like the ostrich or emu, or even of quadrupeds such as the horse or deer. Other factors being equal, performance depends on power to weight ratio, and this is why men's and women's records must be segregated (for example a running man has jumped to clear a horizontal bar 59 cm above his own head, while the best by a woman is 32 cm).

The Extreme in Running

What is the fastest a man unaffected by drug enhancement has run on level ground without a significant following wind and at no advantageous altitude above sea level? It is tempting to answer this question by reference to the current world record for the 100m sprint which stands at 9.86 seconds, representing an average speed of 10.14 m/s (36.51 km/h). This answer must be at fault since the current world record for 4 different men relaying a baton by hand a total distance of 400m (i.e. 4 x 100 metres relay) is 37.40 seconds, which means the men averaged 9.35 seconds for 100 metres, a speed of 10.70 m/s (38.50 km/h).

The apparent discrepancy arises because only the first runner covered his 100m leg from stationary, and the other three had flying starts (meaning that time taken accelerating was not counted). If the "starting loss" were available for the first runner, then an estimate of the fastest average time for the flying 100 metres would emerge and could more satisfactorily answer the original question.

Some estimate of this starting loss may be obtained by assuming that the first runner ran his leg from stationary in a world-class time of 10.00 seconds, leaving 37.40 - 10.00 = 27.40 seconds for the three flying 100m legs. This starting-loss estimate is therefore 10.00 - (27.40/3) = 0.87 seconds, and an improved answer to the question of the fastest runner is 9.86 - 0.87 = 8.99 seconds for a flying 100 metres (11.12 m/s).

The assumption inherent in this method is that each of the three receivers of the baton did so at the full speed of his donor runner. Such a full-speed baton-change requires receivers to reach full speed (say 11 m/s) within the maximum 20 metres each is allowed by the rules for a valid baton-change. On this basis if the fastest man reaches full speed in precisely 20 metres from stationary and incurs a starting loss of 0.87 seconds, then the world record for the 60 metres sprint should be (8.99 x 0.6) + 0.87 = 6.26 seconds. In fact the record is 6.41 seconds, revealing an inconsistency (0.15 second) that spells rejection of the assumption that a sprinter can accelerate to full speed in 20 metres from stationary.

A sounder approach is to compare the world records for 60m and 100m sprints, on the assumption (applicable for such short sprints only) that the 60m record would have produced the 100 metre record if it had continued for the additional 40 metres. It then appears that the final 40 metres of the 100 metre record was run in an estimated 9.86 - 6.41 = 3.45 seconds (11.59 m/s). Pro rata the flying 60 metres would be run in 3.45 x 1.5 = 5.17 seconds, and the starting loss is thus estimated to be 6.41 - 5.17 = 1.24 seconds.

The best answer possible at present to the question of the fastest human being is that a male has sustained a speed of 11.59 m/s by running 40 metres in an estimated 3.45 seconds. Shorter distances may have been run faster, but this is difficult to quantify since the running gait is non-uniform in speed and body attitude, and timing over a reasonable number of paces (say 20, or c.40m) is required to compensate for such fluctuations.

The same question can be similarly addressed for the fastest woman except that, as things stand, a difficult choice seems unavoidable. When in the period 1987/88 a particular male sprinter improved the 100m world record by the most unlikely margin of 1%, enquiry showed that banned drugs were responsible and his performances were deleted from the records book. About the same time a female sprinter improved the women's 100m world record by a quite extraordinary 2.5% and the 200m record by an astonishing 1.7%. Nothing untoward was proved, but comparable female performances have not yet appeared and the particular female athlete never competed again. Her officially-accepted 100m and 200m sprint records are not consistent with the performance patterns (common to both men and women) described later, and consequently the women's world records of early 1988 have been used here.

The result is that a female has sustained a speed of 10.55 m/s by running 40 metres in an estimated 3.79 seconds, some 10% slower than the fastest male. The estimated starting loss for the female sprint is 1.28 seconds (cf. 1.24 for men). While the 0.04s difference may not be significant, the closeness of these starting losses for men and women is reasonable since the marginally lower acceleration of the women is compensated by the fact that the women accelerate to a lower peak speed.

The Onset of Fatigue with Distance Run

The world-class runner who makes his maximum effort for 10 seconds and thus covers 200 metres is not exhausted, but can continue at much the same speed to complete 100 metres in 20 seconds. Even then exhaustion is far away since the world record for 400 metres is 43.29 seconds, which requires a definitely sprinting final 200 metres. However, after 400 metres the sprinter's energy is considerably depleted, and fatigue imposes a fast-diminishing rate of energy release, leading to a lowered finishing speed that is easily observed in 4 x 400m relay running.

Evidently, in the brief span that the 400 metre runner is making maximum effort, the refuelling that can be done by breathing in oxygen is minor, and indeed for distances up to about 200 metres such refuelling is insignificant. Thus the sprinter relies on stored energy and experiences little replenishment, in contrast to the distance runner, who is refuelling with oxygen for the duration of the run (3->30 minutes) and by regulating pace strategically conserves energy for a final exhausting burst for victory. After a race the sprinter soon recovers breath and can run at full pace again well within half an hour, whereas the distance runner experiences a more profound and muscular fatigue, so that recovery times up to a day are common depending on distance.

It is convenient to begin analysis of the fatigue effect by considering distances up to 800 metres and, for this purpose and because fatigue relates more fundamentally to time at maximum effort rather than to distance, the various records are compared using the average time in seconds taken to run a flying 100 metres (t_{100}). Thus in the case of the men's 400 metres, the world record time (43.29 seconds) is reduced by 1.24 seconds (the starting loss) and the result divided by four to give t_{100} = 10.51 seconds. The world records for 60m and 100m have been used to estimate the starting loss itself and together they yield the value of t_{100} for 40 metres and the corresponding running velocity 11.59 m/s. Since 800 metres is a middle distance and not a sprint, the starting loss is taken pro rata on the average (flying) velocity i.e.. 1.24 x (7.93/11.59) = 0.85 seconds. This rule has been used for all longer distances, although the starting loss is of little consequence beyond about 2 km.

Figure 1 shows the relation of t_{100} to flying distance run, d_f metres, and for both sexes a linear relation exists to some distance beyond 400 metres. By 800 metres, however, the linear relation is giving way to a lower dependence of t_{100} on distance. The fatigue effect (evident as an increase of t_{100} with distance) is clearly greatest in the sprints, where maximum effort is exerted throughout the race and opportunity for recuperation is insignificant. As viewers of world-class 100m races perceive, sprinters vary in their styles and finishing talents, but fatigue must eventually intervene and can be detected about 60m after reaching full speed some 40m from the start. The fatigue shows to the extent that for men the second 100m of a world-class 200m

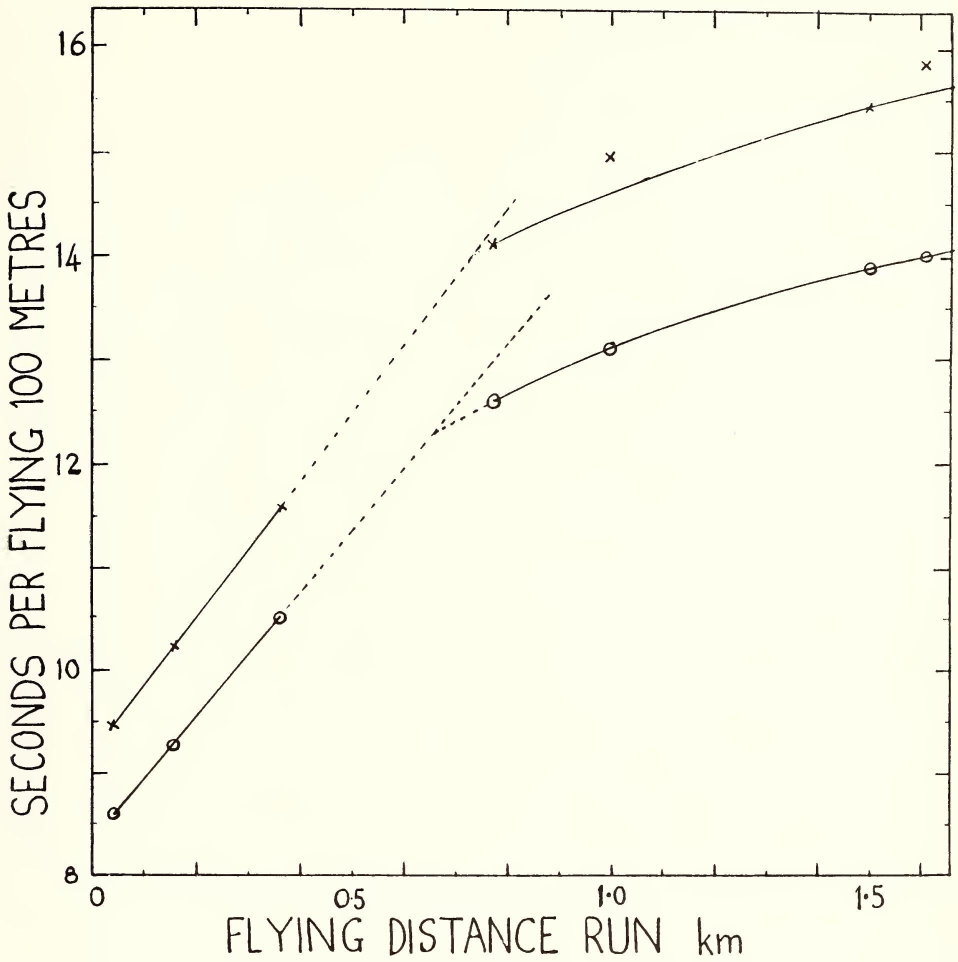

Fig. 1. The fatigue effect in current world-record running for flying distances, d_f, up to 1.61 km.

x---x women. Sprint equation (40-400m) $t_{100} = 9.19 + 0.00659d_f$;

o—o men Sprint equation (40-400m) $t_{100} = 8.33 + 0.00605d_f$

is covered in close to the same time as the first 100m, which, however, includes the starting loss (1.24s). For women sprinters the fatigue effect is slightly greater than for men at the same distance, and persists at the enhanced level seen in sprinting for slightly longer than for men.

At 800 metres the strategy of middle-distance is prevailing over the explosive expenditure of energy demanded in the sprints. For middle distances, which extend to 2000 metres for both men and women, the initial 100-150m are usually run fairly explosively while fresh so as to establish a favourable position, but after this the pace eases in order that each runner retains strength to embark upon a final burst (up to 250m) finely judged so that no more than the beginnings of serious exhaustion are intruding when the "finishing tape" is reached.

To appreciate the contrast between sprinting and distance running, a logarithmic distance scale is most useful (see Fig. 2). It is then seen that the pronounced fatigue effect with increasing sprint distance gives way at longer distances to a more moderate approach to exhaustion evident as a straight line on the semi-logarithmic plot. It is emphasized that no physical or theoretical reasoning is offered for the log-linear relation, which, at various slopes, persists even with races exceeding 1000 km in length and 10 days in duration.

At 2000 metres the limit of the middle distances is reached and thereafter an even more energy-efficient regime of running (also log-linear) characterises the so-called distance events, which these days extend out to 42.195 km (the Marathon). Beyond this distance additional problems of bodily deterioration are encountered and few athletes can run ultra-long distances. The best of these exceptional men and women can run non-stop for up to about 24 hours (covering of the order of 250 km) and their performances also conform to a log-linear relation (not included in Fig. 2).

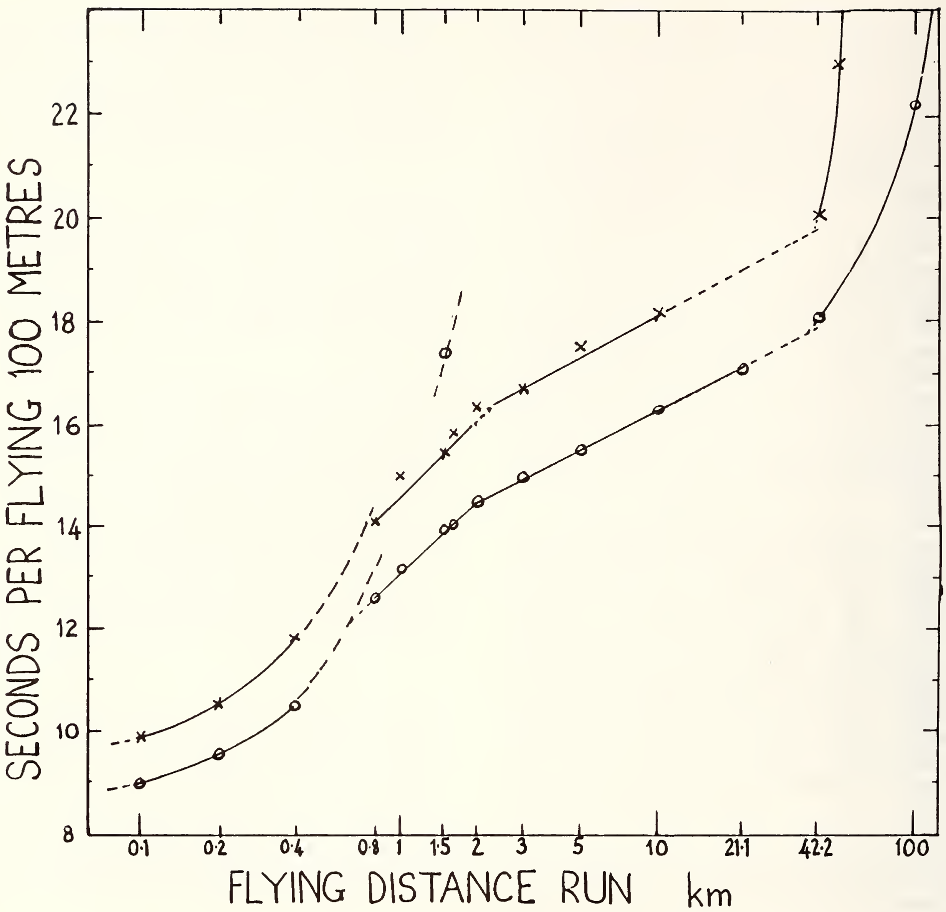

Fig. 2. The fatigue effect in current world-record running for flying distances (log scale) up to 100km.

x---x women. Middle-distance equation $(800 < d_f < 2000\text{m})$
$t_{100} = 0.594 + 4.686\log d_f$
Distance equation $(2\text{km} < d_f < 40\text{km})$
$t_{100} = 7.43 + 2.70\log d_f$

o—o men Middle-distance equation $(800 < d_f < 2000\text{m})$
$t_{100} = 0.507 + 4.55\log d_f$
Distance equation $(2\text{km} < d_f < 40\text{km})$
$t_{100} = 6.085 + 2.55\log d_f$

It is tempting to speculate that specialists in the sprints, the middle distances, and the distance events represent three distinct types of individual each possessing a blend of athletic talents that confer excellence in their class. Support for this idea arises because some of the finest middle-distance runners have turned to distance running when youthful speed appears to be waning, but none ever seems to attain world-class again at the longer distances. Furthermore, sprinters never gravitate to longer distances, except for the decathletes among them, who must compete over 1500m, the only non-explosive event of the ten. If the sprinters' linear fatigue effect with distance (t_{100} = 8.33 + 0.00605d_f) is extrapolated to 1500m (see men's dotted line in Fig. 2) then an improbably slow time of 262 seconds is the result, this being some 50 seconds (nearly 25%) longer than the present men's 1500m world record. However, examination of the performances during the six most recent decathlon world records (by 5 different athletes over the past 20 years) shows that their average time for the 1500m segment of the competition has indeed been 262 seconds (range 253-275 seconds). Moreover, the 1500m time is slower the faster the 100m time by the same athlete in the same competition. It appears, therefore, there is much to commend the idea that sprinters and middle-distance runners come from different moulds.

Can there, however, be a fair contest between these two contrasting types of athlete? It is suggested that the nearest approach to an affirmative answer is to introduce a men's race over 700 metres, which is the extrapolated distance common to both the sprinters' and the middle-distance lines in Fig. 2. This new 700m race (1500m minus the last two laps) would be innovative in that gaps as much as 40 metres can be expected to develop around the halfway stage, only to be closed dramatically at race-end with an estimated world record near 89 seconds.

Do Running Extremes have Extremes?

At any one time at a selected distance run below about 2000m altitude the extreme for undrugged men or women is their respective world record. All world records are broken at irregular intervals so that the running extremes are time-dependent, and the question arises whether each running distance has its ultimate extreme record determined by the furthest capabilities of the human body. The best approach to answering this question is to examine the record history for a distance that has attracted prolonged competition. Such a record is the men's one mile (1609.344 metres) run from a stationary start on a regulation outdoor track having close to four laps to the mile, each lap consisting of two equal straights alternating with two identical curves. Records for this distance date back to 1858, since when the record has been broken 34 times and has been improved overall by 14%. In the seven years since July 1985 the record has stood at 226.32 seconds, but in the past it has remained unbroken for up to 9 years, so there is no good reason to think the present record is inviolate.

The question of the ultimate fastest mile has been speculated upon since at least 1923 when the celebrated Paarvo Nurmi, on lowering the record to just over 250 seconds, judged that 244 seconds was probably the ultimate. Within 20 years that "ultimate" was surpassed, and 11 years later still in 1954 the 240-second barrier was breached. Roger Bannister, the first to beat four minutes, speculated that the ultimate would be 230 seconds, but even this was surpassed 21 years later. In the 17 years since then speculation has lost popular appeal, but the record has been bettered six times and attempts are still being made.

If the 29 mile-records of this century are plotted against date, an irregular sawtooth downward gradation is the visual result. Through this "noise" the profile of an early rapid improvement of the record can be seen, after which for about 40 years up to 1970 the improvement is best described as erratically linear with date. Since 1970 a slight tailing-off has been discernible. To foretell credibly the future downward course of the record directly from such noisy data is little better than guess-work. There is, however, one possible prediction procedure based on the fact that surges or peaks in the record-history have shown an unmistakeable and plausible trend for the past 50 years.

The progress of the mile record is distinguished for the outstanding contributions of a number of particularly-talented athletes. Each of these has had a number of almost equally talented followers, who have broken the record by minor margins pending the appearance of the next especially-exceptional athlete. These surges or peaks (8 so far) have appeared every 3-11 years since 1923, but since 1942 their heights have been decreasing as the record has become harder to beat. Projection of these heights forward suggests that the ultimate mile will be run about the year 2025 and last about 222 seconds. Table 1 and Fig. 3 summarize the situation and indicate inter alia that the existing record stands to be reduced by 3 seconds in the coming 5 years. Fig. 3 shows how the forward projection has been made, erring on the side of greatest plausible achievement.

Nowadays, with the 4-minute mile a commonplace the appeal of the men's mile has largely vanished. However, the question should now arise: will a woman ever run a mile in less than 4 minutes? The women's 1 mile record has stood since mid-1989 at 255.61 seconds. However, as is argued in the next section, this record is relatively poor compared with other middle-distance records and should currently be 251 seconds, a time close to the corresponding men's record in 1922 (70 years ago at the time of writing). If comparisons are made of nine men's and women's records for which reliable data exist, it appears that on average the women's record equals the men's record of 71 years ago (an average based on a range of 51-88 years). Assuming this average will apply, the first women's 4-minute mile may be expected 71 years after a man achieved the same goal in 1954, that is in 2025 give or take ten years or so.

Running Records due for Improvement

Frequent world competition keeps world records compatible with each other and with the continuing physical advancement of the human body. When an exceptional athlete appears on the world scene, the tendency is for him or her to enter competition at the less common (but still internationally recognized) distances and in this way records keep up-to-date with the current ultimate of human running attainment. Exceptions occur, and relatively poor records can be detected by non-conformity with the lines drawn through men's and women's records in Figures 1 and 2. Another method is to look for departures from the current average ratio of men's to women's records compared at the same distances. For example, the male/female ratio of the times per flying 100 metres over most distances from 40 metres to the marathon (over a thousand times longer) is remarkably constant and averages 0.901 ± 0.005 at the present time. However, the ratio for the following four distances is currently below average: 1000m (0.877), 1 mile (0.885), 2000m (0.884), and 5000m (0.887). The present women's records for these four distances are therefore the most-readily breakable and should stand at the times shown in Table 2. The same test justifies this paper's shelving of the present 100m and 200m official world women's records.

A different speculation may be focussed on the marathon (42.195 km), the current records for which lie slightly above the two distance-runners' lines given in Fig. 2.. The two deviations may be genuine in so far as the required physical endurance and mental resolve of the human being just cannot be mustered, but the author does not favour this explanation and has included the marathon in the records ready to fall at any time now.

EXTREMES OF WEIGHTLIFTING

To many a good citizen the pursuit of competitive weightlifting may seem a mindless indulgence for the grotesquely muscle-bound male. In fact it is a safe and

TABLE 1
PAST AND PROJECTED FUTURE PEAKS IN THE SUCCESSION OF MEN'S MILE WORLD RECORDS

Peak Number	Initiating Athlete and Code in Fig. 3	Initiating Date	Associated Athletes	Joint Improvement By Athletes seconds	%	Record Reduced To (s)
1	Nurmi; N	1923.6	Ladoumègue	3.4	1.35	249.2
2	Lovelock; L	1933.5	Cunningham Wooderson Hagg Andersson	3.0	1.20	246.2
3	Andersson; A	1942.7	Hagg	4.9	1.99	241.3
4	Bannister; B	1954.4	Landy Ibbotson	4.1	1.70	237.2
5	Elliott; E	1958.6	Snell Jazy	3.6	1.52	233.6
6	Ryun; R	1966.5	Bayi	2.6	1.11	231.0
7	Walker; W	1975.6	Coe Ovett	2.6	1.12	228.4
8	Coe; C	1981.7	Cram	2.08	0.91	226.32
BELOW THIS LINE, PEAKS AT INTERVALS OF 4, 8, 9 AND 6 YEARS (cf. PEAKS 4-8) ARE SELECTED TO MAXIMIZE IMPROVEMENT OF THE RECORD AFTER 1993.						
9	U	1993	?	1.6	0.71	224.7
10	V	1997	?	1.4	0.62	223.3
11	X	2005	?	0.9	0.39	222.5
12	Y	2014	?	0.3	0.15	222.1
13	Z	2020	?	0.1	0.05	222.0

TABLE 2
WORLD RUNNING RECORDS NOW DUE FOR IMPROVEMENT

World Record Description	Present Record (sec.) and date set	Record should be (sec.)	Improvement sec.	%
Women's 1km	150.6 ; 1978	146.6	4.0	2.7
Women's 1 mile	255.61; 1989	251.2	4.4	1.7
Women's 2km	328.69; 1986	322.6	6.1	1.9
Women's 5km	877.33; 1986	863.6	13.7	1.6
Women's Marathon (42.195km)	8466 ; 1985	8363	103	1.2
Men's Marathon	7610 ; 1988	7549	61	0.8

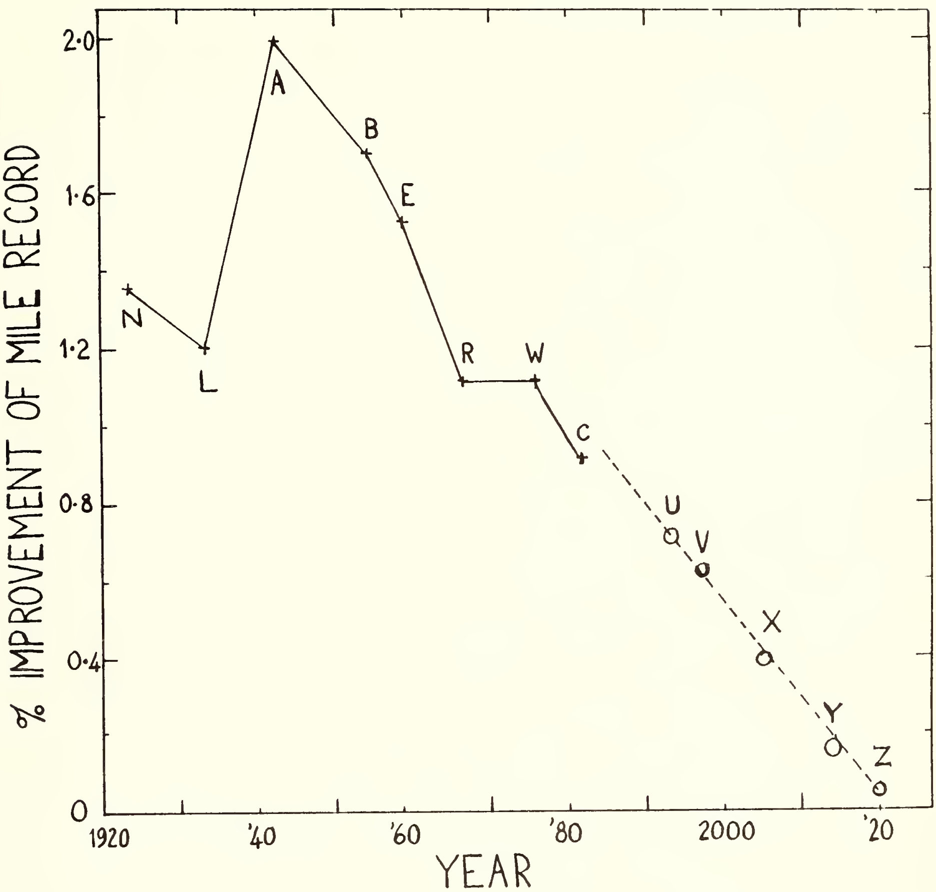

Fig. 3. Projection forward of past peak improvements in the men's world mile record. For explanation of code letters see Table 1.

sophisticated sport where the present levels of attainment owe much to the scientific examination of body mechanics and refinement of technique. Indeed skill and elegance have become so much of the action and the spectacle that women weightlifters have entered the arena and been internationally recognized since 1987.

There are various techniques to lift weights competitively, but for some years the influence of the Olympic Games has been dominant and the emphasis has moved to the techniques known as "the snatch" and "the jerk". In both techniques the competitor's object is to lift the greatest weight (i.e. mass) with both arms from the floor above his or her head and to stand there stably at full stretch for the second or two required to demonstrate a successful lift. In each technique the lift takes place in successive movements with pauses permitted to optimize balance, the disc weights being attached dumbbell fashion to the ends of a strong bar.

In the "snatch" the weight is lifted above the head at the same time as the lifter sinks to the squat position, and the lift is completed by rising to standing with the weight aloft at both arms' length. In the "jerk" the weight is lifted in a double movement to standing with the weight close to the body and underpinned by the arms nearly at shoulder height, and the lift is completed by straightening the arms raising the weight to full stretch above the head. In both techniques the starting and finishing attitudes are the same, but because the snatch needs the greater impulse to project the weight above the head in the initial movement, the greater weight can always be lifted by the jerk technique. Because both skill and strength contribute to the weight that trained individuals can lift, winners in competition are decided from the combined snatch and jerk lifts. Records for combined lifts are not considered here.

Other factors being equal, greater weights can always be lifted by heavier men (the same holds for women), so that

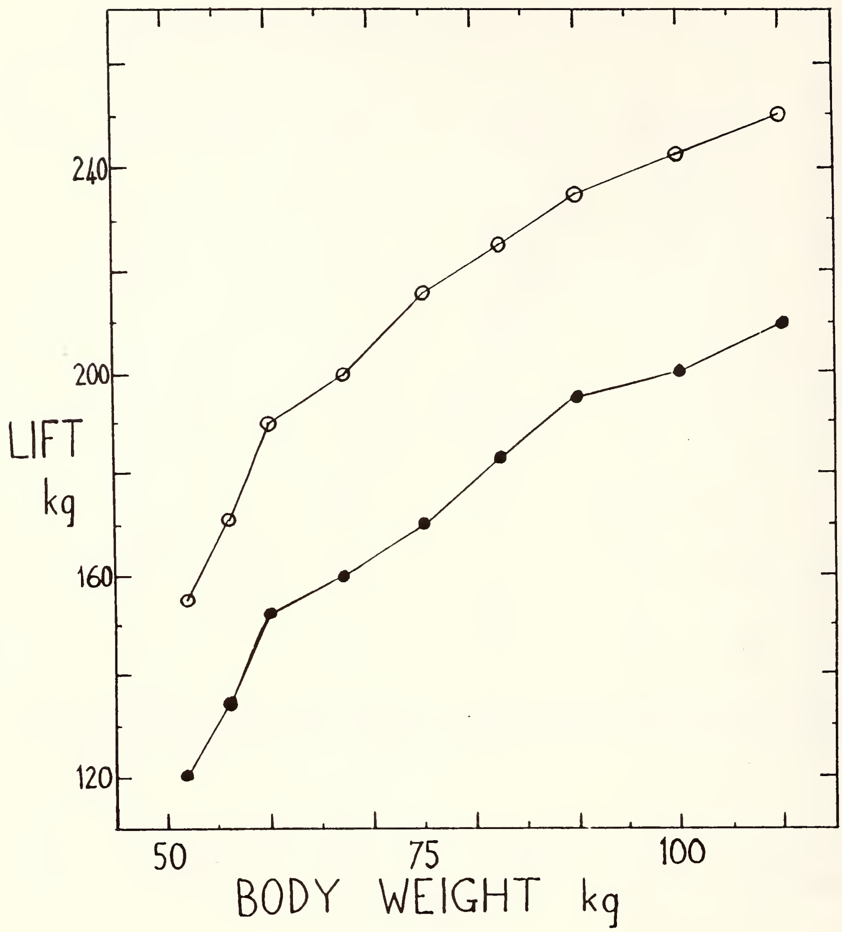

Fig. 4. Current men's world weightlifting records for the maximum weight in each of nine international body-weight classes.
o—o jerk technique ; ●---● snatch technique

competition and records are classified according to narrow non-overlapping ranges of body-weight. Figure 4 shows the 1992 men's world records for jerk and snatch plotted at the maximum body-weight applicable to each of the nine classes (the tenth and heaviest class has no upper limit and is not plotted). Because the exact weights of the record-holders are not known to the author, the points are joined by straight lines and no smoothing is attempted, even though this may be justified.

The straight linkage of points is no impediment to observing the marked non-linearity of both sets of records, to the progressive disadvantage of the heavier lifters. The extra weight lifted in the jerk is reasonably constant (40 $\pm$ 5 kg) over the twofold range of body-weight covered by the nine classes. This is not surprising, since the seeming advantage of additional strength possessed by the heavier lifters is dissipated through the classes by the heavier weights being handled.

Referring to Fig. 4, although a trained 52 kg man(well under normal weight for most full-grown fit young men) has lifted 155 kg above his head, his trained counterpart at double his weight has similarly lifted (interpolating) 246 kg, which is well short of twice 155 kg. This seems to indicate some insufficiency for the heavier lifters, except that the same 52 kg man raised aloft only 103 kg greater than his own weight, compared with 142 kg for the 104 kg man. Apparently, different ways of comparing the extreme lifts across the various body-weight classes yield different conclusions, but one widely-accepted method of comparison uses the ratio of weight lifted to body-weight. Thus Fig. 4 transposes to Fig. 5, and it is now evident that a 52 kg man has lifted in the jerk just less than 3 times his own weight, whereas the 104 kg man has similarly achieved only $2^1/_3$ times his weight.

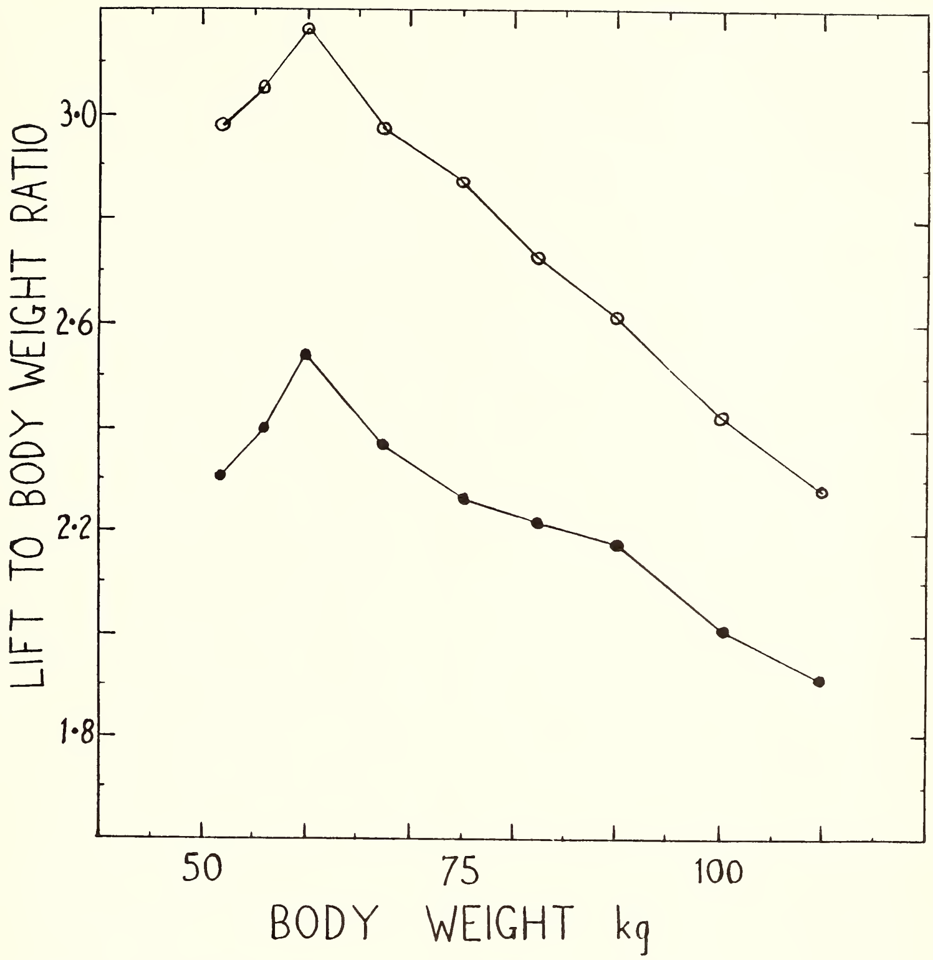

Fig. 5. Current men's world weightlifting records as lift to body-weight ratio for the maximum weight in each of nine international body-weight classes.
o—o jerk technique; ●—● snatch technique

The most obvious feature of Fig. 5 is the sharp peak at 60 kg body-weight for both lifting techniques, a feature that has persisted for at least the past 40 years. The peak inspires the conclusion that the extreme of human efficiency in lifting a mass aloft is to be found in the trained and fit man in his twenties with a body-weight of precisely 60 kg. A lighter man is too puny, and a heavier one is too ungainly to attain the (current) distinction of lifting above his head 3.16 times his own weight. Like most of today's weightlifting records this is probably not far from the ultimate for the male body, since it is only in recent times that monitoring has reduced the incidence of drugged lifters and it takes a number of years for undrugged performances to equal the earlier drugged ones.

It is as yet too early to analyse women's weightlifting records since the scale of activity has been relatively small. It is already evident, however, that the differences between corresponding "snatch" and "jerk" records are constant with body-weight (as they are with men). So far no maximum lifting efficiency for women has emerged (cf. Fig. 5) and the best (2.16 times her own weight) has been exhibited in the lightest body-weight class, 44 kg. At the same body-weight men are currently lifting 1.5 - 1.7 times the best for women, and so far no woman of any weight has lifted greater than the current record for the lightest men's class.

THE SECRET EXTREME

During childhood most of us become familiar with the humble but capricious die (or "dice", as is growing usage, singular or plural). Whenever counters are used to define a path over a playing space through a succession of positions along the track (as with the century-old game of Ludo), the die is cast to decide the permitted length of travel at the thrower's turn. From ancient times the common die has been a cube with its sides differentiated by one to six dots, each face presenting an instantly-recognizable dot pattern.

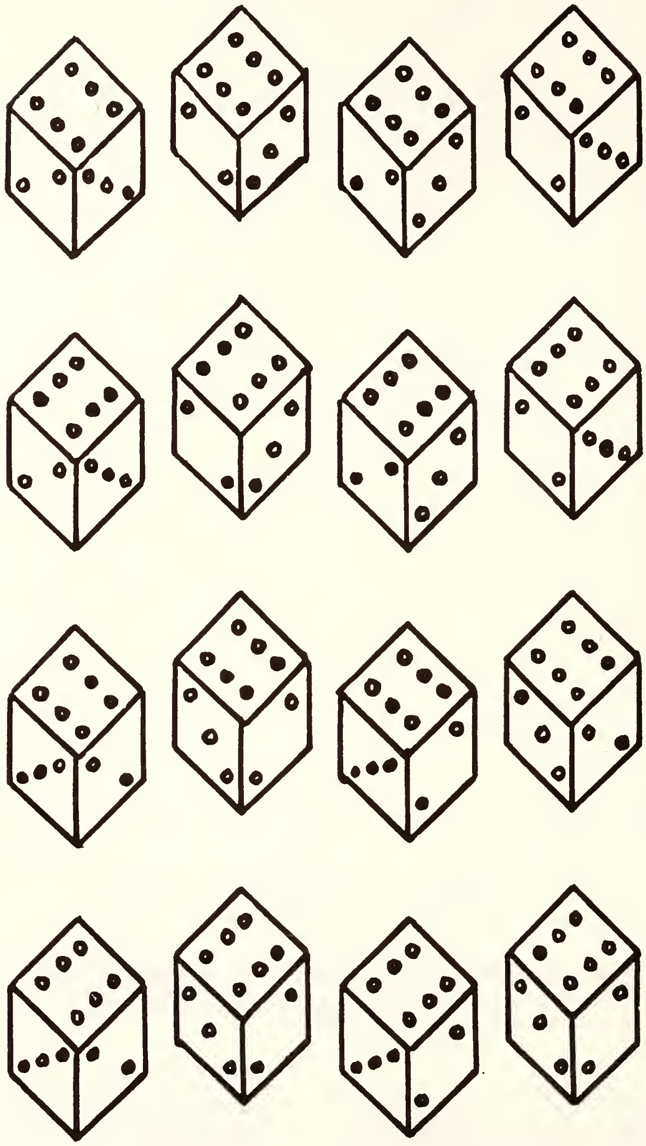

Fig. 6. The 16 different standard dice. The top row has the "six" aligned at right angles to the "six" in the second row. The two upper rows have the "three" on the right of the corresponding "two", and this is reversed in the two lower rows. The two left-hand columns have corresponding "twos" and "threes" in V or in inverted-V formation; the two right-hand columns have corresponding "twos" and "threes" in parallel formation.

Formally, it makes no difference which face identifies any particular score, and this suggests there are factorial five or 120 different dice. However, the time-honoured convention from at least Roman times is to select dots for faces so that opposite (i.e. parallel) faces add up to seven. Thus 1 is opposite 6, 2 opposite 5, and 3 opposite 4. All dice manufacturers observe this "7-rule", and it might be expected (ignoring incidental variations such as size, colour, corner facets, material, and so on) that all dice are the same. This is not so.

In 1974 it was suggested that dice can be left-handed or right-handed. To appreciate this distinction a die is held so that the faces scoring 1, 2 and 3 can be viewed simultaneously. It is then evident that, without violating the "7-rule", the scores can be inscribed to read in the ascending order 1, 2, 3 in either clockwise or anticlockwise direction. The statement was published (Laithwaite, 1980) that all dice present the anticlockwise (called "left-handed") arrangement. Marketplace scrutiny soon shows this is not so, demonstrating that the 7-rule is the only prevailing one, and suggesting that just two different standard (i.e. 7-rule) dice are possible. This surmise is also wrong, and there are in fact 16 different standard dice, which arise in the following way.

Inspection confirms that only the 1, 4 and 5 faces are each unique. Thus, the 1 face has a single central dot, the 4 is a square of dots with its two diagonals common with those of the face it marks, and the 5 (a quincunx) is simply the 1 and the 4 superposed. In contrast, the 2 and 3 are on the diagonal but, since every face has two diagonals, these scores offer four different conformations when taken together (i.e. they can be parallel in two ways, or they can trace out either a V or an inverted V). The 6 is the only face to have any dots (actually two of them) situated off-centre at mid-points of parallel edges, and it has two different alignments (relative to the 2 or the 3) at right angles to each other. So far this makes eight different conformations for the 2, 3 and 6, but if these three faces are put simultaneously on view, either the 2 or the 3 can be on the left, so that the extreme for different standard dice is sixteen (see Fig. 6). In this figure the four dice on the top row have their "sixes" in the same alignment which, however, is at right angles to that of the four "sixes" in the second row. This contrast is duplicated in the bottom two rows, where, however, all eight "threes" are on the left (rather than on the right as they are in the upper rows).

Curiously, dice manufacturers as a class seem unaware of these alignment distinctions and so, once they have individually designed their dice according to the 7-rule, chance prevails and the extreme of sixteen standard dice is potentially available to the ordinary purchaser. So far, by dint of casual, unsolicited, and wide-ranging search over many years, the author has purchased 15 of the 16 from commercial stock and has seen the 16th for sale as part of an expensive gaming set.

For the author this has been the secret extreme, but with this publication his secret is out and, succumbing to cynicism, he imagines that it is merely a matter of time before sets of sixteen fraternal dice will appear on the market in a range of materials from common to precious for the extremophile who has everything.

ACKNOWLEDGEMENTS

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ERRATA: Vol.125 Parts 1 and 2

(i) p 37 Summer School on 'Communication' ,
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(ii) Membership List pages 41-49
Lassak, Erich Vincent ....
.... (1964, P4)
should read:
Lassak, Erich Vincent ....
.... (1964, P8)

Smith, William Eric .... (1963)
should read:
Smith, William Eric .... (1963, P3,
Pres.1970).

Buckley, Lindsay Arthur......
Chelmer, Qld. 4075 (1974)
should read:
Buckley, Lindsay Arthur ....
Chelmer, Qld. 4068 (1940).

Hill,Dorothy,......... (1970,P7)
should read:
Hill,Dorothy,.......... (1938, P7).

McCarthy,Frederick David,.....(1974,
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should read:
McCarthy, Frederick David, ...(1949,
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Richard Owen, Thomas Mitchell and Australian Science
A Commemorative Symposium

DAVID BRANAGAN

On Saturday, 24th October, 1992 the well-known expatriate art critic and author, Robert Hughes, was addressing a distinguished audience at Australia's Parliament House on the topic "What's a museum for?"

At the same time a smaller, but possibly no less distinguished group, of scientists and historians, was meeting at Wombeyan Caves Reserve, a delightful, but somewhat isolated mountain retreat, several hours drive north from Canberra, to discuss the work of several long-dead scientists and their associates.

Although at first glance these events seem quite removed from each other in the level of significance (both politically and socially), in relevance, and presumably in elegance, there were some surprising relationships.

Although he was considering mainly art galleries Hughes used the comprehensive term "museums" in much of his discussion, lamenting the "age of museum triumphalism" and the "advent of mass cultural tourism". Hughes criticised the "blandness of current curatorial policies" He believed that the future "belonged to small, intimate storehouses [of culture]....not plagued with great tides of inattentive visitors... such places are not cathedrals but chapels. It belongs to what is local, and used once to be derided as 'provincial'. In them the pure function of the museum can flourish again". (Sydney Morning Herald, 26 October, 1992).

Hughes's lecture came at a time when the future of the National Museum of Australia is once again being reviewed, after a stop-start history of many years. It comes when University museums are being threatened with closure, and when directors of many of our major storehouse of precious archives of every type (including libraries) are desperate for staff and funding to preserve and display priceless material.

Yet, ironically, it comes also at a time when there is a renewed interest in things Australian by the community at large, but who seem to be unaware of the problems involved in the operation of these chapels of art, science and technology.

Perhaps the saddest aspect of the present situation is that many Australian museums seem to be blindly following international trends and reducing, or completely removing the research sections of their organisations to the detriment of the displays, which become in time mere items for entertainment with little instruction.

What did the Owen-Mitchell Symposium have to do with such matters?

In a sense the story starts in the Cathedral Cave at Wellington in 1830 and ends with the Great Cathedral of Science, the British Museum of Natural History in London, completed in the 1880s.

The meeting considered a number of aspects of the lives of Sir Richard Owen (1804-1892), Sir Thomas Mitchell (1792- 1855) and related nineteenth century figures in a series of papers interspersed with lively discussion. Although the happy coincidence of the centenary of Owen's death and the bicentenary of Mitchell's birth was the initial reason for the symposium, the major link was the involvement by Mitchell in the exploration of the Wellington Caves in the 1830s, the bones of extinct giant organisms which were discovered there and some of which were subsequently taken to England by Mitchell and studied by Owen.

Two papers by David Branagan and Julian Holland outlined aspects of the careers of Owen and Mitchell. The former paper concentrates on the antipodean aspects of Owen's work, which has been generally neglected by earlier workers, while the latter, which is an abstract based on a forthcoming large-scale appraisal of Mitchell's work, considered some formative influences on Mitchell.

A paper by Ann Player discusses a facet of the work of J.E. Tenison Woods, an early student of Australian Caves, who was involved in the discovery of the large emu-like bird, named by Owen *Dromornis* , and who did much to popularise science in the Australian press.

Three papers were given at the Symposium on the fossil material itself. Armstrong Osborne considered the sediments which encase the vertebrate fragments in Wellington and Wombeyan Caves. Jeannette Hope discussed the fossil fauna she had examined from the Wombeyan Caves area, and the influence on her work of earlier vertebrate palaeontologists Robert Broom in the 19th century and Norman Wakefield who had encouraged her work prior to his relatively early death . [This paper is not reproduced here, as Dr. Hope is overseas]. The paper by Paul Willis, Susie Davies and Armstrong Osborne documents the exciting find of previously undescribed material from Wellington, Wombeyan and Clairvaulx, near Glen Innes, the result of what the authors called the "pursuit of three presently unpopular activities - looking backwards, curiosity-driven research and the study of collections", and brings the Russian scientist Maklouho-Maclay, Edgeworth David, Robert Broom and more recent researchers into the story. These papers were followed up by visits to important sites both on the surface and underground

Michael Shortland's paper broadens the story by examining the influence of the study of caves on geological thought from the 18th through much of the 19th century, an influence which Dr. Shortland suggests extends indeed much further, and which has been little researched to date.

The Symposium ended with Nicolaas Rupke's paper on Owen and the Victorian Museum movement, showing his importance in the development of museums, both as sites of popular culture and as research organisations.

Taken in all, this symposium shows the value of looking backwards occasionally, to appreciate both the achievements and failures of the past, and to apply the lessons for the future. What will our museums of the twenty-first century be like? In fact will there be any?

The anonymous author in the "Illustrated Sydney News wrote (1892): "the odd thing about the fossil bones is this - they reveal to us something of the history of Australia, something of the history of our own land as it is written on tables of stone by historians without prejudice, by fingers void of passion. The geological records of a country are true, and the fossil remainders are the dates of the history". However as perhaps the paper above indicates those humans who have attempted to interpret the story are not without prejudice or passion, which is probably not a bad thing. There would be little of interest in a bloodless history of science!

This symposium was organised by the Earth Sciences History Group of the Geological Society of Australia Inc. The Group is grateful to the Royal Society of New South Wales for assistance in publishing the proceedings. Thanks are due to the Wombeyan Caves Reserve Trust for making facilities available for the meeting.

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Richard Owen in the Antipodean Context
[A review]

DAVID BRANAGAN

Abstract: Richard Owen (1804-92) played a central part in the development of Australasian vertebrate palaeontology, although he never visited the antipodes. His identification and description of many fossil (and recent) forms directly influenced several generations of Australasian researchers, and continues, though indirectly, to influence the present researchers, who must perforce return to his work for comparison.

Richard Owen

Owen was born in Lancaster 20 July 1804, the younger son of Richard (1754-1809) and Catherine (neé Parrin) . He was apprenticed to a surgeon and apothecary of that city in 1820, had access to postmortems in the county jail, and became interested in anatomy. He matriculated at Edinburgh University in 1824, but left there the following year to study with John Abernethy at St. Bartholomew's Hospital, London, gaining membership of the Royal College of Surgeons in August, 1826.

In March 1827, Owen became Assistant to William Clift (1775-1849) at the Royal College of Surgeons. He was to remain at the College for the next thirty years, marrying Clift's daughter, Caroline, in 1835, following Owen as Conservator on his retirement, and becoming the first Hunterian Professor of Comparative Anatomy in 1836. His initial appointment at the College was to complete the catalogues of the Physiological Series of the collections made much earlier by John Hunter (1728-1793). Later he became concerned largely with osteology.

During Owen's early years at the College one of the major influences on his work was the French anatomist Georges Cuvier (1769-1832), who visited the College in 1830 and invited the young man to the Museum d'Histoire Naturelle in Paris the following year. Owen learned from Cuvier the interdependence of the separate organs within the same animal body, (such as teeth adapted for grazing vegetation requiring a digestive system able to deal with bulky plant food), and was able to use this knowledge brilliantly in later years to reconstruct animals from few preserved parts, including "the strangest of the old monsters which it has pleased God to blot out of his Creation".

Following disagreements with the Governors of the College, Owen moved to the British Museum as Superintendent of the Natural History Departments in 1856, remaining associated with this institution until 1883. Apart from research his major achievement here was establishing first the idea of a Natural History Museum, and then the reality of the building at South Kensington, despite the opposition of the Director, Antonio Panizzi (1797-1879), John Edward Gray (1800-1875), Keeper of Zoology, and many eminent scientists, including Charles Darwin (1809-1882) and Thomas Huxley (1825-1895), some of whom felt it should remain close to the printed sources of the Museum's library.

Biographical details of Owen's life may be found in Flower (1893), R.S. Owen (1894), Ingles and Sawyer (1979), and Stearn (1981).

Owen and his Peers

Owen is probably best known among the general public for his opposition to Darwin and Huxley at the time of the publication of *The Origin of Species*, but this is by no means a simple black and white story (see Ommaney,1966; Gunther,1975; Stearn,1981; Bowler,1984).

He also played an important role in popularising palaeontology in Britain, in the period before the Natural History Museum was built, specially with his creation of the series of "those vast and unpleasant animals that existed on our planet before man had made his appearance. Specimens of the Iguanadon, the Plesiosaurus, the Pterodactyl and other mercifully extinct brutes....sported on islands specially arranged for them" in the gardens of the Crystal Palace which was rebuilt at Sydenham in south east London in 1852-54. "A dinner party of twenty-one people was held in the body of one of these monsters, and from the skull Professor Owen delivered a stirring address on the labours of geologists" (Markham, 1935).

Among scientists, apart from his taxonomic work, by which he erected a number of orders of fossil reptiles, Owen is remembered for his interest in functionalism and the concept of "archetypes".

However Owen was a difficult character, Huxley remarking "it is astonishing with what an intense feeling of hatred Owen is regarded by the majority of his contemporaries". Huxley himself had been helped by Owen to obtain a position, and although Owen was "amazingly civil" Huxley felt he was "a queer fish, more odd in appearance than ever and more bland in manner. He is so frightfully polite that I never feel thoroughly at home with him", while Gideon Mantell regretted that "this highly gifted man can never act with candour and liberality". [One aspect of the controversy and bad feeling between Owen and Mantell is discussed by Donovan and Crane (1992). However Owen maintained life-long friendships with Thomas Mitchell, and Samuel Stutchbury among others.

Ironically it was the South American fossils that Darwin brought back from the Beagle expedition in 1836 that began Owen's work in palaeontology (Darwin, 1837), as before that he had concentrated essentially on the anatomy of living animals, including the beautiful *Nautilus*. Much of Owen's early research was published in the proceedings of the Zoological Society of London, which was established in 1831, and of which Owen was a foundation member and longterm Council member. From 1847 the Palaeontographical Society was also the vehicle for many of Owen's papers.

His first zoological paper was on the anatomy of the Ourang-outang, but his paper a little later on the anatomy of the *nautilus* attracted more attention. [It is interesting that the fine portrait of Owen, by Henry William Pickersgill (1782-1875), was altered by painting over the bone of *Dinornis* held by Owen with a *nautilus*.] This paper owed its origin to a fine specimen collected by George Bennett at Vanuatu, and donated by him to the Royal College of Surgeons, but which was appropriated by Owen with no acknowledgement (Moyal 1975, Newland 1991). Bennett continued his interest in this remarkable creature for the rest of his life, but Owen moved on to other matters.

However it was Owen's bold diagnosis in 1839 of a fragment of bone received from New Zealand that really established his reputation. Owen recognised it as part of a femur that belonged to "a heavier and more sluggish species than the ostrich" and "as far as my skill in interpreting an osseous fragment may be credited, I am willing to risk the reputation for it on the statement that there has existed, if it does not now exist, in New Zealand, a struthious bird, nearly, if not quite equal in size to the Ostrich". This almost outrageous statement was greeted with scepticism by many scientists, and the Zoological Society of London published the paper with considerable misgivings. However Owen's idea was successfully vindicated in 1843 when he received, through William Buckland, a collection of bones from Rev. William Williams, together with a letter telling of a Maori legend of an extinct giant bird, the moa. Williams at the time of writing was not aware of Owen's previous prediction. On the basis of the New Zealand collection Owen defined the genus *Dinornis*, with five distinct species. [More recent work has allowed the definition of six genera and at least nineteen species of this remarkable extinct genus].

This extraordinary piece of scientific forecasting and essentially correct solution did much to enhance the reputation of science as well as putting Owen firmly in the public eye. However it must not be forgotten that Rev. William Colenso had apparently heard of the Maori legend of a giant bird in 1838. Colenso not long after obtained material which he described in 1842 independently as belonging to a gigantic struthious wingless bird, the paper being published in the *Tasmanian Journal of Natural History*. For a detailed discussion of Owen and the Moa refer to Gruber (1987).

Marsupials and monotremes

The unusual nature of the Australian fauna and flora was of course recognized by the earliest European visitors, who were intrigued first by the unusual shapes and then by questions of reproduction of the marsupials and the monotremes. Both these groups were studied over the years by Owen. The monotremes, observed by Europeans during the 1890s were first described scientifically, but briefly, by George Shaw (1751-1813) (1792, 1799) and in more detail by J.F.

Blumenbach (1800) who named the platypus *Ornithorhynchus* from a specimen provided by Sir Joseph Banks. However detailed study began with the work of Everard Home (1756-1832), at the Royal College of Surgeons. His brief description of the head of the platypus (Home, 1800) was followed by a much more important paper in 1802, which remained the basic description of the anatomy of the platypus for almost a quarter of a century (Gruber, 1991), despite later papers by Home (1803, 1818, 1819). A great difficulty was the unavailability of suitable specimens of either the platypus or the echidna.

As early as 1800 Home was requesting specimens from George Caley, the collector for Sir Joseph Banks, but he was never able to obtain suitable material as specimens deteriorated during the long journey to Europe. As late as 1825 Home was trying to get specimens, writing instructions for Samuel Stutchbury (1798-1859) on what to collect and how to preserve the specimens (Branagan 1984, 1992a). An important link with Home about this time was Henry Dumaresq (1792-1838), private Secretary to Governor Sir Ralph Darling (1775-1858), his brother-in-law. Dumaresq invoked the help of Surgeon Patrick Hill, R.N. a member of the early Philosophical Society of Australasia (Branagan, 1972), and who was actively seeking specimens, as was George Busby (1798-1870) in the Bathurst area.

Darwin noted their presence when camping on Coxs River near Wallerawang, in January 1836 and George Bennett (1804-1893) pursued the problem avidly for much of his life, and got close to the answer. However in 1874 the question of the egg-laying character of the monotremes was still unsolved and Henry Moseley and companions on the Challenger expedition sought specimens with only limited success in the Healesville area east of Melbourne, but Willemoes von Suhm obtained a live echidna later in the Sydney region (Branagan, 1973). It was to be another ten years before W.H. Caldwell's search in the Burnett River area of Queensland finally solved the question.

Home's attitude that most (perhaps even all) questions concerning essential aspects of anatomy could only been solved in the laboratory was carried on by Owen, whom, it is stated (Gruber, 1991) never went on a field excursion in his life. This attitude contrasts with the approach of George Bennett, and even later of Henry Burrell (1873-1945) (1927), who were fascinated by the living creatures rather than the biological objects. Caldwell's solution to the problem was largely the result of following Bennett's "field laboratory" approach (see Newland, 1991).

However Owen's taking over of Home's mantle in relation to the monotremes seems to have happened rather by accident. Owen had shown little interest in the mounted specimen in Cuvier's laboratory, when visiting there, but on returning to London he began to study both the marsupials and monotremes, studies which were to continue for the next fifty years, and between 1832 and 1884 Owen published at least 14 papers on these recent forms, eight of them appearing before 1838, when his interests turned to fossil forms. Even in the case of the kangaroo Owen was ungracious to Bennett and ignored the evidence of others away from Europe in showing that the young developed in the uterus.

However by the end of Owen's life, as Ride (1968) points out, "the general structure of the mammal fauna of Australia, its richness in marsupials, its unique possession of monotremes, and the restricted range of its eutherians has been known for about a century. The speed and thoroughness by which our early predecessors gained this information is amply demonstrated by the fact that in the last fifty years, there has been no discovery of any new group of Australian mammals; the last were the the family of the Marsupial Mole, *Notoryctidae*, in 1889, and the fossil *Wynyardiidae* in 1900". Ride also points out that "although many of our species were known early, they are known from surprisingly few specimens and still fewer localities".

Australian Fossils

Etheridge and Jack (1881) list thirty seven publications by Owen specifically on Australian geology, dating from 1840 to 1880, all save one being on palaeontological subjects. The sole exception is "On the physical configuration of Australia, and its geological causes" (Owen, 1875). In many cases we see Owen coming back to previously attacked problems, adding new observations, describing newly obtained specimens. Mahoney and Ride (1984) list fifty four papers, having located some obscure, but important, papers by Owen scattered in European publications.

Owen's first publication on Australasian fossils, in fact, appeared in 1838, concerning fossils from

Wellington, as an appendix to Mitchell's book (Mitchell, 1838). There was soon a rapid acceleration and papers appeared frequently until 1870, before a marked decline, as matters closer to home took precedence, and other researchers became more involved.

Fossils from Wellington Caves, collected by George Ranken in 1830 were taken by Revd. J. D. Lang to England and passed on to Professor Jamieson in Edinburgh. These were examined by William Clift and later by Joseph Pentland, both associated with the Royal College of Surgeons but Owen seems to have not studied these (Browne, 1983). Lang's interests in geology were considerable (Lang, 1834, 1846) and have been generally neglected, but he played no further part in this story.

However when Mitchell visited England in 1838 he took to Owen further Wellington material, thus beginning a long and fruitful co-operative friendship (Foster, 1985). Aspects of Mitchell's work are discussed in the following paper by Julian Holland.

It was at Owen's urging, in 1867, that the New South Wales Government in 1868 voted funds ($200) for detailed exploration and excavation of the deposits at Wellington in 1869. Although Rev. W.B. Clarke should have been personally involved in this work, he declined, for reasons of health, and the project was undertaken by Gerard Krefft (1830-1881) of the Australian Museum, with Alexander Thomson (1841-1871) the young Professor of Geology at the University of Sydney and Henry Barnes. They succeeded in obtaining large quantities of new material which was forwarded to Owen, together with photographs (Moyal, 1975), but the expedition proved the end of Thomson, who succumbed a few months later to a pulmonary disease. Owen described this material in a series of papers in the *Philosophical Transactions* , which later was gathered to form the basis of his *Researches on Fossil Remains of the Extinct Mammals of Australia* (Owen, 1877).

Australasian Contacts

It is only possible to discuss a few antipodean workers who supplied Owen with specimens and ideas. The contacts between Owen and Dr. George Bennett were the most extensive and possibly the most important, but Owen was content to leave many of Bennett's letters unanswered, but use his material, as discussed by Newland (1991). In Australia, apart from Mitchell and Bennett, they include Frederick Bennett, George's brother, Phillip Parker King, Joseph Beete Jukes, John Gould and his son Charles, Ronald Campell Gunn, Frederick McCoy and Ferdinand von Mueller, Gerard Krefft and Edward P. Ramsay, William Macarthur, George Macleay, Ludwig Leichhardt, Rev. W.B. Clarke and Samuel Stutchbury. In New Zealand Julius Haast, James Hector, Rev. Richard Taylor (who earlier examined Wellington Caves) and William Swainson can be noted (Mander-Jones, 1972) and Ferdinand von Hochstetter discussed the dispersal problems of flightless birds with him on a visit to London in 1860 (Hochstetter, 1959). Study of these relationships could form the basis of much potential fruitful research in future years.

Owen remained friendly with Samuel Stutchbury, who preceded him at the Royal College of Surgeons until the latter's death in 1859, but their scientific contacts concerned mostly other than Australasian matters. However it was through Stutchbury that Ludwig Leichhardt met Owen, and thus received a letter of introduction to Mitchell, a link between the four that continued into the fifties. This concerned material found on the Darling Downs by a Mr. Isaacs, and obtained by Leichhardt. Leichhardt sent some specimens to Owen in July 1844, Owen reporting on the material at the BAAS meeting in 1845. In his letter with the specimens Leichhardt took issue with Owen's placing of the "gigantic Pachyderm" amongst the *Dinotherium*, suggesting that the specimen he sent "will show you that it is an animal with different incisors and really more allied to the dentition of the kangaroo than to any other animal". He added later in the letter "besides the bones of the gigantic animal, there are lower jaws and different parts of the body of four other kangaroos, many of them little different from the living, and probably identic[al] with those of Wellington Valley" (Leichhardt, 1844).

Stutchbury obtained similar material on the Darling Downs ten years later, and initally described it as new, being, at the time, unaware of Leichhardt's previous study. It was characteristic of him that he published an apology for this faux-pas in a later report (Branagan, 1992b).

Monuments

Australasian monuments to Owen are in the form of three mountains. The first named occurs in Queensland, near the headwaters of the Marinoa River, and was conferred by Mitchell on his third journey (Mitchell, 1847). Mitchell named a number of peaks in this area after prominent European (mainly English) geologists. Similarly, Charles Gould, son of John, placed Owen along with Lyell, Darwin and Murchison on the map of western Tasmania in 1862, Blainey (1960) remarking on the relative smallness of Darwin's peak, an indication of Gould's higher regard for Owen!

Julius von Haast, like Mitchell and Gould, liberally scattered geologists' names throughout the South Island of New Zealand, and Owen was not forgotten, "three rugged serrated peak", about 2000m high in west Nelson, being named for Owen in 1860 but Haast's Mt. Darwin is about 3000m high!

Haast and Owen remained correspondents after Haast sent his Nelson report (1861), together with "some fossil remains of a Plesiosaurus from the Middle Island" (Haast, 1948), the latter hoping "I may still live to see the last of the Moas if the species still lingers in the Mid Islands", and to obtain a specimen of *Notornis* , until they finally met in London in 1886.

At this time Haast was somewhat disappointed to find that of six specimens of moa he had sent to the British Museum about 1872, only one, *Dinornis maximus,* had been put on display and appeared on the books. Haast wrote to his son, Heinrich "as Professor Owen is too old to get up a row with him I am now trying to get up the proofs that I have sent those skeletons "[and he asked his son to check the exchange books in the Museum in Christchurch (New Zealand)]. "It appears that many instances of this kind have happened in the British Museum under Owen's management, and the only explanation is that he had somewhere a big hole dug and buried all that was inconvenient to him" (Haast, op. cit.).

Haast had been very involved in the excavation, description and reconstruction of moa remains [more than 1000 individuals] from Glenmark from 1866, and was the first to summarize what was known of the moa and its ecology, and its extinction, reading controversial papers on the subject in 1868 and 1871.

The pattern of Australasian Science

The Owen/Mitchell relation marked the beginning of one long line of important Australasian research. However it was part of a much longer European/ Antipodean history which is in two strands. The first is the recognition of the unusual character of the present day Australasian fauna and flora which led into the fossil story. The second and related is the recognition of the out-of-step nature of the northern and southern hemisphere forms. These have been discussed by Vallance (1975, 1978, 1981 and 1983) Moyal (1975), Branagan (1972), Browne (1983) and many others, and as the relations between Owen and Australasian workers is further investigated will be the studied in more detail by other researchers.

In this context there has been much emphasis on the idea of an all-powerful metropolitan science with the antipodes and other lesser places on the periphery (e.g. Macleod 1982, Stafford 1989). Perhaps Simpson's Scientific Model (1942) for the development of North American Science (Pre, Proto, Pioneer and Classic), of which Australian Science lacks the first phase is also worth following up, as Vallance (1978) proposes. There were also many scientists who virtually ignored Europe in their work and in reporting it, and whose work was likewise ignored in Europe, as Guntau (1992) has recently pointed out. Naumann in Japan is an excellent example, Joseph Milligan in Tasmania probably falls in this category, and even John Lhotsky too. In other words the "periphery" of science had a life of its own, and reliance on all-embracing models at this stage in our investigations of the history of Australian science should be guarded against.

By the 1860s there were numerous people prepared to describe the Australasian vertebrate fauna. Among them were Frederick McCoy, James Hector, and later Robert Etheridge Jnr., H.Y.L. Brown and C.W. De Vis (Etheridge and Jack, 1882). Some of this story has been described in Rich and Thompson (1982).

Interest in the megafauna continued through the years, a find at Wagga Wagga, New South Wales in 1892 causing Etheridge to hurry there in the hope of finding good specimens, and the Illustrated Sydney News devoted almost a page to the find, including reproduction of several figures taken directly from Owen's publications, and its implications for science.

The influence of the work of Owen, stimulated by Mitchell's fieldwork, on Australian Science has been briefly outlined in this paper, and opens the way for much further research. The other side of the coin is the powerful influence that the Australasian fossil megafauna had on the career of

Richard Owen. Rupke (this volume and in a forthcoming work) makes a powerful case that the study of this material was by no means an altruistic aid for struggling colonies lacking scientific expertise, but was the basis of Owen's career as creator of the major museum of natural history in the world, and that his energies were directed largely to this end rather than to the attainment of fame as an anatomist.

The anonymous author in the "Illustrated Sydney News wrote: "the odd thing about the fossil bones is this - they reveal to us something of the history of Australia, something of the history of our own land as it is written on tables of stone by historians without prejudice, by fingers void of passion. The geological records of a country are true, and the fossil remainders are the dates of the history". However as perhaps the paper above indicates those humans who have attempted to interpret the story are not without prejudice or passion, which is probably not a bad thing. There would be little of interest in a bloodless history of science!

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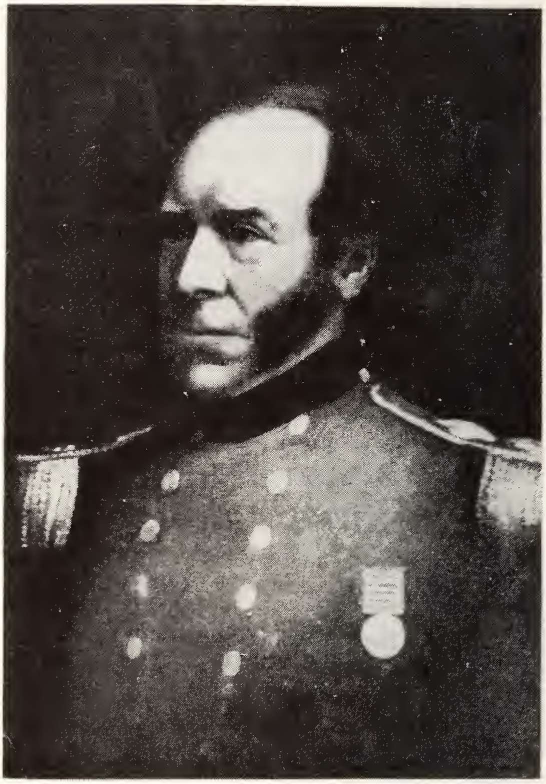

Thomas Mitchell about 1847. (Royal Geographical Society of Queensland).

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Thomas Mitchell and the Origins of Australian Vertebrate Palaeontology

JULIAN HOLLAND

The following is a summary of the Wombeyan symposium paper which was drawn from a larger study - in preparation - of the early history of palaeontological discoveries at Wellington Caves in central NSW.

Thomas Livingston Mitchell: Scotsman, soldier, mapmaker, Surveyor-General, man of self-importance and ambition, knight of the realm, workaholic, dead at 63. Thomas Mitchell discovered no significant palaeontological site, nor was he a skilled comparative anatomist. Yet he was a central figure in fostering scientific interest in Australian vertebrate fossils in the 1830s and 1840s. It was Thomas Mitchell's fossil bones, examined at Mitchell's request, that began Richard Owen's life-long association with our fossil fauna. It is fitting that we consider both these difficult men in the bicentennial year of the birth of one and the centennial year of the death of the other.

Fossil bones were discovered in a cave near the convict settlement in Wellington Valley by George Ranken in 1830. This was the first significant discovery of fossil bones in the colony. No one in Sydney received the news with more excitement than Thomas Mitchell.

Bone caves became a prominent feature of English geology in the 1820s with the work of the Oxford geologist William Buckland. His investigation of Kirkdale cave in Yorkshire led him to explore other bone-bearing caves, and publish his results in *Reliquiae Diluvianae* in 1823. At that time there was a common view that a series of catastrophic events had altered the face of the earth in ancient times, the last of these being identified with the biblical flood. The bones of elephants and other 'tropical' animals had been found in gravels and caves in northern Europe and England, seeming to indicate that these animals had been swept to their resting places from tropical regions by the deluge. Buckland's book, far from revealing 'the relics of the deluge', indicated that communities of animals such as elephant and hippopotamus had lived for generations *in England*, and had fallen victim to hyenas. Kirkdale Cave revealed the relics of the hyenas' larder. The deluge had merely brought an end to a period of life.

This interest in bone caves became important to Thomas Mitchell when he was appointed Deputy Surveyor-General for New South Wales, with the promise of succession to Surveyor-General Oxley, at the beginning of 1827. Mitchell sought geological advice before travelling to Australia, and was elected a fellow of the Geological Society of London. Others no doubt shared Mitchell's expectation that his succession to Oxley would give him the opportunity to make geological observations on exploratory journeys into the interior.

Mitchell investigated the recently discovered Bungonia cave in December 1829 while laying out the Great South Road, but found no bones. His excitement at the Wellington discovery was exacerbated by his frustrations at being detained in Sydney by what he saw as an unreasonable preoccupation with paperwork. When the news reached Sydney towards the end of May 1830, Mitchell was just about to set out to improve the line of road to Bathurst. Having reached Bathurst he proceeded to Wellington Valley, accompanied by George Ranken.

The week or so Mitchell spent in the valley he exhibited his characteristic energy and endurance. He made a thorough investigation of the limestone cave before moving to the red earth cave where Ranken had found the fossil bones some weeks earlier. This is now known as Mitchell's Cave. He gathered bones, made sketches, surveyed the caves, surveyed the valley from the surrounding hills and altogether enjoyed his freedom from the bureaucratic impositions of the office in Sydney.

Mitchell wrote a report on the caves which accompanied Ranken's specimens to Robert Jameson, professor of natural history at

Edinburgh. Jameson published the report together with an account of Ranken's discovery in the *Edinburgh New Philosophical Journal* early in 1831. Meanwhile Mitchell prepared a more detailed report for the Geological Society in London.

Ranken's specimens had been examined by William Clift at the Royal College of Surgeons in London and then by Georges Cuvier and J.B. Pentland in Paris. Most of the bones were recognised as belonging to various species of marsupial. Some were larger than any known species and were thought to belong to a dugong or hippopotamus by Clift and a young elephant by Cuvier. The idea of elephants in Australia in the ancient past did not seem unreasonable in the pre-Darwinian era; the bones of elephants and similar animals, such as mastodons, were being found in many parts of the world.

Following a change of governor Mitchell had undertaken three official inland expeditions through the mid 1830s. He then returned to London for the first time in ten years to prepare for publication an account of his *Three Expeditions into the Interior of Eastern Australia.* This two-volume work, illustrated with his own very competent sketches, contained a final chapter giving an account of the Wellington caves and the fossils found there. Mitchell had approached Richard Owen to describe the fossils sent to the Geological Society several years earlier. Owen, Clift's assistant at the Royal College of Surgeons with a rising reputation as a comparative anatomist, described the specimens in a letter that Mitchell incorporated into his book. Owen determined that the large bones that had puzzled earlier anatomists belonged to a giant marsupial he named *Diprotodon*. Although Owen had already developed an interest in Australia's living fauna, this was the beginning of a major pre-occupation with Australia's fossil species.

Mitchell's book contained several illustrations of the caves, the fossil specimens he had collected, and a plan and section of the two caves at Wellington. Based in part on his own survey work Mitchell also included a 'Geological Sketch' of Wellington Valley, the first published geological map of any part of Australia.

Figure 1. Large cavern at Wellington Valley. Drawn by T. L. Mitchell. (Mitchell, 1838, plate 26).

In the 1840s rich palaeontological sites were discovered in south-east Queensland. When Mitchell could obtain specimens he sent these to Owen or Buckland. Others had appeared on the local scene with a serious interest in vertebrate fossils: W.S. Macleay in Sydney, E.C. Hobson in Melbourne, and the soon to vanish Ludwig Leichhardt. A generation later, in the 1860s, Gerard Krefft represented a strong local voice in the investigation and interpretation of vertebrate fossils, once again from Wellington Caves. But to some extent all these men owed a debt to Thomas Livingston Mitchell for preparing the way.

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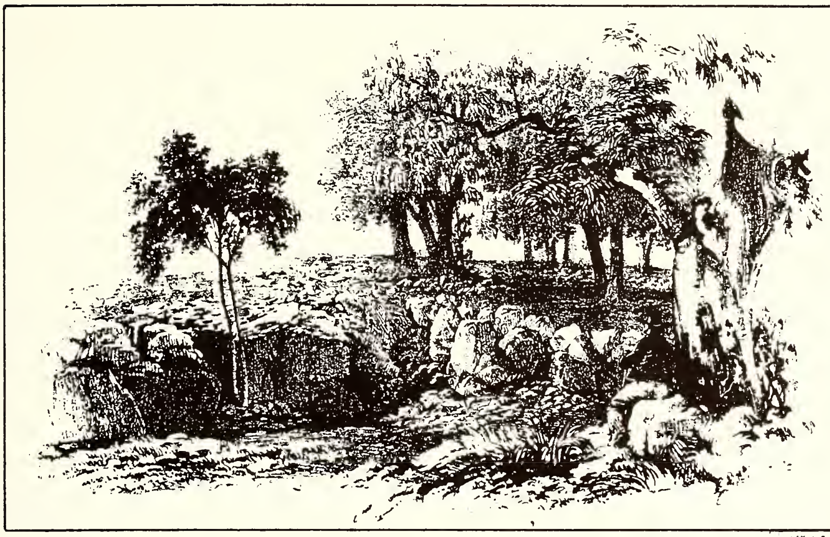

Figure 2. Entrance to the largest cavern, Wellington Valley. Drawn by T. L. Mitchell (Mitchell, 1838, plate 25).

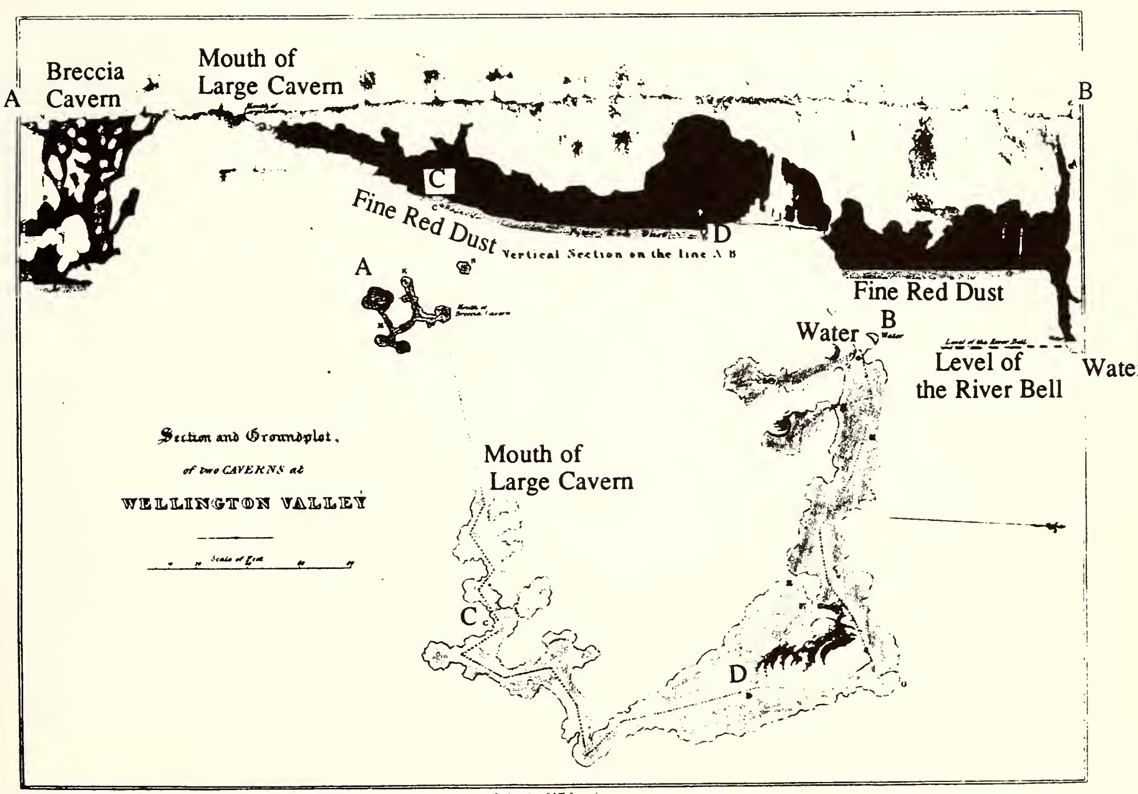

Figure 3. Vertical section (above) and Groundplot (below) of two caverns at Wellington Valley, drawn by T. L. Mitchell (1838, plate 23).

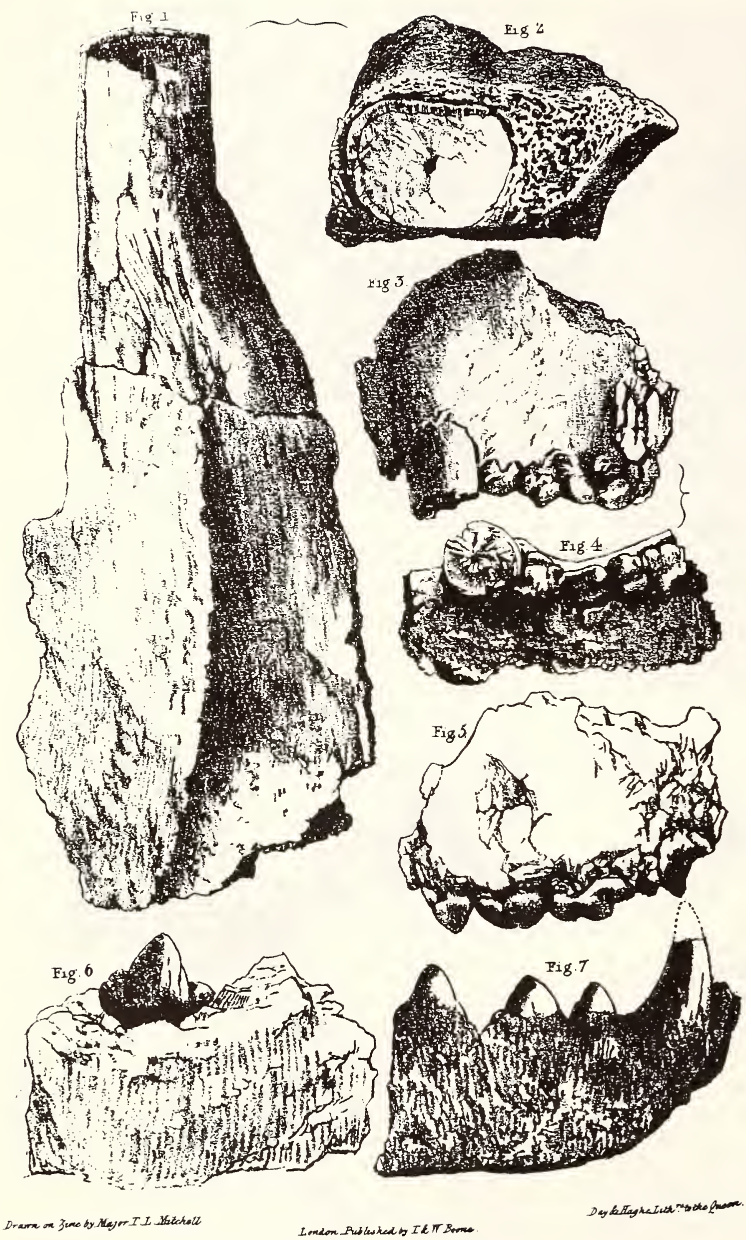

Figure 4. Mitchell's drawings of bone fossils identified and named by Owen in May, 1838, as:-

1: Large procumbent incisor, anterior extremity of right ramus, lower jaw, wombat-like mammal, named *Diprotodon*.

2: View of incisor from above.

3 - 5: Portions of the left side of upper jaw, of new species of *Dasyurus*, named *Dasyurus laniarius*.

6, 7: Lower jaw of *Dasyurus laniarius*. 6, left ramus with last grinders; 7, right ramus, anterior part.

From Mitchell, 1838, vol 2, plate 31 and pp. 362-363.

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Julian Tenison Woods, Richard Owen and Ancient Australia

ANN PLAYER

ABSTRACT. Father J. E. Tenison Woods played a small part in the history of vertebrate palaeontology in Australia. In 1866 he recognised that fossil remains discovered near Penola, South Australia, belonged to a large extinct bird related to the emu. The material was described and named by Richard Owen with scant acknowledgement of Woods. Woods played an important role in popularising scientists' discoveries and interpretations of vertebrate fossils.

In a letter from London on 23 February Sir Richard Owen, the renowned British anatomist and naturalist, addressed 'The Hon. Henry Parkes, etc., Colonial Secretary, New South Wales' on the desirability of the government funding a 'careful and systematic exploration of the Limestone Caves of Wellington Valley, discovered by the colonial surveyor [Thomas Mitchell] in or about 1832'. Such an exploration, Owen argued, would be of great benefit for the 'Museum of Sydney'; it could yield evidence pertaining to the antiquity and origin of the aboriginal races of Australia; it would earn the appreciation of the European scientific community and would thus redound to the honour of 'the present constitutional Government'. Furthermore, Owen offered to 'devote time to the determination and description of such specimens or duplicates' from the caves, either sent to him for examination, or sent for deposition in the British Museum.

The late Sir Thomas L.Mitchell had estimated that the proposed exploration would, under the guidance of a qualified naturalist, cost about two to three hundred pounds in cash, a comparatively small amount for the expected result. A month later Parkes replied to Owen, thanking him for his interest in Australian science and promising that a sum of money would be placed on the estimates (Australasian, 1867). From this action eventuated the important excavations carried out by Gerard Krefft (Australian Museum) and Alexander Thomson (University of Sydney) (Branagan, this volume). Owen, of course, was to benefit considerably as a result of this expedition.

Julian Tenison Woods, priest and naturalist, domiciled in Australia and almost contemporary with Mitchell and Owen, highly approved of Mitchell's proposed exploration. Unlike the explorers Flinders, King and others who included in their published works 'worthless' appendices on geology, Mitchell had, Woods wrote'collected fossils and........... their significance, and what better he sent them to the best authorities'. This course of action enabled Professor Owen to show that the extinct 'giants' of the past, though different from today's living species represented a similar series of kangaroos, wombats and opossums, native bears and marsupial tigers (Woods, 1882).

Years earlier, in 1857, Woods had proposed a similar 'colonial' course of action as that taken by Mitchell. In a letter to the editor of the South Australian Register on the subject of fossil bones recently found in the cliffs of the Murray River he suggested that 'some zealous individual' who had access to the material and who had the 'cause of science at heart' might see 'that drawings or photographs of the bones [be] forwarded either to Professor Owen or to the Illustrated London News for elucidation. From remote Penola where he worked as a Catholic priest, he also offered some comments on the possible geological age of these Murray River deposits and suggested that the remains might be those of an ichthyosaurus (South Australian Register, 1857b).

Woods also made his own contribution of material to the overseas experts, sending invertebrate fossils (polyzoa, foraminifera and corals) to prominent British naturalists during the late 1850s and mid 1860s (Player, 1990, p.26).

However, in one significant instance in his early endeavours in science he trusted his own judgement. On 25 April 1866 he recovered two tibias and two tarso-metatarsal bones from a well being sunk at the edge of a swamp fourteen miles

(22 kms) north-north-west of Penola. On examination he declared them allied to the emu,' from the size of the bones it was evidently a larger, heavier, and more clumsy bird', and he provisionally named it *Dromarius Australia* (Woods 1866, p.7 footnote). Another bone was found in 1869 at Peak Downs ' near the track from Clermont to Broadsound, at the head of Theresa Creek'. Rev. W.B. Clarke and Gerard Krefft examined this bone in Sydney and concluded that it was a species of *Dinornis* or moa. A few years later, after viewing this specimen Owen agreed with Woods's diagnosis that the bird was of the emu type, and named it *Dromornis Australia* (Woods, 1889a).

As Rich (1979, p.1) points out Woods did not figure the specimen; neither did he provide a diagnosis or description sufficiently detailed to validate his name. Consequently it must be considered a 'nomen nudum'. Woods, however, did not quite see the matter in that light. In his work On the Natural History of New South Wales (1882, p.27-28) he merely noted that his name preceded Owen's, but in the series "Ancient Australia' he goes much further. In the first article he simply repeated the story of his prior discovery (Woods, 1889b) but in a second article he stated that the 'singular correspondence of this name [*Dromornis Australis*] with mine [*Dromaius*{sic} *Australis*] leads to the suggestion that Owen knew of the previous discovery, but most probably he did not' (Woods 1888a).

Woods on at least one other occasion employed this same tactic of stating and then denying in order to bring a matter before his readers as a possibility (Player, 1990, p.100). Priority of discovery was an important concern of Woods throughout his career as a naturalist, and in this case of the flightless bird he seems determined to make the point that he made the discovery first, even if officially the credit was given to Owen. Woods' friend Ralph Tate, Professor of Natural Science at the University of Adelaide noted that Woods had been the first to recognise the affinity between the fossil bird and the living emu, commenting 'it redounds to his skill as a comparative anatomist that the opinion he expressed has been corroborated by the greatest living anatomist'.

The ten-part series on 'Ancient Australia' contributed to the Brisbane Courier and eventually discontinued, still incomplete, by Woods (Brisbane Courier, 1889) was written under the disability of failing health. As early as January 1888 he admitted to having been invalided for almost a year and as having almost lost the use of his hands and feet. (Woods, 1888b) As time went on he was reduced more and more to dictating his articles.

Finally in March 1889 work of any kind became an impossibility and 'even dictating very necessary correspondence' was almost beyond him (Woods, 1889b) In spite of the difficulties these articles on 'Ancient Australia' are vintage Woods. One of his concerns had always been to make science interesting and intelligible to the educated 'lay' person. As in his early work on Geological Observations in South Australia so here he argued for what he called the poetry and the romance of the story of science. Originally, he claimed, the discovery of the remains of extinct animals in Australia excited much attention, even popularity, but that interest soon died. Eminent osteologists buried the fascinating finds in dreary technical descriptions and thus stripped the story 'to the very skeleton of all but the driest of facts, much as if Milton's "Paradise Lost" were redistributed in dictionary form'(Woods, 1888c). Woods stressed this same point in the 'Geology of Arnheims (sic) Land NA' (1889c) when he laments that the discoveries of the geologist are now 'enshrined in Blue books and he speaks a language, intelligible only to the accomplished expert.'

Has Woods in 'Ancient Australia' been able to avoid these pitfalls? I think the evidence supports a largely affirmative answer. Throughout the series which focusses on the fossil deposits of Queensland he has woven a systematic story which unfolds logically and which on the whole sustains interest. The example of Cuvier and his work on the fossils of the Paris Basin introduced the reader to the ways palaeontologists unlock the evidence of ancient life held in the rocks (Woods, 1888c) and is followed by a short description of Australian Geology (Woods, 1888d).

As he dealt successively with fish, reptiles, birds, monotremes and marsupials he managed to avoid parochialism and set the unfolding story in a context broadened by his own experience both in Australia and in the Malay Peninsula and other Eastern countries he visited in 1883-1886. His wide reading added its enrichment too (Woods, 1888e). Such an approach was a consistent strength in his more discursive writings. He knew the literature and exploited it and his wide experience effectively (McDonnell, 1989, pp. 124-125)

Whatever the breadth of his treatment in general, in his explanation of the sudden extinction of the ancient fauna in Queensland, however Woods exhibited tunnel vision. In opposition to A.C. Gregory he proposed volcanic eruptions as the cause and supported his case from evidence of the 1883 Krakatoa devastation and the aftermath of the 1886 Taal eruption in the Philippines. His personal experience of these events added much colour to his position (Woods, 1888d). Quite obviously Woods was influenced by his leaning toward a catastrophic rather than an uniformitarian world view. He picked hise 'eruptions' selectively to support his position.

In the very first article of the series Woods, in the context of defending earlier scientists who 'did their duty by their deposit of truth as they saw it' announced that de Vis had found teeth of a peccary in the Queensland drifts. This statement 'was received with great hesitation' by Woods' scientific friends (Woods, 1888c). As he only mentions this find again in passing one must assume that he intended to treat it in a later article which, because of his health, did not eventuate.

His writings in this series add little that is new in the vertebrate palaeontology of his day. Though based on the findings of others, as he clearly stated, he had examined many of the fossils in the museums at Sydney and Brisbane and had discussed them with their learned curators (Woods, 1888a). He consistently quotes the experts in the field, including 'de Vis of the Brisbane Museum' and especially Professor Owen. What he did in these articles was to produce for the layman an up-to-date statement of where research was at the time.

Throughout the years of his active interest in science Woods wrote close to 200 articles - some short, others very long - on invertebrate palaeontology, on stratigraphy, on molluscs, polyzoa, botany, coal deposits and other subjects. With the exception of a few general chapters in Geological Observations in South Australia he wrote almost nothing on vertebrate palaeontology until the 'Ancient Australia' series. He certainly had skill and ability in this area and one can only regret that his contribution was so slight.

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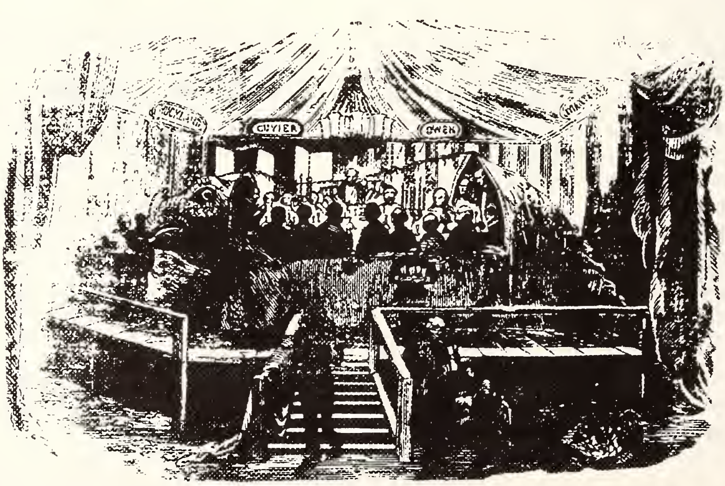
IF THEY LIVED TO-DAY!

Enduring interest in the Australian megafauna. A vivid impression of the giant marsupials whose fossil remains were unearthed at Brigalow, Darling Downs. The artist appears to have had some difficulty conceiving the fauna. (*Sunday Mail*, Brisbane, 28 July, 1929).



"Dinner in the *Iguanadon* model, at the Crystal Palace, Sydenham."

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Australian Red Earth and Bones

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Since 1830 naturalists and palaeontologists have been collecting Pleistocene to Recent vertebrate fossils from Australian red cave earth. Red earth, with or without vertebrate fossils, is found in almost every karst area in Australia, in caves developed in both high purity Palaeozoic limestones and in poorly cemented Tertiary calcarenites. It is found in caves on the top of isolated hills and caves in the bottom of valleys. Deposits are known to reach thicknesses of over 12 m.

Various origins, some quite bizarre, have been proposed for this material (Osborne,1991).The most persistent has been the notion that it consists of insoluble residues derived from solution of the limestone. This is clearly impossible, given the high purity of much of the limestone in which it occurs. The red earth is most likely silt and clay transported from central Australia by the wind during arid phases of the Pleistocene that became preserved in caves and other karst features

Few fossils older than Pleistocene have been found in Australian caves and it has often been suggested that deposits of cemented red earth and other bone breccia found at or near the surface represent the floors of caves whose roofs had been removed either by collapse and / or erosion (Broom, 1896; Thomson, 1870) . In the past this type of explanation would have presented few geological or geomorphic problems. Until the 1980s caves in Australia were regarded by most as having Pleistocene to Recent origins, reflecting the European origin of karst geomorphology in Australia.

Recent work (Osborne & Branagan, 1988; Osborne *in press* ; Webb *et. al.* ,1991), however, suggests that caves, like other landscapes in eastern Australia, are far older, having their origins in Early Tertiary or even Late Cretaceous times. This rules out the possibility of cave roofs being removed by post-Pleistocene erosion and of Pleistocene breccias being older than adjacent caves (Ride, 1960). It raises, however, the interesting and significant possibility of pre-Pleistocene fossils being found in caves.

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Important vertebrate fossils from the palaeontological collections of the Department of Geology and Geophysics, University of Sydney.

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ABSTRACT. A small collection of vertebrate fossils was uncovered during a recent re-organisation of the palaeontological collections of the Department of Geology and Geophysics, University of Sydney. Some of this material is of historical and scientific interest. Fossils from Pleistocene deposits on Clairvaulx Station near Glen Innes were collected by N. Miklouho-Maclay in 1880. A small collection of bones from Wellington Caves may have been made by Edgeworth David in 1900. The Wellington Caves fossils represent taxa of snake, varanid, turtle and bird, previously unknown from that locality. Three small samples of a bone-cave breccia are probably from the Broom Breccia, Wombeyan Caves, and may provide new information on the lithology and petrology of this important site.

INTRODUCTION

In 1992 the palaeontological collections of the Department of Geology and Geophysics, University of Sydney, were relocated and partially catalogued. During this work six drawers of vertebrate fossils were revealed. This material was assembled by the late Jack Mahoney while he was employed in the department.

Most of the vertebrate material in the collections consists of plaster casts and common fossils used for teaching. However some of the fossils were more exceptional, important specimens, but little known. Material from an alluvial deposit in New England, NSW, and from two cave deposits in eastern New South Wales are discussed in this paper. The specimens described, together with some other material, have been transferred to the Australian Museum. The abbreviation SUP precedes specimen numbers in the Sydney University Palaeontology collection.

ORIGIN OF THE MATERIAL

Three principal sources for the vertebrate material in the University Geology Department fossil collections have been identified. Most of the material was collected specifically for the University collections in the latter part of the nineteenth century, and the early 1900s. However some at least evidently was originally in the collections of the Macleay Museum and was transferred to the Department of Geology and Geophysics in the late 1960s by Dr. Peter Stanbury (B. Webby, per. comm.). A third possible source of some vertebrate fossils was collecting by Jack Mahoney, but no documented proof of this has yet been located.

CLAIRVAULX MATERIAL

A small collection of Pleistocene bones (SUP10992, SUP10998, SUP11964, SUP11965, SUP11991 and SUP11992) was found among the fossils in the University collection. This material was distinguished by the handwritten labels that accompanied them, all of which carried the "crossed M's" monogram of Miklouho-Maclay.

Nicholaievich Miklouho-Maclay (1846-1888) was a distinguished nineteenth-century Russian scientist, whose interests included anthropology, zoology and palaeontology. He visited Australia four times between 1878 and 1881 during which he travelled extensively and made significant scientific collections. In late December 1880 he visited 'Clairvaulx' station about 7 kms northwest of Glen Innes with the intention of collecting palaeontological and zoological specimens. He recorded collecting specimens of *Diprotodon australis*, *Nototherium mitchelli*, *Phascolomys gigas*, *Macropus titan* and other species (Miklouho-Maclay 1881: 174). He left Clairvaulx in early January 1881 (Webster 1984: 244).

Most labels with the Geology Department's specimens identify the locality as 'Clairvaulx, New

South Wales', but some refine it as 'Walter's Creek, Clairvaulx'. All labels also carried the date - 27 December 1880.

The Clairvaulx material was almost certainly acquired by the Department of Geology as part of the transfer of fossils from the Macleay Museum. A subsequent search of the remaining vertebrate collections of the Macleay Museum revealed a substantial quantity of Clairvaulx material still in its collection. Unfortunately many of the Macleay Museum's records were destroyed during the First World War, having been given up for pulp salvage (MacIntosh, 1949: 167). Other incidents of the deliberate destruction of Macleay Museum records occurred as recently as the 1950s. Any manifest listing exactly what was transferred from the Macleay Museum to the Geology Department has not been located.

The Clairvaulx material has not yet been studied in any detail. However the following species can be identified:*Diprotodon optatum*, *Phascolonus* sp. cf.*P. gigas*, macropodine and sthenurine kangaroos.

This is a typical megafaunal association. There is an absence of smaller elements and species but it is not known if this is a taphonomic or collection bias. The preservation and known locality information suggests that Clairvaulx is a fluvial or lacustrine deposit.

Many Pleistocene localities similar to Clairvaulx are known from eastern Australia. Clairvaulx appears to be a prolific site. Miklouho-Maclay claimed to have collected 160 fossil specimens from the site (Miklouho-Maclay, 1881). All of the collecting information available suggests that the fossils were collected in a single day (27 December, 1880). However it seems more probable that these specimens were actually gathered over the full period of Miklouho-Maclay's stay at Clairvaulx, something less than two weeks. Alternatively the collection could have been supplemented by Mr. Gunn, the owner of Clairvaulx, giving Miklouho-Maclay specimens that he had picked up on the property before Miklouho-Maclay arrived (in fact one label does record that the specimen was presented by Mr. Gunn). In any event, the collection of more than thirty *Diprotodon* molars still in the Macleay Museum, as well as numerous other elements suggests a rich deposit.

The quality of the fossils from Clairvaulx is particularly impressive. Typically, Pleistocene vertebrate fossils from the Liverpool Plains and similar deposits are crumbly, poorly mineralised and easily destroyed. The preservation of Clairvaulx material is more reminiscent of fossils from Bingara in northern New South Wales or the Darling Downs in southern Queensland. These fossils are solid, robust and heavily mineralised.

The probable abundance and robust preservation of fossils from Clairvaulx suggests that this deposit should be revisited and re-examined. Clairvaulx could be particularly interesting if small fossils, such as rodents, bandicoots and marsupial carnivores, are present.

WELLINGTON CAVES

Among the vertebrate fossils of the University's collection was a small box of bones evidently from a cave deposit. The only identification was a single small label (21mm x 17mm) with a blue border, together with two small labels each bearing a four digit number (1686 and 3607). Two of the labels were loose in the box while the third (1686) was still attached to the proximal end of a mammalian ulna.

The label with the blue border has been partially eaten by silverfish but still clearly reads "........w Cave, Wellington" written in black ink. It appears that the original description was "New Cave, Wellington". The handwriting does not resemble that of any of the previous curators of the Macleay Museum (W.S. Horning, pers. comm.) so it appears unlikely that these Wellington Caves fossils were part of the 1960s transfer. The style of the border on the label is typical of the period from around 1900 to 1915. This suggests that the fossils were entered directly into the Geology Department's palaeontological collections in the earliest part of this century. However, the blue border on the label is quite distinctive, and no similar label remains on any of the older specimens still in the Department of Geology and Geophysics. Similar labels have been found on some fossil specimens in the Macleay Museum and on some aboriginal stone tools transferred from Geology to the Macleay Museum. Although equivocal, this indicates that the label referred to above was affixed in the Geology Department.

The University of Sydney Palaeontological Collection in the Department of Geology and Geophysics has a unique numbering system that was initiated in 1920 and is still in use today. Within this system all vertebrate specimens have registration numbers that end in digits from 950 to 999 (e.g. 13957 and 8996 are registration numbers for vertebrate specimens, but 11608 is not). Neither of the two numbers included with the Wellington Caves material ends in digits between 950 and 999, consequently the specimens are either from some collection external to the Geology Department or they are from departmental collections made prior to 1920. There were numerous fossil collections in the Department prior to 1920, however most of these specimens have been renumbered .

But there is no record of any Wellington Caves material being renumbered. Furthermore, in the older catalogues that still exist, there is no record of vertebrate fossils in the collections under the numbers 1686 or 3607. This suggests that the specimens were originally registered in a (reasonably large) collection elsewhere and that they have been subsequently incorporated into the departmental collection.

Thus it appears that the most likely origin of the Wellington Cave specimens currently in the collection of the Department of Geology was from another collection, but not from the Macleay Museum. This conclusion is equivocal.

WHO COLLECTED THE WELLINGTON CAVES MATERIAL?

Because of the poor records associated with the specimens it is not known who collected the material. However the following scenario is proposed. The catalogue of the geological (i.e. non-fossil) collection of the Department of Geology and Geophysics indicates that Professor Edgeworth David collected an aboriginal stone tool (No. 2870) and some limestone samples (Nos. 137-143) from "30 chains south of Wellington Caves" around 1900. This places David in the right area about the time the vertebrate fossils were likely to have been collected from the recently discovered "New Cave".

David had a strong interest in both palaeontology and caves, as can be noted from his publications (see Branagan, 1973, pp.135 et seq.), and although he did not publish specifically on Wellington Caves, he wrote a report for Government on Wombeyan Caves (David, 1897). When in the Wellington Caves area it is more than likely that he would have collected some of the abundant and well-known vertebrate fossils. He would have been particularly interested in any newly-found deposits such as those in New Cave (now Gaden Cave).

Such material collected by David would probably have been deposited in either the Department of Geology or the Macleay collections. This is a highly circumstantial, but not illogical scenario. Other than this there is no known simple mechanism by which Wellington fossils would have found their way into either of these collections.

Most of the fossils collected at this period at Wellington were made by the Cave Warden J. Sibbald, who sent his specimens to the Mining Museum (Dawson, 1985), and it seems unlikely that he would have sent any specimens to the University. However there is no known record of Sibbald collecting fossils from New (Gaden) Cave, most collecting having been made there as late as 1954 by L.Marcus (Dawson, op.cit.). These would have been sent to the University of California. Furthermore his collections were clearly much later than the labels with the Sydney University specimens suggest. A possible collector from the University was W.R. Browne, at Wellington in June 1948, according to the Geological catalogue, but again this is much too late; furthermore Browne's interests were dominantly petrological.

A possible link in this story is W.S. Dun who was Palaeontologist to the New South Wales Geological Survey and the Australian Museum, and who lectured part-time at the University from 1897 to 1934. Dun was not averse to carry fossils (even type specimens!) back and forth to the University for his lectures (H.Fletcher, pers. comm.), and although his major interests were in the invertebrates the whole range of the fossil kingdom was covered in his lectures. Perhaps some specimens were thus inadvertently acquired by the University.

LOCALITY INFORMATION

It is obvious that some mixing of the Wellington Caves material has occurred. Judging from the remaining sediment that adheres to these specimens, at least three types of deposits are represented. The two red earth sediment types are both typical of cave deposits. One of these is a poorly consolidated, powdery red earth similar to that of Mitchell's cave, at Wellington. The second sediment type is a partially consolidated red earth with a high amount of clay and some unusually large inorganic clasts. Such a sediment is not inconsistent with the deposits in Mitchell's Cave, but could also be from Gaden Cave. The third sediment type is a dusty grey/brown sediment with calcite cement. This dusty material (to which the label "1686" is attached) is unlike that currently seen in Wellington Caves, but may be derived from the now-sealed original entrance of Gaden Cave.

A map clearly identifying Gaden Cave, but which is labelled New Cave, accompanied Trickett's (1901) report on Wellington Caves. Although discovered in 1900 foul air prevented full exploration of New Cave until 1905 (Trickett 1901, 1902, 1904 and 1905) and it is uncertain if any fossil collecting could have been made in this cave before 1905. However fossils do occur in one section of this cave and it is possible that all the specimen material in the Geology Department's collection came from this cave.

The problem is complicated by the fact that another cave containing vertebrate fossils was discovered in 1901 (Trickett, 1902). This cave was named shortly after, Gas Pipe Cave (Trickett, 1903), but for a time it was also referred to simply as the "new cave"and it is possible that the present University specimens originated from it.

All told it seems likely that these fossils originated from Wellington early this century and most likely from Gaden Cave, although they may have come from any of the fossil-bearing caves there. It is even possible, though less likely, that the specimens were originally obtained from one or a number of other Australian caves. Because of the poor records and uncertainty as to the origin and history of these specimens they are best provenanced as "Wellington Caves (?Gaden Cave)".

The particular specimens in the palaeontological collection of the Department of Geology and Geophysics have not yet been studied in detail, but the Pleistocene fauna of Wellington Caves has received considerable attention (see Dawson, 1985 for a review). In the University collection the following species have been identified: *Thylaceo carnifex, Thylacinus cynocephalus, Phascolomys* sp. cf. *P. gigas* (including specimens only from the first sediment type), *Vombatus* or *Lasiorhinus*, *Varanus* sp., rodent and an unidentified turtle. A large snake vertebra is currently being examined by J.Scanlon, and a small collection of bird bones is being studied by W. Bowles. The fauna suggests a Pleistocene age, which is consistent with the age of the better-known faunas from the other Wellington Caves (Dawson, 1985).

WOMBEYAN CAVES

Three small blocks (about 5cm across) of a well-consolidated cave breccia were found in the (SUP 13955). They were identified as having come from Wombeyan Caves. There was no further information either on the label or in the collection catalogues. However Ride (1960) mentions that Mahoney collected some samples of the Broom Breccia, and these specimens may be some of that material mentioned by Ride.

All three blocks had numerous bones of small animals through them. The location given on the associated label as Wombeyan Caves is the Broom Breccia (also known as the *Burramys parvus* Breccia), although similar material was found in the nearby Wombeyan Quarries (Hope, 1982).

The Broom Breccia was discovered by Robert Broom (1866-1951), then a medical practioner in Taralga, who excavated episodically at Wombeyan, apparently when the custodian was away(!). The fossil material was collected around 1894-95 and quickly described (Broom 1895a, 1895b, 1896). After dissolving the matrix, Broom found a rich assortment of bones representing a variety of small animals. Of particular interest was a diprotodontoid with grooved molars that Broom named *Burramys parvus* (Broom, 1895a). This animal was then thought to have been extinct, but the first living specimen was found in 1966.

The Broom Breccia was a small deposit that is almost completely worked out. A few remnants remain on the side of the small surface depression above the xx Cave. Samples removed from the site were usually dissolved in acetic acid to release their vertebrate component. Ride (1960) described the petrology of the breccia and commented that Mahoney collected from the site. The samples in the University collection are similar to those described by Ride and resemble material seen on the site in October 1992. The petrology of the source material is currently being examined by Osborne.

Broom (1896) assessed the age of the breccia as "later Tertiary", and Ride (op. cit.) concluded it was Pleistocene. Wakefield (1972) refined this age to approximately 10 000 years, based on a comparison of the fauna with that of Pyramid Caves in Victoria.

CONCLUSIONS

Very interesting vertebrate fossils have recently been found within the palaeontological collection of the University of Sydney. However, because of poor recordkeeping in the past, compounded by deliberate destruction of records, it is difficult to determine many of the important collection details.

Such poor record keeping has severely compromised the scientific integrity and use of these and other specimens. An attempt has been made to determine the unknowns, but some of the answers remain equivocal.

Miklouho-Maclay is the only known collector to have visited the Clairvaulx site near Glen Innes, and this locality appears to be of greater palaeontological significance than previously realised. The Wellington fossils appear to have come from Gaden Cave, a site where previous collections have been limited, and represent taxa not previously recorded from Wellington. The Wombeyan Caves material belongs to the Broom Breccia, a deposit whose fauna is known in some detail, but its lithology and petrology require further study.

Despite the limitations of these specimens caused by inadequate record keeping, they all provide interesting subjects for further study, and contain new information on the vertebrate palaeontological faunas of New South Wales.

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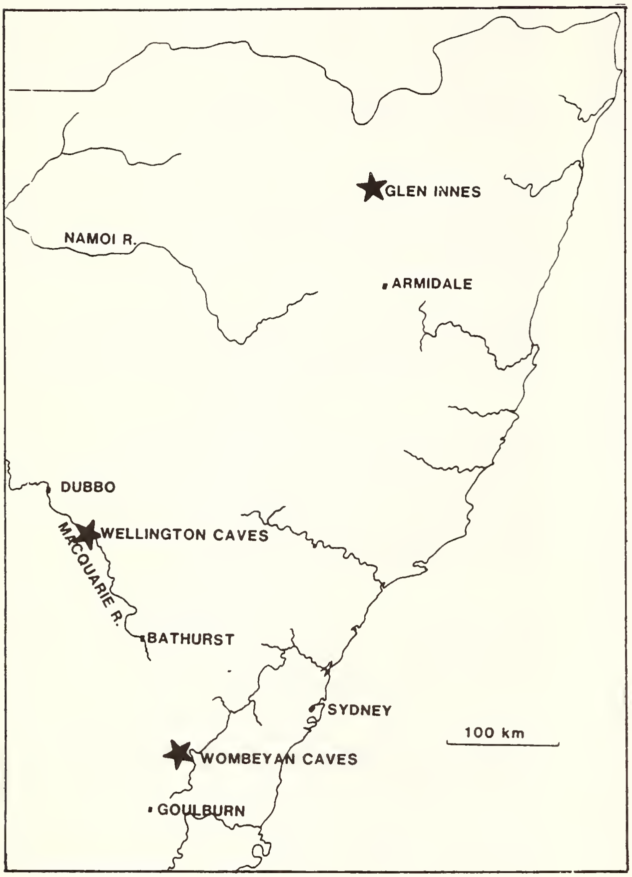


Figure 1. Locality map of vertebrate fossil sites

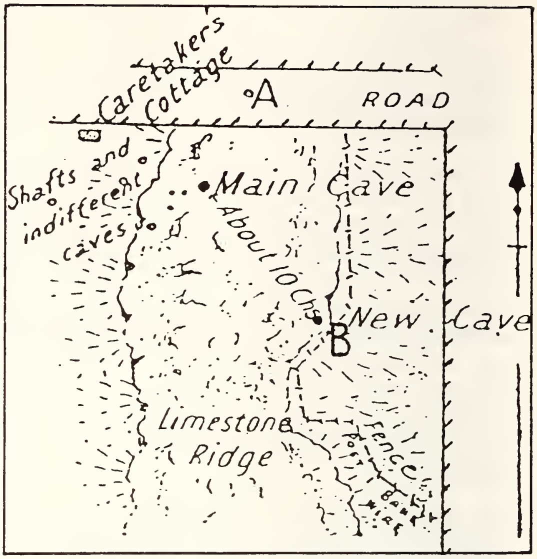
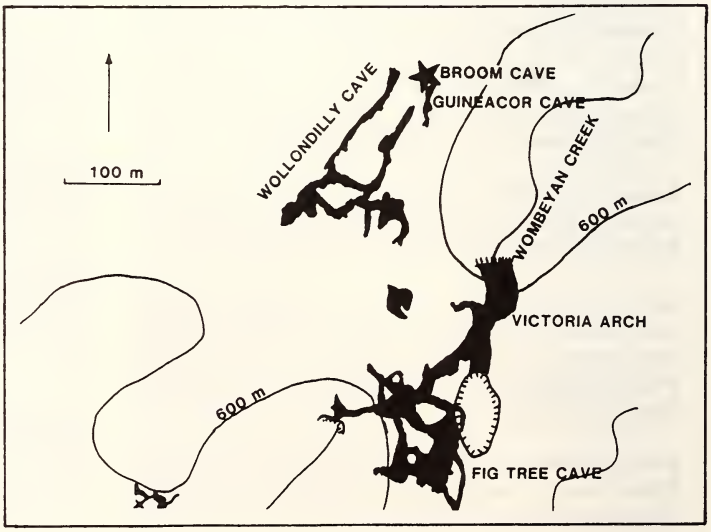


Figure 2. Position of new cave, Wellington, (Trickett, 1901).

Figure 3. Location of Broom Cave in Wombeyan Caves Reserve.



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Plumbing the Depths: on caves and the men of Geology

MICHAEL SHORTLAND

Abstract: While caves were important geologically at the beginning of the nineteenth century, they also served as cultural artefacts with political significance. Cave dwellers and industries were common at the time, and miners were leaders in moves for political change. The Reverend William Buckland was a central figure in the early study of caves, fossil bones and coprolites, and his interests were related to the environment of underground workingmen rather than to that of the "gentlemen geologists". Mining geology is more significant in the history of geology than has been accepted to date.

Fingal's Cave

The thirteenth of August is an unrecognised red-letter day for cave enthusiasts of all shades and hues, for explorers, dwellers and historians of caves, for speleologists and speleolators. It was on this day in 1772 that Sir Joseph Banks, on his way to Iceland, stopped on the small island of Staffa, off the coast of Scotland, to visit Fingal's Cave. He was the first to describe the cave in an illustrated account which breathed life into Thomas Pennant's otherwise ponderous Tour of Scotland in 1774. Banks' short piece fired the imagination.

Banks was not, of course, the first to venture into a cave; for centuries, people across the world have explored them in search of adventure, discovery, knowledge, inspiration and refuge. To contextualise Banks' report and the subsequent development of cave enthusiasm would require a thorough analysis of themes which I shall only touch upon, but I want to start with Fingal's Cave in considering the lure of caves, and the construction of caves, in Britain during the Golden Age of geology. I shall propose that the Romantics played a key role in manufacturing a particular image of the cave and did so for specific ideological ends. The repercussions of this process of manufacture form the substance of roughly the second half of my paper, in the course of which, via a brief examination of mines and mining, and aspects of the cave work of William Buckland, I shall suggest new some new approaches to the history of geology.

I begin by returning to Fingal's Cave, which assuredly was, and remains, quite spectacular. The cave is approximately 40 feet by 70 feet and 200 feet long, and is composed of black and dark brown basalt columns standing on a base of solid, unformed rock [figure 1]. So much for the brute, measurable facts, which do little to capture the experience

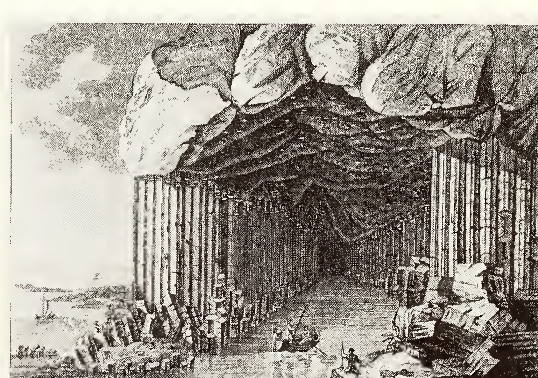

Figure 1.
Fingal's Cave [from Pennant 1774].

of a visit. First there would be a journey by sea in a small fisherman's boat, across notoriously choppy waters. On reaching the cave, the boat would be tied up and visitors taken on a scramble along a slippery pathway to the end of the cave.

They were greeted here with a sight which well repaid their efforts: hanging from the roof of the cave were white, ochre and sometimes crimson stalactites, and facing visitors were enormous rows of columns set up like the pipes of a gargantuan organ. On the right day (Banks spent 12 hours in Fingal's Cave in perfect conditions), just enough light passed through to cast eerie shadows on the waters and walls of the cavern and, if the waves lapped powerfully enough against the columns, the visitor was regaled with tones emerging from the pipes that sounded like music from another time, another world [figure 2].

Figure 2.
The Isle of Staffa [from MacCulloch 1819].

Banks, a veteran traveller inured, one might have imagined, to the spectacular and exotic in nature, was perfectly delighted. 'Compared to this,' he heatedly wrote, proposing a comparison that would be widely reproduced, 'what are the cathedrals or palaces built by men! Mere models or playthings, imitations as diminutive as his works will always be when compared to those of nature' (1774, p. 262). From the publication of Banks' report (circulated in a variety of forms until the mid-nineteenth century), Fingal's Cave drew a stream of intrepid travellers, none more ardent than the Romantics. The poetry and prose of such figures as Walter Scott, Wordsworth, Shelley, Byron and Keats registered their inflamed imaginations. Felix Mendelssohn, after a visit to Staffa in 1829, was inspired to prepare the opening bars to the overture of The Hebrides, one of the landmarks of Romantic music. J.M.W. Turner, after a visit in 1831 provided a vignette for Scott's Poetical Works (1834) [figure 3] which depicts the cave entrance from the right side looking out. Not for the first, nor the last time, we find an apparently realistic, but actually contrived, view: the sea actually prevents access to the right side, and the sun was made to set conveniently in line with the cave better to illustrate Scott's verses.

Figure 3.
Fingal's Cave, Staffa, by J.M.W. Turner [from Walter Scott's Poetical Works, 1834].

Caves and Romanticism

Other, more accessible, regions of Britain became in the wake of Banks' report of Fingal's cave great attractions to cave hunters, and caves assumed gradually more significance in works of natural history. By far the most popular cave region in Britain was the Peak District, rich in caverns. During geology's golden age, no tour of Britain - certainly no geological tour - was complete without taking in the so-called Seven Wonders of the Peak. These included St. Anne's Well, the Ebbing and Flowing Well, Poole's Hole, Elden Hole, and Peak Cavern.

To the historian is posed the obvious question, 'why caves at this particular moment?'. Partly, one quickly answers because of the rise of geology as a newly-fashionable science during the same period. In Britain from around 1790 to 1840, scientific societies opened their doors to geology as never before, newspapers and magazines carried reviews and reports on the earth sciences, and thousands of good folk set off across the country to scan, pick, dig, draw, survey and hammer the land. Almost everyone - scientists, novelists, artists, poets, and musicians, and of course thousands of people of humble birth and with no profession - seemed attuned and ready to respond conspicuously to the revealed wonders of the earth. These were the golden years of geology and of interest in geology, the subject's 'Elizabethan period', one might say. And so, one could suppose that caves formed part of a more general enthusiasm.

The argument above makes ready sense but accepts (or perhaps, assumes) too eagerly that caves are a geological phenomenon. Of course they are this (or, more accurately, they became during the period I am discussing a geological phenomenon), but they are much else besides. They are, as I shall show, cultural artefacts with powerful political resonance. Indeed, my impression is that for all that has been written about the links between geology and Romanticism, the Romantics were not drawn to caves for any actual or proto-geological experience and, when they entered caves, they were uninterested in their geological aspects. When Wordsworth went to Fingal's Cave he did not concern himself with the geological features of the site, with what he later called the 'luckless rock' and 'prominent stone' (Clark and Hughes 1890, I, p. 247). He, like other Romantics, was no more interested in the geological structure of the caves he visited than in the architectural structure of the homes he entered.

Nevertheless, two aspects of caves - or, perhaps I should say, of the Romantics' constructed caves - seemed particularly apposite to the Romantics' aesthetics, and are worth considering. Caves were secluded. And caves were sublime. For these reasons, one might readily suppose, caves were fascinating and irresistable to the Romantics.

Sublimity was not a term newly-minted by the Romantics but indubitably one of their trademarks. It is a difficult and dense term, partly because it appears to bear a mixed ontological status - it is a feature of nature, of one's emotions of nature, and of one's experience of those emotions. Moreover, the sublime excites impressions that are at once powerful and contradictory. Typically, sublime scenes prompt love and loathing, fear and desire in muddled, distorting combinations which were often perceived to be beyond words. And nowhere, it seems, were such sensations produced more readily than in caves. They excited dread and delight, together or in turns, with the result that the emotional tone played double. Alone in the cave, the mind seemed to enjoy a state, as it were, of splendid oscillation.

Let me now turn to the notion of seclusion. To the Romantics, the inaccessibility of caves meant that they maintained a highly attractive metaphorical as well as actual distance from the civilised world, from which Romantics sought escape. One of the contexts of the development of geology was the rise of travel. To the Romantics travel was synonymous with education, and since they liked both to be prodigious, the Romantics ventured to far-flung, neglected regions. Caves presented an ideal destination: they offered partially and momentarily that dream of natural peace - the running to ground, so to speak - so treasured by Romantics. More particularly, the cave presented a site in which the realm of private feeling, under erosion from the power of industrialisation and city public business, could be nurtured.

Is there anything surprising in the Romantics' attraction to caves for the reasons I have just outlined? I think so. Something surprising, even startling, since the caves which they celebrated were not present in nature but in their construction of nature. Consider the 'secluded cave' for a moment. Very few caves were or remained for long secluded. Turner's painting Staffa: Fingal's Cave, exhibited in 1832, indistinct though it is, clearly features the 'Maid of Morven', a steamer newly-established to run large numbers of tourists to Staffa. Such tourists would no more be rewarded by 'nature in the raw' than a visitor to a tourist cave, such as at Wombyean or Wellington today - walkways, ladders, railings, lights, explosions, mounted artefacts ensured that the supposedly solitary experience of a cave was widely shared and carefully mediated.

The cave visit was in truth a piece of theatre, carefully choreographed to present the illusion of nature, strong and sublime. Sublime by illusion perhaps, but by no stretch of the imagination solitary. Far from escaping people by travelling to Peak Cavern, for example, visitors would be sure to meet them, fellow travellers as well as inhabitants. For Peak Cavern played host to several families who lived in the shelter [figure 4], acted as guides (visits without a guide were not permitted), and worked in the cave itself in the manufacture of twine (Westall 1830, p. 46). Even the inhospitable terrain of Staffa played host to several herdsmen and their families. Wordsworth after his second visit to Fingal's Cave wrote with frustration in his poem Cave of Staffa of how in the 'motley crowd/ Not One of us has felt the far-famed sight.'

Figure 4.
Twine-makers in Peak Cavern [from Westall 1830].

The Political Underground

People lived and people worked underground in almost incredible numbers during this period, but the Romantics did not register the fact: the underground remained to them a lonely home to the hermit and recluse. Why might this be so? The answer is, I suggest, to be found in the political realm. Throughout the period of geology's 'Golden Age' the underground was widely associated with mining and miners. Coal was at this time Britain's passport to prosperity and production climbed majestically, from 6 million tonnes in 1770 to nearly 30 million by 1830 (Bodey 1976, p. 45; Kligender 1968, p. 94). Miners and mining were visible and endlessly described and analysed in surveys, commissions, reviews and government inquiries. The public perception was that mines were the site of, and miners the agents of, mighty and threatening political power. During the eighteenth century, the class-conscious miners had taken the lead in many political agitations, and over the next decades they inspired reverence or disgust throughout the country for their radicalism (Ashton and Sykes 1929, pp. 115-33). Price and wage riots, mobs, demonstrations, and labour disputes maintained the threat of revolution, and the provocations came nowhere more sharply than from the miners, those class-conscious heroes of Marx and Engels (Engels 1975, pp. 530-47; Foster 1974, pp. 101-2). In Emile Zola's Germinal (1885), perhaps the only nineteenth-century novel about miners, they figure as amorphous and cruel masses, ruled by their own physics, being produced and consumed by the subterranean mines. They are also, in a marvellously potent image, a force of nature, 'cracking the earth asunder', eroding the foundations of the social order (Zola 1978, p. 499).

Such is the backdrop against which, I suggest, we need to perceive the Romantics' own vision of the underground. As is well known, the Romantics, in recoil from the events in France and the perceived threat to the fabric of British society adopted reactionary political postures. They 'turned bourgeois', to use an apt phrase of Mario Praz (1969, pp. 37-123), and in so doing they turned to the land - a site highly charged with radical and destabilising connotations - with the intention of recovering it for Britain and Britishness. Pre-eminent in the landscape they constructed was the cave. Far from embodying connotations of revolution and change, the cave (symbol of the below-ground) came to signal all that was immoveable and unchanging, peaceful and quiet.

The poem Fears in Solitude (1798), by Coleridge, epitomises the reaction. Coleridge, who had at first preached fervently in favour of liberty and revolution, now fell back upon the defensive (Willey 1980, p. 24). Not for him, the earth resounding to the tremors of revolution and the sounds of picks and shovels: his poem offers praise only to the stability of the English countryside, with its still lakes, silent hills, and 'dark and lovely hiding-places'. Nature has become for him, as for other Romantics, an emblem of peace and solitude, not only a site for anti-industrialisation nostalgia, but also a refuge from political engagement. Nature, indeed, serves to undergird the concept of nationhood: it subsumes cultural and class differences - land and history are bound together through conflated images of caverns, cathedrals and ruins (see Janowitz 1990 and Goldstein 1972). One can see here, I think, the ideological power of Fingal's Cave, and the often-repeated image of the Cave as a cathedral, lofty, funereal and sombre: Keats, Scott, the geologist John MacCulloch, even Sir John Peel, take up the image of the cave as cathedral (MacCulloch 1934, pp. 143, 153; MacCulloch 1819, 2, p. 16). (Interestingly, as Julian Holland has pointed out [in a private communication] similar imagery was already well in place in NSW by 1830. Thomas Mitchell in his description of Wellington Caves refers to 'the great gallery named the chapel where there is also the altar - steps, font, &c - wholly the work of encrustation' (Mitchell 1830, 20 June 1830)).

In The Prelude (XI, 141-4), Wordsworth enjoins us to reject dreams of Revolution which he explicitly allies to the underground, and in an effort to win nature for culture identifies the landscape of Britain with the culture of Britishness. In an image which stands as a mirror reversal of Zola's portrayal of the mine as a natural force for change, the cave serves here as a symbol of a natural force that is restorative and preserving. That key text of reaction, Burke's Reflections on the French Revolution (1790), embodies just such a symbolic load. Burke quotes from The Aeneid the tale of how the winds of destruction were finally secured, by the edict of Neptune, in a vast cavern. In this political topography the cave stands solidly for what can entrap fierce forces, for something reparative and unyielding. A poem such as Keat's Endymion (1818), takes up the image and connotes with the cave and mine variously repose, solitude and sleep, while, against a background of troubles, Keats' so-called 'Cave of Quietude' offers the soul lull and contentment (see IV, 651; IV, 860, 372-84; also Shelley's Epipsychidion (1821), 194).

Purity and Danger: William Buckland and Caves

It is time to return to the connection of Romanticism and geology. Were geologists associated in fact or in the imagination with images of the earth and below-ground which we may link with the Romantics or rather with more radical sources? I believe that the culture of geology was formed within the wider culture of mining and attitudes to mining, that is, not within the context of Romanticism. Moreover, I believe that once this is appreciated, the deeply political and class-based nature of Golden Age geology may be properly appreciated. Clearly, in a paper of this length, it is not possible to do more than hint and how my arguments on these points would be formulated. But I think that a start can be made by considering William Buckland, a pioneer bone-caver and key figure in the development of English geology. I shall proceed now by examining two caricatures concerned with Buckland and his status as a geologist. My reinterpretation of these caricatures reinforces and enhances my comments about geology's debt to the culture of mining.

The first is William Conybeare's The Hyaena's Den at Kirkdale (1822) [figure 5]. The eminent historian of geology, Martin Rudwick, interprets this as suggesting that the geologist has become a participant in the scene he has reconstructed and that the entrance to the cave is a kind of epistemic barrier separating observable present from prehuman past (1989, pp. 244-5). I suggest something different, that what Buckland bears in his hand is not the candle of geological enlightenment (which would, after all, provide a disappointingly feeble illumination), but instead the torch that harks back to our primitive ancestors. The cave conjurs up the era of Neanderthal man, a habitual troglodyte who shifting from one cave domicile to the next - with trepidation, or, as the caricature has it, hair-raising fear - used the scourge of fire to clear his abode of potential foes. The caricature is certainly about the power which geologists possessed to break down the barrier of time, to evoke histories from fossil remains. But it is also a depiction of the willingness of cave geologists themselves to travel in place and time, to forsake their cultivated accoutrements in order coarsely to crawl and scrape and fight against the elements.

This coarseness is a central feature of the next image of Buckland, by Henry De la Beche [figure 6] which, I propose, plays once

Figure 5.
The Hyaena's Den at Kirkdale, by William Conybeare [from Gordon 1894].

Figure 6.
William Buckland's Coprolitic Vision, by Henry De la Beche [from McCartney 1977].

again on the contrast between the appearance of Professor Buckland, dressed in academic gown, weighed down with honours and titles, and his activities as a caveman, activities which exacerbated his reputation for vulgarity. Readers of Buckland's study of the organic remains of caves in Britain, Reliquiae Diluvianae (1823), would have been aware of the contrast. At first impression, Buckland seems a man possessed of more than an ordinary sense of his own distinction and self-worth. The book's titlepage present 'The Rev. William Buckland, B.D. F.R.S. F.L.S.' and then ranked below, the authority of the writer:

> Member of the Geological Society of London; of the Imperial Societies of Mineralogy and Natural History at Petersburg and Moscow; and of the Natural History Society at Halle; Honorary Member of the American Geological Society; Correspondent of the Museum of Natural History of France; Fellow of C.C.C. and Professor of Mineralogy and Geology in the University of Oxford.

Doubtless, Buckland's self-esteem had been raised by the recent award to him of the Royal Society's Copley Medal for his preliminary account of the Kirkdale cave. But, even by the status-conscious standards of the day, Buckland's presentation of his academic honours must have seemed excessive and open to parody - even Charles Lyell announced his magisterial Principles of Geology (1830-3) with 'Charles Lyell, Esq., F.R.S.' and then in one line of small type, 'For. Sec. to the Geol. Soc., Prof. of Geol. to King's Coll., London'.

Buckland's efforts to put his best academic and gentlemanly foot forward find expression in his book's crucial and governing distinction between the 'workmen' and the 'gentlemen' - two classes. The former are amateur geologists, ramblers and miners: they look but do not see, they blunder into caves without sense of their worth, and quite often destroy precious testimony. John Dunmore Lang, in his 1830 report on the bone caves of Wellington Valley, called them 'scientific barbarians' (1831, p. 365). Their only real value is as scout or strongman, and are best deployed removing rubble, nettles, and debris. The gentlemen, by contrast, are observers; it is they who collect, catalogue, store and describe. The question then arises, 'what or who is the Rev. William Buckland?' The cartoon poses just that question. And it provides an answer which draws us, as perhaps only cartoons are able, to the unstated assumptions of the culture of geology.

Figure 7.
Gentlemen and Workingmen Geologists below Ground [from Buckland 1824].

If we examine the contents of Buckland's book with care, we can discover that having passed into the caves he explores, he breaks more than what Rudwick refers to as an 'epistemic barrier'. He foresakes the 'look and manner' which made him in Oxford, 'a thorough English gentleman' and takes up with the workmen (Gordon 1894, p. 36). De la Beche's cartoon has Buckland in - and yet not in - the cavern, with the garb of the gentleman, but before him the task of the miner-geologist. Doubtless, there were cave explorers who went about their business in top hat and coat, but as figure 7 shows, such gentlemen-explorers did not get far. Thomas Sopwith makes clear in his 1833 account of cave and mine explorations in north England that gentlemen had to get 'dressed in the working habiliments of the miners', even if this presented to them a 'grotesque and novel appearance' (1833, pp. 69, 135). One may perhaps conjecture that in entering the cave, Buckland (and perhaps others like him) were entering not the Romantics' world of rest and recuperation but the world of miners and mining.

I do not think that I am here yanking together geology and politics in an unseemly way. Recent research has shown that in a rich variety of ways, the fundamental activities of surveying and mapping encode and display relations of power (Driver and Rose 1992; Stafford 1984; Matless 1988). Studies of nineteenth-century geology have explored its links with politics in satisfying detail, with Morrell (1971) revealing the importance of territoriality and Secord showing that 'for a society increasingly conscious of class and an elite troubled by dissent from the "lower" orders' the appeal of stratigraphy, a science that spoke of position and place, was unmistakable (1986, pp. 33-4). That geology not only offered a vehicle for political uplift but that strata, rocks, fossils and the manifold activities of fieldwork were expressions or embodiments of politics - such notions were almost commonplace and exhibited in the fluid interchange of political and geological idiom in geological discourse. Geology seemed to have served as an efficacious source of political discourse, imagery and ideology.

Again, I ask 'who or what was Buckland?'. Gentleman he proclaimed himself at the start of his book, but Buckland's approach to work in the cave was anything but gentlemanly. He was happy to get dirty, delighted to crawl about on his hands and knees, and never keener than when describing the 'very rugged' appearance of the mines and caverns (1824, p. 8). It has been suggested recently that Buckland launched modern cave research by developing a new method of excavation which 'stressed finesse, not force', but I find very contrary evidence in the historical record (Williams 1990, p. 32). According to at least one contemporary critic, Buckland was an insensitive, blundering, somewhat ham-fisted excavator who on occasion destroyed valuable relics (Boylan 1967, p. 244). Besides any personal aptitude, Buckland's fieldwork was undertaken at speed: the bone cave at Kirkdale occupied him, it seems, for no more than a couple of weeks in December 1821, while a week-long visit in the following July with Sir Humphry Davy took in Kirkdale Cave, Ryedale Windypit, and several other fissures and caves - a tornado-like sweep which startled even Lyell (Lyell 1881, I, p. 155). Buckland was able to produce results in part because, as we shall see, he kept alive a network of informants and so-called 'workers'.

There is, of course, more to De la Beche's caricature. It presents us with the aperture of the cave, cracked and broken, which opens onto a scene in which animals are defecating with wild abandon. Behind them are two evidently coprolitic columns, and around (even beneath) Buckland lie recent faecal deposits. Why the symbols of dirt? They draw attention to an important ingredient - I mean that literally - in Buckland's geological work and suggest, I believe, some important general aspects of contemporary geology.

Buckland's account of his travails in Kirkdale cave is typical of his work underground. Everywhere around he sees dirt: around him and above him, thick casing of stalactites and crusts, stalagmitic accumulations which resemble 'cow's pap' (1824, p. 11), decomposing bones and animal remains, and at his feet, deep blanket of sediment and mud. He conjectures that he is in a den of carnivores occupied in earlier times by such as the hyena, tiger, bear and wolf. This conjecture and its development, indeed, form the core of his study, and its proof, 'conclusive evidence', as Buckland has it, is provided by remains of the animals' excrement. Buckland stands on several inches of what he calls, falling into geojargon, 'an argillaceous and slightly micaceous loam' (1824, pp. 20, 10). The term 'argillaceous' suggests clay, but also, regrettably, something less odorous and more basic. The term was, in fact, a synonym used amongst geologists for faeces, sometimes in distinctly peculiar ways. Here is the Rev. Adam Sedgwick writing to Sir John Herschel in 1844 about Herschel's taking up the President's chair at the forthcoming meeting of the British Association (Clark and Hughes 1850, II, p. 72):

> 'Don't think the chair of State unworthy of you because I once sat on it. The Young Society was then only crawling on all fours, and naturally clung to the earth. And, if an argillaceous impress was left by me on the bottom of the seat, surely twelve years must have dried it, and left time for roses and other sweet-smelling things to grow out of it. So you will have a throne of blossoms sending the sweetest odours to the sky.'

Crawling on all fours... bottom of the seat... sweet-smelling things... this is the language of early Victorian euphemism, and perhaps too, the language of men that will be boys. Somehow or other, talking about dirt, making fun of the excrementory functions, revelling in urinary and faecal puns - this would seem to call for the services of the psychoanalyst as much as the historian. Certainly, Buckland's devotion to excrement, his luxuriation in faeces, brown, black, white or yellow, is at once striking, and this manifestly forms the theme of De la Beche's sketch, its humour deriving from the absurdity of a man of such elevated stature being brought to his knees to pick and lift, hold and cherish, describe and even taste, then collect and hoard samples of the faecal and bone remains of primitive carnivores.

At an early stage in his romance with coprolites, Buckland had dispatched samples to William Wollaston for chemical analysis. Wollaston was able to confirm that the album graecum derived from hyenas. Overjoyed, Buckland expostulated irrepressibly on the dung at a Geological Society dinner in the company of Oxford and Cambridge Professors and other assembled gentlemen, 'with such a strange mixture of the humorous and the serious,' Lyell recounted, 'that we could none of us discern how far he believed himself what he said' (Lyell 1881, I, p. 145). Wollaston cautioned Buckland a few months later that,

> though such matters may be instructive and therefore to a certain degree interesting, it may be as well for you and me not to have the reputation of too frequently and too minutely examining faecal products.

But far from declining, despite some contemporary jibes about his 'relish' for 'feculent matter' (Kirkdaliensis 1822, p. 492), Buckland's interest in what he called 'excrementitious substances' developed through the 1820s - he was delighted to publish a report from India on the hyena's habit of piling faeces up in what his correspondent called 'a spot sacred to the goddess of filth' - and led in 1829 to the presentation of a survey paper on coprolites (Buckland 1827, p. 379; Buckland 1835; Phillips 1857, p. 266). By this time, as Buckland reported, coprolite collections were being formed and geologists of the eminence of Sir Charles Lyell and Sir Roderick Impey Murchison were using them in their work. To Buckland, coprolites offered in their grainy rotundities a kind of microcosm of history, witness to the progress of life on earth, and evidence of 'the general law of Nature which binds all to eat and be eaten in turn' (Buckland 1835, p. 235). 'What rules the world?', Buckland made a habit of asking his classes at Oxford, 'The stomach, sir', came his own answer (Gordon 1894, p. 31). Nicolaas Rupke's comment is apt: 'The study of coprolites,' he writes, 'turned into something of a craze' (1983, p. 142).

Crazy or not, Buckland's enthusiasm for caves or their buried treasures had little in common with the manipulated delights conjured by the Romantics. His own language is blunt and coarse and his idiom hewn from the rock. Mining and manual labour form his world; figure 8, based on a sketch by Buckland, is a scene of primitive mining technology at work - picks and shovels, shaft and plumbline. So I propose that one of the reasons - possibly the main reason - for targetting Buckland with such a number of caricatures and verse parodies and skits was that he had, as gentleman geologist, transgressed the boundary into baser practices associated with working-class geology, indeed, with mining (see on this Fitton 1823, p. 207). In this context, an anecdote from Buckland's early ventures in the field conveys something of what appeared to be distinctly odd about gentlemen in pursuit of geology. During a tour of Ireland in 1813, Buckland and Conybeare sought refuge in a lone hut as night fell. They arrived tired, hungry and covered in mud and dirt, deposited their fossil bags on the floor, and (as Buckland's daughter has it) 'demanded refreshments' of the elderly woman in residence (Gordon 1894, pp. 13-4).

> The old woman, much puzzled to make out their real character, set about her hospitable preparations. By the time they were complete, she had made up her mind. Placing the eggs and bacon on the table, she exclaimed: 'Well, I never! fancy two real gentlemen picking up stones! What won't men do for money?'

Other testimony recalls the kind of atmosphere in which cave research - devoted and committed cave research, rather than day-tripping - was prosecuted. Here's Lyell's account of the labours of the veteran speleologist P.C. Schmerling; Lyell is looking back in awe from the 1860s to work of the 1820s (Lyell 1863, pp. 68-9):

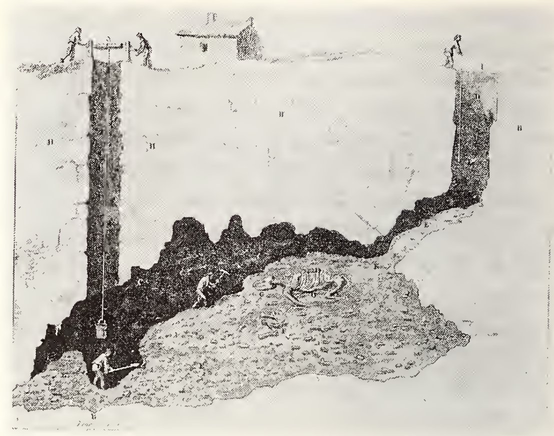

Figure 8.
Mining and Caving [from Buckland 1824].

> Schmerling was [let down], day after day, by a rope tied to a tree, so as to slide to the foot of the first opening of the Engis cave... and, after thus gaining access to the first subterranean gallery, to creep on all fours through a contracted passage leading to larger chambers, there to superintend by torchlight, week after week and year after year, the workmen who were breaking through the stalagmitic crust as hard as marble, in order to remove piece by piece the underlying bone-breccia nearly as hard; to stand for hours with one's feet in the mud, and with water dripping from the roof on one's head, in order to mark the position and guard against the loss of each single bone of a skeleton... [W]e need scarcely wonder... that a passing traveller failed to stop[.]

Such testimony points to cavework, and more generally geology, as workingman's work. And Buckland was more than able to equip himself for the job: he could boast, like other rough-cast mine and cave researchers like William Whewell and Hugh Miller, enormous, even legendary, reserves of brute strength and energy.

Working-Men's Geology

In conclusion, I do believe that we have been seduced away from the real roots of modern geology by the poetic effusions of a few gentlemen geologists by a few over-interpreted hints of geology's debts to Romanticism. These gentlemen-geologists were important and well-connected figures no doubt, and rightfully occupy centre stage in histories of geological power and patronage. But off-stage, or perhaps in a different theatre altogether, other geologists were making discoveries and undertaking research which although creditable received little public credit. (Since I have been speaking about Buckland, I should perhaps mention how very little credit he gives - and how much discredit - to those 'workmen' [and women] who in fact acted as guides, retrieved specimens, and responded to what were often long lists of technical questions dispatched from Buckland's base at Oxford).

In some cases, no doubt, existing relations of doff-the-cap deference ensured that the abuse of such workmen proceeded without much protest. But not always. It is, indeed, the very visible protests of such men as Robert Dick, James Parkinson, Robert Bakewell, Gideon Mantell and Hugh Miller that have alerted me to the existence of another proletarian, masculine culture of geology. Working-men geologists were often richly colourful in their descriptions of those geologists content to work from carriages, to employ others to do their graft, or who made flying field excursions. They were often contemptuous (and sometimes, it is true, envious) of metropolitan science, with its clubbishness and coteries and were proud to be associated with earthlore and the robust etiquette of fieldwork and mining. For them - indeed, even for several metropolitan geologists - the discipline of geology was undertaken by men, for men, and was about the activities of men. It called on men to become engaged in a kind of warfare: Charles Kingsley, writing in 1855, in what appears to us now as a remarkable chant of praise to those men who would renounce effeminacy and the reading of seductive French novels, claims that geology is a science suited especially to former soldiers (he clearly has in mind Murchison and, perhaps, also De la Beche), since it relies on just the kind of attitudes fostered in the army (Kingsley 1890, pp. 40-51).

Camaraderie, camping in the field, mounting campaigns and strategies - all of this was of the essence of early nineteenth-century geology and war craft. So too were the now well-charted controversies which pitched Neptunists against Vulcanists, Uniformitarians against Catastrophists, and other geologists against one another in acidulous disputes. Martin Rudwick's (1985) comparison of the factions in the 'Great Devonian Controversy' to armies in battle is apposite and significant.

Geologists were men who got dirty, who courted danger, who prided themselves on their endurance in the field. They were strong, they were rough, they were celebrated - and often feared - as wild men. Geologists, writes Hershel in a letter to Sedgwick with a mixture of awe and trepidation, are 'hard-working, tough-fisted brawny fellows... who live on three feeds of flints a day' (Clark and Hughes 1850, II, p. 73). There was something regressive and primitive in such rough, touch fieldworkers, Victorians grubbing around on hands and knees collecting dirt, digging amongst bones and decaying animal flesh. And probably their threat resided in part in their unconventional political and religious views. Such were Buckland's and other gentleman-geologists' workmen. They have received very scant treatment in our histories of geology.

In this paper I have attempted not only to explore the dynamics of cavelove and cavelore during a formative period in modern geology, but also to show how caves, no less than other features of the landscape, were manufactured in ideology as much as they were constructed in nature. The power of subterranean political imagery and associations has been examined and I hope that this has not only revealed a new context for the development of the earth sciences but will also prompt further lines of research, for example, into other geological cultures, into the influence of mining and mines on the development of geology, and even into the gendered and scatalogical idiom of Golden Age geology. There have recently appeared, or are projected to appear, biographical studies of Mary Anning, Robert Chambers, Hugh Miller and Gideon Mantell. Perhaps these will help to reconfigure early modern geology. I feel sure that an understanding of caves, cavelove and cavelore will also contribute to that job.

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Richard Owen and the Victorian Museum Movement

NICOLAAS RUPKE

Abstract: The threads of functionalism and transcendentalism in Richard Owen's work were not intertwined as suggested by most historians, but were kept essentially separate by Owen. The dual nature of his work was the result of his ambition to establish a separate, national museum of natural history , requiring Oxbridge patronage, while at the same time co-operating with working scientists, from Edinburgh-Continental backgrounds, at new metropolitan institutions.

A major challenge of Owen scholarship has been to make sense of and unravel the intertwined threads of two intellectual traditions in Owen's work, namely functionalism and transcendentalism. In the *Darwinian Revolution*, Michael Ruse repeated Owen's self--assessment (Figure 1) in stating that 'Owen produced a synthesis between the ideas of two great French biologists, George Cuvier and Etienne Geoffroy St Hilaire [Geoffroy's ideas being similar to Lorenz Oken's]' (Ruse, 1979). Dov Ospovat, in his *Development of Darwin's Theory*, does not go this far, but describes Owen as a judicious eclectic who selected the best from both Cuvier and Geoffroy and who demonstrated that functionalism and transcendentalism are not mutually exclusive (Ospovat, 1981) Others have expressed a similar view, in particular Phil Sloan who in a fine study of Owen's first course of Hunterian Lectures shows how the different Continental schools of thought entered the College of Surgeons and became part of Owen's work. Sloan argues that Owen does not predictably follow the precepts of any one intellectual tradition, but creatively interweaves both German and French lines of research (Sloan, 1991) Underlying these assessments is the assumption that Owen's position was intellectually cohesive and can be satisfactorily explained within the context of the scientific discourse of the period. By contrast, Adrian Desmond, in his *Politics of Evolution*, reduces Owen's stance to a socio-political purpose, arguing that the adoption of transcendental morphology was part of a strategy to defend the College of Surgeons against the threat of radical reform (Desmond, 1989).

These interpretations of Owen's work are enlightening of some of its aspects, but none gives the requisite prominence to the enduring epistemological duality of his oeuvre. The reality behind the façade of Owen's self-presentation showed no synthesis, but two largely segregated bodies of work, one functionalist, the other transcendentalist. Moreover, whenever the two approaches came together, 'form' was used as the primary context of explanation, and 'function' merely as an incidental one. To demonstrate the inadequacy of the teleological method, Owen habitually cited the development of the skull. In the human foetus, the skull, by the time of birth, consists of some twenty-eight separate pieces which ultimately unite into an unyielding whole along a series of rigid sutures. The functional purpose of the loose, dissembled nature of the foetal skull is that it facilitates childbirth by allowing for a change of shape of the head. This function, however, only applies in the case of placental mammals; in various other vertebrates no supple and adjustable cranium is required by the process of childbirth, and yet their crania, too, are composed of uncoalesced skull bones at the time of birth, i.e., in the tiny, 'prematurely' born kangaroo, and in the chick when it breaks through its egg shell. To explain this, a more comprehensive view than the functional one had to be taken, namely that of the vertebrate theory of the skull in which the skull is seen as a composite of several vertebrae, just as the sacrum.

In a forthcoming scientific biography of Owen, I argue that a satisfactory, overarching explanation of the dual nature of Owen's work can be found in the context of his institutional ambitions and in particular in the agenda of his museum politics (Rupke, in press). In order properly to understand Owen, we will have to look at him in the context of his own career objectives. More than most of his colleagues, Owen was a museum man. Nearly all of England's great museums, of art as well as of natural history, were built during Owen's life-time. Museums of natural history, not university departments, were at this time the principal centres for the cultivation of the earth and life sciences. During the first half of his career, Owen was employed as curator at the Hunterian Museum (Figure 2); the second half of his career he worked as superintendent of the natural history departments at the British Museum. At the time, the British Museum housed the library, Near Eastern antiquities, the art gallery, and the natural history collections - all in one. Owen's ultimate career objective was to establish a separate, national collection of natural history, worthy of 'the greatest colonial power on earth'. He summarised his museum ideals in a long essay *On the Extent and Aims of a National Museum of Natural History*. He finally succeeded when in 1881, after decades of frustration, London's Natural History Museum in South Kensington opened its doors.

The people whose support was essential towards the realisation of Owen's museum plans were the museum trustees, both of the Hunterian and of the British Museum. The two boards of trustees were similarly constituted, and heavily dominated by Oxford- and Cambridge-educated members of the Established Church. It was the patronage of these men on which Owen's institutional plans depended. Owen's scientific research was inseparable from his museum plans and must be looked at in the light of the constraints explicitly or implicitly imposed by his Oxbridge patrons. They expected of him that he do their scientific bidding and develop the functionalist epistemology of natural theology. His paymasters advanced Owen's cause in the expectation that he validate the design argument in his studies of vertebrate morphology. To oblige the patrons of his museum plans meant, purely and simply, scientifically to develop the Paleyan design argument. Examples of such Oxbridge-inspired, functionalist work range from Owen's *Memoir on the Pearly Nautilus* to his *Memoir on the Megatherium*, and include his sensational reconstruction of the New Zealand dinornis.

Although Owen's cause was advanced by a circle of Oxbridge friends, his own social background and his own ultimate purposes were different from those of his patrons. Owen was part of a circle of metropolitan bio-medical scientists who did not belong to the Oxbridge ruling elite, but had been educated in Edinburgh or also on the Continent. From there they brought with them a different epistemology, namely the Idealism of Romantic Naturphilosophie, in which not functional adaptation but the transcendental logic of form was the prime criterion by which reality - especially organic reality - was explained. These men were the working scientists at a number of new, metropolitan institutions, such as the Royal Institution, the Hunterian Museum, the British Museum, the University of London, and also the Museum of Practical Geology. Continental transcendentalism provided Owen and his London colleagues with a suitable philosophical framework for a metropolitan, as opposed to Oxbridge, intellectual culture. To adopt a German epistemology symbolised an independence from Oxbridge. It was as part of this metropolitan circle of colleagues that Owen perfected the transcendentalist approach, most famously in his *On the Archetype and Homologies of the Vertebrate Skeleton*. Thus I argue that it was the duality of the socio-political conditions under which Owen laboured that explains the two-track nature of his scientific work.

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Figure 1. Richard Owen, flanked by George Cuvier and Lorenz Oken, symbolising Owen's claims to have produced a synthesis between functionalism and transcendentalism in vertebrate morphology. From: Richard Owen, *The Principal Forms of the Skeleton and the Teeth* (London, 1856), unnumbered figure on first page of text.

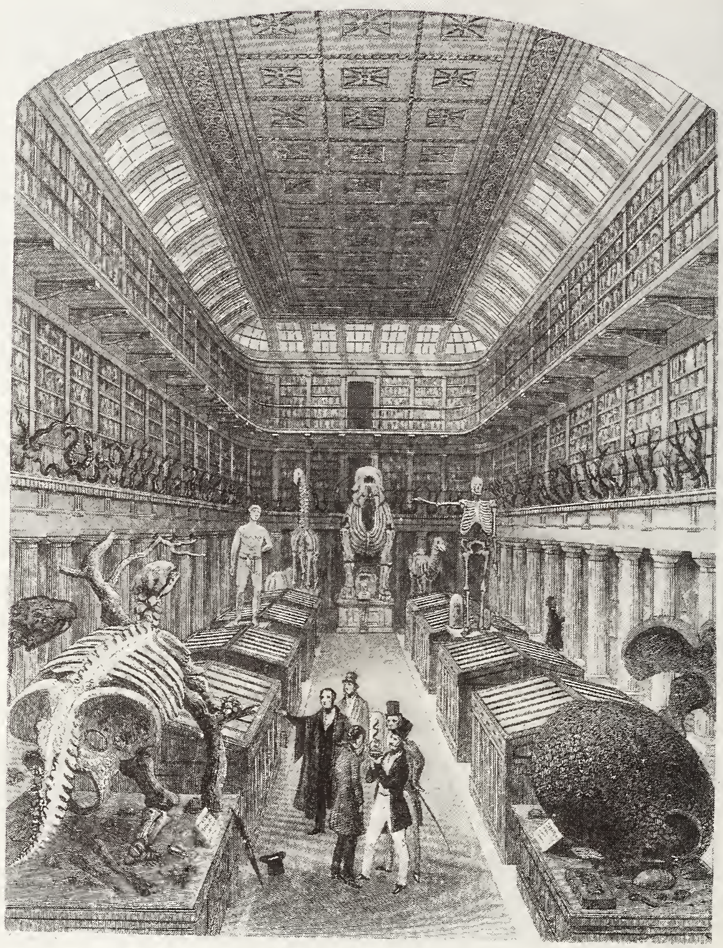

Figure 2. The exhibition hall of the Hunterian Museum, showing the museum context in which Owen carried out his scientific work. From: *London Interiors* (London, 1841-44), opposite p. 129.

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INDEX TO Volume 125

Abstract of Proceedings, 1991 - 92 25

Abstract of Thesis,
Coenraads, Robert R. 19

Address by His Excellency,
Governor of New South Wales -
Annual Dinner 1992 36

Annual Dinner, March 1992 23,36

Australian Science, Richard OWEN,
Thomas MITCHELL and
(A commemorative Symposium) 93

Australian Red Earth and Bones 111

Awards
Citations 31

BECK,R.W.. MIDDLEMOST,E.A.K., DULHUNTY, J.A.
and.Some Mesozo ic Igneous Rocks from North-eastern New South Wales and their Tectonic Setting. 1

Biographical Memoirs 34

Biotas, Island 51

BRANAGAN, David
Richard Owen, THOMAS MITCHELL and
Australian Science. A Commemorative Symposium 93

BROWN, J.K.,
Health Hazard associated with Extremely Low-Frequency Electromagnetic Fields from Power Lines and Home Appliances 13

CLARK, G.M., COOK MEDAL 1991 31

CLARKE MEDAL 1991 31

CLARKE MEMORIAL LECTURE 1991 51

Contents Vol. 125, Parts 1 and 2, 3 and 4 141

COOK MEDAL 1991 31

Council, Annual Report 1991 - 92 23

DAVIES, Susie M., R.ARMSTRONG L. OSBORNE.
WILLIS, Paul M.A.; Important vertebrate fossils from the Palaeontological collections of the Department of Geology and Geophysics, University of Sydney 113

DULHUNTY, J.A. and BECK, R.W.. MIDDLEMOST,E.A.K.,
Some Mesozo ic Igneous Rocks from Northeastern New South Wales and their Tectonic Setting 1

EDGEWORTH DAVID MEDAL 1991 32

ERRATA: Vol. 124, p.85 26
Vol. 125, p.37, pp 41-49 92

Extremes. Interpretation of 79

Financial Statement 27

FREE, Ross, The Hon., Minister for
Science and Technology 37

GEOLOGY
Mesozo ic Igneous Rocks and Tectonics 1
Sapphire and Diamond Deposits, New South Wales 19
A Commemorative Symposium 93

HARPER, A.F.A., Obituary 3

HARVEY, M.S., Edgeworth David Medal 1991 32

Health Hazards associated with Extremely Low-Frequency Electromagnetic Fields from Power Lines and Home Appliances 13

HOLLAND, Julian, Thomas MITCHELL and the
Origin of Australian Vertebrate Palaeontology 103

INDEX 137

JEFFREY, S.W. CLARKE MEDAL 1991 31

MEMBERSHIP LIST 41

Mesozo ic Igneous Rocks from Northeastern
New South Wales and their Tectonic Setting 1

MIDDLEMOST, E.A.K., DULHUNTY, J.A. and BECK,R.W.
Some Mesozo ic Igneous Rocks from Northeastern New South Wales and their Tectonic Setting 1

MITCHELL and Australian Science, Richard OWEN,
Thomas (A Commemorative Symposium) 93

MITCHELL and the Origin of Australian
Vertebrate Palaeontology. Thomas 103

NEW ENGLAND Branch Report 25

NEW SOUTH WALES
Northeastern New South Wales 1
Sapphire and Diamond Deposits of
New England 19

ORDOVICIAN 51

OSBORNE, R.A.L.. Australian Red Earth and Bones 111
OWEN In the Antipodean Contest, Richard 95

OSBORNE, R. Armstrong L.. WILLIS, Paul M.A.,
DAVIES, Susie M. Important vertebrate fossils from the palaeontological collections of the Department of Geology and Geophysics, University of Sydney 113

OWEN, THOMAS MITCHELL and Australian Science.
Richard (A Commemorative Symposium) 93

OWEN and Ancient Australia, Julian Tenison
Woods, Richard 107

OWEN and the Victorian Museum Movement.
Richard 133

Palaeontological Collections of important
vertebrate fossi ls 113

Paleontology, Thomas Mitchell and the Origin
of Australian Vertebrate 103

Physics
Health Hazards and Electromagnetic Fields 13

PLAYER, Ann. Julian Tenison Woods,
Richard Owen and Ancient Australia 107

POTTER, E.C.: On being interested in the
Extreme
(Presidential Address 1992) 79

Presidential Address, 1992 79

RUPKE, Nicolaas, Richard Owen and
the Victorian Museum Movement 133

SINCLAIR, Peter, A.O., His Excellency
Governor of New South Wales 36

SHORTLAND, Michael, Plumbing the Depths:
on caves and the men of Geology 119

Society Medal 1991 33

Summer School "Communications" 1992
OPENING ADDRESS The Hon. Ross Free,
Minister for Science and Technology 37

SYMPOSIUM, Richard Owen, Thomas Mitchell
and Australian Science 93

Victorian Museum Movement.
Richard Owen and 133

WEBBY, B.D.: Ordovician island biotas:
New South Wales record and global
implications 51

WILLIS, Paul M.A., DAVIES, Susie M.,
OSBORNE, R. Armstrong L., Important Vertebrate fossi ls from the palaeontological
collections of the Department of Geology and
Geophysics, University of Sydney 113

WINCH, D.E. Society Medal 1991 33

WOODS, Richard Owen and Ancient Australia,
Julian Tenison 107

JOURNAL AND PROCEEDINGS

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Contents

VOLUME 125 Parts 1 and 2

MIDDLEMOST, E.A.K., DULHUNTY, J.A., and BECK, R.W.:
Some Mesozoic Igneous Rocks from Northeastern New South Wales and their Tectonic Setting. 1

BROWN, J.K.:
Health Hazards associated with Extremely Low Frequency Electro-magnetic Fields from Power Lines and Home Appliances. 13

ABSTRACT OF THESIS:
COENRAADS, Robert R.: Alluvial Sapphire and Diamond Deposits of the New England Gem Fields, New South Wales, Australia. 19

ERRATUM:
Vol.124, p 85 26

ANNUAL REPORT OF COUNCIL 1991-1992:
Report 23
Abstract of Proceedings 25
Financial Statements 27
Awards 31
Biographical Memoirs 34

ADDRESS by HIS EXCELLENCY REAR-ADMIRAL PETER SINCLAIR, A.O., GOVERNOR OF NEW SOUTH WALES at ANNUAL DINNER 1992 36

SUMMER SCHOOL "COMMUNICATION" January 1992, Opening Address by The HONOURABLE ROSS FREE, Minister for Science and Technology 37

MEMBERSHIP LIST 41

Parts 3 and 4

WEBBY, B.D.:
Ordovician Island Biotas: New South Wales Record and Global Implications. (Clarke Memorial Lecture 1991) 51

POTTER, E.C.:
On being interested in the Extreme. (Presidential Address 1992) 79

ERRATA:
Vol. 125, Parts 1 and 2 92

BRANAGAN, David:
Richard Owen, Thomas Mitchell and Australian Science. A Commemorative Symposium. 93

BRANAGAN, David:
Richard Owen in the Antipodean Context (A Review). 95

HOLLAND, Julian:
Thomas Mitchell and the Origins of Australian Vertebrate Palaeontology. 103

PLAYER, Ann:
Julian Tenison Woods, Richard Owen and Ancient Australia. 107

OSBORNE, R.A.L.:
Australian Red Earth and Bones. 111

WILLIS, Paul M.A., DAVIES, Susie M. and R.Armstrong L.OSBORNE:
Important vertebrate Fossils from the Palaeontological Collections of the Department of Geology and Geophysics, University of Sydney. 113

SHORTLAND, Michael:
Plumbing the Depths: on Caves and the Men of Geology. 119

RUPKE, Nicolaas:
Richard Owen and the Victorian Museum Movement. 133

INDEX to Volume 125 137

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Contents

Volume 125, Parts 3 and 4

WEBBY, B.D.
Ordovician Island Biotas: New South Wales Record and Global Implications. (Clarke Memorial Lecture 1991) 51

POTTER, E.C.
On being interested in the Extreme. (Presidential Address 1992) 79

ERRATA: Vol. 125, Parts 1 and 2 92

BRANAGAN, David
Richard Owen, Thomas Mitchell and Australian Science. A Commemorative Symposium. 93

BRANAGAN, David
Richard Owen in the Antipodean Context (A Review). 95

HOLLAND, Julian
Thomas Mitchell and the Origins of Australian Vertebrate Palaeontology. 103

PLAYER, Ann
Julian Tenison Woods, Richard Owen and Ancient Australia. 107

OSBORNE, R.A.L.
Australian Red Earth and Bones. 111

WILLIS, Paul M.A., DAVIES, Susie M. and R.Armstrong L.OSBORNE
Important vertebrate Fossils from the Palaeontological Collections of the Department of Geology and Geophysics, University of Sydney. 113

SHORTLAND, Michael
Plumbing the Depths: on Caves and the Men of Geology. 119

RUPKE, Nicolaas
Richard Owen and the Victorian Museum Movement. 133

INDEX to Volume 125

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Demise of the Dinosaurs and other Denizens II -- by Combined Catastrophic Causes?

F.L. SUTHERLAND

ABSTRACT. Since Charles Darwin's view of geology, the earth sciences have greatly increased in scope and comprehension of processes shaping the evolution of the earth. This is illustrated by the extensive debate concerning extinction of biota at the Cretaceous/Tertiary (K/T) boundary, including the departure of dinosaurs.

Pendulums of opinion on causes of K/T extinctions have oscillated as new geochemical, mineralogical, palaeontological, meteoritical, climatological and geothermal data became available for synthesis and interpretation. Abrupt changes at the K/T boundary promoted concepts of catastrophic extinctions. A meteoritic impact school won early acceptance and a 'volcanic outburst' school developed by 1985. A third catastrophic school, combining both impact and volcanism gained ground in 1988, some workers invoking impact-triggered volcanism and others coincidental but independent impact and volcanic events.

Evidence for major impact and volcanism at K/T time is strengthened by location of impact craters, tektite deposits, diamonds, extraterrestrial amino acids and extensive hotspot volcanism. Craters in the northern hemisphere and more extensive hotspot volcanism in the southern hemisphere may explain geochemical differences in K/T sections. Impact directly triggering volcanism is unlikely. Iridium output from over 35 hotspots can account for lower level Ir over 500,000 years, but the sharp Ir peak could fit an impact source.

This paper proposes that combined impact and volcanism best explains K/T boundary events. Such a coincidence of major extraterrestrial and terrestrial catastrophic events is not improbable over geological time, but is not essential for global extinctions, judging from the Permo-Triassic Siberian volcanism.

The dinosaurs succumbed to complex K/T events, but exact reasons for their demise remain uncertain. Selenium increase in their egg shells towards the K/T boundary correlates with increasing pathology of egg protein, shell fragility and reproductive loss. Dinosaurs disappeared, while other terrestrial vertebrates survived. The dinosaurs do not rest in peace but haunt the human realm in fantasy literature.

INTRODUCTION

"Geology is a capital science to begin, as it requires nothing but a little reading, thinking and hammering" - Charles Darwin, 1835.

This quote is especially appropriate to begin this Presidential Address, both for its historical context and for the perspective it gives to the advancement of geology. In 1835, Darwin was nominally a geologist in his scientific activities and his famous publications on the evolution of biological species were still on the horizon (Darwin, 1839). His quoted view of geology preceded his visit to Australia, where in early 1836 he sailed from Sydney and made some pertinent observations on the geology around Hobart Town (Banks, 1971). This view was expressed sometime after the embryonic foundation of the Royal Society of New South Wales as the Philosophical Society of Australasia in 1821 and thirty-one years before the Society received its Royal Charter and took its present name (Browne and Browne, 1961). Richard Owen had not yet proposed the name dinosaur or "terrible lizard" for this group of extinct reptiles which was established in 1842 (Torrens, 1992).

The extinction of the dinosaurs and many other life forms between the end of the Cretaceous and beginning of the Tertiary Periods (K/T boundary) has fascinated both scientists and lay people over many years. A surprising number of children can name the dinosaur species that vanished from the fossil record. Since 1980, a major scientific debate on the K/T and other extinction events in the evolutionary record has embroiled many scientists and scientific disciplines in seeking answers to the causes of such events. The voluminous earlier literature on proposed causes for dinosaur extinctions is summarised by Glen (1990). The views of two strong groups in the debate, one supporting a meteoritic impact and the other a volcanic cause are presented by Alvarez and Asaro (1990) and Courtillot (1990).

This debate, in its earlier flowering, was the topic of my Presidential Address to the Royal Society of New South Wales in 1988 (Sutherland, 1989). I did not expect to be in this position to present a sequel five years later. However, so sustained has been the controversy that only now the dust generated by the impact versus volcanic argument, literally, is settling out. In my 1989 survey, I concluded that:

"As an antipodean analyst, I would place my geological guess on a combined catastrophe i.e., a coincidence of both impact and volcanic cycles coming together, but not necessarily the first directly causing the other".

This address picks up the debate from that point and discusses its validity in the vigorous climate of subsequent research.

DEMISE OF THE DINOSAURS - CLEAR CUT OR STRUNG OUT?

The extinction arguments fall into two general categories: normal and catastrophic causes. The first considers that normal geological processes, such as global sea-level falls, major upwellings of waters of differing properties, or climatic changes, sometimes aided by other contributing factors such as volcanism, are capable of producing widespread extinctions (Hallam, 1988; Wilde et al., 1990). The second invokes abnormal events to provide drastic changes in conditions and accounts for observed anomalies. These may be extraterrestrial in origin, such as a major meteoritic impact (Alvarez, 1990) or some other astronomical phenomenon, including large meteoric storms (Yang, 1990). Alternatively these may be extraordinary terrestrial phenomena which occur infrequently, such as gigantic volcanic outbursts (Rice, 1990a; Rampino and Calderia, 1993). In considering such arguments it is crucial to know the real nature of the extinction event - its full extent, whether global or local and its precise timing, whether abrupt, gradual or stepped in time (Upchurch, 1989; Archibald, 1993).

The dinosaur record

Did dinosaurs all die out together, or become extinct in gradual stages? Intensive collecting within sections in the western American interior now shows that dinosaur remains continue unabated to within 60cm below the K/T boundary (Kerr, 1991). Furthermore, dinosaur teeth and bones found in the overlying Tertiary sedimentary beds are now shown to be re-deposited Cretaceous remains (Geodigest, 1991). An abrupt demise for dinosaurs therefore is favoured in the well studied North American region. In another section with ambiguous ages at Ocean Point, North Slope of Alaska, dinosaur bones are recovered from sedimentary beds interbedded with layers of volcanic debris from explosive eruptions (Conrad et al., 1992). Earlier dating ranged from late Cretaceous to Early Tertiary in time. New precise dating of volcanic shards in the volcanic beds gives ages between 68-71 million years (Ma). This consigns the dinosaur remains to the Cretaceous, as the K/T boundary is currently dated around 66Ma (see later). The apparent premature demise of these Alaskan dinosaurs, however, may only represent a local extinction due to activity of nearby volcanoes.

An important misconception in evaluating the dinosaur record within the overall K/T extinction event is stressed by Archibald (1993). In this view, the complete extinction of north American dinosaurs only represent some 18% of the then existing vertebrate species and around 50-75% of these vertebrate species survived the K/T extinction. The loss of some 75% of species usually quoted at this boundary (76±5%; Jablonski, 1991) is mostly based on the marine record and is an inferred value derived from the loss of observed K/T genera (47%). The marine % loss may also be over estimated, as recent work has found up to 22 ammonite species at a metre below the K/T boundary, where previously they were only reported to 10 metres below the boundary (Ward, 1990; Kerr, 1991). Some species of planktonic foraminifera also appear to survive for 200,000 years (200Ka) beyond the K/T boundary (Jenkins, 1992).

The dinosaur species in the Late Cretaceous were not world-wide inhabitants and their actual distributions are still poorly documented (Hecht, 1992). Claims for staggered extinctions in different regions (Jaeger et al., 1989; Hansen, 1990, 1991) may still be valid. The Alaskan dinosaur-beds also demonstrate that some species were hardy enough to live under near-polar conditions 2Ma before the K/T extinctions. Thus, the K/T extinctions, which include the dinosaur record, represent a complex and irregular event.

Dinosaur eggs

Recent studies of their eggs give further insight into the demise of dinosaurs. Dinosaur eggs have a distinct pattern of growth fibres which differs from those in eggs of other reptiles and birds (Geodigest, 1992). Their shells may have smooth or ornamented surfaces depending on whether the species nested within shallow sandy sites or buried its eggs in piles of decaying vegetation. The effects of volcanic-induced CO_2 increase on dinosaur hatchings in French and Indian K/T sections are considered by Lockley (1990), who suggested hatchings would be inhibited by elevated CO_2 levels.

The hatching of dinosaurs from eggs (Fig.1) appears to become less successful in beds closer towards the K/T boundary, based on studies from southern France and China (Hansen, 1990, 1991; Zhoa et al., 1992). This failure seems to correlate with increasing concentrations of the element selenium (Se) both in the shell and in the host sediments, particularly as Se fed to hens is known to reduce hatchings (Hansen, 1990). Abnormalities found within the structure of amino acids in dinosaur shells close to the K/T boundary led to pathological formation of eggshells (Zhoa et al., 1992). Thus, the dinosaurs may have suffered from ingestion of trace elements that interfered with the reproductive process. (Fig.2.)

Hansen (1990) considered this ingestion of toxic elements was due to airborne dust that settled on leaves from volcanic eruptions. However, some plants can strongly concentrate Se from soils, particularly where Se is oxidised to water soluble selenates in alkaline soils (Oldfield et al., 1974). It is worth noting that the western American interior presently carries the main distribution of selenium accumulator plants in America where Se exceeds 50 parts per million (ppm). Thus relatively lower levels of Se deposits in soils could produce Se approaching toxic levels in such plants. Further worth noting, when considering extinction of marine-dwelling dinosaurs and other marine groups, is the typical enrichment factor for Se in marine plants at 8,900 times that of sea water (Table 1.2, in Trudinger and Swaine, 1979).

Fig.1. Baby dinosaur hatching from egg. Photograph of an approximately life-size model. Windstone Editions, North Hollywood, California, USA. Photographed by R.E. Pogson.

The supporting plant story

As many dinosaurs were plant eaters and they in turn supported the diet of some carnivorous dinosaurs, extinctions in plant communities at K/T time need examination. High resolution studies of the leaf-fossil record in western American interior sections, combining both palynology and megaflora examination, show a 30% palynoflora extinction and a nearly 80% megaflora turn-over across the boundary, with smaller turn-overs 17 and 25m below the boundary (Johnson et al., 1989). Aquatic leaves from one boundary layer had preserved a structural damage which can be reproduced by freezing experiments in living aquatic leaves (Wolfe, 1991). The reproductive stage reached in the deformed fossil plants at their time of death suggests freezing took place early in June (i.e. the northern hemisphere mid-summer). This leads to the concept of an abnormal climatic cooling, which Wolfe termed an 'impact winter'.

The terrestrial flora extinctions have to be viewed within a global wild-fire, proposed on widely distributed soot (carbon black) of resinous origin at the K/T boundary (Wolbach et al. 1990a, b). The conflagration was attributed to woods ignited by thermal radiation during ballistic re-entry of ejecta after a meteoritic impact (Melosh et al., 1990). Plant recovery following such an impact-induced fire could be severely inhibited due to effects of nickel toxicity on young seedlings (Davenport et al., 1990). The large accumulation of dead organic matter at the boundary may have altered ground water conditions, reducing the oxidation state of minerals within the underlying sediments (Lowrie et al., 1990).

Fig.2. Fragmented fossil dinosaur egg. Cretaceous age from Château-neuf-Le Rouge, Aix-en-Provence, Sth. France. (Australian Museum Palaeontology Collection, Reg.No. F68709). Photographed by R.A.L. Osborne.

PENDULUMS OF K/T OPINIONS

The impact pendulum (1980-1985)

The meteorite impact opinion swung into prominence after a large meteorite impact was proposed to explain abnormally high values of siderophile elements (iron, nickel and cobalt; including Platinum Group Elements (PGE) such as iridium and osmium) in K/T boundary sections (Alvarez et al., 1980). This impact was linked with K/T extinctions and the proposal generated widespread research on and considerable support for such an interpretation. It also stimulated many theoretical models exploring effects of such an impact on climates (e.g. O'Keefe and Ahrens, 1989). This view, termed the Alvarez et al. School here for convenience, and some of its supporting arguments are listed in Fig.3. More detailed discussion on these arguments are given in Sutherland (1989) and Tredoux et al. (1989).

Despite the dating of the Manson crater to K/T time and its interpretation as an impact site (Kunk et al., 1989; Hartung et al., 1990), a weakness for the impact story remained in the lack of an impact site large enough to produce the proclaimed global effects. Most K/T boundaries showed trace element patterns suggesting a continental contribution. However, some suggested an ocean floor contribution and a few lacked the PGE and other siderophile element enrichments even though preserving other K/T features (Tredoux et al., 1989).

The volcanic pendulum (1985-1988)

The detection of Ir in volcanic outgassings at Hawaii and ocean ridge systems and difficulties in matching some PGE and other siderophile element concentrations to meteoritic ratios (e.g. Ir/Ni) dampened the swing of the impact pendulum and encouraged a swing towards volcanic views.

The volcanic case for K/T boundary effects outlined by Officer and Drake (1985) is termed the Officer et al. School (Fig.4). Some of the supporting arguments (e.g. K/T age of the Deccan flood basalts, volcanic shocked quartz, staggered Ir anomalies and extinctions) are listed. However, note that arguments on behalf of an impact continued to advance e.g. proposals of tidal wave (tsunami) deposits, matching of PGE and other siderophile element ratios with meteoritic values, identification of high pressure minerals and dating of impact craters near the K/T boundary (Sutherland, 1989).

The combined pendulum (1988-1989)

To overcome the problem of a missing major K/T impact site, some authors proposed that the Deccan flood basalts masked the site, which was later dismembered by seafloor spreading (Alt et al., 1988; Chatterjee, 1989). An analogy was made to lunar maria. The Alt et al. model (Fig.5) and earlier suggestions for impact-triggered flood volcanism (e.g. Rampino, 1987), encounter problems in paucity of evidence for impact under the Deccan basalts (Kerr, 1989) and in initiation of this volcanism prior to the K/T boundary (Courtillot, 1990) and rifting events (Hooper, 1990). An alternative combined impact/volcanism model proposed co-incidental rather than consequential events (Sutherland, 1989).

Such a dual view is supported by geochemical studies of K/T sections (Tredoux et al., 1989). PGE patterns differ between hemispheres and are difficult to explain by a single geological event, such as an impact alone.

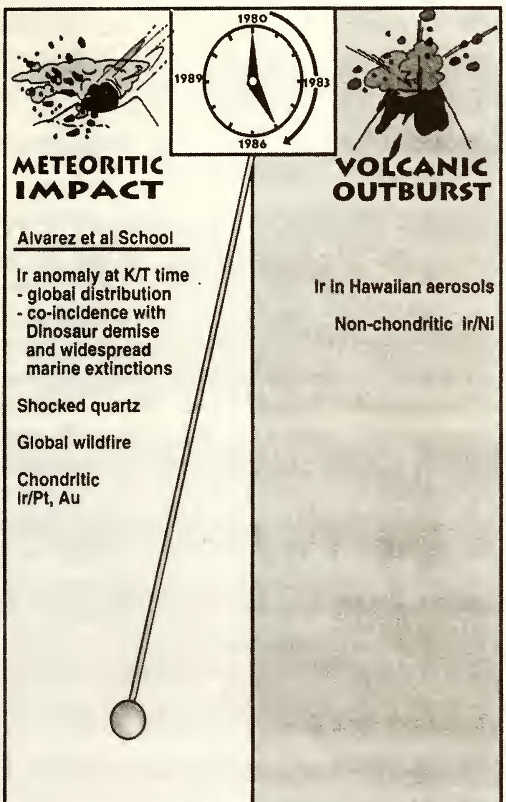

Fig.3. The meteoritic impact pendulum for explaining K/T events, which dominated the extinction arguments from 1980 to 1985.

The European boundary clays show flatter PGE patterns more typical of "chondritic" meteoritic patterns than the New Zealand ones where more "basaltic" patterns were preserved.

Continued K/T research (1989-1993)

The three schools of thought for explaining K/T boundary features (impact, volcanism and combined impact/volcanism) provide a triangular framework for considering newer research results (Fig.6). Some of the claims and counterclaims for impact or volcanic interpretations are listed for discussion.

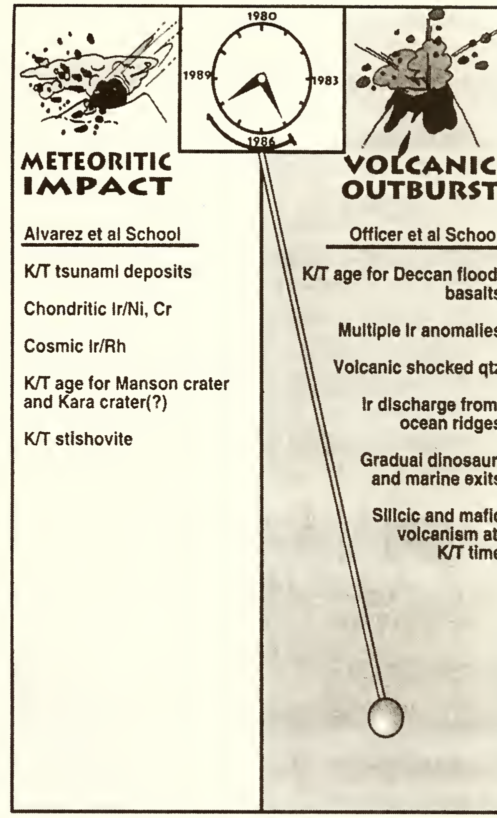

Fig.4. The volcanic "outburst" pendulum, which swung the emphasis away from impact arguments for K/T events from 1985 to 1988.

REVIEW OF LATER K/T RESEARCH

Since 1989, research has revealed further distinct changes at the K/T boundary although some results were equivocal in terms of impact or volcanic interpretations.

The precise age of the K/T boundary is important in correlating events around this time. The best estimates place the boundary in geomagnetic interval Chron 29R, within a depositional time of 40Ka and at an age around 66.2Ma (Groot et al., 1989; Herbert and D'Hondt, 1990; Claire et al., 1991; Swisher et al., 1992a; Hansen et al., 1992).

A bulk value for the Ir content of the Denmark K/T boundary clay is given as 32±2 ng/g (Gwozdz et al., 1992).

Evidence favouring catastrophic K/T changes

Abrupt shifts in geochemistry in the K/T depositional record suggest that catastrophic changes in environmental conditions contributed to observed turnovers in the boundary biomass. These changes are variously interpreted within impact (Alvarez and Asaro, 1990; Swinburne, 1993) and volcanic (Courtillot, 1990; Officer, 1993) scenarios. They include:

(a) strong enrichments in both non-meteoritic elements (Sb, As, Zn) and meteoritic elements (Ir, Ni, Cr, Fe, Co). These are related to impact (Gilmour and Anders, 1989), terrestrial causes (Vannucci et al., 1990), or both (Tredoux et al., 1989).

(b) enrichments in Ir, Ni and other chalcophile elements within the K/T layer. This was interpreted as external additions precipitated under changing geochemical conditions (Graup and Spettle, 1992). A constancy in certain element ratios (e.g. Ni/Co) suggests an extended availability of the external component.

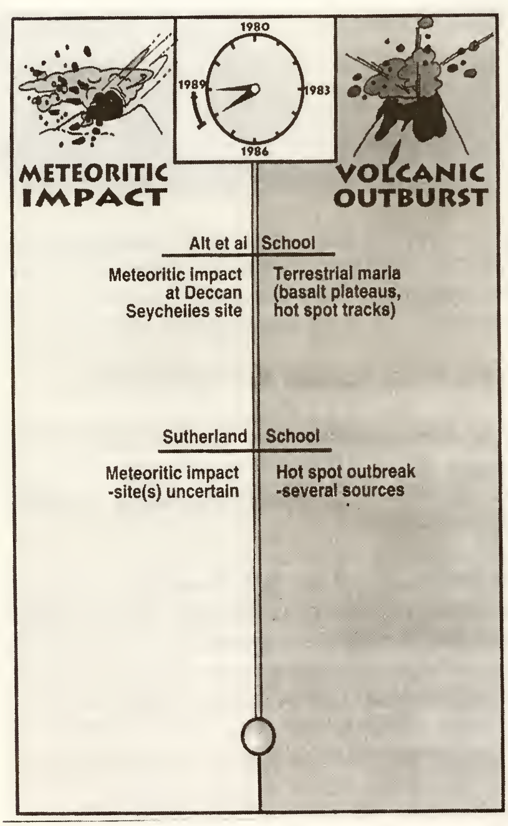

Fig.5. The combined impact/volcanic pendulum which was proposed to explain major K/T features in 1988.

(c) change in strontium isotope ratios ($^{87}Sr/^{86}Sr$). This was interpreted as a rapid increase (28×10^{-6}) related to enhanced weathering from impact-induced acid rain (Martin and Macdougall, 1991). Alternatively, the change was related to a 10% increase in the continental Sr flux, 1.5-2.3Ma before K/T time (Nelson et al., 1991). A better Sr isotope record across this boundary is needed to resolve these two interpretations (Palmer, 1991; Müller and Hsü, 1992).

(d) complex shifts in carbon isotope ratios ($^{\delta 13}C^{\delta 12}C$) mark the planktonic marine record at the boundary (Hsü and McKenzie, 1990). These include smaller, short term (10^3 yrs) and larger, longer term (10^6 yrs) shifts towards negative ratios, which were attributed to planktonic death (Strangelove Ocean) and later bacterial blooming (Respiring Ocean). Such shifts could reflect either impact or volcanic effects, but in a favoured impact scenario were termed Impact Winter and Silent Spring respectively (Hsü et al., 1992). Short term "double shifts" in C isotopes characterise K/T sections containing both inorganic carbon (negative shift in $^{\delta 13}C$) and carbon from organic debris (positive shift in $^{\delta 13}C$) in estuarine K/T sections in China (Yan and Ye, 1992).

(e) sharp enrichments in nitrogen at some K/T layers which show variable enrichments in ^{15}N over ^{14}N (Gardner et al., 1992). This N anomaly was related to presence of an aliphatic amide compound, produced through 'acid rain' reaction with organic matter, rendered lifeless by a presumed meteorite strike.

(f) a temporary drastic increase in $^{34}S/^{32}S$ in whole rock sulphide content in the eastern Hokkaido boundary in Japan (Kajiwara and Kaiho, 1992). This is interpreted as creation of an anaerobic, anoxic oceanic sedimentary environment for 70,000 years following a catastrophic event.

Evidence favouring impact

Mineralogical evidence for high pressure-high temperature K/T phases related to extraterrestrial impact includes:

(a) stishovite, in New Mexico, USA (McHone et al., 1989).

(b) micro-diamonds, in Alberta, Canada (Carlise and Braman, 1991). C and N isotope ratios in these diamonds do not correspond to original meteoritic diamond, but suggest formation from an impact or associated plasma (Gilmour et al., 1992).

(c) shocked-mineral grains found in both K/T boundary sites and proposed impact craters (Bohor, 1990; Sharpton et al., 1990, 1992). Quartz dominates and cathodoluminescence studies of over 1,000 shocked quartz grains from five western American interior sites showed no significant contribution from volcanic quartz (Owen et al., 1990). Other shocked minerals include zircon (Bohor et al., 1990). U-Pb isotope dating of Colorado zircon indicated a re-set K/T age (65.5±3Ma) and original source rocks as old as 550 Ma (Bohor et al., 1992).

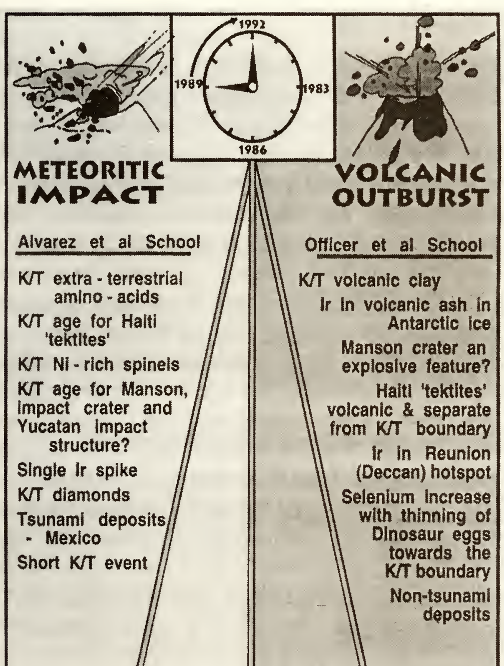

Fig.6. The three main pendulums of opinions on K/T events in 1993.

(d) Ni-rich spinels, related in surface features and composition to ablated impact materials (Robin et al., 1991, 1992). High temperature magnesio-wüstite inclusions in a spinel (magnesioferrite) may also belong to such origins (Kyte et al., 1991).

Organic evidence for an extraterrestrial event is observed in amino acids detected both above and below, but not directly in the K/T boundary (Zhoa and Bada, 1989). These amino acids do not exhibit terrestrial configurations and were related to an influx of comet dust, with those at the boundary being destroyed by impact heating (Zahnle and Grinspoon, 1990).

Re-examination of the geochemical profiles across the Italian section confirm the presence of one sharp Ir anomaly (Alvarez et al., 1990; Rocchia et al., 1990). This favours a sudden event such as an impact, in contrast to multiple Ir enrichments, which would tend to favour volcanic sources. The Ir peak, however, stands on a broader base of above background Ir suggesting an additional, more protracted Ir supply (Rocchia et al., 1990; Courtillot, 1990). A microbial origin for the peak (Dyer et al., 1992) is unlikely, based on detailed examination of the Ir itself and of microspherules within the boundary clays (Kong and Chai, 1992). The latter proposed a mixed extraterrestrial and volcanic process but with volcanism being triggered by impact. Ir/Os ratios (1.02±0.55) within the anomaly are claimed to approach solar system values (Liu et al., 1992) and $^{187}Os/^{186}Os$ values (1.16) to approach chondritic values (Meisel et al., 1992).

Potential impact craters and proposed tektite (glassy spherule) impact deposits with ages close to K/T boundary age (64-66 Ma) are now known at Manson Crater (Kunk et al., 1989; Anderson, R.R. et al., 1992), Chicxulub Crater (Hildebrande and Boyton, 1990; Pope et al., 1991; Swisher et al., 1992b; Sharpton et al., 1992) and Beloc, Haiti spherule deposits (Izett et al., 1991).

Evidence favouring volcanism

The main volcanic case is based on correlation of rapid, extensive basaltic volcanism over the Deccan hotspot (Richards et al., 1989; Courtillot, 1990; Vandamme et al. 1991; Bhattacharje, 1992). An association with K/T iridium can be made, as Ir is detected in sublimates at Reunion Island volcano, the postulated present site of the Deccan hotspot (Toutain and Myer, 1989).

Further features cited as support for K/T volcanism include:

(a) smectite-rich 'volcanic' clay compositions in K/T boundary layers, with some layers 8m above the boundary (Elliot et al., 1989; Vannucci et al, 1990). PGE patterns in the New Zealand K/T section show a more 'basaltic' than 'chondritic' signature (Tredoux et al., 1989). Detailed geochemistry on the Denmark boundary involving vanadium studies shows that the smectites were formed prior to and not after the K/T event (Premović et al., 1993).

(b) multiple iridium anomalies, found in some K/T sections, e.g. Bavarian Alps, where Ir spikes occupy different lithologies and are atypical of other K/T boundaries (Graup and Spettle, 1989).

(c) Ir enrichment in recent bands of volcanic dust found in Antarctic blue ice (Koeberl, 1989).

(d) Os isotope ratios in Ir-bearing aerosols erupted from hotspot volcanoes (Hawaii), which lie within Os isotope ranges found in some iron and chondritic meteorites (Krähenbühl et al., 1992).

(e) multiple shocked mineral and elemental enrichments in K/T sections, e.g. Walvis Ridge, where a strong secondary peak is recorded at 1.9m (corresponding to 10^5yrs in deposition) prior to the K/T boundary peak (Huffman et al., 1990).

THE IMPACT SCENARIO (Fig.7)

Two K/T impact sites are proposed on age dating within the North American-Caribbean region at the Manson and Chicxulub Craters (Anderson, R.R. et al., 1992; Sharpton et al., 1992; Swinburne, 1993), although they were disputed as impact structures (Officer and Carter, 1991; Lyons and Officer, 1992). The relationships of these craters to K/T impact deposits is rather confused in the literature. Shocked quartz grains reach their largest size in North American sections and although shocked quartz is found in Manson crater country rocks (Hartung et al., 1990), the grains in sedimentary K/T beds increase in size south and show no Manson influence (Bohor and Betterton, 1991). In his impact model (Bohor, 1992) identified a melt ejecta layer, with a silicic signature, below a widespread 'fireball' layer carrying a 'basaltic' signature and most of the Ir anomaly, Ni-rich spinels and shocked minerals. In contrast, Shoemaker and Izett (1992) identified two impact layers and proposed earlier Chicxulub (?) and later Manson (?) sources, separated by a period of plant growth. Wolfe (1991) studied palaeobotanical changes in relation to Ir and shocked minerals across a North American K/T section. He suggested an earlier impact in a distant quartz-poor terrain and a second closer impact in quartz-rich terrain, with the botanical evidence suggesting 10-16 weeks between impacts and no evidence for the claimed global wild-fires.

Glassy spherule deposits considered to represent fallout of fused country rocks from the Chicxulub impact have been closely studied at Beloc, Haiti (Izett et al., 1991; Sigurdsson et al., 1992). Although this impact source and timing in relation to spherule deposits was disputed (Lyons and Officer, 1992; Jéhanno et al., 1992), water contents in the glasses resemble those of impact rather than volcanic glasses (Koeberl, 1992). The composition of the Haiti glasses were duplicated in melting experiments which used a mixture of gypsum (hydrated calcium sulphate) and andesite volcanic rock as a mixture representing the continental crust and sulphate-rich evaporite beds found at Chicxulub (Sigurdsson et al., 1992). Chemical links between the Haiti glasses and some glassy melt rocks in the Chicxulub crater were also proposed (Kring and Boyton, 1992). This led to the concept of a severe cooling of the climate and acid rain fallout due to sulphate aerosols injected into the atmosphere after the impact, which contributed to K/T extinctions. However, oxygen isotope studies of the Haitian glasses indicated a mixed impact source of carbonate and silicate rocks and excluded derivation from mixtures of sulfate-rich evaporite and silicate rocks (Blum and Chamberlain, 1992). Other isotopic signatures for the Haiti glasses (U-Th-Pb, Rb-Sr and Sm-Nd) suggest source rocks younger than 400Ma and derived from continental regions younger than 1080Ma (Premo and Izett, 1992).

Other deposits attributed to a large impact in the Mexico Gulf-Caribbean region include tsunami 'tidal wave' deposits and their second generation 'rewash' effects (Florentin et al., 1991; Swinburne, 1993). Some of the Texan deposits, however, may be misinterpreted and not related in time to K/T boundary events

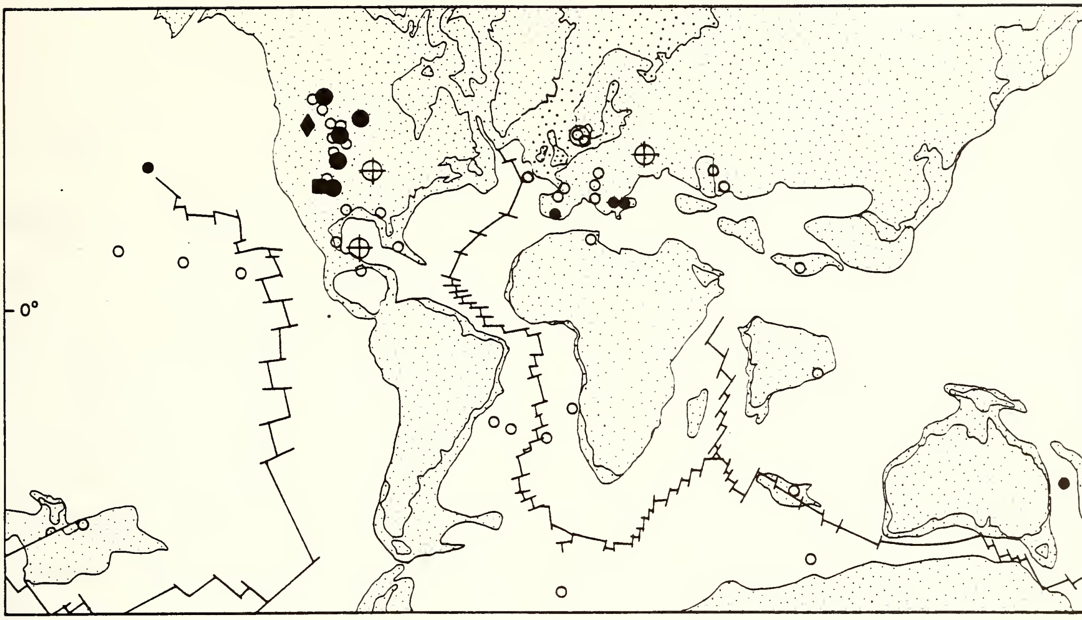

Fig.7. Global distribution of claimed K/T impact features at 65Ma, including iridium anomaly sites (small circles), dated craters (large circles with cross), tektite deposits (tear drops), shocked-quartz sites (small dots for grains up to 1mm, large dots for grains up to 5mm) and high-pressure mineral sites, including stishovite (rectangle) and diamond (diamond). Based on a diagram by Alvarez and Asaro (1990), showing continental crust (stipple) and oceanic crust (clear areas, marked with mid-cean ridges and their off-setting fractures).

(Montgomery et al., 1992) and proposed coarse impact deposits in Cuba are actually weathered, coarse underwater slide deposits (megaturbidities) (Iturralde-Vinent, 1992).

THE VOLCANIC SCENARIO (Fig.8)

This scenario emphasises major volcanic outbursts at K/T time as being capable of producing features such as enrichments in PGE (Ir anomaly) and other, non-meteoritic, elements. Shocked minerals are explained by high pressures developed by explosive detonation in confined magma chambers at depth which can yield pressures of over 50k bars (Rice, 1990b). Climatic effects arise from discharge of major dust, CO_2 and aerosols into the atmosphere as observed in recorded eruptions, but past eruptions a magnitude larger in size are required to produce major global effects (Sigurdsson, 1990). Erupted aerosols produce different cooling effects between northern and southern hemispheres (Handler, 1989) and also affect the ozone layer (Arnold et al., 1990). Calculations by Lockley (1990) suggest that Deccan basalt eruptions produced a 10-25% increase in rate of mantle-derived volcanic CO_2 output. Since this event, however, atmospheric carbon dioxide levels have largely dwindled from early in Palaeocene time (Berner, 1990).

Eruptive events of sufficient size to produce the K/T boundary features require strong thermal plumes termed starting plumes to rise from the core-mantle boundary and then flatten below the lithosphere to mushroom into extended plume heads (Richards et al., 1989; Javoy and Courtillot, 1990; Campbell and Griffiths, 1990; Griffiths and Campbell, 1990). These plume heads entrain large parts of the upper mantle and even of the lower crust to form broad regions of melting and volcanism up to 2,000km across and in this way can erupt lavas of mixed source characteristics. As these starting plumes originate from mantle regions they can provide lavas enriched in PGE, but a critical aspect is whether concentrations of these elements, such as Ir, are enough to meet K/T anomaly levels. Studies of Ir discharging during eruptions in Hawaii show that only 1-12% of the Ir content in the erupting lavas escapes in fumes, whereas over 80% of Ir escape is needed to account for K/T levels based on typical Deccan basalt Ir values (Finnegan et al., 1990). This Ir shortfall, however, may be reduced by several provisos including:

(a) more primitive basalts, more enriched in PGE levels, accompanied the initial starting plume phase of Deccan volcanism;

(b) large volumes of basalts have been eroded from the Deccan sequence since its eruption;

(c) other starting plumes and hotspots made significant contributions at K/T time.

Proviso (a)

The Deccan sequence includes highly magnesian picritic basalts (14-22wt% MgO), which show distinctly different trace element patterns to typical Deccan basalts and are considered to form by higher temperature melting within the plume (Campbell and Griffiths, 1992). A representative picrite with MgO 15wt% contains 650ppm Ni and 1500ppm Cr (Krishnamurthy and Cox, 1977) and the Cr/Ni ratio (2.3) is closer to Cr/Ni ratios in the Spanish Cravaca K/T layer, rather than the chondritic ratios of meteorites (Vannucci et al., 1990). The Deccan picrites, however, are not abundant.

Proviso (b)

The Deccan sequence was initially much more extensive as 65Ma basalt flows and intrusives are present within rifts in eastern India (Mishra et al., 1989) and up to 5.5km of the basalt section may have eroded due to flexural rebound (Watts and Cox, 1989). As the present Deccan section is over 2km thick, this gives a maximum factor of 3 to 4 times the assumed Ir content from remaining Deccan basalts. This is probably an overestimate as most of the picritic basalts of likely higher Ir content appear near the base of the sequence. Thus, the Deccan basalts are unlikely to provide more than 25% of K/T boundary Ir levels at best, assuming an average Hawaiian Ir escape from lava of 6-7%. The actual proportion was probably significantly less as the Deccan sequence presumably thinned away from the axial hotspot trace (Campbell and Griffiths, 1990).

Proviso (c)

The foregoing suggest that considerable

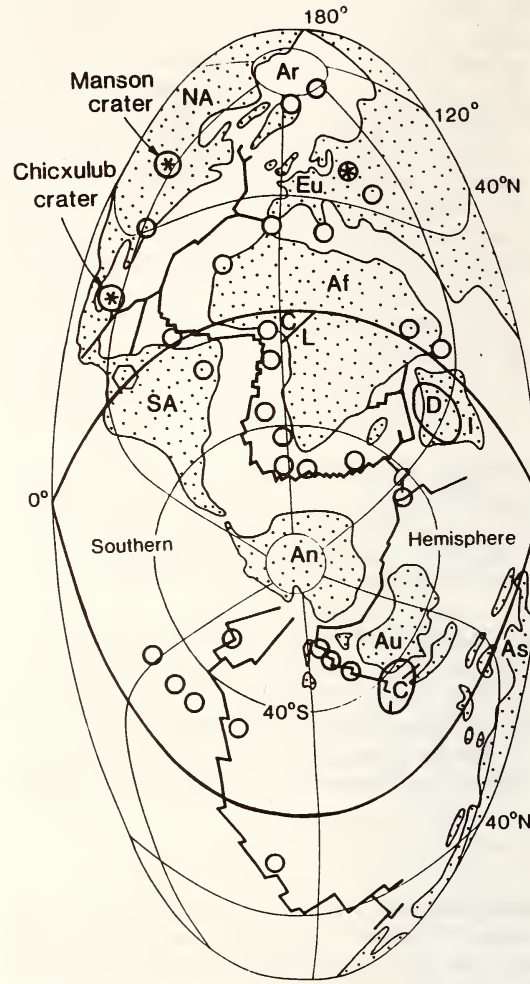

Fig.8. Global distribution of K/T hotspots (open circles), hotlines (lettered lines) and starting plumes (lettered large circles), using a southern-hemisphere centred projection (Weijermars, 1989). The hotspots distribution is shown in relation to dated K/T craters (circles with star). D Deccan plume, C Coral Sea plume, C/L Cameroon Line. Present continental regions (stippled areas) and the K/T ocean-ridge and fault systems (lines) are shown for reference. An Antarctica, Au Australia, As Asia, I India, Af Africa, SA South America, NA North America, Eu Europe, Ar, Artica. Colombian emeralds? (hexagon).

contributions from other potential starting plumes and active hotspots are required to make up K/T Ir levels. The possibilities are examined separately within each hemisphere, to consider the claim for a greater basaltic component in southern K/T sections (Tredoux et al., 1989).

Southern hemisphere K/T activity

Besides the Deccan plume, other extended regions of volcanism were initiated around K/T time. The Cameroon volcanic line became active and may reflect melting of lithosphere modified much earlier by the St. Helena hotspot (Halliday et al., 1990). However, the initial eruptive centres were sparsely spaced and high resolution seismic tomography suggests that the volcanic line may mark a lithospheric crack over widespread hot upper mantle rather than a confined deep mantle plume source (Anderson, D.L. et al., 1992). There is however some argument as to the true depth of mantle thermal features which are derived from the seismic tomographic expressions, and these modifications may indicate greater depths for the hotter regions (Su et al., 1992).

The Coral Sea-North Tasman Sea rift system off northeast Australia opened suddenly across a region of 1500-2000km and initiated oceanic spreading between 64-55Ma (Veevers and Li, 1991). The event was proposed as a major hotspot site for creating the volcanic chains which progress southwards in time along the east Australian-Tasman margin (Sutherland, 1983). This connection was not clear on absolute motion calculations for Australia's Cainozoic movement (Duncan and McDougall, 1989), but these calculated tracks do not match observed trends and ages in volcanic chains older than 35Ma (Sutherland, 1991; Sutherland et al., 1991; Jenkins et al., 1992). The proposed Coral Sea plume (Fig.9) approaches diameters of starting plumes (Campbell and Griffiths, 1990). The present hotspot position near Tasmania lies over hot mantle extending down over 410km (Anderson, D.L. et al., 1992). The continental margins within the proposed plume area contain numerous late Cretaceous/early Tertiary volcanic and intrusive fields (Dickens and Malone, 1973), some of which are dated around K/T time (65±1Ma; Scheibner et al., 1991; Robertson and Sutherland, 1992; Robertson, 1993). The Coral Sea structure is partly dismembered by later tectonic events (Scheibner et al., 1991), and parts may lie in the Philippine basin after migration from the Coral Sea region and subsequent rotation in the last 60Ma (Hickey-Vargas, 1991). The extent of volcanism

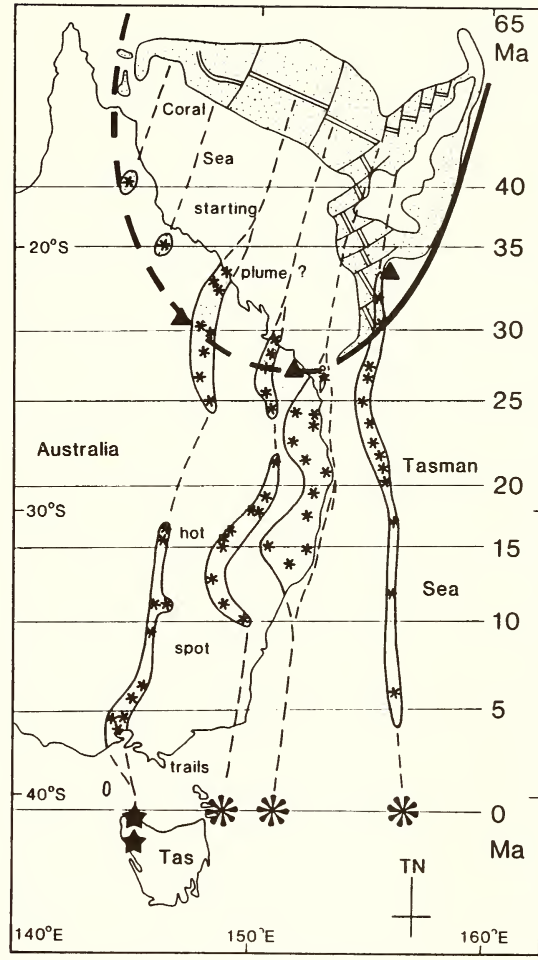

Fig.9. Proposed Coral Sea-North Tasman starting plume (65Ma) containing areas of 64-55Ma sea floor spreading (stippled zones with mid-ocean ridge and fault systems), bounded by limit of activity (thick, dashed curve) and mayor fault (thick line). Associated 64±1Ma volcanic activity (solid triangles). Later hotspot trails are shown by zones enclosing migratory volcanoes (asterisks), with age-progression marked by age lines in Ma. The present hotspot line (0Ma) is marked by seismic zones (stars) and volcanic gas discharges (large asterisks).

associated with Coral Sea-North Tasman structure will need further evaluation.

Many present hotspots were active at K/T time, some being in vigorous discharge e.g. Walvis Ridge

(Huffman et al., 1990; O'Connor and le Roex, 1992). The Austral-Society, Sala y Gomez and Easter Island hotspots occupied a region of long-standing thermal and geochemical anomaly (Staudigel et al., 1991), but these were typically weak plumes (Woodhead, 1992). The Louisville hotspot chain dates back to 65Ma (Lonsdale, 1988) but its position against an active subduction zone is equivocal and may mark a pre-existing rather than a starting plume. The Indian and Southern Oceans contain many plume traces extending beyond K/T time e.g. Kerguelen-Indian plume trace (Davies et al., 1989) and Tasman-Antarctic plume traces (Sutherland, 1989, 1991). All told, over 22 hotspots, hotlines and starting plumes contributed mantle-derived eruptives from the southern K/T zone.

Northern hemisphere K/T activity

Two main hotspots include the Emperor chain in the Pacific (Clague and Dalrymple, 1987) and possibly the North Atlantic-Greenland plume (Hill, 1991), now the Hawaiian and Iceland hotspots respectively. The Emperor activity at Suiko Seamount formed a large complex of coalesced volcanoes at 27°N, some 7° north of the present Hawaiian hotspot, but represented an extant rather than a starting plume. Recent studies have identified high magnesian basalts (15-17wt%MgO) amongst Hawaiian lavas (Clague et al., 1991; Chen, 1993). Such primary melts have potential for increased delivery of PGE, above the Ir and Os levels of aerosols erupted from more typical Hawaiian basalt activity (Krähenbühl et al., 1992). The Hawaiian plume also shows surges in its past production (Davies, 1992), so that past PGE discharge may also exceed the present Hawaiian flux.

The Greenland plume is equated with major North Atlantic doming and uplift at 65±5Ma prior to rifting and extensive volcanism after 63Ma (White and McKenzie, 1989; Hill, 1991; Lewis et al., 1992). A proposed starting plume generated melts over an area 2,500km in diameter and passed southwards where 58Ma syenite of hotspot character is intruded near Kaerven (Holm and Praegel, 1988) and massive volcanism and spreading took place 200kms further south (White, 1993). The K/T plume position may be marked by intense alkali dolerite dyke injection and bimodal basaltic and alkaline volcanism (64±3Ma) in northern Greenland (Kap Washington Volcanics) (Brown et al., 1987). Later West Greenland-Baffin Island basalts include very primitive magnesian lavas (up to 22wt% MgO) formed by melting of mantle incorporated within the plume head (Robillard et al.,

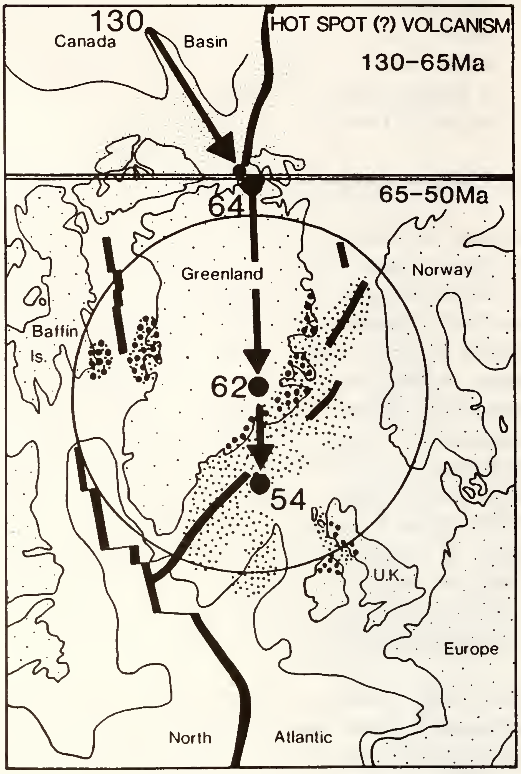

Fig.10. Evolution of the Greenland hotspot through Cretaceous-Early Tertiary time. Cretaceous volcanism (light stipple) and 65Ma hotspot position (small solid circle). Early Tertiary volcanic episodes (stronger stippled areas) and their hotspot positions (large solid circles) with ages marked in Ma. Hotspot tracks (arrows) and ocean-ridges and rifts (thick lines).

1992; Holm et al., 1993). Interpretation of the Greenland plume as a starting plume (Hill, 1991) would increase potential for PGE delivery and mantle degassing at K/T time. However, Canadian Arctic Archipelago basaltic and felsic activity extended from 150 to 70Ma and may mark the passage of a mantle plume along Alpha Ridge within the Canada Basin (Embry and Osadetz, 1988). In this interpretation, the Greenland activity was not a starting plume but an already long-lived plume (Fig.10). The later burst in plume activity either marks an upsurge in plume flux or a thermal build up as the plume passed under the thick continental crust of Greenland. In this reconstruction, volcanic contributions to the K/T boundary were probably insubstantial.

In summary, northern hemisphere K/T hotspot volcanism includes at least 12 centres, with Suiko and Greenland being prominent, but none were starting plumes. The activity provides little more than half the southern hemisphere activity. The Ir donation to the K/T boundary would be even less.

DISCUSSION

Australian science has made little direct contribution to the K/T boundary debate. This stems largely from the paucity of well preserved K/T sections. Finds of late Cretaceous dinosaurs and related groups are almost non-existent apart from rare pterosaur fragments (Long, 1990). Mid-Cretaceous dinosaur remains, however, show that some of Australia's dinosaurs include species hardened to living in near-polar environments (Rich and Rich, 1989; Rich and Rich, 1991; Anderson, 1993). Shocked quartz is recorded in K/T sediments in the northern Tasman Sea Basin east of Australia (Alvarez and Asaro, 1990). but within the continental regions the K/T boundary is less clear, as major seismic unconformities often appear at the top of Cretaceous sections, e.g. Bass, Gippsland and Otway Basins (Baillie and contributors, 1989). Impact craters in Australia, include some Cretaceous features, e.g. Gosses Bluff, but none are dated near the K/T boundary (Grieve, 1991). The late Precambrian Lake Acraman structure in South Australia, nevertheless, is important in demonstrating that anomalously high cosmogenic siderophile elements (including PGE elements such as Ir) are associated with the impact ejecta horizon (Gostin et al., 1989).

The lack of close involvement of Australian workers on the K/T boundary event may assist in a more objective view of the complex scientific claims. This was brought home during the Meteoritical Society Meeting in Perth, Western Australia when the present author proposed both impact and volcanism had contributed to K/T extinctions (Sutherland, 1990). The overseas chairman and speakers in the K/T session were expectedly of the meteorite impact persuasion. In a tightly timed programme for the meeting, the impact school enthusiasts over-ran their presentations. Unfortunately it was felt there was lack of balance between the two schools of opinion.

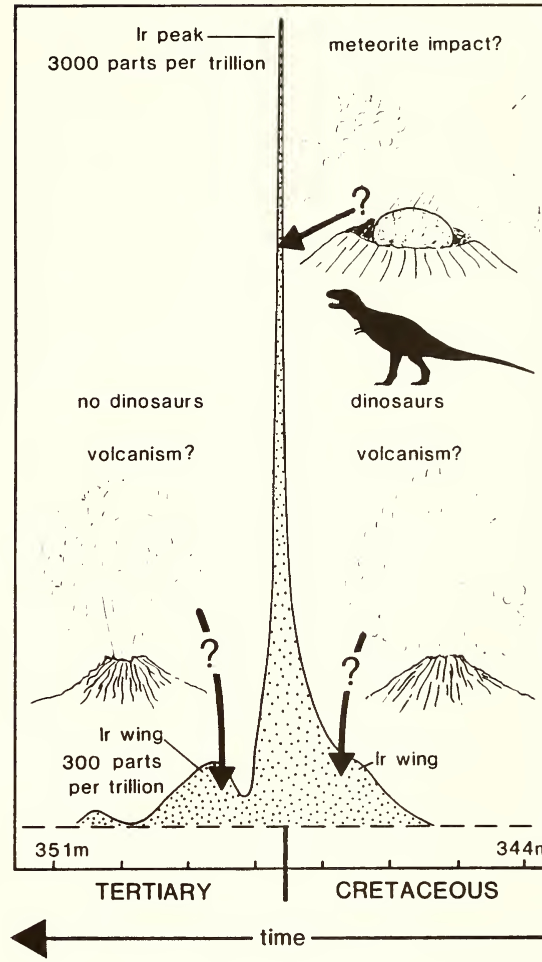

Fig.11. Proposed distribution of volcanic and impact-derived iridium in the K/T boundary anomaly.

Balancing the K/T iridium budget

Assuming that both impact and volcanism contribute Ir to the K/T layers, the most likely distribution for Ir in a northern hemisphere anomaly profile (Italy) is for impact Ir to form the sharp peak and volcanic Ir to compose the lower level wings observed by Rocchia et al., (1990). The wings extend several metres each side of the K/T peak, exceed a time interval of 500,000 years and make up some 20% of the total K/T boundary Ir flux. Such a percentage can be compared with volcanic to impact Ir, although Ir distribution across the boundary is very complex on a fine scale (Alvarez et al., 1990).

Previous considerations assigned significantly under 25% of K/T boundary Ir to potential output from Deccan volcanism. No other starting plumes of comparable dimensions appear in the K/T hotspot inventory, so that Ir contributions from the Coral Sea, Cameroon and 30 or so lesser hotspots probably all together would not exceed the Deccan flux. Thus, volcanic Ir probably remains well under 50% of the K/T Ir deposition. If further weighting is made for nearly two thirds of the hotspot activity being in the southern hemisphere, then a 20% volcanic Ir component in a European K/T Ir budget seems a reasonable first estimate (Fig.11).

Other K/T contributors?

Of the two main impact craters correlated with K/T time, the Chicxulub impact would give the overwhelming proportion of Ir compared to the Manson impact. Additional impacts also may contribute as some craters smaller than the Manson crater are dated around 65Ma in Russia (Kamousk and Gusev craters) (Grieve, 1991). A few K/T sections also hint at an oceanic impact in the Caribbean-Colombia Basin area, although continental mineral grains dominate the K/T sedimentary boundaries (Fig. 7) and signatures (Sharpton et al., 1990).

Fig.12. Colombian emerald with calcite in matrix. Australian Museum Specimen, D 3149. Photographed by Gregory Millen.

Colombian emeralds (Fig.12) seem far removed from the K/T boundary story, but dating of this green gem variety of the mineral beryl now gives these gemstones a formational age (61±5Ma) within an error range of K/T time (strontium-rubidium isotope dating; Vidal et al., 1992). The emeralds are mined from Cretaceous shales and limestones and form in calcite-rich veins (Ringsrud, 1986). These veins emanated from layers of strongly heated 'ash' and were originally injected under pressure as hot briny solutions invaded the strongly folded and fractured rocks following their deformation (Ottaway and Kenny, 1989). Most geologists attribute this emerald mineralisation to a relatively young hydrothermal event (last 5-10Ma) which was associated with the later development of the Andean foldbelt. However, the near-Cretaceous emerald age, in conjunction with original vein fluid temperatures of up to 600°C and an origin of the emerald constituents (beryllium, chromium and water) from marine beds originally at depths of over 5000 metres, requires further explanations than are provided by the hydrothermal postulates (Bosshart, 1991). The possibility of a nearby impact or of volcanism contributing to the special thermal and source conditions for the unique Colombian emerald deposits may be worth investigation.

The general scene

The distribution of known K/T impacts and hotspot volcanoes shows a bias towards northern impacts and southern volcanism (Fig.8). The particular projection used here centres on the southern hemisphere (Weijermars, 1989) and is ideal for showing the volcanic hotspot distribution. Both impact and volcanism will reinforce radiation screening by dust clouds and aerosols to give consequent cooling. Both events can also generate acid rains. Additions to atmospheric CO_2 will produce subsequent 'greenhouse' conditions capable of creating reproductive stress in organisms. The exact global response depends on the lithological or oceanic make up of the impact sites and on the volatiles discharged by volcanoes (O'Keefe and Ahrens, 1989; Sigurdsson, 1990; Arnold et al., 1990; Lockley, 1990; Rice, 1990a; Luhr, 1991; Sigurdsson et al., 1992; Brasseur and Granier, 1992). Global climatic effects also depend on distribution of land and oceanic masses (Handler, 1989). However, a similar uneven land/ocean disposition existed at K/T time (Weijermars, 1989). Thus, in a dual catastrophic scenario, many complex factors will affect K/T boundary features and could produce geochemical variations such as those noted by Tredoux et al. (1989).

The combined impact and volcanic effects would interact most directly with terrestrial and shallow water organisms, rather than with more sheltered benthic biota. This is generally reflected in the K/T extinction pattern which contrasts with a large benthic extinction caused by deep-sea warming in the early Tertiary which hardly affected the shallow water ecosystems (Kennett and Stott, 1991). Some workers would consider coincidence of major impact and large scale plume volcanism improbable and to represent an 'overkill' proposal for the K/T extinctions. However, Hsü (1989) stresses that in the immensity of geological time the improbable is inevitable in relation to catastrophic extinctions. Dual meteoritic impact and plume volcanism, however, is not necessarily essential to produce major extinctions. Present evidence suggests that the largest recorded extinction at the Permian/Triassic boundary was correlated with a larger plume event than for the Deccan basalts, i.e. the more explosive and voluminous Siberian basalts (Renne and Basu, 1991; Sharma et al., 1991; Campbell et al., 1992).

Concluding notes

Some studies claim that links exist between global extinctions, tectonic changes and planetesimal impacts (Rampino and Calderia, 1993). Thus, detailed debates on K/T boundary events are important for assessing future probabilities for both extraterrestrial and terrestrial catastrophes within the human and evolutionary framework. Earth-approaching asteroids are under surveillance (Skwatch Telescope) and to this end a near-miss is already recorded (Scotti et al., 1991). Methods to counter the threat of Earth-crossing asteroids by deflection and fragmentation are under examination (Ahrens and Harris, 1992). The main K/T crater-producing impactor was unlikely to be a comet or carbonaceous asteroid based on the arguments of Chyba et al. (1993) for the 1908 Tunguska explosion. However, the presence of extraterrestrial amino acids at the K/T boundary may suggest an abnormally large carbonaceous asteroid was involved.

The demise of the dinosaurs may not only mark a complex catastrophic event but their initial evolutionary expansion may also spring from an earlier combined impact/volcanic event in the late Triassic (Dietz, 1986; Lucas, 1990). The dinosaurs, now vanished 65Ma ago, live on in the popular mind with dinosaurs featuring on the cover of two issues of Time magazine (May 6th 1985 and April 26th 1993) and in books which bring them back into the human realm (Crichton, 1991; Gurney, 1992).

Since the time of Charles Darwin's quote on geology, which began this address, there have been wholesale advances in knowledge and technology in the earth sciences and their related fields. In the K/T controversy, these advances have been focused on the events which brought down the dinosaurs. It seems appropriate to amend Darwin's view into present day context as follows:

"Geology is a complex science, as it requires a world of study, much reading and multi-disciplinary interaction and the engagement of highly sophisticated equipment in its ultimate pursuit".

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Trace Elements in Some Swiss Coals

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ABSTRACT

Twenty four samples of Swiss coals and coaly material (lignite, brown, anthracitic) ranging in age from Carboniferous to Quaternary have been analysed for their trace-element contents. The values obtained for the Swiss coals are compared with those for coals from Australia and the U.S.A. In general, there is good agreement between all these values and those for most world coals, although some of the Swiss coals have higher concentrations of molybdenum, selenium, thallium, uranium and vanadium.

Key words: Swiss coal, trace elements.

INTRODUCTION

Apart from a study of rare earth elements (Fardy et al, 1987), there are no reported investigations of trace elements in Swiss coals. In view of the need to extend knowledge of trace elements in coals from unusual deposits, samples of coal and coaly material from several parts of Switzerland were analysed for trace elements by atomic emission spectrography, atomic absorption spectroscopy and neutron activation analysis. The samples have been taken from coal deposits of different ages (Quaternary, Tertiary, Mesozoic, Carboniferous). The samples were lignitic, brown or anthracitic and most are from coal mines in production during 1939 to 1945 (Bureau für Bergbau, 1947). The type of coal was assessed on the basis of available chemical information for coal from the same areas (Kündig and de Quervain, 1953). Some information about the samples is given in Table 1 and the locations are shown in Figure 1.

METHODS OF ANALYSIS

Atomic emission spectrographic analysis was carried out on sub-samples that had been ashed at 450°C, except for samples 20, 21, 22 and 23 which required ashing at 820°C. Two techniques were used, namely, a total burn method that covers a wide range of elements, and a selective volatilisation method, which is especially sensitive for volatile elements. The total burn method is similar to that used for Australian coals (Clark and Swaine, 1962; Brown and Swaine, 1964) in which the coal ash is mixed with pure graphite powder and tamped into a graphite electrode. Arcing is carried out using a carbon cathode in a 10 amp DC arc for 2 min 30 sec to 2 min 50 sec, i.e., until the burn is complete. Spectra are taken on Kodak Spectrum Analysis Plate No. 1 and are compared visually against standard spectra in a Judd-Lewis Comparator. The selective volatilisation method is based on that of Tennant (1967), which uses coal ash mixed with a buffer mixture (Al_2O_3 + $CaCO_3$ + K_2CO_3) and tamped into a graphite electrode. Arcing is carried out using a carbon cathode in a 14.5 amp DC arc for 40 sec.

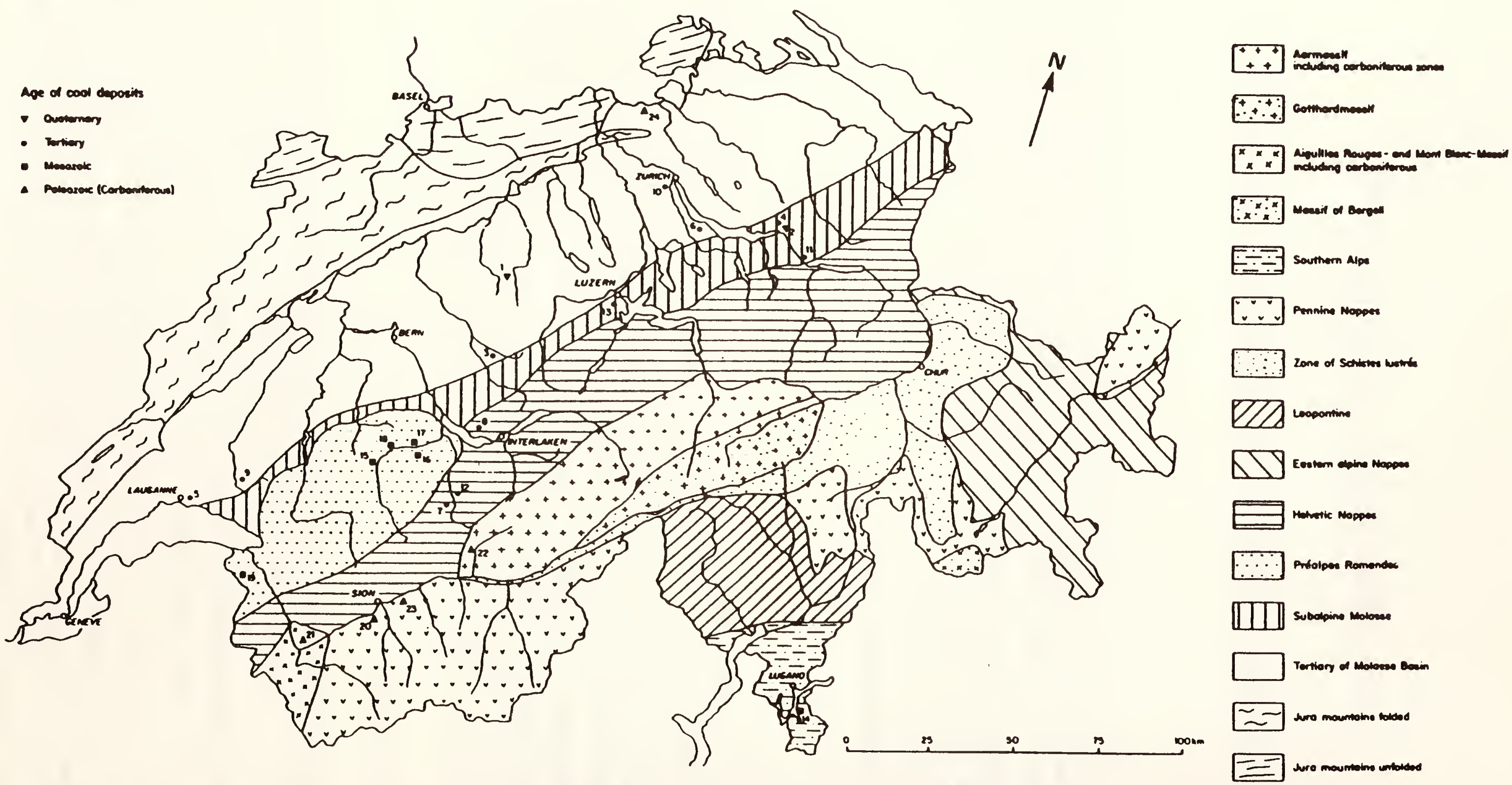

Figure 1. Map showing locations of coal samples.

TABLE 1
LOCALITY, ASH YIELD, AGE AND RANK OF COAL SAMPLES

Sample No.	Locality	% Ash Yield	Age	Rank
1	Gondiswil-Zell (BE)	58.2	Quaternary	L
2	Uznach (SG)	19.9		L
3	Blapbach (BE)	6.1	Tertiary	B
4	Echeltschwil (SG)	11.5		B
5	Flonzel (VD)	8.8		B
6	Gottshalden (ZH)	34.0		B
7	Kandergrund-Horn (BE)	24.1		B
8	Niederhorn (BE)	23.1		B
9	Oron (VD)	4.8		B
10	Riedhof (ZH)	72.2		B
11	Rufi (SG)	40.1		B
12	Schlafegg (BE)	65.4		B
13	Sonnenberg (LU)	8.4		B
14	Arogno (TI)	18.6	Mesozoic	B
15	Boltigen (BE)	6.9		B
16	Diemtigen (BE)	24.0		B
17	Erlenbach (BE)	62.3		B
18	Oberwil (BE)	84.1		B
19	Vouvry (VS)	28.6		B
20	Chandoline (VS)	39.1	Palaeozoic (Carboniferous)	A
21	Dorénaz (VS)	16.2		A
22	Ferden (VS)	19.1		A
23	Grône (VS)	90.8		A
24	Weiach (ZH), Nagra-Drilling	9.0		A

Note: L = lignite, B = brown coal, A = anthracite

Two methods of atomic absorption spectrometry (AAS) were used, namely flame AAS and graphite-furnace AAS, the latter being necessary for some trace elements present in very low concentrations. The AAS instrument used for this work is a Perkin-Elmer 4000 atomic absorption spectrophotometer with an auto sampler and a graphite furnace facility (HGA-500).

For the determination of cadmium, copper, iron, lead, manganese and zinc, a sub-sample of coal was ashed at 500°C and the ash treated sequentially with hydrofluoric, nitric and perchloric acids in a PTFE crucible or with aqua regia and hydrofluoric acid in a closed polypropylene bottle, which was heated on a boiling-water bath for 2 h. Fluoride was complexed with boric acid and the resulting solution was used for the determinations by AAS or graphite-furnace AAS. The method is based on ASTM (1978). Previous experience with cadmium had shown that the AAS-graphite furnace method is viable to 0.01 ppm Cd in coal (Godbeer and Swaine, 1979).

For the determination of arsenic and antimony 1 g of coal was ashed in a platinum crucible with magnesium nitrate (ashing aid) and nickel nitrate (volatilisation suppressant) for about 14 h. The ash was treated with a mixture of nitric and hydrofluoric acids and finally with nitric acid alone to give 50 ml of approximately 5% HNO_3 in the final solution in which arsenic and antimony were determined. This method is based on Haynes (1978) and Riley (1982, 1984).

Details of the methods used for neutron activation analysis are given in Carr and Fardy (1984). The sample of coal (20-80 mg for short irradiations and 100-200 mg for long irradiations) was weighed into a cleaned (nitric acid, demineralised water, A.R. ethanol, air-dried) polyethylene vial. Two irradiations were carried out, namely a short-period one using the X-176® tube and a long-eriod one using the X-6® tube of HIFAR which is a 10-MW DIDO® type reactor system situated at the Lucas Heights Research Laboratory. The thermal neutron fluxes were 5×10^{13} and 5×10^{12} $ncm^{-2}s^{-1}$ respectively. After the irradiations of the samples, the radionuclides formed from the trace elements were measured by Ge(Li) gamma-ray spectrometry. The concentrations of the trace elements were determined by suitable computing procedures.

Methods of analysis for trace elements in coals have been reviewed by Swaine (1985, 1990).

TABLE 2
TRACE ELEMENTS IN QUATERNARY SWISS COALS (ppm in dry coal)

	1	2		1	2
Ag	0.06	0.04	Ni	40	15
As	4.3	25	P	500	500
Au		<0.002	Pb	9.8	2.3
B	60	25	Sb	1.2	0.3
Ba	327	142	Sc	7.9	2.5
Be	2	0.6	Se	0.93	
Br	12	23	Sn	3	1
Cd	0.23	0.072	Sr	138	94
Cl	<74	125	Ta	0.59	0.22
Co	7.6	1.7	Th	8.0	2.7
Cr	75	17	Ti	2580	520
Cs	3.7	1.6	Tl	<2	<0.6
Cu	23	8	U	5.2	1.6
Ga	12	2.9	V	62	16
Ge	1	0.2	W	1.3	<2
Hf	2.7	0.82	Y	30	10
Ir	<0.003	<0.001	Zn	84	10
Mn	276	144	Zr	100	30
Mo	1	2			

COMPARISONS OF TRACE-ELEMENT CONTENTS OF THE SWISS COALS WITH THOSE FOR MOST COALS FROM AUSTRALIA AND THE U.S.A.

Results for trace-element contents for the Swiss coals are given in Tables 2-5 and the relevant data for Australian and U.S.A. coals are given in Table 6. All values for the Quaternary coals are within the ranges for the U.S.A. coals, although arsenic in sample 2 is higher than usually found in Australian coals. Some of the Tertiary samples had relatively high contents of some trace-elements, for example, arsenic in samples 3 and 4, chromium in samples 6 and 10, germanium in sample 9, molybdenum in samples 4, 6, 9, 10, 11 and 13, selenium in samples 4 and 10, strontium in samples 5, 6, 7 and 12, uranium in samples 3, 6, 10 and 13 and vanadium in samples 6 and 10. It should be noted that samples 10 and 12 have high ash yields and are not directly comparable with the coals (<40 per cent ash yield). Of the Mesozoic coals, sample 14 is relatively high in arsenic, cadmium, molybdenum, thallium, uranium and vanadium. There are some values for samples 17 and 18 that exceed those found for Australian and U.S.A. coals, but these samples have high ash yields and cannot be compared directly with other coals where the ash yields are less than about 40 per cent. Sample 24 of the Carboniferous coals is relatively high in bromine, chlorine, vanadium and tungsten. Apart from the exceptions listed above, the Swiss coals have trace-element contents, that fall mostly within the ranges for Australian and U.S.A. coals (Table 6). In general, Australian coals with a mean value of about 2 ppm As are lower in arsenic than coals from most other areas (Swaine, 1983).

MODE OF OCCURRENCE OF TRACE ELEMENTS IN COAL

In general, trace elements occur in coals associated with the organic matter and with the mineral matter (Swaine, 1967), sometimes as specific minerals and also as minor replacement cations in minerals. For example, manganese occurs as a replacement for iron in siderite and for calcium in calcite (Swaine, 1986). Several trace elements occur as sulfides, for example, copper, molybdenum, nickel, lead, zinc or associated with sulfides, commonly pyrite, for example, arsenic, cobalt, mercury, selenium (Swaine, 1984). Cadmium has been found in sphalerite where it is partially replacing zinc (Gluskoter and Lindahl, 1973). Other examples of occurrences of discrete minerals are given by Finkelman (1981) and Swaine (1990).

CONCLUDING REMARKS

For most trace elements the ranges of values found for the Swiss coals are within the usual ranges of values for coals from Australia and the U.S.A., and the ranges for 'most coals' proposed by Swaine (1990).

Some samples of brown coal had high contents of molybdenum, selenium, thallium, uranium and vanadium. The high uranium contents of brown-coal samples 3, 6, 13 and 14, namely 37-176, with a mean of 98 ppm U, are much higher than those of the other Swiss coals. The contents of uranium in these coals are high enough for those coals to be unsuitable for combustion. The high bromine and chlorine in sample 24 (anthracitic coal) are unusual and were probably derived from waters entering the swamp during the early stages of coalification or introduced from overlying brackish sediments (Müller et al, 1984, plate I).

Of the elements that occur in the Swiss coals in concentrations above those commonly found elsewhere, molybdenum, selenium and thallium are probably mainly present as a sulfide or associated with a sulfide, normally pyrite. Pyrite and other fine-grained sulfide minerals are quite common in Swiss coals. Vanadium is probably organically bound (Swaine, 1983). The occurrences of uranium has been reviewed by Finkelman (1981) and Bouska (1981). In most coals, especially those of low rank, uranium is probably mainly associated with organic matter. It may also be enriched in irregularly disseminated fine grains, as

TABLE 3
TRACE ELEMENTS IN TERTIARY SWISS COALS (ppm in dry coal)

	3	4	5	6	7	8	9	10	11	12	13
Ag	<0.01	0.02	<0.01	0.07	0.03	0.02	<0.005	0.1	0.04	<0.07	0.05
As	24	39	4.0	6.2	4.0	2.0	3.7	15	9.5	5.8	7.9
Au	0.002	0.003	0.001	0.005			0.001	0.004	0.002		0.003
B	20	70	90	90	20	50	150	90	100	40	70
Ba	225	342	63	612	205	619	114	525	211	134	292
Be	0.6	1	<0.2	2	2	1	0.8	4	1.5	<2	2
Br	0.34	0.81	1.4	1.5	0.5	1.3	4.3	1.2	0.48	1.1	6.9
Cd	0.052	0.065	0.015	0.11	0.57	0.02	0.028	0.34	0.048	0.079	0.056
Cl	<13		57	<40	<25	12	24	<62	<36	<31	17
Co	1.0	2.9	1.5	5.9	1.1	0.19	1.3	21	2.9	0.67	2.9
Cr	3.3	62	3.8	89	15	18	7.2	125	27	6.1	27
Cs	<19	0.69	0.11	3.6	0.26	1.1	0.15	6.4	2.2	0.61	0.21
Cu	4	10	4	15	5	0.5	6	58	31	4	14
Ga	1.2	2.2	0.2	7.8	1.0	1.6	0.8	16	9.6	<0.4	1.9
Ge	5	6	4	2	0.6	20	40	9	0.8	0.7	10
Hf		0.15	0.10	1.1	0.30	2.0	0.055	4.4	0.43	0.24	0.21
Ir	0.012	0.007	0.002	0.042	<0.001	<0.002	0.004	0.062	0.005	<0.001	0.021
Mn	70	38	91	79	52	3	45	153	97	73	56
Mo	10	50	9	70	10	6	30	50	70	8	100
Ni	2	10	10	30	15	3	15	70	40	<2	15
P	30	100	40	1000			70	300	400		70
Pb	0.6	3	0.1	3.4	1	2	0.5	12	4.3	1	3
Sb	0.5	6.2	0.07	1.9	1.0	0.3	0.08	1.5	1.0	1.4	0.5
Sc	0.47	0.77	0.24	5.8	0.80	1.3	0.26	11	2.6	0.52	0.88
Se	0.95	15	0.93	7.8	5.9	6.3	0.85	12	5.1	2.2	1.3
Sn	0.1	0.2	0.09	3	0.5	0.7	0.1	5	1.5	0.7	0.6
Sr	216	408	740	683	1454	237	468	613	240	2158	360
Ta	<0.04	<0.09		0.37	0.060	0.34	<0.022	0.95	0.13	0.074	0.038
Th	0.25	0.63	0.21	5.7	0.92	3.6	0.22	12	2.1	0.66	0.69
Ti	15	80	60	2000	900	1060	40	2350	2000	150	150
Tl	<0.2	3	<0.3	<1	<0.8	2	<0.2	2	2	<2	0.3
U	37	3.3	4.5	139	7.9	4.9	9.2	118	17	1.1	41
V	4.5	50	3.6	106	45	32	3.6	145	80	15	25
W	9.8	3.1	1.5	4.5	<3	0.7	4.2	2.0	<4	<0.7	4.3
Y	5	7	<2	20	10	7	1	20	8	<7	8
Zn	35	38	20	43	19	5.1	14	159	42	16	12
Zr	<6	<15	<9	50	25	150	<5	150	40	26	8

TABLE 4
TRACE ELEMENTS IN MESOZOIC SWISS COALS (ppm in dry coal)

	14	15	16	17	18	19		14	15	16	17	18	19
Ag	0.6	<0.01	0.1	0.1	<0.2	<0.03	Ni	40	2	30	50	150	7
As	42	0.5	3.0	4.2	16	1.3	P	3000		100			100
Au	0.007	<0.001				0.002	Pb	7.0	0.4	7.9	11	17	2
B	40	15	60	500	700	60	Sb	0.5	<0.2	1.1	1.0	0.6	0.12
Ba	173	60	149	313	143	241	Sc	3.3	3.0	8.2	15	17	2.7
Be	4	5	1	3	7	2	Se	5.3		0.76	2.6	3.8	
Br	<8	<2	1.1	<11	<7	1.0	Sn	1	0.6	0.8	4	3	1
Cd	2.4	<0.005	0.27	0.51	0.50	0.037	Sr	117	414	<79	418		223
Cl	<27	66	<24	<45	<42	81	Ta	0.22	0.13	0.22	0.97	1.1	1.2
Co	4.0	0.27	3.0	6.5	53	1.4	Th	2.3	0.69	4.1	10	12	3.7
Cr	20	5.1	23	82	78	14	Ti	1000	450	690	4015	4360	5450
Cs	5.1	<0.08	1.2	9.8	17	0.44	Tl	15	<0.2	0.7	<2	<3	<0.9
Cu	10	2	18	30	22	4	U	176	2.2	8.0	4.4	2.3	3.6
Ga	6.2	3.7	6.3	23	18	2.6	V	330	4.7	96	121	136	22
Ge	10	9	0.7	3	7	15	W	<1	1.0	<2	<6	1.8	2.0
Hf	0.89	0.39	0.66	2.3	3.3	3.3	Y	15	15	30	30	30	30
Ir	0.056	<0.001	<0.002	<0.005	<0.007	<0.003	Zn	80	9.6	47	91	112	29
Mn	15	7	62	57	87	14	Zr	40	15	30	100	100	250
Mo	200	0.9	20	15	4	0.9							

TABLE 5
TRACE ELEMENTS IN CARBONIFEROUS SWISS COALS (ppm in dry coal)

	20	21	22	23	24		20	21	22	23	24
Ag	0.08	0.1	0.6	<0.1	0.1	Ni	25	15	25	50	25
As	5.4	12	17	21	0.7	P	200	150	80	800	300
Au		0.005	0.011		0.003	Pb	17	8.6	51	15	36
B	20	5	10	60	20	Sb	2.2	4.4	2.1	2.6	4.8
Ba	272	42	108	1009	153	Sc	4.3	0.70	0.88	24	8.7
Be	2	0.5	0.4	5	8	Se	1.1	1.4	4.0		0.65
Br	2.0	3.8	3.2	<67	145	Sn	2	0.3	1	7	2
Cd	0.17	0.022	0.040	0.051	0.24	Sr	<51	<26			
Cl	82	149	108		4809	Ta	0.45	0.036	<0.09	1.8	0.22
Co	6.4	3.4	16	18	9.9	Th	5.1	0.52	0.51	21	5.7
Cr	10	4.1	4.7	90	32	Ti	830	250	120	4820	600
Cs	4.6	2.2	1.2	10	4.9	Tl	<2	0.8	0.8	<3	0.5
Cu	12	11	66	23	26	U	1.9	<0.26	0.34	5.8	4.6
Ga	9.0	2.7	2.0	37	9.5	V	35	8.9	11	138	155
Ge	0.4	0.3	0.4	2	7	W	1.8	2.6	3.6	<10	31
Hf	1.1	0.20	0.11	3.8	0.25	Y	10	8	10	70	25
Ir	<0.002	<0.001	<0.002	<0.006	<0.002	Zn	35	2.5	25	104	65
Mn	137	11	234	1270	9	Zr	40	15	<20	150	9
Mo	6	15	15	0.9	10						

TABLE 6
RANGES FOR MOST VALUES OF TRACE ELEMENTS (ppm in dry coal)

	Switzerland anthracitic	Switzerland brown and lignitic	Australia (1,2,3,4)	Australia (5)	U.S.A. (6)
Ag	<0.01-0.1	<0.01-0.07	<0.2-0.6	<2-<4	<0.01-0.17
As	0.5-12	3.7-42	0.2-10	0.3-5	1-70
Au	<0.001-0.011	0.001-0.007	0.001-0.01	<0.002-0.008	
B	5-50	20-100	4-200		1-130
Ba	42-272	63-342	<40-400	27-350	11-190
Be	0.4-5	<0.2-4	<0.4-5		0.7-5.6
Br	0.5-3.8	0.34-6.9	0.06-0.6	4-10	
Cd	<0.005-0.27	0.015-0.11	0.06-0.15		0.02-1.2
Cl	<25-149	<13-57	<100-400	70-800	240-1700
Co	0.27-6.4	1.0-5.9	<0.6-20	2.6-8	1.5-25
Cr	4.1-23	3.3-27	<1.5-20	3.5-10	3.7-47
Cs	<0.08-4.9	0.11-3.6	-2	<0.2-2	0.2-3.5
Cu	0.5-26	4-15	6-30		5-47
Ga	1.0-6.3	0.2-6.2	1.5-7	3.6-8	1.6-12
Ge	0.3-15	0.2-10	1-20		<0.3-13
Hf	0.11-3.3	0.055-1.1	0.9-4.5	1.3-3	0.2-2.2
Ir	<0.003	<0.001-0.056			
Mn	3-234	15-97	4-600	4-150	2.2-110
Mo	0.9-15	2-70	0.3-4	0.5-5	0.3-10
Ni	2-30	2-40	2-50		3.6-75
P	80-200	30-1000	20-2000		2-300
Pb	0.2-36	0.1-4.3	2-40		1.5-44
Sb	<0.2-2.2	0.07-1.9	<0.1-1.3	<0.1-0.6	0.2-4.1
Sc	0.70-4.3	0.24-0.88	<0.3-10	1.7-4.5	1.3-9.7
Se	0.65-6.3	0.85-7.8	0.25-1.6	0.4-2	0.8-12
Sn	0.3-2	0.1-1.5	<1-7		<0.3-1.8
Sr	<26-414	94-468	<20-400	9-130	17-250
Ta	0.036-0.45	<0.022-0.37		0.09-0.3	
Th	0.51-5.7	0.21-2.7	<0.2-6	0.9-5	<3-9
Ti	120-1060	15-1000	500-1600		190-3200
Tl	<0.2-2	<0.2-3	<0.1-1		<0.3-2.2
U	<0.26-8.0	1.6-41	0.4-3.8	0.3-1.5	<0.2-7.1
V	4.7-96	3.6-106	10-60		4.1-77
W	0.7-3.6	<1-4.5	-5	0.5-1.5	
Y	7-30	1-15	2-10		2.2-18
Zn	2.5-47	10-43	13-46	20-35	2.4-170
Zr	9-40	<5-50	15-300		3-61

References: (1) Clark and Swaine (1962); (2) Swaine (1980); (3) Swaine (1985); (4) Swaine, unpublished; (5) Cahill and Mills (1983); (6) Zubovic et al (1980).

may occur in the coal from Blapbach (sample 3). Prospecting for uranium has been carried out in the Blapbach coal area (URAN AG, 1959). The origin of these high contents of molybdenum, uranium, vanadium and some other elements is probably due to inputs from nearby areas with relatively high concentrations of these elements (e.g. from granitic and gneissic pebbles of the surrounding Nagelfluh-formation, a part of the Swiss Plateau).

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UNDERGROUND SPACE: THE GEOSPATIAL PLANNING OPTION FOR 21ST CENTURY SYDNEY

PART ONE: HISTORICAL OVERVIEW AND RATIONALE FOR THE USE OF GEOSPACE

Sydney A. Baggs

ABSTRACT. In the city of Sydney, Australia, urban surface space is becoming congested, and residual open space overshadowed by high-rise development. The use of the subsurface domain is presented as an alternative planning option that is not only energy efficient in resources utilisation but also land-use efficient in its recycling of industrial land for residential, commercial and recreational purposes. A brief history of the use of geospace is presented, the principles of the ground-heat physics involved are explained and a geopolitan planning concept for the development of urban and suburban Sydney in the next century is outlined.

INTRODUCTION

A recent demographic survey of population growth-rate in Australia reported that there was an overall concentration along Australia's eastern coast between Noosa, Queensland, and Batemans Bay in New South Wales. SE Asia, the Eastern Block and Mediterranean countries are generating additional immigrants. While the whole world watches sea-levels rise, it will morally expect neighbouring countries possibly to accept entire populations from inundated islands. These unforeseen causal events produce the effect of steepening the projected Australian population growth-curve for the next century.

Constrained by the scarps of the Great Divide and retreating sea coasts, the eastern seaboard of New South Wales has only a limited amount of land surface available for development. Options must be found to optimise land space without jeopardising an appropriate balance between development and the natural environment.

Under pressures such as these, together with rising surface land costs, the use of subsurface space—geospace—is an alternative strategy that should be considered by all planning departments up to government level, if a megalopolis type of development with its deteriorating standards of living and escalation of land costs is to be prevented.

The City of Sydney in 50 Years Time

In 1990, the then Lord Mayor of Sydney, Jeremy Bingham, predicted the expansion of pedestrian precincts and walks, the undergrounding of the Circular Quay railway and the Cahill Expressway, as well as the restoration of George Street as a promenade with 19th-century dignity. Central railway station would be moved to Everleigh, while the Central railway and Broadway precincts would become the 'intellectual hub' of the city. The Town Hall, Sydney Square and Queen Victoria Building would remain, and the theatre area in George Street would be upgraded. Opposite Sydney Square, a new city square would be developed on the old Woolworth site (as part of the new transit/commercial tunnel to be constructed under the city, linking Darling Harbour to William Street). Underground pedestrian ways would link Town Hall to Martin Place, Wynyard Railway station would be linked to an underground bus-rail interchange and a mall system (Figure 1). (Such proposals as the latter, some of which are underway, utilise the zone of shallow geospace discussed below.) Yet geospatial planning presents a much more important potential strategy for development than is represented in its present piecemeal use in the City of Sydney.

In the Sydney Morning Herald of May 29, 1993 Geraldine O'Brien reported the city planner John McInerney as saying that the new, recently gazetted planning policy will control 'the way buildings affect people on the street and their environment, rather than judging them by floor space ratios which didn't contribute to the quality of street life'. Environmental principles and urban design will be more important than floor space ratios which have been set at 12.5:1 maximum compared with the previous 1971 maximum of 15:1 (gross floor area to site area). Urban design and heritage

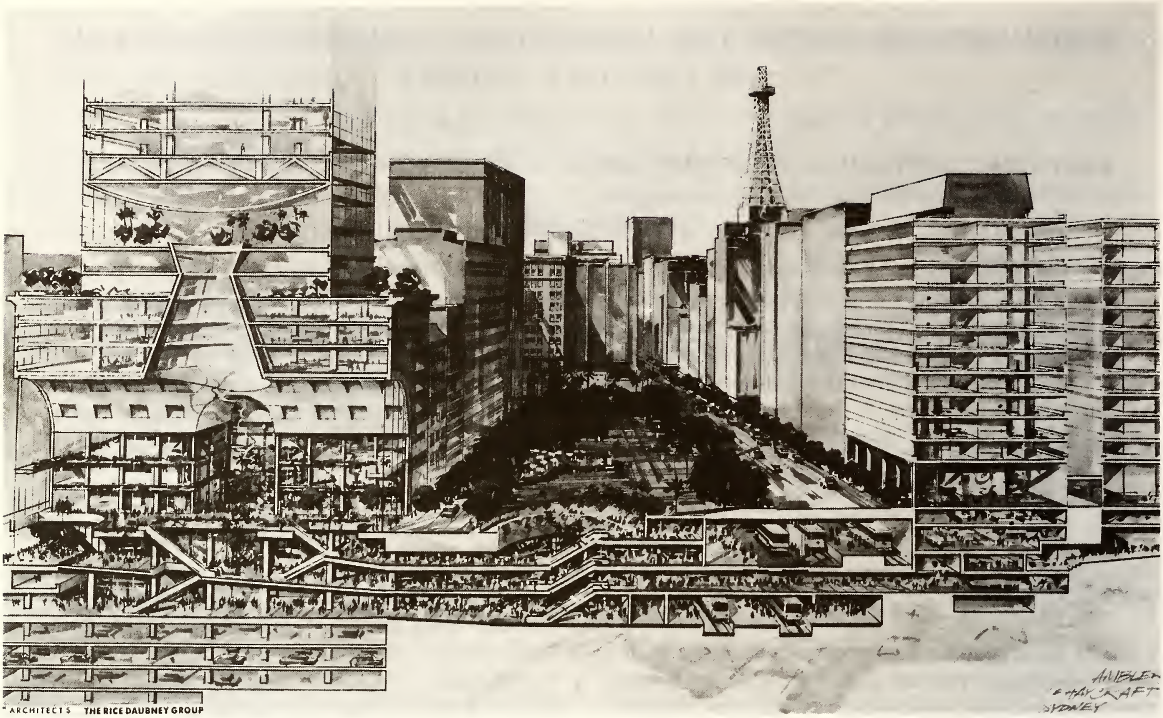


Figure 1:
Kern Corporation Ltd redevelopment proposal for the Wynyard precinct. (Courtesy: The Kern Corporation Ltd)

conservation controls will override floor space ratio limits and particular attention will be given to parklands and civic gardens.

In the future, transport would probably comprise private vehicles when so-called 'smart' cars are introduced that would permit drivers to be computer-guided to avoid traffic congestion. Bingham's 1990 prediction seems to be still correct. He said that cars would be unnecessary in the city as rapid transit systems would bring people into the city from peripheral underground parking stations. In the city, non-polluting buses and taxis would be battery-operated, and most deliveries would be made underground through connecting building basements.

At least 3 more airports would be needed in present tourist trends were to be extrapolated for the next 50 years. Vertical-take-off-landing (VTOL) aircraft will be used to avoid airports. Helipads will be atop many buildings. The under-harbour tunnel from North Sydney to the Eastern suburbs is underway, and a proposal has been made for an underground rail link between the airport and the Central Business District (CBD).

The high densities accompanying such development will be serviced by the present unpleasant patchwork growth of freeways and fly-overs until traffic congests to such an extent that some form of public-transport 'retrofit' will be needed on a grand scale.

However, the problem of the heat-island effect created by masses of heat absorbing walls and roofs and heat-reflecting window walls will continue to compound (Geiger, 1966).

Is There an Alternative?

There is an alternative scenario to the above. It is one that emphasises the use of underground space—geospace—buildings within the earth, geotecture (from *geo*: (Gk) 'Earth' and *tekton*: (Gk) 'builder').

Why endure this traditional city growth pattern? Why not leave the present ground surface development to finish its life-cycle, preserving historically significant structures and recycling the land surface to recreation and parkland? Why not develop a roof-garden city? With geospatial planning the city would be more economical and efficient while serving the city dweller with nature contact and open space at surface level as well as well-lit offices grouped around sunlit atria and sited beneath a continuous roof-garden parkland.

Although the legal problems of geospace are more daunting than the technological problems, they are not insoluble. Apart from the present use of shallow geospace, the first 100-200m below the ground represent such a vast unused resource that, in the words of Dr Ray Sterling (Director of the American Underground Space Association), 'we must learn how to develop...[geospace] wisely, effectively and safely' (Sterling and Circo, 1984). This suggests hybrid development of a roof-garden city with its services in conduits or corridors beneath it maintaining floor-space ratios and controlling upward growth.

Figure 2 shows such a compromise between geospace and traditional ground surface development. It represents an economical compromise which avoids deep geospace development and can be used for underground conditions where groundwater problems prevail. It will be accepted here as a reasonable model for investigating a totally different approach to the development of the city of Sydney through the next century with modifications in height and with the insertion of sunlit atria into the centre of block developments.

But first, consider how people have used the subsurface for cities and towns in the past.

HISTORICAL EXAMPLES OF GEOSPATIAL CITY AND TOWN DEVELOPMENTS

Underground Villages, Cities and Towns, Past and Present

In the Paleolithic, humanity first utilised caves for shelter from danger and the cold climate. In the Mesolithic, pit dwellings were constructed to replace caves as the interglacial climate permitted a wider ranging nomadic life. It was not until major settlements had developed along the trade routes that those towns and cities threatened by invasion and/or located in climatically extreme regions began to utilise geospatial development.

There are innumerable examples of historical geotecture such as cave and 'dugout' dwellings throughout the world, some of which are still in use. These are located in Australia, China, Tunisia, South Italy, Crete, Palestine, Syria, Spain, France, United Kingdom, North America, Bulgaria and Turkey. There are cave temples and monasteries in Turkey, Egypt, Jordan, Georgia, India, Sri Lanka, China and Thailand. However, those human settlements that housed ancient populations (which can be categorised as large villages, towns or even cities) follow.

Turkey.

Probably during the Hittite invasion around 2000 BC (Kostof, 1972) or perhaps earlier, the excavation of single and multiple dwellings into the soft tuffaceous stone of the central Anatolian Plateau of Turkey began (Figure 3). Their inhabitants were referred to by Herodotus as 'troglodytes' (Rawlinson, 1952). Nation after nation of inhabitants subsequently gradually developed these Proto Hittite habitations into elaborate subterranean cities of which some one hundred are presently known to exist (Demir, n/d). These developed not only under the impetus of a need for safety and protection from invasions by Romans and Arabs, but also to escape searing summers and freezing winters, Several of these cities are grouped around Derinkuyu and Kamakli, the former being the oldest (between 17-20th century BC).

Although little is known about these cities, it appears that they are between 8 and 10 storeys deep, with only the first 55m explored so far (Figures 4, 5). Between Derinkuyu and Kamakli there is a 9km-long underground, tunnel-street connection. It is suspected that many other underground sites exist that were built by Arab slaves during Byzantine times. Elaborately planned and autonomous, Derinkuyu has ventilation shafts 75-80m deep, the first 2 storeys contains storehouses, kitchens, many chambers for living, sleeping and dining, wine cellars and water stores, stables and toilets. Below the second storey, third and fourth floors contain armouries, churches and schools. Many wells occupy the lowest floor and other tunnels link nearby cities. Altogether, present estimates indicate that 18-20 storeys once existed covering 4km^2 and housing twenty thousand families (Demir, n/d). Other underground towns in Cappadocia that are famous include Goreme, a tourist attraction. It is recognised as one of the major centres of Byzantine mural painting and one of the most concentrated areas of Eastern monasticism. Although now unoccupied, its original inhabitants were always comfortable in a rock temperature that approximated 20°C in a climate of arid summer heat and freezing winters.

France.

Naors-la-Souterraine. One of the many *souterraine* towns and villages in Europe, the historical underground city of Naors is located 15km north of Amiens in the Region of Picardy, Somme

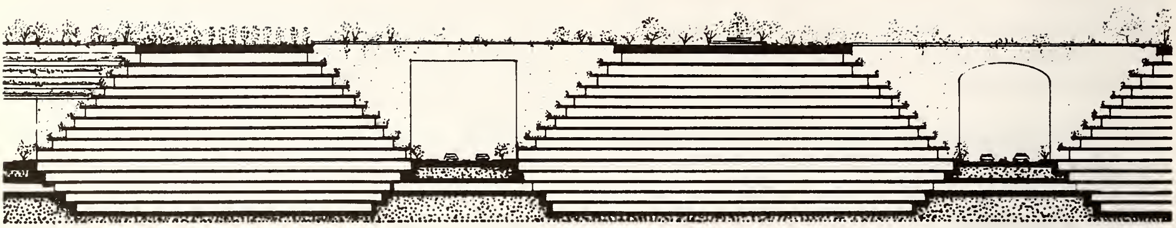


Figure 2a:
The Semi-underground concept described by Professor Yoshiaki Yoshimi (Davidson, 1988). Diagrammatic section showing 10 storeys above ground and 5 storeys below linked by underground passages

Figure 2b:
Japanese geopolitan development proposal. A group of buildings with 10 storeys above ground-level, and 5 storeys below. The buildings are so designed as to almost balance building weight with buoyancy by assuming that the underground water-level is relatively close to the surface. Pedestrian footbridges are constructed in the spaces between the buildings. Spaces between buildings can be used as light wells, atria, passageways or for non-polluting transit vehicles (Davidson, 1988). (Courtesy: Shimizu Corporation)

Prefecture (Figure 6). Opened to tourists in 1949, these spacious caves with 20-30m of soil and rock overburden were occupied and extended during Roman times and throughout the Middle Ages. The complex is the most complete and extensive of the refuges currently known in France. Hand excavated to an average depth of 33m measuring 3000m in length, it comprises 30 galleries the height of which ranges between 1.6-3m.

United Kingdom.

England, Ireland, Scotland and Wales all have geotectural habitations, villages and even towns in their prehistory and history. From the fogues (underground fortified dwellings) of the Cornish tin miners to the Mesolithic settlement of Skara Brae in the Orkneys, ancient cultures as well as those of history (and the present), their occupants used the cosy warmth of dwellings cut into rock or fitted into the earth to escape Atlantic winters.

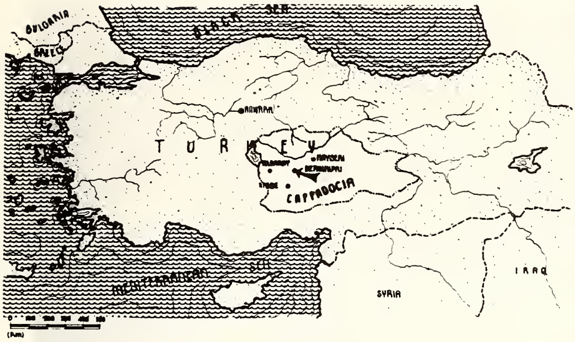


Figure 3:
Map of Turkey showing the province of Cappadocia. (City of Derinkuyu marked with arrow)

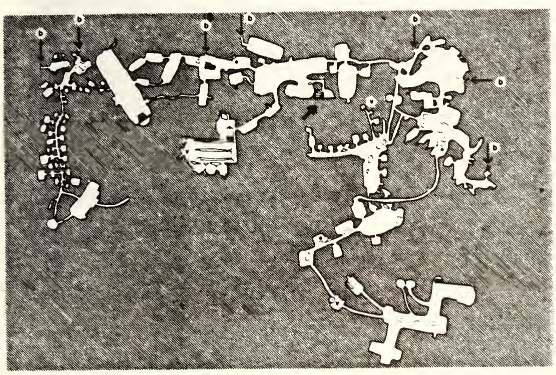


Figure 4:
The underground city of Derinkuyu. Blocked entrances shown with an arrow and 'b'; access is shown with a double arrow. Vent shafts are marked with a 'V'

The City of Nottingham is constructed on an extensive network of cave dwellings which were extend as time went by and are mostly accessed through the basements of modern buildings. However, some cottages are still extant as in the house in the Rope Walk (Figure 7). The village of Sneinton near Nottingham was completely rock-cut (Figure 8).

North America.

North American Indian cliff dwellings were often extensive towns exstructured as well as constructed into the cliff faces of canyons in Arizona, Colorado and adjoining States. Both pit dwellings (*kivas*) and cliff-dwellings (Figure 9), are cool in scorching summers and warm in the freezing winters of these arid regions. There are also innumerable examples of clusters of northern Indian habitations (*mandams)* later copied by the midwest settlers in

Figure 5:
The underground town of Goreme, Cappadocia, Turkey

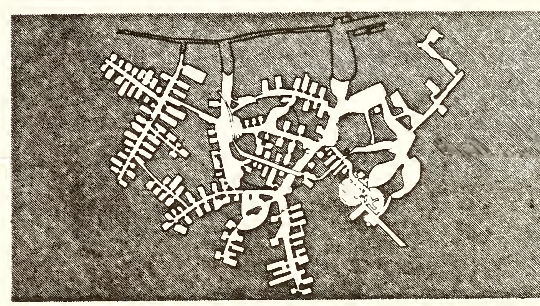


Figure 6:
The underground city of Naours, France
At the intersection of tunnels that served as streets, are spaces that functioned as meeting halls. The most impressive of these is the area known as the Rotunda with a ceiling height of approximately 30m.

their mostly isolated, earth-integrated prairie houses with the earth taken up the walls and over the sod roofs.

China.

The development of urban geospace also occurred in China over the centuries. This type of dwelling (exstructured in soft loess rock) has existed for 6000 years. Estimated in 1981 as housing some 40 million people, it is generally classified in China as pit and hillside types (these have been used in communal groups) (Figures 10, 11). China has built one hundred experimental earth-covered homes but has experienced difficulty in persuading peasants to move out of their comfortable ancient dwellings.

Figure 7:
The United Kingdom is sprinkled with examples of historical geotecture. Cave villages, towns and separate houses are often hidden beneath new structures. Some are still visible as in the Gordon Caves House in the Rope Walk, The Park, Nottingham (this was the condition in 1928). The complete decorative facade is cut from solid sandstone (as in Chinese 'dragon caves' or the temples of Petra, Jordan)

Southern Europe, the Mediterranean and Baltic regions.

In Sicily, geotecture towns abound, e.g., Siculiano, Caltabelotta, Rafadalle, Bronte, Maletto (Kostof, 1972). In Spain, the Baza-Guadix area contains some twelve thousand geotecture dwellings (Figure 12). Armenia and Georgia both have extensive medieval rock monastery settlements mentioned by Zenophon (Pitt, 1986), while Herodotus writes of the troglodytes of Ethiopia (Rawlinson, 1952).

From the Past into the Present

Japan.

In Japan more than 70 huge shopping complexes honeycomb the earth beneath the largest cities. Osaka, Japan's second largest city has several such facilities. These well-lit, climate-controlled 'roads' (in some cases over 1.5km in length with the noisy streets 13m above) are called *chicagai.* They are only shut down between 1 a.m. to 5 a.m. for cleaning, and sewage is pumped to the surface for disposal (Cross, 1989). Further vast shopping complexes and transport interchanges are planned by the Umeda Underground Development Association in conjunction with the Osaka City administration. The stimuli for geospatial development have been demographic pressures, the high cost of urban land and increased safety from seismic disturbances (Baggs, 1981a).

Australia.

Australia has its opal mining 'dugout' townships of Coober Pedy, South Australia, and White Cliffs, New South Wales (Baggs, 1981a, 1981b), with their roots in a past that began with Cornish copper miners who brought the 'dugout' dwelling to Australia in Burra, SA (Baggs, J. 1985).

Modern Geotecture

Modern geotecture ranges from single earth-covered dwellings, to underground shopping centres and industrial complexes. It is found in many countries, e.g., in Russian cities, 35 per cent of all building costs are for underground structures. In Montreal,

Figure 8:
Sneinton Hermitage, one portion of a geotecture village near the City of Nottingham. (The whole city is founded on a vast network of cave systems used since the Paleolithic)

Figure 9:
In the United States of America, this cliff-dwelling complex, the so-called Montezuma's Castle, is one of the best preserved of its type. Pueblo towns and villages were located in arid, dry valleys. This 5-storey castle is still 90 per cent intact

Canada, harsh winters make underground shopping logical, in Los Angeles, cool shopping is possible in a vast complex beneath the Arco building. There is a shopping centre linked to the subway development in Seoul, South Korea, in France, the Metro development of Paris (especially Les Halles) is world famous, as are the UNESCO recessed-atria buildings (Rudofsky), 1977) and the new extensions to the Louvre with its glassed-skylight atrium. Extensive underground developments exist in Sweden, Scandinavia, Norway that include sports centres, swimming pools, hospitals, theatres and bulk storage facilities for liquids, gases and solids, etc.

With its heritage rooted in prehistory and history, present-day geotecture was given new life with the need to find an alternative architecture to save energy during the worldwide oil crisis. The Cuban situation also engendered much anxiety that boosted the building of many thousands of earth-covered residences and at least one school in Abo, New Mexico. Several schools in California were earth-integrated to conserve space and for earthquake protection. The need to conserve surface space in cities and towns as well as on university campuses in the USA and England was also pressing.

Development of modern geotecture in Australia was stimulated by the requirements of both conservation of energy and the desire to preserve the natural beauty of a site. It was introduced to Australians as the outcome of an international conference in 1983 (Baggs, 1983a), and has experienced a steady growth curve since that time. Today, earth-covered houses, churches, a kindergarten, a school and an aboriginal art museum have been constructed in NSW. Many of these buildings have won awards ranging from the HIA 'Most Innovative' to the prestigious RAIA Blackett Award for country architecture, (e.g., the dwelling illustrated in Figure 22 won a National Energy Award because it had used no energy for heating or cooling since 1982 and the home in Figure 23 was awarded 'Most Innovative' in the Housing Industry Awards). In Sydney, many city developments incorporate significant proportions of geotecture in basements and pedestrian networks.

Cities of the Future

Japan leads the world in imaginative and extensive schemes for the future. A 'Geofrontier Project' has just been launched involving a budget of approximately A$150 million to excavate a geospatial cavity 50m diameter x 30m high with a floor 80m below ground level (Cross, 1989). As soft soil

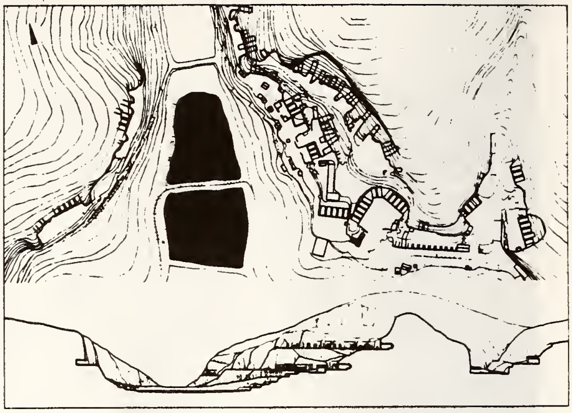


Figure 10:
The small town of Quinghuabian Yan'an, Shaanxi Province, China

excavation is more difficult than the well tried hard rock techniques, the Ministry of International Trade and Industry is still looking for a site. Meanwhile, a deep transit-rail system is being investigated 100m below surface and the project will include magnetic levitation trains, finally leading to whole cities underground.

Taisei Corporation, a large building company, has published concepts for what they have called Alice City Network to contain offices, shopping malls and hotels. Shimizu Corporation also has an imaginative project called Urban Geo-Grid (Figures 13, 14). As the prototype for such developments, it presents an excellent model upon which to base future developments.

The Urban-Geo-Grid is planned on the basis that grid points are located underground on a grid network. (Figure 15). Geotecture Grid Stations are established at each major grid node (Figure 25). Each controls a group of Grid Points, and new traffic systems or communication networks connect them (Davidson, 1988).

There is abundant natural sunlight to the interior of each Grid Point, and above-ground development can coexist in conjunction with this system. The development is planned for the Boso Peninsula through the water front and undersea of Tokyo Bay (Figure 27).

In the CIS (formerly the USSR), the writer has been involved with the Kirghistan Academy of Sciences on education for the development of concepts to extend to the city. This is considered

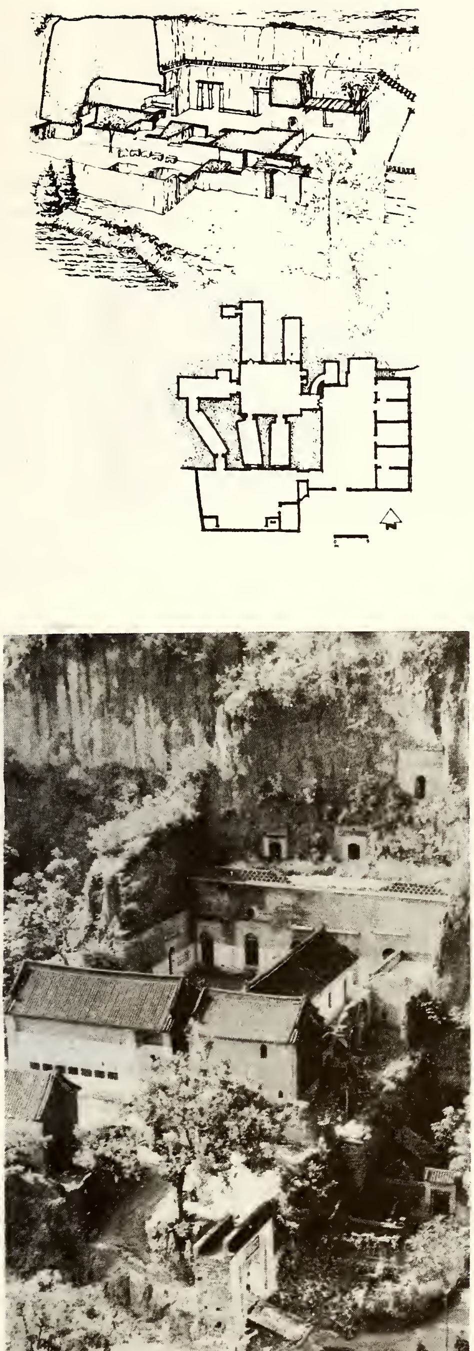


Figure 11:
Hillside town development in China
(a) Plans and sectional perspective
(b) Hillside (elevational) dwelling known as a 'dragon cave' (Kakiuchi and Noguchi, 1985).

necessary because of the conflicting demands of the housing needs of an increasing population and a shortage of arable land. Also, there is a need to construct shelters for sheep because of the severe climate.

THE RATIONALE FOR, AND THE UTILISATION OF GEOSPACE

What are the benefits involved in the utilisation of geospace? This question opens up an array of additional issues, for example, what does 'underground space' mean in definitive terms? (See Appendix I.) What levels of geospace are worth considering and for what reasons? This leads to a consideration of how does the principles of ground heat physics determine what zones of geospace may be utilised for human occupation in terms of the economical allocation of resources. What advantages and disadvantages are associated with its use? What of the psychological aspects of the use of geospace? Where has it already been used in local and overseas urban areas? How can some of the principles of geospatial planning be applied in the future in terms of the existing infrastructure of a city's built areas, open spaces, transit corridors and utility networks? Finally, the question how could the principles be applied to the geospatial development of Sydney and its suburbs is asked? Each of these question will now be discussed.

It is not suggested here that people live underground without windows or access to nature contact, although it will be proposed that it is quite possible for them to work in correctly designed geospace. The contention is that the thermal and acoustic benefits of underground-space use are applicable to residential complexes that are integrated into hills, commercial and industrial complexes into the sides of atria (if the ground-water table does not conflict) or into the sides of artificial hills if the water table is high (Figure 17).

The Ground Heat Physics Rationale for Geotecture

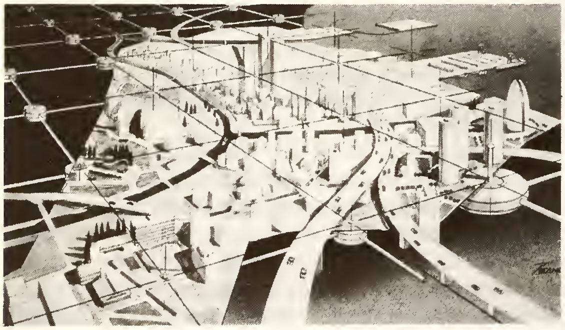
To what depths is geospace economically habitable and how does ground-heat transfer determine the zones involved?

Although underground space covers all space within the upper mantle of the earth that can be utilised by humankind, for present purposes, it will be defined in terms of 3 broad zones, i.e., the upper, the transitional (intermediate or near steady-state) and the geothermal zones. These will be discussed in

Figure 12:
An earth-covered dwelling in the Spanish underground town of Guadix

Figure 13:
Future Japanese geopolitan development: Alice City Network. Cross section through a major mall system (Courtesy: Taisei Corporation, Tokyo)

Figure 14:
Alice City network proposal, aerial view and section through a node



← Figure 15:
Future Japanese geopolitan development: Urban Geo-Grid (Courtesy Shimizu Corporation, Tokyo)

the contexts of the Australian continent and the soil and rock strata not subjected to the mechanics of frost penetration or water table heat-mass transfer.

The following discussion on heat transfer in Australian soils aims to establish the case for the utilisation of geospace on the grounds of energy efficiency.

The upper zone.

The upper zone is presently occupied by the basements of buildings, shallow space terratecture, underground utilities and transit tunnels. It can be defined in general terms as the zone containing those ground strata that are subjected to ground heat transfer as the result of periodic temperature fluctuations. These effects are produced by climatic and environmental factors at the Earth's surface which generate or control heat transference into and out of the earth. This will now be explained in broad detail.

During the hours of sunshine the temperature of the ground surface rises, until the rate of heating by the sun is equal to the rate of heat lost from the ground to the environment. Heat is lost or gained by the ground by conduction, and then through the air by longwave radiation. By mid-afternoon, when the day cools and ground temperatures begin to fall, heat flow is reversed, and heat begins to flow to the surface from below. Heat loss by terrestrial-longwave radiation continues throughout the night and is at a maximum on cloudless nights. Just after sunrise, the terrestrial radiation heat loss equals the heat gain from the sun during the previous day, together with additional contributions from the air above and the geothermal zone below.

These thermal transaction patterns are repeated in the cycle of the seasons and are modified by a multitude of environmental factors. They include the innumerable daily and hourly air-temperature fluctuations and air turbulences which result in continuous minor heat exchanges at the interface of ground surface and atmosphere. The accumulative effect of these heat exchanges can be seen as broad seasonal pulses of incoming and outgoing heat energy.

The long-term result of these processes and the thermal characteristics of the ground is that, given sufficient depth of soil, the overall heat gain from summer is slowed in its passage through the earth to the extent that a building below ground can theoretically receive this heat as an early winter source of heating. This effect is a function of both depth below ground surface and soil thermal diffusivity, the latter being a function of the thermal conductivity, density and specific heat of soil. Conversely, the cooling effects of winter are also delayed, potentially cooling the building in early summer. At levels around 5m depth, the ground temperature hardly responds to seasonal fluctuations. At this level, the much modified 'swing' (equal to twice the amplitude) in the annual ground-temperature curve tends to transfer its relatively stable temperatures to the underground building.

This means that the ground around the building becomes a heat source in winter and a heat sink in summer (when the flow of heat from the interior of the building to the soil keeps the interior temperatures down). Provided all major interior sources of heat are exhausted directly to the atmosphere or recycled, correctly designed geotecture should require much less introduced energy for heating and cooling and should be warm in winter and cool in summer. The potential for the near steady-state ground condition to be used thus depends upon the average ground temperature in the intermediate or transitional zone.

The depth of this interface between the upper and the transition zones is best understood by considering the graphical distribution of temperature in strata of differing average thermal diffusivities over time. Figure 18 shows how strata of low average thermal diffusivity damp amplitude in the ground temperature wave over a period of one year compared with how amplitude is damped when high average soil thermal diffusivity values prevail.

From Figure 18 it may be seen for all practical purposes, that the average annual ground temperature wave is damped in amplitude to zero at a depth varying from 8-20m (30m or so in rock of very high thermal diffusivity). This damping effect is defined in terms of the mathematical expression $A_s e^{-xr}$ where A_s is the amplitude of the annual air temperature wave at ground surface for a given site and x is the depth below ground surface and:

$$r = \left(\frac{x}{365\alpha} \right)^{1/2} \tag{1}$$

where α is the average thermal diffusivity value of the soil. Alpha (α) is an 'apparent' value (West, 1952) (its fluctuations are discussed in detail in Baggs, 1981a, 1983). In general terms,

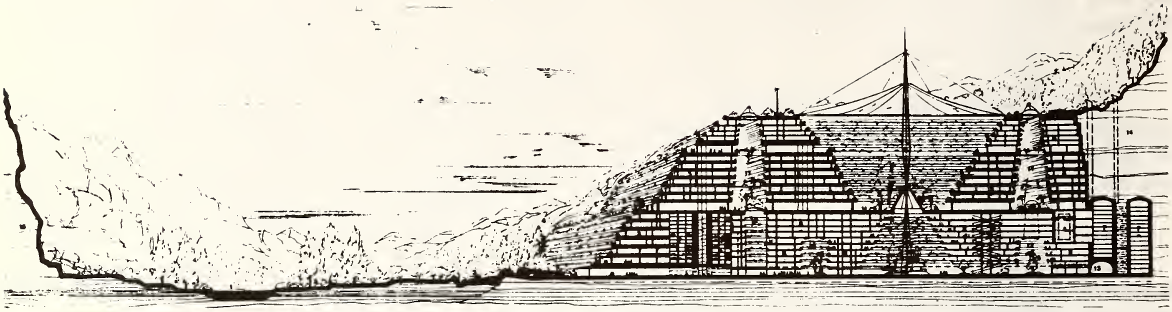


Figure 16:
Proposal for the extension of the city of Bishkek, Kirghistan (formerly Frunze, Kirghizia) into the adjoining mountains to free the valley land for agricultural use. (Architects: ECA Space Design Pty Ltd)

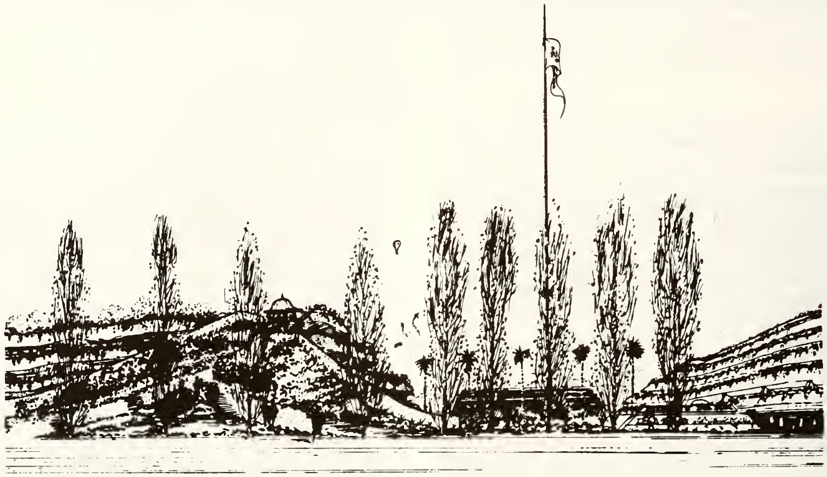


Figure 17:
Artificial hills containing residential complexes in an urban development proposal. (Architects: ECA Space Design Pty Ltd)

$$\text{average } \alpha = \frac{\text{av. ground thermal conductivity}}{\text{av. bulk density} \times \text{av. specific heat}}$$

From a network of ground temperature measurements to 2m depth throughout Australia, an equation was developed that predicted ground temperature at any depth on any day of the year, and the predictions were site tested. A form of the equation that performed satisfactorily for all soils within the Great Soils Groups classifications (but not tested in rock) for all geographical locations on the Australian landmass was:

$$T_{(x.t)} = (T_m \pm \Delta T_m) + 1.07 A_s e^{-0.00316x(1/\alpha)^{1/2}} \cos\{2/\pi[t - t_o - 0.1834x(1/\alpha)^{1/2}]\} \quad (2)$$

where:

$T_{(x.t)}$ = ground temperature (°C) at a given depth x (cm) below ground surface on calendar day (t), (the 'seconds' units cancel out)
T_m = average annual air temperature (°C)
ΔT_m = local site variable for ground temperature

(determined by geographically locating the site on Figure 20, and reading the value from the isotherm passing nearest to the site), (K)

$T_m \pm \Delta T_m$ = average annual ground temperature, (°C)

A_s = amplitude of annual air temperature wave, established from average yearly maximum and minimum recorded daily, (K)

α = average annual soil thermal diffusivity (through the complete soil profile to depth **x**) for undisturbed ground, ($10^{-2}cm^{-2}sec^{-1}$)

t_o = phase of air temperature wave, (day)

In Figure 19, Eqn 2 may be seen best-fitted to the data with the sinusoidal curve having an amplitude of As_2. The curve with amplitude As_1 is a best fit to annual ground temperature data for an inner Sydney suburban area at 0.1m. As was seen from Figure 18, amplitude damping occurs with depth below ground. In typical soils at depths below 10m or so, amplitude approaches zero for all practical purposes, until the geothermal gradient begins begins to have an effect.

From the above explanation on heat flux within the ground, it may be seen that the aim of designing geotecture in this zone is to locate it at such a depth to take advantage of the phase shift in the annual ground temperature wave, as well as its damped amplitude. Both phase shift and amplitude damping are a function of the depth below ground surface. If the structure is located at a depth sufficient to achieve a phase shift of 3-5 months when summer heat reaches the building in winter and vice versa, and the soil heat loss of winter provides a heat sink in summer. Hence, the principal reasons for designing within the upper zone are that: (a) land surface is liberated for alternative uses; and (b) introduced energy to cool/heat is minimised (if not eliminated altogether).

The transitional or intermediate zone.

This zone lies between the 20m deep upper zone and the zone of geothermal gradient. It varies greatly in depth, and for present purposes is taken as 30m. Hence, it lies between the 20m and 50m levels. This zone of transition where the seasonal and diurnal heat fluctuations from ground surface merge with the geothermal flow from within the earth (Gass, *et al.*, 1972) is virtually in a steady-state condition (although some temperature oscillation penetrates to 30m depth in highly conductive rock). It has been found that the earth temperature of this transition zone is equal to the average annual climatic air temperature for any site plus or minus a variable (ΔT_m in Eqn 1), the distribution of which has been mapped for the Australian continental landmass (Figure 20) (Baggs, *et al.*, 1990). ΔT_m was found

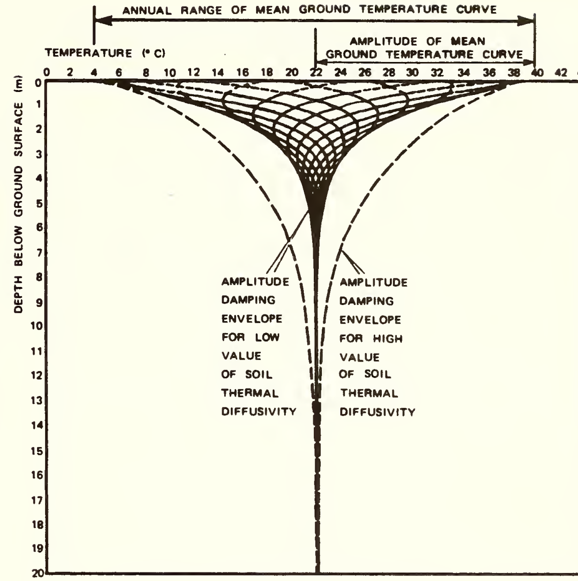


Figure 18:
Amplitude damping envelopes of the annual ground temperature wave as heat transfer moves into the earth for ground of low (full line) and high (broken line) average thermal diffusivity values (Sydney region)

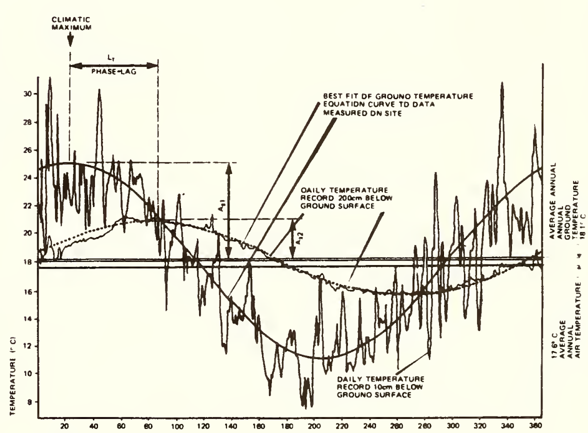


Figure 19:
Annual ground temperature curve for depth of 1m (which tracks average annual air temperature) on a daily basis (amplitude As_1) and at 2m depth (amplitude As_2), Sydney region (Baggs, 1983)

to vary from -1K to +5K, but local topography, climate, groundcover, albedo and density of shade cover can alter these values.

The geothermal zone.

Below 30m or so, the geothermal gradient takes over and averages about 2°C per 110m (Journal of Royal Society of NSW, 1899). Although this was a lower geothermal gradient than was to be expected in the sedimentaries of the Botany Basin (private communication Dr R. Facer, December, 1989), it was accepted for present purposes. These data were published in 1899 (Figure 21), and further enquiries from experts for up-to-date information about the Sydney geothermal gradient were unproductive at the time of writing.

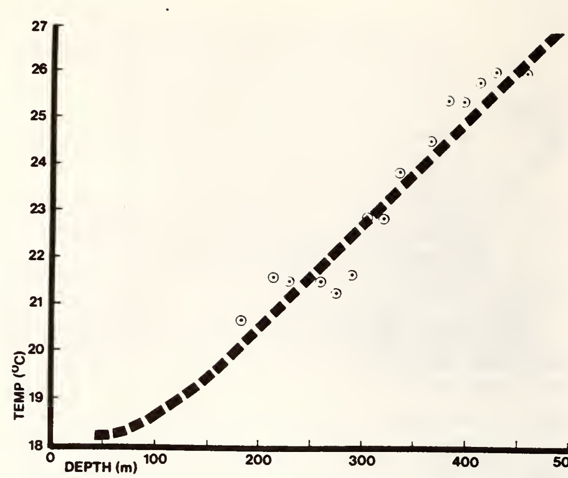


Figure 21:
Ground temperature versus depth below ground surface. Geothermal gradient for the Sydney region with graphical best fit to data extrapolated to the upper zone (Journal of Royal Society of NSW, 1899). (For the Birthday Shaft, Sydney Harbour Colliery, Balmain)

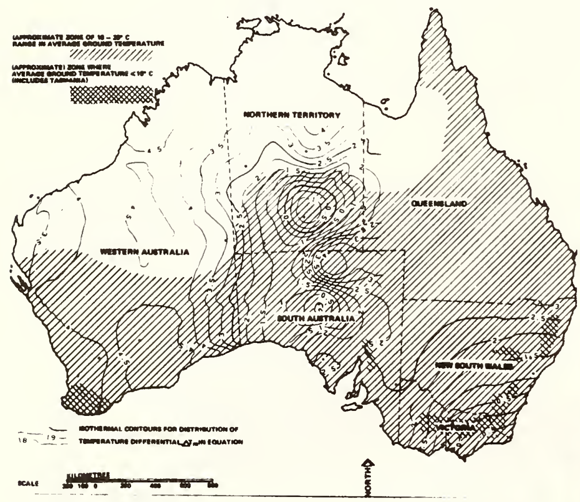


Figure 20:
The 'ΔT_m' map of the main landmass of Australia showing the geographical distribution of the temperature differential between average annual air temperature and average ground temperature for any site (Baggs, 1981b, Baggs, *et al.*, 1990).
For the city of Sydney, the average annual ground temperature was found experimentally to be 18.1 deg.C (with ΔT_m=+0.5K). This is adopted as a reasonable working temperature for the intermediate zone.

Figure 22:
Energy-efficient, prize-winning, Hunter Valley earth-covered house. (Award: National Energy Management Award). (Architects: ECA Space Design Pty Ltd)

Three zones combined.

The full range of zones 0-30m (upper zone), 30-200m (transitional zone) plus x_g (geothermal zone) where x_g is a temperature at which interior heat loads within a geospatial cavity will *not* be transferred to the surrounding strata. For human occupation, and for all practical purposes, x_g conservatively should not exceed, say, 21°C (27°C is the upper limit of comfort for the human body although 29°C can be acceptable with air movement). (This is discussed in detail in Appendix S in Baggs, 1981a.) The temperature differential of 6-8K allows for a positive heat sink effect to ensure that interior heat loadings are always conducted away from inhabited geospace into the infinite thermal heat sink of the Earth's mass.

Depths to which Sydney Geotecture could Extend

With approximately 2°C ground temperature increase for every 100m of depth,and following a best-fit to the data in Figure 21, this means that at a level of 200m, the useful lower level of the combined zones would be reached for occupation by human beings without the introduction of excess energy to counteract the heat source effect of an enclosing rock that is higher in temperature than is desirable for removal of interior heat loadings. However, certain types of geospace-use would be quite appropriate down to the 450m level at which rock temperature would be approximately 26°C.

Hence, from an energy-efficient viewpoint, for Sydney, geotecture would be a viable planning alternative at depths to approximately 200m for human occupation and 450m for bulk storage of appropriate gases, liquids and solids.

THE ADVANTAGES AND DISADVANTAGES OF GEOSPACE

Before the potential of the use of geotecture in the future can be addressed, it is reasonable to consider its pros and cons as well as how and why it has already been used in the 20th century.

Advantages

Economies from increased thermal energy-efficiency.

In the above explanation of the heat physics of geospace, it was seen that geotecture utilises the surrounding earth as a heat sink and source. This is ideal for the use of heat exchange systems and energy consumption is significantly reduced in comparison with above-ground buildings exposed to ambient climatic extremes.

Economies from potential adaptation of mass-production techniques to geotecture.

The fact that the actual building structure is below a landscaped environment means that previous visual monotony of the repetitive forms of mass-produced structures for housing and industry can be concealed. As a result, the developed environment can be one of infinite variety with natural landscapes completely different from the hard landscapes of today's urban fabric.

Economies from reduced maintenance costs.

In terratecture, the elimination of gutters and downpipes and a large proportion of exterior wall finishes reduces first costs and maintenance costs. However, the predominant factor in the degradation of the exterior surfaces of a traditional building is the exposure of surface materials to the damaging effects of solar ultraviolet radiation. Obviously, this cannot occur when the external finish (that is, the waterproof membrane) is covered by soil beneath a low-maintenance roof garden. Only the small proportion of the exterior exposed to the sun is subjected to UV breakdown or to other airborne pollutants that produce chemical degradation of materials. Consequently, there is a resultant savings in maintenance, time, energy and money.

Where open space is limited.

Geospatial development is an ideal planning option where population density has already produced a skyscraper city with fly-over freeways that alienate one precinct of a city from another either by creating barriers to community access, or at least as visual barriers that lower a city's aesthetic quality and amenity.

Examples are the urban and suburban areas of crowded cities, or regional growth areas with geographical limits to their spread, such as Sydney. Sandwiched between the Blue Mountains and the sea, this city is rapidly becoming an ungainly city. In the next century, it could extend between Newcastle and Wollongong, and west to Penrith. Compared to other continents in the world, Australia has the least area of coastal plain in relation to its total landmass, hence, other Pacific coastal cities will probably also tend towards the megalopolis model already present on the US eastern seaboard.

Land is often in short supply on university campuses. Many of these already have underground buildings constructed for reasons that vary from a lack of open space to the need to preserve the visual aesthetic of historical buildings. The Radcliffe Science Library at Oxford University, England, has been built underground to preserve the visual quality of the campus and the historical value of nearby buildings. At Harvard University, the Nathan Marsh Pusey Library was constructed underground to conserve campus open space and allow a clear view of the historical architecture enclosing that space. Similarly, campus space was conserved by undergrounding both the Admissions and Bookstore building and the Civil and Mineral Engineering building (the home of the Underground Space Center) at the University of Minnesota in Minneapolis. The prize-winning design for the library of the University of Illinois, Urbana-Champaign, Illinois, was built underground around a central courtyard. The architect's brief required that the building should not cast a shadow on the oldest historical agricultural experimental plot still in use.

Where space is scarce in city areas, land is expensive. In Japan, it costs 40 per cent less to buy 'land area' underground compared to above ground. One *chicagai* contains two hundred and twenty-five shops which are visited by as many as eight hundred thousand people on busy days. The Place Bonaventure and Villa Marie in the Canadian city of Montreal are typical geospace commercial developments that are integrated with transport networks of the same type as the Metro of Paris with, for example, Les Halles and the Louvre. On a smaller scale, the subway of Sydney has recently been extended to service the eastern suburbs and other extensions are planned. The geotecture section of the Very Fast Train (VFT) is already in the planning stages.

Where large or ugly structures are best concealed.

Consider the advantages if large ugly structures were 'undergrounded' and covered by parks or playing fields. Garaging facilities could be located almost anywhere underground. In Sydney the Domain park is located over a parking station as is the Sydney University oval, and similar situations with parks over parking stations exist in many cities throughout the world. In addition, what if the visual impact of huge storage tanks could be removed from our landscape? The storage of water, petroleum products, molasses and other liquids has been successfully placed underground in several Scandinavian countries. Warehouses and cold stores have been sited deep underground in mined-out limestone caverns in Kansas City, Missouri. These are more economical to run than their above-ground counterparts and also leave surface land available for other purposes.

Ugly buildings and structures are given prominence in the landscape and visual impact is a very new concept to urban development. It can now be quantified as part of in the environmental impact assessment and evaluation process and should be an integral part of that process (Baggs, 1985).

Noise attenuation: where a noise- or vibration-free environment is necessary.

Siting industry in geospace solves the problem of locating machine beds free of vibration for high-precision manufacturing processes. For example, the Brunson Instrument Company of Kansas City Underground, Kansas City, Missouri, had problems with traffic vibrations in an above-ground building which were solved when it moved into a remodelled limestone cavern.

Ambient noise levels from adjoining airports or expressways adversely affect above-ground buildings. These noise-attenuation problems are solved by the strategy of undergrounding. For example, Lake Worth Junior High School at Fort Worth, Texas, was constructed subgrade and windowless because it adjoined Carswell airforce base. The near-constant noise emitted from jet take-off and landing has to be experienced to be believed. When interviewed, the children in this school seemed unaware that they were underground but commented: 'we like it here, it's much quieter than in the above-ground parts of the school'. In Australia, an earth-covered private, primary-school building has been built in a western Sydney suburb so that nearby residents cannot hear the children.

Where unacceptable noise levels are emitted from within a building, as in the case of noisy manufacturing processes, the excessive noise generated can be damped to improve the amenity of adjoining land. For example, some machine shops in Sweden service their defence equipment underground. If noise level requirements vary within the same building, underground there would be successful noise attenuation. However, it must be remembered that solid-borne impact noise, travels easily over long distances underground and requires vibration damping at source to counteract its effect.

Where safety and security are required and the forces of nature produce difficult and dangerous living conditions.

With geotecture, the likelihood of damage from natural threats such as storms, bushfire and grassfire, cyclones and high winds (with their attendant damage from flying debris), lightning strike and earthquake is reduced to a large extent. With shutters, terratecture also provides increased security against burglary and vandalism. Protection from the impact of falling objects, or from vehicles out of control when located near an airport, road or highway, is also inherent in the concept.

Geotecture is ideal where climatic factors impose excessive demands on air-conditioning and refrigeration in hot-arid zone locations such as in the opal-mining township of Coober Pedy, South Australia, or in regions of extreme cold as in Minnesota, Minneapolis. Where climatic factors restrict year-long sporting activities, underground facilities such as the public swimming pool at Gjovik, and the sports centre at Odda, both in Norway, are well patronised.

Where cyclones, tornadoes, or hot desiccating winds, blown sand and glare occur: as in Plainview, Texas, where the Hamman home (called Atomitat, for 'atomic habitat'), designed by J. Swayze in 1962, has been unaffected by destructive tornadoes. The totally underground house is built in a dust-storm belt, and the owner has stated that the only dust that enters the house is brought in on the feet. Schoolrooms have also been constructed as cyclone shelters throughout the United States.

In earthquake zones, good earth-covered construction (and not actually located upon an active fault) would suffer little or no damage in earthquakes. In earthquakes, most loss of life is caused when buildings collapse. As terratecture would move with the earth, the twisting and whipping effect would be minimised, although the structure must be designed to counteract these effects, for example, service pipelines need flexible connections where they enter a building.

An excellent example of this is given in the energy-award winning house shown in Figure 22 which survived the Christmas 1989 earthquake (5.5 on the Richter Scale) without a crack, the epicentre of which was only 8km away.

A significant point is made by Yorihiko Ohsaki (the Vice-president of the Shimizu Corporation and Ohsaki Research Institute, retired professor of engineering at Tokyo University) when he states: 'the acceleration of the surface wave which do most damage to buildings is reduced to about one fifth when the wave reaches 20 metres under the ground. In actual earthquake damage...basements have much less damage' (Davidson, 1988).

Where unusually stringent, safety and security requirements are imposed on the building structure and fabric, geotecture (particularly if windowless) offers a successful solution and a greater degree of security than is possible in above-ground construction. The use of thermal shutters also improves security.

For the storage of explosives, many countries including Australia, Sweden, Scotland, Switzerland, Canada and the United States have storage areas in geospace. For the manufacture and storage of toxic and dangerous materials, such as those of nuclear reactors, it is claimed facilities could be located safely at the 150m level.

Civil defence and communications centres such as the Regional Defense Civil Preparedness Agency, in Maynard, Massachusetts, have been sited underground as one of a network of such centres throughout the United States. The Canadian Forces Air Defense Command, part of the North American Air Defense Command known as 'NORAD', is also subsurface. NORAD's centre is also underground beneath Cheyenne Mountain in Colorado. Safe City, an underground complex with warehouses, archives and offices inside an abandoned cement mine, also has luxury units for wealthy tenants dug 46m deep into Iron Mountain in the upper Hudson River valley. Elsewhere in the United States, many big businesses have provided shelters to house their executives in the event of a disaster. For fire-brigade headquarters, dual land use is possible. The Forest Park Fire Alarm Headquarters, St Louis, Missouri, has a baseball field on its roof.

For bulk storage, near Kansas City, Missouri, there are the largest drygoods and duty-free storage areas in the world, housed in disused limestone mines covering 4.2km^2, extending some 19km on 2 levels. Because security from burglary is almost perfect in these areas, insurance rates are far less expensive than for their above-ground counterparts.

For military defence, at Sweden's Musko Island, underground aircraft hangars have been constructed, as have docks for warships and submarines. Water and petroleum-products storage is also underground to prevent deliberate contamination by sabotage or destruction in the event of a war. Hospitals also have been excavated underground.

Geotecture is used for air raid shelters in many countries. In Norway, sports centres and swimming pool facilities double as wartime or national-disaster shelters as in Odda. In Sweden, every town of more than five thousand inhabitants provides disaster shelters for the entire town population. Houses in Switzerland have shelters, in addition to the disaster shelters provided in cities for inhabitants.

For schools and laboratories, security is generally required today. There are many earth-covered school and university buildings in the United

States. In one US school where vandalism was a problem, an earth-sheltered (bermed) building was constructed. However, this left the roof accessible and particularly vulnerable to attack by vandals, and earth-covering has been incorporated in some subsequent schools to protect the roof area. A particular problem was encountered by the previously mentioned Lake Worth Junior High School, at Forth Worth, Texas, adjoining Carswell airforce base. One of the reasons given for its construction underground was to avoid the likelihood of injury to pupils 'from things falling from the sky' (apart from the need to escape from the excessive noise levels from aircraft). For industrial laboratories, espionage is always a threat, and earth covering has been undertaken to avert certain aspects of this crime by forced entry.

For record storage underground buildings provide a safe environment. For example, the Little Cottonwood Church vaults of the Church of Jesus Christ of Latter-Day Saints, in Utah, have been constructed inside a mountain for permanent storage of vital records. The risk of fire in such circumstances is minimal, and temperature control is more easily achieved than in an above-ground structure.

In Norway, an earth-covered prison provides secure conditions within a forest.

Where control of air moisture or temperature is required.

If specific air moisture content or specific temperatures are required for storage, manufacturing, or laboratory conditions, these are easier to achieve in geotecture than above ground. For example, the previously mentioned vaults of the Church of Jesus Christ of Latter-Day Saints in Utah require low-maintenance, controlled-temperature conditions for the storage of microfilm. Museums, art galleries and theatres around the world have been built underground, or been earth-covered, to provide controlled conditions and to minimise the use of air-conditioning, for example, the Gateway Centre in St Louis, Missouri, with its museum and 2 theatres, and architect Phillip Johnson's art gallery in Connecticut. The vast underground complex at Kansas City, Missouri, which houses both subzero and coolroom facilities (the largest in the world) permits constant conditions of low temperature to be economically maintained. The same complex at Kansas City requires controlled dry-air conditions for the largest drygoods and duty-free areas in the world. The California Institute of Technology has its environmental quality laboratory below ground; quality control of stored products is improved below ground (for example, petroleum products, and substances such as gas, wine and molasses in Scandinavia and France).

Where areas of beauty should be preserved.

Where areas of natural beauty or historical significance should not be ecologically and visually impacted by buildings or structures, geotecture should be used. The residence in Figure 23 backs onto a 480ha nature reserve and a low silhouette was needed to maintain the view of the bushland.

It is suggested that if earth-covered buildings were used in national parks, not only visual quality but also the comfort conditions for the users of such buildings would be considerably improved. If an area is of particular historical significance, imagine the difference that could be achieved if public toilets, information buildings, kiosks and rangers' cottages were all earth-covered and landscaped with native vegetation to blend in with the surroundings. Despite the different type of land use (as in the case of water, petroleum, oil and molasses storage in excavated rock caverns), forests have been retained at the ground surface in some installations in Norway. Similarly, where low-density residential areas would need to incorporate large structures such as schools or churches, the landscape integration of these building with their sites would result in minimal visual impact.

Where certain aspects of public health are involved.

In domestic geotecture incorporating specific ventilation-design strategies, it is possible to expel dust before it enters the building Baggs, 1981a). Also as most of the pathways (except for clothing and soft furnishings) by which dust enters a building are eliminated by the watertight envelope of such a structure, obvious benefits accrue from the reduction of interior maintenance and dust-related illnesses, for example, asthma. For the same reasons, rats, mice, spiders and crawling insects would find it difficult to enter.

However, this whole question is very open. People prefer sunshine and views but these preferences are relative as Carmody and Sterling (1987) determined when office personnel tended to choose a larger office in geospace (at the University of Minnesota) over the possession of a small one with a window. Other reasons that could explain why a vast salt-mine in Poland is successfully used as a hospital and recuperative centre arise from recent research observations, namely:

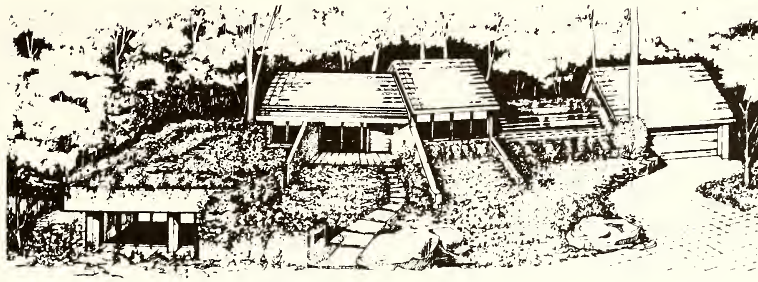


Figure 23:
Prize-winning, suburban, earth-covered house designed for a steeply sloping site to blend with other houses in the streetscape, integrated with the earth, with a garden roof that minimises visual impact upon the bushland reserve beyond, this building exemplifies how terratecture can be adapted to any location to reduce environmental impact. (Awards: HIA 'Most Innovative Design', National Energy Management Award 'Most Energy Efficient over $125 000). (Architects: ECA Space Design Pty Ltd)

(a) that the geomagnetic field has a frequency that peaks at approximately 10Hz, and the human brain operates in the relaxed alpha mode, a frequency having the same average. Induction could be operating to reduce stress and hence, assist healing;
(b) that a higher proportion of negative gaseous air ions to positive air ions has been found to exist in geospatial sites measured by the writer (Baggs, 1981a). This condition has been shown to reduce seretonin levels and with them the associated restlessness, anxiety, irritability, depression, headaches, nausea and eye troubles associated with General Adaptation Syndrome (GAS) as well as with the 'sick building syndrome' (Baggs, 1981a).

Geotecture development also has another advantage over above-ground buildings in that human stress from external noises can be avoided altogether, and internal temperatures can be considerably modified.

Where environmental impact must be minimised.

Although the short-term environmental impact of terratecture can be greater than its traditional counterpart (measures can be taken before and during construction to minimise this), the long-term impact on the physical environment (as well as on visual quality) is far less than for an above-ground building. This is significant in areas of natural beauty or historical importance, or in the regeneration of areas despoiled by mining operations, industry, freeways, etc. Even in low-density residential areas where large buildings such as schools and churches are part of the social fabric, terratecture can reduce visual impact. Such buildings also help to restore some of the natural groundwater seepage patterns, reducing sheet runoff during storms and thereby decreasing both the load on stormwater drainage channels and the resultant environmental damage caused by erosion.

In all geotecture, careful consideration must be given to the environmental impact upon ground water ecosystems arising from such developments. Tunnelling lithotecture produces minimal environmental impact compared to other forms of geotecture.

Where difficult sites require non-standard solutions.

If a site is steeply sloping, or is not facing towards the sun, terratecture can usually provide a solution and render a project viable that under other circumstances would have been abandoned.

Disadvantages

Adverse psychological factors.

It appears that there are some people who unreasonably reject the concept of geotecture, without knowing anything about it. However, such attitudes exist in only a very small percentage of the community. They are probably subjective responses to past experiences. This question of psychological acceptance is discussed later.

Transmission of solid-borne sound.

Low-frequency solid-borne (as opposed to airborne) sound can present a potential problem, although it is possible to damp such noise with vibration damping materials, or to design room sizes that do not coincide with the intrusive vibrations (to avoid standing-wave formation).

Difficulty in making future additions.

Specific allowances should be made for additions to geospace during the planning and construction stages, as unplanned alterations or additions are more difficult than for above-ground buildings.

Costs versus benefits.

Small- to medium-scale terratecture. It is not automatic that construction costs of every earth-covered project will be higher than those of an above-ground equivalent. Even those increases that occur (of necessity) can often be offset by reductions in other areas, for example, by the elimination of guttering and false ceilings. Areas where cost increases may occur are: builders unfamiliar with the concept, who increase tenders to compensate for their inexperience; professional fees not ordinarily associated with traditional dwellings; initial extra landscaping of the roof garden; increased difficulty involved in making later additions; additional (but optional) expense in earth covering garages and carports; the necessity to be more selective in the choice of a site (some of the criteria for site selection relate equally to any passive-solar building) which may be reflected in increased costs; and difficulties associated with collection of rainwater.

Geopolitan geotecture developments.

The question of cost versus benefits in such developments is a serious one. Obviously, extensive tunnelling (lithotecture) has a cost/benefit case that must be made for each project. Professor Gunter Girnau (1982) president of the International Tunnelling Association makes the following point:

> the assessment of costs versus benefits is very popular today, but attention has to be drawn to the fact that are a lot of problems in this field which are still unresolved. It is very difficult to assign a money value to everything. Some of the most important benefits of underground railways are hard to quantify. What, for example, is the economic equivalent of the growing prosperity of a city, of less polluted air, lower traffic noise levels and lower accident rates.

On balance, from the above, it can be seen that the advantages of geotecture far outweigh the disadvantages.

PSYCHOLOGICAL ASPECTS OF THE USE OF GEOSPACE

Before considering its use in the future of public acceptance, some thought must be given to the question asked when geospace is proposed as a design solution, that is, whether people would willingly use it. Such a question involves several aspects of the problem. Firstly, would people be willing to *live* in geotecture? Here it is made clear that windows are an essential part of the design of geotecture for dwellings and offices (Figure 24).

A psychological survey was carried out amongst a sample of the population of the small opal-mining township of Coober Pedy in South Australia. The sample comprised an equal number of respondents who live above- and below ground who had knowledge of the underground lifestyle. It was found that approximately 75 per cent would live in modern geotecture.

Windowless Space

The question of whether people would be willing to use space without windows for working (not living) is another matter. In general, it is common to find that people involved in working or shopping within well lit and well ventilated subsurface space have to be reminded that they are, say 10m below ground. Most people are not conscious of any difference in windowless above- or below-ground space.

Although the proposals described later are based on the use of recessed atria and solar and skylight access to inner city residential zones, there are some cases such as factories and shopping centres that could be developed using central skylit atria with a high proportion of windowless space.

The question of whether people are willing and happy to work in underground windowless space had not been directly and effectively researched in the 1970s. However in 1984 a paper published under the title: 'Psychological reactions to working underground: a study of attitudes, beliefs and evaluations' filled the gap. The results from surveys conducted on a large (312) employee sample in 21 different environments within Kansas City (who worked in windowless space in mined-out limestone mines converted to offices, warehousing and industrial facilities) indicated a positive overall evaluation of working underground (Hughey and Tye, 1984).

The underground space was also rated as safe and efficient, and results were neutral with respect to the overall ratings of work areas, lighting and ventilation. The results also suggest that 'people who work underground may make a trade-off between the advantages and disadvantages of the setting...The type of lighting may be a particularly crucial issue. It is most desirable to replicate the spectral composition of daylight as closely as possible' (Hughey and Tye, 1984).

Figure 24:
Interior of Williamson Hall Admissions Building, Minnesota University, Minneapolis, USA, looking out onto sunlit landscaped atrium

In the 1940s and 1950s, workers in an underground factory in Sweden were assessed. 'The study concluded that no major psychological problems occurred if the proper interior climate was maintained...Adequate ventilation is essential to remove excess heat and the build-up of indoor pollutants...Windowless laboratory and manufacturing environments provoke less criticism than windowless office buildings' (Carmody and Sterling, 1987). Consequently, in the design of the system described later, office space is housed in well lit atria (Figure 25). Entrances need to be spacious and also well lit, and the transition vertically should be gradual. Glass partitions, high ceilings, overlooking galleries and multi-level spaces, large central spaces linking the surface to deep space and optical or electronic devices to provide information about ground surface activities and the weather are all design strategies to be incorporated. A beamed daylight system and full-spectrum artificial light are

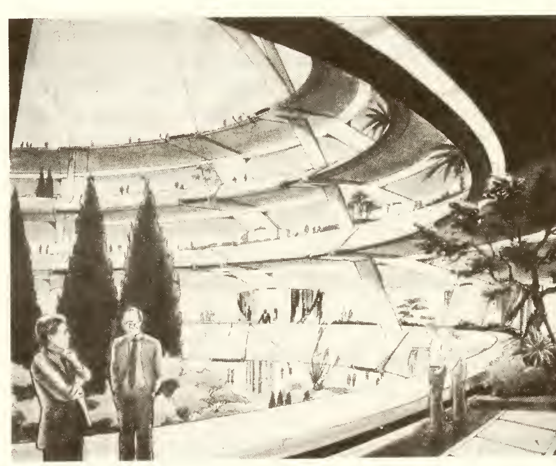


Figure 25:
The Grid Station in the Geo-Grid controlling a grid group

advisable as are the use of warm, bright colours, artwork and well lit interior vegetation (Carmody and Sterling, 1987).

Should employers wish to relocate industry or commerce in geospace, it is suggested that photographic displays or audio-visuals of actual developments in other countries could be shown to potential employees. Those who for good reasons of their own, were not willing to work underground, could be identified by screening procedures during the employment interview. Methods for defining and assessing the factors involved need to be developed (Baggs, 1981b).

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APPENDIX I

A CLASSIFICATION OF UNDERGROUND SPACE

Although there were many types of underground spaces that could be considered generically related, an integrated system of classification was needed with which to order those relationships (Figure 26). (This is given in detail in Baggs, 1981a.) Geotecture, lithotecture and terratecture used here are derived from: *geo*: (Gk) the Earth, *litho*: (Gk) 'stone', *terra*: (L) 'earth', *tekton*: (Gk) 'builder'.

'Geospace' has been adopted in the sense that it includes all space that is earth and/or rock covered and located beneath the natural or surficially altered final interface of the earth with the atmosphere, at both shallow and deep levels.

'Geotecture' has a specific sense as the design and creation of subterranean accommodation.

When 'underground' is used, 'ground' refers to the finished ground surface whether it is predominantly occupied by landscaping or pavement, or whether it is natural or otherwise, i.e., surficial. In all cases, the ground (or grade) is considered as the interface between the earth/rock enclosing an underground space and the atmosphere. Although the simple unambiguous term 'earth-covered' is preferred to underground architecture, both are used.

Terratecture Types A1-A4

Referring to Figure 26, types A1-A4 have their floors located at ground level, or above the ground at the lowest entrance portal or door. As these Type A buildings are earth-coupled at upper ground level and not recessed into the earth where temperatures are relatively stabilised, they are potentially less energy-efficient than Type B. It is used where the excavation should be kept to a minimum because of rock, or where a watertable exists near the ground surface. When compared to buildings sited with their floors below ground surface, A types take longer to 'settle in' as moderators of the atmosphere's seasonal air temperature cycle. Should extra rooms be needed later, they are more easily extended than Type B buildings.

A1 chamber. This type of building has an earth-covered roof and berms (earth-embankments or mounds) around all its sides with no windows.

A2 atrium. In Roman times, urban dwellings in particular, gained privacy by having their open space located centrally in relation to the house as a courtyard (atrium) surround by rooms. Consequently, the atrium-type of earth-covered building has the spatial characteristics of an atrium house (combined with those of the A1 chamber type).

A3 elevational. This is similar to a chamber-type earth-covered building except that it has one wall exposed. This wall has windows probably to a view (and preferably to the sun for passive-solar purposes for which this type is ideal). Side walls may have small areas of windows with earth-berms up to sill level.

A4 penetrational. This type of building has windows to more than one elevation of the building. Of all the types of terratecture, this is the least energy-efficient unless special provisions such as double glazing to doors and windows, or insulated shutters are used to conserve thermal energy.

Terratecture Types B1-4

All these types have their floor levels below the ground surface level at the lowest entrance portal or door of the building. Hence, cool air will 'pool' at floor level to a height equal to the height of the steps necessary for access from floor level up to the door threshold.

B1 basement chamber. This term is used to describe a building completely enclosed by the earth, except for the entrance and exit. It is the type used for cyclone or tornado shelters. If correctly designed, it is suitable for nuclear blast and fallout shelters. In an extreme case, the occupants are completely cut off from the surface environment and hence from both natural and human elements. This is

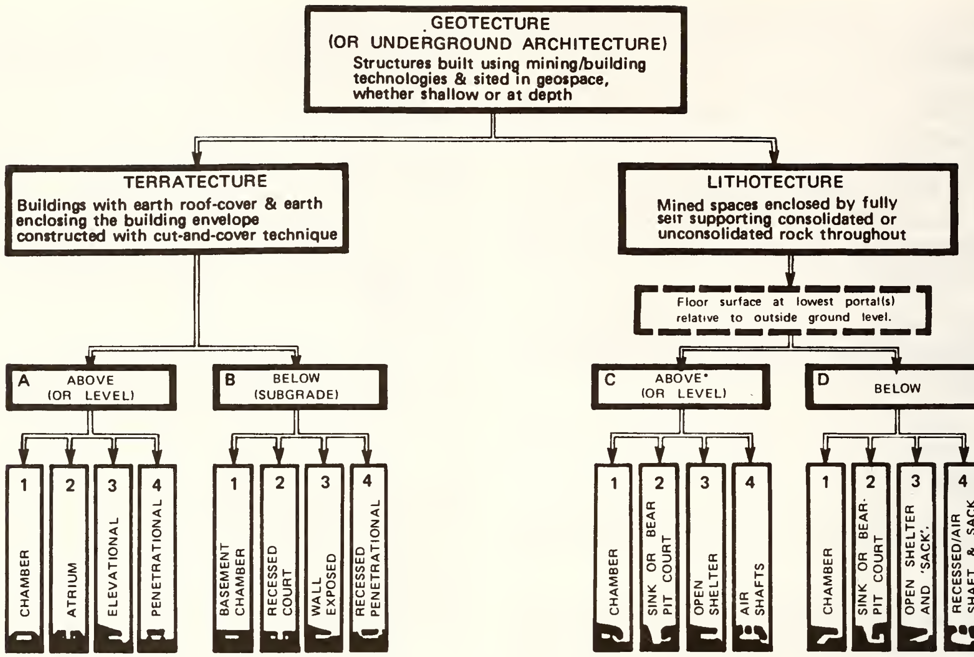

Figure 26:
Classification of underground space

the type of dwelling occupied by many Coober Pedy, SA, and White Cliffs, NSW, residents where the climate is severe. It is often used in combination with tunnelled lithotecture.

B2 recessed court. In an atrium building (described as a recessed court to distinguish it from Type A2), one can stand in the atrium and not be conscious that the building is below ground level. This type optimises the earth-coupling of the building with maximum perimeter wall area and minimises thermal losses to the atmosphere through minimal door and wall openings to the atrium. In very cold/hot climates, the atrium can be covered while still permitting the entry of light into the rooms off the courtyard.

B3 wall exposed. This type is totally buried beneath earth from the front of the roof to its back edge. The front is usually the longest edge of the roof. The rear wall is earth-coupled, and often the side walls are also fully earth-coupled. The elevational building with, for example, an elongated rectangular plan, can balance good earth-coupling of three walls, floor and roof with an exposed front wall that is perhaps earth-bermed. This provides all front rooms with a view and approaches the appearance of a conventional building.

B4 recessed penetrational. This type of building, constructed in an excavation, has windows and/or doors to the back and front elevations. It could be considered as having minimal earth coupling. Hence, it represents only a slight potential thermal improvement upon the A4 penetrational type.

Lithotecture

Shown on the right-hand side of Figure 26 are the various types of lithotecture found at such sites as Coober Pedy, White Cliffs and Burra in Australia where they are referred to as 'dugouts'. In China they are called 'dragon caves' and in France, *souterraines*. Types C and D have been arranged to have a design correlation with Types A and B. This type of building is ideal for use in areas where self-supporting rock is structurally sound and where a completely neutral aesthetic may preserve the appearance of a scarp or cliff face. Terratecture sited on the brink of a cliff, or in the talus below the cliff, would be more visually obtrusive than either of the former alternatives.

The descriptions in Boxes 1-4 of each category shown on Figure 25 also apply to the air-drainage characteristics of underground spaces, i.e., whether night-cooled air is able to drain viscously into the interior space through entrance portal(s), or via ductwork of some description, to provide fresh cooled air either directly into the interior, or indirectly into thermal mass storage to be utilised in the maintenance of comfort conditions during the heat of the day. Conversely, this configuration also creates a design problem to avoid the accumulation of chilled air in winter. This physical property of cold air retention has been called the cold air 'sack' effect when applied to caves, and the term has been adopted here (Geiger, 1966).

GEOSPACE IN THE FUTURE

Having established that the use of geospace is a valid planning option for the future, the question of how it can be applied in the City of Sydney will be addressed in the next issue of this journal.

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Tesselated Pavements in the Sydney Region, New South Wales.

D.F. BRANAGAN and H.C.CAIRNS

Abstract. Twenty five tesselated sandstone pavements, among them perhaps the best examples of the phenomenon anywhere in the world, have been observed on the Hornsby, Blue Mountains and Woronora Plateaux in the Sydney region. We infer that they formed by weathering and erosion processes on an old landsurface, which is now being slowly dissected. While expansion/contraction is the likely cause of formation of the tesselation, the climatic factors involved are not clear. The reason for the lateral limitation of individual pavements and the regional extent of the phenomenon is not yet understood and requires further fieldwork.

Introduction

In an earlier paper, one of us (Branagan, 1968) described an interesting tesselated pavement on the West Head Road, Ku-ring-gai National Park. This is now referred to as the Elvina Track site. At the time the formation of the tesselation was suggested as being possibly the result of metamorphism, caused by a nearby dyke, although thin sections of the sandstone showed little evidence of recrystallisation.

A brief abstract (Branagan, 1973) indicated the presence of several other sites in the Sydney region, but without much elaboration. A longer paper (Branagan, 1983) considered the formation of such pavements in more detail, and the development of tesselation on vertical faces and inclined surfaces , drawing on examples from a number of sites within different rock types, both in Australia and overseas. That paper and the earlier abstract concluded that the formation of the tesselations was the result of weathering/climatic factors, and that metamorphism was not a cause.

However neither publication documented the many fine sites in the Sydney region which have become known to us in the past few years. The present paper discusses in more detail the distribution of the tesselated pavements that have been observed to date in the Sydney region. These are perhaps the best examples of the phenomenon anywhere in the world, and it is surprising that they have attracted so little attention from geologists and geomorphologists. It is certain that the table of 25 sites (Table 1) is not complete, and further fieldwork and photointerpretation should reveal other sites.

One problem that exists is the demarcation of the pavements, and even the decision as to whether tesselation can rightly be said to be present (see Branagan, 1983). In general the boundaries of the patterned ground are gradational. As discussed in the earlier papers the tesselation is not penetrative, but extends perhaps 20cm below the surface. Occasionally penetrative joints may mark the edge of an area of tessellation, and the orientation of major jointing may partly control the development of elongation of the polygons.

The tesselated pavements occur on each of the three plateaux, Hornsby, Woronora and Blue Mountains, (Fig.1) mainly on surfaces of Hawkesbury Sandstone, and will be discussed in this order.

Hornsby Plateau

On this plateau 17 sites have been presently recorded (Table 1, Fig.2).

The largest is the Elvina Track site. This is more extensive than was indicated in Branagan (1968), although it might be possibly regarded as four separate, but closely adjoining surfaces (Fig.3). Taken in all, the

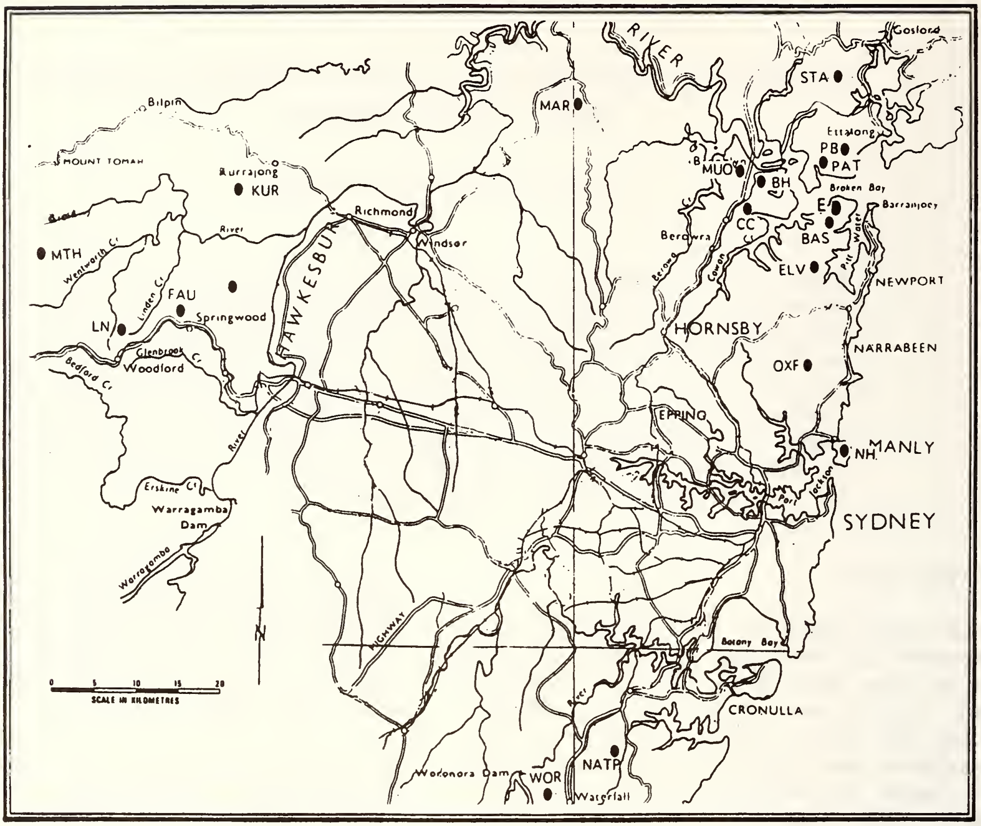

Fig.1. Regional map showing distribution of sites on the Hornsby, Woronora and Blue Mountains Plateaux. (See Table 1 for details of the locations of sites).

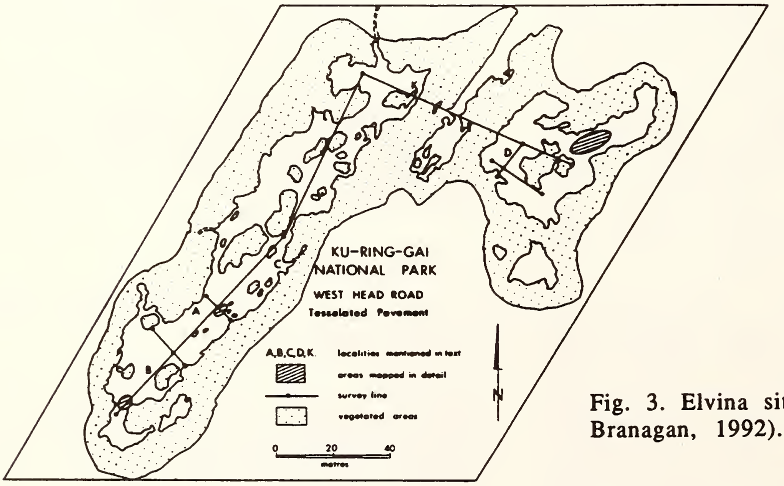

Fig. 3. Elvina site map (from Cairns and Branagan, 1992).

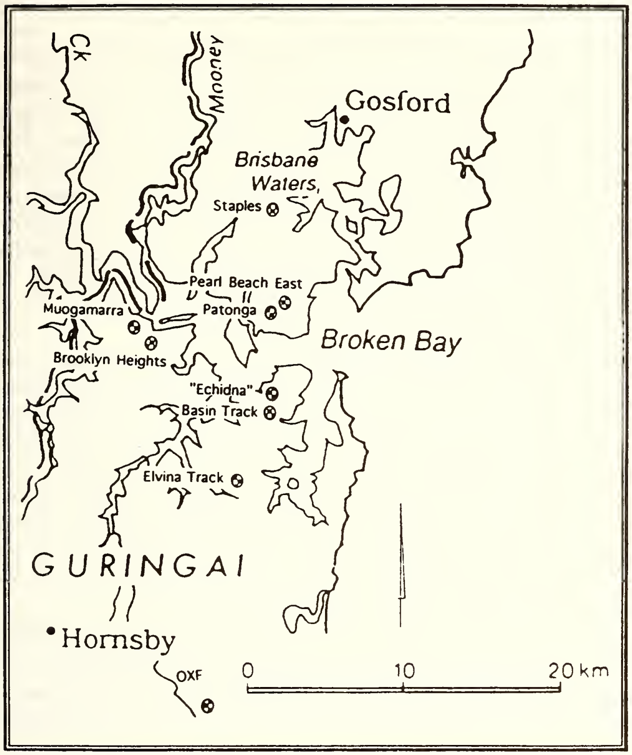

Fig. 2. Map of Hornsby Plateau sites.

4. Aerial view of Elvina site. Note the pits on many polygons. These are discussed in a separate paper (Branagan and Cairns, this volume).

Elvina Track site has an areal extent of about $6500 m^2$. It consists of a main pavement (previously described, Branagan, op. cit.) and several others that extend southeasterly around a rocky knob. The southeasterly edge is marked by a cliffline, the southwestern by a small cliff which is cut by the West Head Road, while the northern edge is covered either by vegetation, soil, sand, or rock rubble, or else dies out and becomes an untesselated sandstone surface.

As indicated in Branagan (op. cit.) the Elvina Track site consists of a variety of polygonal shapes and sizes of tesselations, ranging from elongated rectangles about 6m long by 1m across to almost circular features of about 1m diameter. The large elongated polygons, while relatively uncommon on most pavements, are a feature of the main pavement (Fig.4), the norm of the others being perhaps five or six-sided polygons, varying from .5 to 1.5m in width. Some Aboriginal carvings occur on this site, mostly around the edges. These have been described or mentioned by McCarthy (1954), McDonald (1987), Stanbury and Clegg (1990), Cairns and Branagan (1992), Branagan and Cairns (this volume).

On the plateau surface north from the Elvina Track site tesselation first recorded by Sim (1965) occurs adjacent to the Basin Track. This site is less extensive (about $330m^2$) and is known particularly for its Aboriginal carvings. The polygons are relatively large, usually more than 1m in diameter. A little further to the north, adjacent to (and just west of) the West Head Road is an area ($500m^2$) (referred to hereafter as the Echidna site) where more carvings (of an echidna, and an extensive set of footprints [mundoes]) occur. Sim (1966) says this area is tesselated, but it is better called "incipient" tesselation. A series of elongate cracks has formed on an undulating exposed surface, but there are few complete polygons (Fig.5).

At the northern end of Muogamarra National Park a quite extensive patch of tesselation ($1200m^2$) occurs in a rather coarse-grained sandstone. Here the polygons are large, averaging about 2m across. The polygons often have slightly raised rims, and the lower central areas are somewhat weathered and multi-coloured. Aboriginal carvings occur on this surface.

On the plateau east of Muogamarra, and east of the Pacific Highway and railway, are two sites of interest. A small but perfectly formed zone of tesselation ($100m^2$) occurs on a sloping surface, facing northerly within the closed valley known as Campbells Crater. The sandstone here is quite fine-grained, the polygons average only .5m in width and the rock surface is quite smooth. A few small patches of poorly-developed tesselation occur on the nearby plateau, some 40m higher in elevation than that in the crater.

Overlooking the Hawkesbury Road Bridge and some 4km north of Campbells Crater is a small zone of tesselation ($500m^2$) on a moderately coarse-grained sandstone close to the cliff edge. This surface faces north and unlike the other sites mentioned above slopes quite steeply (Fig.6). It is at an elevation of 185m, some 8m below the highest nearby point on the plateau.

Towards the western side of the Hornsby Plateau, near Maroota, adjacent to the Wisemans Ferry road (Fig.2) is a small zone of tesselation ($200m^2$), containing equidimensional polygons averaging between .5m and 1m width on a generally smooth surface, part of which is flaking off, perhaps the result of bushfires. The pavement is close to an important Aboriginal site (Stanbury and Clegg, op. cit.,96), but does not itself have any observable carvings.

A site adjacent to Oxford Falls contains a variety of polygon shapes over an area of about $4000m^2$ on eight surfaces separated by vegetation. This has been the site of a study of lichen/sandstone relationships by Coates (1986). At this site there is good evidence that the formation of the tesselations is closely related to the present topographic surface.

Several small patches of moderately developed tesselation occur in the vicinity of North Head, and further south a small patch occurs at Balls Head. Branagan (1973) also mentions several small patches on the sloping sides of small cliffs at Northbridge and Clifton Gardens.

North of the Hawkesbury River are five sites of considerable interest. Four of these occur on the plateau surface between Pearl Beach and Patonga, while the other is further north, just east of Staples Lookout on the Woy Woy Road. What we have called Pearl Beach East and West sites are separated by the present Patonga road, and they appear to have always been discrete localities, even if closely adjacent. The eastern site is remarkably similar to the Elvina Track site in some respects (Branagan and Cairns, this volume), although the polygons are, on average, slightly larger, and there are few elongate polygons. It is not as extensive as the Elvina site, being about 1000m^2.

The western Pearl Beach site (400m^2) is generally smoother than the eastern, the polygons are slightly smaller and the surface slopes slightly towards the north.

Just off the Warrah track is a very smooth surface sloping gently north, on which there are well-developed, slightly domed small polygons (300m^2). Adjacent areas of smooth rock of similar composition have no tesselation, and there is no obvious reason for the variation. This site is partly covered by vegetation (mainly lichen), and is poorly drained, the surface often being covered by shallow pools of water.

.5km to the south, and immediately adjacent to the Patonga Road, at a site known as "Crazy Rock" is a quite large zone (1000m^2) of tesselation. This slopes slightly towards the southwest and has been considerably weathered and eroded. There are a few Aboriginal carvings on this surface.

The Staples site is some distance below the general plateau surface. This pavement consists of quite large polygons, some more than one metre across, and covers an area of approximately 300m^2. The sandstone here is very coarse and the rock is both cross-bedded and stained by liesegang banding. There are some pits within the polygons. This surface is just below two separate surfaces, at successively higher levels, neither of which is tesselated, but the highest surface is covered by carvings (Sim, 1966 and Stanbury and Clegg, op. cit.).

Woronora Plateau

Only two tesselated pavements have been seen on this plateau to date. The first of these (through the courtesy of W.Frazer) occurs east of Heathcote, and on the west side of the Port Hacking River, not far below the plateau high point. This is a small pavement (150m^2), with well-formed polygons (.75m diameter) and a fairly smooth surface, slightly case-hardened. The surface is marked by a series of "mundoes" placed within the polygons. A less-well-developed surface occurs some kilometres to the south west, adjacent to the road into Woronora Dam. No "mundoes" are apparent on this surface.

Blue Mountains Plateau

Only four pavements have been studied on this extensive plateau, and several others have been briefly noted, but there are possibly many others yet to be examined.

A small surface (250m^2) is exposed in Ticehurst Park, Faulconbridge, a well-known Aboriginal site (Stanbury and Clegg, op. cit.,109). Here the tesselation occurs on a smooth surface in relatively fine-grained sandstone, close to the edge of a small cliff.

A well-exposed, but small, pavement (30m^2) occurs close to Mt. Hay (Fig.7). Here the polygons are quite deeply indented in fairly coarse sandstone, and are enclosed by a curved iron-rich natural wall. This feature is somewhat isolated from other sandstone surfaces. The iron enrichment is a characteristic of many layers within the sandstones in this area, which may be Narrabeen Group rather than Hawkesbury Sandstone (Osborne and Branagan, 1992). It is topographically the highest pavement yet examined. However a surface is supposed to occur north of Mt Wilson (T. Garbellini, pers. comm.), which has not yet been examined, but which is probably higher.

Two very interesting surfaces occur near Linden in the "lower" Blue Mountains. One of these contains small (less than .5m diameter) polygons, some almost circular, others rectangular (Fig.8), and many are slightly domed. This surface shows evidence of erosion (or possible human clearing) and covers an area of about 300m^2. A second surface, (with a slope of about 10^0 northerly), occurs several kilometres to the north. It consists of coarser grained sandstone over an area of 1000m^2, and has a case-hardened greyish surface with patches of lichen cover. Neither of the Linden surfaces has any Aboriginal carvings on it. Small pavements have been recorded at North Springwood (Branagan, 1985), and at Kurrajong Heights. Tesselated pavements occur near Yerranderie. They will not be discussed in this paper, although they may eventually prove significant in elucidating the history of formation of the pavements.

Discussion

There are various questions which arise:
what controls the size and shape of the polygons?
what controls the lateral extent of each surface?
why are the surfaces so variable in weathering?
what controls the overall distribution of the tesselations ?
when did the polygons form, are they presently forming, being destroyed or both?
What significance and use did they have for the Aborigines?
Of these questions the last is discussed in a separate paper (Branagan and Cairns, 1993, this volume).

The size and shape of the polygons seems dependent to a large extent on the grainsize, texture and coherence of the rock. There is probably a critical thickness of the stratum which determines whether tesselation forms and groundwater probably plays a significant role. A minor factor is possibly the size of the exposed surface, its orientation relative to sun, wind and rain (runoff, retention). The study by Coates (op. cit.) suggests that the activity of algae does not play an important part.

The nature and orientation of the rock surface, in association with the type and duration of ground cover (vegetative, slope wash, rock rubble), and groundwater probably play major roles in determining the extent of tesselation.

Certainly tesselation is best developed in relatively fine-grained, uniform sandstone. At the Oxford Falls site the tesselation can be seen dying out beneath a low shelf of cross-bedded sandstone, which forms the topmost unit on the hillside, and which shows only slight signs of developing quite irregular polygons during casehardening. The tesselated pavement curves over the edge of the cliff before dying out, but less markedly than at the Brooklyn Heights site.

Netoff (1971), in a study of polygonal jointing in sandstone in Colorado, U.S.A., attributed their formation to shrinkage and stated that tesselation formed only in fine-grained sandstones which contained significant amounts of montmorillonite in the clay matrix. However neither of these conditions apply in the Sydney region, where the Hawkesbury Sandstone varies from fine to very coarse-grained, and montmorillonite is absent (Standard, 1969), although expandable, degraded illite is present.

The overall distribution is clearly a function of the presence of quartz sandstone, which is dominant on the three plateaux north, south and west of Sydney. However in many locations where there are good exposures of sandstone, and conditions seem ideal for their formation, tesselation is absent. It is possible that these surfaces may have been previously tesselated and that the polygons have been removed by weathering and then erosion. Nevertheless this seems unlikely, as in places where tesselation of this type is being removed by slabbing off, incipient cracking following the basic polygon pattern seems to form on the newly exposed rock beneath. It is possible that tesselation cracks extend below the exfoliation surface before slabbing actually occurs, but this has not been observed in the present study.

The opinion stated in several tourist brochures, and repeated by Stanbury and Clegg (op. cit., 48), that "the fissures were formed as the sediments dried and hardened into sandstone millions of years ago" cannot be accepted. This idea seems to have been inherited from McCarthy (1954) who gives "geological opinion" but no source for his statement, and it has also been accepted without question by McDonald (op. cit.). Such fossil mudcracking certainly occurs in rocks in the Sydney region, but it is confined to mudrocks, such as shale, and the shapes are different. Mudcracks also often are filled with introduced material (blown or washed in). Such cracking might form the basis of the tesselations in that the pattern could be "repeated" in overlying sediment which covered a mudcracked surface, however such weathering would not produce the elongated type of polygons which occur in some places.

Fig. 5. Echidna site, showing "incipient" tesselation.

Fig. 6. Brooklyn Heights site, showing tesselation on a sloping surface, close to a cliff edge.

Fig. 7. Mt. Hay site, a limited area of tesselation enclosed in an "iron" wall, formed by secondary deposition of iron solutions.

Fig. 8. Linden site, showing a variety of shapes on a fresh surface.

Evidence points clearly to a relationship between an erosional surface and the phenomenon, rather than between an exposed depositional surface and tesselation. In particular the tesselation which occurs on sloping surfaces at the edge of cliffs cannot have formed during sedimentation, so it is likely that none has formed at that time.

As suggested by Branagan (1973) the areas of patterning in the Sydney region seem to be within undulations or on the shoulders of broad valleys, close to, but rarely at the highest elevation on the plateaux. This may mean a certain amount of 'shelter' of the sites from the effects of the weather, and possibly indicates a genetic relation between the tesselation and the formation of the broad valleys developed in the plateaux prior to the incision of the present deep valleys. These were cut by streams during the lowering of sea level in early Pleistocene times. The Brooklyn Heights and Oxford Falls sites are on the edge of such incised valleys, while the Campbell's Crater and Staples sites do not quite fit the suggested model.

It seems unlikely that climatic conditions were severe enough during cold epochs of the Pleistocene to cause shrinkage through freeze-thaw. Although it was postulated in an earlier paper by Branagan (1973) and was rejected by Mitchell (1975) for the Muogamarra site, some such factor may still have played a significant part, perhaps during an earlier epoch in the Tertiary.

The variation in the degree of weathering and apparent freshness of the surfaces suggests that there may have been different periods of formation of the tesselation, but this may be the result of reactivation of the process as surfaces have progressively suffered spalling, either by fire or by the work of lichen, although Coates (op. cit.) does not believe this last-named process was significant.

No direct correlation can be made between the formation of tesselations on rock surfaces and the formation of patterned ground (Washburn, 1956), including stone polygons (Jennings, 1960), which occur essentially in permafrost regions (both episodic and permanent). Nevertheless some general relations may be significant, such as the restricted depth of material involved, the significance of large diurnal and seasonal temperature variation, and possibly even long-term periglacial conditions involved in these soil developments.

Van Dijk et al (1968) in an interesting paper on groundsurface correlations in south-eastern Australia noted that the recognition of older groundsurfaces depended on complex pedological developments. Although their studies were initially concerned with alluvial valley fills and colluvial hillslope mantles, they suggested correlations with lateritic and other "fixed" surfaces, and listed a sequence of five major surfaces, extending well back into the Tertiary.

In a personal communication Van Dijk (1969) suggested the possibility that the formation of the rock surface tesselations in the Sydney region might be related 'to one of our oldest groundsurfaces, the "Kremnos"'. This surface was equated by Van Dijk et al. (op.cit.) with the St. Marys (west of Sydney) laterite profile of Hallsworth and Costin (1953), which would suggest formation in a somewhat humid environment, possibly in the Miocene.

Although the evidence is slight, we conclude that the tesselations are relatively old, no younger than the earliest incision of the plateaux which produced the deep inner valleys. Their location in relatively sheltered positions may indicate formation in the broad upper valleys formed when drainage of the plateaux was by laterally eroding streams rather than downcutting. However complete recording of the location and nature of the sites is necessary to determine the topographic range over which they are found, and other data relevant to elucidating their mode and age of formation. Field studies to this end are continuing.

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TABLE 1 - TESSELATED PAVEMENTS EXAMINED
with Grid References (NSW1:25 000 Series)

HORNSBY PLATEAU, SOUTH OF HAWKESBURY RIVER

Elvina Track, Ku-ring-gai NP-Mona Vale 9130-I-S 388758
Basin Track, Ku-ring-gai NP-Broken Bay 9130-I-N 405814
Echidna Site, Ku-ring-gai NP-Broken Bay 9130-I-N 406824
Muogamarra, Muogamarra NP -Cowan 9130-IV-N 322864
Campbells Crater,-Cowan 9130-IV-N 323825
Brooklyn Heights, Brooklyn-Cowan 9130-IV-N 327855
Oxford Falls-Hornsby 9130-IV-S 370662
Great North Rd - Maroota-9131-III-S 150939
Minor occurrences-Balls Head, North Head, Northbridge, Clifton Gardens

HORNSBY PLATEAU, NORTH OF HAWKESBURY RIVER

Pearl Beach Ridge East-Broken Bay 9130-I-N 407876
Pearl Beach Ridge West-Broken Bay 9130-I-N 406878
Warrah Track (Pearl Beach Ridge)-Broken Bay 9130-I-N 404872
Patonga Ridge (Crazy Rock)-Broken Bay 9130-I-N 400870
Staples, Somersby-Woy Woy Road-Gosford 9131-II-S 409959

WORONORA PLATEAU

Royal National Park-Port Hacking 9129-I-N 194247
Woronora Dam Road-Appin 9029-I-S 115213

BLUE MOUNTAINS PLATEAU

Faulconbridge - Springwood 9030-IV-S693670
Linden -Katoomba 8930-I-S 678673
Linden Ridge -Springwood 9030-IV-S 693716
Mt. Hay -Katoomba 8930-I-S 590755

minor occurrences-North Springwood 774718, Kurrajong Heights

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Stratigraphic and Coal Seam Correlations of the Illawarra Coal Measures in the Ulan and Bylong Areas, Western Coalfield, Sydney Basin, New South Wales

E.K.Yoo

ABSTRACT. Stratigraphic and coal-seam correlations of the Illawarra Coal Measures between Ulan and Bylong, in the western half of the northern sector of the Sydney Basin, have been established on the basis lithofacies studies and downhole geophysical-log profiles. Eastward thickening of the stratigraphic units of the Illawarra Coal Measures occurs across hingelines at Ulan, Wollar and Bylong. The lower-section of the "Ulan seam" is a correlative with the Lidsdale Coal; the upper section of the "Ulan seam" is contemporaneous with the Long Swamp Formation and the overlying Irondale Coal. New units, the Cockabutta Creek Sandstone Member and the Bungaba Coal Member, are named in the Glen Davis Formation, and the geographic extent of the Cockabutta Creek Sandstone Member is shown. The Bungaba Coal Member of the Glen Davis Formation and the Moolarben Coal Member of the State Mine Creek Formation converge towards the western margin of the basin, and form a single coal interval west of the Ulan hingeline.

INTRODUCTION

The stratigraphy of the Illawarra Coal Measures of the Western Coalfield, documented in the Lithgow area by Bembrick (1983)(Table 1), has been widely and successfully applied in the southern part of the Western Coalfield (Standing Committee on Coalfield Geology of New South Wales 1986). However, the present study in the Ulan, Wollar and Bylong areas, in the northern part of the Western Coalfield (Figure 1) indicates that there are significant stratigraphic differences between the two areas, causing difficulties with stratigraphic and coal-seam correlations between them.

The aim of this paper is to establish the stratigraphic and coal-seam correlations between Ulan and Bylong, located in the western half of the northern sector of the Sydney Basin, on the basis of lithofacies and geophysical downhole profiles. A similar study concerning the correlative coal measures in the adjoining eastern half of the Sydney Basin is in preparation.

REGIONAL GEOLOGICAL SETTING

The Illawarra Coal Measures overlie, unconformably and nonconformably respectively, the basement rocks of the Ordovician Lue Beds and the Carboniferous Gulgong Granite near the western margin of the basin, and conformably overlie rocks of the Shoalhaven Group immediately to the east of the margin. The coal measures are overlain by the Triassic Narrabeen Group, which is overlain in turn by the Jurassic Purlawaugh Formation and Pilliga Sandstone in the northern part of the area. West of Ulan, the coal measures are absent, resulting in a nonconformable contact between the Gulgong Granite and the Narrabeen Group (Offenberg *et al.* 1971, Yoo in prep.).

Mesozoic phonolite intrusions are common in the area south of Wollar and Bylong. Tertiary basalt and dolerite also occur as flow-remnants on topographic highs and valley slopes, and as plugs and sills intruded within sporadic diatremes or within the coal measures.

STRUCTURE

The Illawarra Coal Measures dip gently to the east-northeast at an average of 1° from the western margin of the basin to Wollar township. East of Wollar the dip increases to an average of $2^1/_2{}^\circ$, a figure that is sustained to the eastern boundary of the study area. The thickness of the coal measures also significantly increases eastwards across three meridional hingelines located at Ulan, Wollar and Bylong (Figure 2), herein called respectively the Ulan, Wollar and Bylong hingelines. The coal measures are approximately 50 m thick near the western margin of the basin, but thicken by 30 m (from 50 m to 80 m), 40 m (from 80 m to 120 m) and 35 m (from 120 m to 155 m) respectively across the

Table 1

Illawarra Coal Measures - Western Coalfield (Bembrick 1983)

Wallerawang Subgroup	(Farmers Creek Formation	(Katoomba Coal Member
	(	(Woodford Coal Member
	(	(Burragorang Claystone Member
	(	(Middle River Coal Member
	(Gap Sandstone	
Charbon Subgroup	(State Mine Creek Formation	(Moolarben Coal Member
	(Angus Place Sandstone	
	(Baal Bone Formation	
	(Glen Davis Formation	
	(Newnes Formation	(Ivanhoe Sandstone Member
	(Irondale Coal	
	(Long Swamp Formation	(Bunnyong Sandstone Member
Cullen Bullen Subgroup	(Lidsdale Coal	
	(Blackmans Flat Conglomerate	
	(Lithgow Coal	
	(Marrangaroo Conglomerate	
Nile Subgroup	(Gundangaroo Formation	
	(Coorongooba Creek Sandstone	
	(Mt. Marsden Claystone	

three abovementioned hingelines. The thickness of the unit reaches 200 m east of Bylong (Figure 2).

Ulan hingeline

The most westerly thickness increase occurs east of drillhole UCLM C295, close to the western limit of the Denman Formation and the Watts Sandstone (Figure 2). From this hingeline to the western margin, the basal plies of the Lidsdale Coal (Plies E, F and G) are absent (Johnstone & Bekker 1983, Hughes 1991). Also in this drillhole, the Bungaba Coal Member (new name) in the Glen Davis Formation (Figure 2) converges with the Moolarben Coal Member of the State Mine Creek Formation; and the State Mine Creek Formation converges with the Farmers Creek Formation.

Between the Ulan hingeline and the Wollar hingeline, the Lidsdale Coal (the lower section of the "Ulan seam") and the upper section of the "Ulan seam" (equivalent to the total thickness of the Long Swamp Formation) maintain generally a uniform thickness. This same area also marks the western limit of the Gap Sandstone, which thickens abruptly towards the east (figure 2), and thick, fine to medium, lithic sandstone bodies are present in the State Mine Creek Formation.

Wollar hingeline

The Wollar hingeline is a prominent structural feature (Figure 2) located east of drillhole ERC Ulan DDH 24. At this point, the upper section of the "Ulan seam" begins to split, and the beds become widely separated east of this particular hingeline. The Denman Formation and the Watts Sandstone increase substantially in thickness across this hingeline, and the Farmers Creek Formation also thickens. This hingeline trends northwest-southeast through Wollar, Barigan and Growee (Yoo in prep.).

Bylong hingeline

The easternmost hingeline is located east of drillhole AB Bylong DDH 22, where the Lithgow Coal begins to thicken eastwards. The Long Swamp Formation, Denman Formation, Watts Sandstone and Farmers Creek Formation also continue to increase substantially in thickness east of this feature. The State Mine Creek Formation becomes thinner, and the Cockabutta Creek Sandstone Member (new name) of the Glen Davis Formation wedges out west of the Bylong hingeline (Figure 2).

STRATIGRAPHY OF THE ILLAWARRA COAL MEASURES

Most units of the Illawarra Coal Measures thin towards the western margin of the basin, exceptions being the Cockabutta Creek Sandstone Member within the Glen Davis Formation, and the State Mine Creek Formation (Figure 2). The

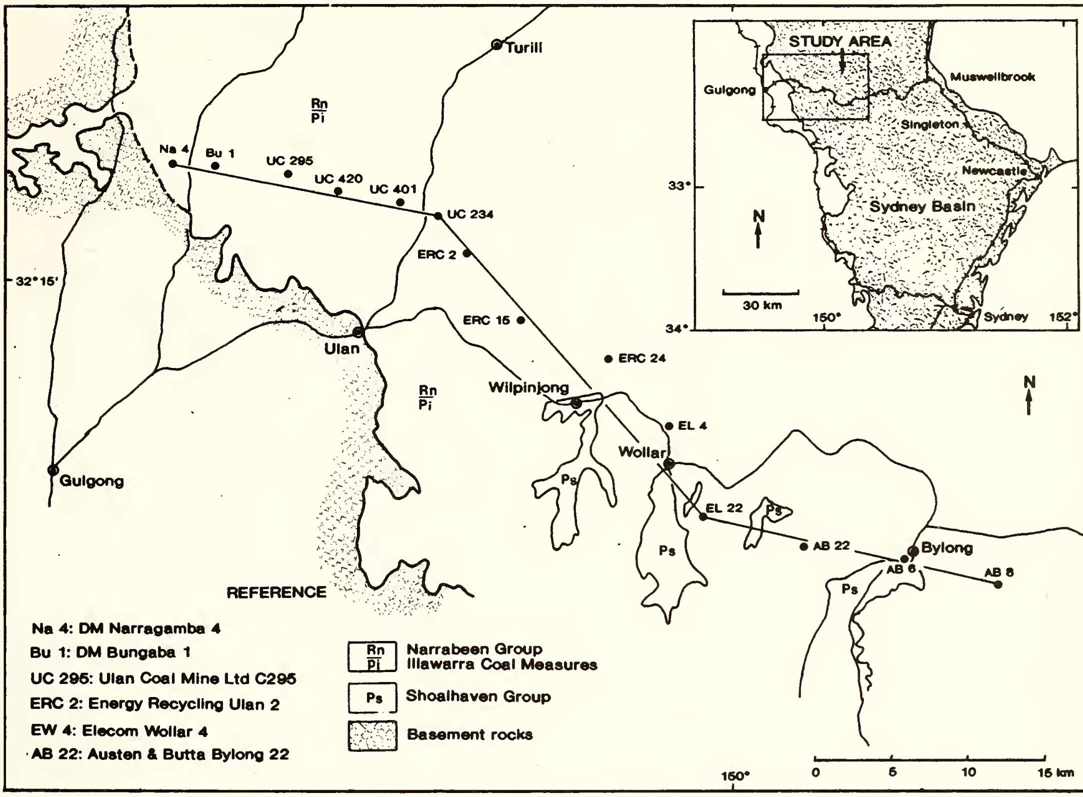

Figure 1. Location map and borehole cross-section line.

Nile Subgroup of the Illawarra Coal Measures and the Shoalhaven Group remain undifferentiated throughout the area due to lack of sufficient information.

Figure 2 has been compiled from lithological and graphic logs and geophysical downhole (density and gamma) logs of 14 selected boreholes. Thirteen formations and four members have been identified within the coal measures; where individual units are correlated with those of the southern part of the Western Coalfield (Bembrick 1983) or with those of the Hunter Coalfield (cf. Beckett 1988), the existing stratigraphic terms for equivalent units in these areas are retained.

Marrangaroo Conglomerate

The Marrangaroo Conglomerate and the lithologically similar Blackmans Flat Conglomerate (see below) consist of quartzose, poorly consolidated, coarse to pebble-bearing sandstone. In the Bylong area, the Marrangaroo Conglomerate is quartz-lithic. Its thickness ranges from 1.5 m on the eastern side of the area to 4 m in the Wollar and Wilpinjong areas to the west. Towards the western margin of the basin, the unit tends to thicken and contains more abundant and larger clasts. The basal part is commonly stained yellow, apparently caused by ground-water movements from the underlying marine Shoalhaven Group.

Lithgow Coal

The Lithgow Coal is developed at the top of a fining-upward sequence formed by the Marrangaroo Conglomerate, and is uniformly dull with minor stone-bands. Agnew and Bayly (1989) indicate that it is correlated with the Coggan Coal, a unit in the Bylong area informally named by McElroy Bryan & Associates (1983, 1985). The Lithgow Coal is up to 5 m thick east of Bylong, but thins abruptly west of the Bylong hingeline (Figure 2). It is represented by a thin carbonaceous claystone band in the Wollar area, and ranges from 0.2 m to 0.8 m thick in the Ulan area.

Blackmans Flat Conglomerate

The Blackmans Flat Conglomerate is

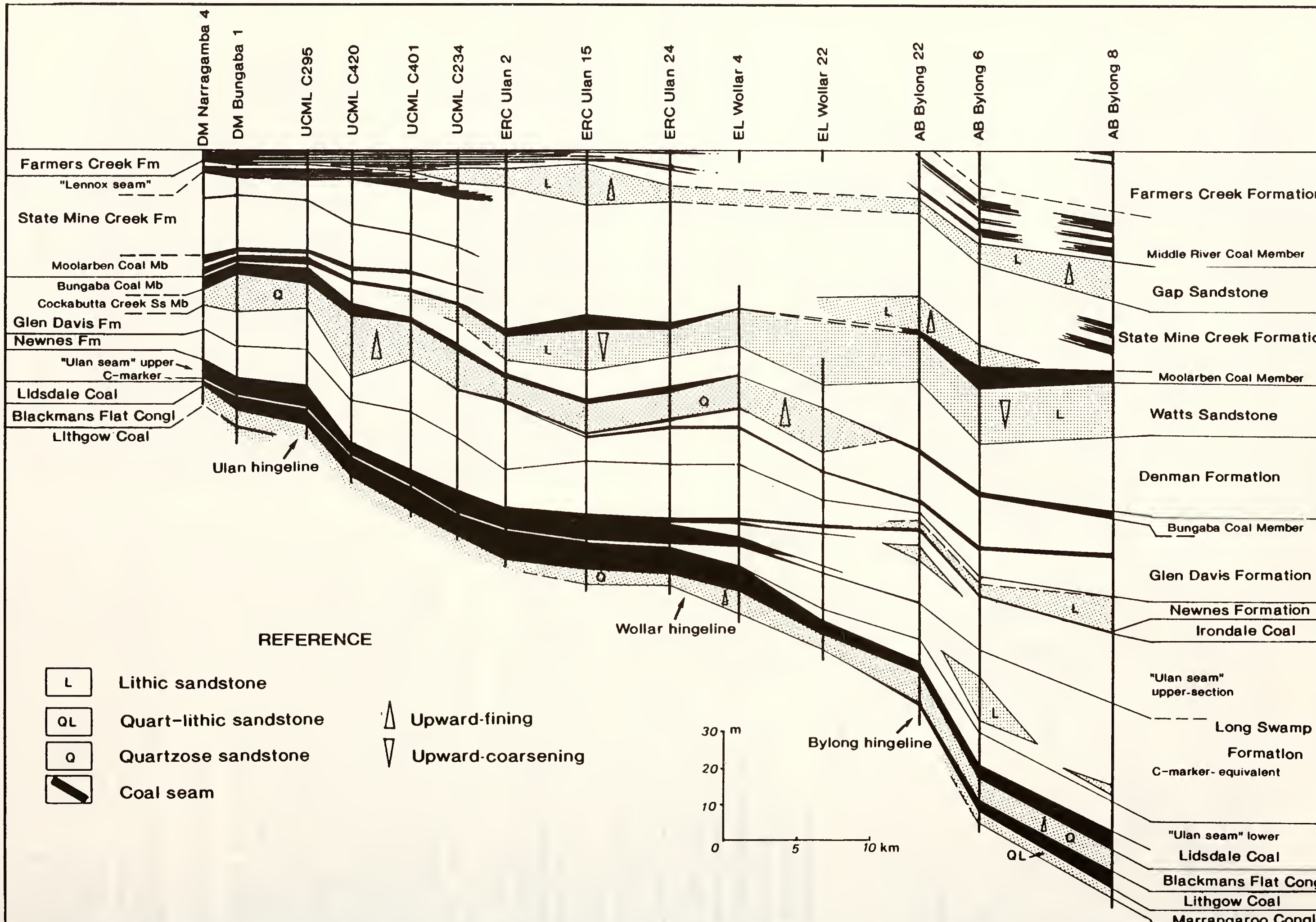

Figure 2. Stratigraphic and coal-seam correlations between Ulan and Bylong. Strippled intervals are conglomerates and sandstones of relatively coarse grain-size.

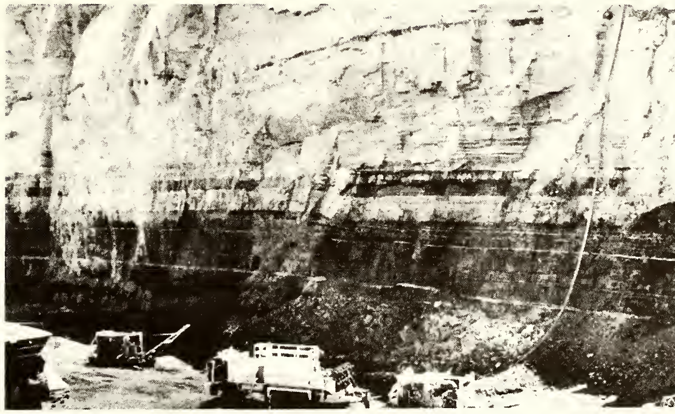

Figure 3. "Ulan seam" at the Ulan Coal Mine opencut overlain by the Newnes Formation. The uppermost ply is correlated with the Irondale Coal. A tuffaceous claystone band (the C-marker) is seen in the middle of the seam. Plies E, F and G (cf. text) are not developed at this locality.

a coarse, often pebble-bearing, quartzose sandstone, developed throughout the entire study area (Figure 2). It is one of the key units within the Illawarra Coal Measures in the Western Coalfield, ranging from 2 m to 5 m in thickness. The unit immediately overlies the Lithgow Coal with a sharp contact and fines upwards. The basal part is very porous.

Lidsdale Coal

The "Ulan seam", informally named in the Ulan area, has been variously correlated with: 1) the Lithgow and Bayswater Coals (Holmes 1975); 2) the Irondale seam and the Newnes Formation in the Ulan-Wollar area (McMinn 1985); and 3) the upper Lidsdale seam (Agnew & Bayly 1989). Shiels and Kirby (1977) also suggested that a thin coal seam beneath the Ulan seam is correlated with the Lithgow Coal. This disparity of opinion has arisen mainly as a result of the paucity of subsurface geological and geophysical information that was available in earlier years to permit correlation of the stratigraphy in the Ulan area with that of the surrounding coalfields.

The "Ulan seam" splits east of Wollar (Shiels & Kirby 1977, Barto & Delaney 1989, Agnew & Bayly 1989). However, no attempt has ever been made to correlate the split plies of the seam with the documented Western Coalfield stratigraphy.

McMinn (1985, p. 304-305) suggested that the "Ulan seam" in the Ulan-Wollar area is slightly younger than the Irondale Coal of the Lithgow and Rylstone areas on the basis of the palynological evidence that *Microreticulatisporites bitriangularis* and *Dulhuntyispora parvithola* first appear simultaneously beneath the Ulan seam. McMinn (1985) further suggested that local erosion of the lower part of the Illawarra Coal Measures in the Ulan area allowed the development of an abnormally thick peat accumulation that subsequently gave rise to the "Ulan seam".

Outside the Ulan-Wollar area, McMinn (1985, p. 305) found that *M. bitriangularis* first appears immediately above the "Ulan seam" and *D. parvithola* first appears either within the Nile Subgroup or at the base of the coal measures. *M. bitriangularis* also appears immediately above the Irondale Coal at the base of the Newnes Formation and *D. parvithola* appears within the thin, non-marine, Gundangaroo Formation of the Nile Subgroup in the Lithgow-Rylstone area.

The results of the present study provide no evidence that significant erosion of the lower part of the coal measures took place in the Ulan-Wollar area. The "Ulan seam" continues in an easterly direction towards Bylong, overlying the characteristic quartzose Blackmans Flat Conglomerate. It is an enigma why ***M. bitriangularis*** **and** ***D. parvithola*** first appear simultaneously beneath the Ulan Seam in the Ulan-Wollar area.

The "Ulan seam" has been divided into seven plies for coal quality purposes (Plies A to G in descending order) by previous workers (Johnstone & Bekker 1983, Barto & Delaney 1989). The seam can be grouped into two sections (upper and lower), separated by a 0.3 m thick tuffaceous claystone (Ply C-marker) occurring in the middle of the seam (Figure 3). The upper section contains Plies A, B and C-upper, and the lower section contains Plies C-lower, D, E, F and G.

Agnew and Bayly (1989) proposed that the "Ulan seam" could be correlated with the upper Lidsdale Coal on the basis of a thin correlatable tuffaceous claystone which has an extraordinarily high gamma response. This claystone band occurs between the upper and lower seams of the Lidsdale Coal in the Rylstone area, and comprises Ply F of the "Ulan seam" at Ulan and Bylong (see Agnew & Bayly 1989, fig. 4).

In the present study, however, it has been found that only the lower section of the "Ulan seam" can be correlated with the Lidsdale Coal. The Lidsdale Coal ranges in thickness from 5 m to 8 m in most of the study area (Figures 2, 4). It thins to 2 m at the western margin of the basin, but thickens to a 13 m interval in the Bylong area including a medium-grained sandstone and claystone band occurring above the coal seam. The Lidsdale Coal contains the best-quality coal plies in the study area.

Long Swamp Formation

The Long Swamp Formation is defined as having its basal boundary at the top of the Lidsdale Coal (Bembrick 1983) and its upper boundary at the base of the Irondale Coal. The formation consists of claystone, mudstone, siltstone, tuff bands, sandstone and thin discontinuous coals. The claystone and siltstone are commonly bioturbated. West of the Wollar hingeline, the formation is represented by a thin tuffaceous claystone band ("Ulan seam" C-marker) and an overlying coal seam (the upper section of the "Ulan seam") (Figure 2).

The upper section of the "Ulan seam" includes Plies A, B and C-upper. The A, B and C-upper plies, totalling up to 7 m thick between Ulan and Wilpinjong, split eastwards into thin multiple, discontinuous coal bands. At Bylong this interval is 20 m thick. The C-marker ply maintains a consistent thickness of 0.3 m from Ulan to Wilpinjong, then thickens eastwards at the Wollar hingeline to split the upper section of the "Ulan seam" further from the Lidsdale Coal (Figure 2). The interval equivalent to the C-marker at Bylong is approximately 25 m thick, and consists of siltstone, lithic sandstone and minor carbonaceous claystone. Density and gamma logs show the seam split throughout the study area (Figure 4).

East of the Wollar hingeline, the Long Swamp Formation contains thick, fining-upward channel sandstone lenses with green and red volcanic pebbles and granules. A similar sandstone occurs in the west Rylstone area (Bayly pers. comm. 1990). These lenses are considered to have been derived from the New England area during uplift of that particular block.

Irondale Coal

As mentioned above, the upper section of the "Ulan seam" is split east of the Wollar hingeline and interfingers there with bioturbated claystone and siltstone of the Long Swamp Formation (Figures 2, 4). The uppermost ply of this section (Ply A top) can readily be traced from Ulan to the Wollar hingeline, where eastward splitting occurs. East of the Wollar hingeline, it is possible to correlate the various split plies between boreholes with the assistance of downhole geophysical log data (Figure 4).

Re-examination of borehole graphics and downhole geophysical logs for the area from Lithgow through Rylstone to Bylong indicates that the uppermost ply of the upper section of the "Ulan seam" at Bylong is correlated with the Irondale Coal of the Lithgow-Rylstone area (Bayly and Yoo in prep.). This confirms the palynological evidence of McMinn (1985) that the top of the "Ulan seam" outside the Ulan-Wollar area can be correlated with the top of the Irondale Coal. The Irondale Coal reaches a maximum thickness of 1.5 m east of the Wollar hingeline.

Newnes Formation

The Newnes Formation in the study area, consists generally of fine to medium-grained, lithic sandstone and interbedded siltstone and claystone west of the Wollar hingeline, and an upward-fining coarse lithic sandstone east of the Wollar hingeline.

The formation conformably overlies the Irondale Coal; its upper limit is marked by the base of a thin coal/ carbonaceous claystone band which is expressed by low density log values (Figure 4). The formation ranges in thickness from 8 m to 13 m west of the Wollar hingeline but thins to 4 m at

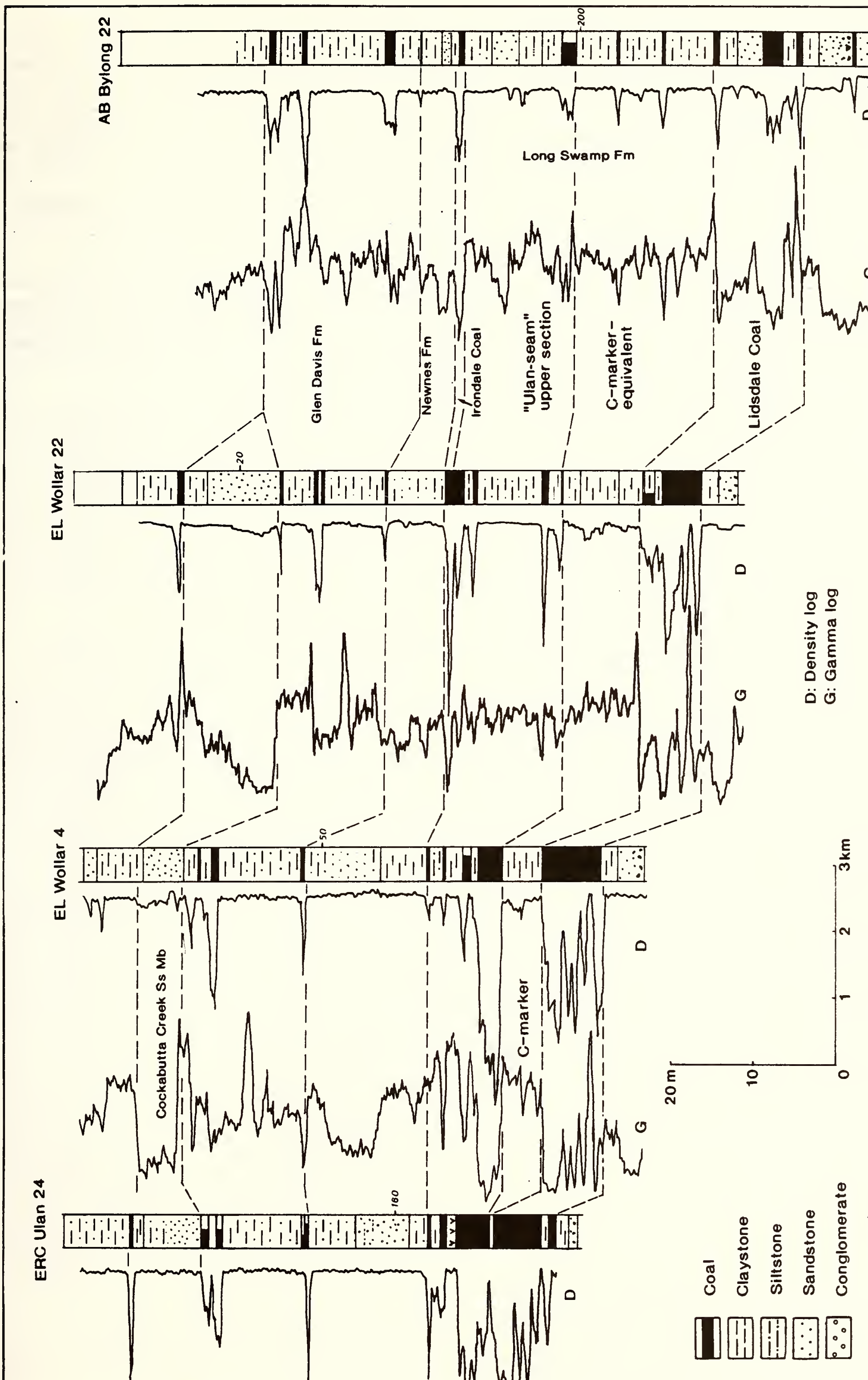

Figure 4. Coal-seam coalescence of the Lidsdale Coal and the upper section of the "Ulan seam" in the lower part of the Illawarra Coal Measures between Wollar and Bylong.

drillhole AB Bylong DDH 4. The sandstone within the formation typically has low gamma log values east of drillhole ERC Ulan 2. This characteristic profile disappears west of ERC Ulan 2, as the lithology of the formation and the lower part of the overlying Glen Davis Formation both become similarly fine to medium-grained lithic sandstone.

Glen Davis Formation

The Glen Davis Formation consists of carbonaceous claystone, claystone, siltstone and sandstone. East of the Wollar hingeline, the claystone and siltsone are commonly bioturbated. The unit is overlain by the Denman Formation east of the Ulan hingeline and by the Moolarben Coal Member west of the Ulan hingeline (Figures 2, 4). It contains two thin, uneconomic coal seams, the upper of which is referred to as the Bungaba Coal Member in this paper. The formation ranges in thickness from 17 m to 26 m throughout the study area.

A thick quartzose sandstone comprises the upper part of the Glen Davis Formation west of the Bylong hingeline. This sandstone is herein named the Cockabutta Creek Sandstone Member, and is interpreted as having been derived from the Gulgong Granite in the immediate west.

Cockabutta Creek Sandstone Member (new name)

The Cockabutta Creek Sandstone Member consists of light grey, quartzose to lithic-quartzose, very coarse-grained sandstone. It fines upward and is poorly cemented towards the base. The thickness ranges from 2.5 m to 9.8 m, and is 7.8 m at the type section.

The type section is taken from JDP Ulan DDH 18, between the depths of 103.83 m and 111.63 m. This drillhole is located 8 km east of Ulan township (Wollar 1:25,000; 8833-2-N, ISG Co-ordinates 377403.7 E, 1427419.7 N).

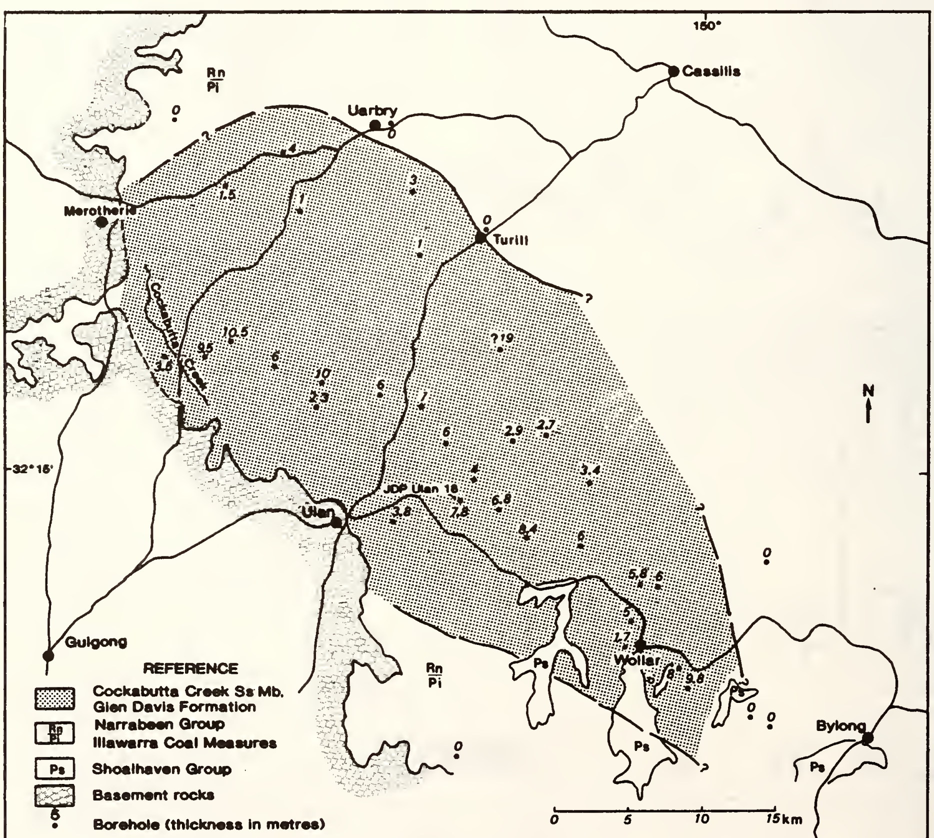

Figure 5. Geographic extent of the Cockabutta Creek Sandstone Member of the Glen Davis Formation.

The sandstone member forms an oval-shaped lobe of approximately 1000km^2 in the Ulan-Wollar area, bounded by Merotherie in the west, Uarbry in the north, Wollar in the east and south, and Ulan in the southwest (Figure 5). It is exposed on the bank of Cockabutta Creek (Narragamba 1:25,000; 8833-4-S, AMG Grid Reference 498 332) and in the Ulan Mine opencut. It is also well exposed in the Goulburn River diversion channel at the Ulan Mine (Conaghan pers. comm. March 1993).

The Cockabutta Creek Sandstone Member is remarkably similar to the Blackmans Flat Conglomerate in that it consists predominantly of quartz, cemented with minor kaolinitic white clay. It has a very porous texture. The member consists of very coarse sandstone with a distinct sharp base, and fines upward. It is considered to have been derived from the adjoining Gulgong Granite in the west, and is strikingly different in lithology from any other part of the formation. The Cockabutta Creek Sandstone Member is overlain by the Bungaba Coal Member developed at the top of the Glen Davis Formation (Figures 2, 6).

Bungaba Coal Member (new Name)

The Bungaba Coal Member is the topmost unit in the Glen Davis Formation. It consists of coal and carbonaceous/tuffaceous claystone. Although this member is thin and variably banded, density-log profiles show it to be continuously developed throughout the study area (Figure 2). At the type section (DM Narragamba DDH 4), it is 3.47 m thick (between 46.97 m and 50.44 m). The drillhole is located 22 km north-northeast of Gulgong (Narragamba 1:25,000; 8833-4-S, ISG Co-ordinates 358210 E, 1438170 N). The member overlies the Cockabutta Creek Sandstone Member and is overlain by a 0.7 m-thick kaolinitic claystone west of the Ulan hingeline and by the Denman Formation east of the Ulan hingeline. West of the Ulan hingeline, this coal member (the lower coal seam in the upper part of the highwall in Figure 6) is coalesced with the Moolarben Coal Member (the middle and the upper coal seams in the highwall in Figure 6) of the State Mine Creek Formation. These coals form a banded coal seam up to 13.6 m thick northwest of Ulan (Bayly 1993). Eastward splitting of the Bungaba Coal Member away from the Moolarben Coal Member with which it is coalesced in the western margin area is illustrated in Figures 2 and 7.

Denman Formation

Synonymy: Baal Bone Formation (Bembrick 1983, p. 110; Standing Committee on Coalfield Geology of New South Wales 1986, p. 156).

The Baal Bone Formation of Bembrick (1983) in the Western Coalfield, the Denman Formation of Britten (1972) in the Hunter Coalfield, and the Dempsey Formation of David (1907) in the Newcastle Coalfield represent the record of a short-lived, widespread marine incursion in those areas of the Sydney Basin (Bembrick 1983). Recent studies within the Western Coalfield (Bembrick 1983, Moloney et al. 1983, Crapp 1985, McElroy Bryan & Associates 1983) and further eastwards, between Bylong and Denman (Holmes 1975, Yoo in prep.) indicate that the genetically-related interval comprising the Denman Formation and the overlying Watts Sandstone has a distinctive and readily recognisable lithofacies in the Illawarra Coal Measures and the Singleton Coal Measures. The interval grades vertically from dark grey claystone through laminated claystone and fine sandstone with common bioturbation, into fine-grained lithic sandstone of possible delta-front environment. Therefore, the term Baal Bone Formation is here regarded as a synonym of the Denman Formation of Britten (1972). The Denman Formation (Standing Committee on Coalfield Geology of New South Wales 1974) has priority over the Baal Bone Formation (Standing Committee on Coalfield Geology of New South Wales 1986), and is proposed to be used in both the Hunter and Western Coalfields. Although the Dempsey Formation has been known to be equivalent to the Denman Formation, the correlation between the two units has not been well established due to discontinuity of the two units over the Lochinvar Anticline and scarcity of drillhole data south of the Lochinvar Anticline. Until further data are available, the term Denman Formation remains valid (Beckett pers. comm.).

The Denman Formation thickens gradually in an easterly direction, from 20 m at Bylong (in AB Bylong DDH 8) to 50 m at Denman (in DM Doyles Creek DDH 13). The western limit of the marine incursion that formed this section occurs in the study area approximately at the Ulan-Turill-Cassilis road (Figure 1). Its northwestern limit is located approximately at Coolah (Yoo *et al.* 1983).

Watts Sandstone

Synonymy: Angus Place Sandstone (Bembrick 1983, p. 110; Standing Committee on Coalfield Geology of New South Wales 1986, p. 156).

For similar reasons to those

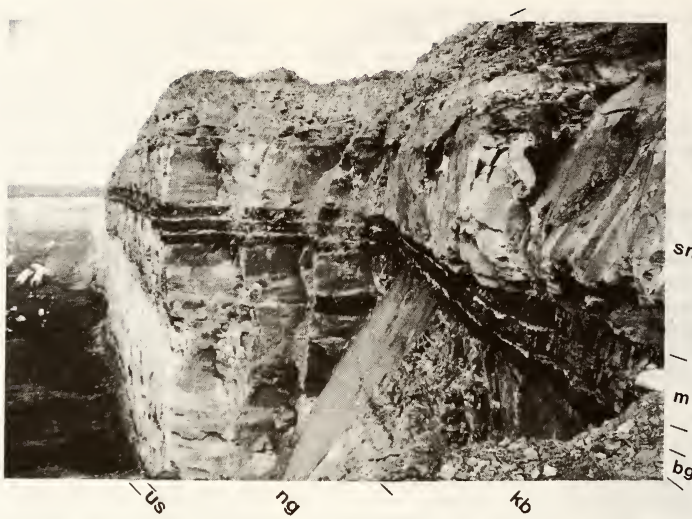

Figure 6. Opencut-mine highwall at the Ulan Coal Mine showing the basal part of the Illawarra Coal Measures documented in this paper and coalesced coal-seam interval at the top of the Glen Davis Formation and the base of the State Mine Creek Formation. The highwall is 50 m high and the exposed succession is as follows: "Ulan seam" (in floor of pit and at base of distant endwall)(us); lithic sandstones of the Newnes Formation and the Glen Davis Formation (light-coloured interval)(ng); Cockabutta Creek Sandstone Member (grey-coloured interval)(kb); Bungaba Coal Member of the Glen Davis Formation (bg); kaolinitic claystone band, representing the base of the State Mine Creek Formation; Moolarben Coal Member of the State Mine Creek Formation (ml); and overlying clastic sediments of the State Mine Creek Formation (sm). The Gap Sandstone and the Farmers Creek Formation are not present here.

applied to the Denman Formation, the Angus Place Sandstone of Bembrick (1983) is regarded herein as a synonym of the Watts Sandstone of Britten (1972). The Watts Sandstone (Standing Committee on Coalfield Geology of New South Wales 1974) has priority over the Angus Place Sandstone (Standing Committee on Coalfield Geology of New South Wales 1986, p. 156), hence, the term Watts Sandstone is used in the present paper.

The Watts Sandstone is 15 m in thickness east of Bylong (in AB Bylong DDH 8) and 28 m at Denman (in DM Doyles Creek DDH 15). It is overlain by the Moolarben Coal Member of the State Mine Creek Formation.

State Mine Creek Formation

The State Mine Creek Formation overlies the Watts Sandstone and is overlain by the Gap Sandstone. It generally contains three coal units, claystone, sandstone and tuff interbeds. The basal seam is the Moolarben Coal Member (Bembrick 1983), and the topmost seam has been informally called the "Lennox seam" (borelogs of JDP Ulan DDH 1 & 2, by Kirby 1975) and the "Goulburn seam" (Hughes 1991). North of the Ulan Coal Mine opencut, this seam and the Middle River Coal Member of the Farmers Creek Formation form one seam approximately 10 m in thickness (Hughes 1991) (Figure 7). The thickness of the formation varies from 20 m to 33 m.

Moolarben Coal Member

The Moolarben Coal Member was defined by Bembrick (1983) as a coal seam developed at the base of the State Mine Creek Formation. The "Goulburn seam" in the Bylong area is correlatable with the Moolarben Coal Member (McElroy Bryan & Associates 1983, McElroy and Rose 1990). The Moolarben Coal Member overlies the Watts Sandstone east of the Ulan hingeline, and coalesces with the Bungaba Coal Member where the Watts

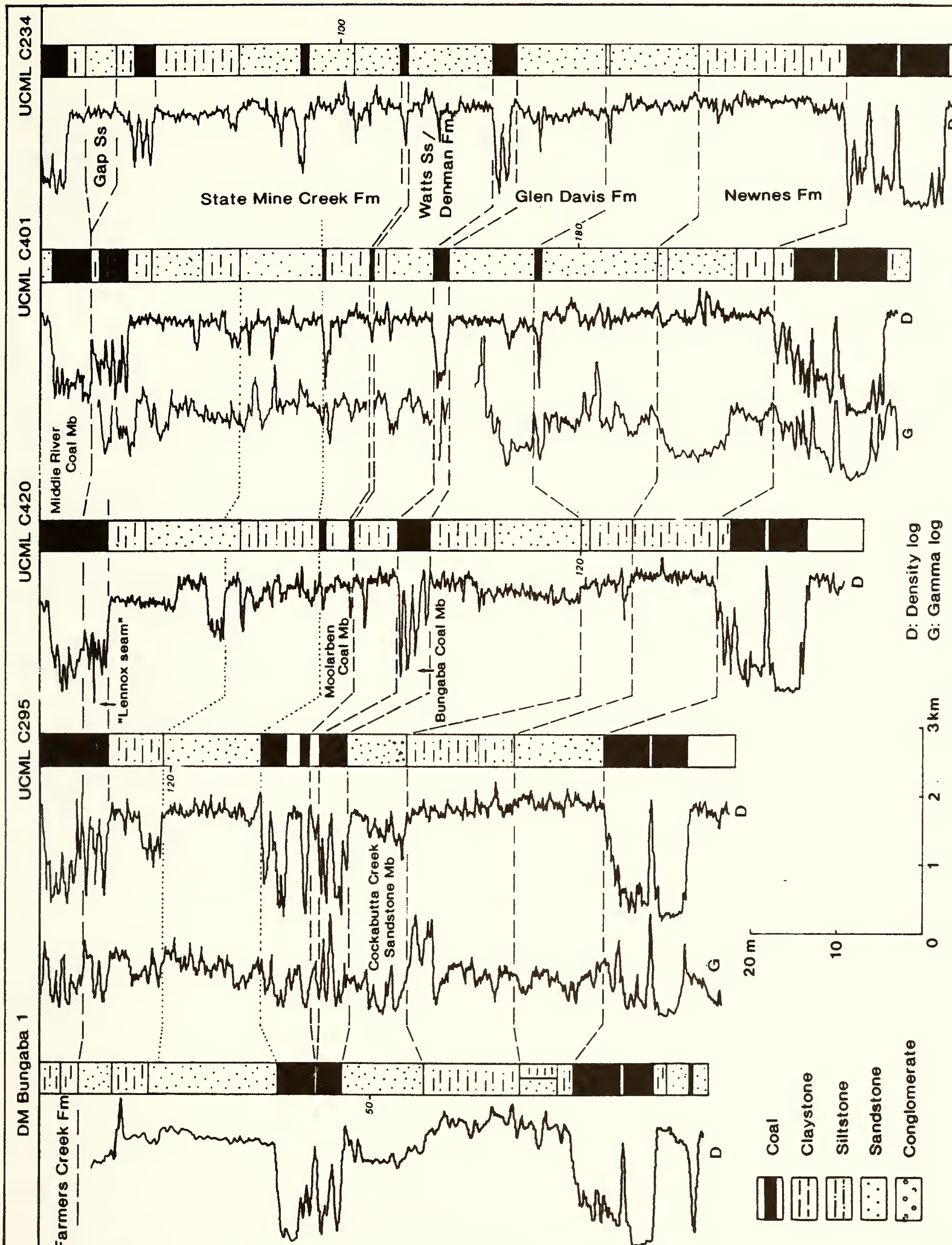

Figure 7. Coal-seam coalescence of the Glen Davis, State Mine Creek and Farmers Creek Formations of the Illawarra Coal Measures in the area immediately north of Ulan.

Sandstone and the Denman Formation have wedged out (Figure 2). The lower limit of the Moolarben Coal Member near the western margin is the top of the kaolinitic claystone band (0.7 m thick in DM Narragamba DDH 4) that occurs towards the middle of the coalesced coal-seam interval. This kaolinitic claystone band can be correlated with the Denman Formation and Watts Sandstone to the east (Figure 2).

The member consists of coal and a number of thin claystone bands. The coals split in an easterly direction as the interbedded claystone bands thicken, and the upper sections of the coal member thin out east of UCML C234 (Figure 2). The member varies in thickness from 1 m to 4.2 m.

The "Lennox seam" (in borelogs of JDP Ulan DDH 1 & 2, Kirby 1975) is the topmost seam of the State Mine Creek Formation, developed locally in the Ulan area. It consists of carbonaceous claystone and thin coal seam. The maximum thickness is 2.23 m at JDP Ulan DDH 1, and it thins out east of UCML C234. The term "Goulburn seam" was used for this interval north of the Ulan Mine opencut (Hughes 1991).

Gap Sandstone

The Gap Sandstone is a persistent off-white to light grey upward-fining, lithic, coarse to very coarse sandstone, commonly with pebbles at the base, and is readily identifiable over most of the study area. It is considered to be a sheet-sand, deposited in a fluvial environment. The Gap Sandstone is generally 4 m to 5 m thick over most of the area, increasing to 10 m in some places. The sandstone thins out towards the western margin of the basin (Figure 2).

Farmers Creek Formation

The Farmers Creek Formation, the uppermost unit of the Illawarra Coal Measures in the Western Coalfield, consists of coal, carbonaceous claystone, tuff, siltstone, claystone and minor lithic sandstone. The formation thins towards the west, being 30 m thick at Bylong, 10 m thick at Wollar and represented by 3 m of coal and tuffaceous claystone at Ulan.

Density-log profiles from the various boreholes indicate that the Farmers Creek Formation thickens eastwards due to the progressive addition of units at the top. The coal/carbonaceous claystone unit at Ulan and the lower part of the Farmers Creek Formation at Bylong appear to correlate with the Middle River Coal Member.

Middle River Coal Member

The Middle River Coal Member is the basal coal seam of the Farmers Creek Formation (Bembrick 1983). The interval was named the "Goulburn seam" in the Ulan area (borelogs of JDP Ulan DDH 1 & 2, by Kirby 1975). It consist mainly of carbonaceous and tuffaceous claystones and thin coal. The member is approximately 3 m in the western margin area, but thickens to 10 m at Bylong.

CONCLUSIONS

Eastward thickening of the stratigraphic units of the Illawarra Coal Measures occurs across hingelines at Ulan, Wollar and Bylong. The Marrangaroo and Blackmans Flat Conglomerates maintain their thicknesses and lithologies throughout the study area. The Lithgow Coal, which is poorly developed at Ulan and Wollar, thickens east of the Bylong hingeline. Only the lower section of the "Ulan seam" is a correlative with the Lidsdale Coal; this interval maintains its thickness throughout the study area. The upper section of the "Ulan seam" maintains its thickness eastwards to the Wollar hingeline, then thickens abruptly to become the Long Swamp Formation. The uppermost ply of the upper section of the "Ulan seam" can be correlated with the Irondale Coal. The Newnes and Glen Davis Formations occur throughout the study area and maintain generally uniform thicknesses. The quartzose Cockabutta Creek Sandstone Member comprises the upper part of the Glen Davis Formation west of the Bylong hingeline. It appears to have been derived from the Gulgong Granite in the immediate west. The Baal Bone Formation and the Angus Place Sandstone are correlatives of the Denman Formation and the Watts Sandstone respectively. Both units wedge out west of the Ulan hingeline where the equivalent interval is represented by a thin kaolinitic claystone band. The Bungaba Coal Member of the Glen Davis Formation and the Moolarben Coal Member of the State Mine Creek Formation coalesce west of the Ulan hingeline. The "Lennox seam" at the top of the State Mine Creek Formation and the Farmers Creek Formation coalesce west of the Ulan hingeline, where the intervening Gap Sandstone wedges out.

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Doctoral Thesis Abstract: ^{19}F NMR of Erythrocytes: 'Split Peak' Phenomenon, Membrane Potential and Membrane Transport

Arron S. L. Xu

Fluorinated solutes such as difluorophosphate (DFP), monofluorophosphate (MFP), hexafluorophosphate (HFP), and trifluoroacetate (TFA) all showed well-resolved ^{19}F NMR resonances when they were added to erythrocyte suspensions. The broader resonances from intracellular solutes were shifted to *high* frequency with respect to their extracellular counterparts.

The ^{19}F NMR chemical shifts of the above-mentioned compounds were shifted to high frequency in the presence of proteins. An increase in temperature also led to a shift of the ^{19}F NMR resonances to high frequency. Results from this work support the hypothesis that the disruption of hydrogen bonding between the fluorine atom and solvent water atoms, by hydrated haemoglobin, is the principal physical basis for the 'split peak' phenomenon seen with erythrocyte suspensions.

The well-resolved ^{19}F NMR resonances of DFP enabled its transmembrane mass-distribution to be determined directly from an erythrocyte suspension. At transmembrane electrochemical equilibrium, the distribution of DFP was governed by the membrane Donnan potential. The membrane potential measured using DFP was independent of the concentration of the probe molecule, and the haematocrit of the suspensions within a large range.

A novel adaption of a ^{19}F NMR magnetisation-transfer technique was derived to measure the rapid membrane transport of DFP. The transport was shown to be mediated exclusively by band-3. The transport was temperature dependent; the 'break-point' temperature of the equilibrium efflux was ~31°C. Under similar conditions, the ratios of the influx rates for solutes at a concentration of 20 mM were DFP : hypophosphite : F^- : Cl^- were 1.0 : 1.5 : 33.0 : 68.1.

The membrane-transport of TFA in human erythrocytes was significantly slower than DFP. By differentiating the inhibition brought about by a number of compounds, including stilbene disulfonates, α-cyano-4-hydroxycinnamate, *p*-chloromercuriphenylsulfonic acid, and N-ethylmaleimide, band-3 was found to be the predominant transporter of TFA uptake into human erythrocytes. A small fraction of the uptake was mediated by the monocarboxylate transporter. Under physiological conditions, transport via simple diffusion via the lipid of the membranes was negligible.

The ^{19}F NMR spectrum showed well-separated quartets arising from beryllofluorides BeF_2, BeF_3^- and BeF_4^{2-}. This phenomenon facilitated the study of the multiple equilibra associated with the complexes in a solution. In erythrocyte suspensions, the ^{19}F NMR spectra showed resonances from the intracellular populations of the complexes shifted to higher frequencies relative to their extracellular counterparts. The erythrocyte membrane-transport of the complexes was completely inhibited by stilbene disulfonates; the results suggested that band-3 was the exclusive transporter for BeF_3^- and BeF_4^{2-}, and intracellular BeF_2 arose as the result of the re-distribution of the various intracellular complexes via the multiple equilibra.

The ^9Be NMR resonances of the complexes were, a quintet, a quartet and a triplet for BeF_4^{2-}, BeF_3^- and BeF_2, respectively, and they overlapped extensively. ^9Be NMR resonances of intra- and extracellular solutes were not resolved. ^9Be NMR decoupling simplified the ^{19}F NMR spectrum. The ^{19}F NMR magnetisation transfer among various complexes in either *cis* or *trans* compartments indicated interconversion among the different species in the *cis* compartment, and the transmembrane exchange occurred within sub-minute time scale.

An abstract from the thesis submitted to the University of Sydney for the degree of Doctor of Philosophy, December 1992.

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DOCTORAL THESIS ABSTRACT

ATLANTIS: A TOOL FOR LANGUAGE DEFINITION AND INTERPRETER SYNTHESIS

Michael John Oudshoorn, B.Sc.(Hons.)

Programming language semantics are usually defined informally in some form of technical natural language, or in a very mathematical manner with techniques such as the Vienna Definition Method (VDM) or denotational semantics. One difficulty which arises from serious attempts to define language semantics is that the resulting definition is generally suitable for a single limited kind of reader. For example, the more formal kind of definition may suit a compiler writer or a language designer, but will be less convenient for other potential classes of reader, such as programmers. The latter frequently make use of some completely separate description (e.g., an introductory text book on the language); not surprisingly, inconsistencies between these separate descriptions and the language definition are commonplace.

This thesis develops a technique for the definition of programming language semantics which is suitable for a wide range of potential readers. This technique employs an operational semantic model which is based on the algebraic specification of abstract data types; the semantic model manipulates multi-layer descriptions of language semantics and supports multiple passes in these descriptions.

The semantic technique described in this thesis lends itself to the semi-automatic generation of an interpreter from the language definition, a fact which acts as an incentive to language designers to produce a formal definition of any new programming language, since the prototype implementation allows experimentation with new language features and their semantics. The system which generates an interpretive implementation from a language definition is called ATLANTIS, A Tool for LANguage definiTion and Interpreter Synthesis, and is also described in this thesis.

August 1992

A THESIS SUBMITTED FOR THE DEGREE OF
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Doctoral Thesis Abstract: Some aspects of the pathogenicity and immunity of bovine leukemia virus infection in cattle and sheep.

MAGTOUF H. GATEI

A series of research studies on bovine leukemia virus (BLV) infection was designed to investigate viral infectivity, oncogenicity and immunological responses in cattle (natural host) and sheep (experimental model). The research also concentrated on the possibility of developing an efficient vaccine against this retroviral infection.

Specific monoclonal antibodies were used to identify lymphocytes bearing surface immunoglobulin, T helper (BoT4), T cytotoxic (BoT8) cells and total T cell phenotypes over a four months observation period. The results showed that the numbers of B cells in BLV infected cattle with persistent lymphocytosis (PL) were significantly ($P<0.01$) higher than those of BLV+PL- and BLV free cows. The percentages of bovine major histocompatibility determinants, BoT4 and BoT8 T cells, were significantly reduced ($P<0.01$) in BLV+PL+ cows.

Serum concentrations of immunoglobulins IgG1, IgG2 and IgM over the same observation period were also studies. There was a significant decrease ($P<0.0001$) in the level of IgM in the sera of BLV+PL+ cattle compared to that in BLV+PL- and healthy cattle. There were no significant differences in IgG1 and IgG2 concentrations between the three cattle groups.

Intravenous inoculation of sheep was used to test the infectivity of blood and nasal and saliva secretions from BLV+PL+, BLV+PL- and BLV free cows. It was found that 200 to 20,000 lymphocytes from BLV+PL+ donors induced infection in recipient sheep within 3 - 8 weeks post infection (P.I.). The inoculation of blood from BLV+PL- donors did not induce seroconversion in recipient sheep over 24 weeks of the observation period. Inoculation of saliva and nasal secretions from all BLV infected donors failed to bring about BLV transmission. A significant but transient increase ($P<0.05$) in the peripheral blood lymphocytes was observed in recipient

Twelve sheep were injected with phytohaemagglutinin cultured peripheral blood mononuclear cells from a naturally infected BLV+PL+ donor cow and their responses compared to 7 control sheep. The massive appearance of lymphoid cells in the blood of infected sheep indicated tumour development as confirmed histologically by peripheral lymph node (LN) biopsy performed at the time of lymphocyte proliferations. Nine out of 12 sheep (75%) died due to lymphosarcoma over a 10 - 22 months period. Gross tumours were usually found in the heart and mesenteric LNs of all leukemic sheep. Occasionally, the tumours were also detected in the abomasum, urinary tract and uterus. The liver, spleen, kidney and lung showed no solid tumours but were infiltrated with malignant lymphoblastic cells whether or not they showed gross involvement. A significant transient elevation of circulating lymphocytes in these sheep was also observed at 2 weeks after infection.

Synthetic overlapping peptides covering the entire sequence of the BLV gp51 antigen (Ag) were tested on peripheral blood mononuclear cells (PBMCs) from BLV infected and healthy cattle and sheep to determine the immunodominant T cell epitopes. The results provide evidence that residues corresponding to the sequences 61 - 70 and 131 - 140 amino acids of the gp51 Ag constitute the immunogenic sites of T4 (CD4) and T8 (CD8) epitopes respectively. The incorporation of these sites may be useful in the development of an efficient vaccine against BLV infection.

Vaccination of recipient sheep with vaccinia virus vectors expressing BLV envelope (*env*) gene (gp51 and gp30) or gp51 alone was carried out. The recipient sheep were subsequently challenged with 4×10^4 PBMCs from a BLV+PL+ donor cow. Vaccination with recombinants of BLV *env* gene induced high levels of T4 proliferation following booster vaccine inoculation. At two weeks after challenge, these sheep developed a slight increase in the gp51 antibody titres. These titres gradually decreased to constant and low levels at 8 months following challenge and remained so over the 16 month observation period. The cytotoxic T cell responses were measured at 16 months after challenge. High levels of cytotoxic activity were observed in sheep vaccinated with BLV *env* gene. At 8 weeks after challenge, these sheep were negative for BLV as detected by the polymerase chain reaction (PCR) and remained so throughout the observation period. Sheep vaccinated with gp51 only and BLV infected sheep (controls) showed titres which gradually rose after an initial delay to a high level which was maintained over 16 months following challenge. These sheep were positive for BLV as detected by PCR continuously after infection. Results obtained here indicated the high immunogenicity of the BLV *env* gene and its capability to induce an immunological memory response in sheep.

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(Manuscript received 8-6-1993)

Journal and Proceedings, Royal Society of New South Wales, Vol. 126, p.90-91, 1993
ISSN 0035-9173/93/010090-02 $4.00/1

DOCTORAL THESIS ABSTRACT: PROVENANCE, DIAGENESIS AND RESERVOIR CHARACTERISTICS OF SANDSTONES OF THE GREAT AUSTRALIAN BASIN SUCCESSION IN NSW.

Fuxiang He

The Middle Jurassic and lower Cretaceous sandstones of the Great Australian Basin (GAB) in NSW (i.e., Eromanga and Surat Basins) comprise two petrofacies: a fluvial quartzose petrofacies and a lacustrine to marginal-/shallow- marine volcanolithic petrofacies. Detrital minerlogy, chemical composition of detrital feldspars (AnAbOr%), detrital mode (QFL%) and regional petrofacies distribution of these sandstones indicate the existence of two major provenances: for the quartzose sandstones, a dominantly cratonic provenance consisting of plutonic/metamorphic basement rocks and/or older sedimentary successions flanking the GAB on the west and south; and for the volcanolithic petrofacies which are rich in andesitic VRFs, a mainly contemporary volcanic orogen located along the northeastern continental margin of Australia. A regionally developed stratigraphic alternation of these two petrofacies defines a recurrent petrologic cycle that manifests contemporary episodic tectonic activity of the volcanic orogen - craton couplet. The Early Cretaceous marine transgression in GAB also extended into the Lower Cretaceous Murray Infrabasin (MIB), but the lithic sandstones of MIB are rich in metamorphic rock-fragments reflecting local provenances different from those that sourced the GAB proper.

Diagenetic processes in the sandstones include physical compaction, clay infiltration (in some quartzose sandstones), dissolution/alteration of labile grains (e.g., VRFs, feldspars and mica) and cementation. In the volcanolithic sandstones, the diagenetic minerals comprise smectite, zeolite, kaolinite, carbonate and minor chlorite and illite; in the quartzose sandstones, the suite consists of kaolinite and quartz plus some carbonate and minor smectite and chlorite. Dissolution and cementation (and the occurrence of secondary porosity) in the volcanolithic sandstones are believed to be related to the acidic pore-fluids partly derived from diagenesis of the intercalated organic-rich mudrocks. The chemical diagenesis (and the development of secondary porosity) in the quartzose sandstones, which constitute some of the main aquifers in the Great Artesian System, results from the interaction between the meteoric pore-fluid and sandstone constituents.

In the lithic sandstones, core porosity ranges from 24.0% to 40.0% (with mean 35.0%), permeability from 1.8 to 4805.2 (md) (with mean 125.0 md); in the quartzose sandstones, these values are 16.3% to 34.2% (with mean 29.0%) and 1.3 - 18400.0 (md) (with mean 676.1 md) respectively. Results of petrography, SEM and mercury intrusion porosimetry show that the volcanolithic sandstones contain mainly microporosity, and the quartzose sandstones contain mainly primary and secondary intergranular porosity. The distribution patterns of porosity and permeability in the lithic and quartzose sandstones have good correlations with their respective depositional environments.

Parameters influencing sandstone porosity and permeability were examined using stepwise multiple regression. Porosity of the lithic sandstones ($Q < 50.0$ whole-rock%) is closely related to sediment age, content of detrital quartz (Q) and pore-fillings and burial depth (the multiple correlation coefficient $r = 0.81$); for the quartzose sandstones ($Q > 50.0\%$), the parameters are burial depth, formation temperature and pore-fillings ($r = 0.78$); porosity of very quartzose sandstones ($Q > 75.0\%$) is correlated closely with sediment age and grain-size ($r = 0.85$). Permeability of the lithic sandstones is related to pore-fillings, burial depth, detrital quartz and pore-fluid chemistry ($r = 0.66$); for the quartzose sandstones, the parameters are grain-size, burial depth, formation temperature and sediment age ($r = 0.75$).

Factor analysis reveals the relationship among the petrological and petrophysical variables, and the relationships between these variables and the geological processes of source-rock weathering, sediment transportation and deposition, and diagenesis. Four factors have been establised: Factor I is defined by grain-size, sorting, and pore-fluid chemistry; Factor II, defined by porosity and permeability and the content of matrix and detrital quartz; Factor III is defined by formation temperature, burial depth and sediment age; Factor IV is defined by the content of cements.

Based on the existing geological and geochemical evidence, there exists no petroleum source within the Eromanga

Basin succession in NSW. In South Australia and Queensland, some of the Eromanga Basin hydrocarbon was likely generated in the Middle Jurassic Birkhead Formation and the Upper Jurassic - Lower Cretaceous Murta Member/Mooga Formation; but much of the Eromanga Basin hydrocarbon is likely to have been derived from the underlying Cooper Basin source rocks.

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Annual Report of Council

FOR THE YEAR ENDED 31 MARCH 1993

PATRON

The Council wishes to express its gratitude to his Excellency Rear Admiral Peter Sinclair, AO, Governor of New South Wales, for his continuing support as Patron of the Society.

MEETINGS

Eight General Monthly Meetings and the 124th Annual General Meeting were held during the year. The average attendance was 24 (range 15 to 36). The Annual General Meeting and seven of the General Monthly Meetings were held at the Australian Museum. A summary of proceedings is set out in a report attached.

A Special Joint Meeting with ANZAAS was held on 17 August 1992 in the Hallstrom Theatre, Australian Museum. Dr. Ditta Bartels, Director of European Affairs at the University of New South Wales, spoke on " Getting more out of Australian Science - Lessons from Europe".

The Biennial Liversidge Research Lecture of the Society was held on 14 October 1992 in the School of Chemistry, University of Sydney. Professor Sever Sternhell of that University delivered a lecture on "Studies in Bonding and Non-bonding".

The Poggendorf Memorial Lecture was held on 8 December 1992 in conjunction with the Agricultural Retired Officers Association at the City of Sydney R.S.L. Club. Mr E.J. Corbin, General Manager, Sludge Applications Programs, New South Wales Department of Agriculture, spoke on " in search of the golden crop, an argosy of crop adaptation".

The Society was co-sponsor of a joint meeting held on 16 February 1993, with the Institution of Engineers (Australia) Sydney Division, the Australian Nuclear Association and the Australian Institute of Energy. The meeting was addressed by Mr Stephen Jones, Super Computer Manager at A.N.S.T.O., who spoke on "The Use of Supercomputers in Industry".

An Annual Dinner was held on 13 March 1993, at the Holme and Sutherland Rooms, University of Sydney Union. The guest of honour was Professor S.K. Runcorn, FRS. The President, Dr F.L. Sutherland, welcomed the guest of honour and invited him to deliver the Occasional Address. Professor Runcorn then presented the Society's Awards for 1992, (except for the Clarke Medal). He presented the Society's Medal to Mr Kim Ford (a vice President), the Edgeworth David Medal jointly to Dr Keith Nugent and Dr Peter Goadsby and the Walter Burfitt Prize to Professor George Paxinos and Professor Istvan Tork (deceased). Each recipient delivered a few words of thanks to the Society. Associate Professor Denis Winch then proposed a vote of thanks to Professor Runcorn. A total of 46 members and their guests attended.

Eleven meetings of Council were held at the Society's Office,134 Herring Road, North Ryde. The average attendance was fifteen.

PUBLICATIONS

Volume 125, parts 1 & 2 and Volume 125, parts 3 & 4 of the *Journal and Proceedings* were published during the year. They incorporated twelve papers, and the Occasional Address by His Excellency, Rear-Admiral Peter Sinclair, the Patron, at the Annual Dinner and Presentation of Medals in March 1992, together with the Annual Report of Council for 1990-91, Biographical Memoirs and the Official Opening Address at the Summer School on "Communication" held in January 1991 by the Hon. R Free, Minister for Science and Technology. The Presidential Address for 1992 was also included. Council is again grateful to the voluntary referees who assessed papers offered for publication

Ten issues of the Newsletter were published during the year, and Council thanks the authors of short articles for their contribution.

Several requests to reproduce material from the *Journal and Proceedings* were approved by Council.

MEMBERSHIP

The membership of the Society as at 31st March, 1993, was:

Patron	1
Honorary members	14
Life Members	21
Ordinary members	199
Absentee members	16
Associate member	5
Retired Members	23
Spouse Members	12
Total	290

The following new members were elected and welcomed into the Society.

David Warwick BAGGS
Robert John COENRAADS

One Associate Member was elected and welcomed into the Society.

Bronson STEELE

Council elected the following Life Members to the Society during the year:

Dr Maxwell BANKS
Mr H.E. BROWN

The award of Honorary Membership was bestowed on Professor S.K. Runcorn FRS of the University of Newcastle-upon-Tyne, U.K. in February 1993.

With great regret, the Council received news during the year of the deaths of the following members:

Dr Henry George GOLDING
Dr Stanley Charles BAKER

AWARDS

The following awards were made for 1992:

Clarke Medal (in Geology):
Professor Alfred Edward Ringwood, Research School of Earth Sciences, Australian National University

Edgeworth David Medal (research under the age of 35 years)
Awarded jointly:
Dr Keith Alexander Nugent, School of Physics, University of Melbourne.
Dr Peter James Goadsby, Department of Neurology, University of New South Wales.

Royal Society of New South Wales Medal:
Mr William George Kinvig ('Kim') Ford, Past President and present Councillor of the Society.

The Walter Burfitt Prize (Awarded Jointly):
Professor George Paxinos, School of Psychology, University of New South Wales.
Professor Istvan Joseph Tork (deceased), School of Anatomy, University of New South Wales.

The Cook Medal and the Olle Prize were not awarded this year.

OFFICE

The Society continued during the year to lease for its office and library half a share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of Macquarie University campus. The Council is grateful to the university for allowing it to continue leasing the premises.

Mrs Margaret Evans, who had been the Society's Assistant Secretary for the previous

20 months, submitted her resignation at the beginning of 1993. Council wishes to thank Mrs Evans for her valuable contribution to the Society, Ms Francis Bluhdorn has accepted the position of Assistant Secretary on a temporary basis.

The office expanded its service to members with the installation of an answering machine.

LIBRARY

Acquisitions by gift and exchange continued as heretofore, the overseas and most Australian material being lodged in the Royal Society of New South Wales' Collection in the Dixson Library, University of New England. The remainder of the Australian material was lodged in the Society's office at North Ryde. The Council thanks Mr Karl Schnude, Librarian, University of New England, for his continuing care and concern in ensuring the smooth operation of the Royal Society Collection and associated inter-library photocopy loans.

An accession list for all material lodged at the Society's office during 1992/93 has been prepared.

Accommodation for the Society's holdings remains limited. Nevertheless, most of the large historical collection housed in glass-fronted cabinets is in reasonably good condition. Some investigation has been undertaken of the most appropriate course of action required to restore some of the more valuable monographs.

NEW ENGLAND BRANCH REPORT

The following successful meetings were held by the Branch during this year:

Tuesday 21 July 1992:
Dr E.C. Potter, Vice-President of the Society spoke "On being interested in the Extreme".

Friday 9 October 1992:
Professor Hawkins, Vice-Chancellor, University of New England addressed a special meeting for students on "The Future of Science at the University of New England ".

Tuesday 20 October 1992:
Associate Professor Peter Flood, Department of Geology and Geophysics, University of New England spoke on "Australia and the Ocean Drilling Programme."

Thursday 30 October 1992:
Professor Fredrick Chong, formerly Professor of Mathematics, University of Auckland, Foundation Professor of Mathematics at Macquarie University and Emeritus Professor of Mathematics at Macquarie University spoke on " A case study of CAT scans and PET scans to illustrate the beauty and power of Mathematics".

SUMMER SCHOOL

This year's Summer School "Science in Medicine", held from 18th to 22nd January 1993 at Macquarie University, was again a great success. One hundred and thirty nine senior high school students from 22 State Schools and 39 private schools state wide attended the week long activities.

Nineteen highly qualified speakers from academic institutions and from governmental and private organisations addressed the students. Two half day excursions to industrial institutions were undertaken. The Summer School was organised by Mrs M. Krysko v. Tryst (Convenor) on the Society's behalf.

Visits were made to the Royal Prince Alfred Hospital and to Telectronics (Tachycardia Operations). The Summer School was opened by the Honourable R.A. Phillips, N.S.W. Minister for Health in the presence of the Society's President and the Vice-Chancellor of Macquarie University who welcomed the students to the University campus.

Council wishes to thank the Honourable Mrs Virginia Chadwick, N.S.W. Minister for Education and Youth Affairs for supporting the Summer School, and to Mr A. Tink, MP and Member for Council of Macquarie University.

Council also expresses sincere thanks to the speakers and organisers of visits whose addresses and demonstrations helped to make the Summer School such an outstanding success. Council's appreciation is also extended to Mrs Krysko v. Tryst and to the various Councillors who assisted the Convener and chaired sessions.

Special thanks go to Prof. Anthony Basten of University of Sydney for so generously advising the organisers on programming the Summer School; to Mrs W. Swaine who so expertly helped during the excursions and by executing the Summer School students' certificates; to Dr and Mrs Lin Sutherland for the hospitality extended to country students of the Summer School; and, to Mrs J. Lowenthal, Mrs M. Potter and Miss N.G.E. Sutherland for their assistance during the week.

Telecom Australia is thanked for sponsoring the booklet of Abstracts of the various addresses delivered during the Summer School 1993.

An analysis of participating students and high schools was prepared.

ABSTRACT OF PROCEEDINGS

April 1, 1992

(a) The 1024th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The President, Dr E.C. Potter, was in the Chair and 27 members and visitors were present.

Robert John Coneraads and David Warwick Baggs were elected to membership.

(b) The 125th Annual General Meeting. The Annual Report of Council for 1991/92 and the Financial Report for 1991 were adopted, and Messers Wylie and Puttock were elected Auditors for 1992.

The following Awards for 1991 were announced:

Cook Medal:
Professor Graeme Milbourne Clark
Clarke Medal (in Botany):
Dr Shirley Winifred Jeffery
Edgeworth David Medal:
Dr Mark Stephen Harvey
Royal Society of New South Wales Medal:
Associate Professor Denis Edwin Winch

The Archibald D. Olle Prize and The Walter Burfitt Prize were not awarded in 1991.

The Following Office-Bearers and Council were elected for 1992-1992:-

President:	Dr F.L. Sutherland
Vice-Presidents:	Dr A.A. Day Mr G.W.K. Ford Mr H.S. Hancock Professor J.H. Loxton Dr E.C. Potter
Honorary Secretaries:	Mr J.R. Hardie Mrs M. Krysko v. Tryst (editorial)
Honorary Treasurer:	Assoc Professor D.E. Winch
Honorary Librarian:	Miss P. M. Callaghan
Members of Council:	Mr C.V. Alexander Dr R.S. Bhatal Dr D.F. Branagan Dr G. Gibbons Dr G.C. Lowenthal Mr E.D. O'Keefe Assoc Professor W.E. Smith Dr D.J. Swaine
New England Representative:	Professor S.C. Haydon

The retiring President, Dr E.C. Potter, delivered his presidential address entitled "On being interested in the extreme". A vote of thanks was proposed by Dr D Swaine.

May 6, 1992

The 1025th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The President, Dr F.L. Sutherland, was in the Chair and 36 members and visitors were present.

Mr Gregory Mortimer presented an address on "The Risk of Cold Injury".

June 3, 1992

The 1026th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The President, Dr F.L. Sutherland, was in the Chair and 20 members and visitors were present.

Mr Barry Pearce, Senior Curator of Australian Art at the Art Gallery of New

South Wales presented an address on "Art and Science".

July 1, 1992

The 1027th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The President, Dr F.L. Sutherland, was in the Chair and 15 members and visitors were present.

Dr Trevor A. Johnston, Research Fellow, Department of Linguistics, University of Sydney gave an address on "A General Introduction to Australian Deaf Sign Language (AUSLAN) and its Relationship to English".

August 5, 1992

The 1028th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The Acting President, Dr E.C. Potter, was in the Chair and 23 members and visitors were present.

Dr Don Boland addressed the meeting on "The Judgment of Paris- A discourse on the Relationship between Philosophic and Scientific Truth".

September 2, 1992

The 1029th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The Acting President, Dr F.L. E.C. Potter, was in the Chair and 27 members and visitors were present.

Professor M.R. Bennett, Professor of Physiology and Director of the Neurobiology Research Centre, University of Sydney spoke on "The Brain, the Centre for Research in the 21st Century".

October 7, 1992

The 1030th General Monthly Meeting was held in the Hallstrom Theatre at the Australian Museum, Sydney. The President, Dr F.L. Sutherland, was in the Chair and 18 members and visitors were present.

Dr R. A. L. Osborne of the School of Teaching and Curriculum Studies, University of Sydney gave an address entitled "New Light on Old Caves".

November 4, 1992

The 1031st General Monthly Meeting was held at the University of Western Sydney (Nepean), Kingswood. The President, Dr F.L. Sutherland, was in the Chair and 16 members and visitors were present.

The address was given by Associate Professor David Bailey, Head of the Department of Physics in the Faculty of Science and Technology, University of Western Sydney who spoke on "Physics: Teaching, Learning, Thinking".

ERRATA: Vol. 125 Parts 3 and 4

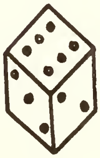
(i) p 82 E.C.Potter 'On being Interested in the Extreme':
right hand column, 11th line from top:
"... and thus covers 200 metres" should read
"... and thus covers 100 metres".

right hand column, 12th line from top:
".the same speed to complete 100 metres.."should read:
".. the same speed to complete 200 metres..".

(ii) p 84 E.C.Potter 'On being Interested in the Extreme':
Caption for Fig.2:
o--o men Middle-distance equation
" 0.507" should read " – 0.507 "

(iii) p 90 E.C.Potter 'On being Interested in the Extreme':
Fig. 6 The 16 different stanrd dice.

Bottom right-hand die should show the 'twos' on the opposite diagonal of the face thus:



Summer School 1992: Participants in the Summer School on "Science in Medicine", January 1992, held at Macquarie University.
Top photo: front row right- Mrs.M.Krysko v. Tryst, Convener of the Summer School. 3.row right- Miss P.M.Callaghan, Hon. Librarian. 4.row right- Dr. D.J.Swaine, Member of Council. Last row to left of centre- A/Prof. W.E.Smith, Member of Council.
Lower photo: front row right- Mrs. M.Krysko v. Tryst, Convener of Summer School. 2.row left- A/Prof. D.E.Winch, Hon. Treasurer; right (with sunglasses) Dr. F.L.Sutherland, President of the Society.

FINANCIAL STATEMENTS FOR THE YEAR
ENDED 31st DECEMBER

AUDITORS REPORT TO THE MEMBERS

Scope

We have audited the attached financial statements (the accounts), being balance sheet, accumulated funds account, notes to the accounts and income and expenditure account, of The Royal Society of New South Wales for the year ended 31 December 1992. We have conducted an independent audit of these accounts in order to express an opinion on them to the members of the society.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the accounts are free of material misstatement. Our procedures included examination on a test basis, of evidence supporting the amounts and other disclosures in the accounts, and the evaluation of accounting policies and significant accounting estimates.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion

In our opinion the accounts of The Royal Society of New South Wales are properly drawn up:

(a) so as to give a true and fair view of the state of affairs of the society at 31 December 1992 and of the results of the society for the year ended on that date; and

(b) in accordance with Statements of the Accounting Concepts and applicable Accounting Standards.

WYLIE & PUTTOCK
Chartered Accountants.

ALAN M PUTTOCK

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the Year Ended 31 December 1992

1 STATEMENT OF ACCOUNTING POLICIES

The accounts have been prepared in accordance with Statements of Accounting Concepts and applicable Accounting Standards. The accounts have also been prepared on the basis of historical costs and do not take into account changing money values or, except where stated, current valuations of non-current assets. The accounting policies have been consistently applied, unless otherwise stated.

The following is a summary of the significant accounting policies adopted by the society in the preparation of the accounts.

(a) Non-Current Investments

Investments are brought to account at cost. The carrying amount of investments is reviewed annually to ensure it is not in excess of the recoverable amount of the investments.

(b) Property, Plant & Equipment

Property, plant and equipment are brought to account at cost or at independent valuation, less, where applicable, any accumulated depreciation or amortisation. The carrying amount of property, plant and equipment is reviewed annually to ensure it is not in excess of the recoverable amount from these assets.

The depreciable amount of all fixed assets is depreciated over their useful lives commencing from the time the asset is held ready for use.

The exception to the above policy is the society's library which is brought to account at its 1936 independent valuation, a more recent valuation not being available.

(c) Unearned Revenue

The unearned revenue shown in the accounts will be brought to account in the next financial year.

(d) Comparative Figures

Where required by Accounting Standards comparative figures have been adjusted to conform with changes in presentation for the current financial year.

2 RECEIVABLES

Included in Current Receivables are:

1702	Debtors for subscriptions	1840
1702	Less: Provision for doubtful debts	1840
0		0

3 OTHER ASSETS

Included in Current Other Assets are:

4835	Prepayments	3767

4 INVESTMENTS

Included in Non-Current Investments are:

149199	Interest bearing deposits	151430

5 PROPERTY PLANT AND EQUIPMENT

Included in Property, Plant & Equipment are:

975	Office equipment and furniture - at cost less depreciation	863
5883	Office equipment - at 1991 valuation less depreciation	4706
13600	Library - at 1936 valuation	13600
10	Pictures - at cost less depreciation	10
20468		19179

6 CREDITORS AND BORROWINGS

Included in Current Creditors & Borrowings are:

2014	Sundry creditors and accruals	0
4345	Unearned revenue	6940
6359		6940

7 OTHER LIABILITIES

Included in Current Other Liabilities are:

24	Life members subscriptions prepaid	17
88	Membership subscriptions paid in advance	163
1418	Journal subscriptions paid in advance	1695
1530		1875

Included in Non-Current Other Liabilities are:

136	Life members subscriptions prepaid	119

8 LIBRARY RESERVE

7311	Balance at 1 January	7311
0	Movement for year	0
7311	Balance at 31 December	7311

9 LIBRARY FUND

6715	Balance at 1 January	9364
2689	Donations and interest	749
9404		10113
40	Library purchases and expenses	15
9364		10098

10 TRUST FUNDS

Included in Trust Funds are:

6438	Clarke Memorial Fund	3888
7337	Walter Burfitt Prize Fund	7533
4011	Liversidge Bequest Fund	4185
7124	Olle Bequest Fund	7387
24910		22993

11 CLARKE MEMORIAL FUND

5000	Capital	5000
	Revenue	
661	Income for year	328
146	Expenditure for year	2878
515	Surplus (deficit) for year	(2550)
923	Balance at 1 January	1438
1438	Balance at 31 December	(1112)
6438	Total fund capital and revenue	3888

12 WALTER BURFITT PRIZE FUND

3000	Capital	3000
	Revenue	
397	Income for year	196
0	Expenditure for year	0
397	Surplus (deficit) for year	196
3940	Balance at 1 January	4337
4337	Balance at 31 December	4533
7337	Total fund capital and revenue	7533

13 LIVERSIDGE BEQUEST FUND

3000	Capital	3000
	Revenue	
397	Income for year	197
6	Expenditure for year	23
391	Surplus (deficit) for year	174
620	Balance at 1 January	1011
1011	Balance at 31 December	1185
4011	Total fund capital and revenue	4185

14 OLLE BEQUEST FUND

4000	Capital	4000
	Revenue	
529	Income for year	263
0	Expenditure for year	0
529	Surplus (deficit) for year	263
2595	Balance at 1 January	3124
3124	Balance at 31 December	3387
7124	Total fund capital and revenue	7387

BALANCE SHEET AT 31 DECEMBER 1992

		NOTE	
	CURRENT ASSETS		
7787	Cash		5171
0	Receivables	2	0
0	Investments		0
0	Inventories		0
4835	Other	3	3767
12622	TOTAL CURRENT ASSETS		8938
	NON-CURRENT ASSETS		
0	Receivables		0
149199	Investments	4	151430
0	Inventories		0
20468	Property, plant and equipment	5	19179
0	Intangibles		0
0	Other		0
169667	TOTAL NON-CURRENT ASSETS		170609
182289	TOTAL ASSETS		179547
	CURRENT LIABILITIES		
6359	Creditors and borrowings	6	6940
0	Provisions		0
1530	Other	7	1875
7889	TOTAL CURRENT LIABILITIES		8815
	NON-CURRENT LIABILITIES		
0	Creditors and borrowings		0
0	Provisions		0
136	Other	7	119
136	TOTAL NON-CURRENT LIABILITIES		119
8025	TOTAL LIABILITIES		8934
174264	NET ASSETS		170613
	EQUITY		
7311	Library reserve	8	7311
9364	Library fund	9	10098
24910	Trust funds	10	22993
132679	Other accumulated funds		130211
174264	TOTAL EQUITY		170613

F L SUTHERLAND President D A WINCH Honorary Treasurer

ACCUMULATED FUNDS ACCOUNT
For The Year Ended 31 December 1992

		NOTE	
6551	Operating surplus(deficit)		(1137)
2689	Donations and interest to library fund	9	749
6927	Equipment donation		0
16167			(388)
119161	Accumulated funds at the beginning of the financial year		132679
0	Prior period adjustment		(1346)
40	Transferred from library fund	9	15
135368			130960
2689	Transferred to library fund	9	749
132679	Accumulated funds at end of the financial year		130211

INCOME AND EXPENDITURE ACCOUNT
For the Year Ended 31st December 1992

	INCOME			
	Membership Subscriptions -			
7806.75	Ordinary			7818.00
	Membership Subscriptions -			
23.67	Life Members			23.87
43.00	Application Fees			6.00
---------				----------
7873.42				7847.87
	Subscriptions and Contributions to Journal			
4718.14	Publication Costs			7819.47
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	Total Membership and Journal			
12591.56	Income			15667.34
16393.12	Interest Received			8219.06
30.00	Sale of Reprints			5.00
63.00	Sale of Back Numbers			435.00
20.00	Sale of Other Publications			70.00
9.18	Photocopying Refunds			0.00
10.00	Research Fees			0.00
58.59	Summer School Surplus			4151.18
---------				----------
29175.45				28547.58
	Less:EXPENSES			
2050.00	Accountancy Fees		2310.00	
23.10	Annual Dinner Deficit		696.60	
1025.00	Audit Fees		1190.00	
	Bank Charges & Government			
103.18	Duties		50.13	
150.00	Branches of the Society		150.00	
465.00	Computer Software		0.00	
1154.00	Depreciation		1289.00	
443.00	Entertainment Expenses		438.60	
541.28	Insurance		542.02	
	Journal Publication and Distribution Costs			
(178.43)	Printing	7349.77		
1523.57	Wrapping & Postage	2345.12		
---------		----------		
1345.14			9694.89	
40.30	Library Expenses		15.75	
1507.11	Long Service Leave		0.00	
792.14	Miscellaneous Expenses		111.40	
410.00	Monthly Meeting Expenses		370.65	
	Newsletter Printing &			
2111.66	Distribution		1982.02	
704.55	Postage		586.76	
	Printing & Stationery -			
849.17	General		993.33	
923.74	Provision for Doubtful Debts		433.92	
2000.00	Rent		2000.00	
88:00	Repairs & Maintenance		0.00	
5642.69	Salaries		6428.86	
255.40	Telephone		400.57	
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22624.46				29684.50
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(6550.99)	DEFICIT for the year			1136.92
=========	====================			==========

STATEMENT OF CASH FLOWS
For The Year Ended 31 December 1992

CASH FLOWS FROM OPERATING ACTIVITIES	
Members subscriptions and donations	8038
Other revenue sources	19645
Interest received	9382
Administration and other operating expenses	(37450)

Net cash provided by operating activities	(385)
CASH FLOWS FROM INVESTING ACTIVITIES	
Net amounts reinvested	(2231)

Net cash provided by (applied to) investing activities	(2231)

NET INCREASE (DECREASE) IN CASH HELD	(2616)
Cash at the beginning of the financial year	7787

CASH AT THE END OF THE FINANCIAL YEAR	5171
	=========

The accompanying notes form part of this statement of cash flows

NOTES TO THE STATEMENT OF CASH FLOWS
For the Year Ended 31 December 1992

1 RECONCILIATION OF NET CASH PROVIDED BY OPERATING ACTIVITIES TO OPERATING SURPLUS (DEFICIT)

Operating surplus (deficit)	(1137)
Prior period adjustment	(1346)
Non-cash flows in operating surplus	
Depreciation	1289
Changes in assets and liabilities	
Reduction in prepayments	1068
Increase in unearned revenue	2595
Reduction in creditors	(2014)
Increase in members subscriptions in advance	75
Increase in journal subscriptions in advance	277
Reduction in life members subscriptions in advance	(24)
Increase in library fund	749
Reduction in trust funds	(1917)
Net cash provided by operating activities	(385)

2 COMPARATIVE FIGURES

No comparative figures have been provided as this is the first period in which Accounting Standard AAS 28 has been applied, and obtaining comparable figures would be impractical.

CLARKE MEDAL FOR 1992

Professor Alfred Edward Ringwood, universally known as "Ted", is truly one of Australia's great home-grown scientists and has been a Fellow of the Australian Academy of Science since 1966. After completing a B.Sc., M.Sc., and Ph.D. at the University of Melbourne between 1950 and 1956, he launched into a career of geochemical studies that won him his world-wide acclaim. Much of his pioneering and distinguished research on the fundamental chemical structure of the Earth and its companion Moon has been based at the Australian National University in Canberra. He has been Professor of Geochemistry there since 1967.

The Award of the Clarke Medal for 1992 in the field of geology to Professor Ringwood is particularly fitting. Early in the recognition of his scientific achievements, the Royal Society of New South Wales showed considerable foresight in nominating him for the Clarke Memorial Lecture in 1970. His topic was: "The Origin of the Moon", and he has been instrumental in reviving the hypothesis that the Moon was created from the Earth's mantle after segregation of the core.

Professor Ringwood's published research includes over 300 papers. His first 25 papers between 1956 and 1962 were all solo works, a remarkable testament to his individual approach to a variety of geochemical studies. Two books summarise the core of his work: "Composition and Petrology of the Earth's Mantle" 1975; and, "Origin of the Earth and Moon" 1979.

Most of his research, some 110 papers, considers the origin and geochemical evolution of the Earth, its core, the Moon, planets and meteorites. His prediction in 1977 that oxygen is the principal light element in the earth's core was tested by experiment he devised and developed in the next ten years. These showed that iron and iron oxide became miscible under core conditions. Several papers illustrate his collaborative research on moon rocks gathered by the Apollo Missions. One particularly intriguing title in his works is: "Water in the Solar System", which was published in 1977 in an Australian Academy of Science Symposium on Water, Planets Plants and People.

Another 100 papers discuss the transformations of minerals into new structures under high pressures and temperatures and their role in understanding the constitution of the Earth. He used pressure-sensitive synthetic analogues of natural minerals to study rearrangements which could occur in the deep Earth. Many of the predicted structures have been confirmed and explored as new technology allows greater temperature and pressure control in experiments. Some 40 papers tackle the composition of the Earth's mantle in its dynamic relationship with molten bodies rising to the surface. This work, particularly in collaboration with D.H. Green, introduced the concept of pyrolite as a fertile mantle source rock for generating the common basalt and andesite lavas erupted by many of Earth's volcanoes, past and present.

The research group built up by Professor Ringwood at Australia's National University has greatly helped to place Australia in the forefront of Earth science research both in the academic and applied research fields. He and associated colleagues have applied for 11 Australian and overseas patents. An example is SYNROCK, a synthetic rock used to trap high-level radioactive wastes. Professor Ringwood's abilities as a research leader are reflected through many of his students reaching research careers almost as illustrious as his.

Professor Ringwood has received nearly 50 impressive appointments, elections, Distinguished Lecture nominations and awards over his career. Recent awards include the Geochemical Society 1991 Goldschmidt Award and the Accademia Nazionale Dei Lincei 1991 Premio Internazionale per la Geologia, Paleontologia, Mineralogia e Applicazioni Award. It is with great pleasure that The Royal Society of New South Wales presents Professor Ringwood with the Clarke Medal in recognition of his long standing geological achievements.

EDGEWORTH DAVID MEDAL FOR 1992

The Edgeworth David Medal, for distinguished contributions to Australian science by a young scientists under the age of 35, is shared by Dr Peter James Goadsby and Dr Keith Alexander Nugent.

Peter James Goadsby

Dr Goadsby obtained the degree of Doctor of Philosophy from the University of New South Wales in 1985, followed by the degree of Doctor of Medicine in 1990. He currently holds a Wellcome Senior Research Fellowship in the Department of Neurology at the Prince Henry Hospital and a Senior Lectureship at the University of New South Wales. Australian Neuroscience Society.

For his contributions to neurophysiology and to the understanding of migraine, Dr Goadsby is a worthy recipient of the Edgeworth David Medal.

Keith Alexander Nugent

Dr Nugent was awarded his Ph.D. from the Australian National University in 1984 and took up a position in the School of Physics at the University of Melbourne in 1985. He has won rapid promotion there and is now one of the youngest Readers in the University.

Dr Goadsby has published prolifically, with over 70 papers in physiology and neurology. His studies have improved understanding of the mechanisms responsible for migraine, by clarifying many aspects of the neural control of the cerebral circulation. Over the last ten years, he has pursued a series of linked experiments to unravel the influence of brain stem nuclei on the cerebral circulation, the feedback mechanisms causing circulatory changes, the areas of the brain stem concerned with the perception of pain and some of the transmitter agents involved in these processes. For example, experiments just completed show that nitric oxide is the coupling substance between blood flow and metabolism during spreading depression. This observation has implications for a range of cerebral disorders from stroke to migraine. In a collaboration with Dr Andrew Grundlach, he has shown that one of the most effective anti-migraine agents can pass the blood-brain barrier, leading to a complete revaluation of previous thinking on the question of central mechanisms in migraine. He has also determined the group of cells most likely to be the mediators of migraine pain, pointing the way to further understanding of the disorder.

Dr Goadsby received the prestigious Harold G. Wolff Award of the American Association for the Study of Headache in 1983 and again in 1991 and has given numerous invited lectures abroad. In 1992, he was awarded the A.W. Campbell Award from the

Dr Nugent's early research led to a new approach from imaging x-ray and neutron emission and the first ever images of the dense fusing region of plasma. Further development of this work with collaborators in the United States won the prestigious RD100 award for one of the most significant technical advances of 1988. With Dr S. Wilkins and Dr H.N. Chapman, he has worked on a new approach to x-ray focussing, based on the principles underlying the eye of the lobster. Groups in England and the United States are developing this technique for use in a satellite based x-ray telescope. Dr Nugent has developed a new and simple description of partially coherent diffraction, with significant applications to the measurement of x-ray laser sources, the apparent rapid fluctuation of quasars and wavefield reconstruction. He has also proposed a new approach to x-ray holography. This work opens up prospects for significant advances in microscopy and sets fundamental limits on the experimental arrangements necessary to ensure reliable results.

Dr Nugent was awarded the Pawsey Medal of the Australian Academy of Science in 1989. He has given invited lectures in Australia, Japan and the United States and has published over 40 papers in internationally recognised journals.

Dr Nugent's contributions to the science of optics make him a worthy recipient of the Edgeworth David Medal.

WALTER BURFITT PRIZE FOR 1992

Instituted in 1929 following a benefaction to the Society from the estate of the late Dr Walter Burfitt, the Walter Burfitt Prize is awarded not more frequently than every three years for progress in science in the preceding six years in Australia or New Zealand. The prize for 1992 is a sum of $1000 and has been awarded jointly to two collaborating scientists at the University of New South Wales, Professor George Paxinos and the late Professor Istvan Törk for their work in neuroanatomy. Their submission for the prize consisted of 4 books and 46 articles describing the morphology and organisation of the rat and human nervous systems. It will be appreciated that the rat brain is frequently taken as a model of the mammalian brain and that investigations of neuroactive substances are more readily pursued with the experimental animal than with man.

George Paxinos received his basic education in his native Greece, and in 1962 moved to the United States of America where in 1968 he graduated in psychology from the University of California at Berkeley. His Masters and Ph.D. degrees were awarded from McGill University, Montreal, Canada for his work on the hypothalamus as a controller of behaviour in the rat. In 1973 he took up a lectureship in Psychology at the University of New rat brain development from birth to maturity and a publication that has become the most frequently cited in neuroscience. George Paxinos can be justly proud also of his community interests. He was founder and secretary of the Migrant Rights Committee, an organisation that assisted around 15000 persons of many nationalities to become Australian citizens.

Istvan Törk graduated in medicine in Budapest, Hungary in 1963 at the age of 24, having already published nine papers describing anatomical and histochemical studies on a variety of vertebrates. In 1969 he and his wife, Emöke moved to the University of Zambia in Lusaka where, two years later, he became Professor and Head of the Department of Anatomy. A renewed opportunity to pursue his theories through research came in 1976 when he joined the School of Anatomy at the University of New South Wales, eventually to become the School's Head in 1988, with the distinction of a Personal Chair in 1991. He became a major figure in Australian neuroscience, being especially admired for his use of morphometric tools, including the electron microscope and the computer, as exemplified by his unravelling of the catecholaminergic centres of the brain stem and the serotonergic pathways in the cerebral cortex. His collaboration with George Paxinos sealed for both of them the Walter Burfitt Prize.

South Wales where he is now Professor in the School of Psychology. Although George Paxinos and Istvan Törk had their separate careers to pursue, the University gradually brought them into collaboration after Istvan Törk joined the School of Anatomy in 1976. So secure did their collaboration eventually become that they jointly authored during the past six years the seminal work entitled: "The Rat Brain in Stereotaxic Coordinates", a precise and novel atlas of

When the judges for the 1992 Burfitt Prize reached their decision, they were communally unaware that Professor Istvan Törk had a few months earlier died of complications resulting from a brain tumour. Dr Emöke Törk has graciously consented to receive in person her late husband's portion of the Walter Burfitt Prize for 1992.

THE ROYAL SOCIETY OF NEW SOUTH WALES MEDAL FOR 1992

This Medal for notable contributions to science and to the advancement of the Society is awarded to Mr George William Kinvig Ford, known to us as Kim.

Mr Ford graduated from Cambridge University, BA with honours in 1941, followed by MA in 1945. After service in the Royal Naval Volunteer Reserve as a specialist in avionics, including service in Australia, he was awarded an MBE. He had a long and varied career in nuclear science in the United Kingdom, starting at Harwell, where he investigated heat transfer from fuel slugs, the development of gas lubricated bearings for an isotopes plant compressor, the possibility of using gaseous uranium hexafluoride as a reactor fuel and the performance of membranes for uranium enrichment plants. His next work was at Dounreay Experimental Reactor Establishment where he was Research Manager of the Experimental Nuclear Criticality Laboratory. Then in 1959, he transferred to the Atomic Energy Establishment at Winfrith where he was a Senior Principal Research Scientist. His work included planning reactor physics facilities, especially the development of original proposals for the "Nestor" research reactor. After becoming Deputy Head of Energy Development he had responsibility for heat transfer and boiling dryout research.

In 1965, Mr Ford joined the Australian Atomic Energy Commission Research Establishment at Lucas Heights, where he was Chief of the Engineering Research Division, later the Nuclear Technology Division. The work of his Division included the study of nuclear power reactor systems and heat transfer problems relating to the Hifar reactor, as well as a wide range of other relevant matters. During this period, he was carrying out high level scientific administration in a changing environment.

Since his retirement in 1985, Mr Ford has been very active in scientific societies, including the Royal Society of New South Wales which he joined in 1974. He was President in 1990-1991 and is currently an active member of the Council. Mr Ford is interested in bringing science to the populace, one way being his weekly radio program. Kim Ford has contributed much to the Royal Society as a dedicated member of the Council and this together with notable contributions to science makes him a most worthy recipient of the Society's Medal.

STANLEY CHARLES BAKER 1910-1992

Stanley Baker died on 30th September 1992 after a life of considerable achievement in science and technology. Born 10th December 1910 at East Maitland, the son of Charles Baker and Amy (née Dyason) he became a scientist almost by accident, attending Sydney University on matriculating from Berrima District High School in 1927, because there were no vacancies in the long-established family brickworks in those depression years.

His interests at the time were geology and chemistry, because of their likely practical use at the brickworks, which the family had established, first at East Maitland, then at Bowral and Parkes, and he had won the Carslaw Medal for his Leaving Certificate chemistry result, but he was soon lured into physics, a subject which had not been taught at his school. There were no jobs available on graduation, so Baker continued to an M.Sc. and a Diploma of Education, supporting himself by tutoring and part-time teaching of physics, maths and science at the University, Sydney Technical College and Glebe Technical School.

His Master's thesis: "Spectroscopic Estimation of Isotope Abundance in Australian Mercury" was awarded with First Class Honours in 1934. Spectroscopy was to remain his chief scientific love.

After several years teaching science at high schools (Drummoyne, Petersham and Mudgee) Baker was appointed Teacher of Physics at Sydney Technical College in 1936. The following year he moved to Newcastle Technical College as Head Teacher of Physics. He remained at Newcastle for 38 years through the various permutations of University College, N.S.W. University of Technology and University of New South Wales to the autonomy of the University of Newcastle, where he was Head of the Physics Department for ten years, becoming Associate Professor in 1973. Initially this meant refusing seniority moves to positions in Sydney, and later rejecting offers from American universities and company research bodies. He retired in 1975, but continued research until his last years.

Baker was an enthusiastic teacher, who prided himself on never taking sick leave or missing a lecture. But he confessed to being late for one laboratory session thanks to ptomaine poisoning on a camping expedition, and the Suez Crisis delayed his return home from sabbatical leave in 1956.

Baker's teaching was not restricted to the tertiary field. He was an examiner for the Leaving Certificate from 1936 until the introduction of the Wyndham Scheme in the 1960s, marking the honours and pass papers for all students in the Hunter Region, organising refresher courses for high school teachers, and publishing: "Intermediate Physics for Students of Technology", which was widely used in high schools. He also lectured to W.E.A. for some years on atomic energy and astronomy.

During the 1930s and 1940s, Baker was associated with many bright students holding trainee positions in various Newcastle based industries. He gained much satisfaction in working with these young men, whose work in practical physics was excellent and who had drive and enthusiasm. Some of them co-operated with Baker in applied research and went on to very influential positions in industry and academia, five students becoming Professors. In 1957, Baker was awarded the Ph.D. degree by the University of New South Wales for his thesis: "Excitation Processes in Spectroscopy", bringing together much of the theoretical material he had accumulated through his practical experimentation.

Baker's expertise was called on by many firms to solve a diverse range of problems concerned with: thermal conductivity of fire brocks, spectroscopic estimation of various elements (particularly boron) in steels, analysis of rock and mineral samples, glass and raw materials, a magnetic sorting bridge, and a the design of research laboratories. During World War II he established (with M. Howarth) an optical workshop producing optical flats and slip gauges, prior to the setting up of the National Standards laboratory. He was also involved with the ELMA lampworks in the maintenance of automatic assembly machines and the production of glass. These activities even involved salvaging glass from portholes of a wreck, and the use of local beach sands.

In 1938, Baker and Howarth demonstrated that the silicon and manganese content of steels could be estimated accurately and quickly by spectroscopic means. Although rejected at the time the method proved important for munitions' manufacture in the United States of America during the war and was later adopted by the Australian steel industry.

Baker recalled reporting when conscription was introduced in 1939. He was recognised by a colonel who said: "You held rank in the Sydney University Regiment and have a higher degree in Physics -- we'll have you a colonel in no time." This was, however, followed by a letter instructing him, as a physicist, to remain at the College until further notice, which never came. Baker's practical contact with the armed forces henceforth consisted of many lectures on camouflage, visual illusions and eye deflects, and infra-red photography. He was particularly involved with W.J. Dakin in designing new camouflage for the American forces, who arrived in Australia with quite ineffective patterns and materials.

The bulk of Baker's research was embodied in the many reports he wrote for local industries, so his publication record was not extensive, some 20 papers in all. His first three published papers appeared in the Society's journal, the wide gap between the first (in 1934) and the second two (1946 and 1948) being caused by his concentration on industrial research, much of it confidential or linked to the war effort.

A series of papers in Australian and overseas journals between 1948 and 1955 established his reputation more widely, and a Fulbright Scholarship took him to M.I.T. in 1955, where he worked with G.R. Harrison and F. Bitter. In 1963, he was Visiting Professor at Rensellar Polytechnic, Troy N.Y. State helping to re-establish optics and spectroscopy in the Department of Physics and Astronomy, returning there again in 1970 to lecture on plasma spectroscopy and to work on polarised light. He also worked with K.L. Andrew at Purdue University on atomic spectra in 1963, and at Argonne National Laboratory.

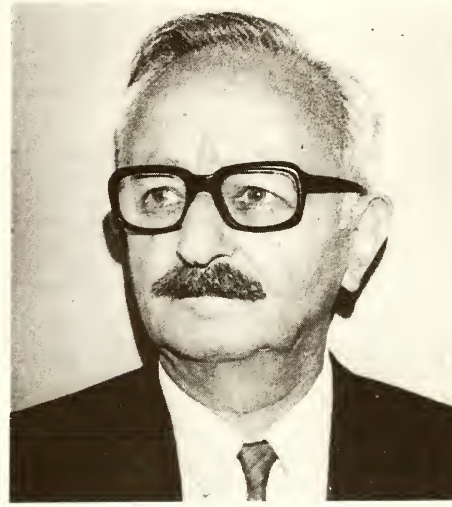
In 1970, he spent almost a year with W.R.S. Garton at Imperial College, London (and again in 1974) working on the spectra of highly ionised atoms of astrophysical interest.

After retirement Baker devoted considerable attention to radioastronomy, spending time at both Parkes and Siding Springs in co-operative research.

Baker joined this Society in 1934, nominated by O.U. Vonwiller (who was an external examiner 21 years later for his Ph.D. thesis) and G.H. Briggs, another distinguished scientist. He was elected a Life Member in 1971. His fourth Society paper was published in 1961. He was a Fellow of the Australian Institute of Physics, American Institute of Physics (Optical Society of America). He was also a long-term member of ANZAAS and the Astronomical Society of Australia. At Newcastle College and University he was an active member, and sometime officer of the Staff Association.

Baker's work epitomises the strength of much Australian science and technology research prior to, during and immediately following the war. It was essentially practical, it relied not on funding but on imagination, skilful innovation and adaptability, and sheer hard work, although he acknowledged the financial and practical assistance given by industry, and the importance of the interaction between the trade schools and higher education, an interaction that has often been sadly lacking in Australia science and technology. His satisfaction was in the work itself. He was content to remain in a regional base contributing to the local community and thus to the wider world, rather than seeking noisy acclaim.

D.F.B.



HENRY GEORGE GOLDING

Henry George Golding or "Bob" as he was known to his friends, passed away at his Lane Cove home on 28th December 1992 after a protracted illness. Born in England in 1911 he obtained a B.Sc. with honours from the University of London in 1931 majoring in geology, after spending several years as a mining geologist in Rhodesia, migrated to Australia just prior to the outbreak of World War II. During the war years he was employed in an important reserve occupation with National Oil Pty Ltd, a part government owned company engaged in the mining and extraction of petroleum from torbanite oil-shales in the Newnes, Glen Davis and Baerami Creek areas of New South Wales. But with the winding down of these operations in the post war era he took up an appointment at the Museum of Applied Arts and Sciences in Sydney where he developed particular interests in conchology and building stones. This apparently heightened his desire to return to academia and in 1952 he transferred to the newly established N.S.W. University of Technology, later to become the University of New South Wales. Here he continued his study of building stones and a thesis covering some of the New South Wales occurrences earned him the M.Sc. in 1956. Part of his thesis pertaining to the Hawkesbury Sandstone was published in the Society's Journal and Proceedings and was judged the outstanding paper for 1959. During the 1950s he also developed an interest in heavy materials, particularly leucoxene, and the several papers containing his findings attracted world wide attention.

In the 1960s his research took a different tack as he became progressively involved with the ultramafic rocks, or more specifically the origin and characteristics of chromites. This arose through a chance investigation of a nickel prospect at Thuddungra in New South Wales, and subsequently he was presented with an opportunity to examine the cores from a drilling program in the Coolac ultramafic belt by the Broken Hill Pty Ltd. In 1966 he was awarded the Ph.D. by the University of New South Wales for a thesis dealing with the constitution and genesis of chrome ores in the Coolac ultramafic belt and, ably assisted by post graduate students notably Dr P. Brown, Dr B.J. Franklin, Dr G. Pooley and Dr A. Ray, he continued this work until his retirement in 1974.

Bob was an excellent researcher with a penchant for detail and coupled with a subtle yet keen sense of humour, was also a popular lecturer, sparing nothing to get the message across. His only dislike appeared to be "new fangle gadgets" and indeed, he never did manage to master the overhead projector leaving such complexities to his long-suffering assistant.

Bob is survived by his wife Mary and his son Maxwell to whom we extend our condolences.

F.C.L.
B.J.F.

SELECTED PUBLICATIONS OF DR H.G. GOLDING

Leucoxenic grains in dune sand at North Stradbroke Island, Queensland, 1955. Journal of the Royal Society of N.S.W., 89, 219-231

The mineralogy of the commercial dyke clays in the Sydney district, N.S.W., 1957. Journal of the Royal Society of N.S.W., 91, 85-91, with F.C. Loughnan

Variation in physical constitution of quarried sandstones from Gosford and Sydney, N.S.W., 1959. Journal of the Royal Society of N.S.W., 93, 47-60

Leucoxenic terminology and genesis, 1961. Economic Geology 56, 1138-1149

The Coolac-Goobarragandra ultramafic belt, N.S.W., 1969. Journal of the Royal Society of N.S.W., Special Publication 3, 321-329

Altered chrome ores from the Coolac serpentine belt, 1968. American Mineralogist 53, 162-183, with P. Bayliss

Variation in gross chemical composition and related physical properties in podiform chromite in the Coolac district, N.S.W., Australia, 1971. Economic Geology 66, 1017-1027, with K.R. Johnson

Relict textures of chromitites from N.S.W., 1975. Journal of the Geological Society of Australia 22, 397-412

NOTICE TO AUTHORS

A "Style Guide" to authors is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarised below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on bond A4 paper. A second copy of both text and illustrations is required for office use. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgements and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigaphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

Illustrations. When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to 1/2 size) must be clearly stated.

Note: There is a reduction of 33% from the master manuscxript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diadrams must be given in BAR FORM.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper.

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Titles of journals should be cited in full – *not* abbreviated.

MASTER MANUSCRIPT FOR PRINTING

The journal is printed by offset using pre-typed pages. When a paper has been accepted for publication the text may either be typed by electric typewriter or produced by word-processor print-out. Print-out or typing should be in a column exactly 105 mm (= 4 1/8 inches) wide. Type size should be 14 point (Roman preferred) or 12 pitch single-spaced (IBM Adjutant preferred).

Reprints An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

Contents

VOLUME 126, PARTS 1 and 2

SUTHERLAND, F.L.
Demise of the Dinosaurs and other Denizens II - by Combined Catastrophic Causes? (Presidential Address 1993) 1

HUGI, Th., FARDY, N.C., MORGAN, N.C., and SWAINE, D.J.
Trace Elements in Some Swiss Coals 27

BAGGS, Sydney A.
Underground Space: The Geospatial Planning Option for 21st Century Sydney. Part One: Historical Overview and Rationale for the Use of Geospace 37

BRANAGAN, D.F., and Cairns, H.C.
Tesselated Pavements in the Sydney Region, New South Wales 63

YOO, E.K.
Stratigraphic and Coal Seam Correlations of the Illawarra Coal Measures in the Ulan and Bylong Areas, Western Coalfield, Sydney Basin, New South Wales 73

ABSTRACTS OF THESES:
XU, Arron S.L.: ^{19}F NMR of Erythrocytes: "Split Peak" Phenomenon, Membrane Potential and Membrane Transport 87

OUDSHOORN, Michael John: Atlantis: A Tool for Language Definition and Interpreter Synthesis 88

GATEI, Magtouf H.: Some Aspects of the Pathogenicity and Immunity of Bovine Leukemia virus Infection in Cattle and Sheep 89

HE, Fuxiang: Provenance, Diagenesis and Reservoir Characteristics of Sandstones of the Great Australian Basin Succession in NSW, Australia 90

COUNCIL REPORT, 1992-1993 93
Report 93
Abstracts of Proceedings 96
Errata: Vol.125 Parts 3 and 4 97
Summer School (Photo) 1992 98
Financial Statement 99
Awards 105
Biographical Memoirs 108

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A Consideration of Humphrey's "Cerebral Sentient Loop" Explanation of Consciousness from "A History of the Mind" by Nicholas Humphrey

MAX BENNETT

The evolution of the nervous system may have started a thousand millions years ago with the sponges or just six hundred and fifty million years ago with polyps like jelly-fish and corals. Sponges are extremely simple multicellular organisms (Figure 1A). A section through a sponge, when stained with silver, shows some cells that connect one side of the body wall of the animal to the other (Figure 1B); it has been claimed that these may be primitive nerve cells. With the evolution of the *Colenterates*, such as hydra, jelly-fish and corals, the identification of nerve cells and muscles is unequivocal: jelly fish have two layers of cells with a jelly-like substance seperating the two, giving the animal some rigidity (Figure 2A). Nerve nets for the control of swimming, tentacle position and feeding are composed of either bipolar or multipolar neurones (Figure 2B). These nerve nets come together in integrating centres, where a mixture of both neurone types may be found (Figures 2C and 2D); these centres are known as ganglia.

A very large increase in the complexity of the nervous system occurs with the appearance of the flatworms (Figure 3). In this case the ganglia are fewer in number and concentrated at one end of the animal, which may be distinguished as the head for primitive eyes and mouth are found there (Figure3) This is the first sign of the head ganglia which are eventually destined to evolve in their most complex form into the brain of *Homo Sapiens* (Figure 4), which receives sensory information from nerve receptors in different areas of the skin called dermatomes (numbered in Figure 4) as well as from the distance receptors such as the eyes, ears and nose.

Nicholas Humphrey, until recently Director of the Unit of Animal Behaviour at Cambridge University, has written a book called " A History of the Mind". Humphrey argues that in the most primitive animals, such as jelly fish,the nerve nets convey information from the body wall concerning sensory phenomenon such as touch towards the ganglia which then issue an outgoing signal for the muscles of the body wall to respond, for example with a contraction giving a wriggle (Figure 5A). Humphrey goes on to suggest that with further evolution of the nervous system the outgoing signal to the muscles of the body wall in response to an incoming sensory signal became modified so as to actually alter the incoming signal as well as to contract the muscles (Figure 5B); this collateral effect, of the outgoing motor nerves altering the signal arriving along the sensory nerves, may even be present in the early evolved nervous system of flatworms. Indeed an even further degree of collateralization can occur in which the motor collateral can give rise to sensory experiences independent of any incoming sensory signals (Figure 5C). Another form of collateralization involves the outgoing motor signal in response to a sensory input modifying the incoming sensory signal, without actually contracting muscles at all (Figure 5D); these collaterals can be used to sustain the sensory experience well after the actual event that gave rise to the initial sensation has passed. This ability to maintain a sensation at will by using the collateralization effect is called 'sustaining the sentient loop'. The final evolution of this process, according to Humphrey, probably only occurs in the higher mammals. It involves the motor output that has been modified to only change an incoming sensory signal now generating and sustaining sensory signals itself within the brain in the absence of any sensory input (Figure 5E). The nervous system is in this way able to voluntarily generate sensations and maintain them at will. It is this ability to use the sentient loop that is the highest form of consciousness.

In order to make these ideas of Humphreys clear it is necessary to look in detail at the functioning of the human nervous system. First of all what are collateral effects and can they operate in such a way as to modify sensory signals? One of the simplest motor acts that engages the brain and the spinal cord is shown in Figure 6: here a sensory stimulus, such as that arising from sensory spindle receptors in muscle cells concerned with indicating the length and velocity of shortening of the muscle, is relayed through the sensory neurones just outside the spinal cord to the nerve cells just inside the cord within an area called the *substantia gelatinosa*; these signals are then sent to the main relay station for sensory activity propagating between the spinal cord and the brain, in the group of neurones called the nucleus *gracilis* and nucleus *cuneatus*; from there the signals are sent to the thalamus in the brain, which is the receiving area for nearly all the sensory input to the overlying mantle of the brain or cortex; finally the thalamus projects the information to that part of the cortex which is called the somatosensory area, concerned with the analysis of information derived from sensory receptors in the limbs. The kind of information in the signals processed by the somatosensory cortex may require that the muscles that gave rise to the sensory input in the first place be contracted. In this case neurones in the part of the cortex concerned with contracting muscles, namely the motor cortex, project a signal to the appropriate motoneurones in the spinal cord connected to these muscles. These are of two different kinds, namely alpha motoneurones that are attached to cells in the muscle in question that produce the force; the other kind are the gamma motoneurones that are connected with cells that contract in the sensory receptor apparatus itself; contraction of these cells changes the characteristics of the sensory receptors so that they rapidly send signals to the sensory neurones outside the spinal cord and from there to the alpha motoneurones, leading to the contraction of the bulk of the muscle cells; they also send signals to the somatosensory cortex via the thalamus along the pathway already described. Two kinds of information are then sent via the sensory neurones to the brain: one of these relates to the signal arising from the sensory receptors in the muscle concerned with the position, tension and movement of the muscle, known collectively as kinesthesia; the other relates to the signal arising from the receptors as a consequence of their being contracted by the gamma motoneurones. This latter signal is gated out before it reaches consciousness by a collateral signal from the motor pathway as shown in Figure 6; the sensory signal concerned with the state of kinesthesia of the muscle is not gated out, but is allowed to reach consciousness. The level in the brain or spinal cord at which this gating procedure is carried out is not known; it is shown to occur at the level of the thalamus in Figure 6 simply for the sake of definiteness. Humphrey is therefore correct in his assertion that modification of sensory signals can occur before they reach consciousness as a consequence of a collateral effect from the motor pathway.

Corollary discharges from the motor pathway can also be used to generate a sensation independent of any incoming sensory signals. They can generate sensations of muscular force or heaviness although they cannot generate sensations of movement. Figure 7A shows how the sensation of the heaviness of an object held in the hand is generated by a collateral effect. The pathway from the motor cortex to the alpha motoneurones is shown to give off a collateral branch at the level of the basal ganglia; this, it is hypothesized, can generate a sensation in the cortex of the degree of heaviness of the object by firing impulses in proportion to those that are being propagated down the motor pathway. It follows that when a muscle is weakened by fatigue, such as when holding a heavy suitcase, a greater number of impulses are required by the non-fatigued component of the muscle in order for the muscle to continue lifting the suitcase; the collateral then receives a greater number of impulses and so a greater sensation of heaviness is experienced. An experimental example of this is given in Figure 7B: here a comparison is made between the extent to which a subject perceives the heaviness of a suitcase held continually in one hand by comparing it with a known weight held in the other for a short period of time. The graphs show that in this matching experiment the known weight chosen to be equivalent to the suitcase gradually increases over time, indicating the increased sensation of heaviness. This sensation is due to the collateral effect.

Humphrey is correct then in his suggestion that collateral effects can modify both the kinds of sensations that enter consciousness as well as generate sensations that did not arise from the workings of our sensory receptors. Figure 7 summarizes the situation. Humphrey speculates that early during evolution nerve pathways were layed down that allowed an animal to respond to say a noxious stimulus to the skin by 'wriggleing ' away; in higher vertebrates this simplest pathway might consist of the primary sensory neurones just outside the spinal cord that receive information concerning noxious stimulation projecting to upper motoneurones in the reticular formation which then project down to the lower motoneurones and from there to the muscles which are to be contracted to produce "wriggleing" (Figure 8A). At a later stage of evolution mechanisms were put in place that allowed the nervous system to 'gate' out sensory information, using projections from the brain to the sensory gate-way to the cortex , the thalamus, as shown in Figures 8B and 8C. We have already seen how information gathered by primary sensory neurones concerned with muscle receptors can be gated out before it reaches the somatosensory cortex by means of a collateral feedback from the motor cortex at the level of the thalamus (Figure 8B). Such a feedback could occur via the well known pathway from motor cortex to basal ganglia and from there to the reticular nucleus that lies just outside the thalamus; this then projects to the somatosensory cortex (Figure 8B). Sensory information that is gathered by the retina is also 'gated' as it passes through the thalamus on the way to the visual cortex, as shown in Figure 8C. The primary visual pathway is from the retina to the thalamus and from there to the visual cortex; neurones exist in the cortex that project back to the thalamus where they can gate the incoming visual information (Figure 8C). There is then evidence for both the modulation of signals arising from the primary sensory neurones as well as from the visual sensory neurones at the level of the thalamus. In this way the brain can determine the sensory information which reaches it.

The question arises as to whether or not the modulatory effect of collaterals on the sensory information passing through the thalamus simply involves just a gating operation, that is the removal of information. We have already seen that this is not the case as a collateral effect generates the experience of heaviness when holding a suitcase, independent of any incoming sensory impulses (Figure 7). Humphrey suggests that collaterals may also sustain impulse traffic in sensory nerves after the sensory perception has passed. The effect of this would be to experience sensations without there be any continuing effect on sensory receptors, although these receptors would have been involved in the initiation of the experience in the first place. This brings up a question concerning the time over which consciousness of a sensation occurs. The tricky nature of the experience of time in consciousness as compared with objective time, measured by a clock for instance, is well illustrated by the 'cutaneous rabbit' perceptual illusion (Figure 8). In this illusion a series of taps to the wrist is followed by taps to the upper forearm and then to the shoulder, as shown in Figure 9A. Surprisingly this is experienced as a series of taps that are equally spread out along the whole length of the arm, rather than confined to just three positions on the arm, as if an animal (a 'rabbit') had run up the arm. Even more surprising is the result of just giving the series of taps to the wrist in the absence of any taps to the forearm or the shoulder (Figure 9B): in this case the taps are all experienced as confined to the wrist without any of them appearing to be spread out along the arm. Why then in the first experiment did the brain interpret the taps at the wrist as experienced spread out along the arm whereas in the second case they remain confined at the wrist? With reference to Figure 8, a plausible explanation why the first five taps in A were experienced as distributed along the arm whereas the five taps in B were confined to the wrist is that the taps are not perceived simultaneous with the events. In a certain window of time (1 to 2 seconds) the brain determines the most likely space-time story relating to the taps: in A the preliminary story that all five taps occur at the wrist is wiped out by the later arriving taps so that the final story that enters consciousness is that the taps are spread out equally in a space-time sequence; in B the preliminary story that all five taps occur at the wrist is not wiped out by any later events and so this enters consciousness. The brain then uses the time available before behavour is acted out to arrive at the most reasonable story based on sensations (the taps) and past experience to arrive at an interpretation. This window in time could be delineated by the earliest time at which sensations enter the brain and the lateset time at which the experiences might be used to modify behavour.

The actual time at which occurrences are first registered in the brain might not then be the same as the times allocated to them by consciousness. Another example of this is illustrated in Figure 10A, which shows the distribution of dermatomes for skin sensations as in Figure 4. The nerves leading from the dermatomes over the buttocks to the brain clearly involve a much longer pathway than do the nerves from the dermatomes over the neck to the brain. It might be naively expected then that if one was to be touched simultaneously on the buttocks and the neck, according to objective timing, then the experience of being touched on the neck would enter consciousness before that of being touched on the buttocks. But this is not the case, as it depends on the context in which this touching occurs as to whether one has the conscious experience of being touched in one place or the other within a certain window of time The hypothetical graph in Figure 10B illustrates that the time of experiencing being touched on various parts of the body (or on different dermatomes) need not coincide with the objective time of the sequence of touchings. The brain creates the most likely story, using the information that it receives from sensory receptors, the context in which this is gathered, and past experience, before allocating times to particular events. Humphrey suggests that collaterals not only gate incoming sensory activity, for example at the level of the thalamus, but they can also sustain that activity after the sensory receptors are no longer stimulated. This would then give rise to a sensation that is extended in time within consciousness. It gives rise to an important idea in Humphreys' scheme, namely that of the 'sustained sentient loop', in which the issuing of an outgoing command over a collateral can give rise to a sensation that is extended over time in consciousness by the sustained activity of the collateral.

The brain can possess neurones which are active and which are not directly involved in either sensation or the issuing of a motor command. By monitoring the rate of local blood flow in different regions of the brain with non-invasive techniques, Roland has been able to determine the areas of neuronal excitability. Active neurons require more oxygen than others and so require a greater blood flow; monitoring this then gives a measure of the areas of high neuronal activity. Figure 11 shows how this technique has been used to determine the distribution of active neurones involved in the intention to perform a motor act. Active neurones are found in the motor cortex if a finger is flexed against a spring as expected; in addition active neurones are found in the somatosensory cortex which is of course receiving kinesthetic information from the muscles being contracted (Figure 11A). However, if a more complex motor act is executed, such as turning a key in a lock, then another set of active neurones is brought into action, in the area of the brain called the supplementary motor cortex (Figure 11B); this area is always active when complex motor activity is taking place. If now the turning of a key in a lock is simply rehearsed mentally, with no motor command being executed, then the supplementary motor cortex possesses active neurones as before but the motor cortex and the somatosensory cortex do not (Figure 11C). This is then an example of the motor system operating in the absence of any motor output at all.

The central idea in Humphreys' scheme is that collaterals, perhaps originally associated with the motor system during evolution, may give rise to a sustained sentient loop without there being any motor act performed. We have seen that the motor system itself, in the case of the supplementary motor cortex, may give rise to activities that do not result in a motor action. The issuing of commands that set up a sentient loop amounts to the experiencing of sensations over time; this is a process that has become modified from the original collateral effects which simply acted on incoming sensory information. Humphreys' ideas concerning the evolution of the 'sustained sentient loop' are summarized in Figure 12. At first there was a simple nerve pathway consisting of a sensory input, which might be related to a noxious stimulus to the skin, resulting in a motor output involving withdrawal from the site of the stimulus. In Humphreys' terminology this amounts to a ' wriggle of rejection'. It is shown in Figure 12A as involving the brain but it would be better represented in vertebrates by a reflex sensory nerve pathway that passes directly from the skin to motoneurones in the spinal cord and from there to the appropriate muscles, as in Figure 6. The next stage in the evolution of the sentient loop involves modification of the incoming sensory signal by a collateral from the outgoing motor signal, as in Figure 12B; examples of this occur in the gating out of components of the signals to do with the action of muscle receptors involved in gamma motoneurone activity by motor collaterals, discussed in relation to Figure 6. With the further evolution of collateralization the motor command could modify and sustain over time the information coming into the brain along a sensory pathway so as to sustain a sensory experience, as shown in Figure 12C; the projection from the motor cortex to the reticular nucleus of the thalamus provides just such as pathway for modifying and sustaining the sensory input arriving from primary afferent fibres, as discussed in relation to Figure 8B. Finally the stage is reached during evolution when collaterals, originally associated with motor commands, are now used to generate sensations independent of any sensory input to the brain, as in Figure 12.

D; the cerebral sentient loop is now independent of the environment. The experience of a sensation involves a positive act of issuing an appropriate outgoing signal from the brain. According to Humphrey sensing is not a passive act but involves participating in the act of 'sentition' or the issuing of a command, originally associated during evolution with the motor system only. Since these commands can be issued without any trigger from the environment it is possible to have a rich 'stream of consconsiousness' that is generated from within the brain itself.

Does Humphreys' thesis stand up to critical attention? I have tried to flesh out the ideas in his book by reference to what we know about collateral effects and feedback pathways that modify incoming sensory signals bringing us information about our environment. The idea of 'sentition' whereby the nervous system issues a command that results in a sensory experience and therefore consciousness is a novel one. According to this idea consciousness first appears during evolution with the species that uses motor collaterals to generate or modify sensory inputs to the brain. It is possible that this occurred as early as the evolution of the flat worms if it can be shown that they are able to modify the sensory input to their central head ganglia by means of motor collaterals. Any animal that can issue commands for altering or generating sensory activity, and can by this means make a sensory response, possesses consciousness. The idea does have the great attraction of providing some basis for continuity in the emergence of consciousness rather than just positing it as the special preserve of *Homo Sapiens* or even of just the mammals. For me its deficiency is that it does not provide a framework that is sufficiently specific to suggest a research plan that allows testing the central hypothesis of the sustained sentient loop as the basis for consciousness. Although consciousness can only be examined by introspection, the non-invasive techniques for examining the neurophysiological concomitants of mental functioning, such as Positron Emission Tomography, may help to clarify the issues. It will be interesting to see if those areas of the brain involved, for example, in forms of cognition that do not involve language, are also active in other mammals than the primates under suitable conditions. The role of collateralization in the evolution of such areas might then be an interesting subject for study.

Some further reading.

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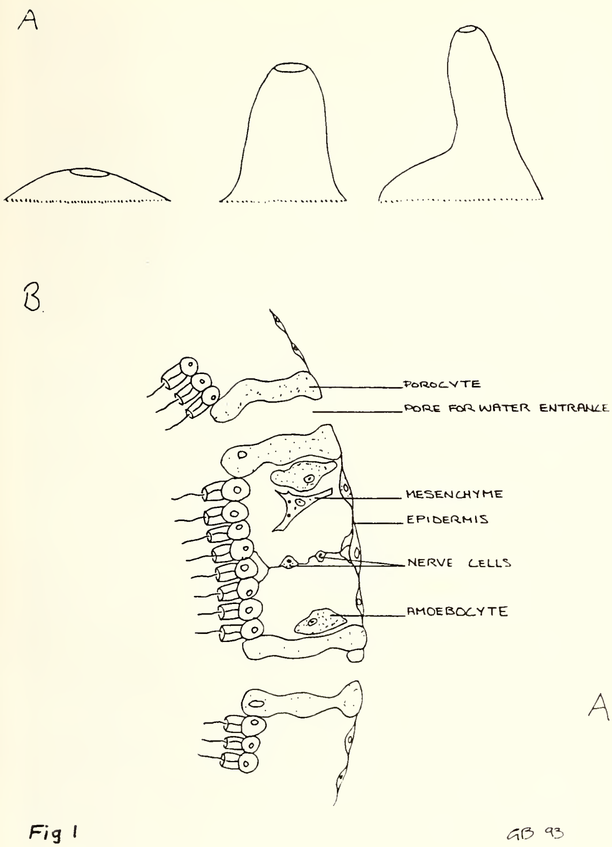


Figure 1. The *Proifera* or sponges are very simple multicellular parasites. They do not possess a nervous system and it is controversial as to whether they have any neurones. In A is shown the simple motor reactions of the fresh water sponge *Ephydrata*, with the mouth chimney changing its' form as water is drawn into the body through small pores and passed out through the mouth. In B is shown some of the cell types that stain with silver in the sponge *Sycon Raphanus*; the outer surface is connected to the inner surface by two cells with long and thin processes that may be nerve cells; the cells on the inner surface are collar cells (called choanocytes).

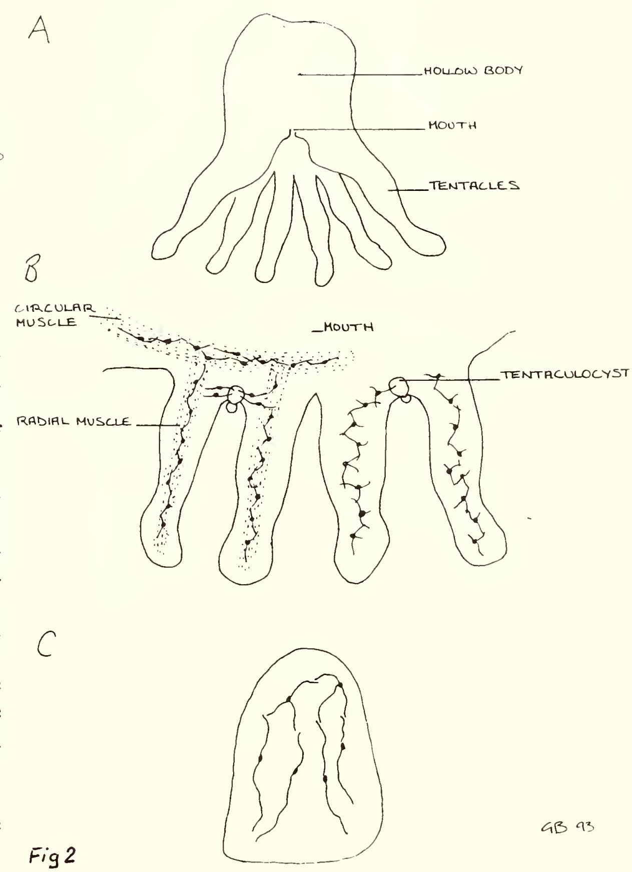


Figure 2. The *Colenterates* or polyps like hydra, jelly-fish, sea-anemones and corals have a sack-like body with tentacles as shown in A. In B are shown the two different kinds of neurone networks present in *Aurells Aurata*: one is composed of neurones that possess two axons (bipolar neurones) and these are promenent in relation to the radial and circular muscles that are exposed in this drawing; the other is composed of neurones with more than two processes (multipolar neurones) and these are shown in relation to the gastric cavity. Both bipolar and multipolar neurones from each nerve net are apposed to each other in collections on neurones called ganglia, as shown in C; here the input to the bipolar cells associated with the muscle is transferred to the multipolar neurones associated with the gastric cavity. This collection of neurones into a ganglion for the purposes of neural integration occurs for the first time in the *Coelenterates*.

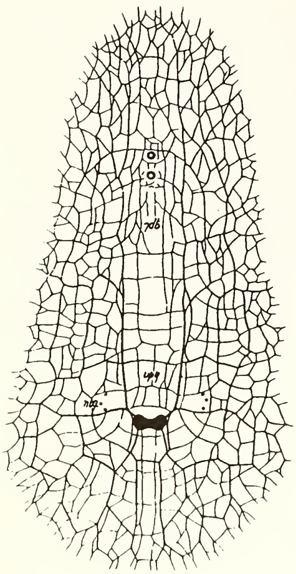


Fig 3

Figure 3. The grouping of large numbers of neurones into an integrating centre or ganglion, which is not symmetrically placed in the animal, first occurs in the *Platyhelminthes* or flatworms. Shown here is the dorsal nerve plexus of *Notoplana Atomata*(*Polycladida*) converging on the head ganglion. The labels refer to the 'gpl' (genital nerve plexus), 'hdn' (posterior dorsal nerve) and 'tau' (tentacle eyes).

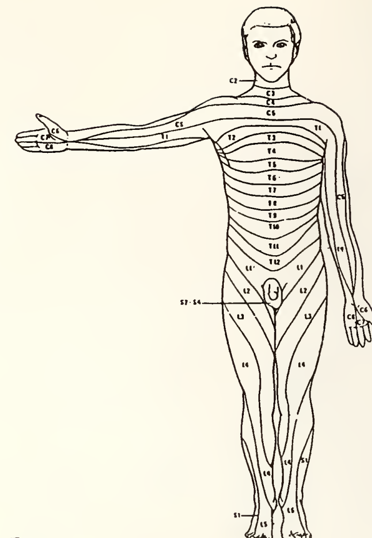


Fig 4

Figure 4. The grouping of neurones into a head ganglion that provides an integrating centre for the nervous system reaches its' most complex level of evolution in the brain of *Homo Sapiens*. Shown are the individual areas of skin, each subserving a different set of neurones, that bring information to the brain concerning such sensations as touch, pressure, temperature and pain. The individual areas are labelled C2 to C5 (cervical spinal cord levels 1 to 5), T1 to T12 (thoracic spinal cord levels 1 to 12), L1 to L5 (lumbar spinal cord levels 1 to 5) and S1 to S4 (sacral spinal cord levels 1 to 4). Nerves enter the spinal cord at each of these levels C2 to S4.

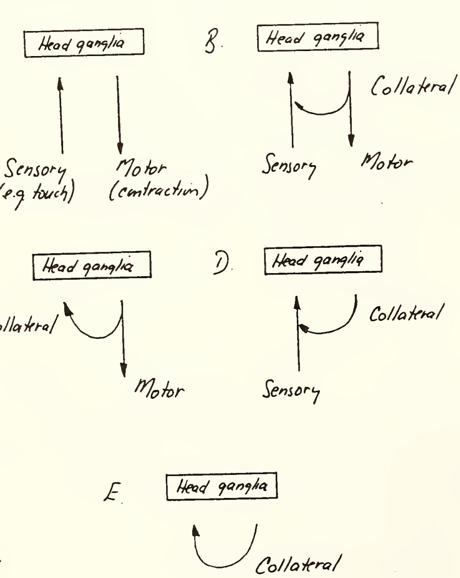


Fig 5

Figure 5. Evolution of the 'sentient' loop according to Humphrey. A: during evolution a most elemental form of nervous system consists of sensory neurones bringing in information, concerning for example touch and pressure, to an integrating centre consisting of a large number of interconnected neurones constituting a head ganglion; this then issues motor command to contract an appropriate muscle given the type of sensory information received by the head ganglion. B: the next level of sophistication was reached with the appearance of collateral nerve branches emanating from the outgoing motor nerves and ending in relation to the incoming sensory nerves; in this way the motor command was able for the first time to modify the sensory input to the head

ganglion (see Figure 6 for an example of this process). C: these collaterals then became modified in two important ways, one of which is shown here; on issuing a motor command the collateral is able to induce a sensory experience independent of any input to the head ganglion along the sensory nerves themselves (see Figure 7 for an example of this process). D: the other important way in which the collaterals became modified is that they could be used to modify incoming sensory signals independently of any motor signals at ali (see Figures 8B and 11 for examples of this process). E: the final level of sophistication involves the appearance during evolution of the 'sentient loop', in which the collateral acts on its own without any motor command being issued or sensory information about the environment being received; the head ganglion or brain can in this way generate its own sensory experiences, and it is this process that constitutes consciousness (for an example of the brain generating activity in a voluntary way, without motor or sensory activity, see Figure 11).

Fig 6.

Figure 6. The corollary discharge. Diagrammatic representation of the brain and spinal cord showing the possible levels of corollary discharge by which motor output from the cortex acts on incoming kinesthetic signals arising from the sensory neurones. Corollary discharges are obtained from motor commands and they can influence perception either by modifying incoming sensory signals (in this case at the level of the thalamus) or by acting independently of the incoming sensory signals. Kinesthesia is the sensation by which body weight, position, muscle tension and movement are perceived. Corollary discharges can alter the way in which such kinesthetic signals arising from sensory endings in muscles are interpreted. Such sensory endings in muscle spindles may send signals relating to the length and velocity of movement of a particular set of muscles; these spindles will also send signals arising from their being activated by a certain class of motoneurones in the spinal cord called gamma motoneurones. The signals due to the gamma activation of the spindles are removed by a corollary discharge, which at the same time allows the signals from the spindles due to the length and velocity changes to be perceived. In the example shown gamma motoneurones are activated from the motor cortex giving rise to spindle receptor discharges; these discharges together with the additional discharges due to the contraction of the muscles are received by the sensory neurones and transmitted through the group of neurones constituting the *gracilis* and *cuneatus* to the thalamus and thence to the somatosensory cortex; here they give rise to the sense of movement of the muscles. However the initial motor discharge of impulses gates out the sensory discharge relating to gamma motoneurones exciting the spindle receptors; this gating may occur at the many

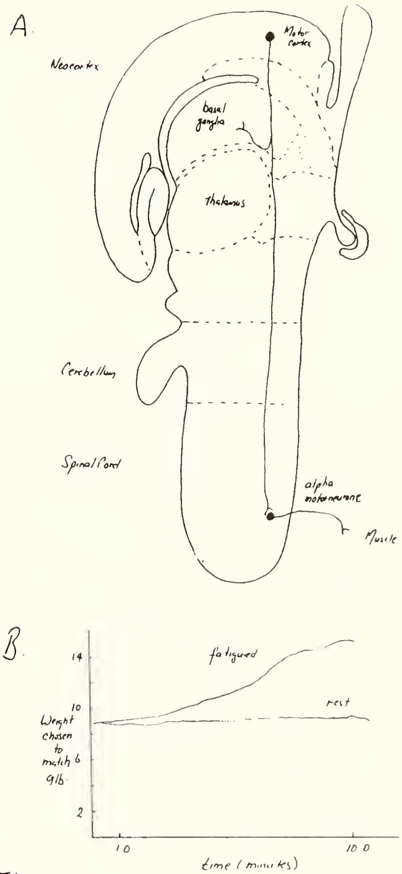


Fig 7

Figure 7. The corollary discharge. This figure gives a diagrammatic representation of the brain and spinal cord illustrating a possible output from the motor cortex responsible for the perception of heaviness of a held object. For definiteness this corollary discharge is shown at the level of the basal ganglia. Such discharges can give rise to the sensation of muscular effort as occurs when lifting and supporting an object. In the example shown neurones in the motor cortex (called Betz cells) that project to the motoneurones in the spinal cord are illustrated; Betz cells may be activated to contract muscles involved in lifting the limbs or an object such as a suitcase; when they do this a corollary discharge is sent (at the level of the basal ganglia?) which gives rise to the perception of heaviness of the limb or suitcase, and this is simply related to the extent of the motor discharge that occurs. Subjects that experience a stroke may have to send a larger than normal discharge down the remaining functional Betz cells to achieve the aim of lifting their arms and so experience them as as an enormous burden.

The graph shows the results of an experiment in which the subject has to support a 9 lb. weight with one arm (the experimental arm) while being asked at intervals to choose what they thought were equal weights to be supported in the same way by the other arm (the control arm). When the experimental arm was allowed to rest between the trials the subject choose weights with the control arm close to the 9lb weight held by the experimental arm (see 'rest curve'). If however the experimental arm had to support the 9 lb weight continuously, then the subject choose weights with the control arm that were successively greater (see 'fatigued ' curve) than the 9 lb weight indicating the increased sense of heaviness. This arises from the increase in corollary discharge with time as muscles have to receive a greater discharge to support the weight continuously. The perception of heaviness does not arise from sensory signals in the muscle being relayed back to the brain. This graph is due to experimental work of McCloskey, Ebeling and Goodwin carried out in 1974.

regions of interaction between motor and sensory pathways in the brain and are shown here as occurring in the thalamus for definiteness only.

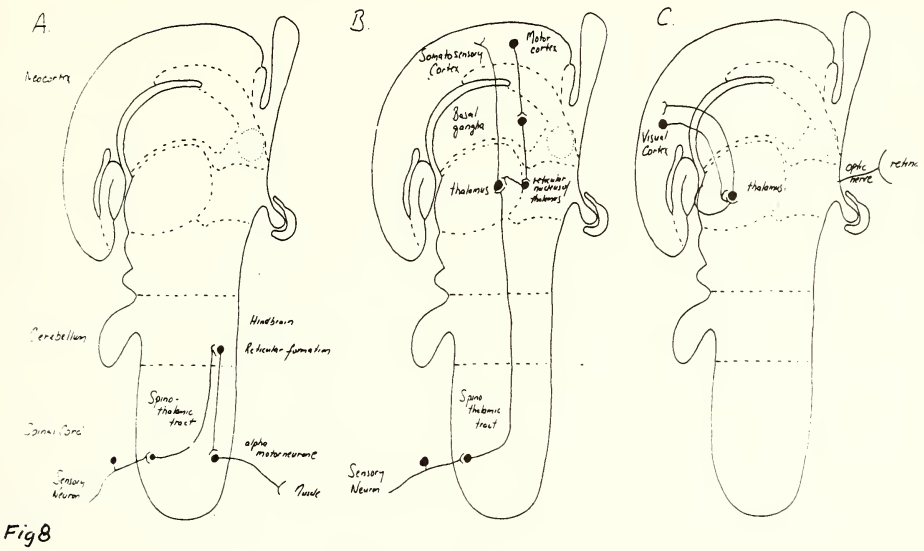


Figure 8. Diagrammatic representation of the brain and spinal cord showing different kinds of interactions between sensory pathways and motor pathways.

A, illustrates the simplest pathway involving the brain in a motor pathway. Primary sensory neurons relay information concerning kinesthesia, temperature and touch via the spinothalamic tract to the reticular formation of the hindbrain. Here a reflex act is initiated by exciting motorneurons to contract muscle in relation to the sensory stimulus.

B, illustrates how kinesthetic gating, referred to in relation to Figure 6, may occur. The motor cortex activates neurons in the basal ganglia which in turn inhibit neurons in the reticular nucleus of the thalamus which normally inhibit neurones in the thalamus that are responsible for conducting the kinesthetic discharge to the somatosensory cortex. Primary motor cortex can then modulate the sensory information that can enter perception through this pathway.

C, illustrates how visual information passes from the retina to the thalamus and from there to the visual cortex. This cortex itself contains neurones that project back to the thalamus; these neurones in the cortex can gate the information allowed to pass through the thalamus to the cortex. Both B and C show how the brain itself can modulate the perceptions of the world which it might allow to reach consciousness.

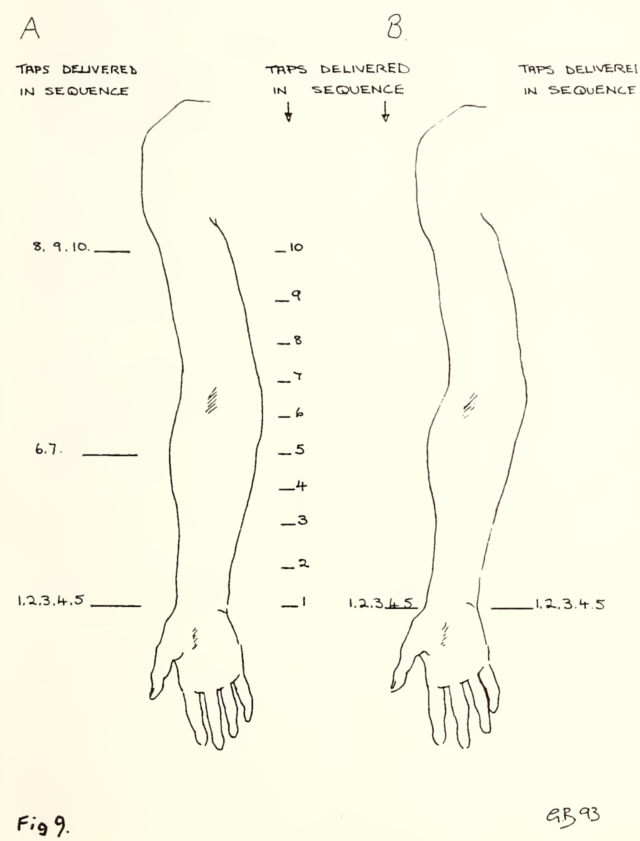
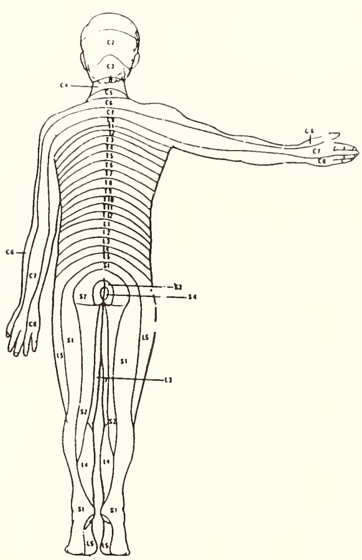


Figure 9. The sense of time in the brain as illustrated by the 'cutaneous rabbit' perceptual illusion. Shown are diagrams of arms in which the

following experiments were carried out to illustrate the subjective nature of the space-time extent of experience.

A: taps were delivered in the sequence shown (1 to 10 on the left) on the arm at one-tenth of a second apart so that the final tap was given at 1.8 seconds; the first five taps occur at the wrist , the next two on the forearm near the elbow and the last three at the shoulder region (the subject was not allowed to observe these procedures). Surprisingly the subject experienced the second tap as displaced from the wrist and the rest of the taps at equal distances along the length of the arm (at 1 to10 on the right). It is in this sense that the brain interprets the taps as if an animal (rabbit?) had run up the arm.
B: five taps were then delivered in the sequence as shown, namely only on the wrist (on the left 1 to 5) and these were experienced as all occurring at the wrist (on the right 1 to 5). The original experiments were performed by Geldard and Sherrick in 1972.

A



B.

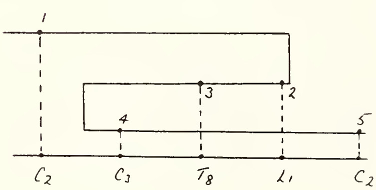


Fig 10

Figure 10. The complexity of the sense of time in the brain is again illustrated by considering the experiences relating to someone touching you simultaneously on the neck (at sensory skin or dermotome level C4 in A) and on the buttocks (at sensory dermatome level S3 in A). The nerves bringing information to the brain from C4 and S3 are clearly very different in length; as they have about the same rate for conducting impulses it would be expected that information concerning touch at S3 would enter consciousness at a later time than that from touching at C4. However, the actual time at which the occurrences are first registered in the brain is only part of the information that is used to allocate times to them entering consciousness; assumptions regarding the circumstances of this touching will also be used to allocate times. The brain then creates a story before it allocates the time to particular events; it does not simply take the actual time of arrival in the brain of impulses as if there were simply some finishing line in the brain which monitored the time at which the line was crossed by impulses.

The graph in B illustrates this process by showing a line of 'events' 1 to 5 that are the experimental time for the objectively timed events of being touched on different sensory dermatomes in the spatio-temporal sequence S3 to C2 shown. The series of touches at one fifth of a second intervals from S3 to C2 in the order shown may be experienced as the temporal series 1 to 5, that is as a spatially continuous stroking from the buttocks to the head, depending on the story created by the brain, given the circumstances.

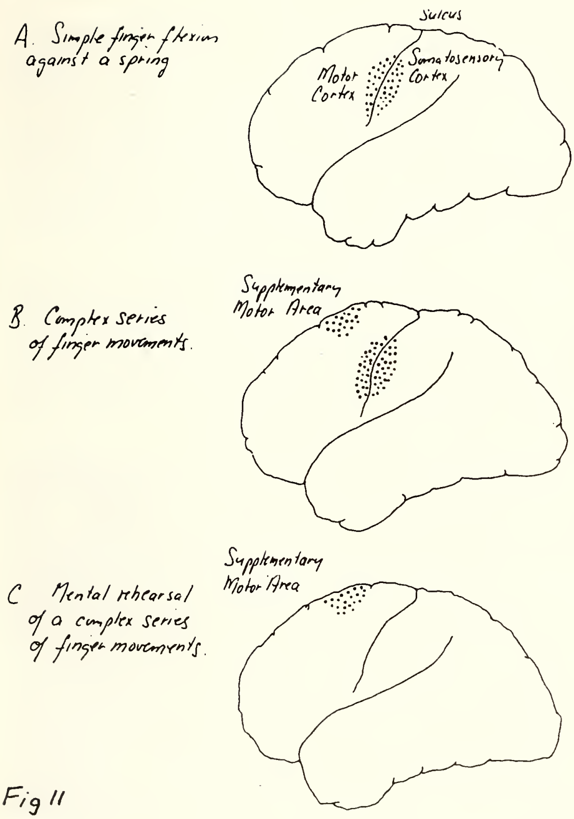


Figure 11. Diagrams showing the regions of high neuronal activity in the brain associated with simple and complex motor (muscular) tasks and with the rehearsal of motor tasks without any muscular activity.
A shows the region of high excitability in the brain that occurs when the subject is asked to simply flex a single finger against a spring. One area of excitability is confined to the motor cortex that drives the motoneurones of the spinal cord necessary for contracting the muscles responsible for finger flexion; the other area of excitability is the somatosensory cortex that receives the sensory stimuli from sensory receptors in the flexing muscle and in the joints that are moved in the finger.
B shows the region of high excitability in the brain that occurs when the subject is asked to perform a more complex motor act, this time involving the placing of a key in a lock and turning it. In this case a new area of excitability is found in the brain in addition to the motor-cortex and somatosensory cortex. This new area is the supplementary motor cortex in the midline of the brain as shown. Supplementary motor cortex carries out the selection of suitable neurones in motor cortex to perform the finger movement sequence involved in the more complex motor task.
C shows the region of high excitability in the brain that occurs when the subject is asked to carry out a mental rehearsal of the complex motor act in B (with the key) only. In this case the supplementary motor area is excited but not the motor or somatosensory cortex. Note that in this case the subject issues commands associated with the complex motor act but does not allow them to be carried out.
These results were obtained by Roland who by monitoring the rate of local blood flow in different regions of the brain with non-invasive techniques, was able to determine the areas of excitability. Active neurones require more oxygen than others and so require a greater blood flow; monitoring this then gives a measure of the areas of high neuronal activity.

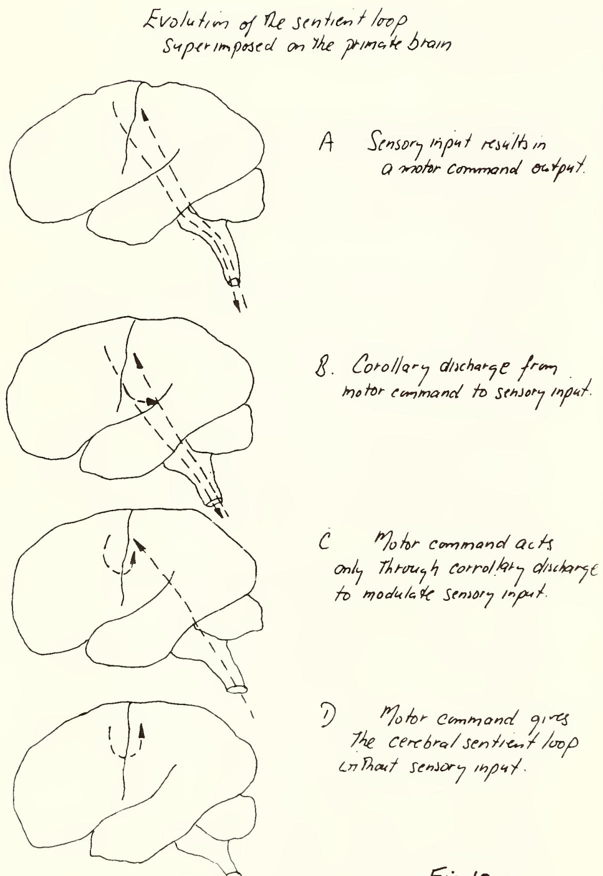


Fig 12

Figure 12. Evolution of the sentient loop and therefore consciousness as envisioned by Humphrey and superimposed on the primate brain. According to Humphrey to feel a sensation in consciousness is to issue a command or outgoing signal; sensation is then the making of the sensory response.

A, shows simple incoming sensory pathways to somatosensory cortex and an associated outgoing motor act initiated by the motor cortex in response to the sensory signal. This may be likened to the 'wriggle of acceptance or rejection' that Humphrey traces back to simple animals like sponges; the wriggle is the motor response to the motor command that is issued in response to the sensory input.

B, the next level of sophistication was the evolution of the corollary discharge, by which the motor command in response to the sensory signal is used to modify that signal. We have seen how corollary discharges may modify the information about kinesthetic experience.

C, Humphrey's suggests that the corollory discharge associated with a motor command in the context of a particular sensory experience may become modified so that the motor command is not executed and the corollory discharge is then used to sustain in subjective time the sensory experience. This gives the 'after glow' of a sensory stimulus, that is the experience is maintained in subjective time even though it has passed in objective time.

D, finally, the motor command can be given without any sensory input from the environment, creating a 'cerebral sensory loop'. To feel a particular sensation is to engage in an appropriate form of sentition (the activity of sensing) and so issue an appropriate outgoing signal from the brain.' It is this process which is consciousness.

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Marks on sandstone surfaces - Sydney Region, Australia: Cultural origins and meanings?

DAVID BRANAGAN AND HUGH CAIRNS

Abstract: Seven tesselated pavement sites on the Hornsby Plateau, north of Sydney, contain a variety of patterns of small pits, which appear to be of human origin.

The patterns of dots resemble, and possibly represent star patterns which have some relation to Aboriginal culture. There may also be subtle spatial relations between marked tesselated surfaces and figurative sites.

There are sightlines between most of the sites, which may prove to have been culturally significant, as the sites are within a region occupied by a single tribal group.

Introduction

In a separate paper (Branagan and Cairns, 1993) the location and formation of twenty-five extensive naturally-occurring tesselated sandstone pavements in the Sydney region were discussed. It was noted in that paper that some of the tesselated pavements were the sites of a variety of Aboriginal carvings, which have been discussed by various authors, among them Campbell (1899), McCarthy (1954, 1956), Sim, (1965, 1966), McDonald, (1987), Stanbury and Clegg, (1990).

In this paper we concentrate on seven of the pavements which occur on the Hornsby Plateau, north of Sydney. These pavements are notable for the occurrence, within the tesselations, of numerous small pits (often referred to in archaeological circles as cups), and which appear to be of human origin, or (in some cases) were natural pits that have been enhanced by humans. These seven pavements stand in marked contrast to the other eighteen sites which do not have cups or pits within the tesselations.

Cups or just holes?

The problem as to whether the alleged cups might just be holes caused by weathering and erosion has been considered in earlier papers (Cairns & Branagan, 1988, 1992, Branagan & Cairns, 1992), but is discussed here in a slightly different context. In the Sydney region there are numerous Aboriginal engravings of humans, animals and ancestral beings. Reproductions of these engravings show clearly that researchers accept, apparently without question, the human origin of engraved cups and lines (e.g. eyes and belts) within, or in close relation to the figures. This is clearly shown in Fig.1. Lines of cups forming tracks are likewise accepted, as in Fig. 2. These are shown, without question as to their origin, in various publications (e.g. Stanbury and Clegg, 1990).

However, in many cases, similar markings, whether or not related to carved figures, are often ignored or are inadequately recorded, as can be seen by comparison of detailed observation of some sites and the published records thereof. For instance in a diagram illustrating carvings at Devil's Rock, Maroota, (Stanbury and Clegg. op. cit.,98) do not show the continuation of a line of cups beyond the mythical figure (Figs. 2 and 3). Perhaps it is a case of seeing only what one is looking for. In general, it appears that researchers have been interested in the figurative marks and have not regarded the exercise of plotting cups as productive or important.

It is obvious that some pits (such as those formed by water droplets from an overhang)

Fig.1 In this human or ancestral figure (Patonga "Crazy Rock" site) we see two cups forming eyes, another within the body and several outside. The two eye "cups" would be immediately accepted as of human origin or use, that at the crotch probably so, while the several outer dots would be largely disregarded.

Fig.2 At the bottom of the photo two pits are part of a long track at Devil's Rock, Maroota, continuing towards the ancestral being, which is illustrated in Fig. 3.

may be of natural origin, and to distinguish these from those of human origin is not easy in many cases. In Cairns and Branagan (1992) we discussed this matter in some detail: it suffices here to mention that we considered various types of weathering and erosion, by both water, wind and sand abrasion, the flow paths of storm water (which are essentially along the sides of the tesselations and not across the polygons). We concluded that lifting of thin sandstone sheets was the more usual mode of erosion on the sandstone surfaces. The work of Coates (1986) also suggests that the action of fungi is not very significant in the weathering of rock surfaces in the Sydney region, and certainly does not cause pitting of the type described here.

In our view it is particularly relevant that only certain pavements, in a relatively constrained area, contain the cups. These selective occurrences make it difficult to accept that the cups could be of purely natural origin. This question has been addressed in much more detail in Cairns and Branagan (1992).

Hornsby Plateau sites

We make the above points because of the arguments brought against us in our discussions on the Elvina site, Ku-ring-gai National Park. Some visitors to the Elvina site were sceptical of the human origin of the cups, maintaining that they were the product of natural weathering and erosion (see MacDonald, 1992,(p.3), Bednarik, 1990, Branagan, 1991). However they were happy to accept that some grooves, (Fig 4) noted by McDonald (1987) and independently by ourselves, previously unrecorded, were human in origin (see also Stanbury and Clegg, op. cit).

The geology of this site was outlined by Branagan (1968), and the occurrence of cups, their nature and possible meaning were discussed by Cairns and Branagan (1988, 1992). Further details of the site are given in Branagan and Cairns (1993).

Our attention (see Branagan and Cairns, 1992) was directed to cups occurring upon several naturally tesselated pavements such as the Elvina site, the fractures forming frames for a variety of patterns of cups (Figs 5 & 6), but there are possibly also sites where cup patterns occur independent of tesselation on the Hornsby Plateau. These are being examined during present fieldwork, but are not discussed in this paper.

It seems particularly relevant to us that in addition to Elvina, the Basin Track site, the "Echidna" site nearby, Muogamarra, Brooklyn Heights, Patonga Ridge, Pearl Beach Ridge East, and a little further north, just below Staples Lookout, Woy Woy all contain cups (Table 1 and Fig 7). The "quality" of the occurrences varies, being largely a function of the nature of the tesselations, coarseness of the sandstone, and the degree of weathering of the surfaces. In addition the presence or placing of Aboriginal carvings on the pavements may distract attention from the cup patterns.

On these terms the "Echidna" site, with its "incipient" tesselation (Branagan & Cairns, 1993), and its abundance of tracks and carvings is not particularly informative, and the cups there seem to be part of a relatively simple "track". The Basin Track site, with its fine carvings occurring within and across tesselations (a relatively uncommon feature) draws the eye naturally to the carvings rather than to the cups. At Muogamarra, the coarse grain of the rock, and apparent surface weathering, together with some carvings (themselves rather weathered) lessen the impact of the cups. Similarly at Brooklyn Heights, weathering on a sloping surface, and some probable naturally-formed holes again lessen the impact. The Staples Lookout site is on the lowest of three adjacent rock surfaces, and there are few marked polygons. Here the rock is quite coarse, cross-bedded and marked by liesegang iron staining. On the intermediate level are some curious rock mounds which may be of human origin (possibly Aboriginal), while on the uppermost surface there are many Aboriginal carvings (Fig. 8).

The site we call Pearl Beach Ridge East (east of the Patonga Road) on the other hand is remarkably like the Elvina site, although it seems to lack figurative carvings.(Figs 9,10). This site, in particular, reinforces our perception of the cultural origin of many dots and lines previously disregarded by other researchers. They show well-formed cups spaced in patterns within polygons. We believe they can only be of human origin, and cannot conceive them as being meaningless doodles.

In addition to the long rows of cups which occur within some elongate tesselations we have recognised at the several sites some 102 varieties of cup (dot) patterns. Sixty two of these patterns are shown in Fig. 11. We have not attempted to indicate any size variation in the cups, because our observations suggest there is little significance in the variation of cup diameters and cup depths. The regularity of spacing, and the straightness of many lines are worthy of note. They indicate that measurements of some kind (angles and distances, rather than mere counts) were being made and recorded with considerable care. Many of the patterns appear at more than one site. In essence the patterns can probably be reduced to twenty three basic types, but this depends to some extent on the degree of accuracy assigned to the spacing and orientation of the cups.

What is the Meaning of the marks?

We believe Aboriginal use of natural geological features, as well as their enhancement and creation of new marks, particularly cups (or pits) may well be significant, and deserves close attention. As we have previously suggested (Cairns and Branagan, 1988, 1992) the patterns of dots resemble, and probably represent star patterns which have some relation to Aboriginal culture (Cairns 1991, Cairns and Branagan 1992). In particular there are repetitions of patterns that can be read as the Southern Cross (C4, Fig. 11), Taurus (H2, Fig. 11), Corvus (C2, Fig. 11). The Pleiades, Orion, Canis Major, Argo, Sagittarius and others, all essentially summer constellations, can also be argued for. Observations of the night sky made on site reinforce this opinion. These and other patterns will be discussed in more detail in later papers. As we have pointed out (Cairns and Branagan, 1992). Aboriginal knowledge of the night sky was considerable - some 40 constellations are specifically named in Aboriginal lore. Such interest is, of course, not unexpected. The relation between the night sky and two major aspects of Aboriginal life (seasonal time, and distance to food sources) is obvious (see Cairns 1991, 1993, and in forthcoming papers).

In an interesting paper MacPherson (1882) on the Astronomy of the Australian Aborigines suggested there is good evidence that the Aborigines of the Victorian Mallee, "where no rivers flow and no hills rise" recorded "three triads of stars" as important in their study of the sky, although he believed that they were essentially concerned with straight line arrangements, rather than groups in squares, triangles and other patterns, such as we are postulating. MacPherson also refers to an earlier paper by W.E. Stanbridge (1857) who notes that Aborigines regarded the moon cycle as being of thirty days, an indication that observation and numeracy was quite a natural feature of their life.

There may indeed be subtle spatial relations between marked tesselated surfaces and figurative or ceremonial sites: some are close, but probably distinct, as at Staples. Apart from the Basin Track site, where the figurative carvings overlap the tesselations, elsewhere, there seems a tendency for figurative markings to be placed around the edges of tesselated pavements Perhaps this indicates a chronological sequence, the cup markings preceding the figures, but there is little clear evidence on this point.

There is an interesting complex of sightlines between the major sites on the Hornsby Plateau (Fig. 7), which may prove relevant. Muogamarra is visible from Brooklyn Heights, and from the Patonga and Pearl Beach sites (a distance of more than 9kms). From Patonga Road the "Echidna" site can be seen, but probably not the Basin Track site. There is a sightline from Elvina Track to the Basin Track site, but the Echidna site is probably just obscured. It is thus possible that the various sites could have been a contemporary network of recording stations, and lends support to the idea of systematic observations being made.

Furthermore the marked sites all seem to fall within the area apparently belonging to the Ku-Ring-Gai People, while tesselated pavements in other nearby tribal areas are unmarked. Officer (1988, 1992), although dealing specifically with figurative art, has commented on the distinct stylistic changes that occur within the Sydney region, and discusses the implications. The spatially restricted nature of the patterned tesselated

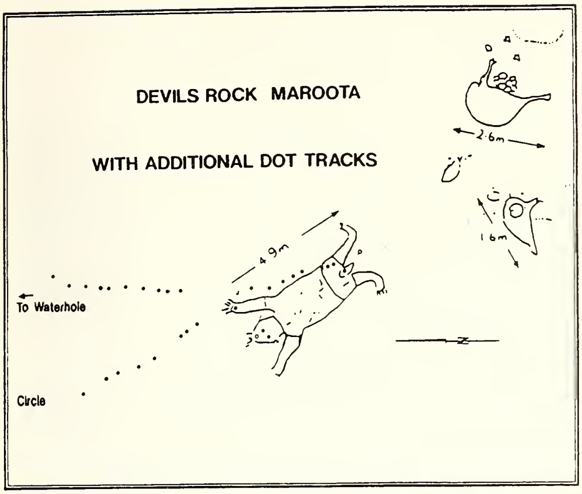

Fig.3 Portion of a figure from Stanbury and Clegg (1990) showing the Devil's Rock track at Maroota. The original figure has been amended showing that the line of cups continues through and beyond the figure, and then splits into two, one line ending at a round circular hollow, the other continuing towards a waterhole.

Fig.4 Grooves and dots at Elvina Track site. The grooves occur in several sets of 15.

Fig.5 An overview of the Elvina Track site, looking southerly, showing the variety of tesselation. The patterns of dots can be clearly discerned.

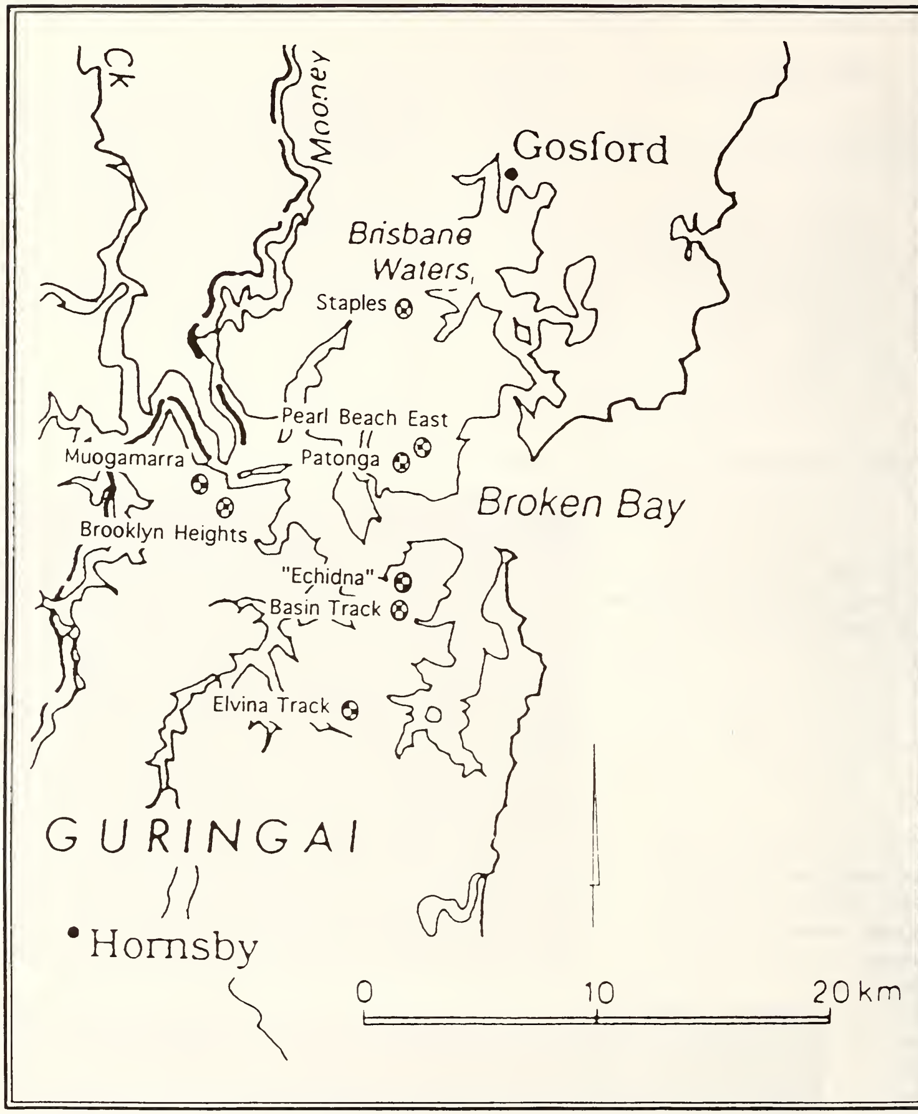

Fig.7 Location of tesselated pavement sites containing engraved pits. Study of the pit patterns (Fig.11) has, to date, concentrated on Elvina Track and Patonga East sites, where certain patterns are duplicated. Some of the simpler patterns certainly occur on other sites.

Fig 6 Ground view of part of the Elvina Track site showing pit patterns. Several shields can be discerned. Modern graffiti also occur.

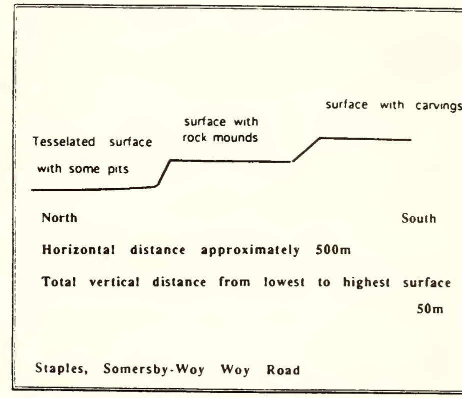

Fig.8 Conceptual sketch showing the possible relation between upper carving site and marked tesselated surface near Staples Lookout, west of Woy Woy.

Fig.9 Patonga East site showing part of the extensive platform.

Fig.10 Detail of the Patonga East site showing several patterns.

surfaces may be an important "variation within the culturally defined boundaries of communication" (Officer, 1992, 6).

There is clearly much more work to do to prove, or at least improve the likelihood, of our hypothesis that these markings represent star patterns. We are undertaking more detailed recording of the patterns, including their spacings and orientations, and an initial project of professional surveying has begun at the Elvina Track site. Whether one would expect accuracy of this nature by the ancient observers is conjectural, but we believe that the quality, spacing and general orientation of the cup patterns, and the ideas behind them which caused them to be executed betoken intelligence of a considerable magnitude.

Acknowledgements

We would like to express our thanks to David Lambert, Alan Henderson, Pat Holland and Steve King of New South Wales National Parks and Wildlife Service for advice about sites of interest, and logistical help, particularly the use of a helicopter. The critical appraisal of our ideas by Jo McDonald, John Clegg and Bill Jobling among others has also been most helpful. We also acknowledge the positive criticism of a reviewer who helped to clarify our ideas and to improve the presentation of the paper.

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TABLE 1 - TESSELATED PAVEMENTS WITH CUPS with Grid References (NSW1:25 000 Series)

HORNSBY PLATEAU, SOUTH OF HAWKESBURY RIVER

Elvina Track, Ku-ring-gai NP-Mona Vale 9130-I-S 388758
Basin Track, Ku-ring-gai NP-Broken Bay 9130-I-N 405814
Muogamarra, Muogamarra NP -Cowan 9130-IV-N 322864
Brooklyn Heights, Brooklyn-Cowan 9130-IV-N 327855

HORNSBY PLATEAU, NORTH OF HAWKESBURY RIVER

Pearl Beach Ridge East-Broken Bay 9130-I-N 407876
Patonga Ridge (Crazy Rock)-Broken Bay 9130-I-N 400870
Staples, Somersby-Woy Woy Road-Gosford 9131-II-S 409959

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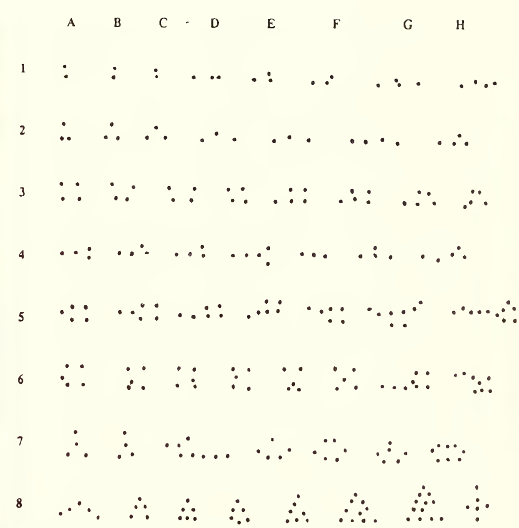

Fig.11 Variety of cup patterns recognised at the several sites (preliminary assessment). Simpler forms are repeated at some sites.

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BONDING AND NON-BONDING,

S. STERNHELL

ABSTRACT. Over the last 10 year our group hs carried out two parallel experimental investigations in physical-organic chemistry. The first one dealt with the development of a new experimental parameter fro the determination of the Π-bond order of the carbon-carbon double bond and the utilisation of this new parameter in the determination of the ground-state electronic structures of some unsaturated systems.

The second investigation dealt with the limitations of a previously proposed (Bott, Field and Sternhell, 1980) semiquantitative treatment for predicting the severity (energy penalty) of repulsive non-bonded interactions from purely structural parameters.

THE Π-BOND ORDER OF CARBON-CARBON DOUBLE BONDS

The notions of the Π-bond order, or the mobile bond order, or indeed the σ-π description of the carbon-carbon double bond, are purely theoretical concepts although elementary text-books give them an air of experimental reality. An examination of the correlation of experimental variables, such as the carbon-carbon bond lengths (Pauling, 1980), vicinal interproton spin-spin coupling constants (Bartle, Jones and Matthews, 1969), and other NMR parameters (Marshall, 1983; Kalinowski, Berger and Braun, 1984; Joseph-Nathan, Garcia-Martinez and Morales-Rios, 1990) shows that they are, at best, semiquantitative whichever calculated set of Π-bond orders is chosen for the comparison.

We have developed (Barfield, Fallick, Hata, Sternhell and Westerman, 1983; Barfield, Collins, Gready, Sternhell and Tansey, 1989) a new NMR parameter, namely the 4-bond *ortho*benzylic interproton coupling constant involving a methyl group (henceforth referred to as $^4J_{OB}$) which shows excellent correlation with either the pauling bond-order (Fig. 1) or the square of the SCF/MO bond-order as required by theory (Barfield, Fallick, Hata, Sternhell and Westerman, 1983; Barfield, Collins, Gready, Sternhell and Tansey, 1989). Moreover, the parameter $^4J_{OB}$ proved insensitive to other structural features such as ring-size and the presence of polar substituents or heteroatoms (Collins, Hatton, Sternhell and Tansey, 1987) within aromatic systems.

It now became possible to investigate by a purely experimental method the Π-bond order in unsaturated systems of interest and hence to gain an insight into the ground-state distribution of Π-electrons in them. We were thus able to demonstrate the following effects:

(i) According to our method, the Mills-Nixon Effect (ground-state bond fixation in tetralins, indanes etc.) does not exist (Collins, Gready, Sternhell and Tansey, 1990).

(ii) Our parameter shows very good correlation with SCF/MO bond-orders in a large variety of heteroaromatic systems (Gready, Hatton and Sternhell, 1992).

(iii) The presence of pairs of +R/-R substituents on a benzene ring in either the *para* or the *ortho* configuration causes significant ground-state bond-fixation (Collins, Hatton and Sternhell, 1992). The same effect can be observed in suitably substituted heteroaromatic systems (Collins, Hatton and Sternhell, 1992) and leads to a novel and completely independent method for the determination of Taft's σ^R substituent parameters (Hatton and Sternhell, 1993).

(iv) The electron distribution in free-base porphyrins (Crossley, Harding and Sternhell, 1992) corresponds to an [18]-annulene with the bond order between the β–β pyrrolic protons within the annulenic system approximately as high as the α–β bond in napthalene. The β–β pyrrolic bonds *outside* the annulenic systems are essentially isolated double bonds.

(v) The ground-state Π-electron distribution in azulene and biphenylene are as intuitively expected, i.e., azulene shows evidence of electron-transfer from the seven-membered ring towards the five-membered ring and biphenylene exhibits a radialene-like distribution (Collins, Sternhell and Tansey, 1990). More unexpectedly, the bond-orders in 1,6-methano-[10]annulene are in accord with intuition (i.e., the Π-electron density in the α–β and the β–β bonds is the same), but *not* in accord with structural data (Collins, Sternhell and Tansey, 1990).

(vi) In a moderately distorted benzene (Hambley, Sternhell and Tansey, 1990) and phenanthrene

(Sternhell and Tansey, 1990), as well as in a number of severely distorted *para*cyclophanes (Gready, Hambley, Kakiuchi, Kobiro, Sternhell, Tansey and Tobe, 1990) the Π-bond orders appear to be normal, i.e., rehybridization occurs to maintain p-p overlap in spite of the distortions imposed on the σ-skeleton.

(vii) Finally, our method gave independent confirmation (Craw, Hush, Sternhell and Tansey, 1992) of the phenomenon of long-range perturbation of electron distribution in benzene rings by apparently isolated double bonds elsewhere in the molecule.

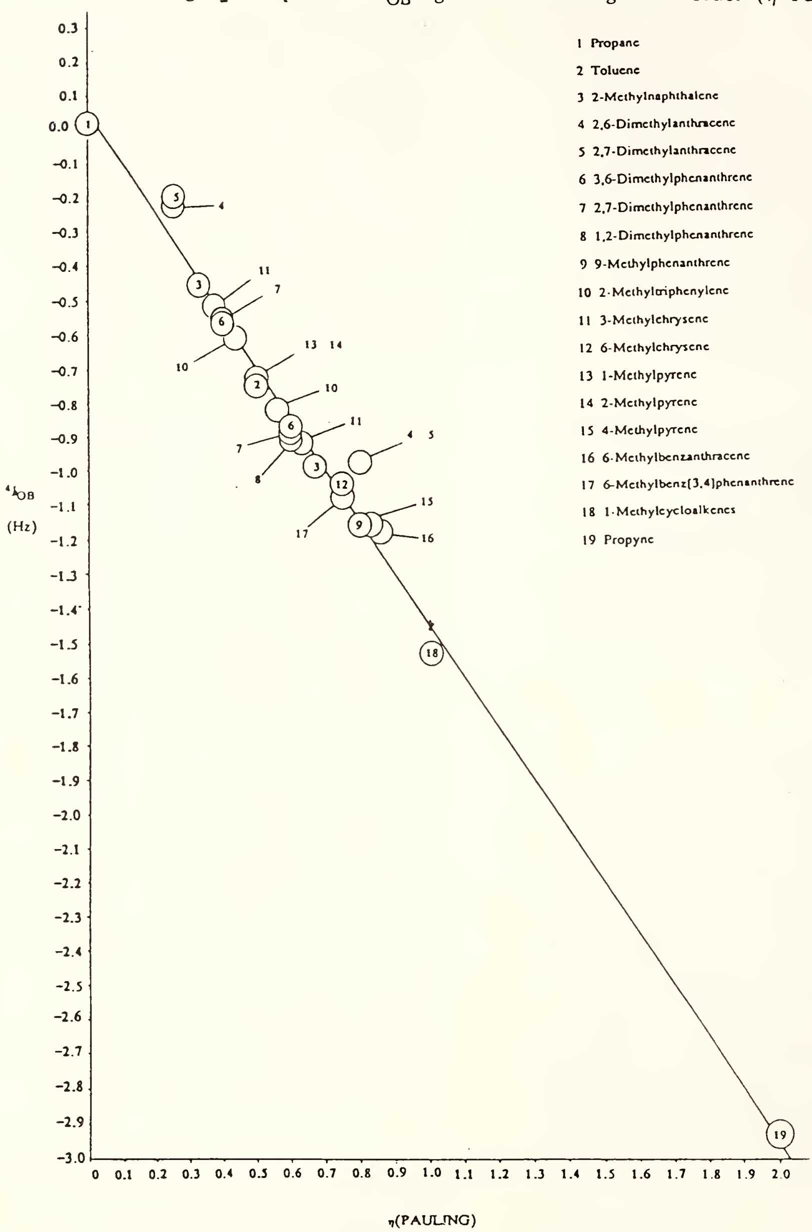
We consider the results summarised under (vi) to be the most interesting outcome of these investigations and they have led us to the wider question of the shape of the potential energy curve associated with the decoupling of the Π-bond in ethylene during a pure rotational distortion of the σ-framework. We are at present engaged in the synthesis of appropriate molecules and the study of the rotational barriers in them.

NON-BONDED INTERACTIONS

Repulsive steric interactions ("steric hindrance") are simple conceptually ("two into one will not go"), but notoriously difficult to investigate in a quantitative manner. Some years ago (Bott, Field and Sternhell, 1980) we proposed a simple measure of severity of steric interactions which we named "apparent overlap". This amounts to measuring the overlap between van der Waals' surfaces involved in repulsive interactions as if the surfaces actually passed through each other, which is clearly not the case and hence the origin of the qualifying term "apparent". It transpired that for a variety of systems (Bott, Field and Sternhell, 1980) not only was the relationship between the height of the rotational barrier ("energy penalty") and apparent overlap linear, but the proportionality constants fell within a narrow range for different systems. Our original work (Bott, Field and Sternhell, 1980) was based mainly on biaryls but we have extended it to imides (Newsom, 1984), 9,10-dihydrophenanthrenes (Cosmo and Sternhell, 1987) and *meso*-tetraarylporphyrins (Crossley, Forster, Harding and Sternhell, 1987). We have also extended this study to the relationship between *static* deformation (Cosmo, Hambley and Sternhell, 1987) and apparent overlap and found surprisingly good correlations.

However, not unexpectedly there proved to be no correlation between apparent overlaps and the equilibrium internuclear distances of the repulsively interacting nuclei emphasising the artificiality of the concept of "apparent overlap". An unexpected, indeed highly counterintuitive result, was that in a number of cases (Cosmo, Hambley and Sternhell, 1987) the same pairs of nuclei (in particular halogens) proved

Fig. 1 A plot of $^4J_{OB}$ against the Pauling bond order (η Pauling).



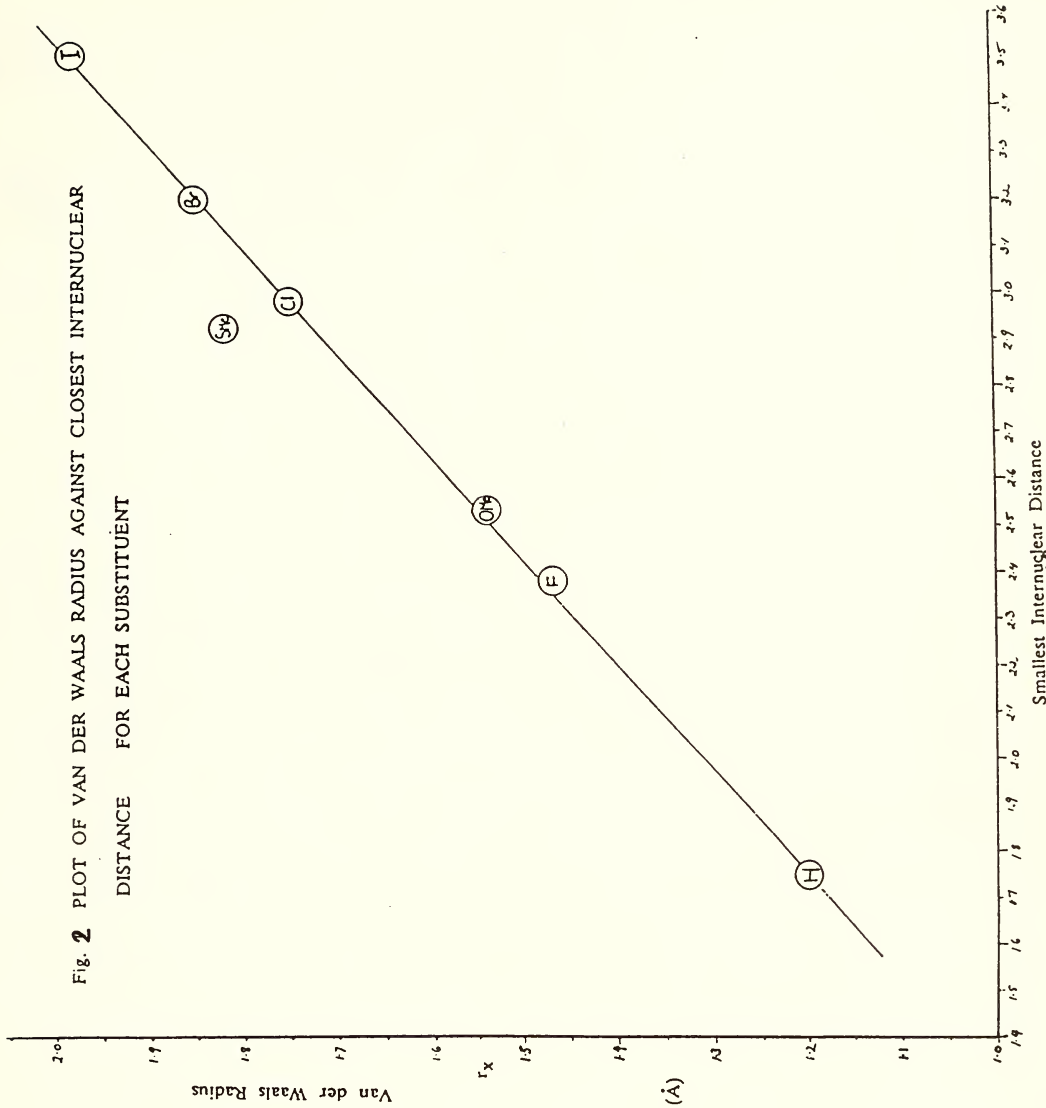


Fig. 2 PLOT OF VAN DER WAALS RADIUS AGAINST CLOSEST INTERNUCLEAR DISTANCE FOR EACH SUBSTITUENT

to be closer (crystallographic results) for cases (1,8-disubstituted naphthalenes) where the σ-framework would predict them to be further than in other cases (4,5-disubstitutedphenanthrenes). This anomaly could have two explanations (Cosmo, Hambley and Sternhell, 1987), viz., that either the *angle* of approach was critical for the distortibility of the van der Waals' surfaces or that the partitioning (Allinger, 1976) of the repulsive energy between the distortion of the van der Waals' surfaces and skeletal distortion caused the "stiffer" naphthalene nucleus to squeeze the halogens in the 1,8-juxtaposition more than the apparently "closer" halogens in the 4,5-juxtaposition of phenanthrenes.

The synthesis of a number of compounds designed to discriminate between these two hypotheses was undertaken and crystallographic data for a total of 11 new highly crowded compounds were obtained. From these results (Hambley and Sternhell, 1992) it was possible to conclude that it was the second of the rival hypotheses that as correct. As an interesting by-product of this investigation, we have collected our own and literature data for the closest intramolecular distances between pairs of atoms, viz., -H, -F, -OMe, -Cl, -SMe, -Br and -I ever reported. While it will never be possible to claim that any such set of data are "the most crowded *possible* cases", two remarkable correlations can be drawn from our data.

(i) The apparently maximum compressions possible appear to be remarkably similar for the above atoms, ranging between 0.45 and 0.72 Angstrom, suggesting that these elements have similar compressible outer layers.

(ii) A plot of the "record" minimum distances from our crystallographic data (Hambley and Sternhell, 1992) (Fig.2) against the van der Waals' radii of the atoms involved is a straight line.

These phenomena are being further investigated by the design, synthesis and crystallographic studies of further crowded compounds.

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I wish to acknowledge the fruitful collaboration with my colleagues Drs M.J. Crossley, L.D. Field, T.W. Hambley and M.M. Harding and Prof. N.S. Hush, as well as of the numerous Postgraduate and Honours students listed in the publications. Both phases of this research were supported by the Australian Research Council.

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Liversidge Research Lecture 1992, Royal Society of New South Wales:

left to right (clockwise): Dr. F.L.Sutherland (President 1992/93), Prof. Sev. Sternhell (Liversidge Lecturer 1992), Prof. Noel Hush (School of Chemistry, University of Sydney), Prof. Bob Gilbert (School of Chemistry, University of Sydney), Dr. Peter Lay (Secretary of the Chemical Society), Dr. Tony Masters (President of the Chemical Society), Prof. Hans Freeman (Liversidge Lecturer 1978).

(photo taken during dinner after the Liversidge Research Lecture and presented to the Society by the Chemical Society)

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UNDERGROUND SPACE: THE GEOSPATIAL PLANNING OPTION FOR 21ST CENTURY SYDNEY

PART TWO (Part One appeared in the last issue)

GEOSPACE IN THE FUTURE, A CASE STUDY: 21ST CENTURY SYDNEY

Sydney A. Baggs

GEOSPATIAL PLANNING

In the previous issue of this journal, it was established that the advantages of using geotecture as a valid planning option for the future far outweighed the disadvantages. In this issue, the question of how the principle could be applied to the future planning of Sydney will be addressed. Such a proposal aims at halting the spread of the ubiquitous skyscraper and challenges the whole principle of vertical city development with its concomitant problems of environmental deterioration and loss of human amenity.

In 1988, it was found that certain types of heart disease and depression are associated with living in high-rise building (9 or more storeys) and in proximity to the main electrical supply cable (Perry and Pearl, 1988, Brooker, 1989). Dr Cyril Smith (Smith and Best, 1989) explained how an electric field folds around an object placed within it and so magnifies its values up to one hundred times the unperturbed field. What must the tower structures of our cities be producing in the way of distortions to the geomagnetic field? (There are also concentrations in alternating current fields with their associated potential to affect health because of increases in extremely low frequency, electromagnetic, non-ionising radiation.) Why have tower buildings at all? These questions lead into the next issue to be raised, that of whether vast towers erected in total ignorance of their potential for creating pathogenic zones around and within them, should be accepted as the only way to proceed in future city development. Such buildings have 40-50 year life-cycles, at the termination of which whole city blocks could be redeveloped.

Consider the alternative, a *horizontal* city, one of geospatial development serviced by underground transit and utility corridors, a city that replaces concrete and metal roofs with an interlinked network of roof-gardens and parks over the whole of the Central Business District. Major streets would be retained and minor streets amalgamated with adjoining sites as a 'trade-off' for overall development control and to boost floor space ratios. This, added to the development of deeper levels of geospace would allow the 1992 planning policy ratios to be retained for viability.

Geospatial Transit Corridors

When the London underground railway was first opened over one hundred years ago, a prototype became fossilised. Over the intervening years, every subway, metro and underground rail network has been modelled upon it. The train tunnel preceded the motor car. 'Piggyback truck' (or wagon) services were established in the Alps 60 years ago. The Channel Tunnel will use this system when it is completed.

Consider these facts (some of which were presented by Professor Frank Davidson (1988), Head of School of Engineering, MIT): 1. the piggyback wagon (or the palleted automated transit, PAT), is very energy and economy efficient; and 2. the personal vehicle in some form or other appeals to the Australians and probably will be with us throughout the 21st century. So why is our city traffic not underground using a combination of the skills of highway and railway engineers. So-called 'smart' cars and trucks would move onto pallets that slot into guideways, combinations of the high-load traffic capability of the railway with the individuality of the personal vehicle. All this beneath the landscape and waterways, freeing the surface from highways and returning it to people and nature. Multiple lanes even become unnecessary as transit times decrease and throughput is increased by factors of 7 to 10.

Imagine the transport of commodities using larger versions of the pneumatic underground tubes

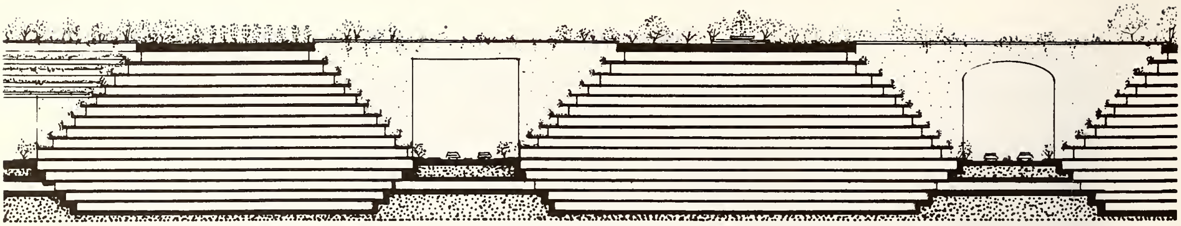

Figure 2 (from Part One) (This figure appeared in Part One and is reproduced here for convenience.)
The Semi-underground concept described by Professor Yoshiaki Yoshimi (Davidson, 1988). Diagrammatic section showing 10 storeys above ground and 5 storeys below linked by underground passages

that were in use in Paris and Vienna years ago to deliver and collect mail. Electropneumatics to convey goods could not only link cities but continents.

THE FUTURE OF GEOSPATIAL DEVELOPMENT

It has been suggested that a hybrid geopolitan design (Figure 2) could be ideal for the development of the city of Sydney, transforming it into a garden city in the true sense of the term.

An amalgam of 2 concepts would be very interesting; firstly, the hybrid form of the Japanese Urban Geo-Grid of the Shimizu Construction Coy Ltd (Davidson, 1988) and secondly, the Subterranean Urban System of Gunar Birketts (1974, 1984). It was thought that the potential for applying geopolitan planning to an existing city could best be demonstrated by undertaking a case study at the conceptual level. It is not intended as a 'solution', it is merely a stimulus to discussion.

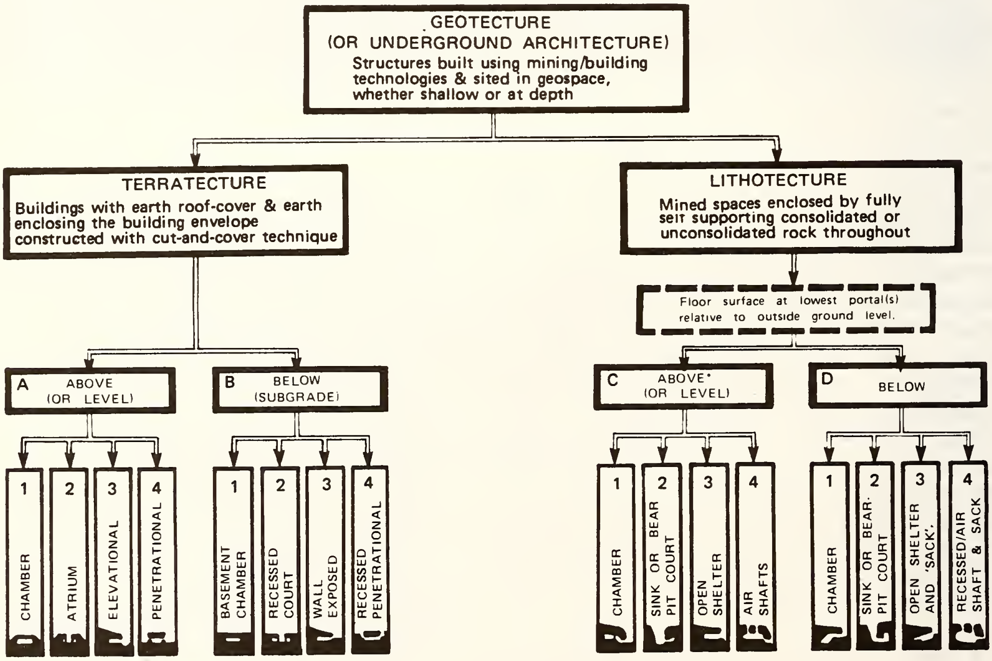

Figure 26:
Classification of underground space

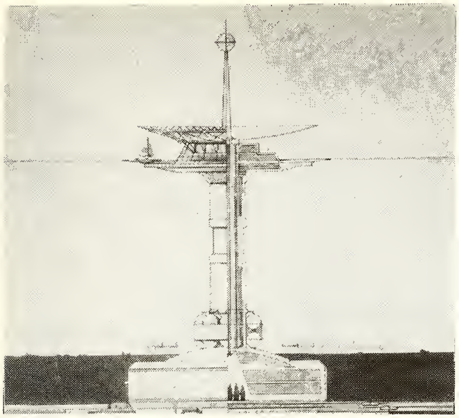

Figure 27:
Undersea Grid Station, a branch from a sea tunnel with leisure facilities at sea surface level

The Urban Geo-Grid

In the case cited in Figure 2, many buildings of a limited number of storeys are raised to the same height to form a podium. Roof gardens are bridge-connected. Basement space contains libraries, museums, conference facilities and the infrastructures described previously. The Shimizu Corporation propose a grid development. At each node, a base facility is constructed below such surface facilities as schools and parks. This 'gridpoint' or grid network (Figure 15) contains those facilities needed in the local community such as convenience stores, exhibition halls, local libraries or public baths.

Grid Stations are control bases comprising a vast atrium surrounded by offices, hotels, shopping centres with a city park at ground surface (Figure 26). A variation on this is the underwater Grid Station linked by underwater tunnels. Leisure facilities are located at sea surface over the Grid Stations (Figure 27).

The Subterranean Urban System

The Urban-Geo-Grid could be utilised to incorporate the type of transit corridors discussed previously, and the principles can be developed along the lines proposed by Gunar Birketts (1974) and applied as a plan for the future development of the Sydney urban region. However, it is first necessary to explain briefly the concept of the Subterranean Urban System.

New planning policies would need to facilitate the integration of the following:

1. the division of three-dimensional space into public and private domains;
2. a transportation system with rapid transit underground fed by moderate speed surface-systems and walking-speed people-movers;
3. an underground goods-handling system for commerce and energy generation industry that connects air, road, sea and rail terminals (with a highly automated component);
4. an underground waste removal system that integrates with all collection points for garbage, sewage and industrial waste, transporting it at high velocity to separation, treatment and reconstitution plants;
5. the zoning of automated and semi-automated industrial processes along the transport conduits for goods and waste removal;
6. the location of all parking and storage facilities in geospace;
7. a fully accessible maintenance and modification system to all of the above;
8. a review of open-space ratios in the light of current knowledge on the necessity of vegetation to modify city heat-island effects and modify atmospheric pollution and a reallocation of a network of open-space zones in the web of public space released by the undergrounding of all the above;
9. the allocation of recreational space (both passive and active) and architectural forms in the landscape that will mark the entrances to commercial, public and industrial facilities (giving them a sense of place).

The underground conduit.

Such a far-reaching proposal for a new city, or the replanning of an existing one such as Sydney, relies upon the practical implementation of a connecting conduit, the spine upon which an array of geospatial functions are disposed.

Birketts (1974) has addressed the design of such an element and suggests that it be between '200 feet and 1000 feet wide'. This application to Australian conditions would have a conduit 40m wide that could widen to 200m or so depending on the local geology and geography. Located either at ground surface, partially or fully subsurface, Figure 28 indicates how such a flexible form of conduit could be integrated into the landscape.

Air and water pollution could be significantly reduced by capturing waste products and processing them within the conduit system. Waste heat could be collected at source and recycled to boost private heating systems, or 'captured' and transported for public use. A total energy system becomes possible

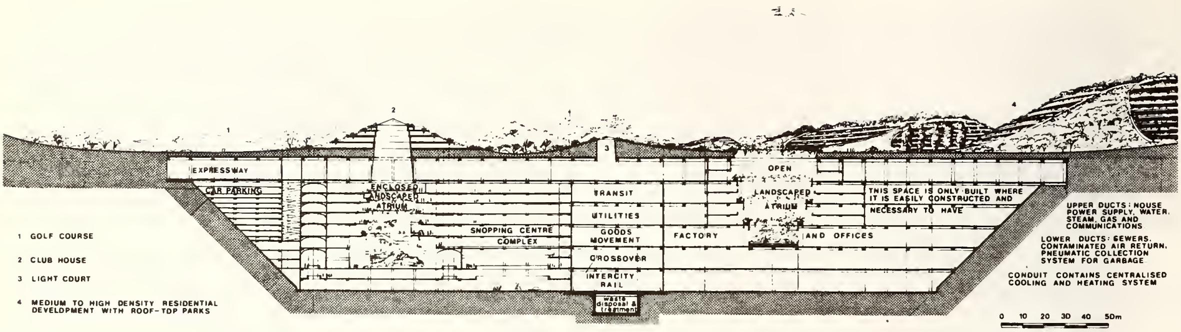

Figure 28:
A main conduit (shown crossed) constructed (by the cut-construct-cover method) with backfill modelled to produce landforms flanking the open-space corridor some of which contain terratecture residential development, schools, libraries, recreational and public service facilities.

reclaiming heat and waste recycling them, receiving the power, utilising it, processing the finished products and transporting them, as well as contaminating waste, all within the conduit system. The complete railway system, relocated underground in such conduits could not only serve for public transit but also to eliminate the immense surface space wastage represented in the marshalling yards of the Sydney system.

Conduit construction.
Built essentially as an above-ground structure, it is backfilled (terratecture). Residual excavated material can be left to be landscaped as hills and mounds to receive earth-covered surficial developments of either high-, medium- or low-density housing, schools and community service-facilities that are set within parkscapes. The potential for reshaping the landscape is limitless.

Where the conduit must pass through an established built area, only its core need be constructed until the life cycles of the above-ground development have expired. This core contains the utilities and transport systems and would be tunnelled through rock, or say, 'stack-drift' lined through soil (Parkes and Robinson, 1983), or constructed in an immersed tube system, floated, sunk and assembled on the harbour or river bed (Kelley, 1986) as in the Geo-Grid system. Orderly expansion and the relief of congested urban and suburban space are of great benefit in the redevelopment of an area such as inner Sydney.

Surficial development.
Covered with backfill and topsoil, the conduit roof is landscaped around exit/entrance lobbies, and vertical cores communicating with geospace occupied by workers, naturally illuminated by skylit atria and light courts. High-density residential areas, public service facilities and schools can be built along the linear conduit park (as illustrated in Figures 17 and 29).

Local roads flanking the linear park and accessing a PAT transport system at regular intervals, also allow emergency access along the parkway. With high-speed public transport stations at 3km intervals located in the conduit core, moving footways connect the high-speed transit terminals and deliver people to their destinations along the conduits.

The surface transit network covers the whole city with all parts of the urban and suburban space being no more than 0.5km from the nearest station. Although personal vehicles can use local roads, a medium-sized commuter bus collects passengers at these stations. At the rapid transit station, the bus driver engages the bus into a computer-controlled PAT system which works in a concentric system as well as in the conduits. Public transport would be favoured by the use of speed controllers on all personal vehicles.

Because all neighbourhoods are encircled by open-space zones, no one would live more than 0.5km from public open space, although with medium-density terratecture, this open space would blend visually with private open space in the form of continuous street commons comprised of garden roofs (Figure 29).

These green zones would amalgamate into the larger areas of linear park along conduits. These could contain botanical and zoological gardens, sports field complexes, universities, schools, etc., and would be accessed by commercial and industrial

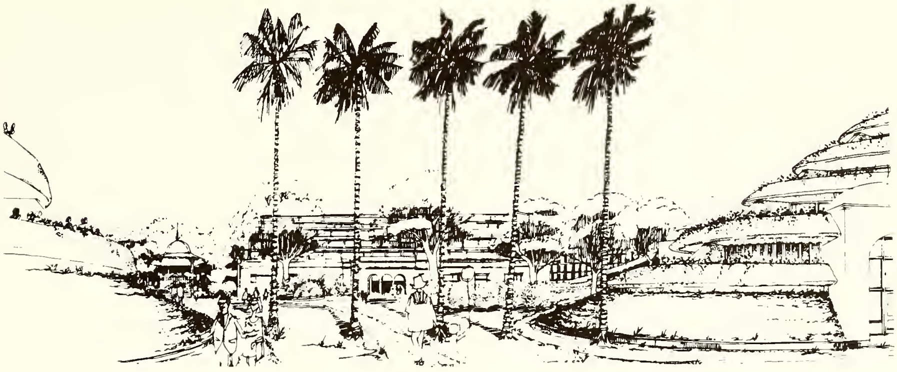

Figure 29:
Public open space in the form of a local common with small parks as roof gardens to medium-density development and with footways, bikeways and equestrian tracks incorporated

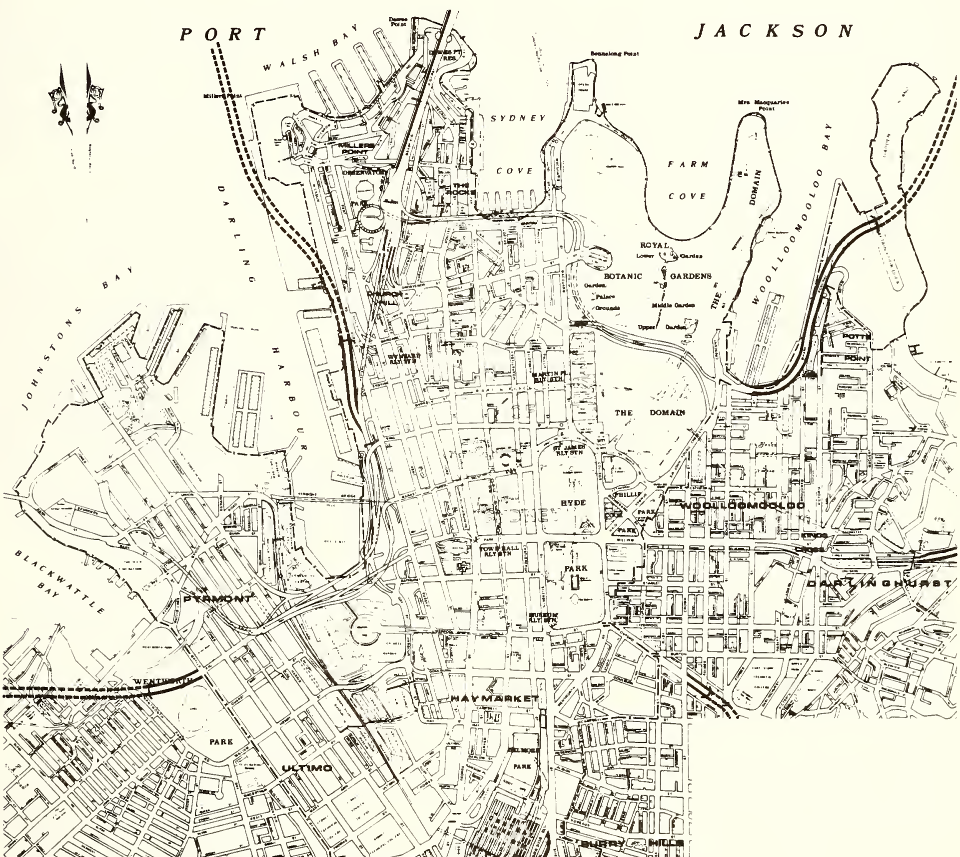

Figure 30:
Map of Central Sydney

works from the geospace below. This green space network would function to provide natural, not piped drainage, keeping the ground water table charged and stable.

Could such a concept be applied to the Sydney inner urban area? Imagine such suburbs as Alexandria and Botany cleared of warehouse, industrial plants, petrol stations, railways, roads and

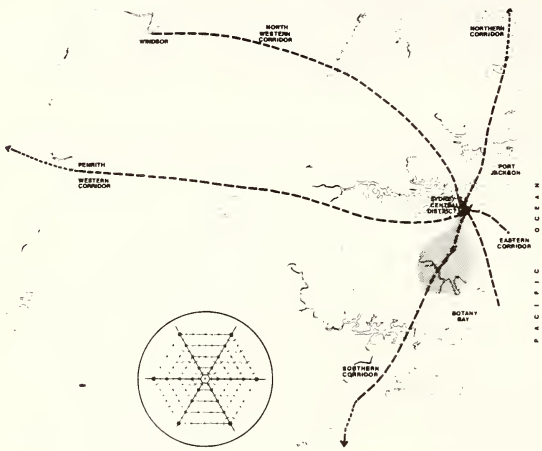

Figure 31:
The Sydney urban and suburban area showing the general principle of conduit corridors (as linear parks) carrying transport, utility and waste collection systems. [Inset: Birketts (1974) theoretical model from which this system was derived]

parking areas, transformed by having its land surface rehabilitated as parkland and its canal system restored as river and river bank. New housing could be introduced using geotecture with sunlit residences, views over Botany Bay and garden roofs with day-care centres, kindergartens, etc., similarly integrated into park landscapes. To investigate this possibility, the Sydney CBD was chosen as the central cell of the pattern (Figure 30) and one corridor was investigated out to the Botany Bay foreshore.

THE STUDY AREA: SYDNEY BUSINESS DISTRICT AND PORTION OF THE SOUTHERN CONDUIT (TO ROCKDALE)

The layout in Figure 30 develops 6 major nodes to begin the network of conduits running into the suburban areas beyond. Some conduits run underwater, the remainder are underground. All carry rail and expressway routes for private traffic as well as utilities, etc., and as soon as industrial zones are encountered, factories can be located underground (see right-hand side of Figure 31).

As the network enters the inner suburban areas, the first node of the network is approximately 2km out and is a stop in the radial public high-speed transit system. Conduits then radiate out (to follow existing main roads or railway reservations where possible), returning the land surface of these corridors to landscaped linear parks and residential development. Utility distribution and collection lines in these conduits reach out into the surrounding communities.

Communities can be redeveloped as existing suburbs are modifed to adapt to form 2km diameter community areas that are surrounded by vegetated belts and by utilities carried in smaller cut-construct-cover conduits (where geology permits) following a generally concentric every-widening pattern which extends into the spaces between the main radial conduits, connecting them at every 2km node as shown diagrammatically in the inset of Figure 31.

Even along the heaviest industrial corridor, the accommodation of all industrial space built

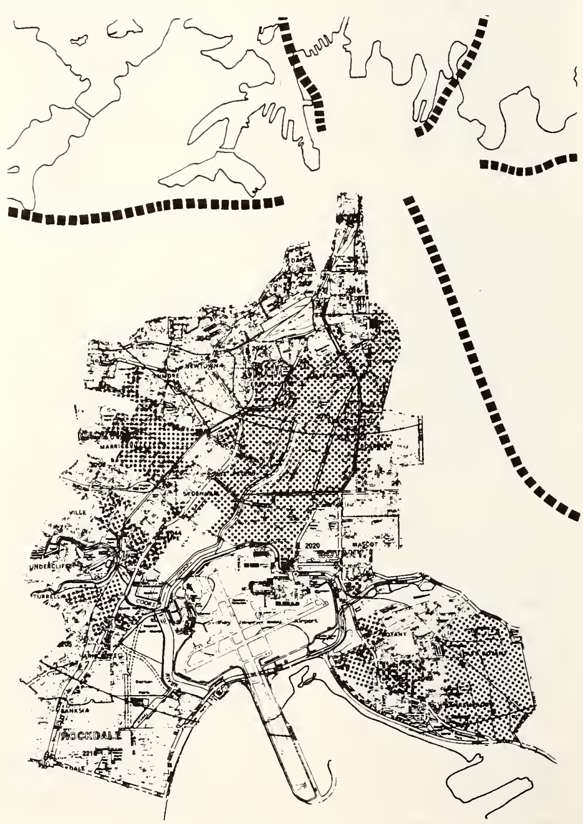

Figure 32:
The Study Area of the first section of the Southern Corridor (City to Rockdale). (Industrial areas shown in dotted pattern.)

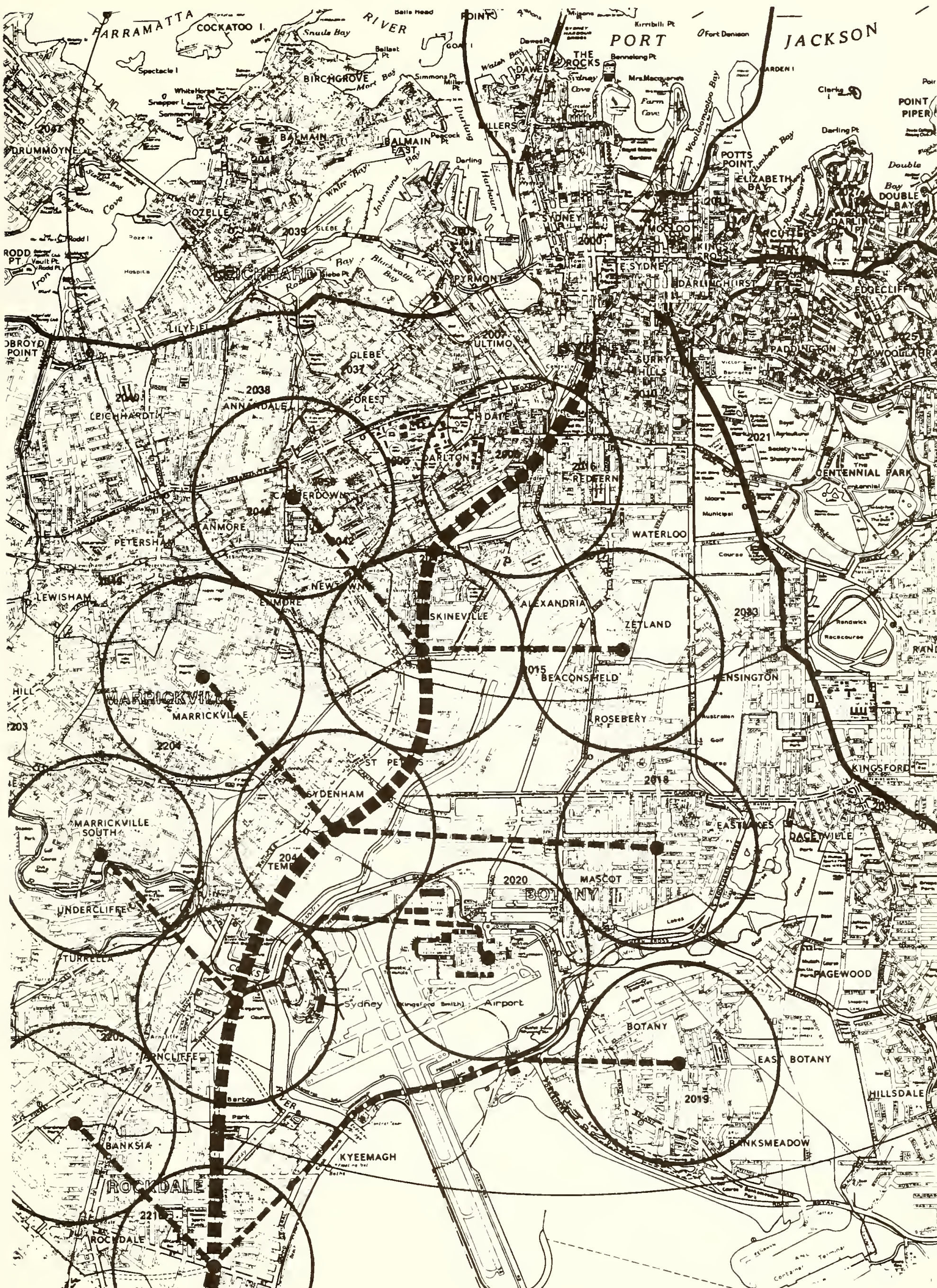

Figure 33:
Diagrammatic indication of the Birkett system applied to the study area, i.e., a portion of the Southern Corridor showing the subterranean transit and goods-handling system. (The Corridor is shown as a broken line.) This would be the route of the conduit flanked by geotecture industrial and commercial buildings and also a linear landscaped park and open space for recreational and residential use. Thirteen communities (2km circles) are shown. Four are high-density nodes along the corridor and together they comprise an urban area serviced by systems in the conduit and its concentric-ring branches.

Figure 34:
New land-use pattern of the Study Area of the Southern Conduit (broken heavy black line) and Corridor (thinner black lines flanking the conduit). Half-tone area shows previous industrial land now available for residential and commercial use once industry is relocated in Corridor geospace.

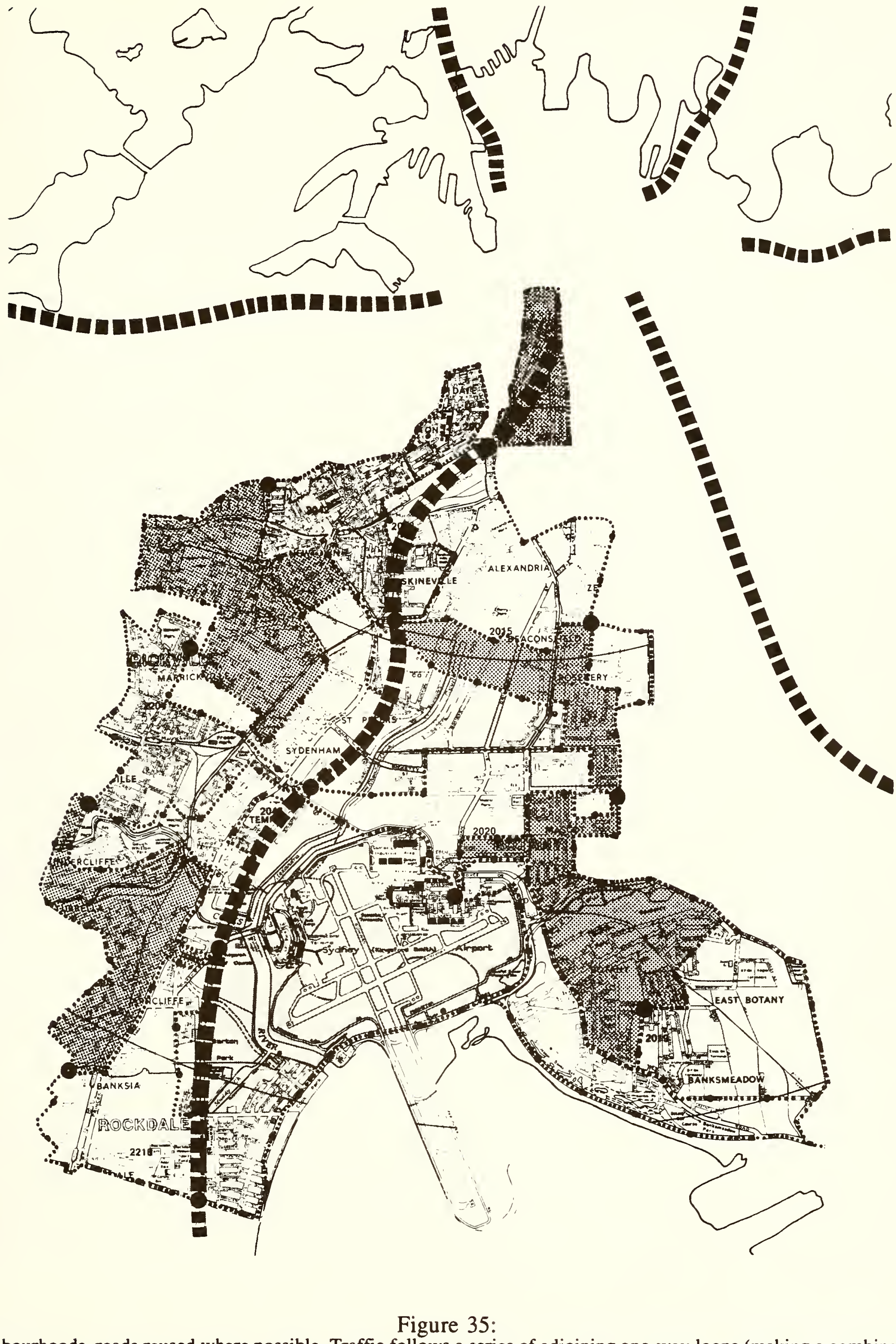

Figure 35:
New neighbourhoods, roads reused where possible. Traffic follows a series of adjoining one-way loops (making a combined two-way system) which connect to 3 intermediate transit stations subsurface

Figure 36:
Conceptual plan of amalgamated city blocks and sites with street-tunnels (for electric commuter transit) running north-south leaving east-west streets for sunlight penetration. (Site ratios take advantage of north-south street areas bridged by such a scheme)

subsurface would liberate sufficient surface land to accommodate dozens of new residential neighbourhoods. Goods movements occur along the subsurface network to arrive at transit and freight terminals in the community centres. From these, surface transport distributes within the neighbourhood.

All utilities in the conduit section are taken from existing sources and carried to industry and residential consumers. All wastes, solid, liquid and gaseous are processed within the conduit at nodes that contain incinerators, purification and decontamination plants as well as recycling, collection and separation facilities. Waste generated in each community is processed at a neighbourhood plant and is not returned in the conduit system.

At neighbourhood level, surface transportation would be based upon personal vehicles and public transport. Both would be best equipped with speed-control devices and would follow as many existing streets as possible. A one-way parkway road divides neighbourhoods as a loop system that runs parallel to the adjoining parkway loop running in the opposite direction (Figure 35). In some cases, corner lots need to be resumed to improve parkway turning radii.

It is useful to compare the land-use patterns that incorporates all new systems (Figure 34) with the existing pattern of development (Figure 32). If we assume that all factories in industrial zones, or within the neighbourhoods served by the South conduit, are, say, 3 storeys deep (they are not but this is a worst-case scenario for comparison purposes) the total industrial area shown in Figure 32 could be replaced by three-storey equivalent geospace within the conduit. All land in the corridor of the conduit, plus all land liberated by the relocation of the industrial zone into subsurface space, could be utilised for residential development. Earth-covered housing would be preferred for this conduit zone in that the whole zone lies within the noise 'footprint' of Sydney airport, and as discussed previously, noise attenuation is a major characteristic of this type of building.

If this development were to be based on medium-density housing at, say, 30 dwellings per hectare, the industrial zones together would yield some twenty-five thousand dwellings. In the conduits open space, assuming 30 dwellings per hectare of earth-covered housing (as in Figures 18 and 29), nineteen thousand dwellings would give a total to be achieved of forty-four thousand in this study area (a relatively minor proportion of the total suburban area of Sydney).

Figure 36 is presented as an idea of how the Shimizu Corporation's scheme (Figure 2) could be modified and applied to provide an economical method of implementing geotecture. While the development of the central cell of the network is presented as a concept only in Figures 36 and 37, it is meant to point the way towards the development of a totally different alternative aesthetic to the present fashion for using high-rise buildings as status symbols.

The tower form of the present-day office building, is energy profligate in its design when compared with geotecture. Rogue reflections are created and the city heat-island effect is aggravated when mirrored glass walls are used for interior energy efficiency in individual buildings. High-rise development could eventually be phased out to make way for a city with a 4-6 storey-high podium (averaging 5 storeys) over which a city park network would be relocated at rooftop level. At the interfaces of the podium parkland with existing street level parks, terraced transitional gardens, ramps and stairs would lead gently from one level to the other. The terracing would embrace conserved historical buildings and vertical access would occur within a multi-storey conservatory containing lifts, escalators, vegetation and boutiques, etc. Each city block would contain at least 2 access structures of this type.

All this could be achieved using the 10:1 floorspace ratio which renders each new amalgamated site economically viable by utilising subsurface space up to the 10:1 limit. Figure 36 is not a solution in itself. It is intended to point the way to a future when all subsurface space will be publicly owned and leased, and when a unified citv aesthetic will make most central urban surface space accessible and available for the recreation and enjoyment of all.

Tunnelling and Satellite Centres of Growth

Beyond the Sydney suburbs, main conduits could extend into the countryside to service satellite growth centres such as Wollongong and Gosford. Only the conduit element would be needed where it passed through scenic zones, e.g., the foot of the Illawarra Escarpment, isolated tourist centres could be connected to a node where terratecture (cut-cover-construct) techniques are uneconomical. For example where rock is encountered, tunnelling would be used.

Figure 38 suggests how tunnelling would apply using current technology in an area of scenic beauty. The geology of the Sydney Basin is ideal for lithotecture, 6.2km of railway tunnels already exist

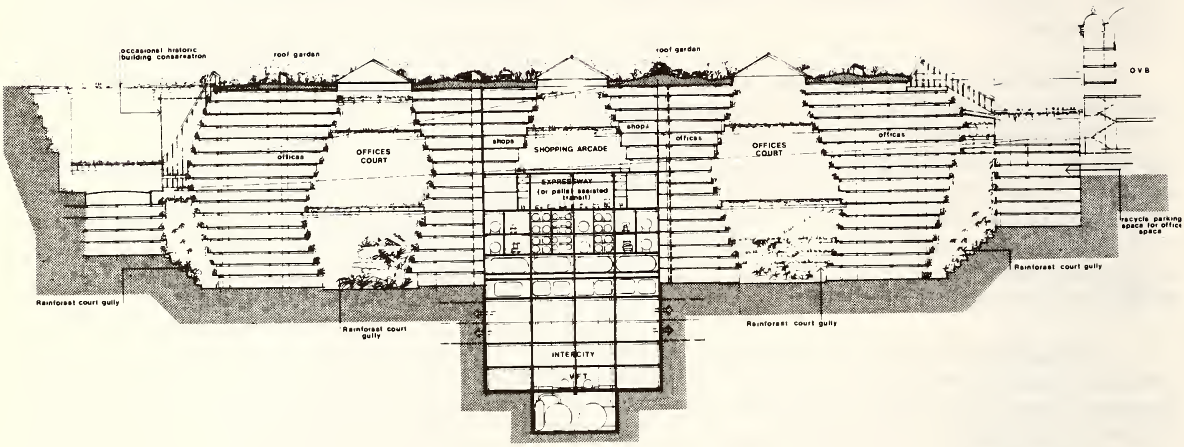

Figure 37:
Section through city block amalgamation podium. As demolition occurs, north/south streets are rationalised to take local traffic only, and east/west streets are retained for solar access to north face of podium and bridged. A low-rise roof park (4-6 storeys) is formed averaging 5 storeys over a major of the city following the pattern of Figure 1. Utilities are rationalised into main and ring conduits freeing space beneath existing roads.

and many are proposed for the future (Braybroooke, 1985).

The use of long tunnels for a Very Fast Train (VFT) inter-city transit system is contentious. The cost of air-pressure modifying strategies may not warrant resiting the tracks to pass through scenery of high visual quality. The complete conduit may need to be sited in the hinterland with nodes servicing developments such as that shown in Figure 38.

RECOMMENDATIONS

Such an approach to the future design of Sydney has heuristic qualities which could be explored as follows:

1. the establishment of a database, an inventory of all geospace in use in the city of Sydney including the extent and relative levels of all existing basements, a determination of geothermal gradient variations and a geological investigation with respect to excavation and tunnelling at depths to 450m;
2. the assessment of the projected sizes of utility conduits into the middle of the next century;
3. alternative energy systems that could be linked into State and city-grid reticulation networks;
4. the present and future needs of Sydney and the Sydney Region with respect to transport, including VFT, PAT and non-polluting vehicles as well as the extrapolation of VFT and expressway conduits into the Sydney region;
5. the present and future needs of Sydney with respect to energy use, future demands on utilities to the mid-21st century and the potential for in-conduit treatment of wastes including recycling waste heat and the floor-space ratios and relevant recommendations of the Central Sydney Strategy, 1988;
6. the potential demands on resources, utilities and transport that could arise because of satellite development around Sydney and its suburbs;
7. the overall long-term planning of amalgamated blocks and roof parks in the inner city;
8. the geoplanning of conduits within the inner city incorporating existing geospace;
9. the geopolitan planning of the Sydney urban and metropolitan areas;
10. the establishment of an interdisciplinary committee to begin the attempt of coordinating all authorities and their records of existing geospace-use. (Members should be chosen with proven records of environmental involvement and understanding.)

Finally, from the legal viewpoint, there are major obstacles to overcome. For example, Professor Toshio Ojima has stated: 'since the land is held by small-scale landowners, cities are now dying' (Davidson, 1988). Geopolitan planning requires a

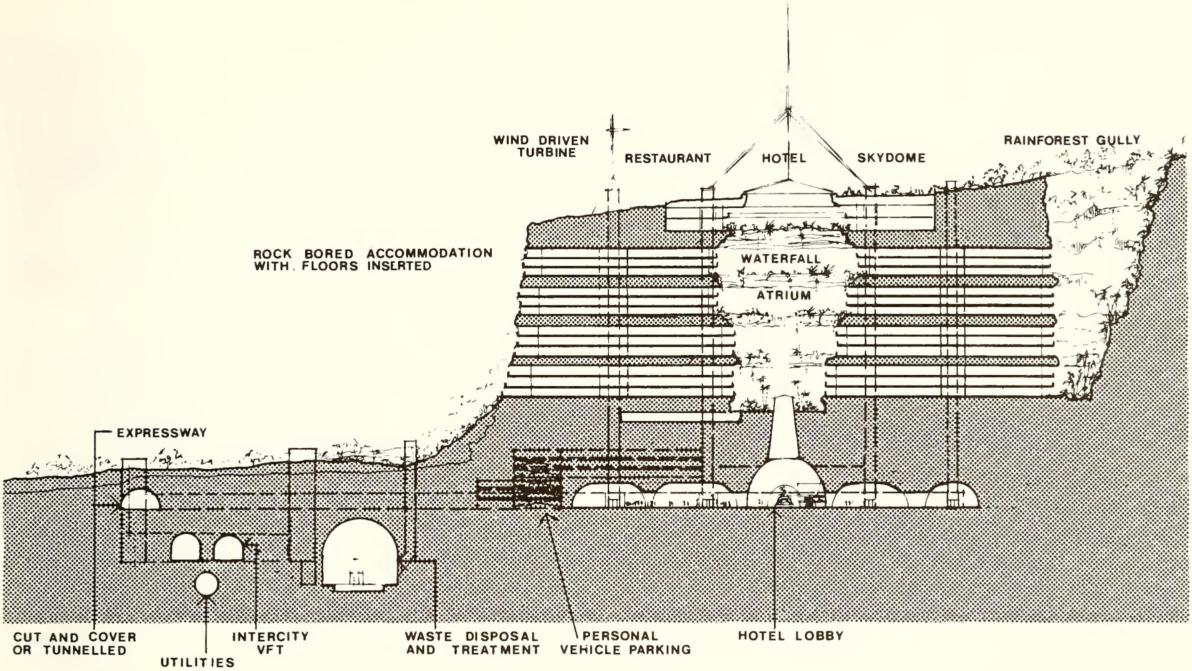

Figure 38:
Conduit in scenic terrain. Rock bored geospace. Tourist node, a hotel at the beginning of the Illawarra Escarpment. (Minimised environmental impact utilising alternative energy systems)

completely different outlook to land ownership which may be best implemented by declaring all subsurface land public land, then leasing it. The legal problems of defining boundaries, access, tenancy rights and, for example, legally describing the extent and shape of rock pillars, represent a totally new area of legal enquiry, which will flow into the legislative and political arenas as well (Sterling and Circo, 1984, Nelson and Rochenstein, 1985).

CONCLUSION

It is clear that this proposal points the way to possibilities rather than dictating procedures to follow. The social structure that accompanies such changes should be given separate consideration although the removal of existing railway and highway barriers to communication between flanking neighbourhoods would generate obvious improvements in communication and reduction in alienation that is presently typified by the fly-over expressway tangle that looms above Darling Harbour.

However, the ideas presented here generated from the groundwork laid by Birketts (1974, 1984) exemplify how geotecture, either as terratecture by the cut-construct-cover method, or as lithotecture by tunnelling technologies (or by a combination of both) can completely transform a major urban and suburban area liberating communities from the barriers that elevated transit systems and freeway represent and visually transforming cities from 'the problems of its city skyline and box-like architecture' (Barnett, 1989) whilst reinforcing the 100-150m stratum of city block development identified as indigenous to Sydney by the Central City Strategy, 1988.

Geotecture could transform Sydney if the will were there and the appropriate interdisciplinary planning body of experts (comprising planners, geologists, architects, civil, structural, mining, tunnelling and mineral engineers, sociologists, psychologists and real-estate consultants) assembled as soon as possible. Probably a decade of forward planning would be needed to precede what would be the first major and significant evolutionary change in the development of Sydney since its foundation in 1788.

If this groundwork were to be undertaken, the 21st century could see a metamorphosis in Sydney. Professor Barnett (1989), a leading urban design expert, described it 'as one of the top modern cities of the world' in an interview (during which he also condemned the Darling Harbour overpass).

With whole industrial zones relocated into corridors of subsurface space built around sunlit atria with services and utilities integrated within conduits in the corridors, one 7km portion of corridor can relocate all the existing industry in its zone and 'recycle' the surface land for landscaped recreation and medium-density residential land use for forty-four thousand dwellings. As high-rise towers with the city central area reach the termination of their life cycles, whole blocks could be amalgamated and a 4-6 storey podium city developed with parks and gardens.

There is a spirit of change in the air. Environmentalists are gaining political power and becoming the new generation of engineers, planners, economists, entrepreneurs, scientists, architects, landscape architects and bureaucrats who will cooperate rather than compete in civic and individual design and planning. If one is middle-aged there is a fair chance the construction and demolition of a city building has been witnessed as it reached the end of its useful life. With the recycling life of a typical city building being 25-50 years, before the middle of the next century, the City of Sydney could become a garden city, with rooftop parks linked by grassed bridges from one amalgamated city block to the next. With waste heat recycled and compact energy-saving buildings and all wastes treated in situ and the residue recycled or pumped out through underground conduits to the western plains for agriculture, the city would be almost benign in its environmental impact.

With non-polluting personal vehicles that utilise very fast pallet-aided transport and 'smart' guidance and return-to-base controlled vehicles, suburbs can share in the stimulus of city life without overburdening metropolitan transit corridors.

With 'high-rise' a bad memory and commercial house identity being a measure of garden design and appropriate 'arrival' lobby design only, a unified building stratum (which still uses the prescribed floor-space ratios for commercial viability) would unify the whole city.

With VFT links through underground conduits and tunnels in built-up areas, interstate and intrastate aeroplane travel could become a secondary option. PAT transport could simplify the distribution and collection of containerised goods in other corridors within the geospace conduit.

Current proposals do not face the serious issue of the lack of an overall concept for the city of Sydney that would integrate both buildings and open space. By attempting to unify the city with landscaping schemes that only deal with the spaces left over between buildings that presently funnel wind and overshadow streets, building volumes continue to dominate the city aesthetic. Why not question the validity of the assumption that buildings must be expressed in their current form?

Why not create a roof-garden city where the pedestrian needs dominate? Sufficiently elevated not to overshadow existing parks and streets below, this podium need be no higher than our historic buildings; however, it would be high enough to achieve the full 10:1 (plus) floorspace ratio prescribed by the planning strategy to be implemented in 1990. By city block amalgamation and the utilisation of a major proportion of geospace in total building volume, a new aesthetic for cities of the future becomes possible.

Whether partially above and partially below natural ground, or completely underground, the geopolis (replacing the megalopolis concept that threatens some major developed countries) creates a new *gestalten* for city development almost anywhere in the world.

As world population soars, such a third millenium city in which nature and humanity blend and cooperate rather than conflict, presents a practical means of modifying the ecological, sociological and visual impacts of city growth upon the planet.

In the words of Victor Hugo (1802-1885): 'all the armies of the world are not as powerful as an idea whose time has come'.

APPENDIX II

Note: APPENDIX I appeared in Part One

EXPLANATORY SKETCHES AND COST ESTIMATES

In the process of developing a concept for the geopolitan plan of Sydney, it was necessary to photograph and survey the 'edges' of the proposal, i.e., where the suggested raised redevelopment of the city business district interfaces with existing streets

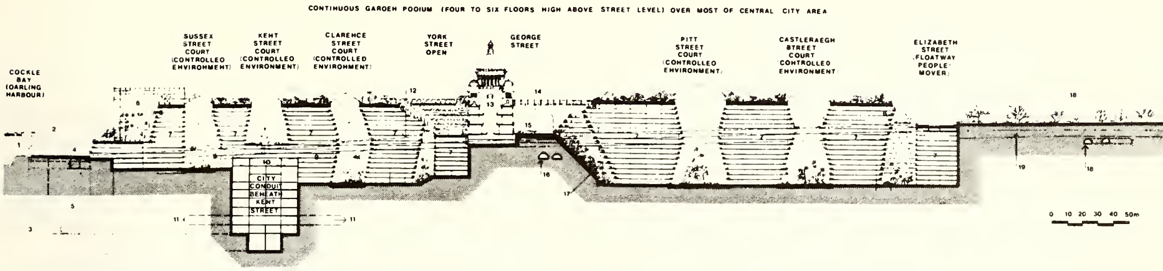

Figure 39:
East/west section through City Commercial Centre, showing raised garden podium as continuous city park

1. Pyrmont Bridge
2. Moving footway
3. Tunnelled VFT link (beneath harbour)
4. Expressway link beneath harbour
5. Conduit entering City
6. North-west gate to podium park (and VFT and expressway)
7. Commercial offices
8. Residential flats to most outward facing podium edges
9. Expressway link to Park Street tunnel project
10. Expressway
11. VFT cross-linked to local traffic
12. Street level
13. Queen Victoria Building
14. Moving footway or floatway
15. Floatway canal (pedestrian transport in gondola)
16. Rail tunnels
17. Rainforest court (controlled environment)
18. Hyde Park
19. Darling Harbour/Eastern suburbs tunnel project (under Park Street)

and parks that surround it (Figure 39). Such edges present critical design problems connected with making transitions from one level to another and with integrating existing ground level spaces that must be retained, for example, Wynyard Park (Figures 40, 41, 42).

Bounded on the north by Circular Quay development, on the east by Hyde Park, the Domain and the Botanical Gardens, on the south by the Central Railway precinct and on the west by Darling Harbour, it was not difficult to imagine a slightly raised city with its upper garden podium at the 4th- or 5th-storey level. Various avilions for the entrances to commercial premis , below would have sculptural architecture suitable to the garden setting.

The podium would be stepped back gradually with only a few storeys around the edges of the Development precinct so that surrounding existing parks and streets blend with the podium. National Heritage buildings would be integrated into the steppings of the podium with appropriate landscaping and with architectural lines carried through through the redevelopment theme (Figure 43).

As an example of how a major public space at present street level could be developed George Street, between Town Hall and Circular Quay, could become a 'river valley' between plateaux (Figure 44). This could be achieved by constructing a shallow canal-mall to replace the existing road and footpaths. Charged with filtered harbour water at Town Hall (and following the bank of the old Tank Stream) the water would gravitate slowly to a shallow lock at Circular Quay. With all electrically-driven traffic being underground only light amphibious vehicles would have access via ramps from the sub-surface road systems which also service tunnel access to commercial premises, electric-vehicle parking, hotels and other city facilities.

EXISTING CITY AESTHETIC

Looking very similar to almost all other western cities the tower structures of Sydney are seldom beautiful, mostly bland, sometimes ugly and aggressive. Such architecture is not a valid holistic solution appropriate to a city of the next century.

It is suggested that as these towers reach the end of their life cycles, they be demolished and not rebuilt. By substituting a geopolitan proposal of the type described here, undergrounding all major facilities (using terratecture as well as lithotecture) and redeveloping the surface for residential use around the edges of the podium, preserving major existing street patterns and utilising the geospace beneath streets, it could become unique in the world, an authentic 'garden city'.

TRANSPORT OF INDIVIDUALS AT GROUND AND ROOF LEVELS

Either non-polluting vehicles, e.g., electricity or hydrogen, could be used. However, because mechanical footways have been proposed, it is suggested here that an equivalent 'people-mover'

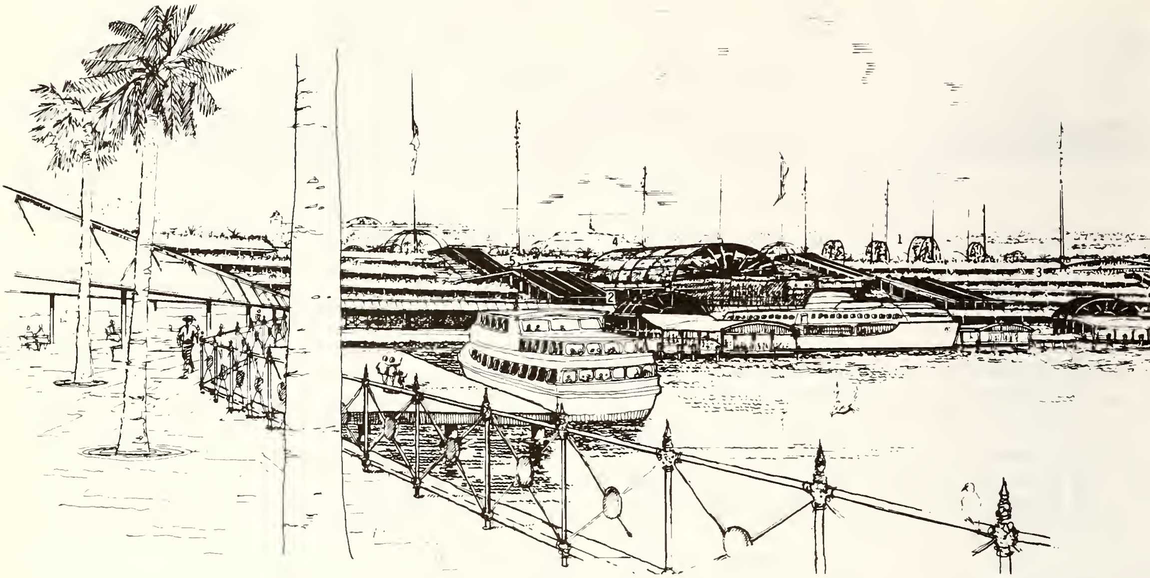

Figure 40:
Circular Quay edge to the Garden Podium of the City, a bustling colourful gateway with full area of all existing highrise in subsurface space
1. Underground commercial geospace with broad sunlit atria; 2.Entrance to underground transit station
3. Terraces rise to 4-5 storeys, N-S streets become landscaped finger parks and malls
4. Conservatoria covering atria, moving footways and floatways; 5. Pedestrian moving-footway bridges linking roof terrace parks and gardens

would be a canal system, that is, a 'floatway'.

Floatways

The concept of floatways as people-movers in this proposal is based on the idea that the energy needed to propel the float-vehicles in their canals would be obtained from the water flow produced by using sea water pump-raised to the highest level of the floatway and allowed to gravitate to sea level. The hydrostatic head created is used to drive turbines that, in turn, create the necessary energy to return the water to its highest level.

Energy dissipation due to frictional loss in the turbines, in channel flow, changes of channel direction and surface texture, turbulence around float vehicles and other such losses would need to be introduced into the closed system from an outside source.

Where street slope (and hence canal tilt) induces higher water velocity than can safely be used by buffered float vehicles, a type of speed-control would be needed that is dependent on feedback on fluid velocity.

COSTS

Cost Estimate on Conduit

A preliminary estimate prepared by Quantity Surveyors (QS) on the conduit indicates a probable cost range of A$64 million to A$96 million. The reason for this wide range of cost arises from possible differences in geological strata through which the conduit would pass. Quoting from the QS preliminary report: 'it is possible that the excavation could generate an income of the order of A$20.2 million per km on the one hand and an additional cost of A$10.1 million due to planking, strutting and/or dewatering on the other'.

At an average unit cost of say A$604 million per km, the study area conduit would cost approximately A$576 million, that is, near the cost of, for example, the 49-storey Gateway building at Circular Quay. (SMH 30.1.90, p.26).

The costs of the purchase of industrial land and the relocation of industry in the conduit corridor would need to be negotiated with individual corporations, and there would be a significant return on the cost of land when resold for residential use.

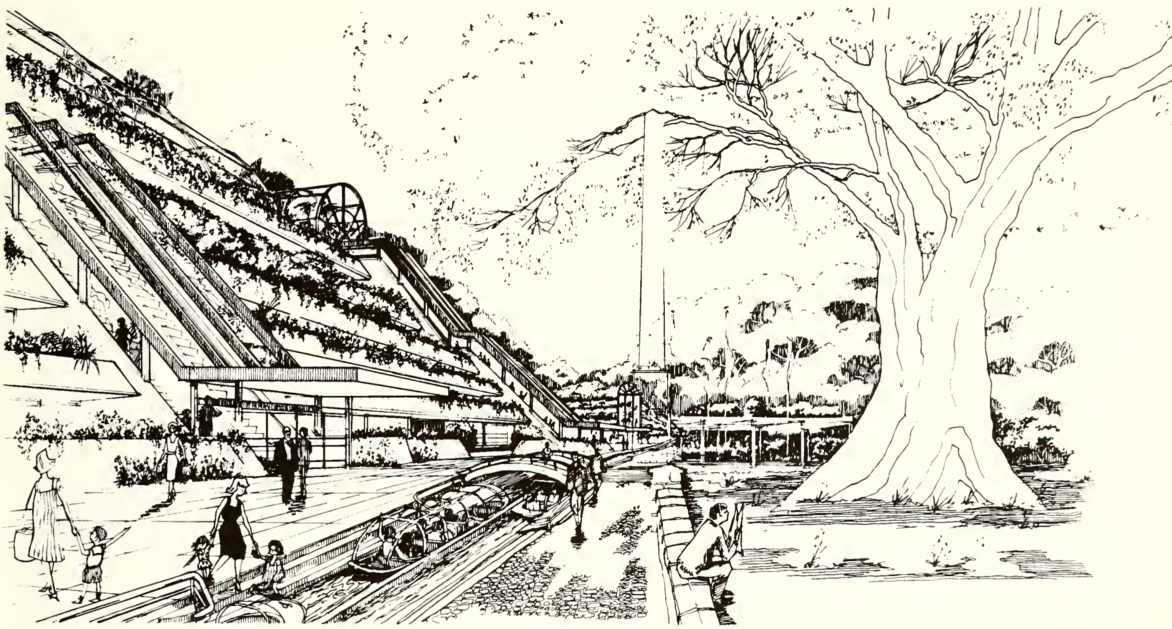

Figure 41:
Redesign of the City of Sydney, a lateral, landscape and geopolitan concept
1. Interface of podium eastern edge with Hyde Park; 2.Elizabeth Street Mall with floatway punt 'people-movers'

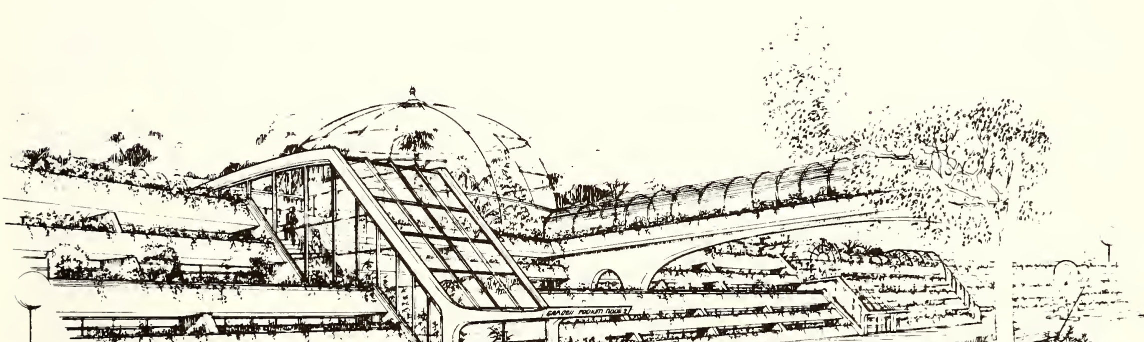

Figure 42:
A major circulation node in Pitt Street Mall

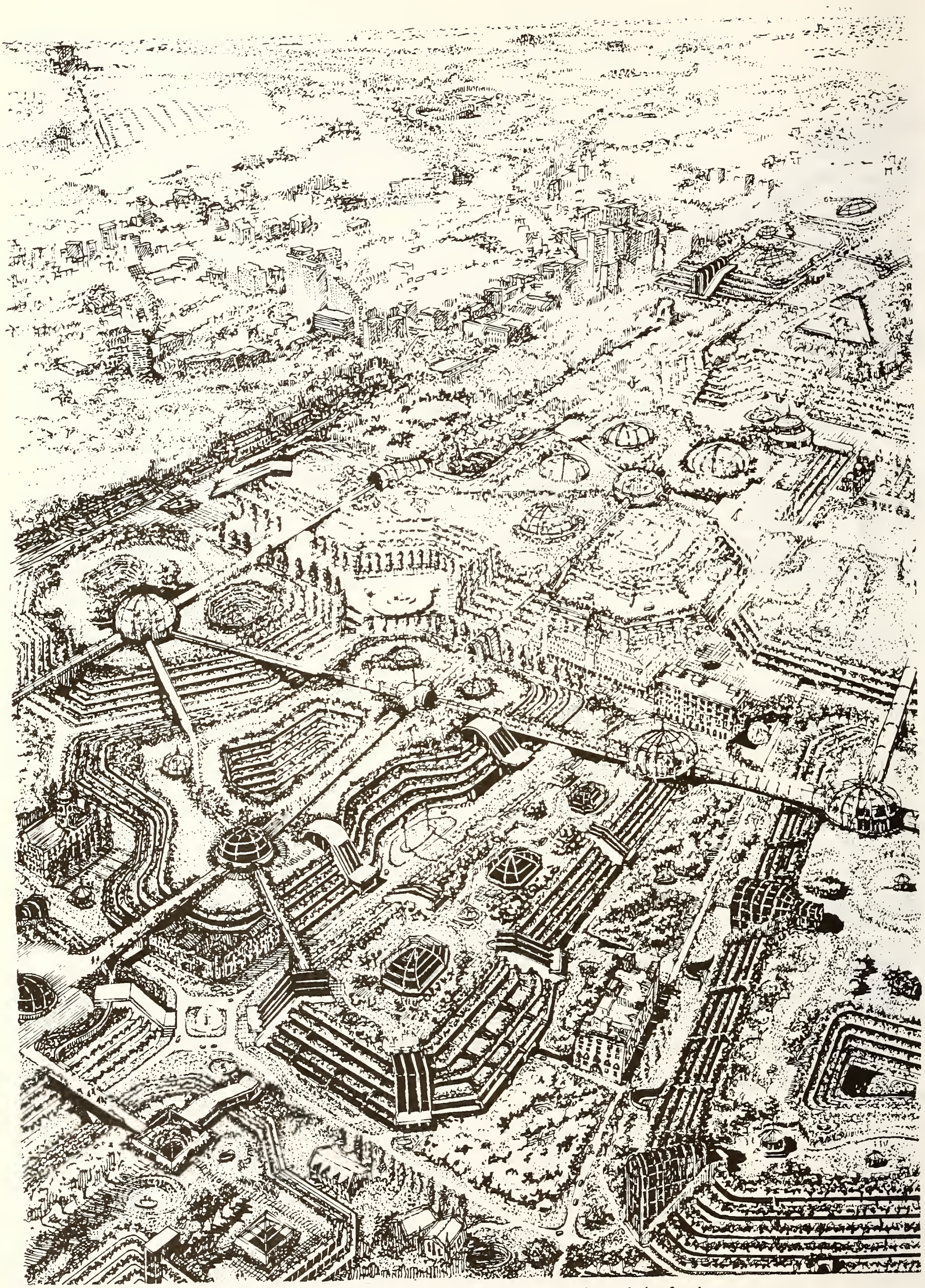

Figure 43: Concept redesign for the City of Sydney, Australia, a geopolitan planned city for the next century

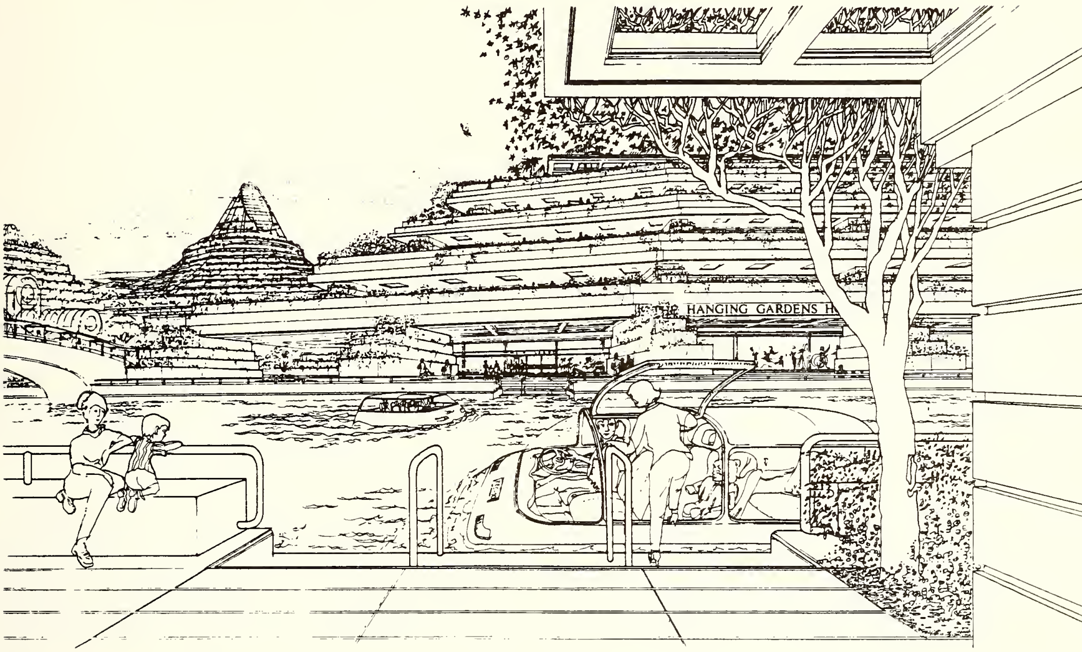

Figure 44:
George Street, between the Town Hall and Circular Quay, could become a shallow canal-mall with cross-over bridges and underpasses. The network of minor (Figure 42) and major canals provide a free public transport mode as well as the ambience of a new Venice.

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Mallardite from Broken Hill, New South Wales

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ABSTRACT. Mallardite, $MnSO_4.7H_2O$, has been observed as an alteration product of alabandite, MnS, from the Broken Hill, N.S.W. deposit. This represents the first reported Australian occurence of the rare mineral mallardite.

In 1967 the Australian Museum, Sydney, obtained several specimens of alabandite, MnS, from the No. 18 Level of the Zinc Corporation Mine Broken Hill (Lawrence, 1968; Ramdohr, 1971). Some of these - massive material associated with minor sphalerite and galena - were thinly coated with a dull greyish-white to pinkish-white efflorescence. Laboratory studies have shown this to be the manganese sulphate heptahydrate mallardite, $MnSO_4.7H_2O$, a mineral not previously recorded from Broken Hill.

Alabandite was found in shear zones in both the Zinc Corporation and the New Broken Hill Consolidated Mines. There were two modes of occurrence of alabandite: as massive material within narrow veins cutting through lead-zinc ore and as arborescent groups in cavities along the shear planes. The latter type was coated with a thin veneer of hausmannite, Mn_3O_4. The mineralogical setting suggests that the alabandite formed from secondary hydrothermal fluids derived during retrograde metamorphism (Lawrence, 1968).

Broken Hill mallardite has been found only on the massive alabandite and not on the arborescent material. The veneer of hausmannite apparently inhibits the oxidation of the manganese sulphide. Mallardite was suspected since the efflorescence was confined to the alabandite and did not appear on the juxtaposed galena-sphalerite. The mallardite forms a thin, microcrystalline layer of a dull greyish-white to pinkish-white colour. X-ray powder diffraction analysis (Table 1) establishes the identity of mallardite unequivocally.

An SEM photograph of the mallardite (Figure 1) shows a larger prismatic crystal elongated along the *c* axis and with a prominent clinopinacoid 010, a steeply sloping hemiorthodome 101, a face of the form *h0l* and possible prism faces 110 weakly developed. The β angle (Palache *et al.*, 1951) of 104°51' suggests that the basal pinacoid 001 is not steeply sloping and may be represented in the photograph by the small terminal face at the apex of the largest crystal.

Mallardite is a comparatively rare member of the melanterite group of monoclinic heptahydrates which includes melanterite, $FeSO_4.7H_2O$, boothite, $CuSO_4.7H_2O$, bieberite $CoSO_4.7H_2O$ and mallardite $MnSO_4.7H_2O$. End-member compositions are given here but extensive solid solution is known to occur between these isomorphous (space group $P2_1/c$) species (Palache *et al.*, 1951; Williams, 1990). However, a spectrographic analysis (ISI 100A SEM fitted with a PGT X-ray detector using Moran Scientific software) revealed only Mn and S with no evidence at all for the presence of any other metal ion. Thus the mallardite here is very close to the ideal, end-member composition. This appears to be in accord with the fact that the sulphate is confined exclusively to alabandite surfaces. It is recorded from only a few other localities, *viz*, the Lucky Boy Mine, Butterfield Canyon, Salt Lake County, Utah, the Banyard area, Grant County, New Mexico, and in the Jokoku Mine, Hokkaido, Japan.

Broken Hill mallardite, as with most secondary sulphate occurrences, particularly the heptahydrates, appears to be a post-mine mineral. The comparative rarity of this phase is probably due to the fact that most manganese minerals occur as oxides, hydroxides or silicates and lack an available source of sulphate ion (from sulphides) to generate mallardite on oxidation.

Fig. 1. SEM photograph of mallardite from Broken Hill, N.S.W. (X2500, ISI 100A instrument).

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TABLE 1
X-RAY POWDER DATA FOR MALLARDITE[a]

Mallardite, PDF[b]		Mallardite, Broken Hill	
d/Å	I	d/Å	I[c]
5.85	8		
5.49	70	5.50	s
4.92	100	4.90	sss
4.88	55	4.89	s
4.57	13	5.59	w
4.04	25	4.02	m
3.79	40	3.77	s
3.74	10		
3.26	35	3.27	s
3.21	12	3.21	f
3.13	30	3.11	s
3.07	12	3.09	w
3.02	9	3.00	f
2.805	13	2.808	w
2.758	40	2.759	s
2.732	9		
2.660	17	2.663	m
2.626	19	2.621	m
2.490	14	2.489	m
2.451	13	2.450	m
2.400	19	2.400	w
2.196	5		
2.096	4		
2.056	12	2.051	w
2.025	8	2.023	f
2.017	14	2.015	w
1.975	17	1.975	w
1.890	9		

[a] Debye-Scherrer camera, 360 mm circumference, CuK_{α} radiation.
[b]ASTM Powder file No. 33-905. [c]Intensities; s = strong, m = medium, w = weak, f = faint.

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Understanding the Brain in the 21st Century

by

Max R. Bennett

with illustrations

by

Gillian Bennett

In 1944, during the second world war, Erwin Schrodinger working in Dublin published a book which had an enormous influence on the history of biological science in the second half of the twentieth century (figure 1). Schrodinger, together with Heisenberg, had created in 1926 the theory of quantum mechanics which was the most revolutionary concept in the history of the physical sciences. Towards the end of the thirties Schrodinger turned his mind to the question of what are our physical origins. He therefore started to consider the structure of genes and the extent to which our development occurs as a consequence of the unfolding of the information in genes. It was not known what the genetic material was made of at the time that Schrodinger wrote his book "What is Life". The guess at that stage was that it was made of protein and it was only shortly after the appearance of Schrodinger's book that it was discovered by an elderly gentleman working in the Rockefeller Institute in New York, Oswald Avery, that the genetic material was made of deoxyribonucleic acid (DNA). What Schrodinger's little book did was to bridge the revolution in physics that occurred in the first part of the century to the new revolution that was to dominate the second part of the century, namely molecular biology. Schrodinger conjectured in his book that there must be a code in the genes which is read out by the cell as a set of instructions that guide its' differentiation so as to give rise to the structure of the human embryo and therefore to our further development. In this way Schrodinger developed the concept of a genetic code, one of the most fruitful ideas in biology. Furthermore he speculated that the structure of the genetic code should be susceptible to physical analysis by means of such new techniques as crystallography. Crystallography had been developed as a science in the United Kingdom by the Braggs, father and son; they were from Adelaide and had won the Noble Prize together in 1915.

After the second World War some of the brightest physicists decided not to go into Theoretical Physics but instead to try their hand at Biology. The end of the heroic period in Physics, which had been dominated by quantum mechanics, occurred about 1948 when Richard Feynman working at Cornell developed the theory which is referred to as Quantum Electrodynamics; this provides a description of how light interacts with matter. It is somewhat fortuitous that only a year after Richard Feynman had developed his theory, bringing quantum mechanics to its highest point of development, that a physicist named Frances Crick began working in the laboratory of the Braggs in Cambridge in 1949 (figure 2). Schrodinger's book had a major influence in Crick making this move. Together with a young and somewhat eccentric American called James Watson he applied the concepts of crystallography to the task of unravelling the detailed structure of DNA itself in 1951. In this way he furthered the research programme in the laboratory of the Braggs laid down by Schrodinger some five years earlier. To some extent the famous paper by Watson and Crick, published in Nature in 1953, completed the research aims of Schrodinger's book by indicating that the structure of the DNA molecule held within it the clues to its own replication. The last forty years of science have been dominated by molecular biology which has as part of its foundations these observations by Watson and Crick made in the Cavendish Laboratory at Cambridge run by Sir Lawrence Bragg from Adelaide.

In 1988 Crick, like Schrodinger before

him, published a book that is likely to have far reaching effects on the future of research as young scientists see it. Crick suggests in "What Mad Pursuit" that the great challenge for science in the next century is not to be found in quantum mechanics, nor in molecular biology, but in the understanding of what it is that develops in the brain of human embryos that gives rise to consciousness (figure 3).

What is this phenomenon of consciousness? In order to tackle consciousness we have to look at the human brain, at its structure and function. There is general agreement that the best path to follow in our quest to understand consciousness is offered by the problem of visual perception. This is because man like other primates receives most of his sensory information via the visual system and our consciousness is closely linked with visual perception. This is because man like other primates receives most of his sensory information via the visual system and our consciousness is closely linked with visual perception. Figure 4 delineates the principal pathways in the higher levels of neocortical function concerned with the identity of objects and their movement in space. The identity of objects and their colour is taken up by a set of retinal ganglion cells and conveyed via the structure called the thalamus, which acts as an interface between the external world and the neocortex, to the visual cortex at the back of the head. From there it is projected down into the temporal lobe and it is here, as is explained in more detail below, that the identification of something as sophisticated as your mother's face is actually carried out. The other main projecting pathway is concerned with determining where an object is located in visual space. This is to a large extent dependent on information concerning the motion of objects in space. Such information is conveyed from the retina through the thalamus up to the visual cortex within the occipital lobe and into the parietal cortex. These two pathways going either to the temporal lobe or to the parietal cortex give us the holistic experience of seeing an object which moves.

To what level of sophistication can the temporal lobe identify an object? In order to determine that Gross and others have put electrodes into the temporal lobe of primates other than man and determined whether there are neurones which fire maximally when the primate is viewing a specific object. Figure 5 illustrates the main results of this kind of experiment. It turns out that there are in the monkey temporal lobes neurones which respond specifically to the presentation of human faces; indeed these neurones discharge specifically when the faces are presented in profile or face on. The firing rate of neurones is given in the upper part of each panel in the figure as the primate looks at the images given n the lower part of each panel. You can see in this set of images that when the primate is looking directly at the image of another primate face on we get maximal firing but when the image of the head gradually turns around so that it only appears in profile then the firing occurs at a much lower rate. Now you cannot fool this neurone into firing at a high rate by presenting an image consisting of bits and pieces of a head. If the picture of a brush of the kind used to clean the toilet is presented then the rate of firing of the neurone is much less than that when the image of another primate face on is presented (figure 5). Also if we present an image consisting of the juxtaposition of different elements of the face in a bizarre geometry again the firing rate is not nearly as high as it is when we put those elements together to make up a proper primate face (figure 5). Furthermore, it can be shown that if we take away different elements of the primates face such as the mouth or the eyes then the firing rate will drop (figure 5). Finally this neurone can distinguish the face of a monkey from the human face (figure 5). Só there are very specific neurones here in the temporal lobe which are specific in the sense that they will fire vigorously only when a particular kind of object, in this case a particular face, is presented.

The problem though that we now face is that we might have in temporal lobe neurones for identifying faces but the experience of whether this face is moving across our visual field is not in the temporal lobe but in parietal cortex. As I indicated in figure 4 the problem now is how do we have an holistic experience in our consciousness when the face is moving past us. We have obtained very recently some insight concerning this problem from the work primarily of Wolf Singer working at a Max Planck Institute for Brain Research in Frankfurt. Singer and his colleagues have shown that neurones firing in one part of the brain, concerned for example with the movement of an object such as in parietal cortex, and neurones firing in a different part of the brain, such as in temporal cortex concerned with the fact that the thing that is moving is a face, are both firing at a rate modulated at a frequency of about 40 to 50Hz. Furthermore they fire in phase together not asynchronously (figure 6). There is then a binding together of the firing pattern of those neurones which are activated by the same visual object even though the neurones are located in different parts of the cortex. This discovery is causing a lot of excitement in neurophysiology because it is only those neurones which are firing in phase with this 40 to 50Hz frequency that are giving us the experience of attending to a different part of our visual field. The rest of the visual scene projects from our retina onto the visual cortex at the back of our skulls. The neurones in our brains subserving those parts of the image on our cortices that is not being attended to are not firing with a modulation of 40 to 50Hz and air not firing in phase.

To some extent it can be claimed that this is all very interesting but that the problem has merely been pushed back one step. You consciousness of phenomena around you might be associated with sets of particular neurones in your brain firing in phase at 40 to 50Hz but how is it that neurones firing off in this pattern give rise to you attending or experiencing a particular facet of your visual world? Only a particular facet of your visual world is entering consciousness. What is there particular about the neurones firing at 40 to 50Hz and in phase which allows you to experience at the conscious level those events which are coded for by these particular neurones? A senior colleague of mine recently commented that this is as far as neurophysiology is going to take us. All that science will illuminate in relationship to your consciousness of the world around you may be that sets of neurones subserving certain specific kinds of functions fire in a certain way. The question of what it is that links consciousness to these sets of neurones is not one which science can answer. If there is any interference with normal brain function at all, for example through disease or injury to the inferior temporal lobe, or through inappropriate development, then we are not capable of consciousness in those areas of experience normally subserved by the injured neurones.

There is another exiting component to the claim that neuroscience is going to dominate research in the 21st Century. It is that a deeper knowledge of the nervous system will lead to the alleviation of neurological diseases whether this occurs through developmental malfunction, through injury, or through for example the invasion of our brains by a particular virus as probably occurs in multiple sclerosis. The inferior temporal lobe which we are emphasising in this essay is involved in the identification of an object. A vascular stroke results in the destruction of certain parts of our brains. Hypertension leads to a breakdown of the vasculature most commonly in certain areas of our brain. One area in which hypertension most commonly leads to stroke is in the temporal lobe where, as we have seen, information is gathered about the identification of objects and our consciousness of them. Figure 7 shows a self portrait of a painter that suffered a stroke. The stroke occurred in the parietal cortex concerned with the location of an object in space. However the parietal cortex is not only concerned with location and movement but it also subserves the process of attention. There is a mechanism in the parietal cortex which determines which sets of neurones will fire off in phase at 40 to 50Hz throughout the rest of the cortex. The stroke had the effect of blocking the attentional mechanisms in the inferior temporal lobe on one side of the brain so that the painter was not able to recognize one side of his face when he looked in the mirror. This did not occur because there had been a direct injury to the temporal lobe. Rather it occurred because the attentional mechanism in the parietal cortex on one side of the brain could not determine that the temporal lobe on that side should contain neurones that fired in phase at 40 to 50Hz. As a consequence when he was asked to paint a portrait of himself the painter ignored that side of his body which was no longer attended to because of the stoke. He then only painted one side of his body (figure 7). But over a period of about 12 months successive self portraits gradually reconstituted the entire image until finally, after a year, he was able to attend to the entire aspect of his face (figure 7), although recovery is not complete even then.

I emphasise the fact that the reason our painter was unable to see, as it were, one side of his face and body when he did a self portrait a few weeks after the stroke was not due to any injury whatever to the visual pathway. What had been injured was the mechanism in parietal cortex which determine the setting up of 40 to 50Hz in phase firing of neurones which then allows consciousness to be expressed. An easy experiment could be carried out to show you that he could see the other side of his body. All that had to be done was to block off that side of the painter's visual field which allowed him to see the side of his body which he could normally paint. When that occurs he wills tart painting the side of his body and face that he normally doesn't attend to at all. In other words it is the attentional mechanism that has been injured. In fact when some experience a lesion of this kind they don't want to know about the side of their body to which they re not attending. When you carry out this experiment with some people who have had a stroke affecting the parietal cortex they get emotionally upset when they are forced to attend to that part of their body that they don't normally recognize as being there. In fact they regard that part of their body as foreign. It is as if they had a Siamese twin attached to them which they did not want to know about.

Strokes which affect the temporal cortex subserving the actual mechanisms by which you recognize yourself and others is usually accompanied by different kinds of psychological disturbances. Injuries to temporal cortex give rise to epileptic seizures (figure 8). This is because temporal cortex is very closely associated with the hippocampus which is the area of your brain concerned with laying down memory. For example injury to temporal cortex may lead to hallucinations that can involve you seeing people or objects that aren't present in the room (figure 8). This is due to epileptic discharges in the neurones of the temporal cortex which, for example, are normally activated by the image of your mother's face but start to fire despite the fact that your mother is not passing through the room at all. So hallucinations are associated with injuries to temporal cortex and of course hallucinations are also associated with schizophrenia (figure 8). In this case subjective phenomena apparently occur in the room that are more real to a person than sets of phenomena which are really occurring in the room. Other forms of temporal lobe epileptic activity occurring as a consequence of stroke in the temporal lobe area are seizures which give rise to the sudden enlargement of the face of someone that you are looking at (figure 8). You may be looking at your mother in the room and then suddenly her face will start to increase in size, become distorted, and fill up the entire room (figure 8). So there are not just perceptions of events occurring in the room which ar not occurring at all but real events in the room may trigger hallucinogenic kinds of phenomena in the way I have just indicated, that is they will distort phenomena in the room as well.

To what extent will we be able in the 21st Century to bring some kind of alleviation of the symptoms resulting from stroke and to diseases of different kinds which afflict the inferior temporal lobe. This really requires us to focus on a number of different technologies and approaches to understanding the diseases of the brain which have been initiated in the last few years. These are concerned with being able to introduce neuronal tissue into the brain that can replace neuronal tissue which has been diseased or destroyed. When this is achieved it is then encessary to get these new neurones tha have been introduced into the brain to form functional connections with the rest of the brain. These must be of an appropriate kind to reconstitute the normal circuitry of the brain. In addition there are now known to be growth factors, referred to as neurotrophic growth factors, which are required in normal health. These provide nutrients for the neurones in your brain and may be introduced exogenously into the brain from outside. They can allow for the survival of neurones which would otherwise degenerate and they can also allow for neurones which have been injured or neurones which have been introduced into the brain to form appropriate synaptic connections.

Rita Levi-Montalcini was able to show something extraordinary in a series of experiments, some of them conducted during hiding from the Nazis in Italy during the last world war. She was able to obtain growth factors that allowed neurones which would otherwise degenerate to survive. Levi-Montalcini won the Nobel prize a few years ago for her discoveries of neurotrophic factors. This work was begun as she hid from the Nazis in a house in Turin. Montalcini had a microtome in an attic room which was used for cutting thin sections through the fixed embryos of birds. This, together with a microscope, enabled her to make fundamental discoveries concerning the development of neurones belonging to that part of your nervous system concerned with the control of your internal organs, such as your heart. Montalcini showed that in this part of your nervous system, called the autonomic nervous system, neurones die normally during development so that you have more neurones very early in your life than when you are an adult. She went on to show that neurones could be rescued from death if they were provided with growth factors which can be supplied by the targets with which these neurones normally make junctional connections. Ten years ago my colleague Bogdan Dreher and I set out to see if what Levi-Montalcini had discovered for the peripheral nervous system, namely that autonomic neurones could be induced to survive if provided with the material from their normal targets such as cardiac muscle or smooth muscle, might also apply for neurones in the central nervous system. We first showed that retinal ganglion cell neurones that connect the retina to the rest of the brain, and are shown in figure 9, normally die during development. Furthermore these retinal ganglion cells could be induced to survive when provided with a nutrient neurotrophic molecule from their targets in the brain. Those parts of the brain are called the superior colliculus and the lateral geniculate nucleus. The neurones survived and sprouted nerve processes profusely in a tissue culture plate if provided with the neurotrophic factor, just as Montalcini had described for autonomic neurones (figure 10). The difference was that in this case the retinal neurones were supplied with a factor from the brain and not from muscle. This was probably the first indication that neurotrophic growth factors exist in the brain not just in the peripheral nervous system and these growth factors can allow for the survival and profuse axon spouting of a central neurone such as a retinal ganglion neurone.

The question then arises as to whether neurones lying deeper in the brain such as those belonging to the temporal lobe and to the hippocampus also have growth factors which will allow for their survival. The neurotrophic factor which keeps retinal ganglion cells alive is not the growth factor that Levi-Montalcini discovered in smooth and cardiac muscle that keeps autonomic neurones alive. The question then is to what extent can we reconstitute an injured temporal lobe or hippocampus by adding in a neurotrophic factor. The hippocampus, a relatively old and primitive type of cortex, abuts onto the temporal lobe (see figure 11). Despite its relative simplicity, the hippocampus is crucially involved in the formation of memories. If a transverse section is cut through this region of the brain many different classes of neurones can be identified (see figures 12 and 13). Some of these are the first neurones to degenerate anywhere in your brain if you have Alzheimer's Disease, particularly those neurones which project into the hippocampus from the part of brain called the septum. Surprisingly, these septal neurones are kept alive by Levi-Montalcini's growth factor, first found to keep autonomic neurones alive in the peripheral nervous system. So if a neurotrophic factor is discovered that saves a certain class of neurones in the periphery it may well work on a class of neurones in the brain.

As already mentioned, rather than introducing growth factors into the brain in the hope of saving a certain class of neurones that are degenerating because of a neurological disease, it is possible to introduce embryonic neurones of the same class that have been destroyed by the disease (figure 14). These can be obtained from a set of neurones that have been genetically manipulated to be of a similar kind to those that have degenerated. If you introduce these neurones into the brain (see figure 14), they reconstitute the normal circuitry, making the correct functional connections. In this way they restore the normal function, or at lease almost the normal function, of that part of the brain which had degenerated.

There are now standard techniques for introducing neurones into the brains of animals. Neurones are taken from an early embryonic rat brain, for example from that part of the brain that degenerates in Alzheimer's Disease. Further purification of these then occurs using various cell sorting techniques. Finally just the specific class of neurones required are placed in a tube from where they are sucked up into a pipette (see figure 14). This pipette is then used to inject the neurones into just that part of the brain which has degenerated or been injured (figure 14).

How do we test out if we have reconstituted normal function after say a transplant into the hippocampus of a set of neurones to replace those that have degenerated? Figure 15 shows one procedure that is used to determine this. It is called the alternating T-maze test. A rat is put at the end of one arm of the T-maze and is allowed to run to the other end where a choice is made of either turning left or right. In the first trial food is placed on the right arm and the rat is forced to turn right because a trapdoor prevents it from turning left. On the second trial there is no trapdoor to force the rat to turn a particular way so tha it may now turn either left or right. However a nasty trick is carried out before this second trial. Before the rat is allowed to run the second trial food is placed on the left arm of the maze, opposite its original position. After this trial the rat is taken out of the maze and allowed to rest for a while before another alternating trial is attempted. Altogether this is repeated about six times a day. It doesn't take very long before the rat appears to figure out what is going on. It turns right on the first trial and gets the food; on the second trial, when you put the food on the opposite arm, the rat immediately turns left and doesn't make the mistake of turning right. The graph in figure 15 shows the rate at which the rat learns to make the correct choice on the second trial, namely to turn left. In a sham trial the neocortex is exposed without any experimentation, and then closed; over a period of about one and a half weeks the rat learns on 100% of occasions to always turn left to get the food on the second trial. If however there has been an injury to the septum, then the rat turns left on the second occasion at random frequency (namely on 50% of the occasions). It hasn't learnt at all; it cannot lay down the memory that it should turn left always on the second trial. But if we do a transplant of healthy septal neurones from an embryonic rat into the hippocampus of this injured adult rat or of a rat whose septal neurones have degenerated because it has a form of senile dementia, then it only takes a matter of about two months before we find that the rats can learn at the 90% level to turn left (figure 15). The rats that received the transplant have learnt to nearly always turn left on the alternate t-maze performance because normal hippocampal functioning has been reconstituted by this septal transplant.

You might well ask how is it that the rat can tell where it is in the T-maze because the maze is symmetrical; how can the rat tell its left from its right despite the fact that it has no visual clues to orientate itself. Well the trick here is that the t-maze is set in a room which has lots of interesting objects in it and these allow the rat to work out exactly where it is. These interesting objects may include curtains, clocks, and pictures of female rats as shown in figure 16. This allows the rat to determine, when it is sitting at the start position n the T-maze, the geometry of the situation around it. The hippocampus calculates the spatial layout of the room from this information, allowing the rat to determine what is its left and its right. These spatial clues are very necessary for it to be always able to distinguish left from right in the alternating T-maze performance.

In the above experiment an attempt was made to mimic the effects of senile dementia or stroke that lead to degeneration of the septal neurones innervating the hippocampus by introducing a lesion into the hippocampus. However it is now possible to distinguish aged rats that suffer from a form of senile dementia from those that do not; the former have a natural loss of septal neurones as a consequence of the dementia. The method used to distinguish rats with senile dementia from those that do not suffer from this complaint involves placing rats in a water tank of the kind shown in figure 16. Rats don't like being forced to swim around in a tank any more than we do so a little stand is placed about an inch under the water, which is opaque so that the rat cannot see the stand; as the rat swims around its feet sometimes bump into this little stand and not being stupid it sits on the stand, rests, and looks around the room. We can trace the movements of the rat in the water before it finds the stand using a TV camera elevated above the trough which is shown in figure 16. In this way the actual locus of movement of the rat in the water before it sits on the stand can be followed, as shown in figures 16 and 17. The rat knows it's position in the water because it can see the interesting objects in the room, such as the clock etc, so that it can form a spatial map of the room in its hippocampus as was described above in relation to the T-maze. When the rat forms this map it has the coordinates of the stand with respect to the spatial layout of the objects in the room.

If we take a young rat about 6 months old and put it into the water for a few minutes, then the locus of its movements on this first trial on the first day are given in the first row and column of figure 17: in this particular trial the rats legs didn't hit the stand beneath the water so the rat just swam around for a couple of minutes. But a few trials later, namely the fifth trial on this first day (see figure 17), the rat has learnt in the intermediate trials the position of the stand and so it swims immediately to it and sits down. Presumably this rat has formed a spatial memory of the position of the stand as a consequence of the normal functioning of its septo-hippocampal circuits. Of course by the fourth trial on the fifth day the rat has no trouble at all, no matter where it enters the water, it immediately locates where the stand is (see figure 17). On the fifth trial of the fifth day a nasty trick is carried out: the stand is removed and the rat is entering the water tank at a random position swims around frantically trying to find the stand; the locus of its movements are then centred on the position where the stand was, as shown in figure 17. We can use this technique to pick out those rats which are suffering senile dementia from those that are not. In the second row of figure 16 the results are shown for a three and a half year old rat, about the equivalent of a human at eighty: it is apparent that even by the fifth trial on the fourth day, after the rat had bumped into the stand many times during the preceding days, it could still not locate the stand using spatial clues. This was an aged impaired rat, that is it had senile dementia. All old rats do not get senile dementia any more than all old humans do: in the fourth row of figure 17 the results are shown for another three and a half year old rat: by the fifth trial on the first day it had evidently formed a good spatial map of the whereabouts of the stand. On succeeding days it did as well as the young rat whose performance is shown in the first row.

Using this water tank technique, invented by Morris, we are able to sort out rats suffering from senile dementia from those that are not suffering from senile dementia. This is we can separate out those whose septo-hippocampal circuit is functioning from those in which these circuits are in bad shape. If we take an aged rat suffering from senile dementia now and operate on it in the way I previously described, that is introducing embryonic septal neurones into its hippocampus, then after a month r so has elapsed to allow the implanted neurones to make connections, the water tank test shows that the rat has recovered its ability to lay down spatial memories (see the last row in figure 17). This approach clearly demonstrates that transplants of neurones from embryonic material which allows the reconstitution of damaged or degenerating neuronal circuits involved in the formation of spatial memory.

In conclusion then I have been proposing that we are confronted in the 21st Century with what I regard as the third great area of mystery concerning natural knowledge. The first involved the discovery of quantum mechanics in 1926 by Schrodinger and Heisenberg. The second was to some extent begun by Schrodinger himself with his little book "What is Life", which attracted physicists of high quality into biology. One of these was Francis Crick who after co-discovering the structure of DNA in 1952 went on to delineate the concept of the genetic code in specific ways which Schrodinger had only dreamed of in his little book. This helped lay the foundations of molecular biology that has come to dominate a good deal of science in the latter part of the 20th century, illuminating our understanding of embryology in particular. The third challenge for us now is the human brain.

There are two questions that I have laid stress on which will dominate science in the 21st century. One of these is what are the actual workings of the brain that give rise to consciousness and how does this develop (figure 18). We have seen that consciousness involved in visual phenomena requires the correct functioning of parietal cortex and inferior temporal lobe. The second question that we have considered is whether our increased knowledge of the workings of the brain, particularly in relation to the search for the neuronal concomitants of consciousness, will provide us with insights into means of ameliorating various neuronal diseases. In particular those diseases which arise as a consequence of vascular stroke and as a consequence of schizophrenia, diseases which produce hallucinations and which completely distort our consciousness of reality. This essay has stressed one possible approach to the problem. This is through the introduction into the appropriate parts of the degenerating brain of neurotrophic factors that allow for the survival of specific classes of neurones. Alternatively a transplant of appropriate viable neurones may be made to replace degenerating ones. The next century offers us the possibility of understanding our own brains.

Acknowledgments

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Further Reading

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Judson, H.F. (1979) "The Eighth Day of Creation". Simon and Schuster. New York.

Moore, W. (1989) "Schrodinger". Cambridge University Press. Cambridge.

Schrodinger, E. (1944) "What is Life?" Cambridge University Press. Cambridge.

Figure 1.

Erwin Schrodinger (1887-1961), the co-founder with Werner Heisenberg of quantum mechanics, and the author of the small book "What is life" in 1944. Schrodinger was in his thirties when he formulated one of the most revolutionary theories of matter in the history of physics. Many, such as the English mathematician Roger Penrose, believe that quantum mechanics holds the answer to the question of what is consciousness, an issue which Schrodinger wrote on extensively himself, especially in his small book "Mind and Matter". The theory of quantum mechanics was brought to a high degree of development by the American physicist Richard Feynman in 1952, with his ideas on how light and matter interact. In his late fifties Schrodinger, inspired by the youthful theoretical physicist who had come over to biology, Max Delbruck, penned "What is life". This speculated on the basis of hereditary and included the revolutionary ideas that the chromosome contained a "genetic code" laid out along its length which constitutes an imprint of the information needed to be read for the formation and functioning of the species. Schrodinger also suggested that the code could be understood at the atomic level providing the chromosomal material can be crystallized as an aperiodic crystal, capable of being subjected to the techniques of X-ray crystallography. These prescient suggestions were to bring some brilliant young physicists into biology, such as Crick and Randall.

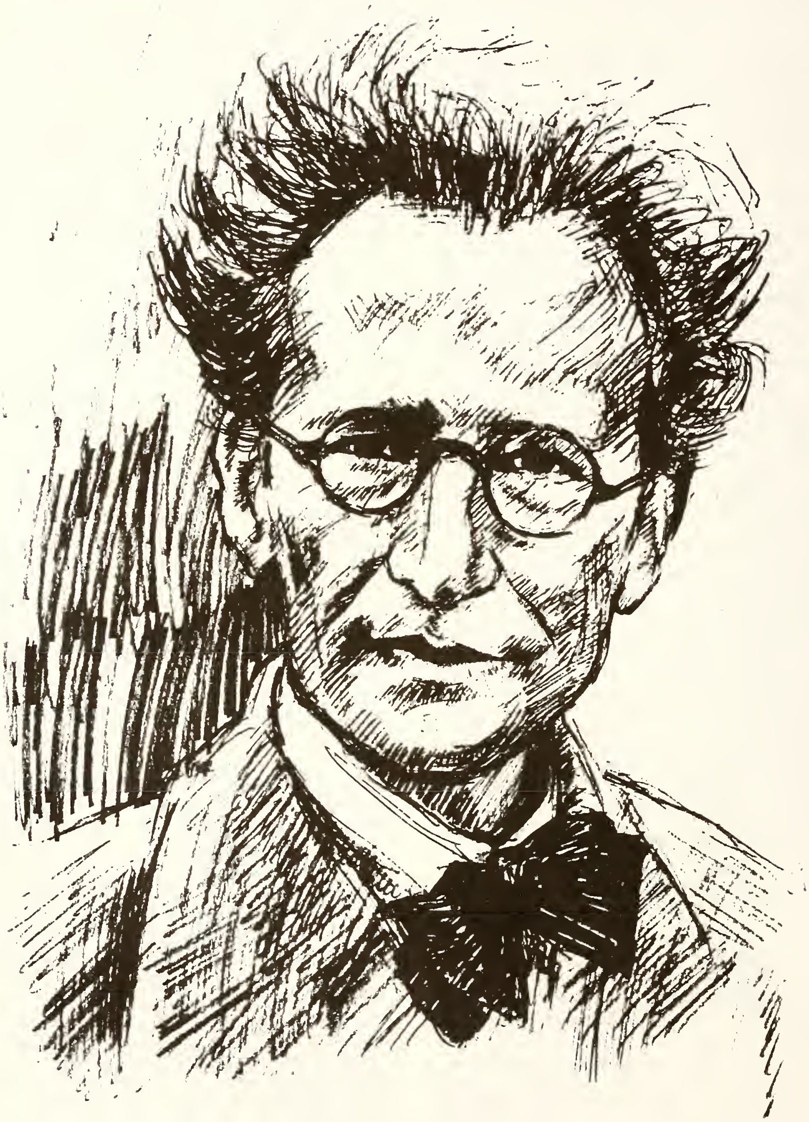


Fig 1

Fig 2

Figure 2.

Francis Crick (born in 1916) was a young physicist who came into biology shortly after the publication of Schrodinger's book "What is life" in 1944. He became the leading intellectual force in interpreting the crystallographic data on the chromosomal material, Dioxyribonucleic acid (DNA), that lead to its known atomic structure in 1952; secondly he designed experiments that solved the genetic code by which DNA gives rise to specific proteins. These ideas helped lay the foundations of Molecular Biology, the dominant area of science in the second half of the twentieth century. In this way Crick brought to fruition the research plan of Schrodinger. Crick now works in Brain Research and in his recent autobiography (1988) "What Mad Pursuit" speculates on how we are going to understand the origins of consciousness. Crick suggests that the clues to understanding this phenomena, so dear to us all, are to be found in the attentional mechanisms of the brain by which we concentrate our sensory and motor systems on some element of our environment, to the exclusion of all else in the environment. He also believes that as the memory of some thing attended to lasts for only about 60 seconds or so, then the molecular and atomic mechanisms involved should have only this time scale of change.

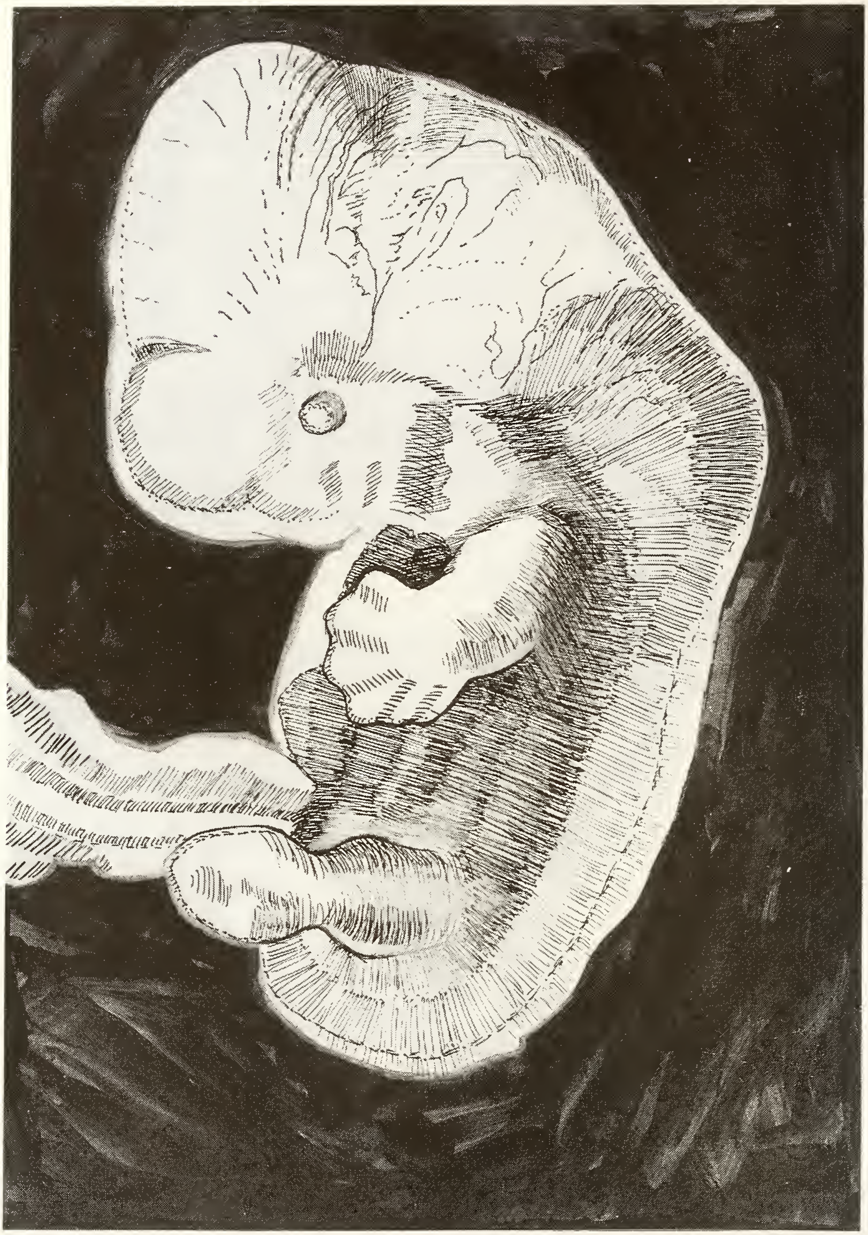


Figure 3.

A human embryo at 5 weeks after conception (11mm long). The hands and legs are already formed but there is only a hint of the digits. The body is clearly connected to an umbilical cord. The brain is developing above the eyes (to their left). The spinal cord is also clearly delineated. The adult brain has some 100,000,000,000 neurons, many of which have about 10,000 connections (or synapses) on them from other neurons. This results in some 100 million million synapses in the brain. As these synapses are capable of modifying their properties according to experience there is a truly wondrous range of possibilities in the wiring of the brain.

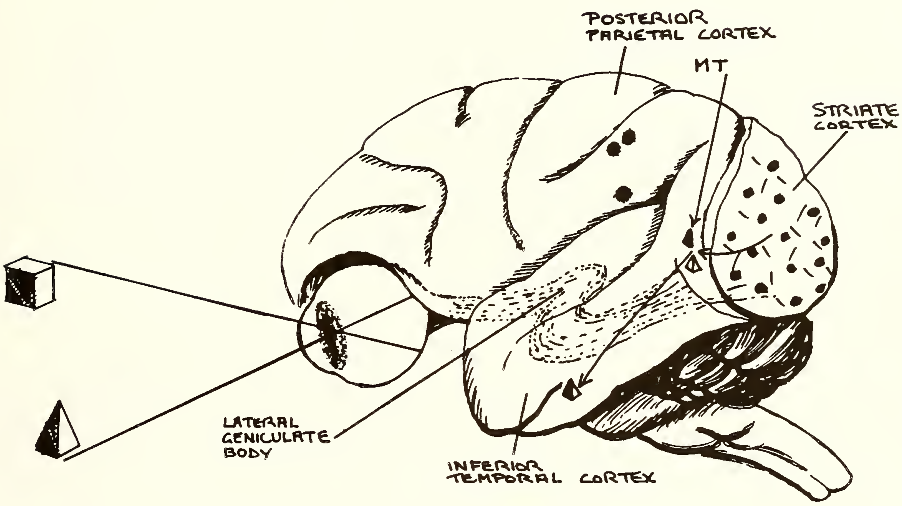


Fig4

Figure 4.

The main pathways in the brain concerned with the visual identification of objects and their location and movement in space. A coloured triangular form is observed moving in the visual field. The information about colour and form of an object on the one hand and about the movement of the object on the other are coded for separately within the retina of the eye. This coded information is then sent in parallel pathways along separate sets of axons, first to a part of the brain called the dorsal lateral geniculate nucleus and from there to the primary visual (striate) cortex in the occipital lobe at the back of the head. Here the coded information undergoes a transformation into the elements that recognisably belong to the object in the medial temporal area (MT) just in front of the striate visual cortex; at this site neurones fire in relation to seeing each of these elements. The other parallel line of coded information is sent to the posterior parietal cortex, also in front of the striate cortex, where neurons fire in relation to the movement of the object. The final pathway for the identification of an object is in the inferior temporal cortex, where reconstruction of the complete object and its colour is carried out. Here specific neurones fire when the object is viewed.

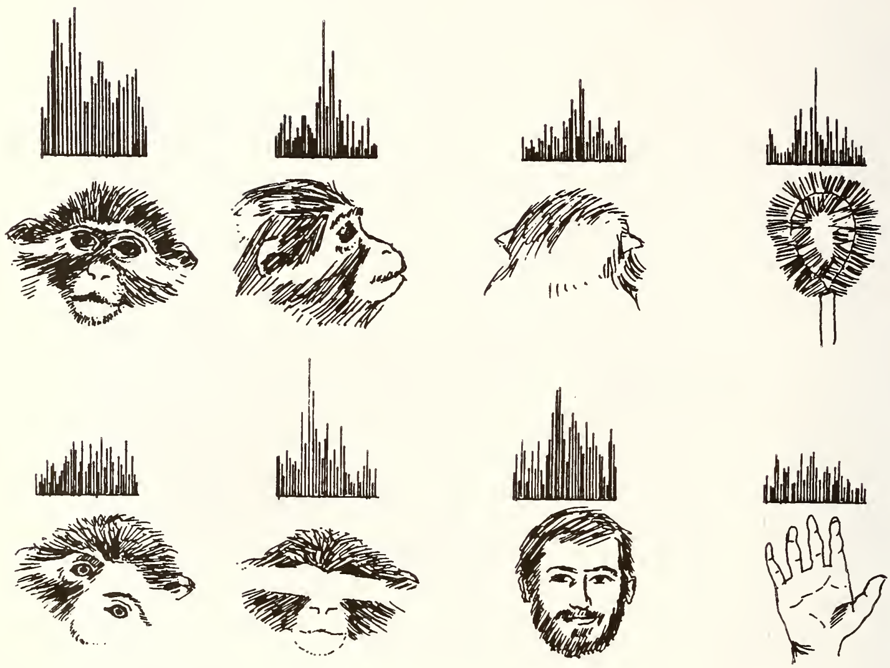


Fig 5

Figure 5.

A neurone that fires action potentials at a maximum rate when a particular face is observed. These face neurones are found in the inferior temporal lobe. Note that for this primate temporal lobe neurone, recorded from an awake monkey, the maximum firing of impulses (given by the black vertical bars) occurs for the frontal view of the face of another primate, as shown by the top row of different face orientations. The bottom row shows that masking out the eyes or substituting a human face for a monkey face results in reduced responses. Very low rates of action potential firing were recorded from this neurone when a scrambled face was presented or a hand or a brush.

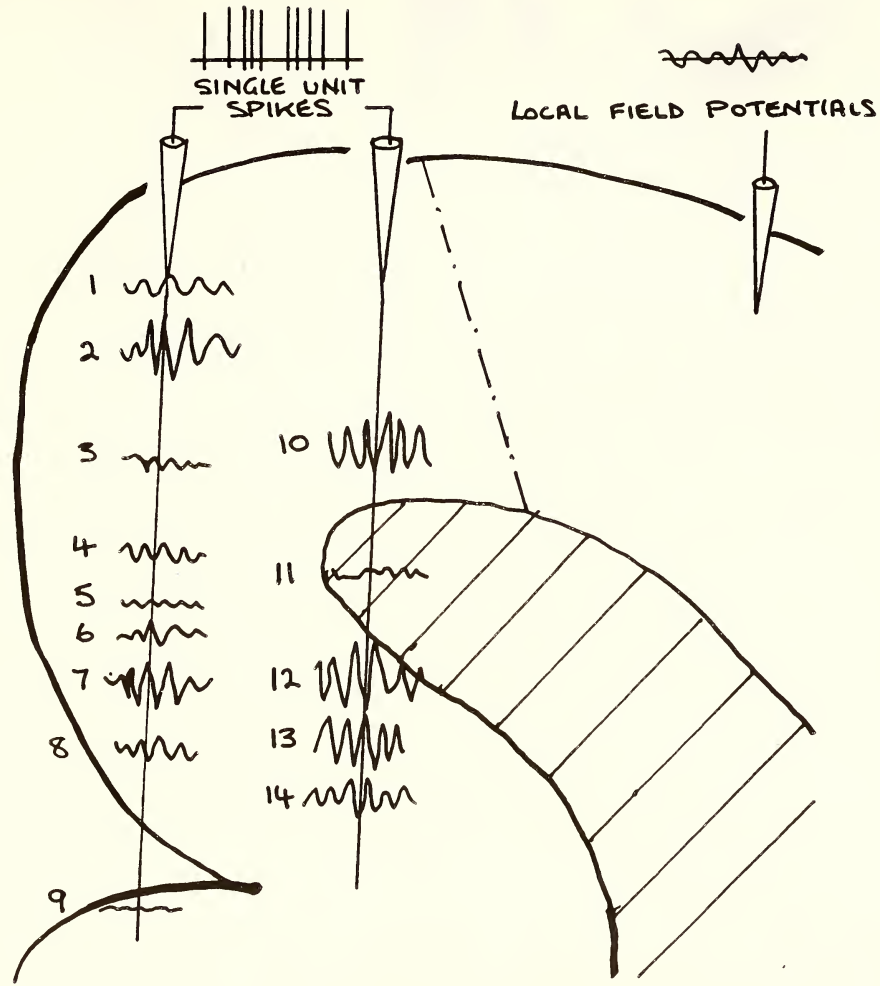


Fig 6.

Figure 6

The main difficulty in trying to understand how we see an object amongst the many different complex impressions that impinge on our retinas involves the linking together of related features that constitute the object. This is referred to as the "binding problem" in which the constituent visual elements of the object must be bound together in the visual cortex so that we identify the object as separate from the other components in the visual image on our retinas. A very important discovery concerning this problem was recently made by two groups in Germany: Wolf Singer and his colleagues as well as R. Eckhorn and his colleagues. They found oscillatory firing of neurones at about 40Hz that were phase-locked between assemblies that represent the linking features of the visual scene; this phase-locked oscillatory firing occurred even for neurones that were found in different cortical areas that coded for different aspects of the object. Visually related activities constituting an object are by this means transiently labelled by a temporal code that signals their momentary association. In the diagram are shown the two main visual areas at the back of the brain called the occipital cortex (area 17 and 18). Highly correlated stimulus evoked resonances were found between neurones in the two tracts through this area of the brain indicated by the two electrodes pictured at the top. The numbers 1 to 8 and 10 to 14 on these two tracts through the brain show correllograms of the impulse firings that are mostly in phase. These coherent-evoked 40Hz resonances were found at distal cortical locations when at least one of the primary coding properties of the object (namely its orientation, position, movement of direction or velocity) was present.

Figure 7

Defects in the ability to attend to parts' of ones' own body following a stroke. This person was an artist, Anton Raderscheidt, who suffered a vascular stroke affecting the right hemisphere of the brain. Shown here are four self-portraits that he painted at different stages of recovery from the stroke. A specific part of the brain, called the parietal cortex, an area of the brain involved in visual attention, was damaged during this stroke. Note that in the earliest painting (upper left) the artist completely ignored the side of his face opposite to the damaged parietal cortex. He then gradually improved over the next few months (upper right and lower left) until in the end (lower right) most spatial relations for his face were reconstituted, although still remaining somewhat distorted. The artist never really recovered. He died several years after the stroke which affected his right parietal cortex.

It should be emphasized that the parietal stroke did not involve any injury to the purely "visual" mechanisms of the brain. For example the artist could se objects perfectly well on that side of his body opposite to the parietal lesion. However, if a second object was then brought into the visual field on the other unaffected side, then attention to the first object was lost and the artist was "blind" to its presence.

Common seizure patterns

Clinical type	*Localization*
1 Somatic motor:	
Jacksonian (local motor)	Prerolandic gyrus
Masticatory	Amygdaloid nuclei
Simple contraversive	Frontal
2 Somatic and special sensory (auras):	
Somatosensory	Postrolandic
Visual	Occipital or temporal
Auditory	Temporal
Vertiginous	Temporal
Olfactory	Mesial'temporal
Gustatory	Insula
3 Visceral: Autonomic	Insuloorbital-frontal cortex
4 Complex partial seizures:	
Formed hallucinations	Temporal
Illusions	Temporal
Dyscognitive experiences (déja vu, dreamy states, depersonalization)	Temporal
Affective states (fear, depression, or elation)	Temporal
Automatism (ictal and postictal)	Temporal and frontal
5 Absence	"Recticulocortical"
Bilateral epileptic myoclonus	"Reticulocortical"

SOURCE: Modified from Penfield and Jasper, *Epilepsy and Functional Anatomy of the Human Brain*, Boston: Little Brown, 1954. Fig 8

Figure 8

Localization of focal epileptic seizures in the brain. The common form of epileptic fit, as the table shows, occurs as a focal seizure originating in a localized region of the temporal lobe, often referred to as the limbic system. These seizures involving the temporal lobe, are accompanied by visual, auditory and olfactory (smell) hallucinations. They also involve their vivid recall of memories because the limbic system includes the hippocampus, required for the laying down of new memories. The temporal lobe itself includes neurones for the identification of objects, such as faces, as shown in figures 4 and 5. Thus the most common human epileptic condition is not tha of generalized seizures, which start out in the entire neocortex of grey matter as in "petit mal" or "grand mal" epilepsy, as commonly thought, but as focal seizures in the limbic system.

Figure 9

The neurones shown are found in the retina and are called retinal ganglion cells. They connect the retina in the eye to the visual centres of the brain. Many of these neurones degenerate during normal development as the retina is making appropriate connections with the visual centres of brain. Present evidence suggest that this naturally occurring cell death occurs as a result of the neurones failing to obtain a growth factor necessary for their survival. This growth factor is synthesized in the visual centres of the brain where the terminals of retinal ganglion cells obtain the factor and transport it along their axons back to the ganglion cell bodies in the retina. There it is utilized to maintain the integrity of the neurone.

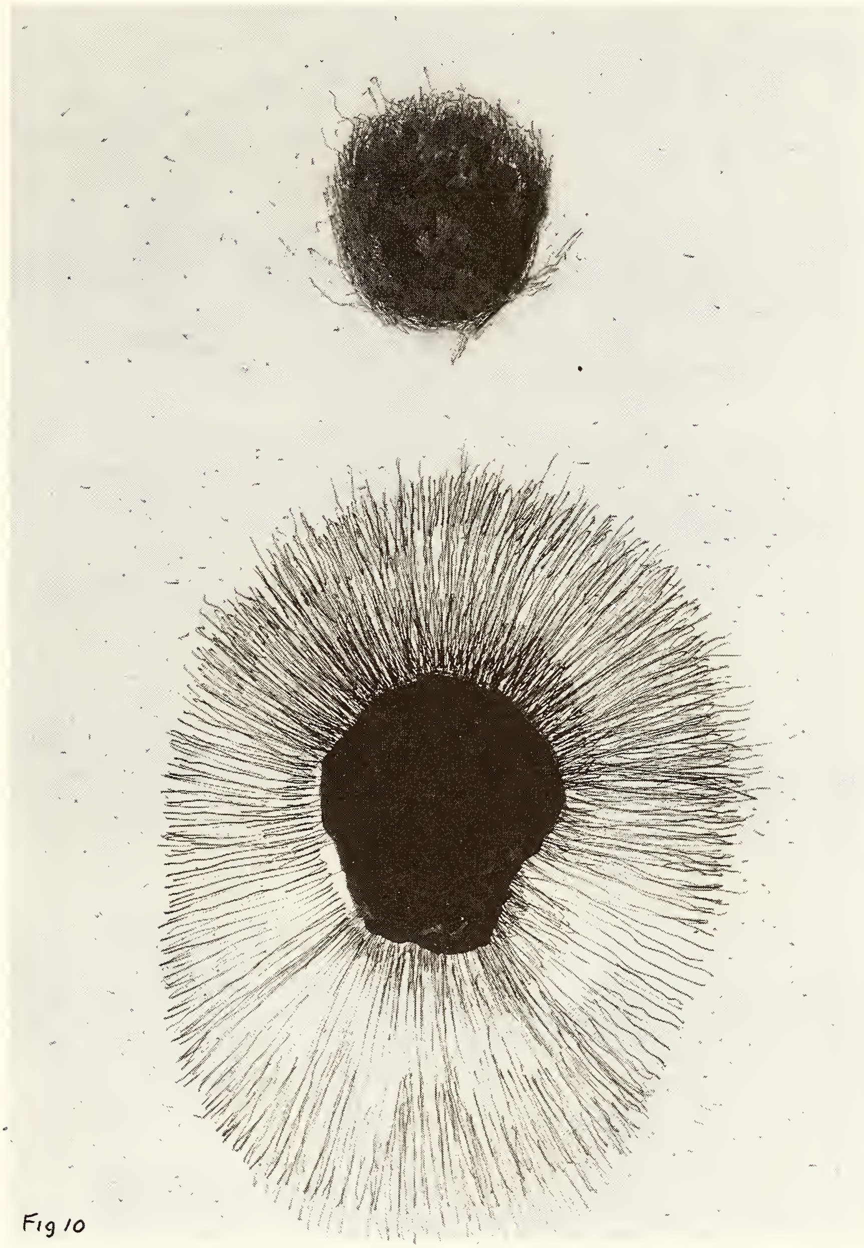


Figure 10.

Neuronal growth factors for the survival of neurones were first discovered in the peripheral nervous system that controls such organs as blood vessels; these are called sympathetic neurones. Rita Levi-Montalcini and Cohen purified this sympathetic nerve growth factor (NGF) down to a single type of molecule. This figure shows a clump of sympathetic neurone cell bodies in a culture dish in the absence of NGF (upper figure) compared with a clump in the presence of NGF (lower figure). Note that hundreds of axon processes emerge from the clump of neurones in the presence of NGF indicating that these neurones are alive and growing.

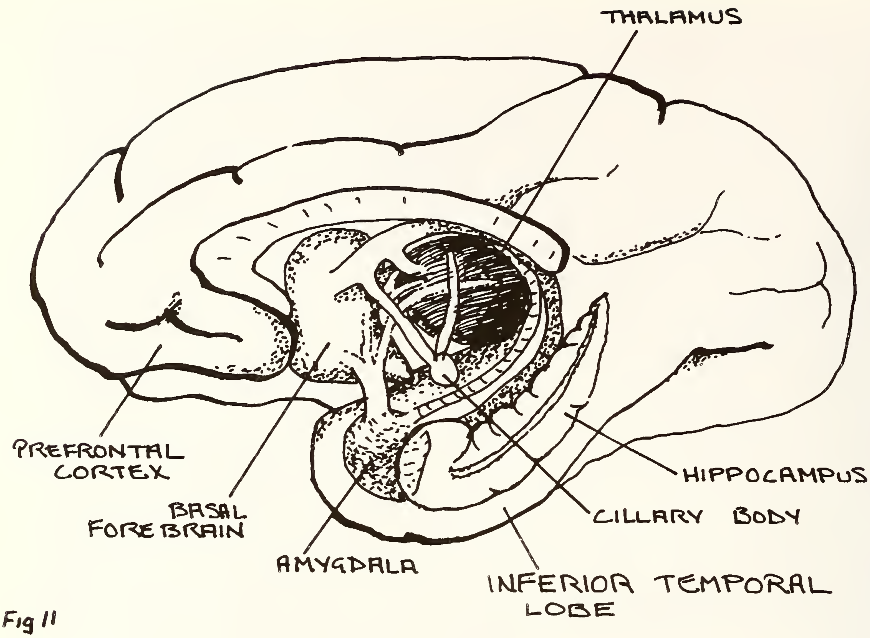


Fig 11

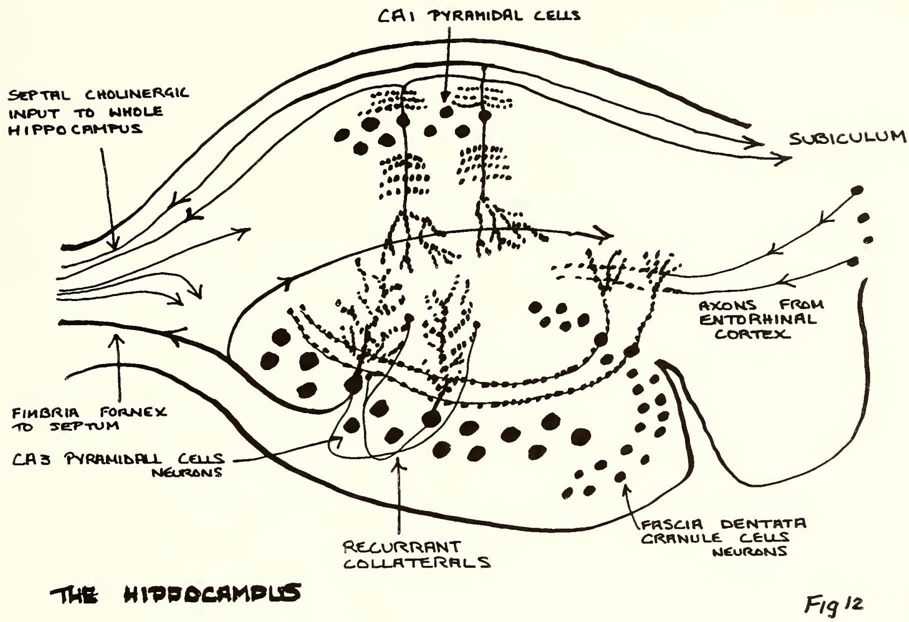
Figure 11

The limbic or "border" system of the brain comprises primarily the inferior temporal lobe, hippocampus and amygdala. The hippocampus and amygdala lie on the medial surface of the brain rather than on its lateral aspect. Not only is the system most frequently involved in epileptic fits but it is also one of the first parts of the brain to degenerate in Alzheimer's disease.

Figure 12

A section through the hippocampus, isolated from the rest of the brain. The diagram also shows the layout of the principal neurononal types (indicated as spheres with branching trees of processes called dendrites) together with their interconnections (indicated by the long thin processes, called axons, with arrows attached). The specific input, bringing information about all sensations from the cortex (such as sight, sound or smell), come from the axons arising in entorhinal cortex which synapse on the dendritic processes of granule cell neurones in the so called fascia dentata. These neurones themselves relay this transformed information to the pyramidal neurones in the CA3 region via their axons that form synapses on the CA3 neurones. These neurones are known to code for memories; they connect with each other through processes called recurrent collaterals (only two of which are shown). It is the excitability of these neurones, in part conferred upon them by these recurrent collaterals, that makes this region of the brain the most likely to trigger an epileptic seizure.

The CA3 neurones in turn project to the CA1 pyramidal neurones on which they synapse. These neurones also code for memories and their axons project to the region called the subiculum in the old paleocortex and from there to the neocortex. Thus the trisynaptic pathway is from entorhinal cortex to fascia dentata to CA3 pyramids to CA1 pyramids back to the cortex. There is another, less specific input (on the left) necessary for the normal functioning of the hippocampus and that comes from the subcortical structure called the septum. These axons synapse on all neurones in the hippocampus. They are the first neurones to degenerate in the brain of people suffering from Alzheimer's disease. This leads to the loss of memory formation that characterized this disease.



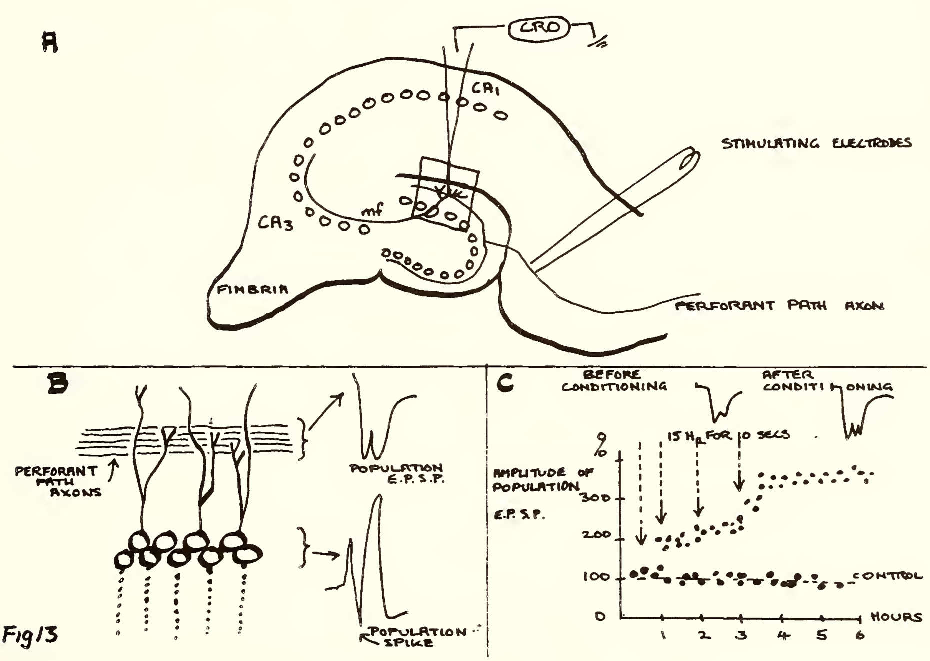


Figure 13.

The functional circuit between different types of neurones, shown in figure 12, the synaptic connections within this circuit have the very special property of remembering over very long periods of time if they have been subjected to impulse traffic. "A" shows a transverse section through the hippocampus, like that shown in figure 12, except that stimulating electrodes have been placed on the nerves from the entorhinal cortex (called the perforant pathway axons) and a recording electrode in the dendritic layer of the granule cells, where the perforant pathway axons synapse. "B" shows an enlargement of the boxed area in "A", with sample electrical recordings of the compound population spike occurring because many granule cells fire in synchrony due to stimulating the perforant path axons; the population excitatory postsynaptic potential (epsp) is recorded from the synaptic regions between the perforant path axons and the granule cells on stimulation and gives a measure of the efficacy of synaptic transmission. "C" shows the results of stimulating the perforant pathway at a frequency of 15Hz for 10 seconds at the four times indicated in the graph of the relative amplitude of the population epsp against time; if the perforant nerves are stimulated every few minutes with a single impulse before, during and after the 15Hz stimulating periods then the amplitude of the population epsp at each 6 minute period is shown to grow over 3 hours until it settles down to a size 300% that of the control (in which no stimulation occurred at 15Hz); two examples of this long-term potentiation of the population epsp are shown one before and one after the 15Hz conditioning period. This enhanced efficacy of transmission through the synapses of over 300% is shown to last for 3 hours after the 15Hz stimulation but may continue for days or months. The mechanisms responsible for this potentiation are required to retain a memory.

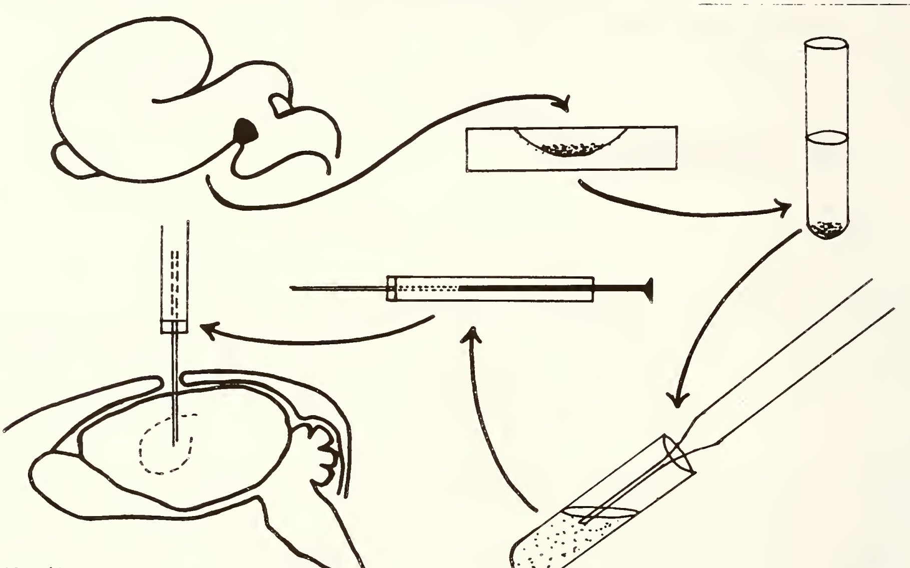


Fig 14

Figure 14.

Procedure for transplanting embryonic septal neurones from the hippocampal region of a foetus to the hippocampus of a mature animal with a degenerating septum. The septal region (black area) is first removed from the foetal brain and placed in a culture dish with enzymes that loosen the tissue into separate neurones. The partly separated neurones are then placed in a test tube and the isolation process taken further by rapidly shaking the neurones up and down in a pipette in the test tube. The completely dissociated neurones are next taken up into a syringe. The syringe needle is then located with great accuracy in the appropriate part of the hippocampus and the dissociated septal neurones injected into this area of the brain.

Figure 15.

Use of the forced alternation T-maze to show that following degeneration of septal neurones transplanted embryonic septal neurones can reconstitute the memory system of the hippocampus. The rat is put in the starting position in the T-maze. In the first trial the door on the right, door 1, is open; the door on the left, door 2, is closed and food is placed at 'a'; the rat runs and is forced to turn to the right where the door is open (it can neither seenor smell the food at the atarting position). In the second trial the door 1 is open and now the doow 2 is also open and the food placed at 'b'. A correct response is regarded as one in which the rat turns left on trial 2. The triall- trial 2 sessions are repeated 6 times per day. The room in which the T-maze is placed contains many items, such as curtains, clocks and computers which despite the rats poor visual acuity appear to allow the rat to orientate itself on the T-maze.

The graph shows the percentage of correct responses performed by the rat on the T-maze alternation task over time. Following lesion or degeneration of the septal region of the hippocampus there is a 50% chance that the rat will turn left on the second trial, so nothing has been remembered and the choice is random. Following a sham operation, in which only a harmless pladebo substance is injected into the hippocampus, the rat learns to make 100% left-hand turns on the second trial within 3 weeks of testing so that at this time its' memory for the T-maze performance is perfect.

Following transplantation of embryonic septal neurones into a rat with a lesioned septum the rat learns to perform at the 90% correct level of performance within about 10 weeks after the operation.

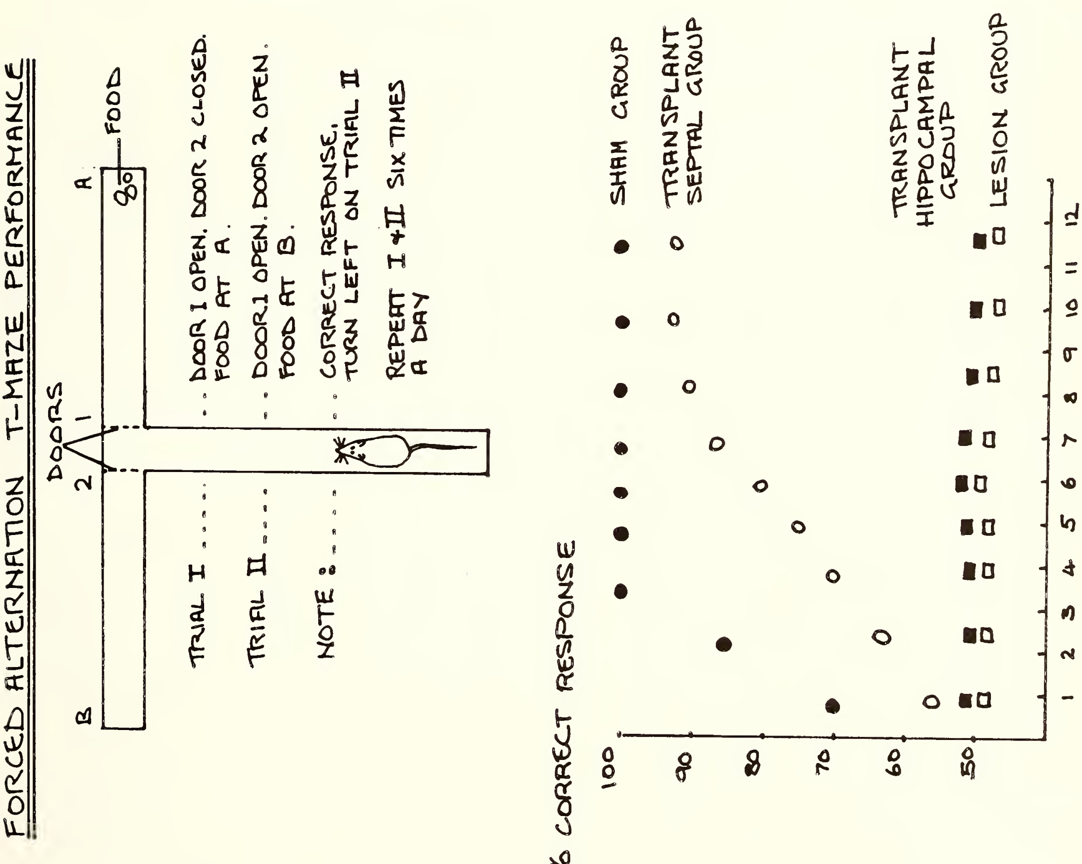


Fig 15

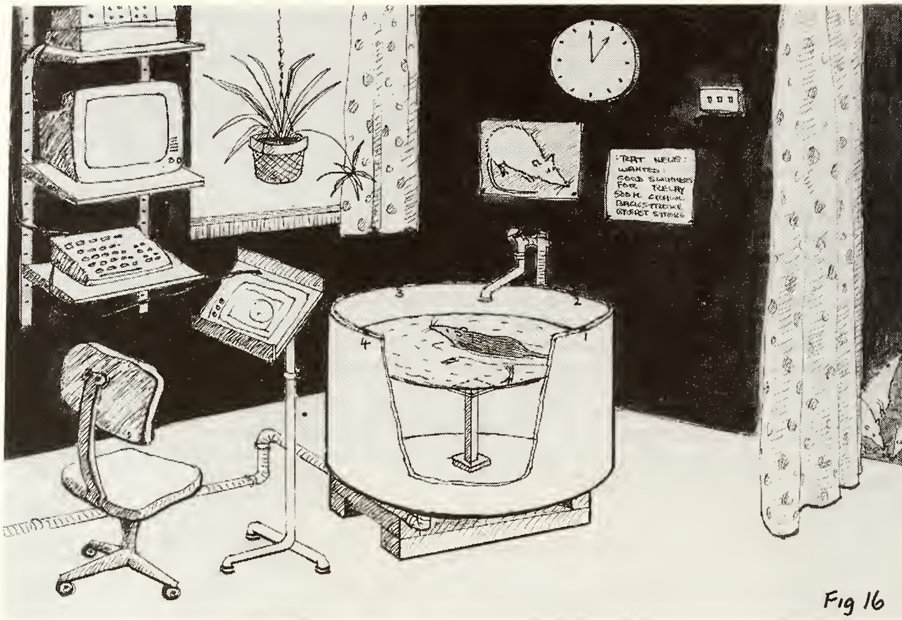


Figure 16.

The Morris water tank used to determine the spatial memory of rats. The water tank is placed in about the middle of the room. It contains opaque water and a stand (shown in the cut-away of the tank wall) which is about one inch beneath the surface of the water; this is sufficiently deep for the rat not to see it when swimming in the tank so that it only becomes aware of the stand if its' feet come in contact with it. Surrounding the tank are objects on the wall, such as curtains, clocks and potplants (and a large picture of other rats) which allow the swimming rat to determine its' orientation; the spatial location of the rat in the water tank is laid down as a spatial memory in the hippocampus and this allows a healthy rat to determine the position of the unseen stand with respect to the objects in the room, once its' feet have come in contact with the stand. A television camera is placed above the water tank which allows the operator at the television - computer terminal shown to monitor the locus of the swimming pathway of the rat once it has been placed in the tank at an arbitrary position.

Figure 17.

The locus of the swimming pathway of rats (determined by the methods given in the legend to figure 16) after they have been placed in the Morris water tank. The view is looking down on the tank, and shows the position of the stand beneath the opaque water in the tank. Each row shows the results for series of trials which determined if a rat found the stand (and then sat on it) during a 5 minute period; there were five trials on each of five successive days and the results are shown for the first trial on the first day (1.1), the fifth trial on the first day (5.1), the fifth trial on the fourth day (5.4) and the fifth trial on the fifth day (5.5). In the first row a young control rat (about 6 months old) was placed at a random site in the tank at 1.1 and left to swim; it will be noted that at 1.1 the rats feet did not accidently make contact with the stand; by 5.1 this had happened and the spatial memory system of the hippocampus had located the position of the unseen stand with respect to the objects in the room enabling the rat to swim directly to the stand and sit on it, as shown; this also occurred at 5.4; at 5.5 the stand was removed and the rat swam repeatedly over the site where the site had been, seeking a rest. In the second row an Aged Impaired rat (about 3 years old) is shown to be unable to lay down a spatial memory of the position of the stand, even though its' feet accidently come in contact with it several times over the 25 trials. In the third row an Aged Unimpaired rat (again about 3 years old) is shown to be able to lay down a spatial memory as well as the Young Control rat, and performs in a like manner. The final row shows an Aged Impaired rat that had a transplant of embryonic neurones from the septum in its' hippocampus; the locus of the swimming pathway of the rat in each case shows that it has formed a spatial memory of the stand as quickly as the Young Control.

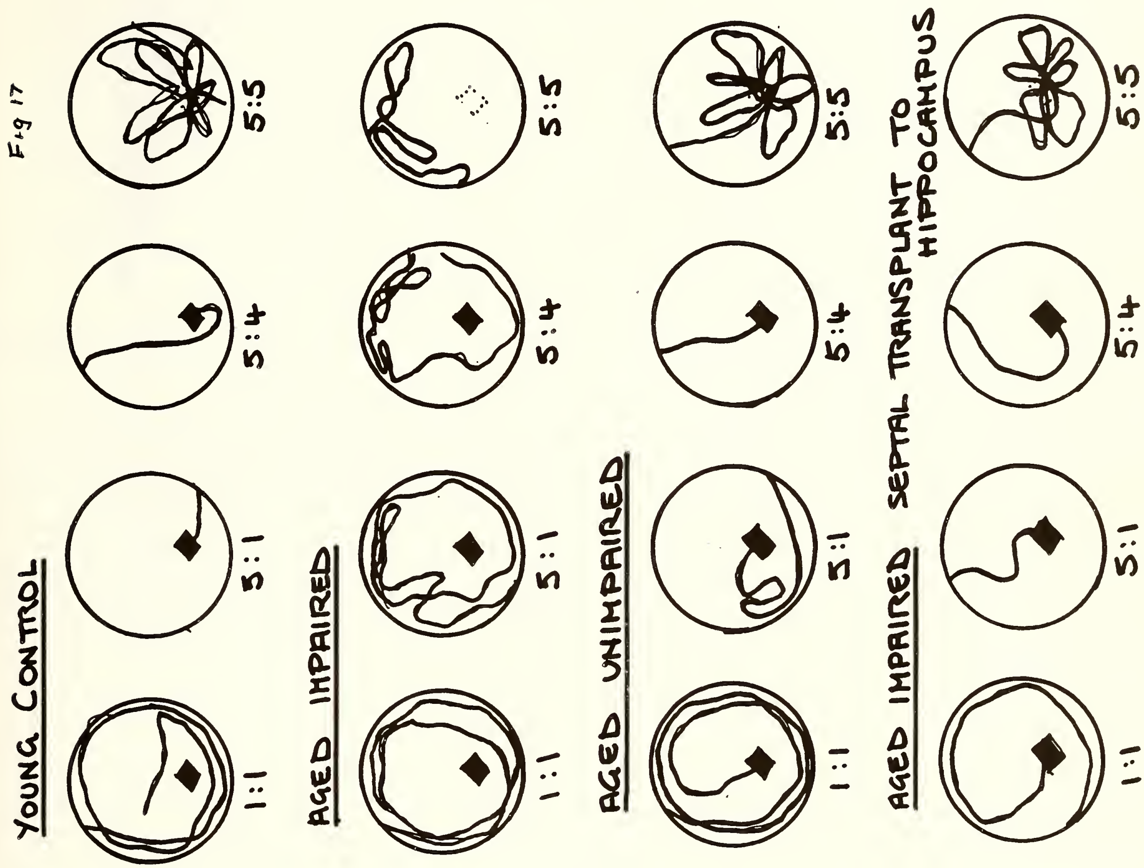


Figure 18.

A human embryo at 6 weeks (15 mm long). The hands are clearly visible with the just clearly delineated fingers. The heart, with liver below, can be seen between the hands; the diaphragm separates the heart and liver. Most striking, are the two halves of the cerebrum which can be seen through the transparent skin of the forehead above the developing eyes.

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The San Calixto Observatory in La Paz, Bolivia. Eighty Years of Operation. Director Dr. Lawrence A. Drake S.J.

ROBERT R. COENRAADS

ABSTRACT. The San Calixto Observatory has played an important role in understanding the earth's interior, seismicity, seismic risk and the meteorology of La Paz since its foundation on the 1st of May, 1913. Since this time it has had only two directors; Pierre M. Descotes S.J., 52 years and Ramon Cabré S.J., 29 years. Lawrence A. Drake S.J. became the Observatory's third director in 1993.

In 1993, San Calixto became one of the first observatories to install a high-gain, broadband station and joined the Global Telemetered Seismic Network (GTSN). Digital data of this type available on a global scale, together with modern computing facilities, are a significant step forward for the field of seismology.

The Jesuit-run observatory offers a high quality international and national scientific service and is dedicated to the progress and development of humanity. It is a testimony to the compatibility between science and faith.

INTRODUCTION

The San Calixto Observatory takes its name from the Bishop Calixto Clavijo (1814-1886), who founded the Sacred Hearts and established the Society of Jesus in La Paz. It is run by Jesuit Fathers with the express aim of assisting Bolivia's advance in the field of science, specifically seismic activity and risk. The present Observatory (Figs 1 & 2) is located at Number 944 Indaburo Street, La Paz, in a colonial building given to the Jesuits by the descendants of Marshall Andrés de Santa Cruz.

The Observatory is responsible for the recording, interpretation and storage of the data from eight seismic stations which listen to the natural and man-made noises of our planet twenty four hours a day. Each daily record may show 15 to 20 earth movements. These records, together with those from more than a thousand other stations around the world permit the accurate location of such natural movements or man-made explosions. The Observatory projects its image through the publication of its raw data and research work, the preparation of a yearly Bulletin, and by keeping the press informed about aspects of its work which may interest the public

HISTORY

In Manchester, July 18-21, 1911, the Second General Assembly of the Seismological Association passed a resolution recommending that the Jesuits install a seismic station at La Paz, Bolivia (Fig. 3) to fill the gap in the central part of South America, (Fig. 4).

In 1911 Brothers E. Tortosa and J. Lizarralde chose the crypt of the church of San Calixto College for the first seismic station. Using anything available - an old clock pendulum to make marks on a smoked paper recording drum driven by the mechanism of an old alarm clock - they constructed the first test seismograph.

In 1912 Father Pierre M. Descotes arrived in La Paz and, under his direction, the first simple seismographs comprising masses of up to several tons were built by Brother Lizarralde. The San Calixto Observatory was officially founded on May 1st 1913 which marked the commencement of the Bulletins of Seismic Data which have continued to be published to date without interruption. Gutenburg and Richter (1949) in their famous book, "Seismicity of the Earth", wrote, "La Paz at once became, and still remains, the most important single seismological station of the world. This is a consequence of its isolated location, the sensitive instruments and the great care with which records were interpreted and the reports issued under the direction of Father Descotes."

In 1930 a three component system of Galitzin - Wilip seismometers was installed in the crypt of the church of San Calixto College.

In 1962 the World Wide Standard Seismograph Network (WWSSN) station commenced operation in Següencoma, La Paz under the control of the Observatory. Designated as LPB, it formed one of a network of 115 standard 3-component long period and 3-component short period stations around the world. (Figs 4 & 5.)

Figure 1. Dr. Laurence A. Drake S.J., at the San Calixto Observatory in La Paz, Bolivia.

In 1965 the San Calixto Observatory assumed responsibility for the seismic station at Peñas (designated PNS, Fig. 5).

In 1972 seismometers were placed in a specially constructed tunnel in the Huayna Potosi granodiorite at an altitude of 4,400 metres in the Andes, 40 kilometres north of La Paz. The instruments are now of the ASRO (adapted seismic research observatory) type and the station is designated ZOBO (Fig. 5). Microelectronics led to the introduction of telemetered ASRO stations from which the data could be sent by radio to the Observatory in La Paz. A station south of La Paz at Chanca (CNCB, Fig. 5) was set up with the assistance of the U.S. Geological Survey. Three stations in the Zongo Valley (Zongo A, B & C, Fig. 5) and one at Cerro Gloria de Tiahuanacu (GLORIA, Fig. 5) were set up with the assistance of the University of Paris. In 1988 another station was installed at San Ignacio de Velasco in Santa Cruz (SIV, Fig. 5).

For the most part, the seismometers are located in sites so quiet that the ground vibrations may be amplified to 500,000 times, or a million times in the case of ZOBO.

ORGANISATION OF THE SAN CALIXTO OBSERVATORY

In Bolivia, the Superior of the Province is presently Luis Palomera S.J. who is responsible for all the Jesuit institutions. The Director of the Observatory is Dr. Lawrence Drake S.J., who replaced Dr. Ramon Cabré S.J. in 1993. The Director of the Observatory is in charge of general administration, scientific investigations, funding and public relations. Below the Director, a number of research associates and postgraduate students work on projects concerning regional seismicity, seismic risk analysis, the interior of the earth and meteorology. Approximately 10 auxiliary staff attend to the operation of the seismic stations, interpretation of seismograms, meteorological observations, the library, secretarial duties, accounts and vehicles.

Figure 2. Spanish colonial style interior courtyard of the San Calixto Observatory at No. 944 Indaburo Street, La Paz. The building was originally the residence of Marshall Andrés de Vera Cruz.

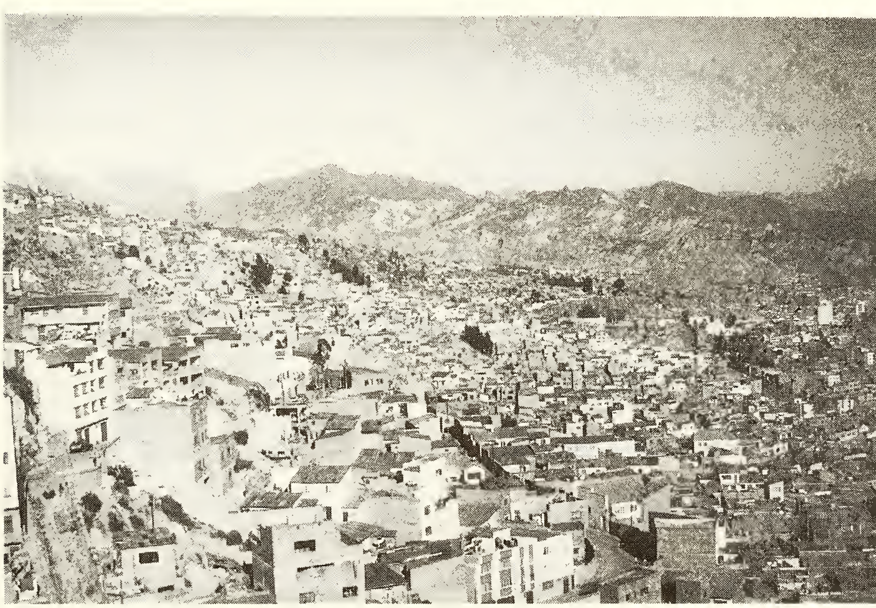

Figure 3. La Paz, situated in a valley in the Bolivian high plain at an altitude of 3,600 metres above sea level, is the highest capital city in the world.

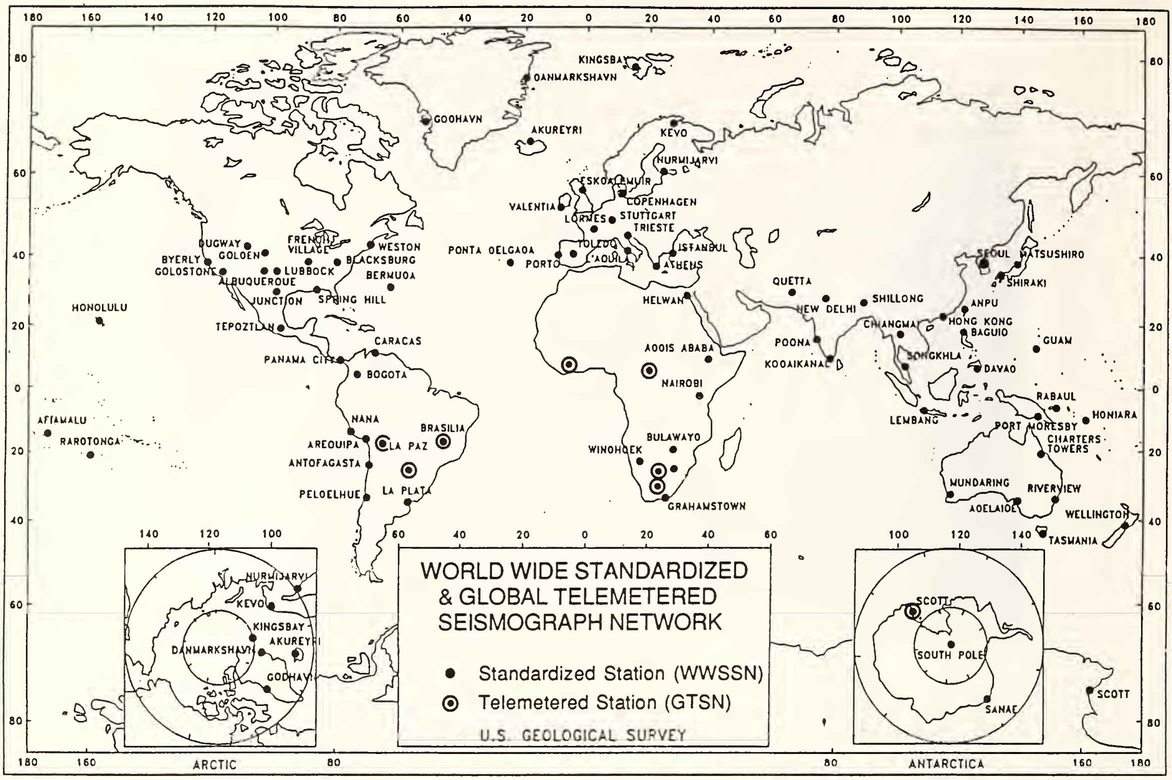

Figure 4. La Paz shown as one of the stations in the Global Seismic Network. The dots represent the original World Wide Standardized Seismographic Network and those circled are the new telemetered GTSN stations.

The San Calixto Observatory is organized in sections:

a) Seismology

This section is the most important and the main fields of investigation are;

- seismic activity and the catalogue of seismic events in Bolivia
- structure of the crust and mantle below Bolivia
- tectonic activity and evolution of the Andes
- seismic risk analysis, mitigation of seismic danger and preparation for natural disaster
- preparation of seismic risk maps for South America.

The official time for the country is maintained by the Observatory.

b) Meteorology

This section operates a station at the Observatory in the centre of the city recording temperature, relative humidity, precipitation, wind speed and direction and barometric pressure. These data have been published by Segaline Nieto and Cabré (1988) in "El clima de La Paz" and extend back to 1907.

c) Astronomy

This section maintains a telescope, donated by Spain in the sixties, which is used to instruct individuals or groups, such as college students, on various aspects of astronomy.

The Observatory works with the National Commission of Geophysics and in collaboration with the National Academy of Sciences, the Science and Technology Department of the Ministry for Planning and Coordination and Civil Defence. The Observatory also works in collaboration with numerous external bodies; the Regional Centre for Seismology for South America, U.S. Geological Survey, the University of Paris, the Institute for Seismic Warning in Argentina, the U.S. Air Force Office of Scientific Research (AFOSR) Geophysical Laboratory and the International Seismological Centre of England.

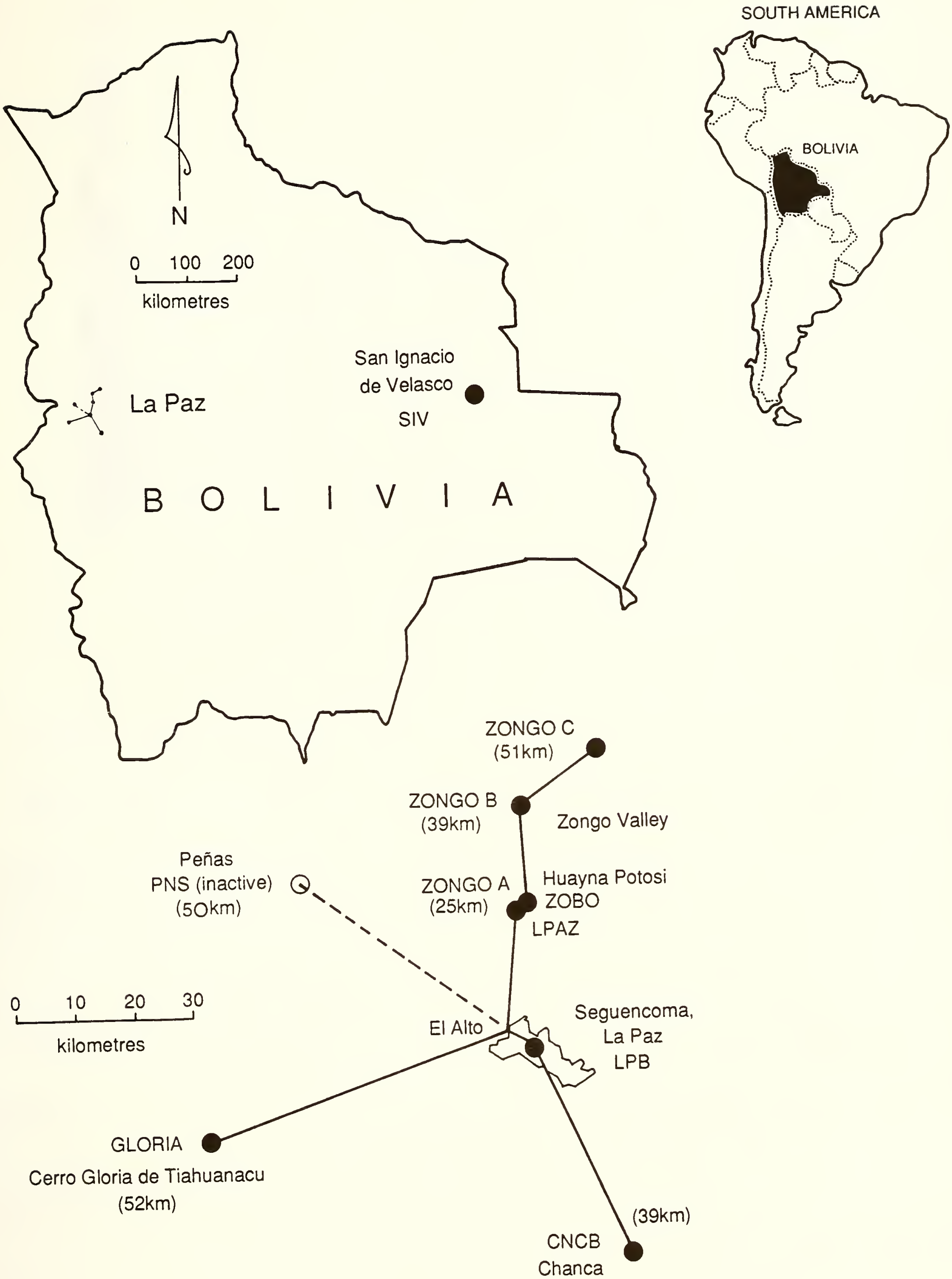

Figure 5. Seismic stations in Bolivia under the control of the San Calixto Observatory. The new telemetered station situated in Huayna Potosi is designated LPAZ.

Figure 6. Dr. Laurence A. Drake S.J., present director of the San Calixto Observatory, (left) and Dr. Ramón Cabré S.J., retiring director, (right).

HUMANITARIAN ACTIVITIES

Apart from their scientific research and teaching the Jesuits of San Calixto Observatory and the associated College are involved in numerous community activities of a humanitarian nature. A few of these include;

- delivering daily Mass to the people in the various Parishes around the city
- striving for the betterment of primary school education and its ease of access by the people
- lobbying for the continuation of the provisions of resources for scientific and technological research in the country
- organization of incentive/education programs for the out of work, for example, small business management
- organization of neighbourhood groups to work with local government to provide essential services, such as water, electricity and sewerage
- lobbying for the beneficiation of primary export products and the development of export technologies in the field of new materials, microelectronics, biotechnology, commun-ications, etc.
- political commentary in local newspapers.

It is only through these means that an elevation in the standard of living and economic development can be achieved in Bolivia.

SAN CALIXTO OBSERVATORY RESEARCH PROJECTS

1) Global Telemetered Seismic Network (GTSN)

In 1989 work commenced on establishing a new global telemetered station on the peak of Zongo, designated LPAZ (Fig. 5). Bolivia is one of the first countries to operate on this network (Fig. 4). Broadband seismometers have been placed in drill holes 100 metres deep in the Huayna Potosi granodiorite and the information will be recorded using IRIS-2, 24 bit seismographs with a magnification of 2 million times. This station commenced operation in August 1993. A broad band of frequencies will be telemetered to the Data Collection Centre at Albuquerque, New Mexico and recorded magnetically on high density digital cartridges. The ready availability of digital data represents a great leap forward for the field of seismology. Using computers it will be possible to obtain all the periods of interest and analyse the frequency spectrum of the Earth's movements, permitting a series of new investigations in attenuation, dispersion, etc. In this way San Calixto Observatory will continue to be a leader in seismology (Cabré, 1992).

Figure 7. Huayna Potosi. This glaciated granodiorite mountain contains seismometers of the station ZOBO in a specially constructed tunnel at an altitude of 4,400 metres. The new global telemetered station LPAZ is also located on this mountain. Such quiet sites allow seismic signals to be amplified up to a million times.

2) International Seismological Observation Period (ISOP)

The quality and amount of seismological information available has so greatly improved since the 1960s that today the data from the thousand-plus stations around the world are under-used in many cases. Information such as singular or multiple reflections from various layers within the earth, changes in wave velocity dependent on rock type, wave scattering, etc. is little used. As the work required to collect all the information would be enormous, ISOP proposes that, for the period 1994 - 1997, all researchers select a few set events - an average of one per day. These events will be studied in detail to gain maximum knowledge of the interior of the earth (Cabré, 1992).

3) International Decade for the Reduction of National Disasters

In the last 20 years, natural disasters have cost the lives of 3 million people, affected the lives of at least 800 million and have cost more than $US 23,000 million (Ayala, 1992). The General Assembly of the United Nations has declared 1990-99 as the international decade for the reduction of natural disasters. The technical-scientific committee is working through national committees, including the San Calixto Observatory, in the following areas:

a) Risk picture - identification of the types of threat and evaluation of their distribution, estimation of their periodicity and effects; Comparison of these data with population density maps and preparation of risk maps.

b) National and local plans- preparation of construction codes, preventative plans to minimise impact of disasters and emergency evacuation plans.

c) Alarm Systems - development of regional and local warning- and if possible, prediction systems capable of detecting threats with sufficient time to initiate action (Ayala, 1992).

DR. LAWRENCE A. DRAKE S. J.

Dr. Lawrence A. Drake S.J. (Fig. 1), director of the San Calixto Obsevatory, replaces, Dr. Ramon Cabré S.J. (Fig. 6), who retired in 1993 at the age of 71 after having served at the Observatory for 34 years and as a director for 29 years.

Dr. L.A. Drake S.J. brings with him much experience having been associated with Riverview Observatory in Sydney (Fig. 4) for 40 years, serving as a director for 27 years, and with 20 years research and teaching in geophysics and geology at Macquarie University in Sydney.

As director of the San Calixto Observatory, Dr. L.A. Drake S.J. proposes to continue to investigate the effects of the complexity of the South American tectonic structure on earthquake data. The specific proposals are as follows:

1) Time - distance curves for P-waves (which give the velocity structure within the earth) recorded at La Paz for earthquakes in the region of Venezuela and for earthquakes of intermediate depth in the region of Colombia look like "shotgun patterns". These need further investigation.

2) To apply particle motion analysis, Fourier analysis and attribute analysis to the P-, and subsequent wavetrains, of earthquakes and explosions recorded in Bolivia.

3) To use a local crustal and upper mantle model to locate earthquakes in the region of Bolivia and to try to allow for at least one dipping layer.

4) To model, using the finite element method, the propagation of Rayleigh and Love waves (including Rg and Lg) across the dipping sections of the Nazca plate beneath Bolivia.

5) To use the new Global Telemetered Seismic Network station and the French high-gain digital seismometers to continue the tomographic work on the crustal and upper mantle structure of northern Bolivia.

6) To apply the waveform correlation method for identifying quarry and mine explosions.

7) To continue the study of focal mechanism, depth, magnitude and seismic moment of earthquakes 20 - 100 km ENE of Cochabamba, and extend it to other regions.

8) To revise the magnitudes of larger earthquakes in southern Bolivia, as they appear to have been overestimated.

ACKNOWLEDGEMENTS

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Doctoral Thesis Abstract: Porphyrin-Based Building Blocks

Steven J. Langford

The work described in this thesis is aimed at the design and synthesis of a range of porphyrin-based molecular building blocks that can be assembled into extended systems or "π-ways". The synthetic strategy involves the condensation of two building blocks: a porphyrin bis-(α-dione) system and a bis-(α-diamine) system; the extended "π-way" being generated through the aromatic nature of the porphyrin macrocycle and their bridging units. The porphyrin-based building blocks fall into three categories; those leading to extensions (*i*) in a linear sense, (*ii*) through a right angle or (*iii*) through metal coordination. In each instance, the porphyrins are extended laterally through the *regiospecific functionalisation of the porphyrin periphery.*

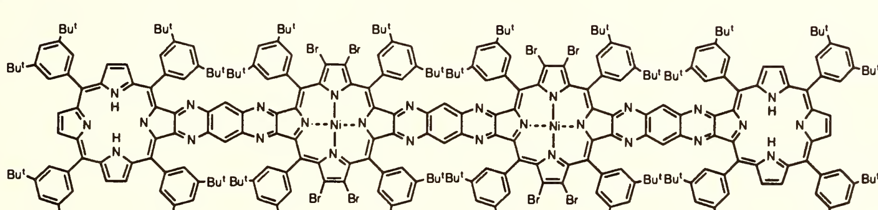
The regiofunctionalisation of the porphyrin periphery is controlled by regiospecific bromination which directs the subsequent nitrations to the desired positions. The tetrabromination of tetraarylporphyrins occurs specifically at $\Delta^{2,3}$ and $\Delta^{12,13}$ through a bond fixed chlorin inter-mediate. The subsequent dinitration at the 7,17- and 7,18-positions illustrate that the bromo groups act as efficient blocking groups. Similarly the bromination of 2,3-dioxo-5,10,15,20-tetrakis(3,5-di-*tert*-butylphenyl)porphyrin occurs regiospecifically on $\Delta^{12,13}$ causing the nitration to be directed onto adjacent pyrrolic rings. The nitro-porphyrins are the precursors to the desired α-diketones. This approach has been successfully used to furnish linear and two-dimensional porphyrin assemblies (**1-3**).

Investigations into the use of phenanthroline-appended porphyrins in the fields pertaining to molecular magnets and molecular electronics have been initiated. These porphyrins have been functionalised in such a way as to complement the aforementioned studies. As a model for extended systems, the zinc(II) and copper(I) bis-porphyrin complexes were synthesised. These compounds show the usefulness of 1,10-phenanthroline as a bidentate ligand and are the first examples of systems in which two porphyrin structures are entirely non-covalently linked to each other.

Functionalisation of the outer periphery with respect to the direct replacement of the bromo groups and a new approach to porphyrin 2,3-diones via 2-hydroxy-porphyrins is discussed. Studies were initiated in which the need for 1,2,4,5-benzenetetramine has been eliminated. Alkyl extensions to TPP derivatives, to enhance solubility, have also been studied.

The molecular structure of 2,3,12,13-tetrabromo-5,10,15,20-tetrakis(3,5-di-*tert*-butylphenyl)porphyrin and its nickel(II) chelate have been unequivocally assigned by X-ray diffraction data. The use of X-ray and ^1H NMR techniques show that the free-base macrocycle is bond fixed into an 18 atom 18 π-electron aromatic delocalised pathway with the isolated double bonds, $\Delta^{7,8}$ and $\Delta^{17,18}$. The observed *ruf* configuration in the monoclinic crystalline form of the Ni(II) porphyrin is a consequence of the very small Ni-N_{av} distance (1.88 Å) and is by far the smallest yet seen in a nickel(II) porphyrin molecule.

July 1993.



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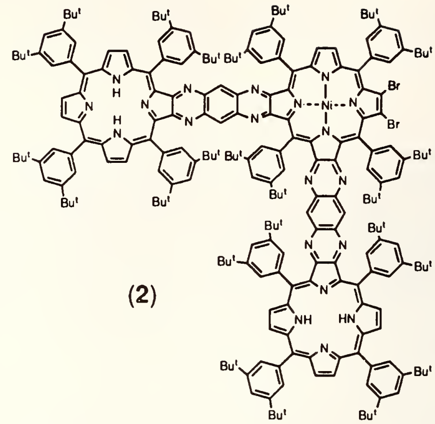

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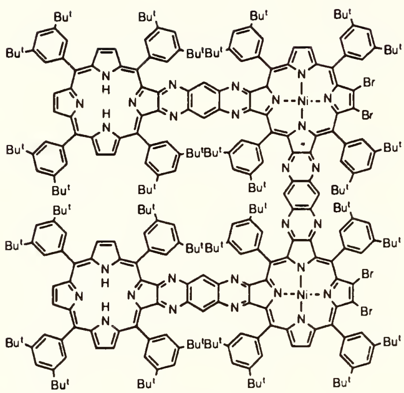

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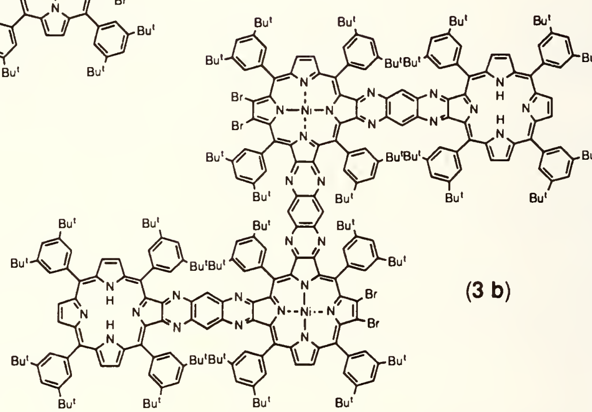

(3 b)

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MASTER OF SCIENCE THESIS ABSTRACT: CRATERFORM ORIGIN DERIVED BY QUANTITATIVE GEOMORPHOLOGY

MARK A. BISHOP

Spacecraft exploration of the solar system has supplied quantitative geomorphology with a plethora of enigmatic landscapes from which to further understand both geologic and geomorphic processes. For example, the relative dating of planetary surfaces using impact crater size-frequency distributions, has identified the exotic diversity of impact morphologies present on both silicate and ice rich planetary crusts.

Impact craters ~2-20 kilometres in rim crest diameter have provided the most meaningful chronological information (Greeley *et al.*, 1987), although it is assumed that only impact craters are sampled, and that crater genesis can be readily determined. However, Pike (1980) has demonstrated that multivariate analysis using morphometric parameters could not differentiate the origin of craters less than 5 kilometres in diameter. This posed an immediate problem with crater size-frequency distributions, as nearly all *simple* impact craters fall below this dimension for Earth, Moon, Mars and Mercury.

Nonetheless, planimetric circularity is a single morphometric element that has previously given limited success in differentiating the origins of impact and volcanic craterforms. Various techniques at determining an index of circularity have been demonstrated by Ronca and Salisbury (1966), Murray and Guest (1970) and Pike (1974). However in these instances, the identification of crater genesis was not absolute.

Although several mensurative methods are possible, in this study, the technique termed circumscribing-inscribing circles *(C2)*, has proven the most accurate and reliable technique with which to measure a crater's planimetry. The definition of circularity using *(C2)*, is a measurement of the ratio of the area of an inscribed circle (fitted to the crater rim crest) to the area of a circumscribed circle (Pike, 1974). For example, a circle has an index of circularity equal to 1.00, while with decreasing circularity the index approaches zero.

Following the derivation of circularity, parametric statistical procedures have shown that the point of segregation between the two crater types, lies at a circularity value of 0.68. It was revealed that impacts are represented by values greater than 0.68 while craters of endogenic origin fall below the 0.68 index. For the 124 craterforms measured, the accuracy for segregating maar and impact morphologies was approximately 86 percent. Although this technique of analysis is relatively simple, it is superior when compared with analyses that use a multivariate approach on craters of *simple* morphologic class.

As this procedure was found to be effective at determining a terrestrial craterform's mode of origin, the application of Pike's method to the lunar Alphonsus dark halo craters was also undertaken. Previous geologic investigations have indicated these features to be of a pyroclastic nature resembling maar-like volcanoes (Head and Wilson, 1979). Quantitative analysis of these structures' circularity, gives further support to this hypothesis. Although there is little debate about the prevalent impact origin of the moon's "pocked" landscape, it is evident that the origin of extra-terrestrial landforms can be accurately derived from morphometric analysis.

The identification of crater origin is an important aspect for both stratigraphic interpretation and the relative dating of planetary surfaces. The study of crater morphometry and morphology will be of immediate use in the interpretation of the Magellan radar imagery of Venus. By the application of standard quantitative geomorphological practices, a fuller understanding of both terrestrial and extra-terrestrial landscapes is achieved.

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Ph.D. Thesis Abstract: The Role of Thrombosis in Ischaemic Necrosis of Bone (INB) and Primary Osteo-arthritis (OA)

P. A. CHERAS

This thesis describes the evolution of a study that commenced as a comparison of idiopathic ischaemic necrosis of bone (INB) and primary osteo-arthritis of the hip (OA). These two conditions were initially regarded as being quite distinct. However the results of the studies presented in this thesis have led to the conclusion that INB and OA are qualitatively very similar and differences are probably only quantitative. The two conditions represent parts of a spectrum.

The **initial hypothesis** was;

"that both non-traumatic ischaemic necrosis of bone (INB) and primary osteo-arthritis (OA) of the hip are caused by intra-osseous small vessel thrombosis".

A **histological investigation** of femoral heads removed at total hip replacement arthroplasty was commenced. The test groups comprised patients who had been diagnosed as having either idiopathic INB (16 femoral heads) or OA (11 femoral heads). The control group comprised patients who died without evidence of either INB or OA (7 femoral heads). The primary aim of the histological study was to seek evidence of microvascular thrombosis in femoral head bone.

Both test groups showed evidence of intra-osseous thrombosis (recent and established), with Haematoxylin and Eosin (H&E) and Martius Scarlet Blue stains. Thrombi were found throughout the femoral heads, particularly in small venous vessels. Furthermore, intravascular lipid deposition was demonstrated in both groups with Oil Red O stain, confirming the appearance of lipid in H&E stained sections. These findings were not observed in the control group.

A novel **double radio-isotope technique** was developed using ^{125}I labelled human fibrinogen and ^{99m}Tc labelled red blood cells. This indicated that femoral head bone from both INB and OA patients contained high concentrations of fibrin and/or fibrinogen compared with control levels.

In both these studies the only differences detected between the two test groups were in the severity or degree of change.

These studies were then followed by further experiments designed to test a **second hypothesis** which was;

"that OA of the hip is associated with systemic coagulopathy".

A **study of the coagulation profiles** of patients with OA was then undertaken to see whether the local changes that had been demonstrated in the femoral heads could be linked with systemic evidence of hypercoagulability.

The results show that in 33 persons with primary OA of the hip compared with 38 age, weight and sex matched controls, there is blood hypercoagulability, increased fibrin formation and decreased fibrinolytic competence. Statistics were performed using Student's two tailed t-test for unpaired samples. Significance was defined as $p < 0.05$. In OA patients there were significantly increased levels of factor VIIIc, platelet response to ADP, euglobulin clot lysis time, D dimer, plasminogen activator inhibitor type I, polymorphonuclear leukocyte elastase, cholesterol, LDL cholesterol and triglyceride versus levels in controls. Platelet aggregation threshold was significantly lower in OA patients.

These studies support a primary role for coagulation abnormalities (modulated by lipids) in the pathogenesis of OA. Osteo-arthritis and ischaemic necrosis of the hip may both result from obstruction of susceptible microvasculature. The difference between the two diseases may only be the degree of the coagulation defects and time-span over which they occur. Haematological tests may be useful for future laboratory diagnosis of primary OA.

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Doctoral Thesis Abstract: Reconciling the Roles of Status and Behaviour in Group Influence: Towards a Status-Confirmation Model

PHILIP B. MOHR

This thesis addresses the task of reconciling two discrete bodies of evidence relating to the emergence of influence hierarchies in small groups. Reviews are presented of research (1) documenting the phenomenon of status generalisation, and (2) identifying individual differences in nonverbal behavioural style as the basis of group differentiation. It is argued that previous attempts to integrate the two fields are flawed on two counts: the failure to differentiate empirically between the effects of nonverbal signals and those of differential task performance, and the corresponding tendency to depict such behavioural signals as a sufficient determinant of group structure. Findings obtained with behaviour separated from performance support the view that effects previously attributed to behavioural stimuli derived, instead, from differential task performance.

A status-confirmation model of the interactive effects of status and behaviour is proposed and evaluated. The primary assumption - that behavioural confidence and the initiation of activity represent claims to situational status - was endorsed by undergraduate subjects' accounts of the likely behaviour of a group member who seeks to attain group leadership. That established, the status-confirmation model proposes behavioural status-claims to be subject to confirmation or denial on the basis of the external status or competence of the claimant. Results of a field study, using extraversion as an index of a status-claiming behavioural style, support this argument; extraversion differentiated observer-rated influence of group members ranked high on either diffuse or specific status, but not those ranked uniformly high or low on both. The latter case, in particular, is inconsistent with the view that behavioural confidence plays an independent causal role, comparable to that of external status, in hierarchy formation.

Evidence, also noted, of the ability of external status to influence the perception of behaviour, permits reconciliation of the status-confirmation model with the research base of status characteristics theory. Indications that the effects of behaviour on hierarchy formation are due to the pre-emption of leadership rather than the communication of confidence are considered, and the implications for the direction and methodology of future research discussed.

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INDEX TO VOLUME 126

Abstract of Proceedings, 1992 - 93 93

Abstract of Theses,
- Bishop, Mark A. 201
- Cheras, P.A. 203
- Gatei, Magtouf H. 89
- He, Fuxiang 90
- Langford, Steven 199
- Mohr, Phil 205
- Oudshoorn Michael John 88
- Xu, Arron S.L. 87

Annual Dinner, March 1993 93

Astronomy
- San Calixto Observatory La Paz, Bolivia 191

Awards (citations) 105

BAGGS, Sydney A.
- Underground Space: The Geospatial Planning Option for 21st Century Sydney. Part One: Historical Overview and Rationale for the Use of Geospace 37

BAGGS, Sydney A.
- Underground Space: The Geospatial Planning Option for 21st Century Sydney. Part Two: Geospace in the Future, a Case Study: 21st Century Sydney 145

BENNETT, Max R.
- A Consideration of Humphrey's "Cerebral Sentient Loop" Explanation of Consciousness from "A History of the Mind" 111

BENNETT, Max R.
- Understanding the Brain in the 21st Century 167

BIOCHEMISTRY
- ^{19}FNMR of Erythocytes 87

Biographical Memoirs 108
- BAKER, S.C.
- GOLDING, H.G.

Bonding and Non-Bonding 135

BRANAGAN, D.F., and CAIRNS, H.C.
- Marks on Sandstone Surfaces - Sydney Region, Australia: Cultural Origins and Meanings? 125

BRANAGAN, D.R., and CAIRNS, H.C.
- Tesselated Pavements in the Sydney Region, New South Wales 63

CAIRNS, H.C. BRANAGAN, D.F. and
- Marks on Sandstone Surfaces - Sydney Region, Australia: Cultural Origins and Meanings? 125

CAIRNS, H.C. BRANAGAN, D.F. and
- Tesselated Pavements in the Sydney Region, New South Wales 63

CHEMISTRY
- Physical Organic Chemistry (Bonding) 135

CLARKE MEDAL 1993 105

COAL
- Seam Correlations of the Illawarra Coal Measures in the Ulan and Bylong Areas, Western Coalfield, Sydney Basin, New South Wales. Stratigraphic and 73

COALS
- Trace Elements in Some Swiss 27

COENRAADS, Robert R.
- The San Calixto Observatory in La Paz, Bolivia, Eighty Years of Operation. Director Dr. Lawrence A. Drake S.J. 191

COMPUTER SCIENCE
- Atlantis: A Tool for Language Definition 88

Council, Annual Report 1992 - 93 93

Culture
- Aboriginal 125

Dinosaurs
- Dinosaurs and other Denizens II - by combined Catastrophic Causes? Demise of the Sutherland, F.L. 1

DRAKE, Dr. L.A.S.J., Director,
- The San Calixto Observatory, La Paz, Bolivia 191

EDGEWORTH DAVID MEDAL 1993 105

ERRATA: Vol. 125 Parts 3 and 4 97

FARDY, N.C., MORGAN, N.C. and SWAINE, D.J. HUGI, Th.,
- Trace Elements in Some Swiss Coals 27

Financial Statement 99

GATEI, Magtouf H.,
- Some Aspects of the Pathogenicity and Immunity of Bovine Leukemia Virus Infection in Cattle and Sheep 89

GEOLOGY
- Mallardite, Broken Hill NSW 165
- Marks on Sandstone Surfaces 125
- Reservoir Characteristics of Sandstone in New South Wales 90
- Stratigraphical and Coal Seam Correlations 73
- Tesselated Pavements 63
- Trace Elements in Some Swiss Coals 27
- Western Coalfields, SYDNEY BASIN, NSW 73

GEOSPACE,
Part One 37
Part Two 145

HE, Fuxiang,
Provenance, Diagenesis and Reservoir Characteristics of Sandstone of the Great Australian Basin Succession in NSW, Australia 90

History of the Mind 111

HUGI, Th., FARDY, N.C., MORGAN, N.C. and SWAINE, D.J.
Trace Elements in Some Swiss Coals 27

HUMPHREY'S
"Cerebral Sentinent Loop" 111

INDEX 207

LAWRENCE L.J., STOCKSIEK, C.M. and WILLIAMS, P.A.
Mallardite from Broken Hill, NSW 165

LIVERSIDGE RESEARCH LECTURE, 1992 135

MALLARDITE
from Broken Hill, NSW 165

MEDICINE
A History of the Mind 111
Understanding the Brain in the 21st Century 167

MORGAN, N.C., and SWAINE, D.J. HUGI, Th., FARDY, N.C.
Trace Elements in Some Swiss Coals 27

NEW ENGLAND Branch Report 95

NEW SOUTH WALES
Geospatial Planning Option, Sydney 37
Sandstones of the Great Australian Basin 90
Stratigraphic and Coal Seam Correlations 73
Tesselated Pavements 63

OUDSHOORN, Michael John
Atlantis: A Tool for Language Definition and Interpreter Synthesis. (Thesis Abstract) 88

PALAEONTOLOGY
Demise of Dinosaurs 1

PRESIDENTIAL ADDRESS, 1993 1

The Royal Society of New South Wales Medal for 1992 107

STERNHELL, S.,
Bonding and Non-Bonding 135
(Liversidge Research Lecture 1992)

SUMMER SCHOOL (Photo) 1992 98

SUTHERLAND, F.L.,
Demise of the Dinosaurs and Denizens II by Combined Catastrophic Causes? (Presidential Address 1993) 1

SWAINE, D.J., HUGI, Th., FARDY N.C., MORGAN, N.C., and
Trace Elements in Some Swiss Coals 27

Understanding the Brain in the 21st Century 167

Urban Design
Underground Space: The Geospatial Planning Option for 21st Century Sydney. Part One: Historical Overview and Rationale for the Use of Geospace 37
Part Two:- Geospace in the Future, a Case Study: 21st Century Sydney 145

Vetinary Science
Bovine Leukemia Virus Infection 89

Walter Burfitt Prize for 1992 106

XU, Arron S.L.,
^{19}F NMR of Erythrocytes: "Split Peak" Phenomenon, Membrane Potential and Membrane Transport. (Thesis Abstract) 87

YOO, E.K.,
Stratigraphic and Coal Seam Correlations of the Illawarra Coal Measures in the Ulan and Bylong Areas, Western Coalfields, Sydney Basin, New South Wales 73

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Contents

VOLUME 126

PARTS 1 and 2

SUTHERLAND, F.L.
Demise of the Dinosaurs and other Denizens II - by Combined Catastrophic Causes? (Presidential Address 1993) 1

HUGI, Th., FARDY, N.C., MORGAN N.C., and SWAINE, D.J.
Trace Elements in Some Swiss Coals 27

BAGGS, Sydney A.
Underground Space: The Geospatial Planning Option for 21st Century Sydney. Part One: Historical Overview and Rationale for the Use of Geospace 37

BRANAGAN, D.F., and CAIRNS, H.C.
Tesselated Pavements in the Sydney Region, New South Wales 63

YOO, E.K.
Stratigraphic and Coal Seam Correlations of the Illawarra Coal Measures in the Ulan and Bylong Areas, Western Coalfield, Sydney Basin, New South Wales 73

ABSTRACTS OF THESES:
XU, Arron S.L.: ^{19}F NMR of Erythrocytes: "Split Peak" Phenomenon, Membrane Potential and Membrane Transport 87

OUDSHOORN, Michael John: Atlantis: A Tool for Language Definition and Interpreter Synthesis 88

GATEI, Magtouf H.: Some Aspects of the Pathogenicity and Immunity of Bovine Leukemia Virus Infection in Cattle and Sheep 89

HE, Fuxiang: Provenance, Diagenesis and Reservoir Characteristics of Sandstones of the Great Australian Basin Succession in NSW, Australia 90

COUNCIL REPORT, 1992-1993 93
Report 93
Abstracts of Proceedings 96
Errata: Vol.125 Parts 3 and 4 97
Summer School (Photo) 1992 98
Financial Statement 99
Awards 105
Biographical Memoirs 108

Parts 3 and 4

BENNETT, Max R.
A Consideration of Humphrey's "Cerebal Sentinent Loop" Explanation of Consciousness from "A History of the Mind" by Nicholas Humphrey 111

BRANAGAN, David and CAIRNS, Hugh
Marks on Sandstone Surfaces - Sydney Region, Australia: Cultural Origins and Meanings? 125

Contents

STERNHELL, S.	
Bonding and Non-Bonding (Liversidge Research Lecture 1992)	135
Liversidge Research Lecture 1992 (photo)	144
BAGGS, Sydney A.	
Underground Space: The Geospatial Planning Option for 21st Century Sydney. Part Two:- Geospace in the Future, a Case Study: 21st Century Sydney	145
LAWRENCE, L.J., STOCKSIEK, C.M. and WILLIAMS, P.A.	
Mallardite from Broken Hill	165
BENNETT, Max R.	
Understanding the Brain in the 21st Century	167
COENRAADS, Robert R.	
The San Calixto Observatory in La Paz, Bolivia. Eighty Years of Operation. Director Dr. Lawrence A. Drake S.J.	191
ABSTRACTS OF THESES:	
LANGFORD, Steven J.: Porphyrin-Based Building Blocks	199
BISHOP, Mark A.: Craterform Origin Derived by Quantitative Geomorphology	201
CHERAS, P.A.: The Role of Thrombosis in Ischaemic Necrosis of Bone (INB) and Primary Osteo-arthritis (OA)	203
MOHR, Philip B.: Roles of Status and Behaviour in Group Influence: Towards a Status - Confirmation Model	205
INDEX to Volume 126	207

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Parts 3 and 4: December 1993

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Manuscripts should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigaphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

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Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

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Contents

VOLUME 126 Parts 3 and 4

BENNETT, Max R.
A Consideration of Humphrey's "Cerebal Sentinent Loop" Explanation of Consciousness from "A History of the Mind" by Nicholas Humphrey 111

BRANAGAN, David and CAIRNS, Hugh
Marks on Sandstone Surfaces - Sydney Region, Australia: Cultural Origins and Meanings? 125

STERNHELL, S.
Bonding and Non-Bonding (Liversidge Research Lecture 1992) 135

BAGGS, Sydney A.
Underground Space: The Geospatial Planning Option for 21st Century Sydney Part Two:- Geospace in the Future, a Case Study: 21st Century Sydney 145

LAWRENCE, L.J., STOCKSIEK, C.M. and WILLIAMS, P.A.
Mallardite from Broken Hill 165

Liversidge Research Lecture 1992 (photo) 144

BENNETT, Max R.
Understanding the Brain in the 21st Century 167

COENRAADS, Robert R.
The San Calixto Observatory in La Paz, Bolivia. Eighty Years of Operation. Director Dr. Lawrence A. Drake S.J. 191

ABSTRACTS OF THESES:

LANGFORD, Steven J.: Porphyrin-Based Building Blocks 199

BISHOP, Mark A.: Craterform Origin Derived by Quantitative Geomorphology 201

CHERAS, P.A.: The Role of Thrombosis in Ischaemic Necrosis of Bone (INB) and Primary Osteo-arthritis (OA) 203

MOHR, Philip B.: Roles of Status and Behaviour in Group Influence: Towards a Status-Confirmation Model 205

INDEX to Volume 126 207

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Parts 3 and 4: December 1993

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THE ROYAL SOCIETY OF NEW SOUTH WALES

THE ROYAL SOCIETY OF NEW SOUTH WALES

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Caves, Cement, Bats and Tourists: Karst science and limestone resource management in Australia.

R. A. L. Osborne

Abstract: There is a long history of acrimonious disputes in eastern Australia between the conservation of caves and limestone (karst) landscapes and the extraction of limestone for industry. These disputes have often set legal precedents that have had important consequences in other areas of conservation. The disputes can be best understood as competition over a limited resource between users who hold conflicting world- views and value systems.

* Can these disputes, which have cost millions of dollars, be avoided in the future?
* Is it possible to achieve effective conservation and management of our karst resources **and** maintain an economically viable limestone industry?
* What should we do to rehabilitate abandoned limestone quarries?
* How do we avoid the environmental and engineering problems that can arise when urbanisation and infrastructure extends over limestone?
* How do we prevent recreational and tourist use of caves from causing irreparable damage?

These issues can only be resolved in the long term by political decisions, but such decisions will need to be informed by sound scientific advice.

Karst studies which could provide this advice are both fragmented and poorly developed in Australia. It is imperative for both economic and environmental reasons to expand and promote quality scientific research into Australia's karst and caves.

INTRODUCTION

Until late January this year I had very firm thoughts about the topic on which I would address you tonight, in fact, I had written a large portion of the text for an address "On the origin of limestone chambers" and was in the process of preparing illustrations. Events in the last week of January, however, resulted in a complete change of tack, so that I am now presenting an address about a highly politicised issue concerning the relationship between science, industry, government and the environment, rather than speculation about the origin of natural phenomena which I have always found somewhat puzzling.

On the 27th and 28th of January 1994 I attended a government enquiry in Adelaide into Sellicks Hill Quarry Cave as an expert witness for the Australian Speleological Federation Inc. This enquiry examined the most recent example of a land use conflict between cave conservation and limestone mining in Australia and illustrated in a microcosm a number of issues which have concerned me for some time, principally, how to balance the resource needs of Australia for limestone with the conservation and proper management of caves and other aspects of the karst environment developed in and on limestones.

FINDING AN OVERVIEW

Disputes between limestone miners and conservationists have often been understood as being about the relative values of resources and activities, such as are caves more valuable than miners' jobs, or is cement more valuable than bats?

In this discussion I have taken a different approach which seeks to understand karst management disputes, not only between limestone miners and conservationists but also between caving groups and karst managers, in terms of three key issues :-

* competition for a limited resource
* conflicting goals and values
* resource security.

Competition for a Limited Resource

One of the most important factors underlying disputes about limestone resource management in eastern Australia is that the disputes involve competition for a limited resource. This factor forms an essential part not only of disputes between conservationists and miners, but also of disputes between members of other competing user groups such as caving clubs.

There are three absolutely fundamental reasons why this is so, firstly limestone, caves and karst landscapes are, in human terms at least, limited and non-renewable resources, secondly the purest and therefore most economically valuable limestone forms the most extensive and most highly decorated caves and the most spectacular limestone karst landscapes, and thirdly limestone deposits close to major cities and transport routes are the most economical to exploit for mining, tourism and recreation. Thus all users and potential users of limestone and limestone landscapes are competing for the same limited, non-renewable, resource; high purity limestone in close proximity to transport and population centres.

It is competition for a limited resource that leads the the perennial issue among recreational cavers of which persons or groups should be allowed access to caves. Some cavers have argued that in order to protect the resource, people (usually , but not always, members of other groups) should be discouraged from taking up the activity. Recreational access to caves on public land in Australia has in many instances been controlled by permit systems operated on a "merit" basis (Hamilton-Smith, 1990). As a result member societies of the Australian Speleological Federation have secured, and jealously guarded, exclusive access to many caves. Conflict has resulted since the Australian Speleological Federation does not represent the majority of people involved in caving.

Secrecy has also been used by cavers to in an attempt to protect caves from vandalism and from damage by persons "lacking in merit". One example of this approach is the suggestion by Webb (1990) that the names and location of caves should be removed for topographic maps available to the public.

Conflicting Goals and Values

Competition for a limited resource would not be difficult to resolve if there was general agreement among the protagonists as to the goals and values on which the management of karst resources should be based. Disputes over karst resources involve competition over which group's values should form the basis of management. Although the public is most aware of disputes between limestone miners and conservationists, karst management has been plagued by disputes between; government agencies involved in resource conservation (e.g. national parks services) and those involved resource exploitation (e.g. mines departments) (Kiernan, 1993), the Australian Speleological Federation and other cavers, recreational users of caves and tourist users of caves, cave managers wishing to restrict access for conservation reasons and various groups wishing to gain access.

Each of these groups considers the limestone and its karst features to be important on the basis of different value systems. While miners and show cave operators both have a financial interest in the limestone, recreational cavers could claim to have a right to enjoy public assets, and that this should not be a privilege extended to certain groups on the basis of assumed "merit". Conservationists and some managers on the other hand hold that the integrity of the resource is the prime value.

Limestone and karst landscapes are thus competed for by those who seem them primarily as a financial resource to be exploited, those who see them as a recreational resource to enjoy, those who claim to have a scientific interest in them, and those who wish to preserve them in a state relatively unaffected by humans.

Resource Security (Tenure Issues)

The third issue common to all disputes concerning the use and management of limestone and karst landscapes is that of resource security. Resource security is generally discussed in terms of access to resources by primary industries and so we are used to hearing resource security raised as an issue by the forestry and mining industries. Resource security, however, is an important issue in all areas of karst management and it

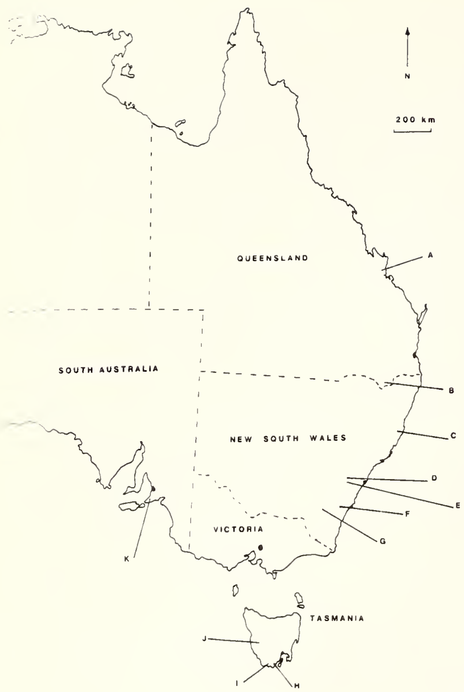

Figure 1:- Eastern Australia:- A, Mt. Etna; B, Texas Caves; C, Yessabah; D, Jenolan Caves; E, Colong Caves; F, Bungonia; G, Cave Island; H, Ida Bay; I, Precipitous Bluff; J, Gordon-Franklin Karst.

has been the desire for secure access to resources or for security for resources from access by other users that has lain at the heart of many environmental disputes concerning limestone.

Limestone miners would expect that once they obtained a mining lease they would be able to pursue their mining plan without disruption or interference. In a number of the disputes I will discuss later, for example Mt. Etna and Ida Bay, this has not been the case.

Similarly conservationists would expect that once a karst area was dedicated as a "Reserve for the Preservation of Caves", activities which damage or destroy caves would not occur. Caves reserves in New South Wales, however, are not exempt from mining title, with mining occurring in the reserves at Wellington and Wombeyan Caves. This issue was central to the Colong dispute of the 1960s. The desire for resource security was also a central factor in the decision by conservationists to take legal action in the case of Yessabah Caves, New South Wales. The current situation in most parts of Australia is that resource security for purposes other than mining, only exists in the case of limestone areas in National Parks where in some states it is clear that mining is prohibited.

Resource security also plays a role in tensions between recreational cavers and management authorities, with cavers wishing to maintain traditional access to caves and some cavers feeling that they have a degree of ownership over caves which they have discovered or initially explored. Management authorities, however, feel that their duty to protect the caves from damage, and their undoubted legal responsibilities outweigh any traditional use rights or rights that come from discovery and exploration.

ENVIRONMENTAL DISPUTES OVER LIMESTONE MINING

There is a long history of landuse disputes in eastern Australia over use of limestone for extractive purposes and the conservation of karst caves and their fauna. The history of these disputes has parallelled the growth of conservation movement in Australia and the outcomes of these disputes have had repercussions for environmental practice and law in areas far broader that cave conservation.

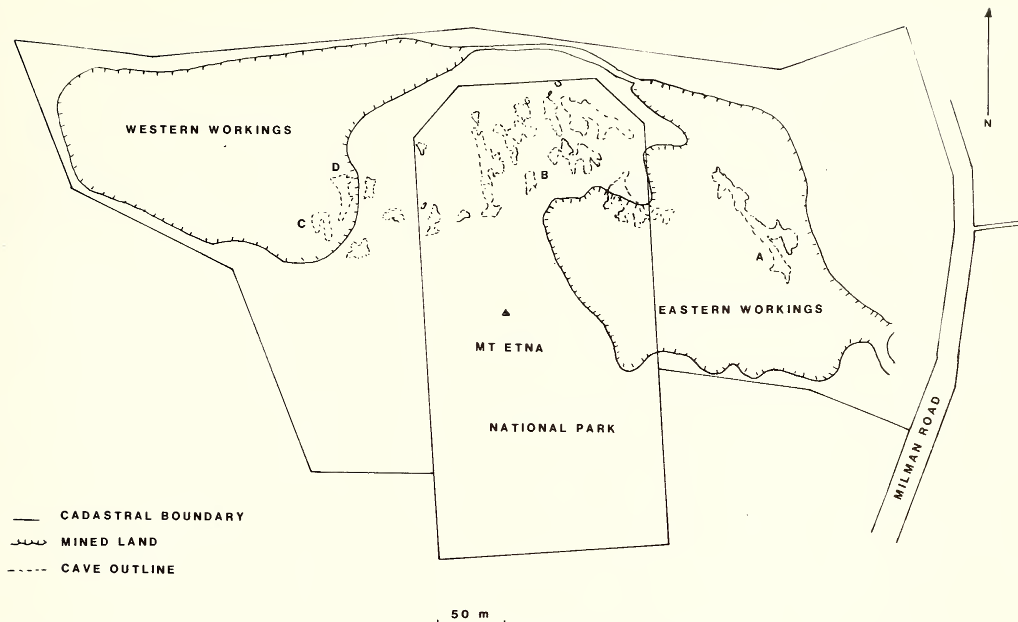

Figure 2:- Mt.Etna, Queensland:- A, Resurrection Cave; B, Bat Cleft; C, Elephant Hole; D, Speaking Tube.

Mt. Etna, Queensland

By far the longest-running and most acrimonious dispute in Australia has centred on Mt. Etna, a conical limestone hill, 25 km north of Rockhampton in Central Queensland (Fig. 1, A). Leases were issued over parts of Mt. Etna in 1962 and mining commenced on its eastern face in 1966.

In April 1967 the mine intersected a blind cave which became known to the cavers as Resurrection Cave and the miners as Quarryman's Cave (Fig. 2, A). An agreement was reached, and has been honoured, that this cave would be preserved in future mining activities. Other restrictions, such as not mining within 66 feet (20 m) of a cave entrance were placed on the operation, but were lifted in 1988 when the company surrendered 13 ha of the central part of Mt. Etna from it leases which became a reserve and later National Park to protect Bat Cleft (Fig. 2, B). Mining operations moved to the western side Mt. Etna in 1970 and operations on the eastern face ceased in 1975. Mining on the western side of the mountain destroyed Crystal Palace Cave in 1982.

Mining at Mt. Etna has been strongly opposed by conservation groups since its inception and a variety of actions have been taken stop the mine's operation including several legal actions, listing of the caves on the Register of the National Estate, filling drill holes with cement, obtaining support from the International Union for the Conservation of Nature and Natural Resources and numerous media campaigns. A number of publications including Sprent (1970), and Anon (1988) were produced during the course of the dispute.

In 1989 a major legal and protest campaign was launched to protect Elephant Hole (Fig. 2, C) and Speaking Tube (Fig 2, D) Caves from being destroyed by the western workings. This involved highly publicised sit-ins in caves adjacent to the quarry, police action against protesters and appeals to international conservation bodies.

Legal action to protect the caves on the basis that either they were the "nest" for ghost bats or that mining would harm the bats themselves was undertaken by the Central Queensland Speleological Society. The Society first had to show that it had standing in the matter. This led to an appeal to the High Court of Australia. On May 26, 1989, after proceedings had been remitted to the Supreme Court of Queensland, Mr. Justice De Jersey ordered the plaintiffs to deposit $ 45,000 with the court as security against the defendant's costs; this could not be raised and the action lapsed.

The dispute left behind a highly divided community and had a significant social impact, as many cavers and mine workers are neighbours in the small village of The Caves. In spite of this, current events at Mt. Etna suggest that new approaches to dealing with environmental disputes over limestone mining may be developing. Under new ownership Central Queensland Cement Ltd. has now included members of the Speleological Society on its committee to advise on the rehabilitation of the eastern mine workings and I have undertaken consulting work for the Company to ensure that rehabilitation work does not damage Resurrection Cave.

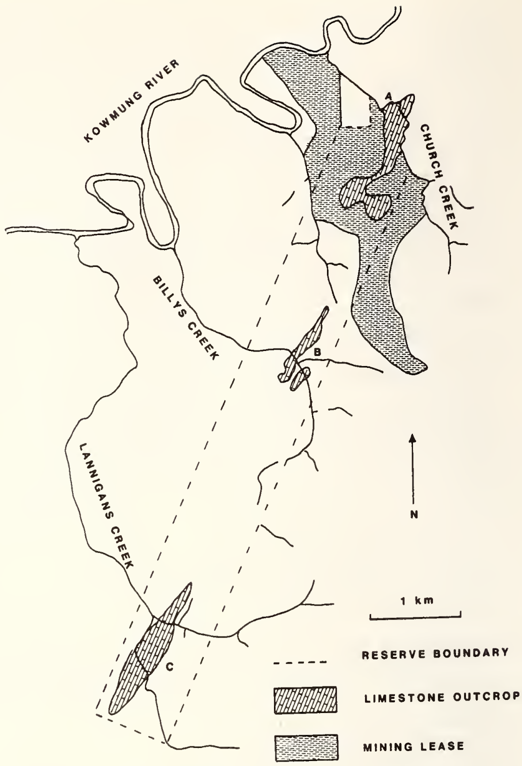

Figure 3:- Colong Caves, New South Wales after Middleton (1969):- A, Church Creek Cave; B, Billys Creek Caves; C, Colong Caves.

Colong, New South Wales

In January 1967 (Middleton, 1969) the New South Wales Government announced that it would grant a mining lease at Church Creek (Fig. 1, E) within the area of the then proposed Kanangra-Boyd National Park and within land reserved in 1899 for "the Preservation of Caves" (Fig. 3) . This action resulted in the so-called Colong dispute and led to the formation of the Colong Committee, now Colong Foundation for Wilderness, which continues to be an active lobby group. One practice that developed during this dispute was to name caves after politicians, a practice used with some controversy in the Franklin Dam dispute (see below). In the end the limestone was not mined, the mining leases were cancelled and the land incorporated in Kanangra-Boyd National Park.

Bungonia, New South Wales

In 1970 applications for mining leases were made at South Marulan (Fig. 1, F), north of Bungonia Canyon, near the site of the present South Marulan Limestone Quarry (Middleton, 1972) (Fig. 4). Objections to the leases were made by the Colong Committee and Mr. W.J. Counsell. At a hearing of the Mining Wardens Court in 1971 the objectors and their expert advisors were able to present evidence, making this the the first time that environmental groups had access to mining tribunals and first time that scientific experts (one of whom is a current Council Member of this Society) were used by environmental groups to develop alternative mining plans.

The Colong and Bungonia disputes made members of the caving fraternity in New South Wales aware of the need to document karst areas which they wished to preserve and resulted in the production of *Sydney Speleological Society Occasional Paper No 4* (Ellis *et .al* . 1972) which for the first time presented an overview of a karst area in New South Wales, including cave maps, in a bound volume available for public sale. Concern about conservation and mining issues at Timor Caves, near Scone resulted in a similar publication (James et. al. 1976).

Precipitous Bluff, Tasmania

Precipitous Bluff rises 1200m above sea level, just 2 km from the sea, on the

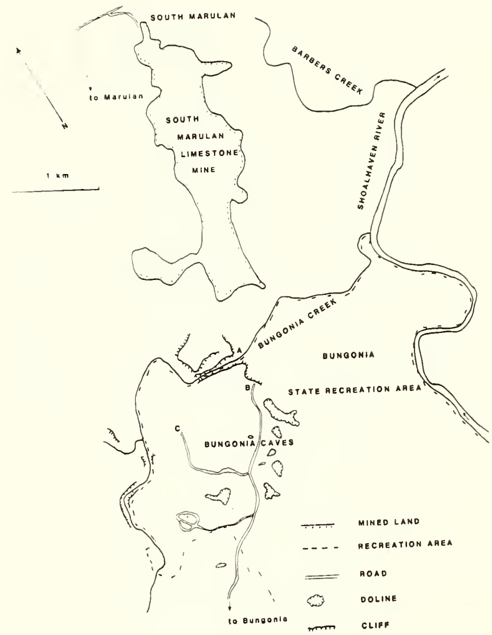

Figure 4:- Bungonia Caves and South Marulan Limestone Mine, New South Wales:- A, Bungonia Canyon; B, Bundonia Lookdown; C, Adams Lookout.

remote southern coast of Tasmania (Fig. 1, I). The Bluff consists of a cliff-lined edifice of Jurassic dolerite overlying the Ordovician Gordon Limestone (Fig. 5).

In December 1971 application was lodged for a Prospectors Licence over the limestone at Precipitous Bluff (Wessing, 1979). The National Parks and Wildlife Service and a number of conservation groups objected to the application which was heard in the Devonport Mining Wardens Court in December 1972. The applicant claimed that the conservation groups lacked standing in the case while the National Parks and Wildlife Service was prevented from appearing by the newly elected (Labor) state government. The Mining Warden, however, decided to hear the conservationists case. The applicant appealed to the Tasmanian

Supreme Court which held in June 1973 that the conservationists did not have a legal interest in the area and ordered that their objections be struck out. An appeal by the conservationists in 1975 was unsuccessful and Tasmania Supreme Court's judgment was upheld.

Despite the legal decisions of the 1970s Precipitous Bluff was never mined and is now part of the Southwest Tasmania World Heritage Area.

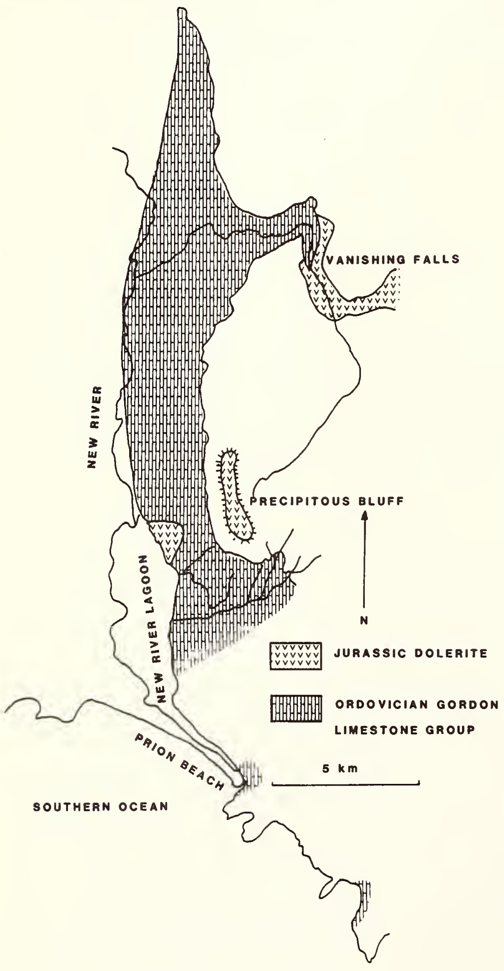

Figure 5:- Precipitous Bluff, Tasmania after Eberhard *et. al.* (1992).

Yessabah, New South Wales

A relatively small mine for agricultural lime operated in the Recreation Reserve at Yessabah Caves, near Kempsey, New South Wales (Fig. 1, C) between 1923 and 1991. The mine is directly adjacent to an area of intensely karstified limestone covered by significant dry rainforest and containing an important bat roosting cave, (Fig. 6). In 1980s the mining lease lapsed and in 1986 a new lease was granted which covered most of the karst area. This lease was later withdrawn and a period of complex negotiations and lobbying followed during

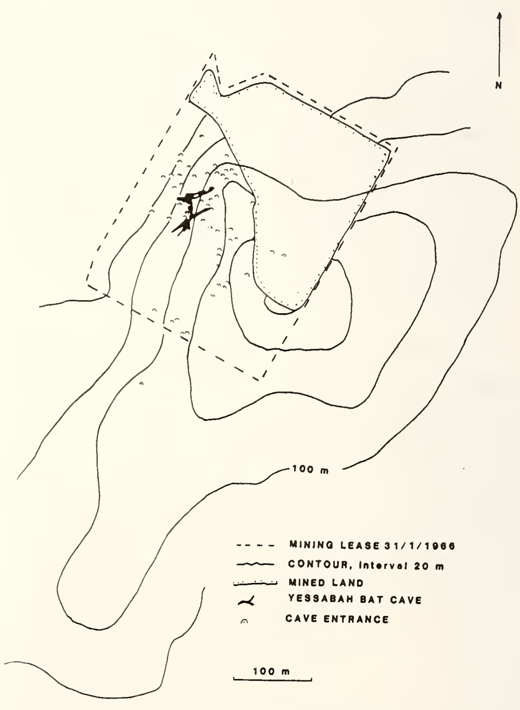

Figure 6:- Yessabah, New South Wales

which various proposals were made which would have restricted the area available for mining.

In 1990 Mr. K.G. Vaughan-Taylor began legal action to to require the miners, David Mitchell-Melcann Ltd., to prepare an environmental impact statement and obtain planning permission. As the legal action proceeded in 1991 the likelihood that mining might do harm and that the mining was likely to significantly affect the environment was conceded by the mining company and the Minister and the case concentrated on two legal issues (Larkin, 1992):-

> Was the mining company entitled to expand the mine laterally and double output without planning approval and therefore an environmental impact statement ?
>
> Was the Minister entitled to grant a mining lease without there being an environmental impact statement for him to consider ?

In June 1991 the Land and Environment Court ruled that mining at Yessabah could continue without an environmental impact statement, but only at a rate of 18,000 tonnes per annum, far short of the Company's mining plan. The case went to appeal and on Friday November 15, 1991 three judges in the New South Wales Court of Appeal ruled that an environmental impact statement was required before the Minister could lawfully grant a new mining lease and that existing use rights only applied to land "actually and physically used" for mining in the past. An injunction was issued preventing further mining until the mining company and the Minister had complied with their legal obligations. This ruling has resulted in the abandonment of mining at Yessabah.

Exit Cave and the Lune River (Bender's) Quarry, Tasmania

Exit Cave near Ida Bay, Tasmania (Fig. 1, H) is the largest cave developed in lower Palaeozoic limestone in Australia and is thought to consist of some 40 km of cave passages. Exit Cave lies just within the South West Tasmania World Heritage Area. Limestone mining at Lune River Quarry, directly north of Exit Cave (Fig. 7, A), became highly controversial in 1990 when water tracing experiments indicated that there was a direct hydrological connection between Exit Cave and the mine (Fig. 7, B). Detailed investigations in November 1991 (Kiernan, 1993) confirmed the connection. A complex series of protests, political actions and state/federal interactions resulted in the mine being closed in October 1992. Rehabilitation of the mine site is now largely complete.

Sellicks Hill, South Australia

At Sellicks Hill Quarry, 50 km south of Adelaide (Fig. 1, K), dolomite is extracted largely for use as high quality aggregate. In September 1991 the mine intersected a large cavity. On the invitation of the operators, Southern Quarries Pty Ltd., members of the Cave Exploration Group of South Australia explored, mapped, and made a video of the cave. The cavers signed a legal document agreeing to keep information concerning the cave secret.

On the tenth of December 1993 the largest chamber of the cave was blasted, using a blast pattern based in part on information obtained from the cavers' map.

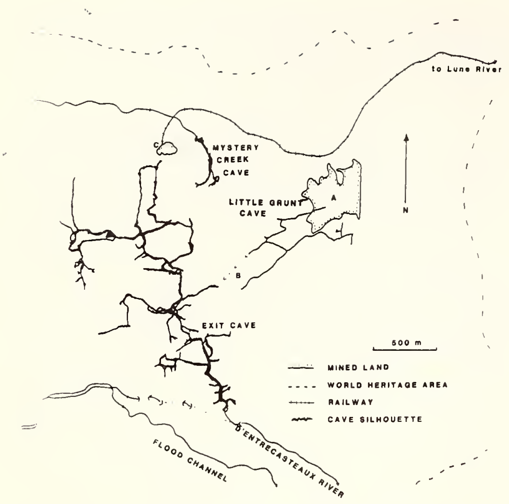

Figure 7:- Ida Bay, Tasmania after Kiernan (1993):- A, Lune River (Bender's) Quarry; B, Hydrologic connection confirmed by water tracing; C, Old Lune River Quarry.

Following the blast the cavers made information about the cave and its unusual aragonite speleothems public, resulting in considerable media and political interest. In January 1994 a closed government enquiry was held into the likely condition of the cave before and after the blast.

Currently the Australian Speleological Federation Inc. is taking legal action in an attempt to protect the cave and a member of the Cave Exploration Group of South Australia has been threatened with legal action for libel by the mining company.

PREVENTING AND SOLVING DISPUTES OVER LIMESTONE MINING

Given the number and severity of the disputes that have arisen between limestone miners and conservationists over the last 25 or so years, and the potential for disputes to arise in the future, there is clearly a need to devise policies and practices that will produce a balance between the need to extract carbonate rocks and the preservation of karst environments.

Preventing Disputes

The factors outlined before indicate that karst resource management will always involve conflicts of interest, however it is not inevitable that these conflicts will become acrimonious and the focus of intense media, political and legal activity. Two measures that will assist in developing less emotional and costly disputes are simply to ensure that proper data is available and to open lines of communication between the different interested parties.

Ensuring Proper Data is Available

Resource information for the limestone industry has been traditionally provided by state geological surveys and departments of mines. This work has been collated into major volumes such as Connah (1958) for Queensland, Carne & Jones (1919) and Lishmund *et. al.* (1986), for New South Wales and Hughes (1957) for Tasmania.

Given the times at which most of these works were produced one it would not be surprising if they contained little information about karst features or the environmental values of the deposits they describe. The two editions of *Limestone Deposits of New South Wales*, however show and unexpected and quite worrying trend. Carne and Jones contains much detail about the caves developed in the State, no doubt influenced by the participation of Oliver Trickett in the project.

The comments about karst features

and environmental issues in Lishmund *et al.* are somewhat surprising for a work published in 1986. There is no reference whatsoever to any scientific literature on Australian karst. This is gravely concerning given that one of the founders of modern karst geomorphology, J.N. Jennings (1916-1984), lived and worked in Canberra from 1952 until his death, published on the karst of New South Wales in local and international journals, and produced an introductory text (Jennings, 1971) which cited many examples from New South Wales. Also a refereed Australian scientific journal, *Helictite*, devoted to cave science, and containing numerous papers on the limestone deposits described by Lishmund *et al.*, has been published regularly since 1962.

Although there have been a number of officers in state mines departments who have extensive knowledge of karst issues (e.g. G.R. Wallis, see Wallis, 1976) there have been few occasions where this expertise has been brought to bear on cases involving conflict over mining and karst conservation (one outstanding exception being Wallis' work at Wombeyan, Wallis, 1965).

Standard works and journals on karst are rare or absent among the volumes in mines department libraries and papers in general scientific journals concerning karst are often not referenced in departmental data collations about limestone deposits.

Limestone miners and mines department staff are thus not necessarily alerted to environmental issues concerning potential limestone mining localities. Expanding the information base available to miners and mines administrators is an essential first step in defusing potential disputes between miners and conservationists over karst. No mines department library should be without a copy of the *Australian Karst Index* (Matthews, 1985), a subscription to *Helictite* and as a minimum a copy of *Karst Geomorphology* (Jennings, 1985) and works on the environmental management of karst such as *The Management of Soluble Rock Landscapes* (Kiernan, 1988).

Opening Dialogue

Frequently mining company decision makers and leading conservationists only see each other in the media or on the steps of the courthouse, neither setting being very conducive to constructive dialogue. It would seem to be very beneficial if a forum could be developed at which issues of limestone resource management could be discussed in a non-confrontational manner. Such a forum should involve representatives of the Australian Mining Industry Council (or state Chambers of Mines) and the Australian Speleological Federation Inc., and could possibly be expanded to include representatives of government agencies concerned with mining and nature conservation.

Initial steps in this direction appear to be underway in New South Wales where dialogue between the Australian Speleological Federation and the Chamber of Mines is imminent. This is an important positive step in improving the management of our limestone resources.

The Environmental Assessment Process

Environmental planning laws in some

Australian states require that an environmental impact statement is prepared for all major developments. Where such requirements exist, limestone mining is usually of such a scale as to require the preparation of an E.I.S. One of the problems with this process is that environmental, conservation and heritage legislation in most states is designed to protect flora, fauna, Aboriginal and European cultural heritage items and lacks specific references to non-living (abiotic) heritage such as geological sites and karst. At present there is no guarantee that karst will be properly addressed (except as an environment for bats or other vertebrates or as a substratum for particular floras) in the environmental assessment process.

Environmental studies prior to limestone mining should include extensive investigation of the hydrogeology of the karst, of the surface karst landscapes and, in particular, should focus on the presence or otherwise of any inter-linked systems of cavities. A major part of such studies should consider the likely effects of any mining activity on the environmental and heritage significance of any cavity system and its contents.

Environmental plans and regulations designed to apply to non-karstic environments can have unexpected bad consequences when applied to limestone areas. This has been highlighted in the case of Sellicks Hill, South Australia where regulations designed to reduce the visual impact of mines on the Adelaide Hills resulted in the mine being sited in a valley between two limestone hills, a locality where the was a greater than average chance of the mine intersecting cavities.

Is is essential that karst and other non-living natural heritage items gain the status afforded to flora, fauna, Aboriginal and built cultural heritage items by being given specific reference in environmental planning legislation and procedures, and that planning regulations are assessed to ensure that they do not cause unintended damage to karst environments.

Monitoring of Mining

Standard procedures for the environmental monitoring of open cut mines may not be appropriate in the case of limestone mines operating in or adjacent to cavernous limestone. The complexity and conduit nature of karst aquifers mean that there are special risks of pollution and hydrological disruption that do not exist when mines operate in rocks that are either insoluble or granular aquifers.

Officials charged with responsibility for inspecting and monitoring mines in limestone should be provided with special training in the karst process and in the environmental management and monitoring of soluble rock landscapes.

The Problem of Chance Intersections

Even with the most exhaustive pre-mining studies, mines in limestone are likely to intersect cavities whose presence was unexpected. Presently operating mines for which prior studies were not carried out are very likely to intersect cavities. Intersection of unexpected cavities by mines is one of the most difficult issues in limestone resource management.

Hearsay evidence, and material observed in mine waste dumps, would suggest that operating limestone mines frequently intersect cavities containing vertebrate fossils and speleothem, and on occasions major hydrological conduits. There have been few occasions where scientists have been permitted to study vertebrate fossil deposits exposed in mines (one case being at Wombeyan Caves, Hope, 1982) or where miners have attempted to preserve fossils by storing fossil bearing muds in separate stockpiles (as D. Kime has done at Mt. Etna).

It would appear that the, entirely understandable, reaction of many mine operators is to quickly fill, remove or otherwise destroy cavities intersected by mining so as not to run the risk of significant and costly interruption to mining. This reaction undoubtably results in the loss of significant information of scientific value and may also result in the loss of heritage items of great value to the community.

A fair and workable approach to the problem of chance intersections would involve a process of compulsory reporting, rapid appraisal, high quality and quickly undertaken scientific study, documentation and where appropriate salvage and, in cases where features are of extremely high value, restriction of mining in exchange for appropriate and fair compensation.

Solving Disputes

Legal Solutions

Mt. Etna in Queensland and Yessabah in New South Wales are two examples where legal processes have been used as a means of resolving disputes between conservationists and miners. In each case the outcome was different, Mt. Etna favouring the miners and Yessabah favouring the conservationists, however, on reflection, both cases illustrate the problems inherent in using the law to settle environmental disputes.

Firstly such legal actions are extremely costly as illustrated by the order for security for costs in the Mt. Etna case; $45,000 was to be set aside to cover the defendant's costs up to and including the first day of the trial. The cost of legal action can not only make legal action inaccessible but can also prove economically disastrous to the losing side

Secondly, legal procedures tend to explore legal issues rather than environmental or resource management issues. In the Mt. Etna case the environmental evidence was never heard because the case did not proceed to trial, while in the Yessabah case the matter was decided on legal grounds and so the environmental evidence was never subjected to the scrutiny of cross examination. Thus neither case resolved the truth or otherwise of the environmental, economic and resource management assertions being made by the disputing parties.

A third major limitation of legal processes is pointed out by Larkin (1992). Environmental law is more concerned with how decisions are made, rather than with the outcome of the decision making process. The role of the courts in general is to ensure that proper and informed decisions are made by those entrusted by law with the responsibility of decision making, e.g. ministers and executive government, not to make decisions in their place. Thus if a court rules that a decision has been made incorrectly, it is possible to start the process again in a correct manner, resulting in exactly the outcome that the legal action was intended to halt.

Legal solutions lack certainty for other reasons. Most environmental law gives great discretionary powers to ministers, and parliaments can enact legislation to overrule court decisions, thus winning the court battle does not, necessarily result in the victor's cause prevailing. It is probably true to say that the success of Vaughan-Taylor's court action in preventing expansion of mining at Yessabah was due more to the volatile nature of the New South Wales Parliament, where independent members held the balance of power, than to any inherent advantages of seeking a legal solution.

Political Solutions

Many more limestone resource disputes have been resolved by political means than by any other. Political solutions have three advantages over legal solutions; firstly they are nowhere near as expensive as legal solutions, secondly they are more likely to result in the losing party gaining some form of compensation or trade off as a result of whatever decision is reached, and thirdly political decisions frequently result in resolutions that provide a high degree of security of tenure for the particular land use favoured by the decision.

Historically these advantages have worked to the benefit of both miners and conservationists. Colong Caves became part of a national park, the South Marulan quarry opposite Bungonia Caves is highly unlikely to be closed prior to the end of its planned working life, Precipitous Bluff is in a World Heritage area and the former operators of the Lune River Quarry have received a compensation package.

Negotiated Solutions

There are no examples of disputes over limestone mining which have been resolved principally by negotiation. In both the Mt. Etna and Yessabah cases there were attempts at negotiation, but these were in a climate of litigation where success was unlikely. It is difficult to see how a negotiated solution could take place outside a framework of litigation unless there were active government involvement, as conservationists have little to offer miners in return for concessions except for good publicity and support for environmentally friendly projects.

Involvement of conservationists through the public decision making process in environmental planning and, as is the current case at Mt. Etna, in decisions about mine rehabilitation do, however, offer an opportunity through which negotiated solutions might be possible. Furthermore should dialogue open between miners and conservationists there is hope that in the future disputes about the merits of mining or conserving limestone resources may be settled through negotiation rather then through legal or political confrontation.

LIMESTONE MINE REHABILITATION

The rehabilitation of limestone mines is becoming a significant issue in eastern

Australia. A number of large mines have ceased, or will soon cease, production, some for economic reasons and some for environmental reasons. How such rehabilitation should be carried out is a new issue for Australia and one in which the international literature is of fairly recent origin.

Doing nothing

From studies I have carried out over the last twelve months it has become clear that doing nothing is not a good management approach for abandoned limestone mines.

Abandoned mines where no rehabilitation has occurred are frequently overrun by exotics such as Blackberry, Lantana, Briar Rose and Tree of Heaven. Vine and cane type exotics such as blackberry and lantana appear to have a great advantage in these areas as they are able to spread from small isolated soil pockets over large areas of bare rock. Where this has not occurred eg. Old Lune River Quarry, Tasmania (Fig. 7, C) and Pilkinton's Quarry at Mt. Etna, Queensland only sparse revegetation by native pioneer species has occurred.

Natural vegetation on karst areas largely depends on talus containing fines, sediment-filled cavities and open joints for its support . Some species (e.g. figs and kurrajongs) are able to send roots great distances down open joints in order to obtain water. In abandoned mines many of these niches for vegetation have been destroyed. Mining generally removes the outer zone of rock where joints are open and small solution cavities which trap soil are common.

Machinery working on benches tends to compact sediment in exposed cavities making it unsuitable for vegetation.

In most mines where there has been revegetation by native species a particular pattern, shown in Figure 8 can be observed:-

a. A zone of bare rock and compacted gravel occurs between the base of talus cones and the disturbed edge of benches. In this zone water often ponds and mosses, sedges and reeds may grow. If ponding does not occur and /or there are no voids or clay masses in the rock, the bench zone will remain as bare rock for decades after the cessation of mining.

b. Plant growth on talus slopes is controlled by the presence of non-limestone fines (usually silt and clay derived from cave sediment bodies intersected by the mine). Vegetation will grow on talus slopes containing fines, but not on those composed of pure limestone rubble.

c. Joint-penetrating species such as kurrajongs and figs are very slow to revegetate abandoned mine areas.

Revegetation

If abandoned limestone mines are unlikely to satisfactorily revegetate of their own accord then it is necessary to actively revegetate them. Because limestone mine

Figure 8:- Revegetation zones on limestone mines showing an idealised profile across a single bench limestone mine.

A partly disturbed zone at edge of quarry.

B Rubble zone at edge of bench with brambles such as lantana and blackberry.

C Bare zone on bench surface, poorly vegetated with reeds and sedges.

D Talus cone, supports small trees and grass where fines are present.

E Undisturbed karst landscape with cacliphile trees such as figs and kurrajongs.

benches are an inhospitable environment for most plants it is essential that seed-bed material containing fines is applied to them. Care must be taken that this material is sterile and it is preferable to use clay waste from the mine itself, rather than to import fines.

There has been some concern expressed about the likely impact of fines laid on quarry benches on the underlying karst system and, clearly, action must be taken to ensure that the fines are retained and do not wash into the underground drainage system. Planting in drill holes also has considerable potential, particularly if the holes intersect joints. From my observations of abandoned mines it is unlikely that revegetation will be successful unless fines capable of holding moisture are provided.

Finding Alternate Landuses

Abandoned limestone mines have been put to a number of uses some of which are good alternatives to revegetation while others are quite unsuitable. Many small abandoned limestone mines have been used as tips for domestic and commercial waste. This is a very bad practice as effluent from the waste can directly enter the karst groundwater system, causing intractable pollution problems.

One very aesthetic use of an abandoned mine is found at Taree, New South Wales where the Chatham Quarry, (see Carne & Jones, 1919 Plate facing page 274) which has filled with water, now forms an ornamental lake in a retirement housing complex. Western's Quarry at Wingham New South Wales (Carne & Jones, 1919, p 273) is now the site for a Sports Complex which includes a velodrome and go cart track. One less environmentally-friendly alternate use is found at the large abandoned limestone mine at Brogans Creek, New South Wales which is used as a film set for scenes involving flammable liquid fires.

Secondary (Restoration) Blasting

One of the most controversial issues in limestone mine rehabilitation involves techniques developed in the United Kingdom called "secondary" or "restoration" blasting. These techniques, pioneered by John Gunn and his associates (Gagen & Gunn, 1988, Gunn & Bailey, 1991), use explosives to reshape limestone mines either after extractive working has ceased, or at a final stage of the mining process. The objective of these techniques is to produce a post-mining landscape that resembles natural karst features, rather the leaving the mine landscape of faces and benches intact.

"Restoration" blasting is particularly suited to the U.K. where broad limestone valleys lined by cliffs with talus slopes at their base are common features of karst landscapes. This type of landform is rare or absent in eastern Australia restricting the applicability of "restoration" blasting.

These techniques were proposed at Lune River Quarry in Tasmania but rejected due to opposition by some conservation groups to the use of explosives. I have suggested that these techniques could be of benefit at Mt. Etna and would go some way to restore the original volcano-like profile of the mountain's eastern face, however there is no indication as yet as to whether these techniques will be used or not.

Earthworks (non-explosive) and Revegetation

Recent restoration work at the Lune River Quarry in Tasmania has seen the development of techniques to prevent mud from entering stream sinks in the mine floor. These techniques are an important advance in limestone mine rehabilitation and are a great credit to those involved.

INFRASTRUCTURE AND KARST

Dams

Karst landscapes with their complex underground drainage systems pose significant problems for dam construction. Dam construction can also result in the inundation of karst areas and cave systems. The best documented cases of karst being inundated in eastern Australia are Cave Flat in New South Wales, now forming Cave Island in Burrinjuck Dam (Fig. 1, G), and Texas (Viator Hill) Caves in Queensland (Fig. 1, B) now inundated by the Glenlyon Dam. Both Cave Flat (see Osborne, 1991) and Texas Caves (Grimes, 1978) are recognised vertebrate fossil localities.

Caves of the Gordon-Franklin River system in Tasmania (Middleton, 1979) (Fig. 1, J) were threatened with inundation by proposed hydroelectric dams on the Franklin and Lower Gordon Rivers. The presence of Pleistocene archaeological material in these caves played a major role in the dispute which was finally resolved as a result of the 1983 federal election when the newly elected Labor Commonwealth Government used foreign affairs power to prevent construction of the dams and protect the South West Tasmania World Heritage Area.

Roads

Road failure is a common problem in karst areas. Of particular concern is sinkhole failure where withdrawal of fines from filled dolines can cause rapid and catastrophic failure. Kiernan (1988) describes a number of such events at Mole Creek in Tasmania, while the most significant recent event in New South Wales involved the failure of the Snowy Mountains Highway near Yarrangobilly Caves in 1986.

Many of these problems can be avoided if appropriate geotechnical surveys are carried out prior to road construction and if drainage is designed to prevent inflow of water into sediment-filled cavities.

Forestry

Forestry can have a severe impact on karst regions in that it can cause significant amounts of erosion, lead to ground instability, alter infiltration rates and change soil and groundwater chemistry. The impact of forestry operations on karst has been a particular issue in Tasmania with significant forestry operations being undertaken in the Mole Creek and Florentine Valley karst areas. Tasmania is unique in having two karst specialists, K. Kiernan and R. Eberhard, employed by its Forestry Commission.

In New South Wales there has been particular concern about the effects of pine plantation forestry in the catchment of the Jenolan River upstream of Jenolan Caves (Fig. 1, D). Detailed studies of the effects of pine forests on limestone caves are being undertaken by K. Kiernan in Tasmania and by A. Spate in New South Wales.

High Tension Lines

High tension lines and their associated access roads can have a significant impact on karst landscapes. During the construction phase erosion increases and surface karst landforms may be destroyed by heavy vehicles. The Mt. Piper to Marulan 5,000 KV line was deviated near Wombeyan Caves in New South Wales to minimise impact on the karst. An example of the unsightly effects of power lines on karst can be found at Rosebrook, near Cooma in southern New South Wales where poles are set into a karst field.

URBANISATION AND KARST

There had been little urbanisation of karst in eastern Australia until quite recently. Karst areas in South and Western Australia have been urbanised for a considerable period of time, the most significant examples being Mt. Gambier in South Australia and the dune limestone areas surrounding Perth in Western Australia.

This situation is now beginning to change. Both small holdings and suburban blocks are currently expanding over limestone areas near Taree in New South Wales and at The Caves, near Rockhampton in Queensland. This has significant implications for resource sterilisation, environmental impact and engineering. Planning controls are urgently needed in these areas to protect viable limestone resources from sterilisation, home owners from foundation failure and the environment from pollution and the possible loss of significant features.

TOURISM, RECREATION AND KARST

Tourists and recreational cavers; like miners, engineers, foresters and householders are users of karst who have a significant environmental impact. Although their use of karst is in conflict with that of limestone miners, and despite the significant contribution made by cavers to conservation, recreational and tourist users have a significant impact on the karst environment.

Show Caves

The ongoing impact of tourists using developed show caves is to a large extent controlled due to the massive modification of show caves undertaken during their development. This "hardens" the environment reducing future breakages, wear and entrainment of mud. Despite this tourists visiting show caves have an impact by introducing lint and altering the composition of the cave atmosphere. Tourists introduce garbage, spores and foreign microorganisms and the lighting systems in the caves allow the growth of algae and moss (so called *lampenflora*) and heat the cave atmosphere.

Cleaning of show caves to remove lint and introduced dirt, now mainly carried out by high pressure washing, erodes the surface of speleothems and has the potential to destabilise mud substrata on which the speleothems have been deposited. An important issue in the management of show caves is thus how to determine the carrying capacity of the cave. Studies to explore this issue are currently underway at Jenolan Caves.

"Wild" Caves

Recreational cavers who use "wild" caves to which have few if any changes have been made, have a significant impact on the caves they use. These impacts include; accidental breakage of speleothems, wear of limestone surfaces, entrainment of mud and in the worst cases deposition of litter and outright vandalism. An excellent review of these issues is provided by Spate and Hamilton-Smith (1991) who begin by stating that:-

> "We have long held that caves, their contents and values are more at threat from cavers and their activities than they are from the activities of quarry operators and other users, or abusers of karst areas."
>
> [Spate & Hamilton-Smith, 1991, p 20]

Clearly the impact of recreational cavers can, and has been, reduced by education, training, developing a conservation ethic, installing track markers and restricting access to caves or parts of caves considered to be particularly fragile. The desire to explore is, however, in the nature of people going caving and this means that cavers impacts, unlike those of tourists are not easily restricted to a single pathway.

If recreational used of "wild" caves is to continue then agreement needs to be reached among all users as to an overarching system of values or ethics, appropriate training standards for leaders and how access and use of a limited resource might best be managed. It is becoming clear that if this does not occur managers may exercise their duty to protect the caves in their care in ways that will severely restrict recreational caving activities.

INCREASING SCIENTIFIC UNDERSTANDING OF AUSTRALIAN KARST

Central to any improvement in the way we manage, conserve and exploit the limestone and karst resources of Australia is an improvement in our understanding of all fields of science as they relate to karst. Karst research in Australia is currently fragmented and underfunded, in fact the largest single recent grant to any individual researcher related to caves has been for a study of the <u>history</u> of cave science in Australia. Karst research also has a major image problem, being seen by science administrators as not being relevant or as being somehow sullied by its association with caving as a recreational activity.

Nevertheless workers and graduate students in academic, scientific and government agencies in Australia, frequently working in isolation, are undertaking high quality research into the biology, chemistry, geology and geomorphology of karst.

What is needed is an institutional focus for karst studies where a multidisciplinary research group above critical mass can be established, where a library of publications, maps and a data bases can be assembled and where graduate students can work knowing they will have access to appropriate supervision and facilities. The institution could take the form of a centre or key centre at a university or it could be a research institute attached to a museum at a major tourist venue such as Jenolan Caves. Karst research needs much more support from government, the show cave industry, research funding bodies and from the mining industry.

We can manage our limestone resources better and it is possible to both extract limestone as a mineral commodity, use caves for tourism and recreation and conserve significant karst landscapes and their ecosystems for posterity. To achieve this we require better basic data, workable decision making processes and a willingness on the part of all involved to communicate and take responsibility.

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FROM *buzzatii* TO BUFFALOES - EXCURSIONS INTO GENETIC VARIATION

J.S.F. BARKER

ABSTRACT. Genetic variation is the stuff of evolution and the basic material of the plant and animal breeder. It also is ubiquitous and the amount of genetic variation is enormous. This variation is most obvious as differences among species - at least 10 million currently present on this planet. Yet there are also vast amounts of genetic variation **within** each species, some of which at least is obvious to us when we note that we recognise individuals of our own species as different. In fact, apart from identical twins, each individual is genetically unique.

In the last 20 years, the primary questions in evolutionary and population genetics have been - Why is there so much genetic variation? or What forces are operating to maintain it? At the same time, the question of interest in applied quantitative genetics (i.e. plant and animal breeding) has been - How can we best use genetic variation? More recently, attention has been directed also to - How can we conserve genetic variation? Two schools of thought have predominated in discussion of the maintenance of genetic variation. One, the neutralists, claimed that the observed variation is essentially unselected mutations that have no or only very slightly deleterious effects on the organism and are effectively irrelevant to evolution. The selectionists, on the other hand, argued that the observed variation is actively maintained by forces of balancing natural selection. As is usual in scientific controversies, the truth is somewhere in between - some variation being neutral, some maintained by selection, so that case by case analysis is necessary. Our contribution to this has been to use *Drosophila buzzatii*, a small fly that breeds in rotting cactus. This species was specifically chosen because its known breeding site allows the possibility of joint consideration of its genetics and ecology, and hence identification of selective forces. Genetic variation has been quantified by analysis of genes coding for enzymes, and results indicating selection effects are presented.

At the other end of the spectrum are the questions relating to the use and conservation of genetic variation in domestic plants and animals. On the global level, there are probably in excess of 3500 breeds and strains of domestic animals. Many breeds have disappeared in the last 30-40 years, and many more are under threat. Particularly in the developing countries, little is known about these breeds, and specifically about genetic differences among them. Using methodology derived from evolutionary genetics, genetic differences among the swamp buffalo populations of south east Asia have been investigated. Large differences were found, but most importantly, this work has laid the foundations for a major global program to determine the genetic differences among all breeds and strains in each of the domestic livestock species. This information is vital for the planning of breeding programs for genetic improvement, and of conservation programs to ensure that potentially valuable genetic variation remains available to meet future human needs.

INTRODUCTION

Genetic variation is recognized by everyone, even though this is usually unconscious, and simply taken as part of common knowledge. Thus, for example, cattle and sheep are recognized as different, as are humans and chimpanzees. Each person, depending on experience and education, will recognize many other such different groups of living organisms, with each group identified by some name. But having recognized the existence of such differences, the questions that need to be asked are: why are they different, and what is the basis of these differences that we accept so readily?

First - why are they different? Because it's all in the genes; they are genetically different.

Second - what is the basis of these diferences? Because each such group represents a separate evolutionary lineage; they are the current products of separate evolutionary pathways.

So it is evolution that results in the genetic differences among these groups that we define as distinct species. Evolution means genetic change, so genetic variation also is the essence of ongoing evolution within each species. Also genetic variation is the basic material of the animal and plant breeder - we use it to mould our domestic species to our needs.

Walter Poggendorf was one of Australia's eminent plant breeders, and I am honoured by having been asked to present the Poggendorff Memorial Lecture for 1993. He would undoubtedly have been fascinated by what is now known about genetic variation. Yet without the benefit of this knowledge and modern plant breeding technology, he used genetic variation to produce outstanding varieties of rice, grapes, rockmelons, peaches and apricots. Clearly Walter Poggendorff used genetic variation in these species to the benefit of Australian farmers and horticulturists.

MAGNITUDE OF GENETIC VARIATION

Animal and plant breeders such as Poggendorff use genetic variation in our domesticated species to produce improved, *i. e.* more productive and more efficient breeds, strains and varieties. But just how much genetic variation is there in the organisms on this planet. To answer, we need to think at two levels - between species and within species. The enormity of the answer is apparent firstly just in the number of species. About 2 million species of plants and animals have been formally described and named, but estimates of the total number of species now living on this earth range from 10 million to 100 million. Of the named species, about 57% are insects and, of these, nearly half are beetles. There is a story (Gould, 1993) that the distinguished British biologist, J.B.S. Haldane, who was one of the fathers of population and evolutionary genetics, once found himself in the company of a group of theologians. On being asked what one could conclude as to the nature of the Creator from a study of his creation, Haldane is said to have answered "An inordinate fondness for beetles."

The total of some 10 million or more species currently existing on this planet inspires a sense of wonder, but there is also enormous genetic variation within species. Some of this is immediately obvious if one just looks at people passing by on a crowded street. Similarly, some is obvious if one looks closely at other species (for example, dogs and cats). In other cases, genetic differences may not be so immediately apparent to us, but of course individuals within those species often can and do distinguish one another. Yet in a real sense, these visible genetic differences among individuals within a species are quite trivial.

The changes in the average level of some character in a population that can be made by artificial selection (as practised in plant and animal breeding) demonstrate the point that there are large amounts of hidden genetic variation - large amounts even for a single character. This is well illustrated by the results of two classic selection experiments, one for oil content in maize seeds, the other for bristle number in *Drosophila melanogaster*. The Illinois corn-oil content experiment is the longest running selection experiment that has ever been done. Started in 1896, response to selection continues after 90 generations (Dudley and Lambert, 1992). The selection involves two separate lines - one for increased, and one for decreased oil content, and the results (Figure 1) show the enormous changes that have resulted from selection. Selection for low oil content has brought the mean of this line almost to the possible limit of zero, while selection for high oil content continues to result in further increase.

In the Drosophila bristle number experiment, Yoo (1980) selected for increased number in six replicate lines that derived from the same initial population (Figure 2). Again all lines showed large changes in the mean bristle number, although responses to selection were slowing down in the later generations. However, the crucial point here is to note the range of variation in bristle number in the initial unselected population. Among some thousands of flies in that unselected population, the largest number of bristles recorded was 15. Yet in that population, genetic variation was present (but not expressed) that allowed selection to increase the mean bristle number to around 40 in each of the selection lines.

Finally, the potential magnitude of genetic variation can be quantified in a different way, in this case, not the variation for some single character, but the total variation in our own species. Humans have about 100,000 different genes, and it is estimated that the average person carries two different forms of a gene (or alleles) at about 10% of these, *i. e.* is heterozygous for on average 10,000 genes. When gametes (eggs and sperm) are produced, only one of each of these alleles is included in each gamete. That is, for each heterozygous gene, half the gametes will contain one form of the gene, and half the other. With 10,000 such heterozygous genes, the number of genetically different gametes that an individual could produce is:

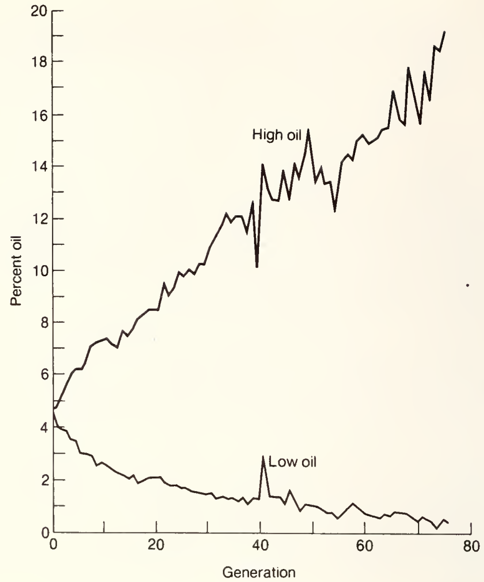

Fig.1. Responses to selection for increased and decreased oil content in maize seeds.

$$2^{10,000} \text{ or approximately } 10^{3000}.$$

Now this is obviously a very big number, but it is edifying to see just how big by way of comparison. This has been done by Bodmer and Cavalli-Sforza (1976, p. 232), who estimated that the total number of sperm ever produced by all human males who have ever lived is only $10^{23\text{-}24}$.

Thus each individual, apart from identical twins, is genetically unique.

WHY IS THERE SO MUCH GENETIC VARIATION?

The real quantification of these vast amounts of genetic variation within species was obtained only in the late 1960's, and since then the questions that have plagued evolutionary geneticists are - Why is there so much genetic variation? or What forces are operating to maintain it? and What is its relevance to adaptive evolution? At the same time, plant and animal breeders have been concerned to know how best to use the genetic variation, while recently becoming concerned to ensure that potentially useful genetic variation is not lost.

My research in recent years has in one way or another been driven by these questions, and the phrase in the title of the lecture 'excursions into genetic variation' was a very conscious choice. The Oxford Dictionary defines an excursion as a journey, a ramble or a pleasure trip - and the last two are particularly appropriate descriptions of at least my experience of scientific research.

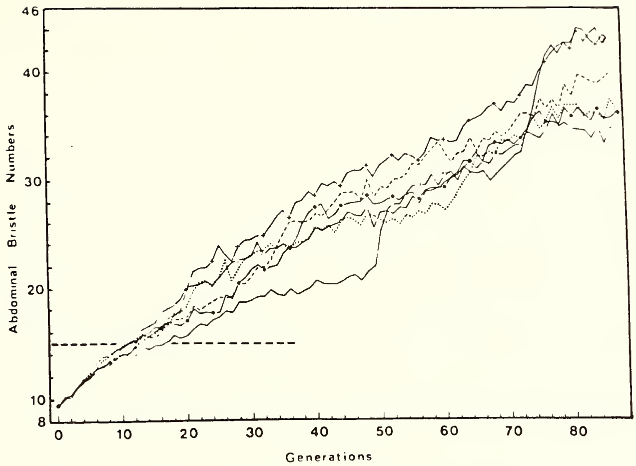

Fig.2. Responses to selection for abdominal bristle number in six large replicate populations of *Drosophila melanogaster*. The dotted line indicates the maximum value of the character observed in the unselected population at generation zero (adapted from Yoo, 1980).

In evolutionary genetics, two schools of thought have dominated discussion of the maintenance of genetic variation for the past 20 years (Lewontin, 1974; Clarke, 1979). One, the so-called neutralists, claim that the observed variation is essentially unselected mutations that have no or only very slightly deleterious effects on the organism, and are therefore effectively irrelevant to evolution. The variation is neutral, in so far as natural selection is concerned (Kimura, 1968; King and Jukes, 1969). The other school, the selectionists, argue that the observed variation is actively maintained by forces of balancing natural selection (Nevo, 1988).

This controversy continues, but as is common in such scientific controversies, the truth is somewhere in between - with some variation being neutral, and some maintained by selection. But how much of each - what proportion of the variation is neutral, and what proportion is maintained by selection? No general theory can answer this; we need a case by case analysis, from which general conclusions might be drawn.

GENETIC VARIATION IN *Drosophila buzzatii*

Which brings me to the first of the two species to be discussed - a small fly, *Drosophila buzzatii*. This species is specialised to utilize the habitat of rotting prickly pears, and it was chosen as a model organism for our studies in evolutionary genetics because its known breeding site allows the possibility of joint consideration of its genetics and ecology, and hence the possibilty of identification of selection forces. Here I can present only some glimpses of the results of this work, work that has many facets and has involved an international collaborative team effort, with contributions from colleagues at institutions in the U.S., Brazil and Denmark, as well as other Australian Universities.

Drosophila buzzatii colonized Australia from South America, and its host plants, the Opuntia cacti or prickly pears, also colonized from the Americas. The history of the Opuntia colonization, spread, control and present distribution is well documented, and is well-known as a classic example of biological control of a pest plant (Dodd, 1940; Mann, 1970).

Nine species of cactus became major pests in Australia, one of these being brought to Australia from Argentina by the first European settlers in 1788. The introduction of other species into Australia is not known, but probably all were introduced as botanical curiosities within the first 100 years of European settlement. The species that became the major pest prickly pear, *Opuntia stricta*, was from the 1840s, commonly used as hedges around homesteads. Thus the pear spread from many foci, and in the absence of natural enemies, was out of control by 1870. By 1920, 27,000,000 hectares were affected, about half this area being covered by pear so dense that the land was useless. At that time, the pear was estimated to be spreading at the rate of 450,000 hectares per year. In 1920, the biological control program commenced. In May, 1925, 3000 *Cactoblastis cactorum* eggs were introduced from Argentina. The potential of this insect as a control agent was soon apparent and by 1940, complete control had been achieved.

Today, both host plant and parasite continue to exist at equilibrium. Thus the present Opuntia distribution is essentially within the limits of the original infestation, but occurring as an island distribution with island size ranging from just a few plants to a few hundred hectares. In southern N.S.W., Victoria and South Australia, outside the limits of the original infestation, some patches of pest pear also remain, but most islands comprise from one to about 30 plants of the cultivated species, *O. ficus-indica*.

The distribution of *D. buzzatii* then is that of an island distribution with considerable variation in island size and *D. buzzatii* population size, variation in inter-island distance, a number of peripheral isolate populations, variation among islands in ecology (both Opuntia species and other flora), with the whole distribution extending over a wide geographical area and climatic range.

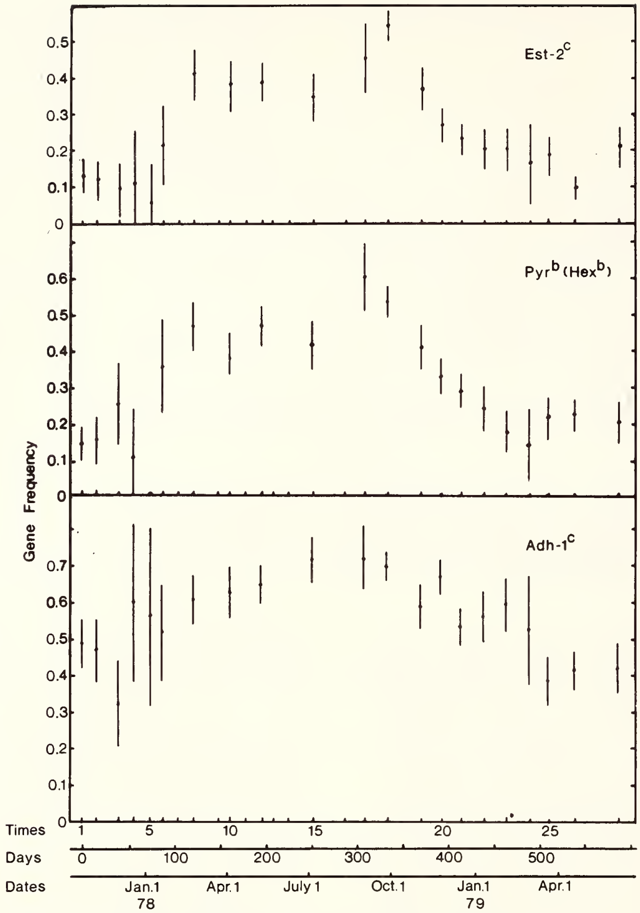

Fig.3. Changes in frequency of alleles at three enzyme loci during perturbation over times 4-18, and following cessation of perturbation. The dotted line through times 1-4 is the pre-perturbation weighted average allele frequency. Times refer to the sequential number given to each collection and/or release (adapted from Barker and East, 1980).

The rots in which the flies live, particularly those in the common pest pear (*O. stricta*) are mainly the result of Cactoblastis attack. Adult flies enter the rotting cladode through holes made by the Cactoblastis larvae, and the Drosophila go through one or more complete life cycles within the rot.

The genetic variation that is being studied is part of the normally hidden variation - in this case variation in genes that control the production of particular enzymes. Using biochemical methods, it is relatively simple to determine the genetic makeup of individual flies for these genes.

Initial studies measured the genetic variation for 36 enzyme genes at many different localities throughout the species distribution. Results from this study of spatial genetic variation were interpreted as indicating some form of balancing selection - based on significant differences in allele frequency among populations, apparent genetic isolation of small peripheral populations with similar levels of variation to central populations, and the occurrence of a number of low frequency alleles at consistent frequency throughout the species distribution. Significant associations of the genetic composition of flies from different localities with climatic factors (Mulley, James and Barker, 1979), and analyses of the spatial patterns of genetic variation (Sokal, Oden and Barker, 1987) provided further indirect evidence that natural selection is affecting gene frequencies.

Direct evidence for selection

More direct evidence that selection is influencing gene frequencies within populations was obtained from perturbation experiments in natural populations. If genetic variation at some

TABLE 1

Proportions of each yeast species within seasons and within types of rot

	Yeast species									
SEASON	1	2	3	4	5	6	7	8	9	10
Summer	0.27	0.45	0.14	0.04	0	0	0.06	0.02	0	0.02
Autumn	0.31	0.23	0	0.11	0.15	0.02	0.05	0.02	0.09	0.01
Winter	0.33	0.28	0.02	0.05	0.04	0.05	0.04	0.05	0	0.14
Spring	0.26	0.18	0.27	0.03	0	0.10	0.04	0.09	0.03	0.01
TYPE OF ROT										
Young cladode	0.27	0.15	0.27	0.02	0.04	0.07	0.02	0.08	0.05	0.01
Old cladode	0.35	0.30	0.07	0.07	0.05	0.05	0.06	0.02	0.02	0.02
Basal cladode	0.18	0.29	0.04	0.14	0.18	0.07	0	0	0.11	0
Basal Rot	0.27	0.28	0.02	0.08	0.09	0.02	0.06	0.06	0.06	0.09

locus is being actively maintained by natural selection, the action of this selection should be detectable following artificial change in gene frequencies produced either by adding certain genotypes to the population, or by removing them from it.

In one large field experiment (Barker and East, 1980), gene frequencies at three enzyme loci were perturbed simultaneously, by continuous release over about 250 days from a laboratory population that had been made homozygous for an allele of each of these genes that was at low frequency in the natural population, *viz.* *Est-2c* and *Hexb* (denoted as *Pyr*^{b} in Barker and East, 1980), and for the intermediate frequency allele *Adh-1c*.

The population we chose to perturb inhabits an isolated stand of *O. stricta* comprising about 40 large plants in an area about 50m x 20m. The surrounding area is cultivated or open grazing land, and the nearest *O. stricta* is some 3km away. Four estimates of gene frequencies in this population (Times 1-4) were made over eight weeks before perturbation commenced (Figure 3). Allele frequencies at all three loci were increased significantly during the perturbation phase, and all decreased to the original levels after release ceased. If this decrease were due entirely to migration, estimated migration rates would be the same for all three loci. However, there was significant heterogeneity among these migration rates, and further, the rates of migration necessary to account for the changes in gene frequency were extraordinarily high at around 90%. Thus the changes in gene frequency must be ascribed to natural selection, and there must have been differential selection among the three loci.

All of this evidence provides strong presumptive support for the hypothesis that selection is indeed influencing enzyme gene frequencies at some loci. However, it does not prove that the selection is acting directly on the enzyme loci themselves. For this to be achieved, the nature of the selection must be understood.

Habitat variability and selection

As noted previously, the flies are apparently specific to the cactus rot habitat. Thus adults feed on the rot surface, taking up microorganisms, compounds derived from the breakdown of plant tissue and microorganism metabolites. They lay their eggs in the rot, and the larvae develop there, potentially feeding on the same range of microorganisms and compounds as the adults. A major stimulus to flies seeking a suitable feeding or breeding site is presumably olfactory, and volatiles produced by microorganisms most likely provide the cue (Fogleman, 1982; Fogleman and Abril, 1990). As yeasts are considered to be an essential component in the diet of Drosophila, we have concentrated on the yeast species present in cactus rots.

While it might be imagined that all cactus rots are the same, in fact they are very heterogeneous. There is a marked diversity of yeast species among rots, both within and among localities, among rots at different times within a locality, and even at different times within the same rot. For example, Table 1 gives the seasonal and rot type diversity for the 10 most common yeast species isolated from 278 rots collected over a 15 month period at one locality (Barker et al., 1983). The most common species (yeast 1) is prevalent throughout the year and in all rot types, but others show substantial variation, *e. g.* yeast 3 common in spring and summer only, yeast 5 in autumn only, yeast 3 in young cladodes, and yeasts 4 and 5 in basal cladodes.

But how do the flies react to this diversity in yeast species - can they differentiate among them, and in what way do they do so? Indeed they do differentiate and they show strong preferences to feed and lay their eggs on some yeasts, and largely avoid others (Vacek et al., 1985). However, while in itself this is an interesting observation on fly behaviour, it would not be very exciting if all flies ranked their preferences for these yeasts in the same order.

Suppose, however, that genetically different females prefer to lay their eggs on different yeasts, and that their larval progeny then grow and survive best on the yeast chosen by their mothers. In this situation, genetic variation will be maintained (Hedrick, 1990), and recent experiments, both in the laboratory and in the field, have shown that there is such genotype-specific habitat selection (Barker, 1992; Barker, Starmer and Fogleman, 1994).

In other species, environmental heterogeneity and this selection of different habitats by different genotypes also may well be a major mechanism for maintaining genetic variation.

Now I recognize that this sort of research may seem a long way from practical plant and animal breeding. However, we need to think not only of maximizing current improvement in productivity of our domestic species, but also to consider future utilization and manipulation of genetic variability. A better understanding of forces that maintain genetic variability in natural populations should direct our thinking to maintaining or conserving variability that may be useful in the future.

GENETIC VARIATION IN SWAMP BUFFALO

On this note, I want now to turn to another species, one that is somewhat larger than *D. buzzatii*, *viz.* the swamp buffalo of southeast Asia. Now the question might well be asked - "Why swamp buffalo?", but let me come to that through a little excursion into some background.

The aim of animal breeding is to improve productivity, product quality and the efficiency of production by either or both of selection within breeds (or strains) or utilization of differences among breeds (or strains) through crossbreeding, grading-up to a superior breed by repeated backcrossing, or formation of a synthetic population. Thus future improvement of livestock to meet human needs is dependent on genetic variation - both the variation within breeds, and the variation between breeds, strains and populations. Genetic variation is the basic material of the animal breeder - we use it to mould our animal populations to our needs, and loss of variation will restrict the options available to meet unpredictable future requirements. While loss of variation within breeds or populations is continually countered by the introduction of new variation through mutation, albeit very slowly, the genetic variation present as differences among breeds, strains or populations cannot be readily regenerated. Each breed or strain is the product of the random processes of genetic drift (due to finite population size) and mutation, as well as separate adaptation and evolution, often over many centuries, with differing selection pressures imposed by climate, endemic parasites and diseases, available nutrition and criteria imposed by man. Each breed thus comprises a unique set of genes.

There are estimated to be in excess of 3500 breeds and strains of domestic animals in the world today (Loftus and Scherf, 1993). In recent years, there has been increasing concern about loss of genetic diversity through various breeds and strains becoming extinct. In the developed world, where animal production has been and is primarily driven by economic considerations, those breeds that are already extinct, or are presently rare and endangered, presumably have been tested by current market forces, and found wanting. Elsewhere, breeds are under threat because of indiscriminate or even planned crossbreeding, because of political instability, or because of national decisions to eliminate some breeds.

However, many of the existing indigenous strains and populations of the developing world are likely to carry valuable genes - genes controlling specific physiological, behavioural and parasite or disease resistance traits. Thus the genotypes of some of these strains could well be crucial to future sustainable animal production systems, at least in the stressful environments where they have evolved by natural selection, and undoubtedly many will contribute also to developed country production systems. There is then a need to ensure that unique indigenous strains are not lost. Nevertheless, we have to accept that not all breeds could or should be conserved until we can determine what useful genes or genotypes they contain.

So we have a dilemma - there are too many breeds for them all to be evaluated, but we do not want to lose any because they may be of much greater value in the future. I suggested some years ago (Barker, 1980, 1985) that the solution was to use the methodology of evolutionary genetics to determine the genetic relationships among breeds. Suppose there are just two breeds that are in danger of extinction. If they were found to be very closely related genetically, the decision could be made to let one go, but to preserve the other. On the other hand, if they were genetically distantly related, every effort should be made to conserve both.

Which brings me back to the swamp buffalo, which we chose to demonstrate the utility of this approach. There was a further reason for choosing this species. All the swamp buffalo of southeast Asia appear very similar, and are not distinguished as different breeds, even though they exist in many largely separate populations. Breeding programs for buffalo improvement are being developed in a number of countries, so that it would be useful to know if these are being based on genetically different populations.

As for the *D. buzzatii* work, genetic variation within populations and genetic relationships among them have been measured using genes controlling enzymes - in this case, some 65 different genes.

This study is still in progress, but the results to date are summarized in Figure 4. The scale of genetic distance quantifies the genetic differences among the 12 swamp buffalo and five river buffalo populations. As expected, the difference between these two types of buffalo is greater than the differences among populations within each of them. However, the important result is that there are large genetic differences among some populations: differences that are larger than those among some of the well-recognized livestock breeds of the Western world. That is, there are significant genetic differences that need to be taken into account in developing breeding programs, and in conserving genetic variability in this species.

This approach is now being taken as the foundation for a major global program that FAO is working to initiate - a program to determine the genetic relationships among all breeds and strains of each of the domestic livestock species. The information from this will be vital for the planning of breeding programs for genetic improvement, and the planning of conservation programs to ensure that potentially valuable genetic variation remains available to meet future human needs.

ACKNOWLEDGEMENTS

The research on *Drosophila buzzatii* has been supported primarily by the Australian Research Council, with support for meetings and collaborative work from the US/Australia Cooperative Science Program and the National Science Foundation (USA), while the swamp buffalo studies were supported by the Australia Centre for International Agricultural Research. I am enormously indebted to the many colleagues who have made such vital contributions to these studies, who have taught me so much, and with whom it has been a pleasure to work.

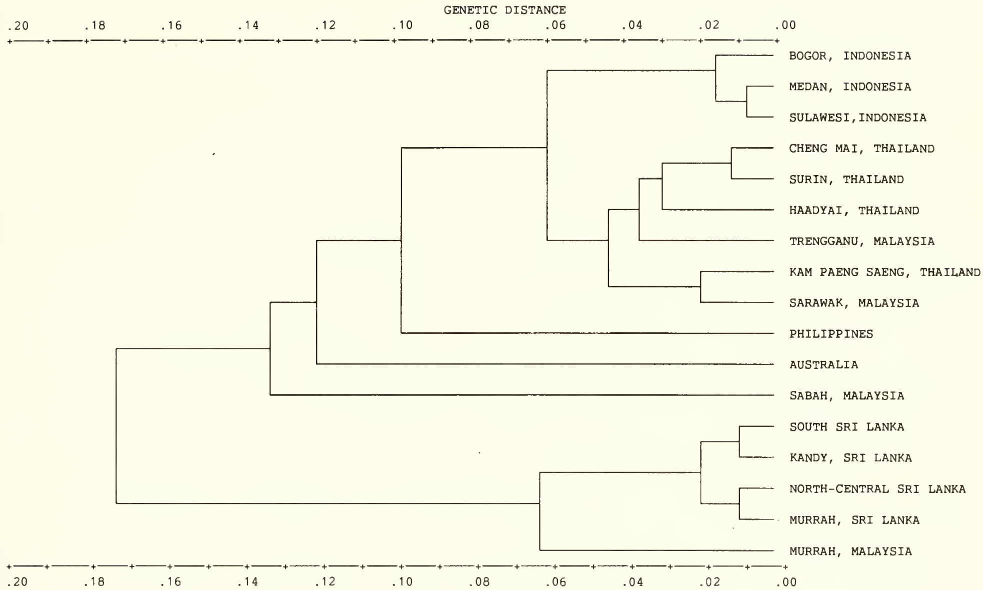

Fig.4. Diagram of genetic differences (measured as genetic distance) among 12 swamp buffalo and five river buffalo populations.

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AN OCCURRENCE OF KRÖHNKITE AT BROKEN HILL, NSW

L.J. Lawrence, C.M. Stocksiek and P.A. Williams

ABSTRACT. The rare, copper-bearing sulphate kröhnkite, $Na_2Cu(SO_4)_2.2H_2O$, is reported from Broken Hill, NSW. It was found as a thin, sky blue crust coating a specimen of gypsum, $CaSO_4.2H_2O$, on garnet sandstone. This is the first recorded occurrence of kröhnkite in Australia.

Kröhnkite, $Na_2Cu(SO_4)_2.2H_2O$, is a rare secondary mineral described originally from the Chuquicamata mines in Antofagasta Province, Chile (Domeyko, 1876). It was subsequently found in other parts of the Atacama Desert copper mining region at El Cobre de Mejillones, at Incahuassi, at Collahurasi and in the Salvador mine, Quetena (Palache *et al.*, 1951). In these localities it is commonly associated with antlerite, $Cu_3SO_4(OH)_4$, leightonite, $K_2Ca_2Cu(SO_4)_4.2H_2O$, atacamite, $Cu_2Cl(OH)_3$, chalcanthite, $CuSO_4.5H_2O$, and natrochalcite, $NaCu_2(SO_4)_2(OH).H_2O$. Kröhnkite in these localities is a product of the oxidation of primary copper ores in arid conditions.

Kröhnkite is also recorded as a sublimate in the volcanic areas of Iceland (Torssander, 1988) where it is associated with thenardite, Na_2SO_4, and aphthitalite, $(K,Na)_3Na(SO_4)_2$. It also occurs as a sublimate at Mount Etna, Sicily, associated with thenardite, aphthitalite and mercallite, $KHSO_4$ (Le Guern and Bernard, 1982). A further mode of occurrence for kröhnkite is in the oxidized zone of the iron ore deposit at Capo Calamita on the island of Elba, Italy (Del'Anna and Quagliarella, 1969). As with the other occurrences it is associated with natrochalcite.

The Broken Hill kröhnkite specimen consists of a crust up to 1 mm thick of a bright sky blue colour discontinuously coating a mass of colourless to white gypsum crystals, 5 to 8 mm long, which in turn invest a 6 cm slab of garnet sandstone. The outer surface of the kröhnkite is somewhat botryoidal with a minutely crystalline surface. Kröhnkite from Chile usually exhibits a fibrous habit normal to the walls of the fracture within which it has grown; no such habit was observed in the Broken Hill specimen.

The exact location from which the single specimen came remains unknown. However, it is possibly from the No. 2 level of the old Block 14 workings (eventually part of the South Mine leases). Plimer (pers. comm., in Worner and Mitchell, 1982) reported the occurrence of chalcanthite, $CuSO_4.5H_2O$, as an efflorescence associated with gypsum in the backs of the No. 2 level in this section of the workings. Both chalcanthite and kröhnkite form under desiccating conditions at comparatively low pH. Otherwise, basic double salts of copper crystallise from aqueous solution (Williams, 1989).

Kröhnkite is monoclinic, space group $P2_1/c$, and is paler in colour than chalcanthite (sky blue compared to light royal blue). Its identity was confirmed by powder X-ray diffraction methods using a Rigaku DMAX IB powder diffractometer employing CuKα radiation. Diffraction data for the specimen, calibrated against elemental Si, are given in Table 1 together with those from the literature (ASTM File 25-826). Wet chemical analysis (with H_2O by thermogravimetric analysis) gave CuO, 24.0; Na_2O, 18.5; SO_3, 47.1; H_2O, 10.6%; calculated composition of $Na_2Cu(SO_4)_2.2H_2O$ is CuO, 23.56; Na_2O, 18.36; SO_3, 47.41; H_2O, 10.67%. Thermogravimetric analysis (Stanton Redcroft TG750A balance, heating rate 5°C min^{-1}, air stream) showed that the first water of crystallization is lost at 170°C (mid-point of weight loss) and the second at 210°C. Evolution of SO_3 was observed at 900°C to leave a residue of CuO + Na_2SO_4.

Although primary copper sulphides are not particularly abundant in the No. 2 and No. 3 lead lenses, veins and disseminations of chalcopyrite were not uncommon in lenses of garnet sandstone throughout the Broken Hill mines (Plimer, 1984). Oxidation of such a suite under acidic conditions in saline solution followed by desiccation would provide an ideal environment for the formation of kröhnkite (Williams, 1989). However, despite these observations, it is obvious that such conditions rarely obtain in that kröhnkite is such a very rare mineral. This find represents its first Australian occurrence.

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TABLE 1
POWDER X-RAY DIFFRACTION DATA
(Å AND INTENSITY RATIOS) FOR KRÖHNKITE

d^a_{obs}	I^a	d^b_{obs}	I^b	d^a_{obs}	I^a	d^b_{obs}	I^b
6.32	100	6.342	100	2.215	15	2.218	16
5.50	10	5.502	28	2.155	15	2.157	12
5.04	20	5.038	30	2.137	5		
4.31	10	4.317	23	2.117	10	2.112	5
4.15	30	4.164	31	2.109	10		
3.71	40	3.712	37	2.076	5	2.079	5
3.35	30	3.343	28	2.062	5		
3.28	75	3.280	57	2.008	10	2.010	13
3.20	30	3.193	27	2.007	5		
3.16	30	3.162	33	1.9689	5	1.973	12
3.10	35	3.099	27	1.9285	5	1.930	11
2.928	65	2.934	39	1.8552	5	1.853	13
2.763	45	2.765	30	1.8529	5		
2.742	15	2.744	24	1.8179	5	1.818	11
2.718	30	2.717	18	1.7912	5		
2.657	15	2.659	24	1.7778	5	1.778	13
2.614	15	2.615	17	1.7650	5		
2.584	10	2.584	14	1.7620	5		
2.351	5	2.351	15	1.7590	5	1.758	11
2.298	10	2.298	17	1.7570	5		
2.292	10			1.7260	5		
2.254	5	2.249	6	1.7080	5	1.709	9

[a] ASTM File 25-826. [b] Kröhnkite, Broken Hill.

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Strength of Cement Stabilised Pressed Earth Bricks with Low Cement Contents

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ABSTRACT: This paper examines the relationship between strength and cement content in pressed stabilised earth bricks for cement contents varying between 0 and 3.5 %. It shows that adequate strength can be obtained from some soils at cement contents significantly lower than is the present practice (5 - 10 %). It also examines the hypothesis that there is a minimum cement content below which the strength of the brick is determined by the soil parameters only and is unaffected by the presence of cement.

INTRODUCTION

The use of soil as a building material dates back to antiquity. Mud bricks are mentioned in the Bible and are still used widely today. Unstabilised earth bricks generally require protective eaves , protective coatings or regular maintenance for long-term survival and are therefore not generally suitable for modern building construction (Fitzmaurice, 1958). Fitzmaurice was the first person to point out that the population today are more demanding of their building materials and that stabilisation of soils(normally with asphalt or cement) is necessary to maintain their integrity when exposed to moisture. Cement as a stabilising agent is widespread in pressed earth brick construction. Stabilised pressed earth bricks are made from soil mixed with a stabiliser and pressed in a steel mould. The amount of cement used depends on the soil type but is generally in the range of 5 - 10 %.. The effect of such cement contents on the compressive strength of the bricks has been studied by a variety of researchers (PCA, 1956; Mitchell, 1976; Heathcote, 1991). In general it can be said that the durability and compressive strength of bricks stabilised with 5 - 10 % cement is proportional to the amount of cement added.

The cost of cement is a considerable part of the total cost of producing cement stabilised earth bricks particularly in low income areas. Greater utilisation of this material will be achieved if there is some means of establishing the minimum cement content required to stabilise various soils. Mehra(1953) in his extensive work in India used 2.5 % cement and achieved a high degree of stability.

This paper is an attempt to investigate whether there is a minimum cement content below which the cement content has no appreciable effect on the strength of the soil mass.

EFFECT OF CEMENT ON STRENGTH OF SOIL MASS

Considerable work has been done on establishing a relationship between cement content and strength of stabilised earth bricks for cement contents over 2.5 % (PCA,1956;Mitchell,1976;Heathcote,1991). In general the results indicate a reasonably linear relationship between cement content and strength with higher strength increases being achieved with granular soils.

Hertzog (1964) proposed that soil cement obtains its strength when branches of cemetitious material (emanating from hydrating cement grains) reach out into the soil mass and link with each other. He postulated that if the soil contained enough cement to reduce grain spacing then the connections between grains becomes the primary load carrying component. His experiments led to the conclusion that at cement contents greater than 2.5 % the soil-cement matrix became non-plastic.

Heathcote (1991) found that the effect of cement content varied depending on the density of the compacted soil between

0.3*C for a density of 1700 kg/m^3 and 1.1*C for a density of 2000 kg/m^3. His tests were carried out with a granular soil.
Mitchell (1976) analysed a variety of data and found that the unconfined compressive strength in MPa varied between 0.3*C and 1.0*C where C is the cement content in %. The lower value was for fine-grained soils and the upper value for granular soils.
The strength of unstabilised adobe bricks results from the cohesive bond developed by the clay matrix. Nelson(Unknown) reports an increase in adobe brick strength with increasing clay content of the soil. It is reasonable to assume then that soils have an inherent bond strength due to their clay content and that the strength afforded by these bonds results in a minimum compressive strength at zero cement content. This strength will be low for sandy soils and higher for clayey soils , where the type of minerals present is also of significance.
Mitchell(1976,p373) reports on the work of researchers who found that the addition of small quantities of cement leads to an increase in the friction angle of the material but not its cohesion whilst larger cement contents increase the soils cohesion as well. He also reports(p374) research that indicates that compressive strength in some soils is relatively unaffected by the friction angle but is directly proportional to the cohesion of the soil.

Based on the above work the senior author came to the conclusion that there must be a minimum cement content below which the cement volume was insufficient to develop any linkages between particles. Below this cement content the strength of the material

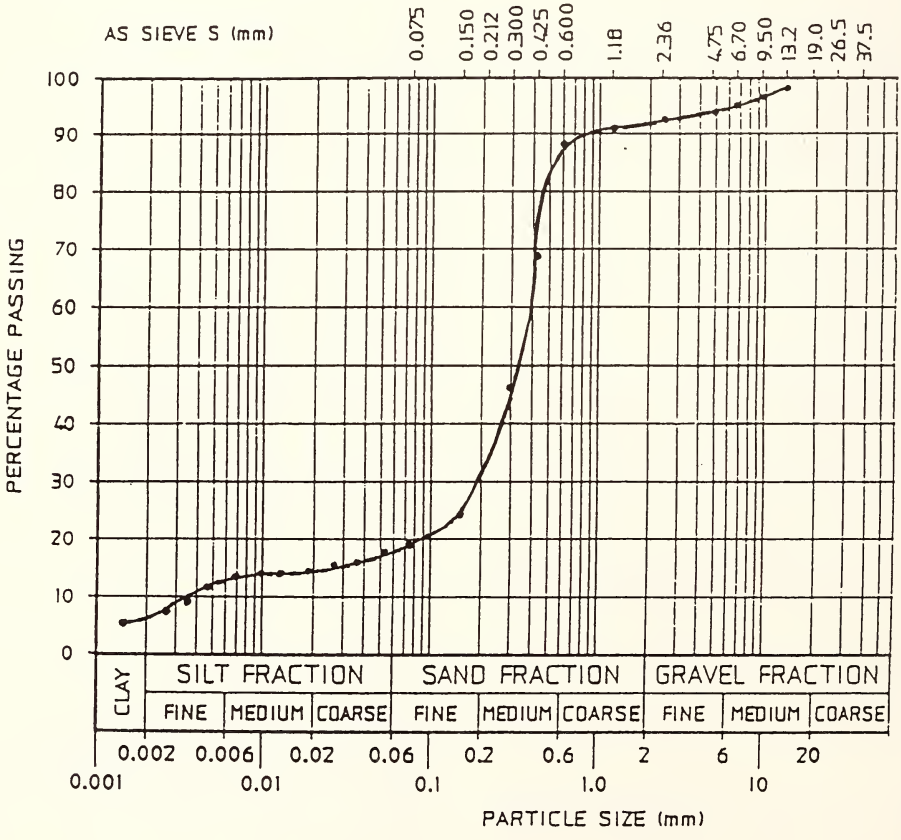

Figure 1 - Particle Size Distribution of Soil Used

is postulated to be inherent in the material. The theory is slightly complicated in clayey soils where part of the cement is initially used to break down the clay bonds and therefore research was initially aimed at granular soils.

EXPERIMENTAL PROCEDURE

Experiments were carried out by one of the authors at the University of Technology (Piper,1993) to determine if there was a minimum cement content below which the strength of a stabilised soil mix was independent of the cement content.
For the experiments 75/ 60 mm by 60mm sample blocks were pressed in a steel mould under a pressure of 7 MPa. The soil used was a sandy soil with 9 % gravel, 73 % sand, 12 % silt and 6 % clay. The particle size distribution of the soil is shown in Figure 1.

The cement content was varied between 0 and 3.5 % in increments of 0.25 % with 5 samples made for each cement content. The sample blocks were air-cured for 28 days and then oven-dried. The blocks were oven dried as previous research (Heathcote,1993) had shown that compressive strength is very sensitive to moisture content for low moisture contents and therefore it was desirous to ensure a uniform moisture content. The sample blocks were then tested in uni-axial compression and the failure stresses modified by a factor of 0.7 to take into account the aspect ratio of the samples.
The characteristic unconfined compressive stress of each cement content was defined as the 95 % value based on a normalised distribution i.e. equal to the mean failure stress of the five samples minus 1.65 times the standard deviation.

Results of the tests appear below in Table 1.

CEMENT %	AV DENSITY (kg/m^3)	MEAN STRESS (MPa)	S.D. (MPa)	CHARACTERISTIC STRESS (MPa)
0.00	1666	0.288	0.101	0.12
0.25	1705	0.295	0.072	0.18
0.50	1718	0.291	0.069	0.18
0.75	1764	0.322	0.048	0.24
1.00	1740	0.497	0.114	0.31
1.25	1745	0.689	0.071	0.57
1.50	1739	0.794	0.043	0.72
1.75	1756	1.007	0.106	0.83
2.00	1759	1.252	0.157	0.99
2.25	1764	1.455	0.147	1.21
2.50	1775	1.642	0.163	1.37
2.75	1793	1.683	0.156	1.43
3.00	1776	2.122	0.31	1.61
3.25	1784	2.048	0.142	1.81
3.50	1789	2.097	0.15	1.85

Table 1 - Test Results

CONCLUSIONS

The results of the tests are graphed in Figure 2 below.

The results show that significant strength can be achieved at relatively low cement contents. Although low in comparison to materials such as fired clay sample blocks and concrete the strength achieved at 2.5 % cement is adequate for most single storey buildings given that the walls of earth buildings are generally around 300 mm thick.

Figure 1 indicates a transition from a position where the strength is relatively independent of cement content to that where the strength is directly proportional to the cement content. That transition occurs at a cement content of around 0.75 %. A line of best fit has been drawn through the data and this indicates the effect of cement content to be 0.6 * C for cement contents over 0.75 % (C = Cement %).

The evidence as presented gives strong support to the authors proposition,viz., that there is a limiting cement content below which strength is independent of cement content. However further work will need to be carried out with soils of varying composition, in particular of varying clay content , before a generalisation can be made.

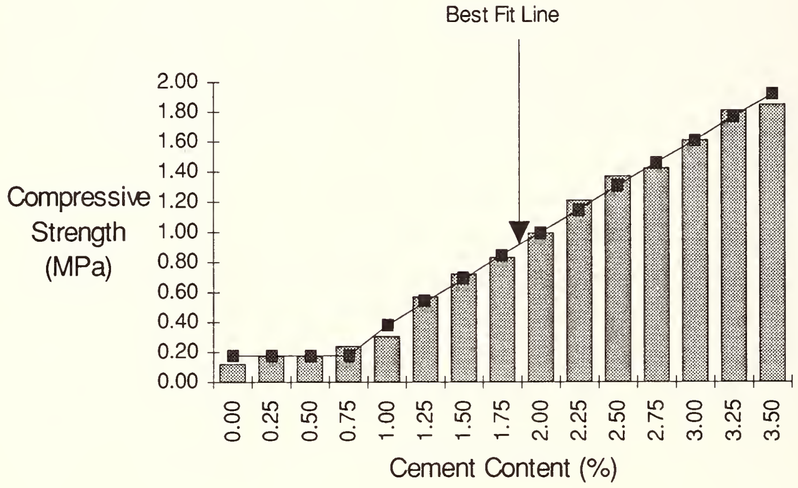

Figure 2 - Graph of Strength versus Cement Content

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BRECCIA FILLED DIATREME IN PERMIAN ILLAWARRA COAL MEASURES and TRIASSIC STRATA, KANDOS, NEW SOUTH WALES.

ANDREW DOVE AND GRAHAM LEE
(Communicated by P.C. Rickwood)

ABSTRACT: A previously unknown diatreme has been mapped at the ground surface and in underground colliery workings at Kandos in the western Sydney Basin, New South Wales.

The diatreme intrudes the Lithgow Coal of the Permian Illawarra Coal Measures and penetrates through the overlying Early Triassic Narrabeen Group sandstone strata to crop out at the surface, where it is almost circular (330 x 260m). In the colliery, 260m below the surface, it is a much smaller elliptical shaped body (200 x 60m). Large fragments of rock rafted from overlying strata occur within the diatreme and are exposed in the colliery workings. Along the diatreme margins flow banding indicates multiple injections of magma, while sulphide mineralisation is also developed. Coal at the contact is relatively unaltered, but at the ground surface the sandstones surrounding the diatreme have been metamorphosed to quartzite.

The diatreme is thought to have been emplaced by a phreatomagmatic reaction, arising from interaction of magma with the ground water contained in the Marrangaroo Conglomerate or the Berry Formation, underlying the Lithgow Coal. These units were probably about 300m below the water table at the time the diatreme was injected.

(All locations are indicated by Australian Map Grid references that relate to the CMA 1: 25,000 Topographic Maps 8832-1-S Ilford, 8832-1-N Kandos, and 8932-3-N Olinda. Only the sheet names are given subsequently.)

INTRODUCTION

The cement manufacturing town of Kandos is located on the western edge of the Sydney Basin, about 87km north of Lithgow. Coal for cement manufacture has been mined from the Lithgow Seam since 1917, commencing at the Kandos No. 1 Colliery and then mining was moved to the north when the No. 2 Colliery was opened. Igneous intrusions were encountered (Hamilton, 1968 p84-89) during the operation of both of these collieries.

The Kandos No. 3 Colliery [Olinda 193 613] which is located about 2km north-east of Kandos (see Figure 1) was opened in the early 1960's in the Permian Lithgow Coal beneath Triassic Narrabeen Group sandstones and small areas of Tertiary basalt, which together form an outlier, known as Cumber Melon Mountain.

In 1988 planning was undertaken to secure the long term future of the colliery by transporting remaining production to the surface on a conveyor belt haulage system. Options available for locating the required new headings were restricted by old abandoned workings. Two (2) exploratory drill holes were drilled by the authors on behalf of the colliery, to provide information on the nature and quality of the coal resources in the south-eastern part of the colliery holding. The first hole (DDH 1) [Kandos 192 602], was drilled on top of Cumber Melon Mountain (Figure 1) and a previously unknown igneous intrusion was encountered at relatively shallow depth, with the result that much of the material recovered was either igneous, or highly faulted and altered sedimentary rock. The Lithgow Coal was intersected, however the coal was broken by large sections of igneous material, had cindering, and contained sulphide bands and carbonate inclusions.

The second hole (DDH 2) [Kandos 193 605] was drilled 314 metres north of DDH 1, on a proposed alternative route for the new conveyor belt headings, but none of the problems associated with the initial hole were encountered and three (3) metres of Lithgow Coal was intersected.

GEOLOGIC SETTING

Permo-Triassic Stratigraphy

Figure 2 details the stratigraphy of the Western Coalfield as reported by Bembrick (1983) and Goldbery (1969), but modified to show only recognisable units and measured thicknesses at Kandos.

In the Kandos district the Illawarra Coal Measures are about 130m thick and the section above the Lithgow Coal has been observed in a number of colliery drill holes. Beneath the Lithgow Coal there is less information available as the strata are observed only in occasional outcrops. The coal measure sequence is dominated by non marine, dark grey claystone, mudstone and siltstone with some lithic sandstone units, and relatively thin conglomerate units at the base. Coal occurs principally near the top and bottom of the coal measure sequence.

The Blackmans Flat Conglomerate and Lidsdale Coal which occur as distinct formations along the

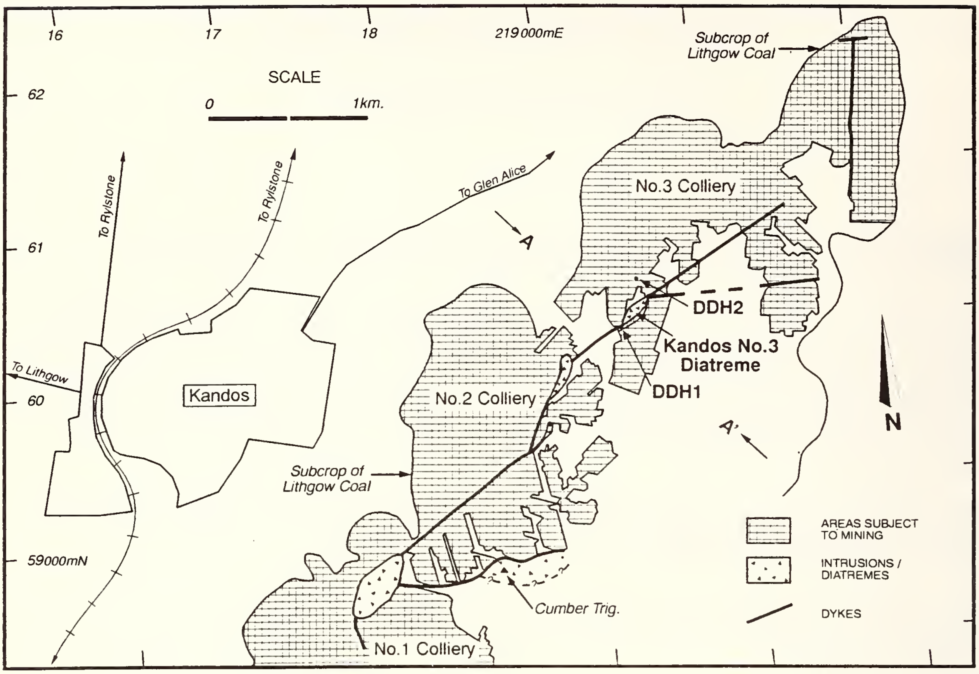

Figure 1.

Plan of Cumber Melon Mountain showing known intrusions and extent of colliery workings in the Lithgow Coal in 1990.

margin of the Sydney Basin in parts of the Western Coalfield are not recognisable, so the Long Swamp Formation includes correlatives of both of these units.

The Lithgow Coal typically occurs as five coal plies separated by thin claystone bands which range up to 100mm in thickness. The top claystone band is the thickest and has the highest ash content, and hence the coal above it is generally not removed during mining.

The Lithgow Coal is about 3.3m thick in the Kandos No. 3 Colliery, with the bottom part (approximately 2.5m) being the working section which yields a coal product with ash between 18% and 24%

The Narrabeen Group sandstones are of a distinctively different lithology to the underlying coal measures and comprise quartz sandstone with some pebble layers and only minor pale grey to white claystone units.

Intrusives

The first record of an igneous intrusion at Cumber Melon Mountain was made by Carne (1903, p155) and (1908, p100) from data gathered prior to the commencement of mining in the area. Subsequently, Bradley et al (1984, abstract and p9) noted that in the area east of Rylstone there are about 80 confirmed occurrences of igneous rocks and they recognised three (3) categories:

"(i) Diatremes, ...

(ii) Basalt caps/plugs, in which basalt and/or dolerite feeder vents intrude pre-existing diatremes ....

(iii) Basalt flows, ...

Sills and dykes can be associated with all three categories listed above."

Mitchell (1986 p74), defines diatremes as "Cone-shaped, downward-tapering, inclined or vertical structural units, composed wholly, or partly, of angular or rounded clasts of cognate or xenolithic origin, with or without matrix."

In the Kandos district diatremes usually have a negative topographical expression, while caps plugs and flows are always a positive feature. The diatremes poorly outcrop, but have rich soils that support tall trees and lush grass; rocks around the margin are often iron-enriched/silicified and brecciated.

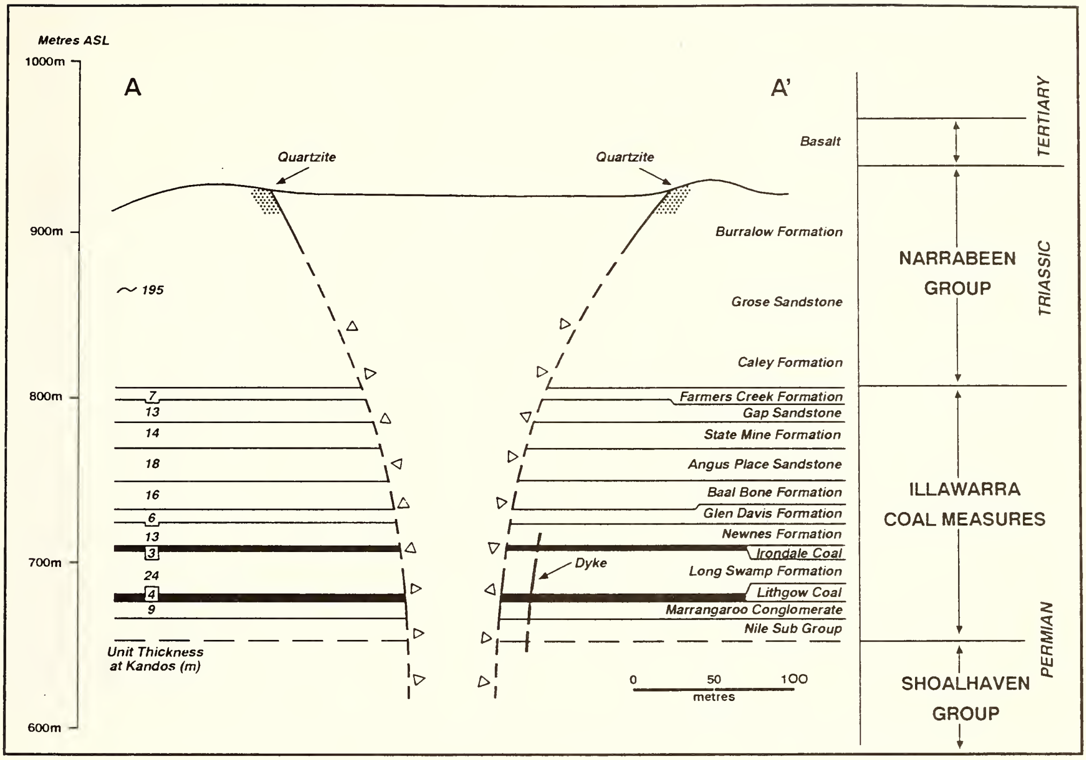

Figure 2.
North-west to south-east cross section through the Kandos No. 3 diatreme, including major stratigraphic units.

Regarding intrusions encountered as a result of coal mining beneath Cumber Melon Mountain, Bradley et al (1984, p25-27) record:

- two (2) basalt/dolerite plugs, with dimensions 300 x 200m and (beneath Coomber Trig) 200 x 150m with a 60-80m wide rim of cindered coal.
- two (2) breccia filled diatremes, with dimensions 100 x 60m and 80 x 60m.
- a dyke 1.6km long, and between 2m and 20m wide, which extends into a breccia dyke adjacent to diatremes and links with the plugs and diatremes.

Embleton et al (1985, p61) have dated basalt from Cumber Melon Mountain as Eocene in age (43.6 ±0.5 Ma by the K/Ar method), but O'Reilly (1989, p129) stated that the Kandos basalts have both Tertiary ages (ranging from 50 to 45 Ma), as well as Jurassic ages (190 to 170 Ma).

THE KANDOS No. 3 DIATREME

Figure 1 shows the extent of the Kandos No. 3 Colliery workings in 1990, approximately 2 years after commencement of the investigation. The new headings were in place and the first workings completed so as to expose the diatreme at the Lithgow Seam floor level, 257.8m below the collar of DDH 2.

The first drillhole (DDH 1) in 1988 was located on the southern end of the diatreme, near where it joins the dyke system and it penetrated the narrow contact zone at the level of the Lithgow Coal.

At the surface, the diatreme is a roughly circular shaped depression with maximum dimensions of 330m northeast-southwest and 260m northwest-southeast. The ground slopes evenly from the north to the south with a total fall of 28m and the soil is a dark greyish brown and is usually well covered with grass and scattered trees. Surrounding the diatreme are Narrabeen Group sandstones, which, except in the north and south-west, have been contact metamorphosed to form an erosion resistant rim of quartzite around part of the circumference, as shown in Figure 3. This rim is up to 5m higher than the eroded diatreme and is approximately 25m wide at its greatest development in the south-east, though generally it is much narrower.

The quartzite rim varies from an indurated sandstone with all sedimentary features and grain boundaries still apparent through various degrees of metamorphism to a highly altered, jointed quartzite with obscured grain boundaries and quartz vein development, Figure 3. Quartz veins are usually only 1 or 2mm wide forming a stockwork, but iron oxide enriched veins can be up to 300mm wide, often standing vertically and parallel to the margin of the diatreme; although smaller veins and stockworks mostly occur.

Columnar or "prismatised" sandstone has also been reported from elsewhere on Cumber Melon mountain - Bradley et al (1984, p29).

Surface mapping around the diatreme has not revealed any evidence of the dyke system that is exposed in the colliery workings below. Whether this is due to preferential weathering and erosion of the dyke material or non-intrusion at this level is not known.

Figure 1 shows the mapped boundary of the diatreme and dykes at the level of the Lithgow Coal where the diatreme is much smaller than at the surface. The shape has changed to an ellipse with major and minor axes (200 x 60m) and there is a dyke extending out from each end of the long axis. Effectively the diatreme is a bulge in a dyke structure. A parallel dyke also occurs on the south-eastern side, with an average separation of 15m from the main diatreme.

Structural disturbance of the Lithgow Coal is minimal, being just an increase in the frequency of small faults as the diatreme is approached and these have little impact upon mining.

Figure 4. Diatreme contact at the southern end near where it narrows to a dyke, at the location close to DDH 1.

Magma injection features are apparent, occuring as veins and veinlets along bedding and joint planes, as well as some apparently blind dykes. Disturbance to the coal is apparent by the bedding displacement in the lower centre of the figure.

The intrusion at this point dips away from the observer towards the south. Blocks of diatreme material which have fallen from the roof of the workings are on the floor in the foreground.

Figure 3. Close up of the quartzite from the surface rim of the diatreme showing development of quartz veins.

Magma injection features, (Figure 4) are veins and veinlets along bedding planes, joint planes (and cleats in coal) and less often, apparently randomly, as blind "dykes" into what appears as solid rock.

From the surface and underground exposures it is possible to obtain some definite control on the shape of the diatreme and Figure 2 shows this as a cross section. Also shown is the surface topographic expression of the quartzite in the contact zone.

Carne (1908, p100) described the igneous rock at Cumber Melon Mountain as olivine-basalt, but Bradley et al (1984, p26) in a cross section showed both basalts and dolerites. Underground at Kandos No. 3 Colliery the igneous rock is now weathered and largely altered, with brown and white clay minerals present. A relict texture which could be consistent with dolerite is apparent in some exposures of both the diatreme and the adjoining dyke, and clay particles which could be derived from weathering of feldspars or filling of amygdules are aligned parallel to the margin, suggesting flow banding possibly due to multiple intrusions or pulsating phases of a single intrusive event.

Alteration of the Coal

Cindering and alteration of the coal is restricted to a narrow zone, usually less than 1m wide, and is mostly indicated by coking of the bright coal laminae in the otherwise dull coal. Only within a few tens of centimetres of the intrusion is there any apparent alteration of the dull coal.

Towards the intrusion ash levels in the coal increase slightly, by about 2 or 3%, for the full working section including bands, and the amount of visible sulphide minerals on cleats also increases. None of the coal produced shows any significant change in other properties from those normally expected.

Xenoliths

For the most part the xenolith and breccia fragments are surrounded by a matrix of lava but the relative proportions vary significantly throughout the observed exposures of the diatreme. Breccia is only observed within 0.3m of the walls, and may have a subordinate amount of associated larger xenolith material. The largest xenolith blocks occur in zones which are free of breccia.

Only very narrow zones of finely brecciated fragments occurring along the margin of the diatreme are not supported by a lava matrix. They contain clasts of coal measure lithologies, together with fragments of volcanic rock which are similar to the lithologies exposed in the adjacent workings and diatreme areas. In a few zones a sulphide mineral (marcasite?) is abundant together with volcanic breccia but little, or no, brecciated coal measure lithologies.

Exposures of the southern end of the diatreme, in the vicinity of Figure 4 (near DDH 1 on Figure 1) contain little xenolith or breccia material; instead these areas are dominantly composed of lava.

Figure 5.

Diatreme at the north-eastern end showing vetical face and sloping roof containing large xenolith of country rock rafted from the strata above the Lithgow Coal. The western contact between the coal and the intrusion is apparent on the right hand side of the figure, showing flow banding near the margin of the intrusion. Rounded and milled surfaces are showing on some xenolith blocks particularly near the centre of the figure.

Material fallen from the roof is in the foreground.

The xenoliths are of two types:

(i) coal measure derived rocks appear to be derived from above the level of the Lithgow Coal. They constitute more than 90% of the xenoliths.

(ii) exotic rock types, of which granite and acid volcanics are the most frequently observed and were presumably derived from beneath the coal measures.

Coal measure derived xenoliths (Figure 5), which range in size up to blocks with at least one dimension exceeding 2m in length, often have rounded and polished surfaces, and in places are slickensided. The largest block exposed in the workings is estimated to have a mass in the order of 20 tonnes. The most abundant xenolith type is dark grey claystone and laminite typical of the Long Swamp Formation, which occurs immediately above the Lithgow Coal, but similar lithologies are also present in parts of the Newnes and Baal Bone Formations higher in the coal measure sequence. Other xenolith compositions include fine grained, well bedded sandstone and laminite lithologies which are randomly orientated (Figure 5).

DISCUSSION

Mitchell (1986, p81) considered that diatreme root zones originate as enlargements of dykes and Lorenz (1985, p467 & 1986, p270) gave instances of dykes being precursors, and inferred that the magma in the dyke fissure encountered ground water within the zone of structural weakness, and hence the phreatomagmatic eruption was localized.

Thus a series of diatremes may occur along the line of a dyke, as is the case at Kandos (Figure 1).

Other features of the No. 3 diatreme that are consistent with the Lorenz model include:

- Conical shape (Figure 2).
- The blocks of country rock at seam level appear to have been mostly derived from higher stratigraphic horizons.
- There is little or no visible thermal metamorphic effect on intruded blocks, even though many of them are highly carbonaceous, black and dark grey claystones, mudstones and siltstones.
- The rounded and milled surfaces on many of the blocks of country rock are consistent with the blocks being tumbled in an explosive environment.
- There are at least two possible aquifers which may have provided the water required to drive a phreatomagmatic eruption:

    i) the Marrangaroo Conglomerate

    ii) parts of the Berry Formation.

Both the Marrangaroo Conglomerate and Berry Formation are well developed along the Western margin of the Sydney Basin, and Dove (1986, p83) recognised the Marrangaroo Conglomerate and the top of the Berry Formation as aquifers in areas near Baal Bone 48km south of the Kandos site. Based on the thickness of the stratigraphic interval from the base of the Tertiary basalt to the top of the Marrangaroo Conglomerate on Cumber Melon Mountain, it is estimated that when the No. 3 diatreme was emplaced, the Marrangaroo Conglomerate was buried beneath approximately 315m of overlying Permo-Triassic sediments.

The underlying Berry Formation would therefore have been covered by at least 325m of sediment. Both of these aquifer units occur in or near the zone of eruption initiation, which Lorenz (1985, p466) suggests should be in the order of 200-300m below the water table.

Modern day basalt capped plateau areas in the Kandos region, such as Cumber Melon Mountain, can reasonably be assumed to have been Tertiary valleys or plains at the time the Tertiary basalts were extruded. It is therefore fair to assume that the water table at the time of eruption was at about the level onto which much of the extruded basalt flowed at Kandos. That is, that the water table was close to the base of the Tertiary basalt beds. The distance between the base of the basalt and the Marrangaroo Conglomerate at the base of the Lithgow Coal would have provided an appropriate cover thickness and water table depth to initiate a phreatomagmatic eruption.

The Kandos igneous system is evidently related to a deep NE-SW fracture zone which is partly occupied by dykes. At the level of mining the NE-SW dykes are offset sinistrally at the Kandos No. 2 Colliery the segments are linked by a connecting dyke. The SW dyke segment has two diatremes, one near its SW end at Kandos No. 1 Colliery and the other at the end of the 'horn' that extends beyond the connector to the NE segment in the Kandos No. 2 Colliery, (Figure 1). The large diatreme at the southern end of the dyke system is linked by a curved dyke extending to the east and joining into another large intrusion which is beneath Coomber Trig. The NE segment has one diatreme at its SW end and another roughly midway along its proven length.

At the time of dyke injection, the stress field at the Kandos No. 2 Colliery area was rotated clockwise relative to locations towards the ends of the dyke system and this produced the sinistral offset, yet the dyke remains relatively straight. However, near both the Kandos No. 1 and Kandos No. 3 Colliery diatremes there are dykes with apparent pronounced curves; that are atypical of dykes. At both locations there are subsidiary dykes that for part of their known length follow the regional NE-SW trend but curve so as to link with the diatreme.

At the Kandos No. 1 Colliery the dykes are radial to the diatreme but at the Kandos No. 3 Colliery the dyke follows a path that is almost a full quadrant of the circumference of a circle (Figure 1). Both radial and ring features occur around 'sub-elliptical' intrusions so it seems probable that these dykes, and that at Kandos No. 3 Colliery in particular, have occupied a pre-existing fracture system generated by intrusion of the diatremes. Hence, it is suggested that at least two intrusion episodes occurred - first the main NE-SW dykes and associated diatremes and later a second phase of dykes. At this stage neither composition and age differences are known.

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Lachlan and New England: Fold Belts of Contrasting Magmatic and Tectonic Development

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ABSTRACT. New South Wales contains significant parts of two fold belts, Lachlan and New England, which provide contrasting examples of tectonic development. The Lachlan belt is of distinctive and unusual character, with little evidence for its development according to processes of subduction and plate tectonics. The massive ca 400 Ma magmatic event in the Lachlan involved the vertical redistribution of older crust with little production of new crust. Granites of this age were apparently continuous from northern Victoria Land to at least Cape York Peninsular, a distance of 3600 km, in what is termed the Lachlan-Cape York Granite Belt. In contrast to the Lachlan belt, New England shows excellent evidence for modern-style tectonic development, including the some of the sedimentary, metamorphic, plutonic and volcanic rocks found in younger fold belts. In contrast to the Lachlan, the evolution of New England during the late Palaeozoic involved substantial production of new crust, consistent with the primitive isotopic compositions, and the uplift of the belt. Granites provide a useful tool in studying the crust because they compositionally image their source rocks in the deep crust. Application of this principle has shown that large areas of the Lachlan belt are underlain by a thick layer of sedimentary rocks that are less evolved, i.e. more feldspar-rich, than the exposed Ordovician sediments. To overcome the problems associated with the deposition of the deep water marine Ordovician sediments on older sedimentary crust, it is proposed that the older basement may have been thinned by crustal extension, which could have lead to deposition of the Ordovician sediments on a depressed basement, and an enhanced heat flow that resulted in massive amounts of melting. I-type granites of the Lachlan are dominantly granodioritic and unlike those of a Cordilleran belt. In contrast, the Clarence River Supersuite of the New England Batholith is distinctly Cordilleran in character. Among the other rather diverse granites of New England, the Moonbi Supersuite may represent an analogue of the potassic rocks of the Sierra Nevada Batholith. The Clarence River type probably represents the partial melting of a basaltic underplate, while the Moonbi source rocks were distinctly shoshonitic and in some cases enriched to very high levels in elements such as Sr, Ba, Pb and Th. The isotopic composition of all of the New England granites, including the S-types, is relatively primitive, consistent with the development of the belt as new crust during the late Palaeozoic. While the igneous rocks of the Lachlan belt can be used to argue strongly against its development by the accretion of new crust, those of New England have features that point strongly the other way. A comparison of the granites in the two belts thus confirms the distinctive character of the Lachlan. It is suggested that some of the significant structural features of the Lachlan belt may be related to events in New England. The strong late-Devonian (Tabberaberan) deformation in parts of the Lachlan was coeval with activity in the Baldwin Arc and may have resulted from the collision of a major part of the evolving New England Orogen with the cratonic Lachlan belt. Likewise, the later Carboniferous (Kanimblan) deformation may have been related to the Andean volcanic chain that later developed in western New England.

INTRODUCTION

This paper is presented in honour of the Rev. W.B. Clarke, who was the first person to record many of the geological features of the area south of Berridale where with Allan White, I started my own studies of the Lachlan Fold Belt in 1963. In his reports on gold in southern New South Wales written for the New South Wales government, Clarke (1860) mentioned the presence of granites intruding the slates in what we now call the Berridale Batholith. That batholith was the starting point for our studies of granites that have since extended throughout the Lachlan belt. These granites have many distinctive features that distinguish them from the younger granites of the New England Fold Belt to the north-east, just as other features of the two fold belts show some distinct differences. The contrasting features of the granites have important implications for the tectonic evolution of these two fold belts, which will be considered here.

TWO CONTRASTING FOLD BELTS

Significant segments of two major and contrasting fold belts, Lachlan and New England, comprise the basement of the eastern part of the state of New South Wales. This is a particularly opportune time to review the evolution of these two belts, with the publication within the last few years of two important volumes of research papers. The volume edited by Ferguson and Glen (1992) contains the proceedings of the LFB91 symposium on the Tectonics of the Lachlan Fold Belt. Flood and Aichison (1993) have subsequently compiled a volume of papers submitted to the NEO93 symposium on the New England Fold Belt.

Studies of the granites of these two belts have inevitably lead to considerations both of the tectonic settings of the granites, and what they tell us about broader aspects of the evolution of the Earth's crust. Granites are a valuable tool in studying the crust of the Earth. This is because as magmas they come mostly from the deeper parts of the crust and carry information with them about the composition of those deeper zones. They can provide a depth dimension to our studies that would otherwise be much less detailed. We can also compare these granites with those in younger belts whose evolution is better understood. Granites do not of course provide the complete picture of the evolution of the crust in any area, but they are a significant element in developing that picture. It is the contribution provided by their study that will be examined here.

GRANITES AND THEIR SOURCE ROCKS

Granites that have come from the deep crust to higher levels carry compositional information about their source rocks: they "image" the deep crust (Chappell, 1979). There is a great deal of empirical evidence that they do this. For example, the subdivision of granites in both the Lachlan and New England fold belts into I- and S-types is based on the observation that the latter group have chemical characteristics such as low Na and generally low Fe^{3+}/Fe^{2+} that they have inherited from sedimentary rocks. The provincial character of some elements or groups of elements can only be the result of the inheritance of source characteristics, e.g. the high Ba and low Fe^{3+}/Fe^{2+} of all granites in the region north of Melbourne (Melbourne Basement Terrane), the low K and very low Rb of the Clarence River Supersuite and the very high Ba, Sr, Pb and Th of some units of the Moonbi Supersuite. The striking transverse patterns for some elements in the Bega Batholith must be the result of similar patterns in the source rocks since they correlate so strongly with isotopic patterns (Chappell *et al.*, 1990). It is this correlation between source and granite compositions that results in granite suites, where each suite can be correlated with a source rock of distinct composition.

A correlation between the composition of a granite and its source rock can result either from a granite melt carrying unmelted refractory material from the source, the *restite model* (Chappell *et al.*, 1987), or by melting proceeding to a higher temperature so that the more refractory components are incorporated in the melt (Chappell and Stephens, 1988). The relative importance of these two mechanisms is controversial (e.g. Wall *et al.*, 1987) but in the present context the mechanism is perhaps less important than the empirical observation that imaging does occur, discussed in the previous paragraph. A similar correlation between granite and source rock compositions would also result from magma mixing, with each granite

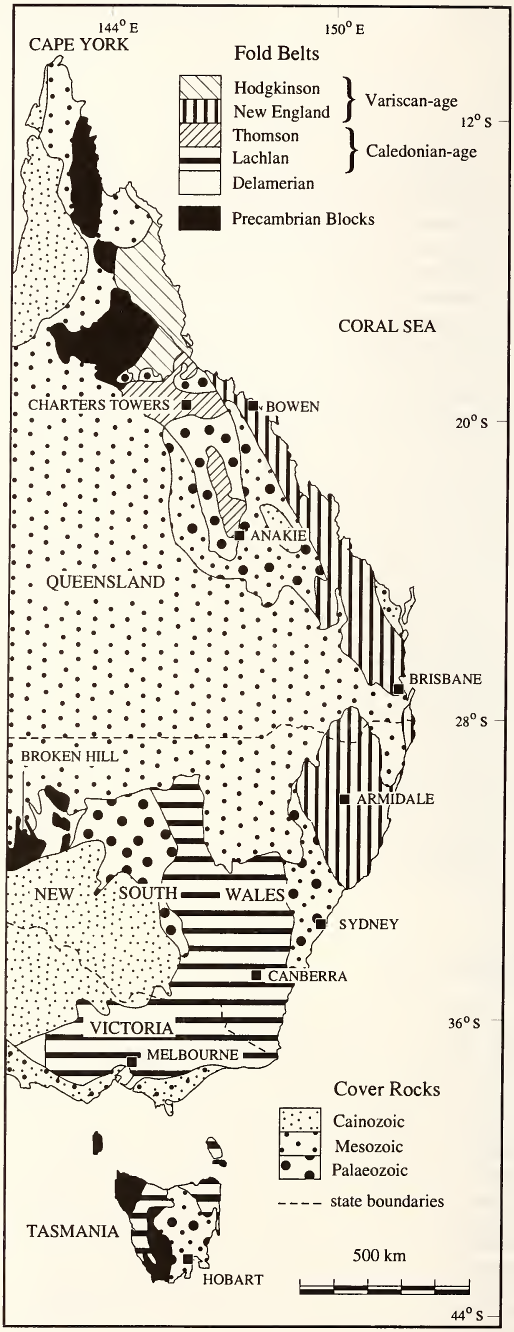

Fig. 1

Figure 1. Sketch map showing the Palaeozoic Fold Belts of eastern Australia. The Delamarian Fold Belt extends further west of the map area and the granites within it are Ordovician in age. Granites intruding both the Lachlan and Thomson Fold Belts and the Proterozoic rocks of North Queensland and Tasmania are Silurian to Carboniferous in age and are assigned to the Lachlan-Cape York Granite Belt. Granites intruding the New England and Hodgkinson belts are of Carboniferous to Cretaceous age. The New England Batholith occurs within the southern segment of the New England Fold Belt, mainly in New South Wales. The Permian-Triassic Sydney-Bowen Basin separates the New England Fold Belt from the Lachlan and Thomson Fold Belts and is itself partly covered by the eastern extension of the Great Artesian Basin.

composition reflecting a composition between those two source components. However, such mixing on a large scale to produce the compositional ranges seen in granite suites is untenable, at least in these two fold belts, because of the correlation in abundances of elements at both the mafic and felsic ends of groups of suites.

LACHLAN FOLD BELT

The Lachlan Fold Belt (LFB) of southeastern Australia evolved during the early and mid-Palaeozoic at the active margin of the Australian continent (Figure 1). The belt was located at the eastern edge of the older continent and the early Palaeozoic Delamarian Fold Belt. It probably included components now located in western New Zealand (Cooper and Tulloch, 1992; Gibson, 1992). It is now separated from the younger New England Fold Belt or New England Orogen (NEO) by the sedimentary rocks of the Sydney Basin. The belt is 750 km wide and it has been claimed (e.g. Coney, 1992) that if shortening of the sedimentary sequences is allowed for this width could have been as much as 2000 km before deformation. VandenBerg and Stewart (1992) have suggested that this width could be due to doubling up of the belt by large-scale strike slip faulting.

There are two dominant components to the LFB. First are the rather monotonous sequence of deep water deposits of Ordovician age. Second are the more than 800 distinct bodies of granite that together comprise 20% of the total area, for which the Ordovician sediments form the matrix. Granites comprise 36% of the area of the eastern one-third of the belt and related volcanic rocks are also particularly abundant (15%) in that eastern part (see map of Chappell *et al.*, 1991). Other components of the belt include an area of mafic shoshonitic volcanic rocks in the northern part (Wyborn, 1992) and a strip of high temperature-low pressure regional metamorphic rocks near the centre, the Wagga Metamorphic Belt, known as the Omeo Metamorphic Complex where it is best developed in Victoria (Morand, 1990).

The LFB is an anomalous orogen (Fergusson and Glen, 1992), at least by the standards of young fold belts. It is wide and is also part of a zone of magmatic activity at least 3600 km long, discussed below. It lacks extensive high grade metamorphic rocks and thrust belts, and structures while sometimes complex are generally upright. Melange and high-pressure low temperature metamorphic rocks are absent. The same lithotectonic assemblages and general structural style and level are found across the entire orogen, so that juxtaposed tectonostratigraphic terranes are not seen (Coney, 1992). However the granites of the belt do have distinct provincial characteristics which have been taken by Chappell *et al.* (1988) to imply the present of "basement terranes" at depth. During the Silurian and Devonian, this belt had an exceptionally high heat flow. Granites and related volcanic rocks are extraordinarily abundant and S-type granites are slightly more abundant than I-types, with a minor component of A-type granites (~0.7%). The I-type granites and associated volcanic rocks never have compositions similar to those of modern arc rocks, and very rarely to the tonalites of the Cordilleran magmatic belts, so that there is no petrological evidence for subduction. Most of the S-type granites have compositions inappropriate for a derivation from the surrounding Ordovician sedimentary rocks. This has lead to the proposal that those Ordovician flysch rocks were deposited on continental crust (White *et al.*, 1976) which, if true, is the most unusual feature of the belt. Finally, the abundance in places of volcanic rocks and the lack of high pressure metamorphic rocks point to the belt never having undergone significant uplift.

Despite these distinctive features, numerous attempts have been made to fit the LFB into tectonic models developed for younger belts, with, for example, growth having occurred through the lateral accretion of islands arcs (e.g. Crook, 1980; Collins and Vernon, 1992), or through the assembling of tectonostratigraphic terranes (e.g. Fergusson *et al.*, 1986; Leitch and Scheibner, 1987). The geological development of the LFB has been a controversial subject during the last twenty years as efforts have been made to fit this rather unusual belt into a framework provided by plate tectonics, despite its unusual characteristics. As Coney (1992) has put it, "a number of scenarios have been proposed down the years ranging through almost every plate tectonic setting imaginable to sentiments that the belt has nothing to do with plate tectonics".

Ages of Lachlan granites

Reliable radiometric ages on granites of the LFB are sparse. Most are in the 440 to 390 Ma interval with some plutons to 360 Ma in the central part of the belt north of Melbourne (e.g. Williams *et al.*, 1975; Compston and Chappell, 1979; Richards and Singleton, 1981; Williams, *pers. comm.*). The granites of western Tasmania are distinctly younger, with a total range from 380 to 330 Ma reported in the summary of Williams *et al.* (1989). 2800 km^2 of plutonic rocks of Carboniferous age, ranging from 340 to 312 Ma and peaking at 325-320 Ma (Shaw and Flood, 1993), are present in the most easterly part of the belt, north and south of Bathurst. The compilation of granite ages of Powell (1984) suggests that there was a regular eastward migration of the pre-Carboniferous granite magmatism in the eastern half of the belt. This suggestion has been taken up recently by Collins and Vernon (1992) in their tectonic model and more recently by Collins (1994). However, SHRIMP ion probe data (I.S. Williams, *pers. comm.*) show that the Cooma Granodiorite in the eastern part of the belt is significantly older than was previously thought, with an age close to the oldest reported age in the LFB from 200 km further west, while the Kameruka Granodiorite near the eastern edge of the Bega Batholith, has an age ~420 Ma (Williams, 1992), comparable with that of the I-type granites of the Berridale Batholith, 150 km to the west. The only area of systematically younger ion probe ages among the pre-Carboniferous granites is at the eastern edge of the Bega Batholith and within the Moruya Batholith, close to the eastern edge of the belt (I.S. Williams, *pers. comm.*).

A Lachlan-Cape York Granite Belt

The most southerly occurrence of granite in the LFB is in southeastern Tasmania (Figure 1). Before the opening of the Southern Ocean these rocks were continuous with the Admiralty Intrusives of northern Victoria Land. The latter rocks are restricted to the northernmost part of the Trans-Antarctic Mountains so that granites of this age appear to have a natural southern limit. The northern limits of the LFB are imposed by cover rocks of the Eromanga Basin but the belt is likely to have a very considerable extension beneath that basin, as indicated by four radiometric ages ranging from 426 to 405 Ma on basement rocks (Murray, 1986; Figure 1 this paper) and the lithology of those rocks in about 45 wells that penetrated basement. Murray (1986) reports that the basement is remarkably similar over a large area and includes metamorphosed greywacke and mudstone. Further north, rocks of Lower Palaeozoic age appear from beneath cover rocks in the Thomson Fold Belt, although these are in part, probably older than the Ordovician rocks of the LFB.

K-Ar dating suggests that the rocks of the Anakie Metamorphic Group were deformed and metamorphosed at around 510 Ma, corresponding to ages in the Delamarian Fold Belt (Withnall *et al.*, 1994). These metamorphic rocks could be equivalent to at least part of the unexposed basement rocks of the LFB. They are intruded by the mainly I-type Retreat Batholith for which ages ranging from 385 to 366 Ma have been reported by Withnall *et al.* (1994). Further north, granites of Silurian-Devonian age occur in the Cape York Plutonic Belt that extends from the Charters Towers district to the northern end of the Coen Inlier (Bain *et al.*, 1994), intrusive into both Palaeozoic rocks and Proterozoic rocks in the Georgetown and Coen Inliers. A major deformation and intrusion event occurred in the Georgetown Inlier at about 430 Ma (Bain *et al.*, 1994). Knutson *et al.* (1994) report an average age of 407 Ma for the extensively developed Silurian to Devonian age granites of the Cape York Peninsula Batholith.

It is apparent that prior to the opening of the Southern Ocean, granites which formed at a time close to 400 Ma occurred between northern Victoria Land, and at least Cape York, a distance of 3600 km. It is here proposed to call this major belt of magmatic activity at the edge of the Gondwana continent, the *Lachlan-Cape York Granite Belt*. There is a close similarity between the ages of this belt and those of the Caledonian belt of northwestern Europe and the Appalachian Fold Belt of north-eastern North America.

APPLICATION OF GRANITE STUDIES TO THE LACHLAN FOLD BELT

In an early application of granites to studying the deeper parts of the crust, White *et al.* (1976) defined an I-S line marking the eastern limit of exposures of S-type granites in the LFB. They stated that this line marks the eastern limit of thick crystalline crust, possibly of Precambrian age. Within the Berridale Batholith, where the line was first recognised, the line separates I-type granites in the east from mainly S-type granites to the west. Chappell *et al.* (1988) later extended this line from Bass Strait to the northern limit of LFB exposures at the southern edge of the Eromanga Basin.

Some implications of studies of S-type granites

The occurrence of the strongly peraluminous and hence distinctly S-type granites of the Bullenbalong Supersuite west of the I-S line implies the presence of thick metasedimentary crust. Those granites can not have been derived by partial melting of the exposed Ordovician sediments. This can be seen from the plot of CaO against total SiO_2 for 151 Ordovician sedimentary rocks and 68 samples of the Bullenbalong Suite in Figure 2. It is clear from that diagram that the sedimentary rocks do not contain sufficient Ca for them to have been the source material for those granites, and that either more Ca-rich sedimentary rocks were involved, or an additional Ca-rich component was present in the source. A similar situation exists for the other elements, Na and Sr, lost when feldspars are weathered to clay minerals. There are also significant differences between the isotopic compositions of these granites and those of the sedimentary rocks, with the granites having significantly less evolved Sr and Nd isotopic compositions (McCulloch and Chappell, 1982). These data have been interpreted in terms of deriving the Bullenbalong Suite from source material less mature than the Ordovician rocks (White and Chappell, 1988), and forming the basement to those rocks. This is consistent with these S-type rocks (the batholithic S-type granites of White and Chappell, 1988) occurring as intrusive masses in a contact aureole environment, and with geobarometry (Wyborn *et al.*, 1981) indicating that the S-type volcanic magmas were generated at depths ~15-18 km. Since this interpretation of the data is critical to understanding the tectonic evolution of the LFB, it is necessary to examine an alternative model that has been proposed.

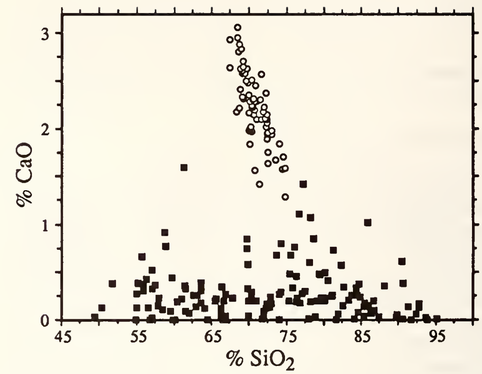

Figure 2. Plot of CaO against SiO_2 for 151 Ordovician sedimentary rocks from the Lachlan Fold Belt (filled squares) and 68 granites of the Bullenbalong Suite (open circles).

Gray (1984) argued that the variations in initial $^{87}Sr/^{86}Sr$ values in the Lachlan granites result from mixing of basaltic material and granitic melt derived from the melting of the Ordovician sedimentary rocks. Gray (1990) states that "the basaltic component is possibly intrusive into the source as dykes or their metamorphosed equivalents, but more likely intrusive into the granitic magma and dispersed into it by the mechanical breakdown of mafic xenoliths". However, metaluminous enclaves that could have been derived from such basaltic material are extremely rare in the mafic S-type granites of the LFB (Wyborn *et al.*, 1991; Chappell *et al.*, 1994a; c.f. Vernon, 1983; Wall *et al.*, 1987). This is a strong argument against the basalt mixing model. While such a mixing model might account for the isotopic systematics of the granites, it does not accord with some of their chemical features. Mixing of basalt with material derived from the Ordovician sedimentary rocks would increase the Ca, Na and Sr abundances as required, although not necessarily by the appropriate amounts. The amount of any mantle component in the mafic S-type granites is limited by their strongly peraluminous nature. Within individual suites of the Bullenbalong Supersuite, the degree of Al saturation (or of per cent. normative corundum) increases with Fe content as the rocks become more mafic (Figure 3). This is not consistent with the presence of a larger basaltic component in the more mafic rocks. Gray (1990) argued, however, that the trend of decreasing Al saturation as the rocks become more felsic was due to fractionation of a previously mixed composition, rather than a decreasing basalt component within the suite. Fractionation of Al-rich minerals such as biotite and cordierite that are present in the more mafic rocks would have that effect, but would imply a strongly peraluminous starting composition. The mafic and most peraluminous rocks are not cumulates enriched in Al-rich minerals; they are magmatic (a fluid mix of melt plus solid) compositions, shown by the complete equivalence in composition between S-type plutonic and volcanic

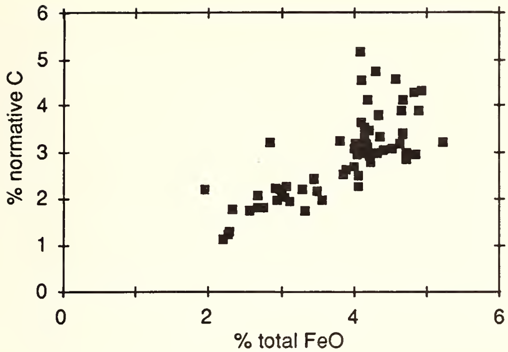

Figure 3. Plot of normative corundum versus total FeO for granites of the Bullenbalong Suite.

suites in the Kosciusko Province west of the I-S line (Wyborn *et al.*, 1981; Wyborn and Chappell, 1986; Chappell *et al.*, 1987). The implication is that mixing to produce the source rock must have been between a peraluminous S-type melt containing more normative corundum than is typically observed in the mafic rocks of the Bullenbalong Suite (~4%) and a metaluminous mafic composition. The Cooma Granodiorite composition nominated by Gray (1984) as his crustal melt end member contains 5.8% normative corundum (sample CC1). This is an appropriate amount of corundum, but difficulties remain. Such a composition (72% SiO_2 and 0.95% Na_2O; also 1.49% CaO) would be extremely refractory in terms of completely melting, and there is a general consensus that the strongly peraluminous Cooma composition is not that of a melt. To make things even more difficult, it is now commonly accepted that the Cooma granite was not derived from typical Ordovician sedimentary rocks (an average of 151 analyses contains 0.27% CaO and 0.90% Na_2O), but either from relatively feldspar-rich Ordovician material, or from unexposed older rocks of that character (Steele *et al.*, 1991). Any melt derived from the Ordovician sedimentary rocks, as postulated by Gray (1984), would have been derived from an even more refractory source than was the Cooma Granodiorite! The granite end-member of Gray (1984) is therefore not easily produced, and certainly not in the volumes required, also there is no direct evidence for the basalt end-member. Hence, the argument for a less mature sedimentary source which partly melted to give granite melts containing ~1% normative corundum plus a mafic and strongly peraluminous restite fraction, to account for the composition of the Bullenbalong Suite and other similar S-type granites, seems unequivocal. A detailed discussion of the petrogenesis of the more mafic S-type granites of the LFB is being prepared by Chappell *et al.* (1994b).

A mantle component is not required by the composition of these rocks, there is no evidence for such material, and if it is present it must be in small amounts. Therefore the view is taken that the S-type granites were effectively derived exclusively from sedimentary material within the crust (Chappell and White, 1992). Since this material was different in composition from the exposed Ordovician strata, there is the important implication that there is a thick metasedimentary substrate to those rocks, at least in areas in which S-type granites are present. This is the view originally expressed by White *et al.* (1976) which has become more generally excepted, in spite of the implied difficulties with tectonic models (e.g. Crawford, 1983; Crawford *et al.*, 1984; Fergusson *et al.*, 1986; Glen *et al.*, 1992; Glen, 1992). Those authors propose either that the metasedimentary substrate was underthrust beneath the belt following the deposition of the Ordovician sediments on oceanic crust, or that the Ordovician sediments and their oceanic substrate were thrust over metasedimentary rocks. Gibson (1992) has suggested that the metamorphosed Lower Palaeozoic rocks of Fiordland, New Zealand, may give some indication of what lies at depth beneath the LFB.

The problems raised by the acceptance of a thick metasedimentary substrate to the LFB will be examined at after the I-type granites of the belt have been considered.

The significance of the I-type granites

Strong arguments can also be made for a crustal origin for the I-type granites of the LFB. Following Chappell (1984) they include the fact that many of these granites, including some mafic ones bearing a substantial restite component, involved melting at 'minimum' temperatures in equilibrium with quartz and two feldspars, so that the depth of feldspar stability was not exceeded. Second, most of the rocks are potassic, in contrast to the calcic granites of some young fold belts which might contain a component of mantle or subducted oceanic crust origin. Third, all oxygen isotope compositions are significantly higher than mantle values and, finally, most Sr and Nd isotopic compositions are more evolved than mantle values.

All I-type granites are derived ultimately from the Earth's mantle, either by fractional crystallisation of a melt, or by fractional melting of previously solidified mantle-derived material. Either process of fractionation would occur within the crust and undoubtedly both do occur. However, in the LFB the second is favoured in the general case because first, the amount of unfractionated mantle-derived material (gabbro) is very small, comprising less than 0.1% of the total area of the plutonic rocks, and second, the granites are often isotopically distinct from mantle materials, and there is evidence that this is due to aging of mantle-derived materials rather than mixing with isotopically evolved older crust (Compston and Chappell, 1979; Chappell and McCulloch, 1990). Under this scenario, the I-type granites of the LFB are of *indirect* mantle origin (Chappell and White, 1992).

The more mafic I-type granites of the LFB range from very rare quartz diorite through tonalite and dominant granodiorite to monzogranite. Mafic cumulate rocks are uncommon and appear be restricted to the Boggy Plain Supersuite (Wyborn *et al.*, 1987). Associated gabbro masses occur but are rare. The more felsic I-type granites are granodiorite and monzogranite. For many suites, the most felsic rocks are thought to be close to primary melt compositions and extended crystal fractionation from such melts was uncommon. These rocks are dominantly granodioritic in contrast to the mainly tonalitic rocks typical of many parts of the Cordillera, such as the Peninsular Ranges Batholith (PRB). This difference is shown clearly in Figure 4 which also makes the important point that while there is overlap in compositions between the two areas, their modal compositions are quite distinct. K_2O is much more abundant in the Lachlan rocks (average 3.46% vs 1.95%), Na_2O is a little lower (3.15% vs 3.62%). The PRB granites are distinctly more calcic (average 5.10% CaO) than the Lachlan (3.16%)(PRB averages from Silver and Chappell, 1988). In only one case, in the most mafic rocks of the Moruya Suite, do the granites match the composition of Cordilleran tonalites at all closely and in that case they are associated with dominant felsic rocks. Chappell and Stephens

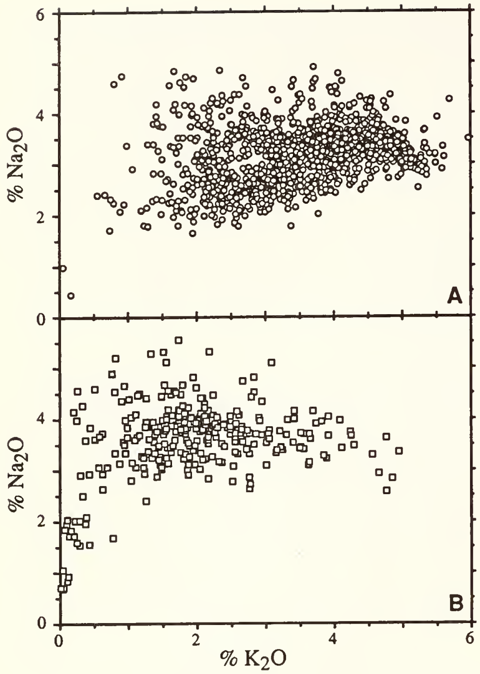

Figure 4. Plot of Na_2O against K_2O for I-type granites and related gabbros of (A) the Lachlan Fold Belt (1156 samples) and (B) the Peninsular Ranges Batholith (323 samples).

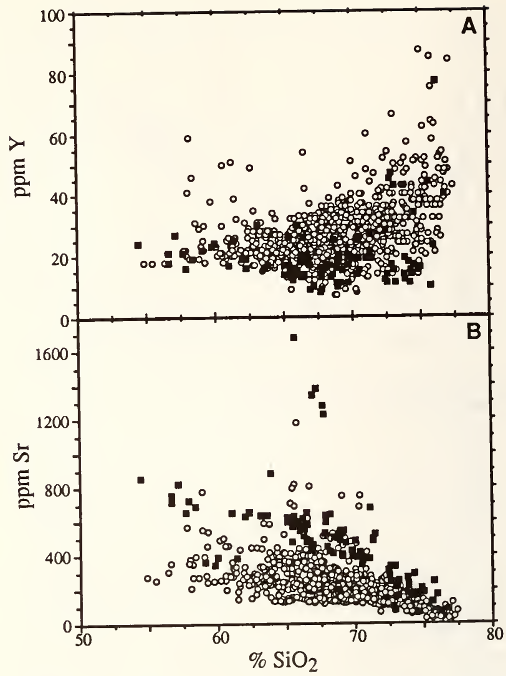

Figure 5. Plot of Y and Sr against SiO_2 for 106 Carboniferous granites (filled squares) and 807 other I-type granites of the Lachlan Fold Belt (open circles). Rocks of the Boggy Plain Supersuite are excluded as well as granites containing more than 270 ppm Rb, taken as evidence of feldspar fractionation. Three other samples with lower Rb but which appear to have undergone such fractionation are also excluded. Fractionated samples are excluded where possible because Y levels rise and Sr falls in abundance in such rocks. Because rising Y contents are a very sensitive measure of fractionation in I-type granites, some increase in that element is seen at the more Si-rich compositions.

(1988) have attributed those mafic compositions to remagmatisation of older rocks of Cordilleran tonalite compositions, so that the rocks are probably representative of an earlier tectonic regime.

The differences in composition between the Lachlan granites and those of the PRB, a typical Cordilleran tonalite province, implies a different character for the source rocks in both areas. This has been used as an argument (Chappell and Stephens, 1988) for the Lachlan I-type granites not having any close relationship with subduction. It also implies that the source rocks for the Lachlan granites were more evolved (e.g. higher K and lower Ca) than those of the Cordillera. Chappell and Stephens (1988) suggested that the Lachlan rocks might represent a further stage in the evolution of continental crust by partial melting, with Cordilleran tonalite compositions being generally a suitable material for generation of the Lachlan granites by partial melting.

A significant feature of the Lachlan I-type granites is that apart from the Carboniferous granites on the eastern side of the belt, and the distinctive Boggy Plain Supersuite, they contain relatively high Y and low Sr contents. This is illustrated in Figure 5. None of the pre-Carboniferous I-type granites have strongly depleted heavy REE patterns, which implies that they could not have been derived from a diopside-normative garnet-bearing source (Ellis, 1987); the significance of this observation is discussed below. In contrast, the Carboniferous granites contain very low Y and high to very high Sr abundances, consistent with a garnet-bearing and perhaps a feldspar-deficient source for those rocks. The Carboniferous granites resemble some granites of the Moonbi Supersuite of the NEB in this regard.

A notable feature of the I-type granites of the LFB is that for those zircons that have been dated using the SHRIMP ion probe, there is a component of inherited zircon (Williams *et al.*, 1988; Williams, 1992). This is consistent with the conclusion that these rocks were generally derived from old sources, a conclusion that follows from from the isotopic and chemical compositions of those rocks.

HEAT SOURCE FOR THE LACHLAN GRANITES

We have seen that granites and related volcanic rocks are very abundant in the LFB. Such an occurrence required a major heat source which, at least in the eastern third of the belt, was probably sufficient to partly melt most the lower half of the crust. Where voluminous igneous complexes formed, that is the major batholiths such as Kosciusko and Wagga, the crust was sufficiently fertile in terms of felsic granite components, and the amount of heat sufficiently great for the amount of melt to exceed that required for movement of large volumes of granite magma into the upper crust, and to the surface. The source of this massive amount of heat has been a central problem in understanding the formation of the Lachlan granites, which will be addressed here. Also, the possibility will be explored that a successful solution is also related to the other principal problem in the LFB, that of the deposition of the widespread Ordovician flysch sequence on continental-type crust, as required by the data for the S-type granites. Any model involving the deposition of the Ordovician sedimentary rocks on thick older sedimentary substrate immediately raises the problem of how such buoyant material could remain below sea level over the extended period of deposition of those sediments. The suggestion of an underthrust sedimentary substrate in the LFB which has been favoured by many persons is an interesting suggestion that would overcome this problem.

Crawford (1983) and Crawford *et al.* (1984) suggested that following the late Ordovician, the Cambrian greenstones of the LFB and associated crust were underthrust by a sialic continental block for several hundred kilometres; such a model would allow for the deposition of the Ordovician strata on oceanic crust while also providing a suitable compositional source for the S-type granites. Gray *et al.* (1991) argued from the analysis of upper crustal seismic reflection profiling in central Victoria that the Ordovician sequence of the LFB is allochthonous with respect to the lower crust, with westward underthrusting of the lower crust occurring from the Silurian to Middle Devonian. Fergusson and Coney (1992) state that the late Proterozoic lower crust of the LFB may have been underthrust from the east. In a kinematic reverse of the Crawford model (Glen, 1992), Glen *et al.* (1992) have proposed that part of the south-eastern LFB, their Melbourne-Mathinna terrane, became detached from its oceanic lithosphere in the late Silurian and moved north as a crustal flake over Precambrian crust which provided the source for granites.

Two major problems arise with these models. First, thickening of the crust by inserting in some way a slab of colder material beneath the Ordovician sediments and an oceanic substrate would have lead to a significant decrease in the geothermal gradient, at a time when magmatic activity was building to a climax and metamorphism was occurring within the Ordovician rocks at Cooma and in the Wagga Metamorphic Belt. Also it requires that the underthrust material be very rapidly brought to magmatic temperatures since that layer was the source of the voluminous batholithic S-type granites and related volcanic rocks. Wyborn *et al.* (1981) obtained a value of 800 °C at 500-600 MPa for the source region of the S-type Hawkins Volcanics of the Canberra region, which are part of the Bullenbalong Supersuite. That temperature, within what would have been the lower plate, and an average geothermal gradient ~50 °C/km to that depth, would have had to be reached with ~30 Ma of its insertion beneath the Ordovician sediments. The assemblages in the S-type volcanic rocks, involving hypersthene, garnet, cordierite, and biotite, with sillimanite and hercynite as less common accessories, implies that much of the lower crust of the LFB underwent granulite facies metamorphism at depths of 15-20 km during the Silurian (Sandiford and Powell, 1986). Morand (1990) showed that in the Omeo Metamorphic Complex, peak temperatures ~700 °C were developed at about 350 MPa, implying a gradient of 65 °C/km in the Ordovician rocks of that area. The significance of such high gradients has been appreciated most clearly by Wyborn (1992) who also pointed out that relatively high Y contents of the I-type granites of this belt, discussed above, are consistent with a derivation at depths of less than 30 km, below the stability limit of garnet in gabbro at about 1 GPa, again implying a significant geothermal gradient.

The second problem arising from thickening of the crust is that it would have also resulted in uplift, the effects of which are not seen.

Since thickening of the crust in the manner that has been proposed would have produced both a colder and uplifted crust, precisely the opposite to the effects that are observed, the view is taken here that thinning of the crust or the lithosphere, in some way, occurred in the LFB. If the crust or lithosphere were thinned at ~500 Ma, then this less buoyant crust could have sunk below sea level and provided a basement for deposition of the Ordovician flysch sediments shed from the Delamarian Fold Belt, which process commenced at about that time. Sedimentation was completed before the end of the Ordovician at ~445 Ma and by 430 Ma the Ordovician strata were being intruded by major S-type batholiths derived from the underlying pre-Ordovician basement.

The mechanism of crust or lithosphere thinning is uncertain. Wyborn (1988, 1992) has suggested a model involving the foundering of dense subcontinental lithosphere with subsidence of the overlying continental crust to allow the deposition of the Ordovician sediments on depressed continental crust. Rising hot asthenosphere took the place of the foundering lithosphere and this lead to the crust being conductively heated. Collins (1994) has also proposed a delamination model commencing in the latest Ordovician under the Wagga Metamorphic Belt, with the detachment being related the presumed eastward progression of ages in the eastern half of the belt proposed by Powell (1984). We have previously seen that, based on ion probe ages, there is probably no such progression, which is a serious weakness of this model; also, because of the lateness of the delamination event, it does not account for the deposition of the Ordovician sediments in the same way as the earlier suggestion of Wyborn (1988). Ellis (1992) has argued that gravitational instability of the lower crust is unlikely and such a mechanism therefore needs further examination.

A second mechanism for heating the Lachlan crust to produce the intense magmatism, that of crustal extension, has not been generally considered in the past for several reasons (but see Sandiford and Powell, 1986). First, the structures of the belt are related to compression rather than extension, e.g. Morand (1990) points out that an extensional environment for the Omeo Metamorphic Complex seems incompatible with the formation of tight upright folds during metamorphism, so that extension was not operating near the end of the Ordovician. Second, the amount of mantle-derived magmatism throughout the period from Ordovician to Devonian was very limited, except in the north-eastern part of the LFB where there is a significant Ordovician shoshonite province. Third, at least in the eastern half, the crust of the LFB must have remained thick, since it was the source of the voluminous S-type granites from depths ~15-18 km in some cases (Wyborn *et al.*, 1981), and of the I-type granites from greater depths. These problems are generally removed if extension occurred before deposition of most of the Ordovician turbidites, since any structures and magmatic activity related to it would have been hidden and the deposition of the Ordovician strata would have significantly re-thickened the crust. There is no direct evidence to favour this hypothesis, but it should be seriously considered because it could account for the Ordovician to Devonian development of the LFB, and in particular its most problematical elements, the Ordovician sediments deposited on continental basement, and the voluminous granites and related volcanic rocks.

Hill *et al.* (1992) noted that the granites of the LFB are difficult to interpret in plate tectonic terms. They suggested that reworking above a plume deserves consideration as a potentially important process so that the Lachlan is a "candidate for a plume head province". It is not a strong candidate. Wyborn (1992) in considering such a model, pointed out that while the observed cycle from mafic rocks to granites and orogenesis through a period ~100 Ma observed in the northern part of the LFB would closely fit a plume model, the early mafic igneous rocks are shoshonitic rather than the voluminous tholeiitic changing to alkali basalts that characteristically are associated with a plume. Two more general arguments can be made against a plume model for the LFB. First, it would be an extraordinary coincidence if a plume were to appear at that time just east of the slightly older Delamarian Fold Belt, near the edge of the growing continent, given that plumes rise from the core-mantle boundary and have no relation to earlier tectonic events. Second, the crustal heating outlined by the Lachlan-Cape York Granite Belt extended for a distance of at least 3600 km and while the dimensions of the LFB in southeastern Australia would be appropriate for a plume, the elevated temperatures there were only part of a significantly longer belt of high temperatures.

Hence while there is probably a strong genetic connection between the two most remarkable features of the LFB, the deposition of extensive and monotonous Ordovician flysch on a continental substrate, and the later production of the voluminous granites and volcanic rocks during the Silurian and Devonian, linked by thinning of the crust, the mechanism by which that occurred remains obscure at this time.

NEW ENGLAND FOLD BELT

The NEO forms the most easterly, and youngest, part of the Australian continent, extending from just north of Newcastle to the vicinity of Bowen in central Queensland, a distance of 1500 km (Figure 1). It is flanked on its western side by the sedimentary rocks of the Sydney-Bowen Basin, which separates this belt from the LFB and its northerly extensions. Granites occur throughout the length of the NEO and they have been studied most intensively in the southern part, in the New England Batholith (NEB) that is located mainly in New South Wales. This discussion is concerned with that southern segment of the belt although all of its parts have similar stratotectonic and structural histories and are correctly placed in the same orogen (Murray *et al.*, 1987).

The NEO contains a much greater diversity of sedimentary and volcanic rocks than the LFB. Despite a very much greater complexity than the LFB, at least as far as surface exposures are concerned, there is a greater consensus about its general nature and evolution. This is largely because it has features that resemble those of presently or more recently active continental margins and it therefore conforms in a more obvious wav to models constructed from the analysis of those younger tectonic regimes. This conformity with younger belts has meant, as Flood and Aitchison (1993) pointed out in their introductory article to the NEO93 volume, that the interpretation of the evolution of the NEO has been strongly influenced by conceptual models in vogue at the time. The present understanding of the belt, that it is an assemblage of diverse tectonostratigraphic terranes, seems to be soundly based. These terranes are intruded by very large granite batholiths, which while adding to the complexity of the belt, provide the opportunity to indirectly examine its deeper parts.

Granites of the NEB are exposed over an area of 15,000 km^2 in the centre of the southern part of the NEO, with an appreciable area being covered by younger basalt flows. Shaw and Flood (1981) recognised five distinct plutonic suites among these granites, here termed supersuites to accord with usage in the LFB. The oldest group, the Hillgrove Supersuite has recently provided a zircon ion probe age of 303 ± 3 Ma (Kent, 1993). The Copeton Supersuite (previously the Bundarra Plutonic Suite; Flood and Shaw, 1975) has given a Rb-Sr total-rock age of 287 ± 10 Ma (Hensel *et al.*, 1985). Both of these early units are S-type and comprise ~30% of the outcrop area of the batholith. Most of the younger I-type granites are assigned to the Moonbi, Uralla and Clarence River Supersuites. K-Ar ages, mostly unpublished, for these units generally range from 260 to 240 Ma. Carboniferous-Permian granites in the Urannah Batholith at the northern end of the fold belt south of Bowen have ages in the range 306 Ma (SHRIMP zircon age; Allen *et al.*, 1994) to 276-265 Ma (K-Ar age; Webb and McDougall, 1968). Cretaceous granites are also present in that area (Webb and McDougall, 1968), with data including a preliminary SHRIMP age of 131 Ma (Allen *et al.*, 1994).

In addition to the plutonic rocks of the NEB, two important subduction-related volcanic arcs were located in the southern NEO, an important difference between that belt and the LFB. The Baldwin Arc was late Devonian in age (~365 Ma) and while it is now covered by rocks of the Sydney Bowen Basin, it was the source of the very distinctive sequence of volcanic greywackes comprising the Baldwin Formation in the western NEO. That detritus is andesitic in composition with ten analysed rocks having SiO_2 levels between 55.0 and 60.7% on a volatile-free basis (Chappell, 1968). At a higher level in the stratified rock sequences of the western NEO, Late Carboniferous ignimbrite sheets that erupted from the Currabubula Arc extend north-south for approximately 300 km in what McPhie (1987) argues is an analogue of the modern Andes. This younger arc is inferred to have been only just to the west of the exposed volcanic rocks but it is also covered by the Sydney-Bowen Basin. Rocks of the Currabubula Arc are more felsic than the Baldwin Arc, ranging from andesite to rhyolite in a generally high-K series.

APPLICATION OF GRANITE STUDIES TO THE NEW ENGLAND FOLD BELT

Evidence of a crustal origin for the granites of the NEO is less certain than for the LFB. The two New England S-type supersuites, Hillgrove and Copeton, have distinct but less pronounced S-type features than their Lachlan counterparts. For all of the New England I-type suites, the isotopic compositions are much closer to mantle values (Hensel *et al.*, 1985). The I-type Clarence River Supersuite has distinctly more primitive chemical features than any other group of granites in south-eastern Australia, which makes it the most likely candidate for mantle derivation. Never the less, the view is taken here that the New England granites are the products of partial melting of the crust, but of a less evolved nature than that which produced the granites of the LFB. One interesting feature of the NEB is that there appear to be no A-type granites; certainly all of those very fractionated granites with high abundances of some of the elements that characterise that third type, appear to be I-type. The absense of A-type granites and their presence in the LFB may mean that their production requires the presence of a thick continental basement.

S-type granites in New England

It should first be noted that S-type granites do occur in the

NEB, so that a feature of the LFB that is sometimes regarded as anomalous is shared by its younger neighbour. Second, S-types are in a relative sense less abundant in New England, comprising approximately one-third of the area, but are still a significant granite type. Third, unlike the Lachlan where they are widely distributed within five of the nine Basement Terranes (Chappell *et al.*, 1988) and are often associated closely with subordinate amounts of I-type granite, they occur in two belts in the NEB, flanking major areas of I-type granites. Fourth, they are never as chemically evolved as they frequently are in the Wagga, Bassian and Taswegia provinces in the LFB; enrichments in trace elements as a result of crystal fractionation are infrequent and never strong and there is no mineralisation apart from a minor alluvial tinfield at Watsons Creek associated with granites of the Copeton Supersuite.

Flood and Shaw (1975) recognised the significant occurrence (3400 km^2) of rather felsic and uniform S-type corundum-normative granites in the western NEB. Flood and Shaw (1977) showed that these granites, here referred to as the Copeton Supersuite, with $^{87}Sr/^{86}Sr$ ~0.706 were isotopically more primitive than the S-type granites of the LFB. The Hillgrove Supersuite (1650 km^2), east of the central axis of the NEB, has similar a isotopic composition (Shaw and Flood, 1981), is more variable in chemical composition, does not contain cordierite and sometimes contains Al-poor amphibole, and probably includes some deformed I-type granites. Also, the plutons are also more dispersed. Shaw and Flood (1981) conclude that these two supersuites were derived by the partial melting of young volcanogenic metasedimentary rocks, with differences in detail between the compositions for the two supersuites. Hensel *et al.* (1985) showed that the Sr and Nd isotopic compositions of the NEB S-type granites correspond closely with those of associated sedimentary rocks. This contrasts with the situation in the LFB. For the smaller, more dispersed and compositionally variable plutons of the Hillgrove Supersuite, an origin by partial melting of the associated rocks, but at greater depth, seems reasonable. The Copeton Supersuite, occurring in a major belt along the western edge of the NEB is more problematical, since large volumes of source rock would have been needed beneath that belt. Perhaps a relationship with material shed from the slightly older Currabubula Arc of western New England might be inferred.

I-type granites in New England

The I-type granites of the New England are chemically very diverse. The extremes are the low-K high-Ca tonalites in the Clarence River Supersuite and the strongly potassic monzogranites of the Moonbi Supersuite. Even in an unfractionated state, the latter rocks often show extraordinarily high abundances of some trace elements, again in contrast with the Clarence River Supersuite, and the Moonbi Supersuite also includes many fractionated rocks. While there is a wide chemical compositional range to the New England I-type granites, a distinctive feature is that they are all relatively primitive isotopically, again in contrast to the LFB where the isotopic compositions are quite disparate. These differences between the two belts imply that the compositions of the source rocks for the New England granites were relatively diverse and all young, compared with the a variably aged but chemically more restricted source rocks of the Lachlan granites.

Most of the I-type granites are assigned to one of three supersuites, Clarence River, Uralla, and Moonbi. The Uralla Supersuite is less well understood than the other two, requires more work to fully understand its details, and is generally intermediate in compositional character between the other two supersuites; it will not be considered further here.

The Clarence River Supersuite

The Clarence River Supersuite occurs over an area ~900 km^2 on the eastern side of the NEB. It has been studied recently by Bryant (1992) and Bryant and Arculus (1993) and the following notes are from those sources and from Bryant (*pers. comm.*). The granites of this supersuite are the most mafic in the

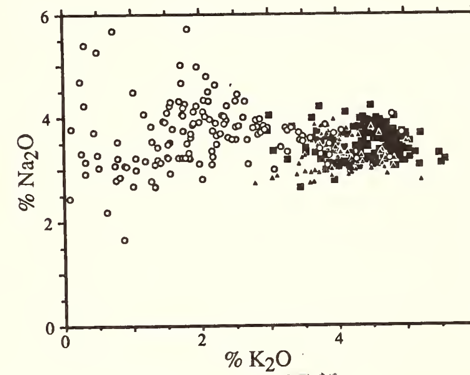

Figure 6. Plot of Na_2O against K_2O for I-type granites and related gabbros of the New England Batholith. Circles are Clarence River Supersuite (136 samples), triangles are Uralla Supersuite (67 samples) and squares are Moonbi Supersuite (191 samples).

NEB and are very diverse, ranging from gabbros through to monzogranites. However, in contrast to the other two I-type supersuites, monzogranites are relatively minor. This is a low-K suite, in contrast to the Moonbi Supersuite (Figure 6) and the I-type granites of the LFB (Figure 4A). The Clarence River rocks have very low abundances of P, Rb, Nb, Pb, Th and U. They are very similar in these respect to the PRB, particularly to the rocks of the western part of that batholith (Silver and Chappell, 1988). The Clarence River granites show more diversity than the rocks of the western PRB but the chemical similarities are very striking. These comparisons can be extended to initial $^{87}Sr/^{86}Sr$ isotopic compositions which are very primitive in both cases, ~ 0.704 for the Clarence River Supersuite and generally less than 0.705 for granites of the western PRB (Silver and Chappell, 1988). It is these similarities that are the most significant feature of this supersuite because it establishes a clear connection between these rocks of the NEB and the most thoroughly documented example of Cordilleran tonalites formed at an active continental margin and places the Clarence River Supersuite and the NEB in a comparable tectonic environment. Silver and Chappell (1988) have argued that the tonalites of the western PRB were derived from the melting of relatively young basaltic lithosphere. Bryant and Arculus (1993) have proposed a similar origin for the granites of the Clarence River Supersuite.

The Moonbi Supersuite

The Moonbi Supersuite occurs in the axial parts of the NEB, at the northern and southern ends. Granites of this

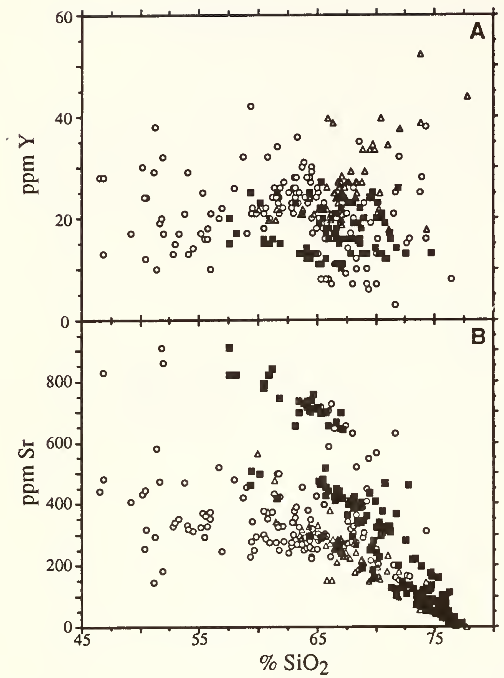

Figure 7. Plot of Y and Sr against SiO_2 for I-type granites and related gabbros of the New England Batholith. Circles are Clarence River Supersuite, triangles are Uralla Supersuite and squares are Moonbi Supersuite. Fractionated samples are excluded where possible for the reasons given in the caption of Figure 5.

supersuite are dominantly monzogranite with some quartz monzogranite and abundant leucogranite. The rocks are K-rich and often have distinctive trace element contents with very high concentrations of Sr, Ba, Pb and Th (Chappell, 1978), with the abundance of these elements being very suite-dependant. There are compositional similarities with the Carboniferous I-type granites in the eastern part of the LFB, notably in the high Sr and low Y contents (Figures 5 and 7). As with the Clarence River Supersuite, the Moonbi rocks are distinct from all the pre-Carboniferous I-type granites of the LFB. Also, the Moonbi Supersuite rocks underwent extended feldspar fractionation much more commonly than did the I-type granites of the LFB.

The Moonbi Supersuite, despite its very potassic character and the unusually high abundances of many trace elements not generally associated with the granites of active continental margins, can be accommodated within a Cordilleran model for the NEO. While tonalites are the plutonic rocks that come to mind in association with the Cordillera, K-rich types do occur. The compositional criteria of Pitcher (1982) placed tonalites in a "Cordilleran" type, distinct from his more potassic "Caledonian" granites. However, K-rich granites are found in the Cordillera, perhaps most notably in the Sierra Nevada Batholith of California (e.g. Bateman and Chappell, 1979), just as rare Cordilleran tonalite compositions may be found in Caledonian belts (Chappell and Stephens, 1988). With this in mind, Chappell and Stephens (1988) suggested that Pitcher's subdivision into I-(Cordilleran) and I-(Caledonian) be modified to I-(tonalitic) and I-(granodioritic). This preserves the important general distinction made by Pitcher (1982) but recognises that tonalitic rocks are found in Caledonian-type fold belts, and the reverse. It is here suggested that the Moonbi Supersuite is analogous to the granodioritic (or monzogranitic) rocks found in Sierra Nevada Batholith of the Cordilleran belt. That comparison is not as precise as between the Clarence River Supersuite and the Cordilleran tonalites, but that would not be expected. More potassic granites occurring in Cordilleran-style belts form from older crust that was magmatised during that Cordilleran heating event. In the Sierra Nevada, isotopic compositions (e.g. Kistler and Peterman, 1973) show that the source material was significantly older than the magmatic age. While a tighter constraint is placed on the age of the source rocks of the Moonbi Supersuite by the data of Hensel *et al.* (1985) ($^{87}Sr/^{86}Sr$ ~0.705 for the Moonbi Suite), an older late Palaeozoic source rock for the Moonbi rocks is consistent with those isotopic data. The high Ba and Sr abundances in some rocks of this supersuite suggest a source-rock of shoshonitic character (Chappell, 1978). At the same time, the high Sr and low Y contents (Figure 7) suggest a feldspar-free garnet-bearing source similar to that which has been proposed for the Carboniferous granites of the eastern LFB.

RELATIONSHIPS BETWEEN THE TWO BELTS

This paper has contrasted many features of the Lachlan and New England belts. Is there any evidence that in fact the two belts interacted in any way? The western part of the NEO (Gamilaroi Terrane) accreted to the LFB in the late Devonian, shown by the occurrence of LFB-derived clasts in the Keepit Conglomerate (Flood and Aitchison, 1992). Did the two belts interact before or after that time?

Shaw and Flood (1993) have suggested that the late Carboniferous vulcanism at the western side of the NEB and the plutonism of similar age on the eastern side of the LFB might be related to a single subduction event. Chappell *et al.* (1988) noted that those Carboniferous granites of the LFB have similarities with the Moonbi Supersuite. It is possible that the development of those granites are more closely related to the NEO than to the rest of the LFB and that in that area we are seeing effects of the younger belt superimposed on the LFB.

The LFB is older and its history overlapped the earlier major events in the NEO. Glen and Scheibner (1993) have listed eight geological features of the New England region that are pre-late Devonian that they refer to as "Lachlan rocks". They assigned any Silurian to mid-Devonian accretionary prisms that developed along the eastern margin of Gondwanaland to the LFB and argued that these may have been incorporated in the NEO when it developed fully in the Late Devonian and Carboniferous. The view taken here is that any older rocks that accreted into the NEO are intrinsically part of that belt. The very nature of accretion is to incorporate, among other things, a diverse assemblage of fragments of oceanic and continental crust that formed before the event. In any case, the tectonic style of the LFB is not one of accretion, unless one considers the formation of the NEO as the final stage in the evolution of the LFB!

What effects did the accreting NEO have on the LFB? The development of the Baldwin arc and the accretion of New England to the edge of the LFB in the late Devonian (Flood and Aitchison, 1992) is at least approximately coeval with the episode of deformation in the LFB long known as the Tabberaberan Orogeny. Likewise, the late Carboniferous Kanimblan deformation of the LFB could have been related to the development of the Andean volcanic arc in western New England at that time. In the context of a fold belt that had passed through its most intense magmatic phases and for which accretionary tectonics is an unlikely mechanism of development, such externally imposed tectonism is a likely scenario. This still leaves the precise nature of earlier deformations in the belt to be defined, with the point being made here that they took place at a time when the intensity of magmatic activity was very high. The contribution that magmatic activity made to the development of the early structural history of the LFB still has to be assessed. Perhaps the Lachlan Fold Belt would be better called the Lachlan Magmatic Belt!

CONCLUSIONS

The overall differences in style between the Lachlan and New England belts are also shown by their granites. In the Lachlan, the production of the granites involved vertical redistribution of old crust, both igneous and sedimentary. In contrast, the evolution of New England during the late Palaeozoic involved substantial production of new crust, consistent with the more primitive isotopic compositions and the uplift of the belt. The igneous rocks of the Lachlan belt can be used to argue strongly against its development by the accretion of new crust. Those of New England have features that point the other way. A comparison of the granites in the two belts confirms their contrasting character and shows that the use of modern tectonic analogues is worthwhile in New England but unlikely to be fruitful in the Lachlan Fold Belt.

ACKNOWLEDGEMENTS

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Doctoral Thesis Abstract: Reproductive Ecology of Five Species of Australian Alpine *Ranunculus*.

CATHERINE M. PICKERING

Current hypotheses in reproductive ecology were investigated using the Australian alpine perennial herbs *Ranunculus muelleri, R. dissectifolius, R. graniticola, R. millanii*, and *R. niphophilus*. Based on the results from these experiments, reproductive strategies are proposed that may also apply to other perennial herbs.

Direct limitation of seed set by pollen and resources was investigated by the experimental manipulation of pollen and resources in the field. Seed set was not limited by pollen in *R. graniticola*; was limited only at one time during the flowering season in *R. millanii;* was slightly limited by the amount of pollen transferred by pollinators in *R. muelleri* and *R. niphophilus;* and was significantly limited by pollen in *R. dissectifolius*. The addition of nutrients to plants had no effect on seed set in any of the species. Removal of all but a single flower from plants increased seed set on the remaining flower only in *R. dissectifolius*. Removal of half the leaves from a plant had no effect on total seed set in *R. muelleri, R. dissectifolius, R. graniticola* and *R. niphophilus*.

Seed production is directly proportional to plant size, as measured by leaf number, in *R. muelleri, R. dissectifolius, R. graniticola* and *R. niphophilus*, with bigger plants producing more seed by producing more flowers. Plant size affected the flowering pattern of all five *Ranunculus* species, with plant size being correlated with the number of flowers produced which, in turn, was correlated with the duration of flowering of the plant and, in some species, the amount of synchrony with conspecifics. These correlations applied both within and among species.

Based on ovule estimates of plant gender, *Ranunculus* plants were phenotypically as well as morphologically hermaphrodite. However, seed estimates indicate that populations of *R. muelleri, R. dissectifolius* and *R. millanii* had irregularly bimodal distributions of gender with non-seeding and functionally bisexual plants; population of *R. niphophilus* had amodal distributions of gender with plants exhibiting a range of genders from nearly non-seeding to very female; and populations of *R. graniticola* were unimodal with plants being functionally as well as phenotypically hermaphrodite. Plant size was correlated with several aspects of gender in *R. muelleri, R. dissectifolius, R. graniticola* and *R. niphophilus*.

Flowering of *Ranunculus* species is restricted by snow cover early in the season, and appears to be restricted by drought later in the season, but the date of flowering did not affect the amount of seed produced by a plant nor seed set per flower. When the overlap in flowering among species was quantified using the novel measure, interspecific synchrony, only moderate levels of synchrony were found for most combinations of species, indicating that there was some temporal displacement of flowering among the five species. Moderate to high levels of seed set for interspecific crosses, compared with intraspecific crosses, were obtained for all combinations of crosses among the five species in the field. These high levels of interspecific compatibility indicate that the alpine *Ranunculus* species are likely to experience selection for temporal divergence of flowering which would reduce the loss of reproductive resources associated with the production of hybrid seed.

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Doctoral Thesis Abstract: A Study of Conducting Polyrrole Films in the Microwave Region.

Akif Kaynak

This thesis is a comprehensive characterisation of conducting polypyrrole films in the microwave frequency region. Microwave investigations presented in this thesis can be grouped under three interrelated sections, namely, i) transmission, reflection, absorption behaviour, ii) shielding effectiveness studies and iii) microwave dielectric properties. Reflection, transmission and absorption behaviour of polypyrrole films with dc conductivities ranging from 0.001 S/cm to 50 S/cm are presented. Results show that the electrical conductivity of the doped polypyrrole films have a significant effect on transmission, reflection and absorption of microwaves. Samples with low conductivity (low dopant concentration) exhibited high transmission whereas highly conducting films were reflective. Significant absorption of microwave radiation was only observed for samples of intermediate conductivity. Transmission and reflection experiments on polypyrrole films were simulated by using finite element methods. Solutions obtained by theoretical methods were in excellent agreement with the experimental results, confirming the dependability of the measurement methods used. The agreement between experiment and theory for 50 micron films provided confidence to extend the theoretical methods to include the effect of sample thickness on microwave reflection, transmission and absorption properties of films with a wide range of conductivities. Having access to such data including the effect of dopant concentration, conductivity and sample thickness on microwave transmission, reflection and absorption, would be extremely valuable for the design of microwave devices and fundamental understanding of material properties.

The wide range of modulation of conductivity and dielectric properties of semiconducting and conducting polymers allows variation of reflectivity and absorption of electromagnetic waves not available with conventional materials. Therefore a study on the shielding effectiveness of conducting polypyrrole assumes particular importance. A method of measuring plane-wave shielding effectiveness (SE) is presented. Shielding effectiveness as a function of conductivity and frequency (300 MHz-2 GHz) were studied. Shielding effectiveness of PPy films was found to increase with the increase in conductivity. SE measurements carried out on PPy samples aged in room temperature for a period of about 2 years revealed that shielding effectiveness degraded by 10 to 15 dB over the test frequency band. However highly doped films retained relatively high levels of shielding. A shielding effectiveness of above 40 dB was obtained with highly doped (0.1 M p-TS) conducting polypyrrole film over the frequency range 300 MHz to 2 GHz, making it attractive for consideration in shielding applications.

Microwave dielectric properties of the electrochemically synthesised polypyrrole with a wide range of doping levels are presented. Methods for determining the complex permittivity in the microwave regime are discussed. The variation of the complex permittivity as a function of polymer dopant concentration at room temperature using cavity perturbation methods at frequencies of 2.45 GHz and 10 GHz are presented. Measurements indicate that the real (ε') and imaginary (ε'') parts of the dielectric constant increase in magnitude with increasing polymer doping level. Both ε' and ε'' were small for lightly doped samples, but increased at higher dopant concentrations. Complex dielectric constant measurements were also performed on semi conducting polypyrrole films for the temperature range 90K-400K. The real part ε' of the complex dielectric constant increased slightly with increase of temperature whereas the imaginary part ε'' increased significantly with temperature. Results were verified by using theoretical methods.

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Masters Thesis Abstract: Representation Issues in Genetic Algorithm Function Optimization

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This work examines representation issues in the optimization of real parameter numerical functions using genetic algorithms. The optimization of these functions has applications in many areas. The genetic algorithm (GA) is a search technique that evaluates populations of candidate solutions using an objective function. It selects the better candidates for reproduction and so generates new candidate solutions for testing. The standard genetic algorithm and its relationship to other optimization methods is described. The method of representation of candidate solutions affects the optimization performance of genetic algorithms.

The desirable properties for experimental test function suites are discussed. De Jong's test suite has been widely used in previous work. These functions are shown to be hill-climbing easy. It is shown that simple hill-climbing algorithms are faster and more accurate than genetic algorithms on this test suite. Genetic algorithms are better suited to optimizing hill-climbing hard functions. A new test suite is introduced and its suitability assessed. It is proposed that the new suite is a more test-bed for genetic algorithm optimization performance, its functions are multi-modal and hill-climbing hard.

Genetic algorithms are then shown to efficiently optimize hill-climbing hard functions. The effects of different integer coding functions on the performance of the genetic algorithm optimization are investigated. The reflected Gray code is found to perform better than the other Gray codes analyzed on the old test suite. However the Binary code is found to do better on the new test suite. The balanced Gray code is implemented and its performance assessed. Three relevant code characteristics are identified as promoting genetic algorithm performance. An acyclic, near-Gray code is then presented with these characteristics. This insight into code characteristics suggests a new interpretation for some previous results by Caruana and Caldwell.

The relative performance of binary and real number coding representations is investigated. This is an area of some controversy as practitioners use real number coding because it works. However existing genetic algorithm theory suggests binary coding should do better. Contrary to some claims, binary codings are found to generally outperform real codings on the high dimensional multi-modal test functions when similar selection and reproduction operators are used. The experimental methodology employed and the significance of the results are discussed.

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Doctoral Thesis Abstract: The diamond path: a study of individuation in the works of John Keats

MAUREEN B. ROBERTS

Romanticism as a particular phase in the evolution of Western consciousness is characterised by a creative reconnection to the collective unconscious as a key aspect of introverted thinking. Individuation as self-realisation involves, as does the Romantic imagination, the struggle to unify recreatively through the balance and synthesis of opposites. After a brief discussion of these ideas, this thesis examines the development of Keats' poetry in terms of a basic pattern of transformation in which an initially unified state of consciousness is divided, then re-collected as a "higher" unity through a process of maturation.

Two important uniting symbols - the diamond orb in *Endymion* and the square edged stone at the end of *The Fall of Hyperion* - form the two ends of a thread of development along which Keats' poetry is self-creative through its healing of the "dis-ease" of inner division to reform the unified self. This quest for unity is examined through several paradigms of individuation, all of which are harmonious with the basic principles of Romanticism and Jungian thought. These are, in order, the Neoplatonic quest for the One as Truth and Beauty, the alchemical synthesis of opposites to form the Philosophers' Stone, the Gnostic paradox of the "fortunate fall" into self-division, and the creative tension between the unified Apollonian self and the Dionysian self-divided sufferer who is in principle synonymous with Milton's Satan. Keats accordingly inverts the significance of the Miltonic Christian Fall by ascribing a positive potential to the Dionysian transitional state of paradox. Within this perspective Keats' philosophy of "Soul-making" expresses the Gnostic striving of the divine "spark" as the latent individuality of the self to ascend through the ambivalent space of individuation to conscious realisation.

Through the progressive integration of all these principles, Keats is seen to be an intuitively Gnostic and primarily introverted thinker whose quest for redeeming self-knowledge reflects his own maxim: "That which is creative must create itself."

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Barotropic depth-averaged and three-dimensional tidal programs for shallow seas.

Doctoral Thesis Abstract

PETER J. BILLS

This thesis reports the development and testing of three programs for computing tides in shallow seas and their particular application to Spencer Gulf, South Australia.

The first program solves the three-dimensional barotropic non-linear long-wave equations discretised using finite differences. The σ-transformation is used in the vertical with non-uniform depth-level spacing. The overall difference scheme is three-level in time and of leap-frog type for the computation of tidal elevations, and two-level in time for velocity calculations. It uses explicit differencing in the horizontal direction and implicit differencing in the vertical. The second program solves the depth-averaged analogue of these equations. The third program is an adaptation of the depth-averaged program to include the modelling of the covering and uncovering of tidal flats.

All three programs are designed to handle general boundary configurations while using only four distinct element types. Appropriate forms of the discretised equations for a particular element configuration are automatically selected using the element type numbers in algebraic switches.

The coding and accuracy of the differencing used is checked by comparing predicted results with analytical solutions for idealized basins. Wave propagation analyses of the difference formulations for linearized forms of the equations are also carried out.

Depth-averaged and three-dimensional models of Spencer Gulf are developed with the open boundary at the entrance to the Gulf. Height-specified and combined radiation/height-specified open boundary conditions are compared in the case of the depth-averaged model. Three formulations for bottom stress (depth-averaged model) and two forms for vertical eddy viscosity coefficient (three-dimensional model) are examined. The role of the horizontal eddy viscosity terms in introducing artificial friction is discussed. Both models are driven simultaneously by the four major tidal constituents O_1, K_1, M_2 and S_2. Comparisons of results using linear and non-linear equations are made in the depth-averaged case. Results clarify and extend the work from earlier numerical models of Spencer Gulf and predict new features of tidal flow near Wallaroo.

A modification of the method for incorporating the wetting and drying of tidal flats due to Flather and Heaps (1975) is presented and applied in a depth-averaged fine-grid model of Northern Spencer Gulf. It gives stable predictions over a 32 day simulation. Stability and accuracy are enhanced if a de Chèzy coefficient of quadratic friction is used. This suggests that a locally depth-dependent coefficient of quadratic friction is more suited to very shallow tidal modelling than a constant coefficient. An appraisal of the built-in filtering behaviour of some common finite difference formulations and their role in suppressing grid-scale oscillations is presented.

The Northern Spencer Gulf tidal flat model numerically confirms the observation of a residual eddy south of Lowly Point. A complementary eddy is predicted to the north of Lowly Point. The model predicts that Ward Spit, a large sand bar to the east of Port Bonython, is uncovered only at low springs. This prediction is supported by annotation on an old map of the region. A mechanism for the creation and maintenance of Ward Spit is suggested based on a plot of residual vectors for depth-averaged velocity.

Reference:

Flather, R. A. and Heaps, N. S. (1975), Tidal computations for Morecambe Bay, *Geophysical Journal. Royal Astronomical Society*, **42**, pp. 489–517.

(Manuscript received 13-1-94)

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Journal and Proceedings, Royal Society of New South Wales, Vol.127, p. 66, 1994
ISSN 0035-9173/94/010066-01 $4.00/1

Doctoral Thesis Abstract: Tannin Toxicity Studies in Mice and Sheep

JIN ZHU

Toxicities of tannic acid (TA), oak and yellow-wood (YW) tannins were studied in mice and sheep following oral or intraperitoneal (i.p.) administration. Oral dosing of mice with tannin extract from oak leaf or acorn produced severe periacinar liver necrosis without kidney damage when the tannin content was high - a relationship previously reported with YW. Oak leaves (*Quercus robur* and *Q. acutissima*) with a tannin content of 3.03 to 8.79% TA equivalent (TAE) did not produce toxicity when given to sheep by gavage daily for 4-18 days. However, *Q. robur* leaf with a tannin content of 13.92%TAE produced severe liver necrosis without renal injury in one sheep after 2 days dosing. These preliminary studies suggest that oak leaf in Australia is generally non-toxic unless the tannin content is high; and that the oak tannin is hepatotoxic rather than nephrotoxic.

Punicalagin, a hydrolysable tannin isolated from YW leaf, produced periacinar coagulative liver necrosis in mice but not kidney necrosis when given orally or i.p.. The oral dose (>0.50 g/kg bw) required to produce toxicity was at least 20 times greater than the i.p. dose. The i.p. toxicity of punicalagin in sheep was similar to that in mice and, prior to necrosis, steatosis in the liver was a consistent finding but this was not found in sheep given YW leaf. Serial liver biopsies in sheep given YW leaf orally showed that the liver necrosis was initially midzonal before becoming periacinar. Terminalin, another tannin isolated from YW leaf produced renal tubular necrosis similar to that described in cattle following naturally occurring YW poisoning and liver necrosis similar to that produced by punicalagin in mice and sheep.

Liver necrosis was not observed histologically or detected biochemically in sheep dosed orally with TA, but transmission electron microscopy showed focal hepatocellular necrosis, steatosis and acicular crystal cleft formation. There were significant increases in blood methaemoglobin concentration ($P<0.05$) and decreases in blood pH ($P<0.01$) and oxyhaemoglobin concentration ($P<0.05$) by 32 h after dosing. When TA was given i.p. in sheep, liver necrosis similar to that seen in punicalagin intoxication was produced, together with metabolic acidosis and compensatory respiratory alkalosis, but not methaemoglobinaemia. Sheep given TA intra-abomasally developed liver, kidney and abomasal necrosis. Thus while TA is hepatotoxic when given parenterally to sheep, when given orally it does not produce renal or significant hepatic injury, but rather causes metabolic acidosis and methaemoglobinaemia.

In sheep intoxicated i.p. with punicalagin, terminalin or TA, or orally with YW leaf, or intra-abomasally with TA, plasma liver enzymes and bilirubin levels significantly ($P<0.05$) increased, while plasma glucose and total protein concentrations significantly ($P<0.05$) decreased. The decrease in plasma protein was considered to be due to tannin precipitation.

When TA was dosed intra-abomasally in sheep, TA and its metabolites (gallic acid, 4-O-methyl gallic acid and ellagic acid) were found in the plasma. With oral dosing, gallic acid and pyrogallol were found in the plasma. Gallic acid gradually decreased in both urine and ruminal fluid, while pyrogallol increased and resulted in methaemoglobinaemia.

TA produced periacinar liver necrosis in mice dosed orally. Gallic acid, ellagic acid and pyrogallol did not produce hepatic or renal lesions, although pyrogallol caused death due to methaemoglobinaemia. Thus TA, rather than its metabolites, is responsible for liver necrosis in animals. When given orally to ruminants, TA is metabolised to pyrogallol, which in turn produces methaemoglobinaemia.

In conclusion, this study showed that two tannins, punicalagin and terminalin, are the toxic principles in YW leaf; tannin metabolites, gallic acid, pyrogallol and ellagic acid, are not hepatotoxic or nephrotoxic; and TA, when given orally, produces liver necrosis in monogastric animals and methaemoglobinaemia in ruminants.

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(Manuscript received 23-12-1993)

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Doctoral Thesis Abstract: Multi-Frequency MF/lower HF ocean radar studies of wind-wave transients.

MURRAY L. PARKINSON

A Medium-Frequency (MF: 0.3-3 MHz)/lower High-Frequency (HF: 3-30 MHz) phased-antenna array on Bribie Island, Queensland, Australia, consists of a 1-km line of 10 transmitter antennae aligned east-west, and orthoganol to a 1-km line of 10 receiver antennae. The array is normally phased to produce a near-vertical radar beam, but for these studies it was converted to operate as a surface-wave radar used for coherent ocean-backscatter studies. This was accomplished by changing impedance-matching circuits at the base of transmitter antennae, thereby converting them from crossed-horizontal dipoles to top-loaded vertical dipoles which emit maximum radiation in the horizontal plane.

A new body of MACRO-11 machine control software was developed to direct the crossing of transmitter and receiver beams in the horizontal direction and steerable in azimuth. A computer model describing the effective radiation pattern formed by the array was also developed, and it was used to calculate the radiation pattern across an entire celestial hemisphere of any chosen radius.

Transmitting at frequencies 1.98, 3.84, and 5.80 MHz, the Bribie Island radar is sensitive to first order to sea waves of length 75.7, 39.0, and 25.8 m respectively (radio waves coherently backscatter form sea waves of half the radio wavelength). Similar experiments to those reported here have usually been performed at the upper HF to very-high-frequency (VHF: 30-300 MHz) range. The experiments reported here were thus partly novel because of the use of lower frequencies with a large steerable array achieving a high angular resolution.

Complex time series of sea echoes recorded at frequency 3.84 MHz showed random modulations in amplitude and phase which were adequately explained by beats between Doppler-shifted echoes from the different portions of the radar footprints encompassing turbulent surface-current flows. An alternative explanation was the direct observation of random modulations in the sea-wave Fourier components.

Hundreds of sea-echo Doppler spectra recorded during four field studies were analysed to show the limited coherence of sea waves. Generally, sea waves were less coherent than a continuous tone, with coherence deteriorating for shorter waves, and possibly during shoaling. Because of the noise-like quality of the waves, it was shown that incoherent spectral averaging is the optimum procedure for revealing spectral information otherwise buried in noise.

Shallow water depths may have had another important effect on the observed sea-echo spectra. It was suggested that the first-order sea echoes were broadened because the phase speeds of gravity waves (and thus the Doppler shifts they produce) were modified by the bathymetry of radar footprints. Allowing for contributions by familiar broadening mechanisms, it was further suggested that the proportion of the footprints corresponding to various water depths may be inferred from the remaining Doppler broadening. A best-case error analysis showed that a MF surface-wave radar transmitting at frequency 0.5 MHz should remotely sense the bathymetry of the sea down to water depths of 145 m with >15% accuracy.

A new technique for deducing the time constant for evolution of the wind-wave peak in scalar sea spectra down the frequency range was developed - it involved a comparison between the observed growth rates of Bragg-peak amplitude (first-order sea echoes) and theoretical growth rates implied by established scalar sea spectrum models. A time constant of 1.3 ± 0.4 h was estimated for $U_{10} \approx 7$ m s^{-1}, an area of sea ≈ 19 km, and an integration time of 0.48 h, but the time constant values were controlled by the

temporal resolution of the measurement process.

Because the radar-derived time constant was in good agreement with the accepted buoy-derived value, it was suggested that no dilemma is presented by the fact that VHF radars are known to track the observed sea-truth changes in wind direction to within minutes (as opposed to hours). This is because the short sea waves to which VHF radio waves are sensitive probably veer rapidly in azimuth (in the order of 0.1° s^{-1}), and in general the time scale for veering of directional sea spectra may depend upon the degree of wave spreading, as well as wave frequency.

The directional factor of sea spectra is an important oceanographic quantity which is infrequently measured by a limited number of techniques. I showed how the large phased-antenna array might be used to measure directional factors by inverting the observed first-order sea echoes measured simultaneously at many azimuths (and a number of ranges and frequencies) through rapid control of beam direction. This new measurement technique was made possible by the advanced digital beam-steering and signal-processing capabilities of the Bribie Island radar. Preliminary observations demonstrated that, in principle, this new technique can be used to measure the directional factor automatically, including dominant sea direction and angular spread with high resolution (± 2°) in near real time, especially if the radar is relocated to a more favourable geographic site.

Other cursory studies presented here included the range sensitivity of the Bribie Island radar, an explanation of mysterious 'ground' echoes, and the results of initial searches for skywave-propagated sea echoes. It is advocated that the Bribie Island radar may operate in the sky-wave mode to remotely sense, for example, sea-direction vortices associated with tropical cyclones off the coast of North Queensland. However, care will be required to ensure that ionospheric echoes are not confused with genuine sea echoes.

In summary, the work described in this thesis is clearly original, but it can only be considered a pilot study on the use of the Bribie Island radar for sea-scatter studies. This is because it is also apparent from the work presented within that HF measurements in complex oceanographic environments are not straight forward. Many follow-through experiments with the deployment of *in situ* probes collocated with radar footprints will be necessary to obtain more convincing results confirming (or refuting) the present interpretations. Thus, this work contributes to scientific knowledge in the sense of posing new ideas and questions, rather than providing definitive answers.

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Doctoral Thesis Abstract: 'It's so strange when you stay sick': The challenge of chronic fatigue syndrome

Roslyn Woodward

Chronic Fatigue Syndrome (CFS) remains poorly understood, despite the recent definition of the syndrome by the United States Centers for Disease Control (Holmes et al, 1988), and the growing biomedical and public interest in it. This thesis explores the nature of the condition, its explanations, effects and management. It also highlights important concerns for people who have chronic conditions which medical science has yet to understand or recognise, and discusses doctors' dilemmas about appropriate care for such conditions.

The research relies principally on information gathered from interviews over a two year period with fifty people who have been given a diagnosis of CFS. The related issue of appropriate care is examined from the perspective of people with CFS, but is complemented by the views of twenty doctors.

Drawing on the experiences of people with CFS, I present an account of the illness, beginning with a detailed description of the symptoms over time and their effects on people's lives. This natural history of the condition also reflects people's concerns about their problem. It shows how the erratic and sometimes peculiar symptoms brought feelings of uncertainty and estrangement, feelings that became increasingly pronounced as their health deteriorated.

The account then broadens from a description of the illness and its pervasive effects to encompass the impact of social and medical responses on people as they sought help and advice about their condition. Although viruses were triggers in people's initial deterioration into poor health, the development appears to have been influenced by the medical uncertainties about the condition. The decline into poorer health was moderated when people had understanding and a meaningful framework for interpreting the problems. Over time, two related contrasts emerged. There was a contrast between the long term health and sense of well being of those people whose doctors had been consistently respectful, and the majority of participants who received responses that they felt disregarded their symptoms. Secondly, there was a contrast between people's deteriorating health prior to diagnosis, and their health afterwards. As the majority of doctors in the study expressed reservations about the value of providing people with a diagnosis for this condition, these findings about the changes associated with diagnosis have important implications for the management and care of this and other conditions which create uncertainty.

The study also suggests that individuals who have developed this illness have characteristics in common. They have been active, productive and conscientious people. Their style of coping with illness has been one of active denial and defiance, characterised by an early and often enduring determination to ignore symptoms and overcome difficulties. In combination with demanding life circumstances, this style of coping with illness and with medical doubt seems to be implicated in the onset and the development of the condition. Many individuals began to question this coping style only after they had a diagnosis. The changes that occurred in people's health over time seemed to be related to their ability to relinquish this coping style. On the basis of this finding, I argue that management of CFS rests on early identification of the problem and change in the individual's style of coping.

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(Manuscript received 11-1-1994)

ANNUAL REPORT OF COUNCIL

FOR THE YEAR ENDED 31 MARCH 1994

PATRON

The Council wishes to express its gratitude to his Excellency Rear Admiral Peter Sinclair, *AC*, Governor of New South Wales, for his continuing support as Patron of the Society.

MEETINGS

Eight General Monthly Meetings and the 125th Annual General Meeting were held during the year. The Annual General Meeting and seven of the General Monthly Meetings were held at the Australian Museum. A summary of Proceedings is set out below.

Special meetings & events in 1993/94:

August 19th 1993 (at New England Branch Armidale)
The 3rd Poggendorf Memorial Lecture was delivered by Professor Stuart Barker Professor in Animal Science and Head of Department, University of New England. It was entitled: "From *buzzatii* to Buffaloes: Excursions into Genetic Variation".

October 20th 1993: (at Australian Museum Sydney)
The 47th Clarke Memorial Lecture was delivered by Professor B.W. Chappell, Department of Geology Australian National University, Canberra ACT, on: "Lachlan and New England: Fold Belts of Contrasting Magmatic and Tectonic Development".

February 15th 1994 (at IEAust Auditorium)
The Society was co-sponsor of a joint meeting with: the Australian Institute of Energy, Sydney; the Australian Nuclear Association and Nuclear Engineering Panel, Institution of Engineers, Australia, Sydney Division.

The Meeting was held at the IEAust Auditorium at Milsons Point. Ms Jan Murray, General Manager, External Relations, North Broken Hill, spoke on: "The Future of Uranium and Nuclear Energy".

March 22nd 1994
The Society's Annual Dinner was held at the Holme & Sutherland Rooms, University of Sydney Union Building. The Guests of Honour were His Excellency Rear Admiral Peter Sinclair, *AC*, Governor of New South Wales, and Mrs Sinclair. The President Dr R.A.L. Osborne, welcomed the guests of Honour, and introduced His Excellency who delivered the Occasional Address. His Excellency then presented the Society's Awards for 1993:

Clarke Medal in Zoology: Professor John Gordon Clifford Grigg (accepted on behalf of the award winner by Dr Ron Strahan because of Professor Grigg's absence overseas in Borneo).

Edgeworth David Medal (research under 35 years of age): Dr. John Howard Skerritt.

Royal Society of New South Wales Medal: Dr Harold George Royle, Armidale NSW.

Each recipient presented a brief speech by way of appreciation of the Award.
A Vote of Thanks was made to His Excellency by Dr Dalwood Swaine, Vice-President.
(46 Members and guests attended)

Eleven meetings of the Council were held at the Society's office, 134 Herring Road, North Ryde. The average attendance was 15.

PUBLICATIONS

Volume 126, parts 1, 2, 3 & 4 of the *Journal and Proceedings* were published during the year. They incorporated ten papers including the Liversidge Research Lecture for 1992 and the Presidential Address for 1993. Eight abstracts of post graduate theses were also published in this volume apart from the Annual Report of Council for 1993-94. Council again wishes to thank the voluntary referees who assessed papers offered for publication.

Ten issues of the Bulletin were published during the year, and Council thanks the authors of short articles for their contribution.

Council granted permission to reproduce material from the *Journal and Proceedings* in several instances.

AWARDS

The following awards were made for 1993:-

Clarke Medal (in Zoology):-
Professor Gordon C. GRIGG,
Head of Department of Zoology, The University of Queensland.

Edgeworth David Medal (research worker under 35 years of age):-
Dr. J.H. SKERRITT, C.S.I.R.O. Division of Plant Industry, Canberra ACT.

Royal Society of New South Wales Medal:-
Dr. Harold George ROYLE, Armidale NSW

The Walter Burfitt Prize, the Archibold D. Olle Prize and the Cook Medal were not awarded this year.

MEMBERSHIP

On the 31st March, 1994, the membership of the Society consisted of the Patron, 15 Honorary Members, 256 Members, and 20 Associate Members, a total of 292, representing an increase of 2 over the total on 31 March, 1993.

The Council wishes again to express its gratitude to our Patron, His Excellency Rear-Admiral Peter Sinclair, *AC*, Governor of New South Wales, for the practical interest he has taken in the Society.

During the year the following were elected to Membership:

Maxwell Richard BENNETT
Phillip Alexander CHERAS
Maxwell John CROSSLEY
Lucy Helen GILLESPIE
Francis Harold HIBBERD
Michael Ray LAKE
Colin Robert NORTHCOTT
Daniel John O'CONNOR
Jill ROWLING
Arron Si Lao XU

With great regret, the Council received news during the year of the deaths of the following members:

Richard Hewitt Christopher CARRINGTON
George Frederick DAVIES
Peter James GILLESPIE
Petro MAJSTRENKO

OFFICE

The Society continued during the year to lease for its office and library a half share of Convocation House, 134 Herring Road, North Ryde, on the southeastern edge of the Macquarie University Campus. The Council is grateful to the University for allowing it to continue leasing the premises.

SUMMER SCHOOL

The Summer School for 1994 on "Cities of the Future" was conducted once again at Macquarie University from 17-21 January 1994. Twenty students were enrolled from 10 private schools and 1 state school within the State of New South Wales. Eighteen voluntary speakers from private, government and academic institutions addressed the students during the week-long activities. Two half-day excursions were carried out: one to a Government Institution and one to a private enterprise establishment. These excursions play a vital part in the programming for the Summer School as they provide industrial insight for the students. The Summer School was organised by Mrs. M. Krysko on the Society's behalf.

Visits were made to the Air-monitoring Station at Lidcombe and to the Clinical Waste Australia Pty Ltd establishment at Silverwater. Council thanks both establishments for their generous co-operation.

Council of the Society also wishes to thank the speakers and organizers of the visits, whose well presented addresses and demonstrations contributed to the success of the School. Council's appreciation is extended to Mrs. Krysko and to the various Councillors who assissted Mrs. Krysko and chaired meetings.

The Official Opening was undertaken by Mr. Andrew Tink MP and Member of the Council of Macquarie University in the presence of the President of the Society, Dr. R.A.L. Osborne and Professor D.M. Schreuder, Deputy Vice-Cnahcellor (Academic) who represented Em. Professor Di Yerbury, Vice-Chancellor of Macquarie University.

LIBRARY REPORT FOR 1993/1994

Acquisitions by gift and exchange continued as heretofore, the overseas and some Australian material being lodged in the Royal Society of New South Wales' Collection in the Dixson Library, University of New England. Other Australian material was lodged in the Society's Office at North Ryde. The Council thanks Mr. Karl Schmude, University Librarian, University of New England for his continuing care and concern in ensuring the smooth operation of the Royal Society Collection and associated inter-library photocopy loans.

An accession list of journal/literature received in the Head Office Library at North Ryde during 1993/1994 has been prepared.

NEW ENGLAND BRANCH REPORT

The Branch held three main meetings during 1993:-
Thursday, 22nd July 1993:- Associate Professor G.A. Woolsey of the Department of Physics, University of New England spoke on "Optical Fibres Keep us in Touch".
The speaker provided the following notes:-

"Four years after Alexander Graham Bell invented the telephone in 1876, he invented the photophone - a device which allowed sound to be transmitted through the air on a beam of sunlight. Until he died in 1922, Bell insisted that the photophone was his greatest invention, although it never progressed beyond being a scientific curiosity.

One hundred years on, signal transmission using light is rapidly taking over the world's communications systems, and this has come about as a result of two scientific discoveries - the laser and the optical fibre. The talk will describe the principles of optical fibre communication, and will include details of the nature of the glass fibres that make up the optical cables now criss-crossing Australia and linking us with other countries.

As invariably happens with the advent of a new technology developed for a specific purpose, innovative scientists and engineers seek out additional applications. Optical fibres are now being used in medicine, to explore the inner recesses of the body; in industry, as sensors for measurement and control, and in aviation, where optical fibre gyroscopes provide precision direction control. Some of these applications will be described.

The lecture was illustrated with practical demonstrations. 76 members and visitors attended.

Wednesday 18th August, 1993:- It was Council's suggestion to hold the 3rd Poggendorff Memorial Lecture at the New England Branch of the Society. Professor J.S.F. Barker, FTS delivered the memorial lecture before 76 members and visitors at the Department of Physics University of New England. The text of the lecture is included in this volume (Vol 127 1/2, 1994).

Thursday 7th October 1993:- Mr. F.K. Rickwood addressed members and visitors on the subject of "Oil in New Guinea". His talk covered the formation of oil within sedimentary rocks, its accumulation in rock formations and how this affects the exploitation of oil resources. The lecture was based on outstanding first-hand knowledge of the history of oil exploration in Papua and New Guinea. An assessment of the likely hydrocarbon reserves of Papua-New Guinea and their role in future world markets were discussed. The lecture was illustrated with colour slides of New Guinea.

ABSTRACT OF PROCEEDINGS

7th April 1993

(a) The 1032nd General Monthly Meeting. Location: Hallstrom Theatre, the Australian Museum, Sydney. The President Dr F.L. Sutherland, was in the Chair and 27 members and visitors were present.

(b) The 126th Annual General Meeting. Same location. The President, Dr. F.L. Sutherland was in the Chair, and 27 members and visitors were present. The Annual Report of Council for 1992/93 and the Financial Report for 1992 were adopted; and Messrs Wylie & Puttock were re-elected Auditors for 1993.

The following Awards for 1992 were announced:
Clarke Medal:
    Professor Alfred Edward Ringwood
Walter Burfitt Prize (joint award):
    Professor George Paxinos
    Professor Istvan Joseph Tork
Edgeworth David Medal (joint award):
    Dr Keith Alexander Nugent
    Dr Peter James Goadsby
Society's Medal
    Mr George William Kinvig Ford

The Archibald D. Olle Prize and the Cook Medal were not awarded for 1992.

These Awards had been presented by His Excellency Rear Admiral Peter Sinclair, AC, on the occasion of the Annual Dinner on March 10th 1993.

The following Office-bearers and Council Members were elected for 1993/94:

President:	Dr R.A.L. Osborne
Vice-Presidents:	Dr F.L. Sutherland
	Dr A.A. Day
	Professor J.H. Loxton
	Dr E.C. Potter
	Dr D.J. Swaine
Honorary Treasurer:	Assoc/Prof D.E. Winch
Honorary Librarian:	Miss P.M. Callaghan
Honorary Secretaries:	Mrs M. Krysko v. Tryst
	Mr G.W.K. Ford
Members of Council:	Mr C.V. Alexander
	Dr R.S. Bhatal
	Dr D.F. Branagan
	Mr J.R. Hardie
	Dr G.C. Lowenthal
	Mr E.D. O'Keefe
	Assoc/Prof W.E. Smith
New England Representative:	
	Professor S.C. Haydon

The retiring President, Dr F.L. Sutherland, who had chaired both the Meetings to this point, yielded the Chair to the incoming President, Dr R.A.L. Osborne, and then delivered his Presidential Address: "Demise of the Dinosaurs and Other Denizens". A vote of thanks was proposed.

May 5th 1993
The 1033rd General Monthly Meeting was held in the Australian Museum Sydney. The President, Dr. R.A.L. Osborne was in the Chair and 40 members and visitors attended. Mr F.R. Blanks AM presented an address on:- "A Centenary Tribute to Sir Eugene Coossens". A vote of thanks was proposed by Dr. G.C. Lowenthal.

June 2nd 1993
The 1034th General Monthly Meeting was held at the Australian Museum, Sydney. The President Dr. R.A.L. Osborne was in the Chair and 23 members and visitors attended. The President welcomed Prof. Paul Adams who represented ANZAAS (NSW) at this joint meeting, the first of four joint meetings on the theme:'The impact of humans on the physical environment, particularly the Sydney region". Dr. R. Mullette, of the Scientific Division of the AWT (formerly the Sydney Water Board) spoke on: "The Aquatic Environment". A/Professor Paul Adams proposed a vote of thanks.

July 7th 1993
The 1035th General Monthly Meeting was held at the Australian Museum, Sydney. The Past President, Dr. F.L. Sutherland, was in the Chair and 20 members and visitors were present. The speaker Dr Graham M. Johnson, of the Centre for Pollution Assessment and Control, CSIRO

Division of Coal and Energy Technology, was introduced by Prof. Paul Adams (ANZAAS) and addressed the meeting on "Air Quality". This was the second topic of the series of Joint Meetings with ANZAAS (N.S.W.). Dr. Sutherland proposed a vote of thanks.

August 4th 1993
The 1036th General Monthly Meeting was held at the Australian Museum. The President, Dr. R.A.L. Osborne was in the Chair and 16 members and visitors attended. Dr. P.B. Mitchell, of the School of Earth Sciences, Macquarie University gave the third address of the series of Joint Meetings with ANZAAS (N.S.W.): "Soils and Soil Landscapes". Prof. Paul Adams proposed a vote of thanks.

September 1st 1993
The 1037th General Monthly Meeting was held at the Australian Museum. The President Dr. R.A.L. Osborne was in the Chair and 16 members and visitors were present. Mr. Peter Hamilton, Manager, Metropolotan and Regional Management Branch, NSW State Department of Planning, gave the fourth address of the Joint Series:- "Planning for the Sydney Region". Professor Paul Adams proposed a vote of thanks.

October 6th 1993
The 1038th General Monthly Meeting was held at the Australian Museum. The President, Dr. R.A.L. Osborne was in the Chair and 16 members and visitors were present.
Dr. Sydney A. Baggs, Architect, the PEOPL Group Sydney, addressed the meeting on "An Overview of the Human Use of Underground Space (Geospace) from the Paleolithic to Recent Times".
Dr. F.L. Sutherland proposed the vote of thanks.

November 3rd 1993
The 1039th General Monthly Meeting was held at the University of Western Sydney, Nepean Kingswood Campus. The President, Dr. R.A.L. Osborne was in the Chair and 25 members and visitors attended.
Prof. P.A. Williams, Foundation Professor of Chemistry, University of Western Sydney, Nepean delivered an address on:- "The Ignoble Geochemistry of Platinum".
Dr. Sutherland proposed a vote of thanks.

Participants in the Summer School on "Cities of the Future", 17-21 January 1994, held at Macquarie University.
First from Left:- Dr. R.A.L. Osborne, President of the Society.
Second last from right:- Dr. F.L. Sutherland, Vice-President of the Society.
Last on right:- Mrs M. Krysko v. Tryst, Hon. Secretary of the Society and Convener of the Summer School.

FINANCIAL STATEMENTS FOR THE YEAR ENDED 31st DECEMBER 1993

THE ROYAL SOCIETY OF NEW SOUTH WALES

AUDITORS REPORT TO THE MEMBERS

Scope

We have audited the accounts, contained on pages 2 to 9 of The Royal Society of New South Wales for the year ended 31 December 1993. We have conducted an independent audit of these accounts in order to express an opinion on them to the members of the society.

Our audit has been conducted in accordance with Australian Auditing Standards to provide reasonable assurance as to whether the accounts are free of material misstatement. Our procedures included examination on a test basis, of evidence supporting the amounts and other disclosures in the accounts, and the evaluation of accounting policies and significant accounting estimates. These procedures have been undertaken to form an opinion as to whether, in all material respects, the accounts are presented fairly in accordance with Australian Accounting Concepts and Standards as to present a view of the society which is consistent with our understanding of its financial position and the results of its operations.

The audit opinion expressed in this report has been formed on the above basis.

Audit Opinion

In our opinion the accounts of The Royal Society of New South Wales are properly drawn up:

(a) so as to give a true and fair view of the state of affairs of the society at 31 December 1993 and of the results of the society for the year ended on that date; and

(b) in accordance with Statements of the Accounting Concepts and applicable Accounting Standards.

WYLIE & PUTTOCK
Chartered Accountants

ALAN M PUTTOCK

The accompanying notes form part of these financial statements

THE ROYAL SOCIETY OF NEW SOUTH WALES

BALANCE SHEET AT 31 DECEMBER 1993

1992		NOTE	1993
	CURRENT ASSETS		
5171	Cash	2	5454
1846	Receivables	3	4093
0	Investments		0
0	Inventories		0
1921	Other	4	1479
8938	TOTAL CURRENT ASSETS		11026
	NON-CURRENT ASSETS		
0	Receivables		0
151430	Investments	5	146485
0	Inventories		0
19179	Property, plant and equipment	6	18049
0	Intangibles		0
0	Other		0
170609	TOTAL NON-CURRENT ASSETS		164534
179547	TOTAL ASSETS		175560
	CURRENT LIABILITIES		
6940	Creditors and borrowings	7	7607
0	Provisions		0
1875	Other	8	1421
8815	TOTAL CURRENT LIABILITIES		9028
	NON-CURRENT LIABILITIES		
0	Creditors and borrowings		0
0	Provisions		0
119	Other	8	103
119	TOTAL NON-CURRENT LIABILITIES		103
8934	TOTAL LIABILITIES		9131
170613	NET ASSETS		166429
	EQUITY		
7311	Library reserve	9	7311
10098	Library fund	10	9494
22993	Trust funds	11	21854
130211	Other accumulated funds		127770
170613	TOTAL EQUITY		166429

R A L OSBORNE President　　　D E WINCH Honorary Treasurer

ACCUMULATED FUNDS ACCOUNT
For the year ended 31 December 1993

1992		NOTE	1993
(1137)	Operating surplus (deficit)		(5692)
749	Donations and interest to library fund	10	647
0	Bequest	16	2000
(388)			(3045)
132679	Accumulated funds at the beginning of the financial year		130211
(1346)	Prior period adjustment		0
15	Transferred from library fund	10	1251
130960			128417
749	Transferred to library fund	10	647
130211	Accumulated funds at end of the financial year		127770

STATEMENT OF CASH FLOWS
For the year ended 31 December 1993

1992		NOTE	1993
	CASH FLOWS FROM OPERATING ACTIVITIES		
8038	Members subscriptions and donations		7735
19645	Other revenue sources		11433
9382	Interest received		7180
(37450)	Administration and other operating expenses		(31010)
(385)	Net cash provided by (used in) operating activities	17	(4662)
	CASH FLOWS FROM INVESTING ACTIVITIES		
(2231)	Net amount reinvested		0
0	Net reduction in investments		4945
(2231)	Net cash provided by (applied to) investing activities		4945
(2616)	NET INCREASE (DECREASE) IN CASH HELD		283
7787	Cash at the beginning of the financial year		5171
5171	CASH AT THE END OF THE FINANCIAL YEAR		5454

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1993

1 STATEMENT OF ACCOUNTING POLICIES

The accounts have been prepared in accordance with Statements of Accounting Concepts and applicable Accounting Standards. The accounts have also been prepared on the basis of historical costs and do not take into account changing money values or, except where stated, current valuations of non-current assets. The accounting policies have been consistently applied, unless otherwise stated.

The following is a summary of the significant accounting policies adopted by the society in the preparation of the accounts.

(a) Non-Current Investments

Investments are brought to account at cost. The carrying amount of investments is reviewed annually to ensure it is not in excess of the recoverable amount of the investments.

(b) Property, Plant & Equipment

Property, plant and equipment are brought to account at cost or at independent valuation, less, where applicable, any accumulated depreciation or amortisation. The carrying amount of property, plant and equipment is reviewed annually to ensure it is not in excess of the recoverable amount from these assets.

The depreciable amount of all fixed assets is depreciated over their useful lives commencing from the time the asset is held ready for use.

The exception to the above policy is the society's library which is brought to account at its 1936 independent valuation, a more recent valuation not being available.

(c) Unearned Revenue

The unearned revenue shown in the accounts will be brought to account in the next financial year.

(d) Comparative Figures

Where required by Accounting Standards comparative figures have been adjusted to conform with changes in presentation for the current financial year.

2 CASH

1992	Included in cash are:	1993
0	Cash on hand	23
5171	Cash at bank	5431
5171		5454

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1993

1992		1993
	3 RECEIVABLES	
	Included in Current Receivables are:	
1840	Debtors for subscriptions	2128
1840	Less provision for doubtful debts	2128
0		0
1846	Debtors for contributions towards printing Journal and Proceedings	4093
1846		4093
	4 OTHER ASSETS	
	Included in Current Other Assets are:	
1921	Prepayments	1479
	5 INVESTMENTS	
	Included in Non-Current Investments are:	
151430	Interest bearing deposits	146485
	6 PROPERTY PLANT AND EQUIPMENT	
	Included in Property, Plant & Equipment are:	
863	Office equipment and furniture - at cost less depreciation	674
4706	Office equipment - at 1991 valuation less depreciation	3765
13600	Library - at 1936 valuation	13600
10	Pictures - at cost less depreciation	10
19179		18049
	7 CREDITORS AND BORROWINGS	
	Included in Current Creditors & Borrowings are:	
0	Creditors and accruals re Journal and Proceedings printing and distribution	6607
0	Other creditors and accruals	50
6940	Unearned revenue	950
6940		7607

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1993

1992		1993
	8 OTHER LIABILITIES	
	Included in Current Other Liabilities are:	
17	Life members subscriptions prepaid	16
163	Membership subscriptions paid in advance	283
1695	Journal and Proceedings subscriptions paid in advance	1122
1875		1421
	Included in Non-Current Other Liabilities are:	
119	Life members subscriptions prepaid	103
	9 LIBRARY RESERVE	
7311	Balance at 1 January	7311
0	Movement for year	0
7311	Balance at 31 December	7311
	10 LIBRARY FUND	
9364	Balance at 1 January	10098
749	Donations and interest	647
10113		10745
15	Library purchases and expenses	251
0	Contribution towards printing Journal and Proceedings	1000
15		1251
10098	Balance at 31 December	9494
	11 TRUST FUNDS	
	Included in Trust Funds are:	
3888	Clarke Memorial Fund	3917
7533	Walter Burfitt Prize Fund	6514
4185	Liversidge Bequest Fund	3837
7387	Olle Bequest Fund	7586
22993		21854

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1993

12 CLARKE MEMORIAL FUND

1992		1993
5000	Capital	5000
	Revenue	
328	Income for year	249
2878	Expenditure for year	220
(2550)	Surplus (deficit) for year	29
1438	Balance at 1 January	(1112)
(1112)	Balance at 31 December	(1083)
3888	Total fund capital and revenue	3917

13 WALTER BURFITT PRIZE FUND

1992		1993
3000	Capital	3000
	Revenue	
196	Income for year	150
0	Expenditure for year	1169
196	Surplus (deficit) for year	(1019)
4337	Balance at 1 January	4533
4533	Balance at 31 December	3514
7533	Total fund capital and revenue	6514

14 LIVERSIDGE BEQUEST FUND

1992		1993
3000	Capital	3000
	Revenue	
197	Income for year	150
23	Expenditure for year	498
174	Surplus (deficit) for year	(348)
1011	Balance at 1 January	1185
1185	Balance at 31 December	837
4185	Total fund capital and revenue	3837

NOTES TO AND FORMING PART OF THE ACCOUNTS
For the year ended 31 December 1993

15 OLLE BEQUEST FUND

1992		1993
4000	Capital	4000
	Revenue	
263	Income for year	199
0	Expenditure for year	0
263	Surplus (deficit) for year	199
3124	Balance at 1 January	3387
3387	Balance at 31 December	3586
7387	Total fund capital and revenue	7586

16 BEQUEST

During the year the Society received the following bequest:

1992		1993
0	Estate late Dr H G Golding	2000

17 CASH FLOW INFORMATION

Reconciliation of net cash provided by operating activities to operating surplus (deficit)

1992		1993
(1137)	Operating surplus (deficit)	(5692)
0	Bequest	2000
749	Library fund donations & interest	647
(1346)	Prior period adjustment	0
	Non-cash flows in operating surplus	
1289	Depreciation	1130
	Changes in assets and liabilities	
999	Reduction (increase) in receivables	(2247)
69	Reduction in prepayments	442
2595	Increase (reduction) in unearned revenue	(5990)
(2014)	Increase (reduction) in creditors	6657
51	Increase in members subscriptions in advance	103
277	Increase (reduction) in journal subscriptions in advance	(573)
(1917)	Reduction in trust funds	(1139)
(385)	Net cash provided by (used in) operating activities	(4662)

INCOME AND EXPENDITURE ACCOUNT
For the year ended 31st December 1993

	INCOME	
	Membership Subscriptions -	
7818.00	Ordinary	8156.00
	Membership Subscriptions -	
23.87	Life Members	17.04
6.00	Application Fees	45.20
----------		----------
7847.87		8218.24
	Subscriptions and	
	Contributions to Journal	
7819.47	Publication Costs	8744.41
----------		----------
	Total Membership and Journal	
15667.34	Income	16962.65
8219.06	Interest Received	6240.85
5.00	Sale of Reprints	234.75
435.00	Sale of Back Numbers	1105.21
70.00	Sale of Other Publications	20.00
0.00	Research Fees	10.00
4151.18	Summer School Surplus	3536.72
----------		----------
28547.58		28110.18

	Less:EXPENSES			
2310.00	Accountancy Fees		2310.00	
0.00	Advertising		490.30	
696.60	Annual Dinner Deficit		117.90	
1190.00	Audit Fees		1190.00	
	Bank Charges & Government			
50.13	Duties		67.35	
150.00	Branches of the Society		0.00	
0.00	Computer Software		350.00	
1289.00	Depreciation		1130.00	
438.60	Entertainment Expenses		240.00	
542.02	Insurance		616.99	
	Journal Publication and Distribution Costs			
7349.77	Printing	11045.85		
2345.12	Wrapping & Postage	2962.99		
----------		----------		
9694.89			14008.84	
15.75	Library Expenses		251.00	
111.40	Miscellaneous Expenses		38.40	
370.65	Monthly Meeting Expenses		297.00	
	Newsletter Printing &			
1982.02	Distribution		2381.58	
586.76	Postage		568.60	
	Printing & Stationery -			
993.33	General		735.95	
433.92	Provision for Doubtful Debts		1057.31	
2000.00	Rent		2000.00	
6428.86	Salaries		5151.26	
0.00	Secretarial Services		210.00	
	Superannuation Contributions			
0.00	- Employees		220.00	
400.57	Telephone		370.27	
----------			----------	
29684.50				33802.75
----------				----------
1136.92	DEFICIT for the year			5692.57
==========	===================			==========

CLARKE MEDAL FOR 1993

Professor Gordon C. Grigg has made an outstanding contribution to the study of Australian Zoology and to the conservation of a diverse range of organisms at an international level.

After completing a BSc with First Class Honours in Zoology at the University of Queensland in his home town of Brisbane in 1965, Professor Grigg travelled to the US where he gained his PhD at the University of Oregon in 1968. He returned to Australia in 1968 taking up a Queen Elizabeth II Post-doctoral Fellowship at the University of Sydney. He was awarded a DSc by the University of Sydney in 1987 and remained at Sydney University until 1988 firstly as a lecturer, then as a Senior Lecturer. He was appointed Associate Professor in Biology in 1982. Professor Grigg is currently Professor of Zoology and Head of the Department of Zoology at the University of Queensland.

The award of the Clark Medal for 1993 to Professor Grigg is particularly fitting as, unlike many natural scientists in the late twentieth century, Professor Grigg's research interests emulate those of the Reverend William Branwhite Clarke by covering both a wide range of organisms including fish, frogs, reptiles and mammals, and a variety of aspects of their biology ranging from physiology to ecology.

Professor Grigg's published research includes over 100 papers and some 20 popular articles. He is the author of over twenty reports to state governments and the Commonwealth on matters relating to wildlife management.

Professor Grigg's primary research interests are in whole animal vertebrate biolody and consider the interface between physiology and ecology with particular emphasis on the physiological adaptions of animals to their environments. The animals he has studied have included, among others; Queensland lungfish, teleost fishes, sharks, crocodiles, echidnas, camels and kangaroos. His work is marked by an integration of physiological researches with studies of animals in the wild. These have involved the development of novel techniques for animal tracking and have often formed the basis for practical policies for faunal conservation.

Since his involvement in a kangaroo tracking project in 1975, Professor Grigg has gained public attention by his promotion of the use of Kangaroo harvesting as a tool for the sustainable management of Australia's rangelands.

Professor Grigg is an outstanding Australian zoologist who has made significant contributions to our understanding of the Australian fish, reptile and mammal fauna. There can be few zoologists in the world who, like Professor Grigg, are members of international specialist groups dealing with the conservation of such diverse animals as amphibians, reptiles and mammals. It is with great pleasure that the Royal Society of New South Wales presents Professor Grigg with the Clarke Medal in recognition of this outstanding and wide ranging zoological achievements.

EDGEWORTH DAVID MEDAL FOR 1993

The Edgeworth David Medal, for distinguished contributions to Australian science by a young scientist under the age of 35, is awarded to John Howard Skerritt, *BSc (Hons), PhD, Sydney.*

John Skerritt is a Principal Research Scientist at the CSIRO Division of Plant Industry. He joined the Sydney laboratory of the Division in 1983 and moved to Canberra in 1993 where he now heads the subprogram in grain protein manipulation.

He already has an outstanding scientific career. In recent years, the major accent of his work has been on the use of specific antibodies to probe the structure and function of cereal and grain proteins and to adapt the specificity and speed of antibody reactions to increase the efficiency of test systems for grain quality.

He has adapted technologies from medical diagnostics for the benefit of the Australian agricultural and food industries, permitting more efficient on-the-spot quality control. Several of his test systems have been commercialised and marketed overseas. These include a simple test for the gluten content of processed foods and a systematic test for the analysis of pesticides. He has used antibodies specific for wheat-grain proteims to identify the amino acid sequences relevant to dough strength and to certain diseases and to examine the genetic relationships between cereals. In several instances, his innovations have been applied back in the medical field.

John Skerritt is a prolific researcher and in demand as an invited speaker at International conferences. His work has been supported by grants from industry and Government schemes and he has a number of patents. He has been very effective in collaboration and has built up a small active team in his Division.

John Skerrit's contributions to agricultural science and genetics make him a very worthy recipient of the Edgeworth David Medal.

THE ROYAL SOCIETY OF NEW SOUTH WALES MEDAL FOR 1993

Harold George Royale, recipient of the Society's Medal, was born in 1917, attended the King's School, Parramatta (the school to which the Rev. W.B. Clarke had been appointed Headmaster in 1839), and went up to Sydney University as a medical student in 1936. He graduated M.B., B.S. at the end of 1941 and joined the Australian Imperial Force in 1942 as Captain in the Australian Army Medical Corps. He saw action with the 2/5th Field Ambulance at Milne Bay and with the 2/10 Infantry Battalion, in the Ramu Valley and at Shaggy Ridge.

Upon discharge in 1946 he took up general practice in Armidale, quickly finding the city's medical facilities to be limited to what was little more than a cottage hospital. Among its many limitations, the hospital had no facilities for blood transfusion or intravenous anaesthetics and, most importantly, no pathology department. So, at the age of 29, the young Harold Royle marshalled some glass ware he had managed to acquire from his last Army hospital, and his student microscope, and proceeded to establish proper pathology facilities at the Armidale and New England District Hospital. In 1987, in recognition of his role as founder of the Pathology Department, Honorary Consulting Pathologist, Honorary Physician, as President of the the Medical Board and many other services over a period of some 42 years, the Hospital named its then newly completed medical library the Harold Royle Library in his honour.

Throughout his career - unfortunately terminated by sudden illness in 1988 - Dr Royle has poured enormous energy and well-informed enthusiasm into the improvement of medical practice, the extension and application of medical science and the proper documentation of the Australian medical history. He is a Fellow of the Royal Australian College of General Practitioners and was a member of the Education and Examination Committee of that body. He has been a member of various committees involved with drug abuse and education, was medical officer to the University of New England from 1948 to 1962, and was appointed to its Scientific Ethics Committee in 1978. He is one of the foremost authorities on the health of the First Fleet and early colony of New South Wales: his paper on "The health of Sydney in the 1820's" was published in the Australian Medical Journal of 1973, and that on "Some aspects of health on the First Fleet" (jointly with R. Simpson) in the same journal in 1984. In addition to this, and to a monumental contribution to the health, welfare, and intellectual life of the New England community, Harold Royle has been a member of the Royal Society of New South Wales for over thirty years, and Chairman of, contributer to, and constant loyal supporter of its New England Branch.

There could be no more worthy recipient of the Society's Medal than Dr. Harold George Royle.

BIOGRAPHICAL MEMOIR

George Frederick Davies, 1910 - 1993

George Davies, who died on 11th June 1993, joined the Royal Society of New South Wales in 1952. He regularly attended monthly meetings of the Society until quite recently.

Mr. Davies was born in 1910. He became an Apprentice Fitter and Turner with the Colonial Sugar Refining Co. Ltd. in 1926. After attending Sydney Technical College Trade Classes, he studied by correspondence and became an Associate Member of the Institute of Engineering Technology, London.

In his career with CSR, he was promoted to Engineer, Supervising Design Engineer, and in 1969 Senior Project Engineer. He retired in 1972. He was highly respected and liked by all who worked with him. As a member of the Royal Society of New South Wales, he showed a strong interest in, and enthusiasm for scientific and technical research and development. He was a keen reader of information on many subjects and retained a great store of knowledge, which he would share happily with friends and associates.

In his private life, George was a lover of sport and the outdoors. He played cricket with the Moore Park Cricket Association (of which he was a life member), where he received many awards, particularly for his bowling prowess. It was while he played with this club, that he met his future wife, Elsie.

In winter he played Rugby Union, with Western Suburbs, and later the Parramatta District R.U. Club as a winger, joined by his younger brother John at five-eight. George remained a member of the club throughout his retirement, and with great pleasure and excitement accepted an invitation to be Guest Speaker at the Club's 50th Anniversary Dinner.

As a member of the Australian Jockey Club, the National Parks and Wildlife Foundation, the Sydney Cricket and Sportsground Trust etc. he was often invited to speak on occasions and this he did with amazing ease.

George was a keen fisherman and lover of nature. When time allowed, he would travel long distances in search of the tranquility that would signify the "right-spot" for catching the elusive trout. From these trips he often returned with stones or rocks of unusual characteristics which would eventually be placed in his garden. George tended his garden in his meticulous way, keeping a diary of the passage of every seedling through to its coming of age as a fully grown shrub or plant in glorious bloom, which he would even photograph so that he and others would enjoy their beauty again at some later time.

George was a man of integrity and compassion. He regularly supported organisations such as the Sydney Eye Hospital, the Children's Hospital, the Cancer Foundation, the Royal Blind Association and the Prince of Wales Hospital. He was never too busy to assist those who sought his direction in any number of matters. He knew the value of friendship. Having no children of his own he "adopted" those around him as his "family", and they adopted him.

George Davies was a good man, with a fine mind, who could have found a career in any of many scientific pursuits.

George and his younger brother and sister were a close-knit family who grew up with his leadership.

These Personal Notes were contributed by Mr. Davies niece, M/s. Pamela M. Poole.

P.M.C.

BIOGRAPHICAL MEMOIR

Richard (Dick) Carrington, *Th.A.*

Vale Richard Hewitt Carrington. He was born in 1919 at New Farm, Queensland, and educated at Cranbrook School, Sydney. He was considered a slow learner, although both his parents were well respected teachers. His problems seemed to climax during his service as a medical orderly in the army during the Second World War, and he was invalided out. At the same time, he developed a leg ulcer that stayed with him the rest of his life and caused him to limp. From then on, his life was dominated by his burning desire to become a scholar - which he virtually considered his birthright-and by his struggle against the mental condition that made him depressed and lethargic.

It is testimony to his perseverence that he was still attending university courses in his sixties and seventies and by then had made great progress towards his goal of scholastic respectability. His main interests were theology, the natural sciences and bibliography. He was a supporter of a number of charities and a member of several societies. He was admirably supported by his neighbours and community at Gordon, as well as by the staff at the Lady Davidson Hospital, especially during his many bouts of illness. He died in Lady Davidson on March 25th 1993.

He was a member of the Royal Society of New South Wales since August 1983.

C.R.

NOTICE TO AUTHORS

A "Style Guide" to authors is available from the Honorary Secretary, Royal Society of New South Wales, PO Box 1525, Macquarie Centre, NSW 2113, and intending authors *must* read the guide before preparing their manuscript for review. The more important requirements are summarised below.

GENERAL

Manuscripts should be addressed to the Honorary Secretary (address given above).

Manuscripts submitted by a non-member must be communicated by a member of the Society.

Each manuscript will be scrutinised by the Publications Committee before being sent to an independent referee who will advise the Council of the Society on the acceptability of the paper. In the event of rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere, nor is likely to be published substantially in the same form elsewhere. Well-known work and experimental procedure should be referred to only briefly, and extensive reviews and historical surveys should, as a rule, be avoided. Letters to the Editor and short notes may also be submitted for publication.

Original papers or illustrations published in the Journal and Proceedings of the Society may be reproduced only with the permission of the author and of the Council of the Society; the usual acknowledgements must be made.

PRESENTATION OF INITIAL MANUSCRIPT FOR REVIEW

Typescripts should be submitted on bond A4 paper. A second copy of both text and illustrations is required for office use. Manuscripts, including the abstract, captions for illustrations and tables, acknowledgements and references should be typed in double spacing on one side of the paper only.

Manuscripts should be arranged in the following order: title; names(s) of author(s); abstract; introduction; main text; conclusions and/or summary; acknowledgements; appendices; references; names of Institution/Organisation where work carried out/or private address as applicable. A table of contents should also accompany the paper for the guidance of the Editor.

Spelling follows "The Concise Oxford Dictionary".

The Systeme International d'Unites (SI) is to be used, with the abbreviations and symbols set out in Australian Standard AS1000.

All stratigraphic names must conform with the International Stratigraphic Guide and must first be cleared with the Central Register of Australian Stratigraphic Names, Bureau of Mineral Resources, Geology and Geophysics, Canberra, ACT 2601, Australia.

Abstract. A brief but fully informative abstract must be provided.

Tables should be adjusted for size to fit the final publication. Units of measurement should always be indicated in the headings of the columns or rows to which they apply. Tables should be numbered (serially) with Arabic numerals and must have a caption.

Illustrations. When submitting a paper for review all illustrations should be in the form and size intended for insertion in the master manuscript. If this is not readily possible then an indication of the required reduction (such as reduce to 1/2 size) must be clearly stated.

Note: There is a reduction of 33% from the master manuscript to the printed page in the journal.

Maps, diagrams and graphs should generally not be larger than a single page. However, larger figures can be printed across two opposite pages.

Drawings should be made in black Indian ink on white drawing paper, tracing cloth or light-blue lined graph paper. All lines and hatching or stripping should be even and sufficiently thick to allow appropriate reduction without loss of detail. The scale of maps or diagrams must be given in BAR FORM.

Half-tone illustrations (photographs) should be included only when essential and should be presented on glossy paper.

Diagrams, graphs, maps and photographs must be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

References are to be cited in the text by giving the author's name and year of publication. References in the reference list should follow preferred method of quoting references to books, periodicals, reports and theses, etc., and be listed alphabetically by author and then chronologically by date.

Titles of journals should be cited in full – *not* abbreviated.

MASTER MANUSCRIPT FOR PRINTING

The journal is printed by offset using pre-typed pages. When a paper has been accepted for publication the text may either be typed by electric typewriter or produced by word-processor print-out. Print-out or typing should be in a column exactly 105 mm (= 4 1/8 inches) wide. Type size should be 14 point (Roman preferred) or 12 pitch single-spaced (IBM Adjutant preferred).

Reprints An author who is a member of the Society will receive a number of reprints of his paper free. An author who is not a member of the Society may purchase reprints.

CONTENTS

VOLUME 127, Parts 1 and 2

OSBORNE, R.A.L.
Caves, Cement, Bats and Tourists: Karst Science and Limestone Resource Management in Australia. (Presidential Address 1994) 1

BARKER, J.S.F.
From *Buzzatti* to Buffaloes - Excursions into Genetic Variation (3rd Walter Poggendorff Memorial Lecture, 1993). 23

LAWRENCE, L.J., STOCKSIEK, C.M. and WILLIAMS, P.A.
An Occurrence of Kröhnkite at Broken Hill, N.S.W. 31

HEATHCOTE, K.A. and PIPER R.
Strength of Cement Stabilised Pressed Earth Bricks with Low Cement Contents 33

DOVE, Andrew and LEE, Graham
Breccia Filled Diatreme in Permian Illawarra Coal Measures and Triassic Strata, Kandos, New South Wales 39

CHAPPELL, B.W.,
Lachlan and New England: Fold Belts of Contrasting Magmatic and Tectonic Development (47th Clarke Memorial Lecture, 1993). 47

ABSTRACTS OF THESES:-

PICKERING, Catherine M.:	Reproductive Ecology of Five Species of Australian Alpine *Ranunculus*.	61
KAYNAK, Akif:	A Study of Conducting Polyrrole Films in the Microwave Region	62
BAXTER, Rohan A.:	Representation Issues in Genetic Algorithm Function Optimization	63
ROBERTS, Maureen B.:	The Diamond Path: A Study of Individuation in the Works of John Keats.	64
BILLS, Peter J.:	Barotropic Depth-Averaged and Three-Dimensional Tidal Programs For Shallow Seas	65
ZHU, Jin:	Tannin Toxicity Studies in Mice and Sheep	66
PARKINSON, Murray L.	Multi-Frequency MF/Lower HF Ocean Radar Studies of Wind-Wave Trasients	67
WOODWARD, Roslyn	'It's so Strange when you stay Sick': The Challenge of Chronic Fatigue Syndrome	69

COUNCIL REPORT, 1993-1994
Report 71
Abstract of Proceedings 73
Summer School Photo 74
Financial Statement 75
Awards 80
Biographic Memoirs 82

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THE ROYAL SOCIETY OF NEW SOUTH WALES

Address:- Royal Society of New South Wales
PO Box 1525, Macquarie Centre NSW 2113, Australia

THE ROYAL SOCIETY OF NEW SOUTH WALES

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science through the following activities: Publication of results of scientific investigation through its Journal and Proceedings; the Library, awards of Prizes and Medals; liaison with other Scientific Societies; Monthly Meetings; and Summer Schools for Senior Secondary School Students. Special Meetings are held for the Pollock Memorial Lecture in Physics and Mathematics, the Liversidge Research Lecture in Chemistry, and the Clarke Memorial Lecture in Geology.

Membership is open to any interested person whose application is acceptable to the Society. The application must be supported by two members of the Society, to one of whom the applicant must be personally known. Membership categories are: Ordinary Members, Absentee Members and Associate Members. Annual Membership fee may be ascertained from the Society's Office.

Subscriptions to the Journal are welcomed. The current subscription rate may be ascertained from the Society's Office.

The Society welcomes manuscripts of research (and occasional review articles) in all branches of science, art, literature and philosophy for publication in the Journal and the Proceedings.

Manuscripts will be accepted from both members and non-members, though those from non-members should be communicated through a member. A copy of the Guide to Authors is obtainable on request and manuscripts may be addressed to the Honorary Secretary (Editorial) at the above address.

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BIBLIOGRAPHY of THE REVEREND W.B. CLARKE (1798-1878)

"Father of Australian Geology"

M.K. Organ

Abstract: Throughout his lifetime, the Rev. W.B. Clarke was a prolific writer of letters and articles for publication on a variety of topics, including geology, meteorology, astronomy, natural history, zoology, theology, literature, Australian exploration, politics, and various miscellany. Previous bibliographies such as Etheridge and Jack (1881) have listed approximately 150 works by Clarke, and upon such information analyses of his role in the history of Australian science have been made. Such lists mostly excluded his substantial collection of published writings which appeared in local newspapers and overseas journals. The present bibliography redresses these omissions, listing some 837 works, of which 545 are by Clarke. This revelation of the quantity, and variety, of his published work highlights the significant part he played in the promotion of science in colonial New South Wales.

Introduction

W.B. Clarke is widely recognised as the "Father of Australian Geology", a title given him early this century by a younger generation of earth scientists. However he was also a prolific author of non-geological material, a commentator and correspondent on a variety of topics ranging from science and natural history through to politics and the arts, not to forget his role in the formation of the Royal Society of New South Wales in 1867.

The numerous publications referred to within this bibliography, along with the large volume of correspondence located in the Mitchell Library and miscellaneous archival collections, are testament to Clarke's coverage of a variety of disciplines. A knowledge of the breadth of his output leaves one with the belief that to simply proclaim him "the Father of Australian Geology" is to fail to do justice to his lifeswork. This bibliography is just one part of the process of making W.B. Clarke's large body of research and writing known to a wider audience. Its publication may perhaps lead to a reassessment not only of his science, but also of his role in raising the level of awareness of such issues amongst the general reading public in Australia during the nineteenth century. Publication of sections of his voluminous correspondence will also add to this valuable resource.

Biographical

William Branwhite Clarke was born on 2 June 1798 at East Bergholt, Suffolk, England, and died in Sydney on 16 June 1878, at the onset of his eightieth year. The son of William Clarke and his wife Sarah (nee Branthwaite), he was educated at the East Bergholt school where his father was headmaster, before entering Jesus College, Cambridge in 1817 and subsequently attained a B.A. in 1821 and M.A. in 1824. During this period he was a student of, and much influenced by, the noted geologist Professor Adam Sedgwick. In 1823 Clarke was ordained a minister in the Church of England, and following the completion of his studies in 1824 took up religious and teaching duties at various parishes and schools, all the while continuing to pursue his interests in the arts and natural sciences. He was at this stage of his life a veracious reader and busy with the pen. According to his own testimony, his began to publish in 1816, and between 1819-22 his poetic effusions were numerous. The first geologically related article of which Clarke is the known author appeared during 1828.

By 1830 the Rev. Clarke was acting headmaster of the Bergholt Free Grammar School, however he resigned early in 1831 as the grind of teaching was not to his liking. During the late twenties and early thirties he travelled widely throughout the British Isles and Europe on geological excursions. After a disastrous love affair during 1830-1 which saw him parted from his true love and almost resulted in litigation, William subsequently married Maria Moreton (nee Stather) on 13 January 1832. The couple were eventually to raise two children - Mary and Morduant. Another died during infancy.

In 1833 Clarke was installed as first incumbent at the church of Saint Mary Longfleet, Poole, Dorsetshire, with the family taking up residence in the nearby 'Stanley Green.' They remained there until departing for Australia in January 1839, the decision to emigrate largely due to ill health (rheumantic fever) and financial reasons on the part of William, though he was also interested in the unexplored geology and geography of the fifth continent and saw the opportunity to achieve much in the area of original research. Their ship the **Roxburgh Castle** arrived in Sydney on 27 May 1839, and despite a languishing illness during the latter stages of the voyage, William almost immediately took up ministerial duties, such were the needs of the Colony. His vocation and sense of duty to the Church remained a priority for the remainder of his working life.

From July 1839 to December 1840 W.B. Clarke was headmaster of the King's School, Parramatta, however due to continuing ill health, small financial remuneration, and the stress of work he decided to resign at the end of 1840 and return to his ministry. Over the next four years he was responsible for the young parishes of Castle Hill and Dural, covering a large area to the north and west of Sydney. Between 1844-6 he also served at Campbelltown, though during this period he was somewhat of a roving parson, able to travel widely throughout the settled districts of New South Wales by swapping ministries for short periods. This enabled him to increase his knowledge of the local geography and build up a collection of geological specimens.

W.B. Clarke was eventually appointed rector at the new St Thomas's Church, North Sydney (St Leonards), in 1846 and remained there until his retirement in 1871. The family continued to live at St Leonards up to the time of William's death in 1878. During those final years he spent a rather tranquil period surrounded by a large family and free to complete some of his scientific researches, along with supporting the newly formed Royal Society of New South Wales where his deteriorating health allowed.

William's domestic situation was not always so stable. Early in 1842 the family returned to England without him - Maria was homesick and the children needed a comprehensive education, something which William believed the Colony could not adequately provide. The family did not return to Australia until December 1856, and only then after Clarke had suffered a mild stroke and his parishioners were moved to raise the necessary funds to pay for their passage from England. Throughout the sixteen years of separation he was forced to support his wife and children with money sent from the Colony. This proved to be an almost unbearable strain on his always meagre income as a parish priest; an income which was only supplemented by payments for journalistic endeavours. The decade of the 1840s was also one of economic depression in the Colony, thus aggravating the situation. It was not until the late 1850s and early 1860s that Clarke was financially reimbursed for some of his geological work in the Australian goldfields on behalf of the government.

Following a busy life as a full-time minister, part-time scientist, journalist, and parent, W.B. Clarke died on 16 June 1878 at his St Leonards residence 'Branthwaite', shortly after completing the manuscript for the fourth edition of his REMARKS ON THE SEDIMENTARY FORMATIONS OF NEW SOUTH WALES (1878). Clarke's valuable mineral and fossil collection, plus some personal papers and a comprehensive scientific library, were subsequently purchased by the New South Wales Government for £7000 to form part of a national collection. Unfortunately they were all destroyed in the Sydney Garden Palace fire of 22 September 1882, whilst in storage awaiting cataloguing. Only the relatively small archive of private papers once held by the family - and now in the Mitchell Library, Sydney - along with various items of correspondence in libraries and archives throughout the world, plus Clarke's large store of published material, survive as a record of his many years endeavour in the field of Australian science. The bulk of his original geological field books, maps, notes and manuscripts were destroyed in the 1882 fire, setting the course of New South Wales and Australian geology back a number of years - though thankfully during his latter years Clarke had correspondended with young geologists such as C.T. Wilkinson and Richard Daintree and passed on to them much of the geological knowledge he had acquired since coming to Australia in 1839. He had also published regularly during his lifetime, and the numerous publications referred to in this bibliography are testament to his on-going endeavours and wide-ranging influence.

From the earliest days of his arrival in the Colony, W.B. Clarke had pursued a special interest in local geology and meteorology, pursuing detailed investigations where time allowed right up to the time of his death in 1878. For a period of almost 40 years he carried on a lively correspondence regarding the geology, palaeontology, meteorology, and geography of Australia with friends and fellow scientists both locally and in Great Britain, Europe and America. He was a focus for scientific studies in the Colony, especially during the period 1840-60. Numerous articles by him were published in both local and overseas journals, and he was a regular writer for Sydney newspapers such as the *Sydney Morning Herald* and *The Empire*. Clarke was responsible for leading articles and letters to the editor on scientific issues and subjects such as Australian exploration and education. Unfortunately, as was common for the time, the majority of this material was unsigned, possibly to protect him from public rebuke and litigation in the case of lead stories, or perhaps it was merely standard journalistic practice in a time when by-lines rarely appeared. None of these newpaper effusions are cited in Robert Etheridge Junior and R. Logan Jack's 1881 bibliography of Australian geology, perhaps the most comprehensive so far published outlining Clarke's scientific publications.

The Bibliography

> "Considering the great number of separate papers which issued from Mr Clarke's busy brain and pen, it is somewhat remarkable that he did not, except to a limited extent, seek to collect and condense his vast stores of information into convenient volumes for scientific libraries. It is probable that want of means in addition to want of leisure was the chief cause of this apparent neglect, but whatever the cause the fact is to be regretted, for the difficulty of referring to papers scattered over many periodicals and many years is such that practically they drop into oblivion, and it is difficult now to form a just conception of Mr Clarke's enormous labours." (John Smith, Anniversary Address, Royal Society of New South Wales, 28 May 1879)

Due to strained finances, ever-present ministerial duties, and the demands of maintaining a voluminous correspondence (which he obviously viewed as a priority), W.B. Clarke was never able to publish the results of his work as freely as he would have liked, and only ever publically issued two substantial scientific monographs whilst in Australia, namely RESEARCHES IN THE SOUTHERN GOLDFIELDS (1860), and REMARKS ON THE SEDIMENTARY FORMATIONS OF NEW SOUTH WALES (1867-78), both of which saw limited circulation. Despite these constraints, Clarke was a prolific author, and the bulk of his Australian writings can be found in the now-obscure scientific journals, parliamentary papers, and contemporary newspapers cited within this bibliography.

As the following listing reveals, W.B. Clarke played an important role in the intellectual development of the Colony between 1839-78, via his work with local newspapers and journals, whether it be in publishing his own material, stimulating public debate, or bringing to attention items of scientific interest from local and overseas sources. This role has remained largely unknown due to the difficulties of identifying and gaining access to his many published works. The extend of Clarke's ever active pen has therefore never been fully revealed, mainly due to the ephemeral nature of newspapers, the destruction by fire of his lifetime collection, and the difficulties of transcribing his handwriting. It is hoped this current work may partially remedy such neglect, and, by revealing some of the true extent of his work, reinforce his status as "Father of Australian Geology" and "nestor of Australian philosophers" (Warung, 1895).

For those unfamiliar with the life and work of W.B. Clarke, and requiring more detailed biographical information, reference should be made to the works of James Jervis (1944) and Elena Grainger (1982) listed below. See also Section 5 of the Bibliography for references to the numerous biographical pieces written since his death in 1878, discussing various aspects of his life and work.

A dictionary definition of 'bibliography' is "a list of books and writings dealing with a particular subject, or written by a particular author". The following bibliography therefore follows this broad definition and lists published works both by and about the Reverend W.B. Clarke. For the period covering Clarke's lifetime, it is arranged chronologically according to publication date - or date of writing, whichever is earliest - and includes references to all published material located by the compiler. The internal choronological arrangement of the first four sections was adopted to both simplify the on-going process of locating material and mirror the manner in which W.B. Clarke worked.

The bibliography was initially based on a listing of 150 works by Clarke which was contained in the *Sydney Mail* of 7 July 1872 (said list having obviously been supplied by him), together with the 103 entries under 'W.B. Clarke' in Etheridge & Jack's 1881 bibliography of Australian geology. These two listings have since been greatly expanded to include the 837 references contained in the current work, of which some 545 are by Clarke. A few of the items mentioned in the 1872 *Sydney Mail* list have not as yet been located, whilst a number of major articles and books by Clarke's contemporaries - including J.D. Dana, F. McCoy and J.B. Jukes - which discuss his scientific findings or use original research material provided by him are also included, as are later biographical works and contemporary commentaries.

The bibliography includes references to poems, literary reviews and criticisms; scientific articles and reports on topics such as geology, mineralogy, meteorology, and other natural sciences; letters to editors of newspapers; published religious treatises, hymns, reprints of sermons, and letters to parishoners. Clarke's numerous journalistic endeavours for literary publications in England (especially prior to 1839) and local newspapers such as the *Sydney Morning Herald*, *Sydney Gazette*, and *The Australian* (all between 1839-1878), have also been included where known.

The bibliography is presented in five sections according to publication date and subject: 1 Great Britain and Europe (1819-1839); 2 Australia (1839-1851); 3 Researches in the Australian Goldfields (1851-1853); 4 Australia (1852-1878); 5 Biographical and Related Works (1878-1994).

Section 1 includes material from the period prior to Clarke's arrival in New South Wales in May 1839. It begins with an epic poem published in 1819 whilst he was still a student at Cambridge, though poems written earlier are to be found in his later compilations. The section ends with an article on volcanic ashes based upon observations made near the Cape Verde Islands whilst on board the **Roxburgh Castle** en route to Australia. This latter piece Clarke had posted to England during a stopover at Cape Town in March and was further worked upon in Australia. The 21 year period from 1819 to 1839 saw his interests and researches move from an early concentration on literature, religious studies, poetry and natural history, through to specialising in the relatively new sciences of meteorology and geology during the late 1830s. Many of Clarke's pieces for the *Magazine of Natural History* and newspapers during this time are short communications and commentaries only, containing a couple of paragraphs; others are substantial articles issued in parts.

Section 2 covers the first phase of Clarke's life in New South Wales, up to the time of the announcement of the discovery of gold in May 1851. After arriving in Sydney on 27 May 1839 he almost immediately began working and writing, producing material on a variety of Australian subjects, all the while carrying out his religious duties. Due to physical isolation from traditional avenues of publication in England, such as the *Magazine of Natural History* and *Journal of the Geological Society of London*, Clarke was forced to make use of local newspapers to air his views and publish the results of various scientific investigations, whilst continuing to use the normal British and overseas scientific journals from afar, where practicable. Being so prolific, the time delay between England and Australia .in transmitting correspondence (3-6 months, one way), would have been especially frustrating.

From 1839 to 1851 W.B. Clarke produced a vast amount of work, on a wide variety of subjects. Following the return of his wife and young family to England early in 1842, he was free to devote more time to his research and writing, though he still had to bear the weight of supporting them financially. An easy means of supplementing his income was as a writer, reviewer, and scientific contributions editor for the local newspapers. The editor of the *Sydney Morning Herald* quickly realised his talents, placing him on a retainer during the forties and fifties.

Section 3 deals with the results of Clarke's geological surveys in the Australian goldfields between 1851-3. On his first official expeditions, from September 1851 through to October 1853 (with a break between June and October 1852), he was involved in a geological survey of the goldfields for the New South Wales Government. Samuel Stutchbury and Edward Hargraves also carried out surveys during this period. Between September 1851 and June 1852 Clarke investigated the Southern Districts of New South Wales, travelling south from Marulan to the Snowy Mountains and east to the coast near Bega, while submitting 19 reports delineating the geology and mineralogy of those localities. From November 1852 to October 1853 he surveyed the Northern Districts as far as southern Queensland and submitted 10 detailed reports. These reports were despatched to the Colonial Secretary Edward Deas Thomson, who passed them on to Philip Parker King for editing. They were then presented to the Legislative Council and published in the *Votes and Proceedings* of that body under the title 'Papers Relative to the Geological Survey of New South Wales' (1851-53). They also appeared shortly thereafter in Sydney newspapers such as the *Sydney Morning Herald* and *The Empire*, usually under the heading 'Geological Surveys of New South Wales' or 'Council Papers - Geological Surveys.' This would occur anywhere from 1-6 months after being written and/or published. They were eagerly awaited and widely read by prospectors of the time, of which there were many.

The Legislative Council goldfield reports and associated correspondence were also printed in London between 1853-54, by order of the House of Commons and within the *Parliamentary Blue Books*. They were therein titled 'Further Papers Relative to the recent Discovery of Gold in Australia.' During the 1970s this material was made available via reissue in facsimile form, as part of the volumes of BRITISH PARLIAMENTARY PAPERS (Irish University Press, 1974-78). Clarke's Australian goldfields reports, along with those by Stutchbury and Hargraves, are to be found in volumes 16 and 20 of the 'Colonies - Australia' volumes.

The original manuscript reports are located within the Colonial Secretary Correspondence series, Archives Office of New South Wales, Sydney. They can be found in various sub-series' such as 'Gold Discoveries 1851-52' (2/8292), 'Goldfields Papers 1852' (4/3180), 'Northern Goldfields, Liverpool Plains 1852-53' (4/713.1), etc. Some of Clarke's original goldfields notes are to be found within the Fisher Library, Sydney University collection. In 1860 Clarke's southern districts reports were compiled and edited within his RESEARCHES IN THE SOUTHERN GOLDFIELDS OF NEW SOUTH WALES, along with additional material.

Section 4 covers the years 1852-78 and is similar in scope to section 2, containing references to published papers plus newspaper items. During this period Clarke began to use *The Empire* along with the *Sydney Morning Herald*, and after 1866 the journal of the Royal Society of New South Wales provided him with a regular avenue for publication.

Section 5 (1878-1994) deals with the period since Clarke's death. It contains a few posthumous works, plus contemporary obituary notices, biographies, and general or specific assessments of aspects of his work.

Extant manuscript material pertaining to Clarke and held by the Mitchell Library and other public and private institutions is not described in this work. Reference should be made to the Mitchell Library's comprehensive 'Guide to the Clarke Family Papers' (ML MSS139/1).

Attribution

Within this bibliography W.B. Clarke is the **known** or **attributed** author of all material listed, unless otherwise indicated. Where a newspaper article is unsigned (as was common), attribution to Clarke is based on a number of factors, including: references contained in the *Sydney Mail* list of 1872, wherein Clarke identified those he had written; references within other published or manuscript articles; inclusion in Clarke's personal newscuttings files within the Mitchell Library 'Clarke Family Papers' collection (though this criteria is somewhat suspect at times, as these files obviously include a number of newscuttings on items of interest to Clarke, but by other authors); the editor's opinion, based upon internal factors such as Clarke's writing style, which was scientific, precise, and forthright, usually containing numerous references to overseas books and journals, and appropriate quotations; and finally, the opinions of recent workers in the field, such as E.M. Webster (with regards to Clarke's association with the explorer Ludwig Leichhardt) and David Williams (on meteorology).

Difficulties in attribution arise due to a number of factors, including the fact that Clarke often made reference to himself - in the third person - within articles which he had obviously written. Also, almost all his lead newspaper articles are unsigned, and throughout his lifetime he used abbreviations or pseudonyms such as 'Latimer', 'Plutus', a circle with a cross in it, or 'C' upon letters to editors and reviews. W.B. Clarke tried very hard to disguise his journalist identity during the 1840s and 1850s, only rarely coming out into the open via letters to the editor. Furthermore, where an unsigned article which is believed to come from his pen appears as a lead in the *Sydney Morning Herald* or *The Australian*, a number of possibilities exist: Clarke is the sole author; Clarke was the author of a substantial section of the article, whilst the relevant editor - such as Charles Kemp at the *Herald* - also made a contribution; or, Clarke is not the author.

These doubts over various attributions may be resolved with further research and transcription of his correspondence, however said articles are included in this bibliography where there is the strong possibility that Clarke was the author. Material included in curly brackets, thus: {.........} throughout the bibliography is purely biographical.

List of Abbreviations

Aust	The Australian, Sydney
JGS	Quarterly Journal of the Geological Society of London
JRS	Journal of the Royal Society of London
JRSNSW	Journal and Proceedings of the Royal Society of New South Wales, Sydney
MNH	The Annals and Magazine of Natural History, London
ML	Mitchell Library, Sydney
PGS	Proceedings of the Geological Society of London
PLSNSW	Proceedings of the Linnean Society of New South Wales, Sydney
SG	Sydney Gazette
SMH	Sydney Herald & Sydney Morning Herald
TGS	Transactions of the Geological Society of London
TRSNSW	Transactions of the Royal Society of New South Wales (1867-74)
TPRSNSW	Transactions and Proceedings of the Royal Society of New South Wales (1875)
TPRSV	Transactions and Proceedings of the Royal Society of Victoria, Melbourne
V&PLC	New South Wales Legislative Council Votes & Proceedings
V&PLA	New South Wales Legislative Assembly Votes & Proceedings

Section 1

Great Britain and Europe 1819 - 1839

1819

1 POMPEII. R. Deck, Ipswich, 1819, 28p. A Poem written for the Chancellor's gold medal competition at Cambridge. Author's inscribed copy at ML MSS139/9.

1820

2 A SMUGGLER'S SONG. (Poem), n.p., 1820.

3 *The London Magazine*, London, 1820-8. Clarke wrote verses for this publication during the early 1820s.

1821

4 CARMEN EXEQUALE. (Poem), n.p., 1821, 28pp.

1822

5 THE RIVER DERWENT, PART THE FIRST; AND OTHER POEMS. Longman, Hurst, Rees, Orme and Brown, London, 1822, xv, 111. ML MSS139/118/31. Reviews of this collection of poems are to be found in the *Literary Register*, 27 July 1822; *The London Literary Gazette*, 27 July 1822; *Leeds Intelligence*, 5 August 1822; and the *Bristol Journal*, 17 and 24 August 1822.

1823

6 *Address Written for the Anniversary Meeting of the Suffolk Pitt Club, on Thursday August the 21st 1823.* N.p., 1823. Signed 'W.B. Clarke.'

1824

7 *Cambridge Quarterly Review and Academical Register*, Cambridge, *1*, March-July 1824. W.B. Clarke was the co-founder and co-editor of this journal, along with Dr. Dale, the Reverend William Trollope, and Mr. Torriano.

1828

8 Geological Hammer. *MNH*, 1829, *II*, 247. The original article is signed and dated 'W.B. Clarke. East Bergholt, Suffolk, Nov. 24. 1828.' Includes a drawing of the hammer.

9 RECOLLECTIONS OF A VISIT TO MOUNT BLANC. (Poem), n.p., 1828.

10 *The Christian Remembrancer; or the Churchman's biblical, ecclesiastical, and literary miscellany*, London, 1819-40. W.B. Clarke submitted various articles to this religious journal between 1828-38.

11 MITRE HYMN BOOK. N.p., 1828. W.B. Clarke was co-compiler and wrote a number of hymns for this publication.

12 *New Monthly Journal*, London, W.B. Clarke submitted various articles to this literary journal between 1828-38.

13 *The Literary Gazette*, London. W.B. Clarke submitted various articles to this literary journal between 1828-42.

1829

14 LAYS OF LEISURE: A COLLECTION OF ORIGINAL AND TRANSLATED POEMS. Smith, Elder & Co., Cornhill, London, 1829, xii, 251. Copies at ML SC547, MSS119/118/19.

15 Conia parosa. *MNH*, 1830, *III*, 152. Signed and dated 'W.B. Clarke. East Bergholt, Suffolk, September 3. 1829.'

16 A very unusual Appearance in the Sky. *MNH*, 1830, *III*, 199-200. Signed and dated 'W.B. Clarke. East Bergholt, Oct. 5. 1829.' Based on observations taken on 10 July 1829 in the eastern sky at sunset, along the road between Quatre Bras and Namur, in Belgium.

1830

17 Aetites or Eagle-stone. *MNH*, 1831, *IV*, 190-1. Signed and dated 'W.B. Clarke, East Bergholt, Suffolk, September 7. 1830.'

18 Snakes taking the Water. *MNH*, 1831, *IV*, 82. Signed and dated 'W.J. Clarke, East Bergholt, Suffolk, Sept. 13. 1830.'

19 Zoology: Hares taking the Water. *MNH*, 1831, *IV*, 143-4. Signed and dated 'W.B. Clarke, East Bergholt, Suffolk, Sept. 16. 1830.'

20 Anecdotes of a tame Hawk. *MNH*, London, 1831, *IV*, 19-20. Signed and dated 'W.B. Clarke, East Bergholt, Suffolk, September 21. 1830.'

21 Partridges and Moorhens (Notes from a Journal - 1826). *MNH*, London, 1831, *IV*, 91. Signed and dated 'W.B. Clarke. East Bergholt, Suffolk, Sept. 30. 1830.'

22 Lord's Island, Derwent Water. *MNH*, London, 1831, *IV*, 92. Signed and dated 'W.B. Clarke, East Bergholt, Suffolk, October 1. 1830.'

1831

23 Common Sea-Gull. *MNH*, London, 1833, *VI*, 147-8. Signed and dated 'W.B. Clarke, East Bergholt, Suffolk, March 5. 1831.'

24 Hares taking the Water. *MNH*, London, 1832, *V*, 100-1. Signed and dated 'W.B. Clarke, Brussels, May 13. 1831.'

25 Hares taking the Water. *MNH*, London, 1832, *V*, 101. Signed and dated 'W.B.C. Brussels, Oct. 15. 1831.'

1832

26 The very fragile Texture of the Limestone which forms the secondary Marble from the

Meuse. *MNH*, 1833, *VI*, 76-8. Signed and dated 'W.B. Clarke, Parkstone, Dorset, Sept. 6. 1832.'

27 Geology - The Red Sandstone along the Meuse is merely the Rubbish cast up from the Limestone. *MNH*, 1833, *VI*, 368. Signed and dated 'W.B. Clarke, Parkstone, near Poole, Sept. 8. 1832.'

28 A Notice of the Effects of Wind on Trees growing on the Coast near Poole, Dorsetshire. *MNH*, 1833, *VI*, 547-50. Signed 'Rev. W.B. Clarke, Parkstone, near Poole, Dorsetshire, September 13. 1832.'

29 Posthumous Hares. *MNH*, 1833, *VI*, 365. Signed and dated 'W.B. Clarke, Parkstone, near Poole, Sept. 28. 1832.'

30 Fungus on the Bill of a Hedge Sparrow (*Accentor modularis*, Cuvier). *MNH*, 1833, *VI*, 153-4. Signed and dated 'W.B. Clarke, Parkstone, near Poole, Dorsetshire, Dec. 21. 1832.'

31 Singular Subsidence in the Chalk. *MNH*, 1833, *VI*, 180-2. Signed and dated 'W.B. Clarke, Parkstone, near Poole, Dec 22. 1832.'

1833

32 THE DUTY AND INTEREST OF EDUCATING THE CHILDREN OF THE POOR IN THE PRINCIPLES OF THE NATIONAL RELIGION. J.G. & F. Rivington, London, 1833, 28pp. Copy of a sermon delivered.

33 Chalk in Belgium. *MNH*, 1833, *VI*, 460. Article signed and dated 'W.B. Clarke, Parkstone, Jan 9. 1833.'

34 Is Pitchstone found in Scotland? *MNH*, 1833, *VI*, 191-2. Comments, signed and dated 'W.B.C., Feb. 2, 1833.'

35 Locality for a Kingfisher. *MNH*, 1833, *VI*, 150. Signed and dated 'W.B. Clarke, Parkstone, Feb. 4. 1833.'

36 Meteorology - Mildness of the Present Season, at Parkstone, near Poole, Dorsetshire. *MNH*, 1833, *VI*, 157-8. Article signed and dated 'W.B. Clarke, Parkstone, Dorset, Feb. 5. 1833.'

37 Geology - The Lava of Neidermennig, employed for Millstones by the Romans, found in Fragments in England. *MNH*, 1833, *VI*, 460-2, Article signed and dated 'W.B. Clarke, Parkstone, May 21. 1833.'

38 Remarks on some Statements respecting the Inland Seas of Southern Europe. *MNH*, 1833, *VI*, 477-80. Article signed and dated 'W.B. Clarke, Parkstone, May 23. 1833.'

39 An Ore which acquires a white Incrustation. *MNH*, 1833, *VI*, 480. Signed and dated 'W.B.C. Parkstone, May 31. 1833.'

40 On Certain recent Meteoric Phenomena, Vicissitudes in the Seasons, and prevalent Disorders, contemporaneous, and in supposed connection, with Volcanic Emanations. (Part 1). *MNH*, 1833, *VI*, 289-308. Signed and dated 'W.B. Clarke. Parkstone, May 11. 1833', with a postscript 'W.B.C. Parkstone, June 17. 1833.' This was Clarke's first substantial paper for the *Magazine of Natural History*, and was issued in 7 parts plus supplement during 1833-5.

41 Birds' Nests in Singular Places. *MNH*, 1833, *VI*, 523-4. Signed 'W.B. Clarke, Parkstone.'

42 A Snow Bunting's nest in the Skull of an Esquimaux. *MNH*, 1833, *VI*, 524. Signed and dated 'W.B. Clarke. Parkstone, July. 1833.'

43 Review of Le Comte de Bylandt: RESUME PRELIMINAIRE DE L'OUVRAGE SUR LA THEORIE DES VOLCANOS. pp.50. Naples 1833. *MNH*, 1834, *VII*, 83-8. Signed 'W.B.C.'

44 Gooseberry-eating Dogs. *MNH*, 1834, *VII*, 137-9. Article signed and dated 'W.B. Clarke. Stanley Green Cottage, near Poole, July 2. 1833.'

45 A few Words on Cats. *MNH*, 1834, *VII*,

139-41. Article signed and dated 'W.B. Clarke. Parkstone, near Poole, Dec. 18. 1832', with a postscript 'W.B.C. August 1833.'

46 A Ferrugenous Duck or Ruddy Goose. *MNH*, 1834, *VII*, 151. Signed 'W.B.C.'

47 The Fern Owl, its Time of Migration. *MNH*, 1834, *VII*, 156. Article signed and dated 'Stanley Green Cottage, near Poole, 24 August. 1833.'

48 One of the Habitats of the Fern Owl, or Night Jar. *MNH*, 1834, *VII*, 156. Article dated '12 September, 1833.'

49 *Hymn to be Sung at the Consecration of Longfleet Church on Wednesday, 25th September 1833*, Lankester Printer, Poole, 1p. Signed 'W.B.C.'

1834

50 Remarks on some Barnacles of the Species *Lipas anatifera* found floating off St Adhelm's Head, on the Coast of Dorset, on February 7, 1834. *MNH*, 1835, *VIII*, 55-9. Article dated 'Stanley Green, Poole, Feb. 10. 1834.'

51 On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations. No.2. *MNH*, 1834, *VII*, 193-202. Article signed and dated 'W.B. Clarke. Stanley Green, near Poole, Dorset, March 4. 1834.'

52 Ruskin, J.R. and Clarke, W.B., 1834. Enquiries on the Causes of the Colour of the Water of the Rhine; by J.R. [John Ruskin]: with Remarks, in Contribution to an Answer; by the Rev. W.B. Clarke, A.M. F.G.S. *MNH*, *VII*, 438-42. Remarks signed and dated 'W.B. Clarke. Stanley Green, April 3. 1834.'

53 THE HISTORY AND PRACTICE OF PSALMODY: BEING THE SUBSTANCE OF TWO SERMONS DELIVERED AT LONGFLEET, ON 13 APRIL 1834. H. Wix, London, 1835, 26pp.

54 A Notice of Exotic Localities of the Glowworm. A Question on the Kind of a certain Exotic Species of Luminous Insect. *MNH*, 1836, *IX*, 487. Article signed and dated 'W.B. Clarke. Stanley Green, May 10. 1834.'

55 On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations. No.3. *MNH*, 1834, *VII*, 289-309. Signed and dated 'W.B. Clarke. Stanley Green, May 16. 1834.'

56 Causes of the Colour of the Water of the Rhone and Rhine. *MNH*, 1834, *VII*, 442-3. Signed and dated 'W.B. Clarke. Stanley Green, Aug. 8. 1834.'

57 On the Meteors seen in America on the Night of Nov. 13. 1833. By the Rev. W.B. Clarke, A.M. F.G.S. (A Supplement to Mr. Clarke's Essay, No.3., in p.289-308., On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations). *MNH*, 1834, *VII*, 385-90. Dated 'Stanley Green, August 9. 1834.'

58 On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations. No.4. *MNH*, 1834, *VII*, 609-30. Article dated 'Clifton, Oct. 13. 1834.'

59 Ruskin, J.R. and Clarke, W.B., 1834. Facts and Considerations on the Strata of Mont Blanc; and on some Instances of Twisted Strata observable in Switzerland; by J.R. [John Ruskin]: with Remarks thereon, by the Rev. W.B. Clarke, A.M., F.G.S., &c. *MNH*, *VII*, 645-54. Contains numerous geological drawings.

60 A Postscript to Mr Clarke's Communication, ending in p.630 - The appearing of Meteors in November, in different Years (p.386, 387). An Instance for 1834. *MNH*, 1834, *VII*, 654-5. Signed 'W.B. Clarke.'

61 On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations. No.5. *MNH*, 1835, *VIII*, 1-28. Article dated 'Stanley Green, Nov. 1834.'

62 Migration of the Cuckoo. *MNH*, 1835, *VIII*, 301. Article signed and dated 'W.B. Clarke. Stanley Green, near Poole, Dorsetshire, Dec. 6. 1834.'

63 Remarks on the Deposition of Salt in the Mediterranean Sea. *MNH*, 1835, *VIII*, 225-6. Article dated 'Stanley Green, near Poole, Dorsetshire, Dec. 15. 1834.'

64 On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations. No.6. *MNH*, 1835, *VIII*, 129-61. Article dated 'Stanley Green, near Poole, Dec. 31. 1834.'

65 *Impromtu, on being told that the Privy Councillors of P... have refused to allow the Magistrates to hold their Sittings in the Council Room, Poole.* N.p., [1834], Pamphlet.

1835

66 Instances of the Effects of Forest Vegetation on Climate. *MNH*, 1835, *VIII*, 475-82. Article dated 'Stanley Green, May 14. 1835.' Refer also *Journal of the Royal Society of New South Wales* (1876) for an updated and expanded version of this paper.

67 Nitizen Aus dem Gebiete der Nature und Heilkunde. *Notizen*, 1835, *XLVI*, 161-8. A German edition of Clarke's paper of 14 May on 'Instances of the Effects of Forest Vegetation on Climate.'

68 The Pied Wagtail is the Foster-parent of the Cuckoo, perhaps more frequently than in any other Species of Bird. *MNH*, 1835, *VIII*, 381-2. Signed and dated 'W.B. Clarke. Stanley Green, near Poole, Dorsetshire, June 18. 1835.'

69 On certain recent Meteoric Phenomena, Vicissitudes in the Seasons, prevalent Disorders, &c., contemporaneous, and in supposed connection, with Volcanic Emanations. No.7. *MNH*, 1835, *VIII*, 417-53. Includes comments from various writers. Dated 'Stanley Green, June 18. 1835.' with a PS dated 'July 10. 1835.'

70 Notices of Facts in Application to the Question of the Occurrence of an extraordinary Display of the Meteors every Year, on about Nov. 13; and on Displays of Aurora on Nov. 17, 18-19, 1835. *MNH*, 1836, *IX*, 29-30. Article dated 'Stanley Green, Nov.19. 1835', with an addition dated 'Stanley Green, Dorsetshire, Nov.28. 1835.'

71 On Earthquakes at Phillipi. N.p., 1835. Referred to in the *Sydney Mail* 13 July 1872 list, though article not located.

1836

72 THE REVIEWER REVIEWED; OR, OBSERVATIONS ON A DISCOURSE ENTITLED 'CAUTION NECESSARY IN THE APPLICATION OF SCRIPTURE LANGUAGE,' IN WHICH IS SHOWN THAT DUDLEY IS NO 'ABUSER OF SCRIPTURE PHRASEOLOGY,' PAUL NO 'SOCINIAN,' AND ROWNTREE NO CRITIC. BY A MEMBER OF 'THE CHURCH ESTABLISHED BY LAW.' J. Sydenham, Poole, 1836, 12p. The 'Reviewer' referred to was Mark Rowntree, a Unitarian minister.

73 Rowntree, Mark, 1836. REPLY TO A CHURCHMAN [W.B. CLARKE] ON HIS 'OBSERVATIONS,' ENTITLED 'THE REVIEWER REVIEWED,' ETC. Poole.

74 PAUL' SHEWN TO BE NO 'UNITARIAN'; BUT UNITARIANISM PROVED TO BE ANTISCRIPTURAL IN ITS ORIGIN, DOCTRINES, AND TENDENCY: BEING AN ANSWER TO MR ROWNTREE'S 'REPLY' TO THE 'REVIEWER REVIEWED.' J.G. & F. Rivington, London, 1836, 93p. Copy of a sermon delivered by W.B. Clarke.

75 THE 'APOSTLE JOHN' SHEWN TO BE NO 'UNITARIAN'; BEING A FURTHER REFUTATION OF MR ROWNTREE, IN ANSWER TO HIS 'LETTERS.' J. Sydenham, Poole, 1836, 20p. Copy of a sermon delivered.

76 A PLAIN EPISTLE, TO THE AUTHOR OF 'ANIMADVERSIONS': IN WHICH HIS BLUNDERS ARE RECTIFIED, AND HIS SCOLDINGS REPROVED. J. Sydenham, Poole, 1836, 11p.

77 Additional Remarks on *Lepas anatifera*. *MNH*, 1836, *IX*, 638-40. Article dated 'Stanley Green, Oct.22. 1836.' Refer also article of 10 February 1834.

78 Note on a Cruise off Cherbourg - Sept. 1836. *MNH*, 1836, *IX*, 641-2. Article signed and dated 'W.B. Clarke, Stanley Green, Oct.24. 1836.'

79 On two springs on the north side of Hale's Bay, Poole Harbour. *Journal of the British Association for the Advancement of Science*, London, 1836, 94.

80 *Geology in Reference to Natural Theology*. N.p., 1836. Article referred to in Clarke's 1872 list of publications. Not located.

1837

81 *Statement of Facts, in reply to a Letter addressed by "John Sydneham, Jun., to the Rev. W.B. Clarke, A.M., Minister of St Mary's, Longfleet*, Lankester Printer, High St, Poole, 1p. Signed and dated 'W.B. Clarke, February 15th, 1837.'

82 On the Geological Structure and Phenomena of Suffolk, and its physical relations with Norfolk and Essex. *PGS*, 1838, *II(50)*, 528-34; *TGS*, 1840, *V*, 359-84. Read by Clarke on 18 January and 8 March 1837.

83 Notice of a singular electrical Phenomena on the Night of Feb. 18. 1837. [Read at the Meteorological Society, March 14. 1837.] *MNH*, 1837, New Series, *I*, 220-1. Article dated 'Stanley Green, near Poole, Feb. 21. 1837.'

84 Examples of Natural Phenomena observed in 1833, and registered. *MNH*, 1837, New Series, *I*, 229-34. Article dated 'Stanley Green, April 11. 1837.'

85 Signs of Spring, 1837. *MNH*, 1837, New Series, *I*, 279. Article signed and dated 'W.B. Clarke. Stanley Green, April 19. 1837.'

86 Illustrations of the Geology of the South-east of Dorsetshire. No.1. The vertical and curved Chalk Strata of Ballard Head, near Sandwich. *MNH*, 1837, New Series, *I*, 414-21. Includes geological drawings and sections.

87 On the Geological Structure and Phenomena of the Northern Part of the Cotantin, and particularly of the immediate Vicinity of Cherbourg [1837]. *PGS*, 1838, *II(48)*, 454-5. Read on 21 April 1837.

88 Illustrations of the Geology of the South-east of Dorsetshire. *MNH*, 1837, New Series, *I*, 461-9. Article dated 'Stanley Green, near Poole, April 26. 1837.' Includes geological drawings and sections.

89 Meteorological Errors in Vol.VIII. p446. *MNH*, 1837, New Series, *I*, 556-7. Article signed and dated 'W,B. Clarke. Stanley Green, August 1. 1837.'

90 Notes of Observations made on the Night of Nov. 12, 1837. (Read at the Meteorological Society). *MNH*, 1837, New Series, *I*, 633-5. Article dated 'Stanley Green, Nov. 15. 1837.'

91 Illustrations of the Geology of the South East of Dorsetshire. No.II. On the Strata between Durlstone Head and Old Harry Rocks. *MNH*, 1838, New Series, *II*, 79-88. Includes geological drawings and sections.

92 Illustrations of the Geology of the South East of Dorsetshire. *MNH*, 1838, New Series, *II*, 128-36. Article dated 'Stanley Green, 5th Dec. 1837.' Includes geological drawings and sections.

93 On the Phenomena exhibited by the Plastic

Clay Formation in the vicinity of Poole, Dorsetshire. *Journal of the British Association for the Advancement of Science*, London, 1837, 93-4.

94 On the Red Water of Edom. N.p., 1837. Article referred to in 1872 list of publications. Not located

1838

95 THE SIGN OF THE TIMES; AND THE CLAIMS OF THE CHURCH OF ENGLAND TO SUPPORT FROM ITS MEMBERS; CONSIDERED IN TWO SERMONS ON BEHALF OF THE NATIONAL SOCIETY. J.G. & F. Rivington, London, 1838, 62pp. Copy of two sermons delivered.

96 The Peat Bogs and Submarine Forests of Bournemouth, Hampshire, and in the neighbourhood of Poole, Dorsetshire. *PGS*, 1838, *II(54)*, 599-601.

97 Note on the Crag Beds of Suffolk and Essex. *MNH*, 1838, New Series, *II*, 162-3. Article signed and dated 'W.B. Clarke. Stanley Green, near Poole, Feb. 8th. 1838.' Includes editorial comment.

98 Letter from the Rev. W.B. Clarke, in reference to the alleged occurrence of the bone of terrestrial Mammalia in the red and corralline Crag of Suffolk. *MNH*, 1838, New Series, *II*, 224-5. Letter signed and dated 'W.B. Clarke. Stanley Green, March 1st. 1838.'

99 Letter from The Rev. W.B. Clarke, on the Non-Identity of Suffolk Diluvium and Crag. *MNH*, 1838, New Series, *II*, 285. Letter signed and dated 'W.B. Clarke. Stanley Green, April 10th. 1838.'

100 *On the State of Geological Knowledge*. N.p., October 1838. Text of a lecture delivered to the Literary and Scientific Institute, Blanford. Article referred to in 1872 list of publications. Not located.

1839

101 Illustrations of the Geology of the South East of Dorsetshire. No.III. Studland. *MNH*, 1839, New Series, *III*, 390-401. Includes a map, plus geological drawings and sections.

102 Illustrations of the Geology of the South East of Dorsetshire. *MNH*, 1839, New Series, *III*, 432-8. Includes geological drawings and sections.

103 Illustrations of the Geology of the South East of Dorsetshire. *MNH*, 1839, New Series, *III*, 483-9. Includes geological drawings and sections. Signed 'Presteigne, Radnorshire.'

104 Notices of the gales of November 29, and Christmas Day 1836, and of November 29, 1837. *Transactions of the Meteorological Society*, London, 1839, *I*, 91-2.

105 A notice of showers of ashes which fell on board the Roxburgh, at sea off the Cape de Verd islands, February 1839 [Abstract]. *PGS*, 1842, *III(65)*, 145-6. Read to the Society on 6 November 1839.

Section 2

Australia 1839 - 1851

1839

106 *King's School, Parramatta: Prospectus*, Tegg & Co., Sydney, 1839, 4p. Contains testimonials to the Reverend W.B. Clarke upon his appointment as Headmaster around July 1839, plus a selected list of his English publications., especially those relating to matters of religious education.

107 Popish Oaths. *SG*, 10 August 1839. Letter to the editor, signed and dated 'Latimer. 8th August 1839.'

108 Anon. Parramatta Anniversary Meeting. *SG*, 20 August 1839. Report on the meeting of the Parramatta District Committee of the Society for Promotion of Christian Knowledge, at which W.B. Clarke was present.

109 Dr. Ullathorne and Dr. Murray. *SG*, 29

August 1839. Letter to the editor, signed 'Latimer. August 22, 1839.'

1840

110 A SERMON PREACHED IN THE CHURCH OF ST. JAMES, AT SYDNEY; ON THURSDAY, 24TH JUNE, 1840, AT THE ANNIVERSARY OF THE DIOCESAN COMMITTEE OF THE SOCIETIES FOR THE PROPOGATION OF THE GOSPEL IN FOREIGN PARTS, AND FOR PROMOTING CHRISTIAN KNOWLEDGE. Sydney, 1840, 20p.

111 Australia. *Literary Gazette*, London, 20 February 1841, 119-22. Copy of a letter from Clarke to Sir Roderick Murchison. Includes a criticism of P.E. de Strzelecki and his claimed discovery of Gippsland. Letter dated 'Parramatta, New South Wales, 14th August, 1840.'

112 *A Christmas Offering.* Sydney, December 1840. Copy of a sermon delivered to W.B. Clarke's Dural parishioners, pleading for funds to build a church.

1841

113 Anon. Parramatta - The Church. *SG*, 2 February 1841. Editorial calling for the building of a church at north Parramatta and the installation of the Rev. W.B. Clarke as its incumbent.

114 Earthquake. *SMH*, 9 February 1841. Letter to the editor, signed and dated 'W.B. Clarke. Parramatta, 2nd Feb., 1841.' See also under 1868 for a summary account of earthquake activity in Australia.

115 Parramatta - The Church. *SG*, 9 February 1841. Letter to the editor, signed and dated 'G.B. Clarke. Parramatta, 4th Feb. 1841.' Reply to the editorial of 2 February. See also editorial comment on page 2 of this issue.

116 Anon. The Rev. W.B. Clarke A.M. *SG*, 9 February 1841. Editorial comment, welcoming Clarke's contribution to the Sydney Gazette.

117 On the Geological Phenomena in the Vicinity of Cape Town, Southern Africa. *Athenaeum*, London, October 1841 [Abstract]; *PGS*, 1842, *III*, 418-23; *Philosophical Magazine and Journal of Science*, Supplementary Number, January 1842; *Polytechnic Journal*, 1842 [Abstract]; *SMH*, 25 June 1842. Read at the Geological Society of London on 21 April 1841. Clarke had visited Cape Town briefly in March - April 1839 whilst en route to New South Wales.

118 THE LOGIC OF THE TIMES. Sydney, 1841. A compilation of sermons delivered by the Rev. W.B. Clarke - reviewed in the *SMH* June 1841, & *SG*, 14 June 1841.

119-20 The Sabbath Bill. *SMH*, 22 & 24 June 1841. Lead articles, unsigned.

121 The Sabbath Observance Report. *SMH*, 21 August 1841. Lead article, unsigned.

122 Australian Mining Company. *SMH*, 24 September 1841. Letter to the editor, signed and dated 'Carbonarius, Barangara, September 17.' Discusses conformability of coal seams located at depth at Concord, near Parramatta.

123-4 Review - *The Tasmanian Journal of Natural Science, Agriculture, Statistics, &c. SMH*, 7 October & 16 November, 1841.

125 Anon. Colonial Education. *SMH*, October - November 1841. Series of letters to the editor discussing aspects of colonial education and the merits of a university degree. Signed 'Parsus Australis' (15 October, 25 October, 3 November), 'Philomath' (29 October), 'Oxford Bachelor (1 November), and 'Benedict' (18 November). Clarke is possibly one of the correspondents, namely 'Parsus Australis', though this remains unclear.

126 The Legitimate Objects and Benefits of Natural History and Science - The Rev. W.B. Clarke's Lecture at the New Grammar School. *SMH*, 23 October 1841.

127 Tornado at Parramatta. *SMH*, 24 December

1841. Letter to the editor, signed 'W.B. Clarke. Parramatta, December 21, 1841.' See also ML MSS139/99 for original data.

128 Anon. *Report of the Church of England Clerical Book Society 1841; together with the opening Address (by W.G. Broughton).* Sydney, 1841. Clarke was one of the founders of this society and possibly the editor of this report.

1842

129 On the Occurrence of Atmospheric deposits of Dust and Ashes, with remarks on the Drift Pumice of the Coasts of New Holland. *Tasmanian Journal of Natural Science*, Hobart, 1842, *I(V)*, 321-41.

130 On falls of dust or sand on vessels traversing the Atlantic. *Edinburgh New Philosophical Journal, XXXII*, 1842, 134-6.

131 Tornado of December 21, 1841. *SMH*, 10 January 1842. Letter to the editor, signed 'W.B. Clarke, Parramatta, Jan. 6, 1842.'

132-51 Meteorology as applicable to Australia, Nos. 1-20. *SMH*, 15 January - 17 June 1842. These articles were all published anonymously, and though unsigned, they are referred to in the 1872 list of Clarke's publications and in his 1864 lecture 'Remarks on Australian Storms.' They usually appeared as leads: 1 (15 January), 2 (22 January), 3 (7 February), 4 (12 February), 5 (1 March), 6 (7 March), 7 (11 March), 8 (7 April), 9 (14 April), 10 (16 April), 11 (22 April), 12 (26 April), 13 (30 April), 14 (6 May), 15 (16 May), 16 (24 May), 17 (3 June), 18 (13 June), 19 (15 June), 20 (17 June).

152 Anon. The Wonders at Parramatta. *Australasian Chronicle*, 18 January 1842. Letter to the editor, signed 'An Observer', criticising Clarke's first *SMH* Meteorology article.

153 The Rev. Mr Clarke's reply to "Observer". *Australasian Chronicle*, 22 January 1842. Letter to the editor, signed and dated 'W.B. Clarke Parramatta, 20th January, 1842.'

154 Murchison, R.I., 1842. Presidential Address. *PGS, III*, 645. Delivered on 18 February 1842. Briefly refers to Clarke's geological investigations in Australia. See also *SMH* 6 April 1843 where Clarke makes reference to it.

155-9, 161-5 *Notitiae Australasianae*. A series of review articles published anonymously by W.B. Clarke appeared under this general heading within the *Sydney Morning Herald* between June and September 1842. They are described individually below.

155 Review of articles from the *Annals and Magazine of Natural History*, Nos. 50 & 51. Including 1. Notice of a new genus of mammalia, *Antechinus Stuartii*, by J. Stuart; and 2. Sponges. *SMH*, 14 June 1842.

156 Review of the *Tasmanian Journal of Natural Science*, Vol.1, No.III. Including 3. On Irrigation in Tasmania, by Captain A.F. Cotton. *SMH*, 24 June 1842.

157 Review of the *Tasmanian Journal of Natural Science*, Vol.1, No.III. Including 4. Varieties of Australasian Coal, by P.E. de Strezelecki. *SMH*, 27 June 1842.

158-9 Review of MONOGRAPH OF THE MACROPODIAE, OR FAMILY OF KANGAROOS, by John Gould. *SMH*, 4 & 16 July 1842. In 2 parts. Includes a plea for the donation of specimens to the Australian Museum, and consideration of possible future extinction of certain species.

160 Survey of New South Wales. *SMH*, 23 August 1842. Lead article, unsigned. Being a defence of T.L. Mitchell's surveying work in the Colony, following on recent criticisms by Governor Gipps. Also includes a copy of Mitchell's 1833 article 'On the Trigonometrical Survey of New South Wales'. See also Phillip Parker King's letter to the newspaper of 27 August 1842.

161-5 Review of the JOURNALS OF TWO EXPEDITIONS OF DISCOVERY IN NORTH-WEST AND WESTERN AUSTRALIA, by George Grey. *SMH*. In 5 parts: 1 (29 August); 2 (31 August 1842); 3

(15 September); 4 - Origin of the Aborigines (20 September); 5 (23 September).

166-7 Supply of Water. *SMH*, 26 July & 5 August 1842. Lead articles, unsigned. Refer ML MSS139/99. The second article includes meteorological data from Bulli, compiled by Captain R.M. Westmacott - refer ML MSS139/94.

168 Post Office. *SMH*, 29 August 1842. Lead article, unsigned.

169 On a Fossil Pine Forest at Kurrur-Kurran, in the inlet of Awaaba [Lake Macquarie], East Coast of Australia. *PGS*, 1843, *IV(I)*, 161-4 [Abstract]; *The Sydney Weekly Register*, 1845, *V(107)*, 68-9; *Annual Report of the Department of Mines of N.S.W. for the Year 1884*, Sydney, 1885, 156-9 plus map and figures. Original article signed and dated 'W.B. Clarke. Parramatta, 29th August 1842.'

170 Mr a'Beckett's Lecture. Temperature of Boiling Water. *SMH*, 12 September 1842. Letter to the editor, signed 'C. September 2, 1842.' See also a'Beckett's reply of the 16th.

171 Temperature of Boiling Water. *SMH*, 23 & 24 September 1842. Two letters to the editor,signed 'C. September 17, 1842' and 'C. September 23, 1842.'

172-8 Fossil Bones, Nos. I-VI. *SMH*, 8 October 1842 - 2 January 1843. Unsigned, though referred to in the 1872 list of publications. Published as follows: I (8 October); II (19 October); III (26 October); IV (11 November); V (19 November); VI (9 December); Addenda (2 January 1843).

179 Meteorology - Spring Equinox 1842. *SMH*, 13 October 1842. Signed 'W.B.C.'

180-1 The Ancient and Present Condition of the River Drainage of New South Wales. *SMH*, 12 December 1842 & 3 January 1843. Lead articles, unsigned.

1843

182 Comets. *SMH*, 9 March 1843. Unsigned. A summary history of comets. See also 19 October 1858 for an updated version, and *SMH* 24 March 1843 for a paper on 'Ancient Theories of Comets' by Robin Goodfellow.

183 Notes of Observations on the Great Comet of March. *Proceedings of the Royal Astronomical Society*, London, 1843.

184 Progress of Scientific Enquiry in Australasia. *SMH*, 6 April 1843. First reference to the discovery of trilobites in New South Wales. See also 29 May 1846 below.

185 Church Book Society - W.B. Clarke's First Lecture on Geology. *SMH*, 7 April 1843. Delivered at St James' Grammar School on Tuesday 4th. Clarke delivered the remaining lectures on 'The Physical Constitution of the Earth' on 23 August, 5 September, and 20 September.

186 Anon. New Church on the North Shore. *SMH*, 15 June 1843. Report on Clarke's appointment as pastor of the new church to be built at St Leonards, and the laying of the foundation stone.

187 Cumberland Election Debate. *SMH*, 13 July 1843. Letter to the editor, signed 'W.B. Clarke.'

188 Meteorology. Temperature at Parramatta, from 17th to 21st November 1843. *SMH*, 27 November 1843. Letter to the editor, signed and dated 'W.B.C. Parramatta, Nov. 22, 1843.'

189 Meteorology. Temperature at Parramatta, from 17th to 21st November. *SMH*, 30 November 1843. Letter to the editor, signed and dated 'W.B.C. Parramatta, Nov. 27, 1843.'

190 Meteorology. Mean Mensual Temperatures indicated by external Barometer, Macquarie-street, Parramatta, from 1st December 1842, to 30th November 1843, both inclusive. *SMH*, 4 December 1843. Signed and dated 'W.B.C. Parramatta, 1st December.'

191 Anon. Museum Curatorship. *SMH*, 28 December 1843. Report on a petition from W.B. Clarke presented to the Legislative Council by Dr Nicholson.

1844

{Clarke wrote lead articles solely for *The Australian* during this year, breaking his ties with the *Sydney Morning Herald*, though he returned in 1845 as co-editor of contributions}

192 Australian Museum. *SMH*, 4 January 1844. Letter to the editor detailing recent acquisitions. Signed and dated 'W.B. Clarke. Parramatta, January 1.'

193 Notes on the gyratory storms of Sunday, January 14, 1844, as observed at Dooral. *Aust*, 23 January 1844. Signed 'W.B.C. Parramatta, 15th January 1844.'

194 The Late Storm. *Aust*, 25 January 1844. Signed and dated 'W.B.C. January 22, 1844.' See also similarly titled letter to the editor of 30 January 1844, signed 'G.N.' which is critical of Clarke.

195 Australian Museum. *SMH*, 26 January 1844. Signed and dated 'W.B. Clarke, Parramatta, January 15, 1844.'

196 High-ways and By-ways. *Aust*, 15 February 1844. Unsigned.

197 Anon. Report on Rev. Clarke's fall from a horse. *SMH*, 1 March 1844. Clarke sustained serious head injuries as a result of this incident.

198 H.M. Ship **Fly**. *Aust*, 26 March 1844. Unsigned.

199-201 Roads. *Aust*. Unsigned. In three parts, as follows: 1 (28 March); 2 (9 April); 3 (26 April 1844).

202 Free Traders and Malthusian Philosophers. *Aust*, 2 April 1844.

203 The Tractarians and their Sydney Advocates. *Aust*, 4 April 1844. Unsigned.

204 Dr. Pusey and his Sydney Reviewers. *Aust*, 5 April 1844. Unsigned.

205-7 United States Exploring Expedition. *Aust*, 18, 20 & 24 April 1844. Unsigned. A review of the work of Captain Wilkes' expedition of 1838-42, members of which party Clarke had met at Sydney during 1839-40. These articles are rather critical of the exploration and scientific work of the Expedition and the motives of its instigators.

208-11 English Notions of Australia. *Aust*, 4, 7, 10 & 15 May 1844. Review of Rev. W. Pridden's AUSTRALIA, ITS HISTORY AND PRESENT CONDITION. Unsigned. In four parts.

212-14 Colonial Emigration. *Aust*, 25, 27 & 28 May 1844. Unsigned. In three parts.

215 Murchison, R.I., 1844. Presidential Address. *Transactions of the Royal Geographical Society*, London, *XIV*, xcix-c. Read on 27 May. Includes a comparison of the geology of Russia and Australia, and comments on information supplied by P.E. de Strzelecki. This address was to form the basis for Murchison's later claim as scientific discoverer of gold in Australia, a claim which Clarke refuted. Refer Stafford (1988).

216 Police Protection. *Aust*, 3 June 1844. Unsigned.

217 The "Chronicle" and the Aborigines. *Aust*, 13 June 1844. Unsigned.

218 Anon. Testimony in Respect for Mr Justice Burton. *SMH*, 21 June 1844. Includes a report on Clarke's speech.

219-20 Popular Education in New South Wales. *Aust*, 4 & 11 July 1844. Unsigned, in two parts.

221-2 Exploration of New Holland. *Aust*, 9 & 17 July 1844. Unsigned, in two parts.

223 Progress of Internal Discovery - Dr Leichhardt's Expedition to Port Essington. *Aust*, 25 July 1844.

224 Mr Macarthur's Treatise on The Culture of the Vine, and the Manufacture of Wine. *Aust*, 18 July 1844. Unsigned. Review of LETTERS ON THE CULTURE OF THE VINE, by Maro [William Macarthur].

225 The Botanic Garden. *Aust*, 31 July 1844. Unsigned.

226 The Roads of the Colony. *Aust*, 1 August 1844.

227-8 The Injurious Effects of Hail on the Vine. *Aust*, 6 & 13 August 1844. Unsigned. In two parts.

229 Progress of Internal Discovery. *Aust*, 14 August 1844.

230 Paragreles, or Hail Guards. *Aust*, 23 August 1844. Unsigned - referred to in the 1872 list of publications.

231-2 Anon. Education on the Principles of the Church of England. *SMH*, 4 & 10 September 1844. Report on public meetings held on 2nd & 9th. Includes a summary of Clarke's speech at the latter meeting.

233 Anon. Report on Clarke's attendance at meeting of the Society for Promoting Christian Knowledge. *SMH*, 7 September 1844.

234 Ross, Rev. R., 1844. [Untitled]. *SMH*, 11 September 1844. Letter to the editor in reply to Clarke's personal comments regarding the Rev. Ross made at the education meeting referred to in the *SMH* of 10 September.

235 [Untitled]. Letter in reply to Dr. Ross. *SMH*, 12 September 1844. Signed and dated 'W.B. Clarke. Parramatta, September 11.'

236 Anon. St Leonard's Church, North Shore. *Aust*, 2, 3, 10 & c.20 December 1844. Signed 'Lycidas.' These letter raise questions as to why the Reverend Clarke had not taken up residence at the new St Thomas's Church, St Leonards. They may include replies by Clarke, though all are anonymous.

1845

237 On Dykes of Marble and Quartz in connection with Plutonic Rock in Argyle County, New South Wales. *JGS*, 1845, *I*, 342-4; *Edinburgh New Philosophical Journal*, 1846, *XL*, 201-4; *Tasmanian Journal of Natural Science*, Hobart, 1849, *III(1)*, 51-4.

238 Anon. Report on the presence of Clarke at the laying of the foundation stone for a church at Balmain. *SMH*, 2 January 1845.

239 The Late Meteor and Present Comet. *SMH*, 9 January 1845. Letter to the editor, signed and dated 'W.B.C. 3rd January 1845.'

240 Meteorology - Notes on the condition of the year 1844. *SMH*, 24 January 1845. Signed 'W.B.C.'

241 The Late Meteor. *SMH*, 4 February 1845. Letter to the editor, signed 'W.B.C. Muswellbrook, January 24', with PS '27th January.'

242 The Pentonville Exiles. *SMH*, 25 April 1845. Signed and dated 'W.B.C., Parramatta, April 22.'

243 Mesmerism in Australia. *SMH*, 16 July 1845. Lead article, unsigned.

244-6 Lightning Conductors. *SMH*, 10, 17 & 20 November 1845 Lead articles, in three parts, unsigned. Referred to in the 1872 list of publications and in a 4 March 1859 article on 'Death by Lightning.'

247 Departure of the Exploring Expedition. *SMH*, 18 November 1845. Unsigned. Refers to Edmund Kennedy and T.L. Mitchell.

248 Thunder Storms of November 20, 1845. *SMH*, 11 December 1845. Letter to the editor, signed and dated 'W.B.C. Paramatta, November 28.'

249 Lightning Conductors. *SMH*, 18 December 1845. Letter to the editor, signed and dated 'W.B.C. December 16.' Reply to a letter on

the 15th from 'L.E.T.' [Rev. Lancelot Threlkeld].

1846

250 Murchison, R.I., 1846. A brief review of the classification of the sedimentary rocks of Cornwall. *Transactions of the Royal Geological Society of Cornwall, VI*, 317-26. Includes a comparison of the geology of Russia and Australia with regards to the possible existence of gold. This article would play an important part in the later debate over who was the true scientific discoverer of gold in Australia - Clarke or Murchison.

251 Jukes, J.B., 1846. A few remarks on the nomenclature and classification of rock formations in new countries. *Tasmanian Journal of Natural Science, II(6)*, 1-12. Written following discussions with the Reverend W.B. Clarke during 1844-5.

252-4 Review of Count Strzelecki's THE PHYSICAL DESCRIPTION OF NEW SOUTH WALES, London, 1845. *SMH*. Unsigned. This book was the first major work on the geology of New South Wales and Tasmania, and Clarke reviewed it warmly. In three parts, as follows: 1 (16 March); 2 (27 March); 3 (3 April 1846).

255 Hot Gale of 11th April, 1846. *SMH*, 1 May 1846. Signed 'W.B.C. Campbelltown, April 14', with a postscript 'W.B.C. April 29.' See also comment by Lower Murrumbidgee correspondent on 27 May.

256 Meteorology. Mean temperature of the periods from 1st October to 30th April inclusive, in three consecutive years, from 1843 to 1846, deducted from daily observations made at Macquarie-street, Paramatta, at 8.30AM, 2.30PM, sunset. *SMH*, 5 May 1846. Signed and dated 'W.B.C. Paramatta, May 1, 1846.'

257 Piesse, Louis, 1846. Flooding of the Inland Rivers of NSW. *SMH*, 8 May. Letter to the editor, written in reply to Clarke's 'Hot Gale' paper of 1 May.

258 Hot Gale. *SMH*, 29 May 1846. Letter to the editor, signed 'W.B.C. May 27, 1846.' Replying to the Lower Murrumbidgee correspondent of 27 May.

259 On the Occurrence of Trilobites in the Protozoic Rocks of New South Wales. *Tasmanian Journal of Natural Science*, October 1849, *III(1)*, 1-12. Article signed and dated 'Parramatta, 29th May 1846.' Clarke had discovered trilobites at Burragood, on the Paterson River, on 2 December 1842 and mentioned the find in the *SMH* of 6 April 1843. See also 16 June 1847 for a variant of this article.

260 Meteorology - Notes on the conditions of the month of May, 1845 and 1846, from observations made at Macquarie-street, Parramatta, with some general remarks illustrative of the climate during the winter months. *SMH*, 9 June 1846. Signed 'W.B.C. Paramatta, June 5.'

261 On the conditions of June and July, 1846; and of the present season in general. *SMH*, 27 August 1846. Signed and dated 'W.B.C. Paramatta, August 20.'

262 The Coburg Peninsula. *SMH*, 15 September 1846. Lead article, unsigned. Review of the explorations of G. Windsor Earl.

263 Parramatta Water Grievance. *SMH*, Supplement, 3 October 1846. Letter to the editor, signed 'W.B. Clarke. Paramatta, September 25.'

264 Report - Parramatta Water Committee. N.p., 1846. Referred to in Clarke's 1872 list of publications. Not located.

265 Tropical Australia and its Prospects - The Growth of Cotton. *SMH*, 28 September 1846. Lead article, unsigned. Review of the explorations of G. Windsor Earl.

266 Review of REMARKS ON THE PROBABLE ORIGIN AND ANTIQUITY OF THE ABORIGINAL NATIVES OF NEW SOUTH WALES ..... by a Colonial Magistrate [William Hull]. *SMH*, 3 October 1846. Unsigned.

267 Captain Stokes's Discoveries. *SMH*, 13 October 1846. Lead article, unsigned. Review of the explorations and surveys of Captain Stokes and the **HMS Beagle**.

268 River Albert. *SMH*, 19 October 1846. Lead article, unsigned. Continuation of a review of the discoveries of Captain Stokes.

269 Victoria River. *SMH*, 27 October 1846. Lead article, unsigned. Continuation of a review of the discoveries of Captain Stokes.

270 On the Geology of the Island of Lafu, one of the Loyalty Group, east of New Caledonia, in the Southern Pacific. *JGS*, 1847, *III*, 61-4. Article presented to the Society on 4 November 1846.

271 Fitz Roy River. *SMH*, 12 November 1846. Lead article, unsigned. Continuation of a review of the discoveries of Captain Stokes.

272 Adelaide River and North-west Coast. *SMH*, 17 November 1846. Lead article, unsigned. Review of the discoveries of Captain Stokes.

273 Meteorology. State of the Atmosphere at Parramatta, from 10th to 14th (3.53 PM), inclusive November, 1846. *SMH*, 17 November 1846. Signed 'W.B.C.'

274 Captain Stokes's Discoveries. *SMH*, 25 November 1846. Lead article, unsigned.

275 Captain Stokes's Survey of the Eastern Entrance to Bass's Strait. *SMH*, 1 December 1846. Lead article, unsigned.

276 Sir Thomas Mitchell's Despatches. *SMH*, 9 December 1846. Lead article, unsigned.

277 Captain Stokes's Survey of the Western Entrance to Bass's Strait. *SMH*, 10 December 1846. Lead article, unsigned.

278 The Recent Discoveries. *SMH*, 21 December 1846. Lead article, unsigned. Review of the discoveries of Mitchell, Stokes, Sturt, and Leichhardt.

279 Account of a Thunderstorm. *Walker's Electrical Magazine*, *II*, 1846, 326-31.

1847

280 Fossiliferous limestone of the Burdekin and a coral *Cyathophyllum Leichhardti*, in L. Leichhardt, JOURNAL OF AN OVERLAND EXPEDITION IN AUSTRALIA, FROM MORETON BAY TO PORT ESSINGTON ... DURING 1844-45. London, 1847, 212-3.

281 The Practical Value of the Recent Discoveries. *SMH*, 1 January 1847. Lead article, unsigned. Review of the discoveries of Mitchell and other explorers.

282 A.D.M., 1847. [Untitled]. *The Atlas*, 16 & 30 January. Letter to the editor, critical of Clarke's anonymous writings for the Herald on Australian exploration.

283 Hodgson's Journey in Search of Leichhardt. *SMH*, 18 January 1847. Lead article, unsigned. Preliminary critical review of C.P. Hodgson's REMINISCENCES OF AUSTRALIA. (See also 23 January 1847 below).

284 Anon. A.D.M. *SMH*, 21 January & 4 February 1847. Comments, possibly by the editor of the *Herald*, on the criticisms expressed in *The Atlas* of 16 January 1847. See also *The Australian* of 30 January 1847 which suggests that T.L. Mitchell was 'A.D.M.'

285 Review of REMINISCENCES OF AUSTRALIA, WITH HINTS ON THE SQUATTERS LIFE by C.P. Hodgson. *SMH*, 23 January 1847. Unsigned.

286 The Australian and the Surveyor General. *SMH*, 4 February 1847. Article pointing out reasons why T.L. Mitchell could not be 'A.D.M.'

287 Jukes, J.B., 1847. Notes on the Palaeozoic Formations of New South Wales and Van Dieman's Land. *JGS*, *III*, 240-9. Presented to the Society on 24 February 1847. Partially based on discussions and excursions with Clarke. Also published under the title: On the Palaeozoic Rocks of

the neighbourhood of Sydney. *Tasmanian Journal of Natural Science*, Hobart, *III*, 1849, 376-87. Clarke considered the article as much his as Jukes', and was somewhat miffed that he was not cited as a co-author.

288 Meteorology. Conditions of the year 1845 in the Northern Hemisphere, compared with the nearly corresponding period in Australia. *SMH*, 2 March 1847. Lead article, signed 'W.B.C.'

289 The Intellectual Barrenness of New South Wales. *SMH*, 12 March 1847. Lead article, unsigned.

290 On Climates Suitable for the Production of Wine. *SMH*, 2 April 1847. Lead article, unsigned.

291-2 Law of Storms. *SMH*, 6 & 17 May 1847. Lead articles, unsigned.

293 On the Genera and Distribution of Plants in the Carboniferous System of New South Wales. *JGS*, 1848, *IV*, 60-3. Presented to the Geological Society of London on 16 June 1847.

294 On the Occurrence of Trilobites in New South Wales, with remarks on the probable age of the formation in which they occur. *JGS*, 1848, *IV*, 63-6. Presented to the Geological Society of London on 16 June 1847. See also under 29 May 1846.

295 Meteorology. On the fall of rain in the Lake Districts of Cumberland and Westmoreland in 1845; with remarks in reference to the falls in New South Wales. *SMH*, 16 June 1847. Signed and dated 'W.B.C. St Leonard's, June 11.'

296 Review of SAVAGE LIFE AND SCENES IN AUSTRALIA AND NEW ZEALAND by George French Angas. *SMH*, 9 July 1847. Unsigned.

297 Gun Cotton. *SMH*, 12 July 1847. Lead article, unsigned.

298 Meteorology. On the great Barometrical Depression of June and July, 1847. *SMH*, 30 July 1847. Signed and dated 'W.B.C. St Leonard's, July 26.'

299 Review of RECOLLECTIONS AND HISTORICAL NOTICES OF CAMBRIDGE by J.K. Walpole. *SMH*, 24 August 1847. Unsigned.

300 McCoy, Frederick, 1847. The Fossil Botany and Zoology of the Rocks associated with the Coal of Australia. *MNH*, Series 1, *XX*, 145-57, 226-36, 298-319; *Tasmanian Journal of Natural Science*, 1849, *III*, 429-43; *Proceedings of the Royal Society of Van Dieman's Land*, January 1851, *1(III)*, 303-34. Identifies and lists Australian fossils collected by the Rev. W.B. Clarke, and sent to Professor Sedgwick in England during November 1844. Sections republished by Clarke in the *Sydney Morning Herald* between December 1848-March 1849.

301 Various. Report from the Select Committee on the Coal Inquiry, with Appendix and Minutes of Evidence. 16 September 1847. *V&PLC*, Sydney, 1847, *II*, 50, 335-95. Clarke's evidence and correspondence is located at 339-41, 347-53.

302 Geology - Comparison of Russia and Australia. *SMH*, 28 September, 1847; *Tasmanian Journal of Natural Science*, 1849, *III*, 365-70.

303 Fossil Bones - Remarks on Fossil remains of Gigantic Marsupials from King's Creek, Darling Downs, brought to Sydney by a Mr Turner. *SMH*, 30 November 1847. Lead article, unsigned. Article also published in the following: Appendix to W.B. Clarke's Northern Districts Report X. Papers Relative to Geological Surveys, New South Wales. *V&PLC*, Sydney, 21 December 1853, 11-13; Further Papers Relative to the Recent Discovery of Gold in Australia. *Parliamentary Blue Book*, London, December 1854, 38-9.

304 Macleay, W.S., 1847. Fossil Bones. *SMH*, 4 December. Letter to the editor, in reply to Clarke's of 30 November.

305 Dana, J.D., 1847. A Description of Fossil Shells of the Collections of the Exploring Expedition under the Command of Charles Wilkes, U.S.N., obtained in Australia. *Silliman's American Journal of Science*, 2nd series, *IV*, 151... Includes reference to material collected with Clark. during 1839-40.

1848

306 Mr Kennedy's Expedition. *SMH*, 22 & 26 January 1848. Unsigned, small notes.

307 Mitchell's Victoria. *SMH*, 25 January 1848. Lead article, unsigned. Review of T.L. Mitchell's 1846-7 exploration of the Victoria River.

308 Mr Woore's Report on the Proposed Railway in New South Wales. *SMH*, 26 January 1848. Unsigned.

309 THE CLAIMS AND SUPREMACY OF THE SCRIPTURES AS THE RULE OF FAITH AND PRACTICE, APPLIED TO THE DOCTRINES OF THE CHURCH OF ROME; A SERMON PREACHED IN ST. THOMAS'S CHURCH, WILLOUGHBY, ON SUNDAY, 27TH FEBRUARY, 1848, WITH ILLUSTRATIVE NOTES. W. & F. Ford, Coleman & Piddington, Sydney, 1848, 60p.

310-15 Are the Interior Waters of Australia Navigable? *SMH*, 15 March - 18 May 1848. Lead articles, unsigned. In six parts, with follow-up article on 23 November 1850: I (15 March); II (16 March); III (7 April) Basin of the Darling; 4 (24 April) Basin of the Murray; V (16 May) River Murray (Sturt's Voyage); VI (18 May) River Murray and Lake Alexandria.

316 Remarks on the Identity of the Epoch of the Coal Beds and Palaeozoic Rocks of New South Wales. *MNH*, 1848, 2nd Series, *II*, 206-10. Signed and dated 'St Leonards Parsonage, North Shore, Sydney, April 7th, 1848.' This article was Clarke's reply to McCoy's description of the fossils he had despatched to England in 1844.

317 Mr Kennedy's Expedition. *SMH*, 26 April 1848. Lead article, unsigned.

318 The Observatory. *SMH*, 30 May 1848. Lead article, unsigned.

319 The Australian Botanic and Horticultural Society. *SMH*, 20 & 27 June 1848. Unsigned. Report on the formation of this Society, of which Clarke was a member of the Committee.

320 On the Extraction of Silver from Lead by the Blowpipe. *SMH*, Tuesday, 11 July 1848. Lead article, unsigned. Referred to in 1872 listing.

321-2 Review of JOURNAL OF AN EXPEDITION INTO THE INTERIOR OF TROPICAL AUSTRALIA, IN SEARCH OF A ROUTE FROM SYDNEY TO THE GULF OF CARPENTARIA by T.L. Mitchell. *SMH*, 5 and 8 August 1848. Unsigned.

323 Review of MAGNETISM AND METEOROLOGY - OBSERVATIONS MADE AT THE MAGNETICAL AND METEOROLOGICAL OBSERVATORY AT ST. HELENS, by Colonel Sabine. *SMH*, 1 November 1848. Signed 'C.' Copy at ML MSS139/100 is signed 'W.B.C.'

324 The Carboniferous Formation of New South Wales. *SMH*, 14 November 1848; *Tasmanian Journal of Natural Science*, 1849, *III*, 459-65. Signed 'W.B.C.'

325-6 Fossil Botany of New South Wales. *SMH*, 2 & 5 December 1848. Review of F. McCoy's 1847 analysis of Clarke's Australian fossils. Unsigned. In two parts.

327-34 Fossil Zoology of New South Wales. *SMH*. In eight parts, as follows: I (21 December 1848); II (4 January 1849); 3 (10 January 1849); 4 (30 January 1849); 5 (12 February 1849); 6 (3 March 1849); 7 (10 March 1849); 8 (16 March 1849) 'W.B.C. St. Leonard's, February 28th, 1849.'

335 Dana, J.D., 1848. Fossils of the Exploring

Expedition under the Command of Charles Wilkes, U.S.N., a Fossil Fish from Australia. *Silliman's American Journal of Science*, 2nd series, *V*, 433...; *MNH*, 1848, *II*, 150-1. Includes references to fossils collected with Clarke during 1839-40.

1849

336 Dana, J.D., 1849. Geological Observations on New South Wales, in UNITED STATES EXPLORING EXPEDITION .... UNDER THE COMMAND OF CHARLES WILKES, U.S.N. VOL. X., GEOLOGY. C. Sherman, Philadelphia, 449-537; plus Appendix 1 - Description of Fossils, 'Fossils of New South Wales', 681-720 & plates 1-20. Dana had carried out geological investigations and discussions with W.B. Clarke during his visit to New South Wales in 1839-1840, the results of which are contained in this publication, along with descriptions of fossils collected during that time.

337 Gold Hunting. *SMH*, 16 February 1849. Letter to the editor on the supposed gold discovery in Victoria. Signed 'Plutus. February 14.'

338 The Fate of Kennedy's Expedition. *SMH*, 6 March 1849. Lead article, unsigned.

339 The Late Mr Kennedy. *SMH*, 7 March 1849. Lead article, unsigned.

340-2 The Dead Sea. *SMH*, 6, 16 & 24 April 1849. Letters to the editor, signed and dated 'W.B.C. St. Leonards.' In three parts. Written in reply to letters from Arthur T. Holdroyd, published on 3, 9 and 23 April.

343 Metalliferous Deposits of the Malay Peninsula. *SMH*, 12 May 1849. Lead, unsigned.

344-6 Mining. *SMH*, 29 May - 16 August 1849. Lead articles, unsigned. In three parts as follows: 29 May 1849 Mining; 3 July 1849 Mining; 12 July 1849 Mining.

347 Mineral Veins. *SMH*, 19 July 1849.

348 On the Probable Occurrence of Tin in New South Wales. *SMH*, 16 August 1849.

349 P.P. [Untitled]. *SMH*, 12 June 1849. Letter extracted from the *Maitland Mercury*, possibly written by P.P. King, asking for Clarke's comments on Sir R.I. Murchison's speech of 27 May 1844 to the Royal Geographical Society wherein he intimated that gold would be found in Australia.

350-2 Review of NARRATIVE OF AN EXPEDITION INTO CENTRAL AUSTRALIA by Charles Sturt. *SMH*, 4, 9 & 23 June 1849. Unsigned. In three parts.

353 Aneroid Barometer. *SMH*, 28 July 1849. Signed and dated 'W.B.C. St. Leonard's, 23rd July, 1849.'

354 Anon. Geological Surveys. *SMH*, 28 August 1849. Report on a discussion in the Legislative Council referring to Clarke.

355 Anon. Legislative Council - Geological Researches of the Rev. Mr. Clarke. *SMH*, 29 August 1849.

356 Mount Keera Coal Seam. *SMH*, 29 August 1849. Letter to the editor, signed and dated 'W.B. Clarke. St Leonard's, August 28.'

357 Alley, George Underwood, 1849. Illawarra. *SMH*, 6 September. Letter to the editor in reply to Clarke's letter of 29 August.

358 Mount Keera Coal Seam. *SMH*, 7 September 1849. Letter to the editor, signed and dated 'W.B.C. September 5.'

359 Review of NARRATIVE OF AN EXPEDITION, UNDERTAKEN UNDER THE DIRECTION OF THE LATE MR ASSISTANT SURVEYOR E.B. KENNEDY, FOR THE EXPLORATION OF THE COUNTRY BETWEEN ROCKINGHAM BAY AND CAPE YORK, by William Carron. *SMH*, 10 September 1849.

360-2 California. *SMH*. Unsigned. In three parts, as follows: 1 (22 October 1849); 2 (27

October 1849); 3 (6 November 1849). Extracts from J.D. Dana's journal notes of 1841 describing the geology and geography of the area between Fort Vancouver and San Francisco. Originally published in the *American Journal of Science*. Extracted and edited by Clarke.

363 Anon. A Military Geologist. *Bell's Life in Sydney & Sporting Reviewer*, 1 December 1849. Humourous piece making reference to Clarke.

364-5 Gold Mining. *SMH*, 19 & 21 December 1849. Unsigned. In two parts.

366 Anon. The Supply of Water. *SMH*, 20 December 1849. Lead article suggesting a committee be formed to deal with the problem of Sydney's water supply. Composed of Clarke, Colonel Baddeley, Edmund Blackett, and Francis Clarke.

367 A.A. [Artesian Wells]. *SMH*, 20-25 December 1849. A series of letters to the editor, to which Clarke wrote replies during January-February 1850: Artesian Wells (20 December); Artesian Well at Grenette (21 December); Artesian Well at Grenette (24 December); On the Best Means of Obtaining a Supply of Water for Sydney 25 December 1849. 'A.A.' or 'An Amateur' was Colonel Baddeley of Dawes Point Battery. See Clarke's RESEARCHES IN THE SOUTHERN GOLDFIELDS (1860, 300). He was a mineralogist and friend of Clarke's who published a number of rock analyses in the *Sydney Morning Herald* during 1849-50.

1850

368 California. *SMH*, 12 January 1850. Lead article, unsigned. Comparison of the geography of the United States with Australia.

369 The Philosophical Society. *SMH*, 24 January 1850. Lead article, unsigned.

370-2 Supply of Water. *SMH*. Leading articles on the problems of the supply of water for Sydney. Unsigned. Three parts known, as follows: 1 (30 January 1850); 2 (18 February 1850); 3 (4 March 1850).

373 Artesian Wells. *SMH*, 7 February 1850. Letter to the editor, signed and dated 'W.B.C. St. Leonards, February 2.' See also replies by 'W.T.G.' of 12 February, and 'X.Y.Z.' of 16 February, which are critical of Clarke.

374 Artesian Wells. *SMH*, 14 February 1850. Letter to the editor, signed and dated 'W.B.C. February 13.'

375 Artesian Wells. *SMH*, 18 February 1850. Letter to the editor, signed 'W.B.C.' See also letter to the editor by 'A.A.' of 12 March which refers to Clarke.

376-80 Artesian Wells. Nos. I-V. *SMH*, 23 March - 14 May 1850. Letters to the editor, signed 'W.B.C.' and dated as indicated below. In five parts as follows: I (23 March); II (27 March); 3 (11 April); IV (11 May); V (14 May).

381 Murchison, R.I., 1850. Siberia and California. *Quarterly Review,* London, *87*, 396. Makes reference to Clarke.

382 Anon. Australian Gold. *The Spectator*, London, April 1850. Republished in September 1851. Includes extract of a letter from W.B. Clarke. Refer 1861 Select Committee, Appendix A, for a copy.

383 Review of AUSTRALIAN GEOGRAPHY, WITH THE SHORES OF THE PACIFIC AND THOSE OF THE INDIAN OCEAN. DESIGNED FOR THE USE OF SCHOOLS IN NEW SOUTH WALES by Sir T.L. Mitchell. *SMH*, 24 May 1850. Unsigned.

384 Attack by Hoodlums. *SMH*, 25 May 1850. Letter to the editor re the attack on the Rev. W.B. Clarke and a fellow priest by some hoodlums in Sydney.

385 Where is Dr. Leichhardt? *SMH*, 6 August 1850. Lead article, unsigned.

386 Review of *Papers and Proceedings of the Royal Society of Van Dieman's Land*. *SMH*, 31 August 1850. Unsigned. Second notice.

387 Letter from W.B. Clarke to Robert Brown. *Quarterly Review*, London, September 1850.

388 Anon. Report on meeting of Australian Philosophical Society. *SMH*, 5 September 1850. Includes comments by Clarke on Red Cedar, the Moa (an extinct New Zealand bird), and a paper on fossil bird bones of New Zealand.

389 Kennedy and Leichhardt. *SMH*, 1 October 1850. Letter to the editor, signed and dated 'W.B.C. St. Leonard's, September 30.'

390 The Freak's Hurricane. *SMH*, 12 October 1850. Letter to the editor, signed and dated 'W.B.C. St Leonards, October 11, 1850.' Investigation of a hurricane observed by the brig **Freak** in a new portion of the hurricane area about Hong Kong, with remarks by W.B. Clarke. Refer to hand written original at ML MSS139/100.

391 Geological Surveys, Great Britain and Ireland. *SMH*, 4 November 1850. Unsigned. Critical of the selection of Samuel Stutchbury as geological surveyor for New South Wales.

392 Geological Surveys, England and Wales. *SMH*, 16 November 1850. Unsigned. See also a similarly titled article (?extracted from a London paper) in the *SMH* of 28 July 1851 which discusses some of the background to this issue.

393 A.A. Mineralogy. *SMH*, 16 November 1850. Letter to the editor outlining the results of analyses of samples sent to Colonel Baddeley by W.B. Clarke and Alexander Berry.

394 A.A. Geological Surveys. *SMH*, 20 November 1850. Letter to the editor, signed 'A.A.' and praising Clarke as 'the Australian [William] Smith.'

395 Navigation of the Murray. *SMH*, 23 November 1850.

396 Progress of Settlement - Leichhardt's Expedition. *SMH*, 7 December 1850. Unsigned.

397 Jukes, J.B., 1850. A SKETCH OF THE PHYSICAL STRUCTURE OF AUSTRALIA, SO FAR AS IT IS AT PRESENT KNOWN. T. & W. Boone, London. Written following Jukes' own observations in Australia and lengthy discussions with the Reverend W.B. Clarke. Many of the comments on Australian geology are a reiteration of Clarke's ideas.

398 Review of A SKETCH OF THE PHYSICAL STRUCTURE OF AUSTRALIA, SO FAR AS IT IS AT PRESENT KNOWN by J.B. Jukes. *SMH*, 21 December 1850. Unsigned.

399 Meteorology. Thunder storm of Saturday 21st, and Sunday, 22nd December, 1850. *SMH*, 28 December 1850. Signed and dated 'W.B.C. St Leonard's, December 26.'

400 Dana, J.D., 1850. On the Degradation of Rocks of New South Wales, and Formation of Valleys. *American Journal of Science*, 2nd series, *IX*, 289... Article refers to discussions Dana had with Clarke on this topic whilst exploring Kangaroo Valley, Illawarra, during 1839.

1851

401 Ethnology. *SMH*, 14 January 1851. Being a review of the 1850 London edition of Charles Pickering's THE RACES OF MAN & THEIR GEOGRAPHICAL DISTRIBUTION, initially issued as volume IX of the records of the United States Exploring Expedition of 1838-42. Unsigned.

402 Leichhardt. *SMH*, 18 January 1851. Lead article, unsigned.

403 *Cyatsphyllum leichhardti*, neue versteinerte Koralle aus Australien. *Frorieps Tageberichte uber die Fortschritte der Naturund Heilkunde*, February 1851, *262*, 97-8. See also under 1847 for reference to this fossil coral.

404 Ordeal by Fire - Spheroidal Condition of Bodies. *SMH*, 1 February 1851. Unsigned.

405 Science v. Superstition. Spheroidal State of Bodies. *SMH*, 8 February 1851. Unsigned.

406 Observations made at Paramatta during the Eclipse of the Sun, on Saturday, 1st February, 1851. *SMH*, 15 February 1851. Signed 'W.B.C. St Leonard's, February 12'; *Astronomical Society Monthly Notice*, London, *XI*, 1850-51, 223-5.

407 Observatory. *SMH*, 20 February 1851. Lead article, unsigned.

408 *Survey of the Aborigines of New South Wales*. N.p., April 1851. Circular to all Anglican clergy of New South Wales requesting information on the Aboriginal residents of various parishes. Signed by Clarke. ML MSS139/25.

Section 3

Researches in the Australian Goldfields. 1851 - 1853

On 12 February 1851 Edward Hammond Hargraves 'discovered' a workable goldfield at Summer Hill Creek, near Bathurst. It was publically announced in the *Sydney Morning Herald* on 3 May, upon which point Clarke immediately put pen to paper regarding the geology of gold and claims re its discovery in Australia.

409 The Gold Discovery. *SMH*, 5 May 1851. Unsigned letter to the editor, dated 'May 3.'

410 Gold. *SMH*, 15 May 1851. Lead article re the discovery of gold in Australia. Unsigned.

411 Gold Discovery. *SMH*, 18 May 1851. Letter to the editor, signed and dated 'A Friend to Strzelecki. May 17.' Possibly by Clarke, or a Mr Walker. Refer RESEARCHES IN THE SOUTHERN GOLDFIELDS (1860, 289).

412 On Australian Gold. *SMH*, 20 May 1851; Correspondence relating to the Recent Discovery of Gold in Australia, *Parliamentary Blue Book*, 3 February 1852, 5-8.

413 Anon. Gold. *Goulburn Herald*, 20 May 1851. Mentions W.B. Clarke's 1842-7 predictions of gold in the area of Goulburn.

414 Australian Board of Missions - Report. *SMH*, 21 May 1851. Includes a report by Clarke, who was Secretary.

415 Gold. *SMH*, 25 May 1851. Signed and dated 'W.B. Clarke, St. Leonard's Parsonage, May 24.' Comparison of the geology of Australia with other gold areas, such as California and the Ural Mountains.

416 The Discovery of Gold in Australia. *Evening Mail*, London, 1851. Signed and dated 'W.B. Clarke, St. Leonard's Parsonage, May 24.'

417 PLAIN STATEMENTS AND PRACTICAL HINTS RESPECTING THE DISCOVERY AND WORKINGS OF GOLD IN AUSTRALIA. Sands and Kenny, Sydney, 24 June 1851, 32p.

418 Metalliferous Quartz and its Commercial Value. *SMH*, 5 July 1851 (republished 8 July). Letter to the editor, signed and dated 'W.B. Clarke, July 3.'

419 Gold Working - Associated Minerals, &c. *SMH*, 24 July 1851. Signed and dated 'W.B. Clarke, St. Leonard's July 22.'

420 Hale, Thomas. Metalifferous Quartz and the Proper Use of Quicksilver. *SMH*, 24 July 1851. Letter to the editor, with an attached note by Clarke (?).

421 Anon. The Australian Gold-bed. *The Spectator*, London, 6 September 1851. Includes extract of a letter from W.B. Clarke which had been published in April 1850.

422 Anon. On the probable influence of the

recent discoveries of Gold Mines, in various parts of the world, on the relative value of Gold and Silver. *Illustrated Australian Magazine*, Melbourne, October 1851, *III*, 211. Includes an editorial note on Clarke.

423 Anon. The Distribution of Gold Throughout the World. *The Times*, London, 17 November 1851. Makes reference to Clarke. Republished in *SMH*, 5 March 1852.

The following is a listing of the various goldfield reports initially published by the Reverend W.B. Clarke between 1851-53. There are 19 Southern Districts reports and 10 (plus an appendix) for the Northern Districts of New South Wales.

On the Southern Districts

424 (I) Bungonia, 20 September 1851. *V&PLC*, 1852, 54-6; *SMH*, 21 February 1852; *Parliamentary Blue Book*, London, 1853, *16*, 22-4.

425 (II) Mount Elrington, 10 October 1851. Report on the Geology of the Neighbourhood of the Shoalhaven River and Araluen. (Reports 1 and 2). *V&PLC*, Sydney, 1852, 81-8; *SMH*, 21 February 1852; *Parliamentary Blue Book*, 1853, *16*, 24-7.

426 (III) Jineroo, 21 October 1851. Report on the Geology of the Gourock Range, the Carwang Country, and the Southern Division of the County of Murray. (Report 3). *V&PLC*, 1852, 88-93; *SMH*, 21 February 1852; *Parliamentary Blue Book*, 1853, *16*, 27-32.

427 (IV) Camp at Bulonamang, 10 November 1851. On an Examination of the Country between Jineroo and Bullanamang, plus minor reports. (Report 4). *V&PLC*, 1852, 93-5; *SMH*, 21 February 1852; *Parliamentary Blue Book*, 1853, *16*, 32.

428 (V) Bulonamang, 15 November 1851. On the Chemical Analysis of Quartz from the Merriwa and Lake George Ranges. (Report 5). *SMH*, 21 February 1852; *Parliamentary Blue Book*, 1853, *16*, 33.

429 (VI) Cooma, 17 November 1851. On the Geology of the right bank of the Upper Murrumbidgee. (Report 6). *SMH*, 21 February 1852; *Parliamentary Blue Book*, 1853, *16*, 33.

430 (VII) Jindebain, County Wallace, 24 December 1851. On the Gold Localities S.W. of Cooma, and the Geology of the Counties of Beresford and Wallace. (Report 7). *V&PLC*, 1852, *1*, 1-5; *SMH*, Supplement, 16 June 1852; *Parliamentary Blue Book*, 1853, 16, 33-7.

431 (VIII) Cooma, 3 January 1852. On the occurrence of Gold on Bobundara Creek, &c. (Report 8). *V&PLC*, 1852, *2*, 5-6; *SMH*, 16 June 1852; *Parliamentary Blue Book*, 1853, *16*, 37-8. See also 15 January 1852 below for a letter on 'Gold in Granite' written from Coocoocmanulla and subsequently published in the *Sydney Morning Herald*, though not included in the later published reports.

432 (IX) Camp at Buckalong, 29 January 1852. On Gold Localities at the Source of the Umaralla and other Rivers.' (Report 9). *V&PLC*, 1852, *3*, 6-10; *SMH*, 19 June 1852; *Parliamentary Blue Book*, 1853, *16*, 38-41.

433 (X) Brogalong Creek, 6 February 1852. On the Metalliferous Rocks of Merinoo. (Report 10). *V&PLC*, 1852, *4*, 10-11; *SMH*, 19 June 1852; *Parliamentary Blue Book*, 1853, *16*, 41-2, 65-6.

434 (XI) Maharatta Creek, 26 February 1852. (Report 11). *V&PLC*, *6*, 12-19; *SMH*, 26 June 1852; *Parliamentary Blue Book*, 1853, *16*, 66-71.

435 (XII) Eden, Twofold Bay, 6 March 1852. On the Geology of the south-east parts of the County of Wellesly, with remarks on Maneroo generally, &c. (Reports 12). *V&PLC*, *6*, 12-19; *SMH*, 26 June 1852; *Parliamentary Blue Book*, 1853, *16*, 66-71.

436 (XIII) Boroungoma, Bendoc River, 22 March 1852. On the Auriferous Character of the Country along the Bendoc and Deleget

Rivers. (Report 13). *V&PLC*, 1852, *7*, 20-5; *SMH*, 26 June 1852; *Parliamentary Blue Book*, 1853, *16*, 72-6.

437 (XIV) Pambula, 10 March 1852. On the occurrence of Gold in the County of Dampier, New South Wales. (Report 14). *V&PLC*, 1852, *8*, 26; *SMH*, 6 July 1852; *Parliamentary Blue Book*, 1853, *16*, 76.

438 (XV) Jejedzic, 3 May 1852. On the occurrence of Gold in Granite and Quartz on both Flanks of the Alps, between Tumut and the Snowy Rivers. (Report 15). *V&PLC*, 1852, *11*, 33; *SMH*, 6 July 1852; *Parliamentary Blue Book*, 1853, *16*, 77.

439 (XVI) Yarralumla, 20 May 1852. On the existence of Gold along the Rivers and Creeks flowing from the Muniong Range, &c. (Report 16). *V&PLC*, 1852, *1*, 1-3; *SMH*, 31 July 1852; *Parliamentary Blue Book*, London, 1853, *16*, 81-3.

440 (XVII) Winderreedeen, 1 June 1852. On the Metalliferous Prospects of the Country of Murray, and on the vicinity of Lake George. (Report 17). *V&PLC*, 1852, *2*, 3-6; *SMH*, 31 July 1852; *Parliamentary Blue Book*, 1853, *16*, 83-6.

441 (XVIII) Marulan, 3 June 1852. On the existence of Gold at Shelley's Flat. (Report 18). *V&PLC*, 1852, *3*, 7; *SMH*, 31 July 1852; *Parliamentary Blue Book*, 1853, *16*, 86-7.

442 (XIX) St Leonard's, 28 August 1852. On the Geological Formation of the Country between the Maneroo Highlands and the Sea Coast of the County of Auckland. (Report 19 - Supplement to Report 12.) Including a map of the 'General Appearance of the Country along the Upper part of the Maharatta Creek to illustrate the Rev. W.B. Clarke's Twelfth Geological Report and Supplement thereto.' *Parliamentary Blue Book*, 1853, *16*, 7-18.

On the Northern Districts

443 (I) Camp on Cann's Plains, Peel River, 6 November 1852. On the Geological Structure of the Country between Marulan and the Peel River. (Report 1 - Northern Districts). *Parliamentary Blue Book*, 1853, *16*, 26-30; *SMH*, Supplement, 8 December 1852.

444 (II) Camp, near the Assistant Gold Commissioner's Tents, Peel River, 15 November 1852. On the Geological Character and probable extent of the "Hanging Rock Diggings", &c. (Report 2). *Parliamentary Blue Book*, 1853, *16*, 30-4; *SMH*, Supplement, 20 December 1852. Includes a sketch 'Quartz veins in quartzite, on the range S.E. of Duncan's Creek.'

445 (III) Camp at Tamworth, 24 November 1852. On the dispersion of Gold in Australia. (Report 3). *Parliamentary Blue Book*, 1853, *16*, 35-9.

446 (IV) Crown Land's Office, Liverpool Plains, 30 November 1852. On the occurrence of Alluvial Lead Ore. (Report 4). *Parliamentary Blue Book*, 1853, *16*, 39-40; *SMH*, Supplement, 20 January 1853.

447 (V) Camp near Tamworth, 7 December 1852. On the General Prospects and Physical Conditions of the "Hanging Rock" and Peel River Gold Fields. (Report 5). *Parliamentary Blue Book*, 1853, *16*, 40-2; *SMH*, 22 January 1853.

448 (VI) Camp at Walcha, 28 December 1852. On the Geological Structure and Auriferous Condition of the Country along the Upper waters of the Namoi and Apsley Rivers. (Report 6). *Parliamentary Blue Book*, 1853, *18*, 24-9; *SMH*, 21 May 1853.

449 (VII) Armidale, 14 February 1853. On the Geological Structure and Auriferous Condition of the Country between the Heads of the Macleay and Gwydir Rivers. (Report 7). *Parliamentary Blue Book*, 1854, *18*, 30-41.

450 (VIII) Tarahmbwoan, Ranger's Valley, Severn River. 7 May 1853. On the Geological Structure of the Western Slopes

of the Highlands of New England, &c. (Report 8). *Parliamentary Blue Book*, 1854, *18*, 42-55.

451 (IX) Coolambaurra, County of Stanley, 24 June 1853. On the Geology of the Clarence River District, &c. (Report IX). *V&PLC*, 1853, 13; *Parliamentary Blue Book*, December 1854, *20*, 3-13.

452-3 (X) St Leonard's, 14 October 1853. On the Geology of the Basin of the Condamine River. (Report 10). With maps and appendices. *V&PLC*, 1853, 1-11; *Parliamentary Blue Book*, December 1854, *20*, 29-38.

Remarks on the Bones brought to Sydney by Mr Turner, and published in the *SMH*, 30 November 1847. (Appendix to Report X). *V&PLC*, 1853, 11-13; *Parliamentary Blue Book*, December 1854, *20*, 38-9. Includes a geological map titled 'Sketch of the Country between Moreton bay and the River Condamine.'

Section 4

Australia 1852 - 1878

During the years 1852-3 Clarke was heavily involved in his official researches into the Southern and Northern Goldfields of New South Wales, reference to which is contained in the previous section.

1852

454 Kennedy, Edmund, 1852. Extracts from the Journal of an Exploring Expedition to Central Australia, by Edmund Kennedy, (W.B. Clarke, editor). *Journal of the Royal Geographical Society*, London, *XXII*, Appendix.

455 J.G. Tamworth Gold Field. *SMH*, 27 January 1852. Letter to the editor, praising Clarke's preliminary geological investigations in the Maitland area during 1845.

456 Anon. The Rev. W.B. Clarke. *SMH*, 29 January 1852. Lead article, giving an account of Clarke's researches in the southern goldfields, based on letters to a Sydney friend (possibly P.P. King).

457 Anon. The Australian Ophir. *SMH*, 3 February 1852. Extracted from the *London Examiner*. Critical of Clarke, and praising Murchison for his scientific discovery of gold in Australia.

458 On the Discovery of Gold in Australia [Abstract]. *JGS*, 1852, *VIII*, 131-4; *Mining Journal*, London, 1852, *XXII*, 81. Read to the Geological Society of London on 4 February 1852.

459 Murchison, R.I., 1852. On the Anticipation of the Discovery of Gold in Australia; with a General View of the Conditions under which that Metal is Distributed [Abstract]. *JGS*, *VIII*, 134-6. Read to the Geological Society of London on 4 February 1852. This paper is a reply to Clarke's *SMH* article of 20 May 1851, and contains a reference to Clarke and his claim as discoverer of gold in Australia.

460 Anon. Mems About Gold. *SMH*, 14 February 1852. Report that Clarke had despatched a sample of Mitta Mitta gold to Mr Hale of George Street, Sydney, for analysis.

461 P.P. King (editor). Geological Survey of the Colony of New South Wales - Journals of the Rev. W.B. Clarke on the Southern Goldfields. *SMH*, 21 February 1852. One of a series of reports edited by King on the geological surveys being undertaken in the New South Wales goldfields by Clarke, T.L. Mitchell, Samuel Stutchbury, Edward Hargraves, J.R. Hardy and others. Previous reports had appeared on 7 and 14 February.

462 Gold in Granite. *SMH*, 24 February 1852. Letter to the editor, signed and dated 'W.B. Clarke, Camp at Coocoocmanulla. Jan. 15th, 1852.' Reproduced in RESEARCHES IN THE SOUTHERN GOLDFIELDS (1860, 46-8).

463 Sir R.I. Murchison and the Australian Gold Fields. *SMH*, Tuesday, 24 February 1852. Letter to the editor, signed and dated 'W.B. Clarke, Buckalong, February 18.' Reply to an editorial from the London Examiner, published in the *SMH* of 3 December 1852.

464 Geological Report. *SMH*, 6 March 1852. Errata to Clarke's geological reports of 1851, published by the Legislative Council.

465 Albury and Mitta Mitta Gold Fields. *SMH*, 3 June 1852. Copy of a letter to a resident of Albury. Signed and dated 'W.B. Clarke. Gungarlin River, Snowy Plain, 13th May, 1852.'

466 Zoological Garden. *SMH*, 24 June 1852. Letter to the editor, signed and dated 'W.B. Clarke. St Leonard's, June 23.' See also W.S. Macleay's letter of same date.

467 Sir R.J. Murchison and the Geology of Australia. *SMH*, 26 June 1852. Letter to the editor, signed and dated 'W.B. Clarke. St. Leonard's, June 24', and enclosing a letter by Murchison dated 10 February 1852.

468 Anon. The Proposed Zoological Garden. *SMH*, 26 June 1852. Letter to the editor, signed 'The Reporter.' Refers to the Rev. Clarke.

469 Zoological Society of London. *SMH*, 28 June 1852. Letter to the editor, signed and dated 'W.B. Clarke. St. Leonard's, June 25, 1852', enclosing a copy of a letter from Sir Stamford Raffles dated 11 May 1826.

470 Anon. History of the Gold Discovery and the Present Condition and Production of the Mines. *The Empire*, 31 August 1852. Discusses the role W.B. Clarke and Edward Hargraves played in the discovery of gold in Australia.

471 Various, 1852. Select Committee on the Management of the Gold Fields. *V&PLC*, Sydney, 22-28. W.B. Clarke appeared before the Committee on 24 September 1852 and 19 August 1853. He submitted a number of letters as evidence for his claim as scientific discoverer of gold in New South Wales, and these were reproduced as an appendix. Sections of his submission were also published in the following: Further Papers Relative to the Discovery of Gold in Australia. *Parliamentary Blue Book*, London, 1854, *20*, 24-26; *Discovery of Gold in Australia*, Government Printer, Sydney, 1854, 4p; Claims of the Reverend W.B. Clarke, Government Printer, Sydney, 1861, 41-4.

472 Anon. Sir Roderick Murchison and the Rev. Mr. Clarke. *Australian and New Zealand Gazette*, 30 October 1852; ?English newspaper, 1 March 1853.

473 Anon. The Australian El Dorado. *Dorset Country Chronicle*, Dorset, 1852. Article on W.B. Clarke and his Australian goldfields investigations.

1853

474 Murchison, R.I., 1853. Presidential Address. *Journal of the Royal Geographical Society*, London, *XXIII*, 70. Delivered on 23 May 1853. Discusses Clarke's role in the discovery of Silurian fossils in Australia.

475 James Pye, 1853. Parramatta Water Works. *SMH*, 9 July. Advertisement which includes a copy of an 1846 letter by W.B. Clarke.

476 Anon. Mr Hargraves. *SMH*, 18 July 1853. Lead article, unsigned.

477 Australian Board of Mission. *SMH*, 18 & 30 July 1853. Advertisement for subscriptions. W.B. Clarke signed the notice as Secretary.

478 Anon. Church of England College. *SMH*, 1 August 1853. Report on meeting of the Sydney University Church of England College committee, of which W.B. Clarke was a member.

479 Various, 1853. Report of the Board appointed for the Sinking of an Artesian Well at Darlinghurst Goal. [Ordered to be printed by the Legislative Council, 23 June 1853]. *V&PLC*, *1*, 729-33. Clarke was chairman of the Board which had been

constituted around March 1850, He was engaged in survey work on the goldfields when the final report was prepared.

480 Review of ON THE GEOLOGY OF THE GOLD-BEARING ROCKS OF THE WORLD AND THE GOLD FIELDS OF VICTORIA by Evan Hopkins, Melbourne, 1853. *SMH*, 30 November 1853.

481 Anon. Gold in New Zealand. *Illustrated London News*, 3 December 1853, 465. Contains references to Clarke's involvement in the discovery of gold in New Zealand.

482 Anon. Report on meeting of Australian Board of Missions. *SMH*, 9 December 1853. Unsigned. W.B. Clarke was Secretary. Includes comments by Clarke on the Aborigines.

483 Dr. Leichhardt's Mother. *SMH*, 17 December 1853. Letter to the editor, signed and dated 'W.B. Clarke. St. Leonard's, December 13.'

484 Anon. Tasmania. *SMH*, 20 December 1853. Report on Clarke's studies of Tasmanian geology.

485 Letter from W.B. Clarke to the Honorable The Colonial Secretary, on the subject of Correspondence between Sir R.I. Murchison and the Colonial Minister, relative to anticipations of the Discovery of Gold in Australia, *in* New South Wales Discovery of Gold (Sir R. Murchison's Claim), *V&PLC*, Sydney, 1854, 1-3; *Parliamentary Blue Book*, London, 1854, *20*, 21-3. Letter signed and dated 'St Leonard's, 21 December 1853.'

486 Gold in Van Dieman's Land. *SMH*, 21 December 1853. Letter to the editor.

487 Review of Anniversary Address to the Royal Geographical Society by Sir R.I. Murchison. *SMH*, 24 December 1853. Makes reference to Clarke.

488 Anon. Note on the Discovery of Gold in Australia. *Quarterly Review*, London, *XCIV*, December 1853 - March 1854, 606.

1854

489 Murchison, R.I., 1854. SILURIA. THE HISTORY OF THE OLDEST KNOWN ROCKS CONTAINING ORGANIC REMAINS, WITH A BRIEF SKETCH OF THE DISTRIBUTION OF GOLD OVER THE EARTH. London, 1st edition. Contains references to the work of W.B. Clarke and his discovery of Silurian fossils in New South Wales.

490 Tin Ore. *SMH*, 15 January 1854. Letter to the editor, signed and dated 'W.B. Clarke. St. Leonard's, 13th January, 1854.'

491 Anon. The Scientific and Practical Discovery of Gold [in Australia]. *The Times*, London, 16 January 1854. Republished in *SMH*, 18 April 1854.

492 Is there to be no further search for Leichhardt?' *SMH*, 17 January 1854. Lead article, signed 'A.'

493 Review of *Papers and Proceedings of the Royal Society of Van Dieman's Land. SMH*, 25 January 1854. Second notice.

494 Report of the Select Committee of the Legislative Council on Claims for the Discovery of Gold in Victoria, *Parliamentary Papers of Victoria*, Government Printer, Melbourne, 3(2), 10 March 1854. Contains a copy of a letter submitted by W.B. Clarke. The Committee eventually voted £1000 to Clarke for his role in the Victorian gold discoveries.

495 Omeo Diggings. *SMH*, 26 April 1854. Signed and dated 'W.B. Clarke. 19 April 1854. Reproduced in Clarke's RESEARCHES IN THE SOUTHERN GOLDFIELDS (1860, 136-8).

496 Calvert, John 1854. *SMH*, 29 May & 6 June 1854. Lead articles, unsigned. Critical review of Calvert's book GOLD ROCKS OF GREAT BRITAIN AND IRELAND, AND A GENERAL OUTLINE OF THE GOLD REGIONS OF THE WORLD, WITH A TREATISE ON THE GEOLOGY OF GOLD (London, 1854).

497 *To the Members of the Church of England of Gordon.* Letter to parishoners, signed and dated 'W.B. Clarke, St Leonard's, 1st October 1854.' Privately printed pamphlet, 3p.

498 Anon. Further Papers relative to the Discovery of Gold in Australia. *British Parliamentary Papers*, London, July 1855, 21, 17-21. Correspondence from various authors - including W.B. Clarke - re his involvement in the discovery of gold in New South Wales. Includes two letters from Clarke to the New South Wales Colonial Secretary dated St Leonard's, 1 & 19 October 1854.

499 Anon. Select Committee on Clergy Stipends. *SMH*, 27 October 1854. Editorial, including comments by Clarke.

500 The Elevation of the Australian Continents. *SMH*, 18 November 1854. See also 13 December 1854.

501 Catalogue of Geological Specimens illustrating the Succession of the Rock Formations in New South Wales, *in* CATALOGUE OF THE NATURAL AND INDUSTRIAL PRODUCTS OF NEW SOUTH WALES. Government Printer, Sydney, 1854, 41-51. Signed 'W.B.C., 4th December 1854.' This was the first comprehensive catalogue of New South Wales geological specimens to be published. The introductory comments, without the attached list, were published in the *SMH*, 12 December 1854. See also *SMH* 30 November & 1 December regarding Samuel Stutchbury's involvement, following on questions in the Legislative Council by George Macleay on 7 September.

502 The Gold Fields of New South Wales, *in* CATALOGUE OF THE NATURAL AND INDUSTRIAL PRODUCTS OF NEW SOUTH WALES. Government Printer, Sydney, 1854, 60-2.

503 Clarke, W.B. and Johnston, W., 1854. Catalogue of the Drift deposits dug through in sinking for Gold on the Turon River, *in* CATALOGUE OF THE NATURAL AND INDUSTRIAL PRODUCTS OF NEW SOUTH WALES. Government Printer, Sydney, 62-3.

504 On the Coal Fields of New South Wales, *in* CATALOGUE OF THE NATURAL AND INDUSTRIAL PRODUCTS OF NEW SOUTH WALES. Government Printer, Sydney, 1854, 68-70.

505 Scientific: The Recent Elevation of the Land at the Cape of Good Hope. *SMH*, 13 December 1854. Refer 18 November 1854.

506-8 The Gold Fields of the Russian Empire. *SMH.* Unsigned, in three parts. Possibly by W.S. Jevons. I (23 December 1854), II (6 January 1855), III (14 February 1855) - The Auriferous Deposits of Siberia and the North Flank of Altai.

509 Gold in the territory of Madras. Referred to in Clarke's 1872 list of publications.

1855

510 Sedgwick, Adam, 1855. Introduction, *in* SYNOPSIS OF THE BRITISH PALAEOZOIC ROCKS AND FOSSILS IN THE GEOLOGICAL MUSEUM OF THE UNIVERSITY OF CAMBRIDGE. Cambridge, xciii. Pays tribute to Clarke.

511 Catalogue of a Collection containing several hundred specimens illustrative of the Mineralogy and Geology of New South Wales, *in* BRITISH CATALOGUE OF THE EXPOSITION UNIVERSALLE. PARIS. London, 1855, 99-103.

512 On the Gold Fields of New South Wales, *in* BRITISH CATALOGUE OF THE EXPOSITION UNIVERSALLE, PARIS. London, 1855, 103-5.

513 On the Coal Fields of New South Wales, *in* BRITISH CATALOGUE OF THE EXPOSITION UNIVERSALLE, PARIS. London, 1855, 105-8.

514 Alma and Sebastopol. *SMH* 10 January

1855. Letter to the editor, signed and dated 'W.B.C. St. Leonards, 5th January 1855.'

515 Calvert, John. On the Supply of Gold from Australia, and from English Rocks. *SMH*, 20 January 1855. Copy of a paper read to the British Association and extracted from the *Mining Journal* of 7 October 1854. Critical of W.B. Clarke's views.

516 Sebastopol - Being a review of THE BALTIC, THE BLACK SEA, AND THE CRIMEA: COMPRISING TRAVELS IN RUSSIA, A VOYAGE DOWN THE VOLGA TO ASTRACHAN, AND A TOUR THROUGH CRIM TARTARY by Charles Henry Scott. *SMH*, 25 January 1855.

517 Review of THE HISTORY OF TRANSMUTED ROCKS, OR BIBLE GEOLOGY by E.W. Rudder. *SMH*, 5 February 1855.

518 Davidson, Simpson. The Origin of Alluvial Gold. *The Empire*, 8 February 1855. Letter to the editor. Critical of the gold theories of Clarke and Murchison.

519 Review of SCENERY, SCIENCE AND ART, BEING EXTRACTS FROM THE NOTEBOOK OF A GEOLOGIST AND MINING ENGINEER by D.T. Ansted. *SMH*, 22 February 1855.

520 On the Occurrence of Obsidian Bombs in the Auriferous Alluvia of New South Wales [Abridged]. *JGS*, 1855, *XI*, 403-4. Read on 7 March 1855.

521 On the Occurrence of Fossil Bones in the Auriferous Alluvia of Australia. *JGS*, 1855, *XI*, 405-8. Read on 7 March 1855.

522 Notes on the Geology of New South Wales (Permian, Devonian, and Silurian) [Abstract]. *JGS*, 1855, *XI*, 408. Extracts from a letter to Sir Roderick Murchison. Read on 7 March 1855.

523 The Earthquake in New Zealand, of 23 January, 1855. *SMH*, 12 March 1855. Signed and dated 'W.B.C. March 7, 1855.'

524 Sydney Buildings. *SMH*, 10 April 1855. Letter to the editor, signed and dated 'W.C. Sydney, 7th April, 1855.' Possibly by Clarke.

525-6 The Old World and the New. *SMH*, 20 & 27 April 1855. Discussion of a lecture given by M. Marcel de Serres, Professor of Mineralogy and Geology at Montpellier. Lead articles, unsigned.

527-30 Gold in India. *SMH*, 23 May - 19 September 1855. Letters to the editor containing extracts of reports on aspect of Indian geology, incorporating material from individuals such as Lieutenant Aytoun. I (23 May); II (23 August); III (10 September) - Lt Aytoun's Geological Report on the Belgaum Collectorate. Part I; I V (1 9 September) - Lt Aytoun's Geological Report on the Belgaum Collectorate. Part II.

531 Review of *Further Papers relative to the Discovery of Gold in Australia, presented to both Houses of Parliament, by command of Her Majesty, December 1854*, London 1855. *SMH* 25 June 1855. Includes geological reports by Clarke.

532 Davidson, Simpson, 1855. The Discovery of Alluvial Gold. *The Empire*, 17 September. Letter to the editor, critical of Clarke.

533-4 Tasmanian Contributions to the Paris Exhibition. *SMH*, 8 & 15 October 1855. Review of the accompanying catalogue.

535 Funeral of Sir Thomas Mitchell. *SMH*, 10 October 1855. Includes detailed obituary notice.

536 Review of *Meteorology - Notice of an accurate and easily applied Method of Ascertaining the Direction of the Wind by observing the reflected Image of Clouds, by Thomas Stevenson, FRSE, CE*, as originally published in Anderson's Journal. *SMH*, 2 November 1855. Signed 'W.B.C.'

537 Gold on the Hunter. *SMH*, 12 November 1855. Signed & dated 'W.B.C. St Leonard's, November 7, 1855.'

538 Anon. Gold Discoveries. *Nottingham Guardian*, 6 December 1855. Letter re W.B. Clarke's involvement in Australian gold discoveries.

539 Select Committee on the City Commissioners. *SMH*, 20 December 1855. Letter to the editor, signed & dated 'W.B. Clarke, St Leonard's, December 19.'

1856

540 *The Dead which are Blessed: a sermon preached in the church of St Thomas, Willoughby, N.S.W. on Sunday, 2nd March, 1856, the day after the funeral of the late Rear-Admiral Phillip Parker King, M.C.* Joseph Cook & Co., Church Press, Sydney, 1856. Copy at ML MSS119/118/5.

541 Davidson, Simpson, 1856. William Howitt on Gold. *The Empire*, 3 April. Letter to the editor. Discusses Clarke's gold theories and discoveries.

{Easter Sunday - Clarke suffers a mild stroke and his parishioners send him to his sister in Green Ponds, Tasmania for rest. Whilst there he undertakes a survey of the Fingal goldfield}

542-7 *Tasmanian Goldfield Reports.* Clarke wrote 4 reports for the Fingal Gold Committee (19 June and 11 November 1856), and 2 for the Tasmanian Gold Committee in 1859.

542 Report of the Fingal Gold Committee. *Colonial Times & Tasmania*, 23 May 1856; *Hobart Town Gazette*, 23 June 1856; *SMH*, 24 June 1856; *Daily News*, 24 June 1856; *Hobart Town Gazette*, 12 August 1856, p115; *Colonial Times & Tasmania*, 13 August 1856. See also under 15 May 1859.

543 Report on the Gold Field at Fingal, Tasmania (No.1). *Hobart Town Government Gazette*, June 1856; *Parliamentary Blue Book*, London, 1857, *22*, 82-4. Dated 'Green Ponds, 19 June 1856.'

544 Report on the Analysis of two specimens of Auriferous Quartz, from Fingal, Tasmania (No.2). *Hobart Town Government Gazette*, August 1856; *Parliamentary Blue Book*, London, 1857, *22*, 87-9. Dated 'Parsonage, St Leonard's, New South Wales, July 28 1856.'

545 Report on the Analysis of Auriferous Quartz specimens from Frenchman's Gap, Macquarie Harbour, Tullochgorum House, and Black Boy Flats, Tasmania (No.3). *Hobart Town Government Gazette*, October 1856; *Parliamentary Blue Book*, London, 1857, *22*, 95-7. Dated 'St Leonard's, New South Wales, September 27, 1856.'

546 Further report on the Analysis of Auriferous Quartz, from the neighbourhood of Fingal and Swanport, Tasmania (No.4). *Hobart Town Government Gazette*, November 1856; *Parliamentary Blue Book*, London, 1857, *22*, 99-101. Dated 'St Leonard's, New South Wales, November 11, 1856.'

547 Table of the Product of rocks from Port Davey and Clerk's Reef. *Parliamentary Blue Book*, London, 1857, *22*, 102. Dated 'St Leonard's, New South Wales, November 12, 1856.'

548 Davidson, Simpson, 1856. The Granite Gold of New England. ?*SMH*, August. Signed and dated 'Simpson Davidson, Sydney, 13th August 1956.' Article critical of Clarke's gold theories.

549 The Discovery of Gold in Australia. *SMH*, 3 September 1856. Unsigned. Extracts from Clarke's northern goldfields reports of 1853.

550 Additional Notice of the occurrence of Volcanic Bombs in Australasia [Abstract]. *JGS*, 1857, *XIII*, 188; *Philosophical Magazine*, London, 1857, *XIII*, 147. Read to the Geological Society on 17 December 1856.

1857

551 Observations made at St. Leonards during the Solar Eclipse. March 26, 1857. *SMH*, 9 April 1857; *Transactions of the Royal Astronomical Society*. London, 1857. Article signed and dated 'W.B.C. 29th March 1857.'

552 Dr. Leichhardt. *SMH*, 18 June 1857. Signed 'Z.'

553 Observations made at St. Leonards, North Sydney, during the Eclipse of the Sun, 18 September, 1857. By Rev. W.B. Clarke, M.A., &c. *SMH*, 25 September 1857.

554 Influence of the Monsoons on the climate of Sydney. *SMH*, 27 October 1857. Letter to the editor, signed and dated 'W.B. Clarke, St Leonard's, 22nd October.'

555 Viscomte d'Archaic, 1857. PROGRES DE LA GEOLOGIE. Paris, Appendice, *VII*, 689-92. Discusses the problem of the age of the New South Wales coal beds, mentioning Clarke's views.

1858

556 Notes on Some Geological Specimens collected by Charles Grant Robertson, Esq., of Duntroon, near Queenbeyan, N.S.Wales. *Sydney Magazine of Science and Art*, 1858, *I*, 135-6.

557 Anon. Indian Mutiny Relief Fund. *SMH*, 13 April 1858. Report on meeting held at St Leonard's, at which Clarke was elected chairman of the committee.

558 Anon. Tribute to W.B. Clarke. *SMH*, 20 May 1858. Contains a tribute to W.B. Clarke's Australian geological work, plus an itinerary of his European, British, and other geological tours between 1817-39, prior to his arrival in New South Wales. Reprinted *SMH* 10 June 1858.

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1864

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1868

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1871

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Brittle deformation of the Bathurst Batholith: A coeval behaviour with megakinking in the Lachlan Fold Belt, southeastern Australia.

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(communicated by D.F. Branagan)

Abstract: The Bathurst Batholith is a post-kinematic granitic body in the northeastern Lachlan Fold Belt, west of Sydney. A survey of weathered granites in limited outcrops leads to the conclusion that the Bathurst Batholith has been penetratively deformed in a brittle manner. Typical deformation structures are subparallel joint/fault sets and fault gouges, which trend dominantly NNW to NE. Conjugate faults and feather fractures indicate north-south shortening. These brittle deformation structures can be interpreted as related to post-kinematic deformation during late Palaeozoic time, possibly including megakinking, in the Lachlan Fold Belt.

Key words: structural geology, granite, joint, fault, megakink.

INTRODUCTION

The Bathurst Batholith is a "subsequent bathylith" (Browne, 1931), or a post-kinematic granitic body (Valiance, 1969), which is located in the northeastern Lachlan Fold Belt (Fig.1). The batholith is made up of several types of granitoid, collectively termed the "Bathurst Granite", all of which are massive and non-foliated (Vallance, 1969). Because of their massive textures, extensive weathering and limited outcrops, deformation structures have not been studied in detail since the petrological investigation by Mackay (1964). This paper describes the brittle deformation structures such as joints and faults formed penetratively in the Bathurst Batholith and discusses their significance to north-south shortening, related to late Palaeozoic megakinking in the Lachlan Fold Belt.

One outcrop of the Davies Creek granite (Fig.1), just south of the Bathurst Batholith, is also discussed here because of its important fractures. The Davies Creek granite is considered to have intruded into the Rockley district in the "?Early Carboniferous" (Fowler, 1989: Fowler & Lennox, 1992) or in the Devonian (Shaw *et al.*, 1982).

GEOLOGIC SETTING

The Bathurst Batholith, about 100 kilometres long in the WNW-ESE direction, intruded discordantly across the generally N-S trending, folded Ordovician to Late Devonian strata (Brunker and Rose, 1969), after the Kanimblan Orogeny (Stevens, 1974) (Fig.1). Its K-Ar ages were reported as 300 and 308 Ma (biotite: Evernden and Richards, 1962) or 301±6Ma to 318±17Ma (biotite or whole rock: Facer, 1978). Its Rb-Sr ages are from 340 to 312 Ma (Shaw & Flood, 1993), indicating late Early/early Late Carboniferous age of intrusion. The Bathurst Batholith is composed of coarse-grained (biotite-) granite with orthoclase megacrysts or coarse-grained biotite granite and hornblende-biotite granodiorite without megacrysts. The Granite contains quartz veins, microgranite dykes, and also contains mafic enclaves (Branagan, 1972).

The Bathurst Batholith and the enclosing country rocks are nonconformably overlain by the Shoalhaven Group which forms the basal part of the western Sydney Basin. The Shoalhaven Group resting on the Bathurst Batholith is uppermost Early Permian (upper Artinskian or Kungurian) (Branagan *et al.*, 1976: Briggs, 1991).

The Bathurst Batholith is situated along a zone of east-southeasterly trending lineaments through Orange (Fig.1) which constitutes the northern edge of the 50 kilometres-wide Lachlan River lineament (Scheibner & Stevens, 1974). The latter is interpreted as a large megakink band with 25 kilometres dextral offset of the Late Devonian strata (Powell *et al.*, 1985).

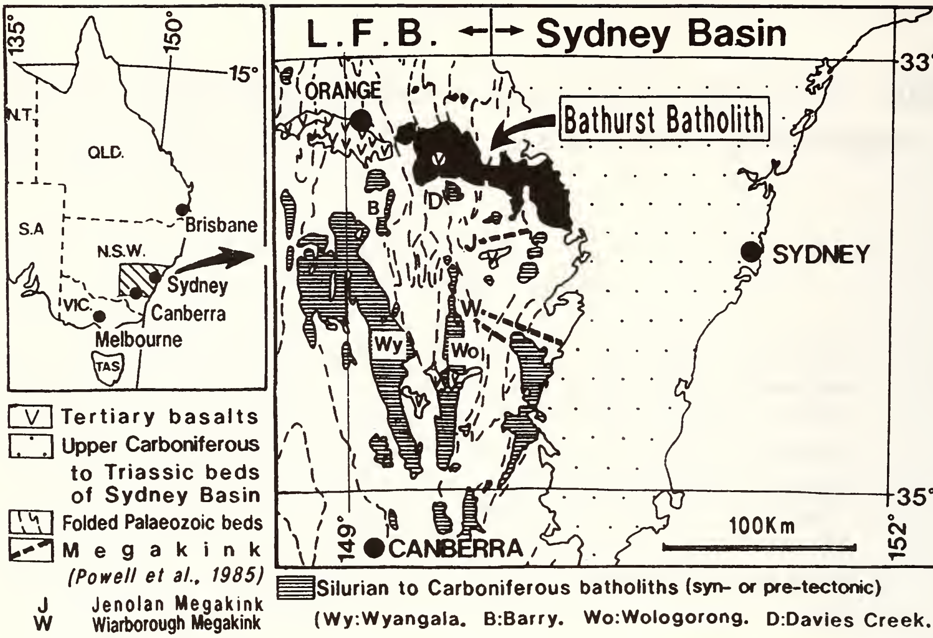


Fig.1. Index map and geologic outline of the Bathurst Batholith. L.F.B.=Lachlan Fold Belt (Compiled mainly from 1:3,000,000 Geological Map of New South Wales, Geol. Surv. N.S.W., Dept. Mines).

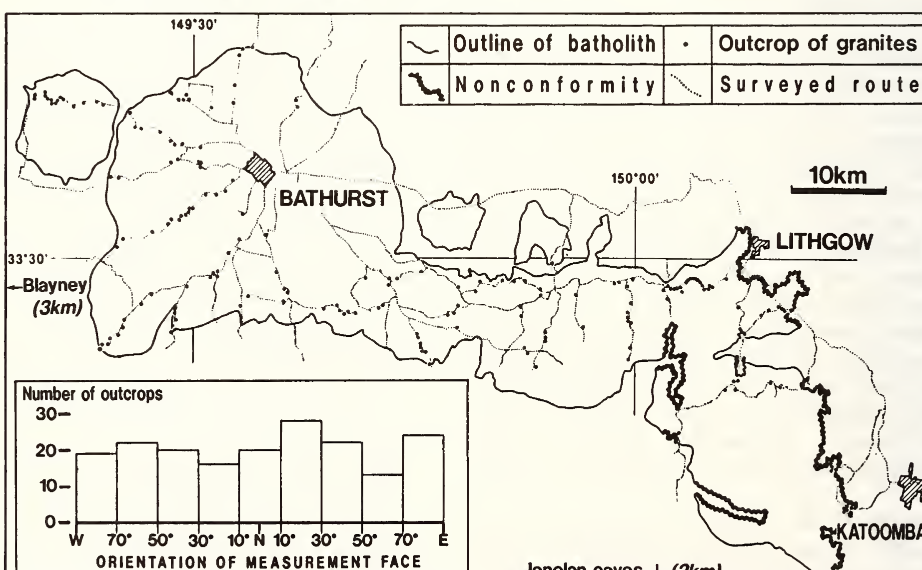


Fig.2. Locality of granite outcrops. Most of the observed 185 outcrops are of weathered granites. The lower left histogram shows the frequency of measurement face orientations of 185 outcrops.

The Bathurst Batholith generally forms a low-relief surface and is topographically lower than the surrounding annulus of regionally-metamorphosed sedimentary rocks. It displays similar granite landforms to those elsewhere in the Lachlan Fold Belt (Branagan, 1972). Outcrops of Bathurst Batholith are limited and are extensively weathered. One hundred and eighty-five outcrops have been examined along roads, railway cuttings and creeks (Fig.2). Measurement faces of outcrops are variously oriented and thus there is no noticeable "cut effect" (Ramsay and Huber, 1987), which might bias orientations of observations of particular joint/fault planes (Fig.2, lower left).

BRITTLE DEFORMATION STRUCTURES

Representative deformation structures

Sets of high-angle subparallel joints/faults, most of which dip subvertically, are formed penetratively in the batholith (Fig.3a). They extend from the bottom to top of outcrops. Spacing varies from centimetres to metres (Fig.4a), and orientations range within about 20° for each set (Fig.4b). The Bathurst Batholith can be tentatively divided into western and eastern areas based on the general trends of these joints/faults (Fig.5). The boundary is close to the junction of two separate granite phases identified by Stevens (1973). The main trends are NNW to NNE with subordinate E trend in the western area, while N to NE trends occur in the eastern area (Fig.5, upper right).

Displacements along these joints/faults are recognizable even in massive granite by displaced markers, such as coarse-grained granitic textures, orthcclase megacrysts, enclaves, veins/dykes, or joints/faults. When joints/faults are used as markers, at least three joints/faults should be systematically displaced, or other evidence of displacement should be recognized (Fig.3b). Striated surfaces in granite are also evidence of faults along which displacement has occurred, though striations are obscure in many places due to weathering. About 40% of the measured 365 joints/faults show striations, most of which plunge 0° to 30°S on northerly-trending subvertical fracture surfaces (Grid Reference(G.R.)290867, Fig.4c). Striations have been used only to note directions of displacement as it is difficult in the weathered Bathurst Granite to deduce with confidence the sense of displacement from striations alone. Zones of fault breccia and gouge are easily recognizable in outcrops. They are centimetres to a metre in width and lack primary cohesion. They are made up of breccias and decomposed mineral grains of granite.

Each set of joints/faults shows evidence of displacement, mainly slickensides and subordinately displaced markers and fault breccias/gouges (e.g. , Fig.4c). Thirty-six percent of the measured 134 sets of joints/faults show evidence of displacement.

Intense brittle deformation zones are formed in places where sets of closely spaced subparallel joints/faults of varying orientations intersect with each other. Granite is fractured to form slabs and blocks of various sizes (Fig.6a). Displaced markers, striated surfaces and gouges indicate that many slabs and blocks moved relative to one another. When veins/dykes are used as displacement markers, relative movements between slabs and blocks can be clearly established (Fig.6b). Layered structures such as subparallel fractures or veins/dykes show drag folding (Fig.3c). Densely spaced fractures may also be folded directly adjacent to the minor gouge zones, particularly where they bifurcate or terminate (Fig.6c). Gouge zones with sliced and displaced megacrysts are formed in some places (Fig.6d). They are generally bounded on both sides by planar fracture surfaces. Subparallel fractures are spaced less than a centimetre apart, and serve as evidence of displacement by millimetres or more, as shown by displacement markers.

Feather fractures associated with fault gouges are another type of intense brittle deformation. Feather fractures are striated and folded along gouge zones (Fig.6e). Gouge zones are composed of dense subparallel slip surfaces, irregularly oriented fractures, and scaly clays.

Low-angle subparallel faults occur locally in the batholith (Fig.7: G.R.319957, 687811, 374843). They have reverse components of displacement, with centimetres to tens of centimetres magnitude, as shown by displaced markers (Fig.3d). Striations and displaced markers show oblique-slip movements on the faults. Closely-spaced fractures are developed parallel to faults in zones a few metres wide adjacent to main faults, indicating a brittle deformation.

The Bathurst Granite was capable of being folded, in an analogue way to that reported by Davies and Pollard (1986), as it has planar structures such as subparallel fractures and veins/dykes in many places. Drag folds associated with faults provide evidence of the nature of the displacement along fractures. Slabs of subparallel-jointed granites are displaced across fault surfaces to produce open kink folds at some localities (Fig.7: G.R.302025, 246844, 687813: Fig.3e), though no kink bands have been observed.

Deformation structures as indicators of palaeostress axes directions

Two sets of conjugate faults have been recognized in the eastern area of the batholith (Fig.7: G.R.437639 and 279876: Fig.3f), based on opposite sense of displacements and cross-cutting relations. Displacements along each fault vary from one centimetre to 25 centimetres. They show σ3 (minimum principal stress) axes gently plunging E or W, and σ1 (maximum principal stress) axes gently plunging N or S. The half shear angles are about 25° and about 20° (Fig.8a, b).

Two feather fractures have been recognized in the western area and in the Davies Creek Granite (Fig.7: G.R.269042, 432794: Fig.6e). Rotational axes of the drag folding and disposition of principal stress axes are inferred stereographically (Fig.8c, d). Both sets of feather fractures show σ3 axes gently plunging E to ESE, and σ1 axes moderately plunging SSW. The half shear angles are 15°, 23°, and 25° to 30°.

The direction and sense of displacement can be determined for seven high-angle faults in the western and eastern areas (Fig.7: G.R.307069, 319957, and 617863) using a combination of striations on slickensides and displaced markers. The principal stress directions are computed stereographically (Ramsay & Huber, 1987, p.607): Firstly, σ2(intermediate principal stress) lies on the fault plane oriented at 90° to the striations. Secondly, σ1 is situated in a plane (great circle with pole σ2) at half shear angles. Lastly, σ3 is constructed by finding a point on the great circle with pole σ2 at an angle of 90° - x° (x=half-shear-angle) from the slip direction on the opposite side of the fault. As the half shear angle is about 15° (minimum) to 30° (maximum), σ3 axes plunge gently or moderately easterly and σ1 axes plunge gently or moderately northerly or southerly (Fig.8e). Graphical determination of principal stress directions for slickensides populations using "M-planes" (Aleksandrowski, 1985) shows gently plunging σ1 and σ3 axes and subvertically or steeply-plunging σ2 axis, though the directions of σ1 and σ3 axes are not determined.

DISCUSSION

Deformation styles of the Bathurst Batholith

Deformation structures in the Bathurst Batholith are composed of joints and faults, all of which were formed by fracturing or brittle deformation. Folds of layered structures also show brittle hehaviour. Fractures without gouges appear like joints and are not recognizable as faults unless there are displaced markers, striations, or drag folds. However, most fractures in the Bathurst Batholith are probably faults and not joints. No ductile deformation structures are developed in the Bathurst Batholith,

Fig.3. (Opposite Page)

Photographs of representative outcrops. The length of the hammer in photographs is 26 centimetres. Localities are indicated by grid references (G.R.'s) of 1:100,000 National Topographic Map Series; Blayney 8730, Orange 8731, Oberon 8830, Bathurst 8831, and Katoomba 8930.

(a) Subvertical subparallel joints/faults (arrows) (G.R.329817, 9 kilometres south of Lithgow).

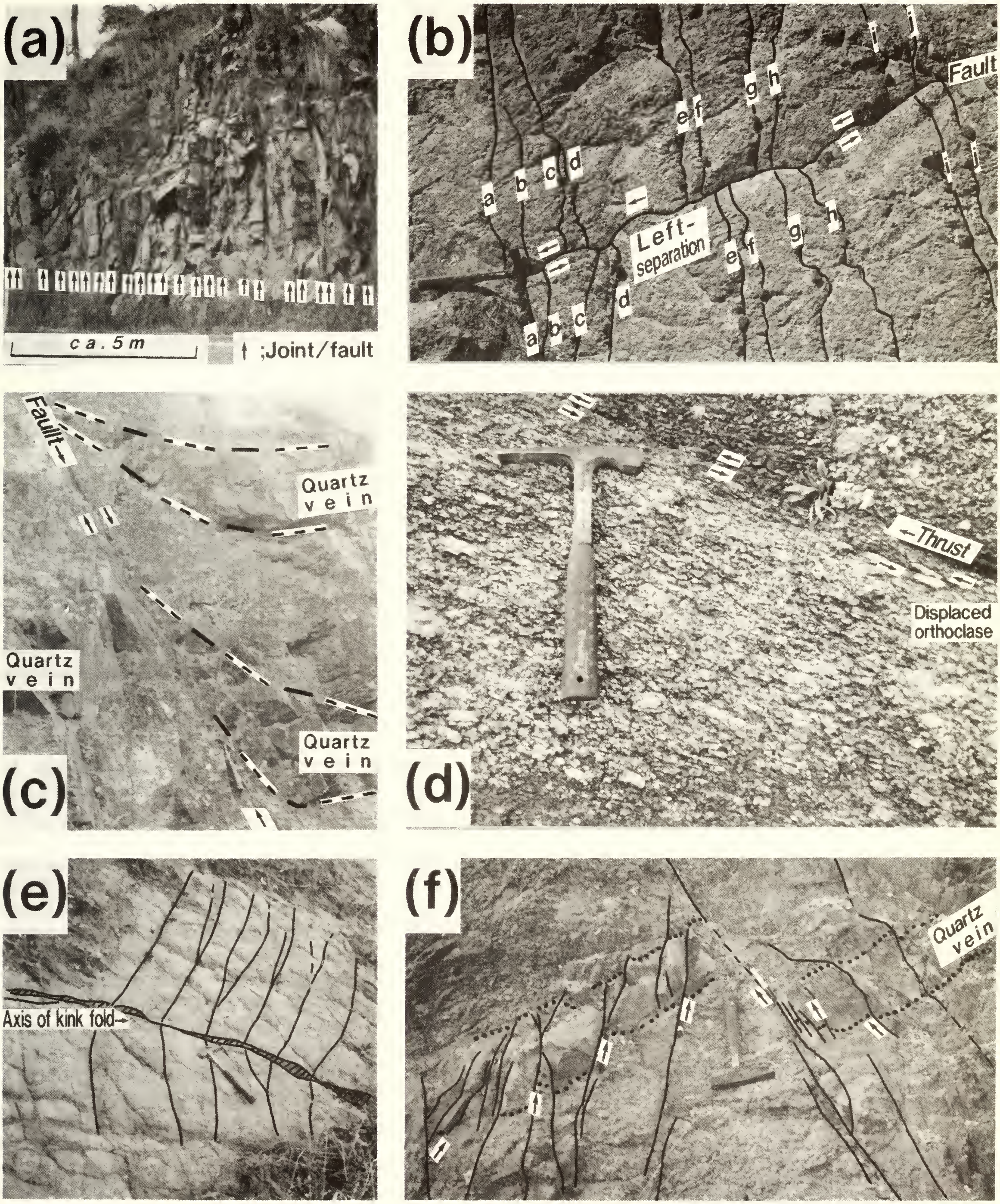
(b) Ten subparallel fractures (a to j) displaced by a fault. The left-separation is about tens centimetres (G.R.307874, 5 kilometres southwest of Lithgow).

(c) Drag folding of quartz veins (G.R.617863: See Fig.7 for locality). (Outcrop sketch in Fig.6b).

(d) A minor thrust (G.R.319957: See Fig.7 for locality). Millimetres-spaced subparallel fractures are formed densely in the foot wall. Note the displaced orthoclase). (Outcrop sketch in Fig.6a).

(e) Kink fold of a fractured granite (G.R.687813: See Fig.7 for locality).

(f) Conjugate minor faults displacing a quartz vein (G.R.279876: See Fig.7 for locality. Wulff net in Fig.8b).



(a)
ca. 5 m
;Joint/fault
(b)
a b c d
e f
g h
i j
Fault
Left-separation
(c)
Fault
Quartz vein
Quartz vein
Quartz vein
(d)
Thrust
Displaced orthoclase
(e)
Axis of kink fold
(f)
Quartz vein

except for some drag folds of brittle-ductile transitional behaviour. Even biotite grains, the most plastic mineral in the Bathurst Granite, show no signs of plastic deformation. This phenomenon is in contrast to nearby Silurian/Devonian syntectonic or pre-tectonic meridional granitoids, such as the Wyangala Batholith (Morand, 1988: Paterson *et al.*, 1990), the Barry Granite (Lennox *et al.*, 1991), and the Wologorong Batholith (Shaw *et al.*, 1982) (Fig.1), in which some biotite grains are warped and kinked even in non-foliated I-type granitoids (Vernon and Flood, 1988). The Bathurst Batholith is considered to have attained high level in the crust and a part of the Batholith apparently crystallized under quite shallow cover (Vallance, 1969). The half shear angles of about 15° to 30° suggest that the conjugate faults and feather fractures were formed under limited overburden. Therefore, the batholith is considered to have been deformed under low confining pressure/temperature which enables only brittle deformation.

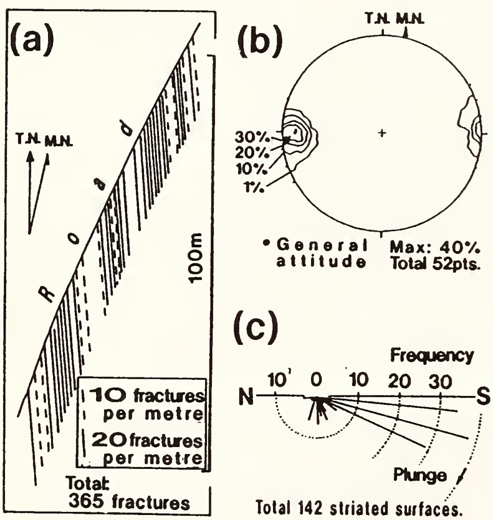


Fig.4. An example of a set of subvertical subparallel joints/faults (G.R. 290867, 6 kms southwest of Lithgow).

(a) Plan view of joints/faults along the route. Spacing between joints/faults ranges from several centimetres to 0.2 metre.

(b) Contoured pole density diagram of the joints/faults (equal area projection; lower hemisphere). The general attitude indicates the average strike and dip measured by "sighting-method" (Davis, 1984).

(c) Frequency of striation plunge. Most striations plunge shallowly southward.

Stress and strain

All the deformation structures used as indicators of palaeostress axes directions show northerly oriented σ1 axes and easterly oriented σ3 axes. It is probable that other penetrative fractures were also formed, at least in part, under a stress system with north-trending σ1 axis and east-trending σ3 axis.

The NNW- and NE- trending subparallel fractures are also likely to have been formed under the influence of north-south trending σ1 axis (Fig.8a to d), and possibly contributed to north-south shortening. In intense brittle deformation zones in the Bathurst Batholith, a stress analysis is impossible because of anisotropy due to fracturing and the later complex strain history affecting the Sydney Basin (Branagan, 1985: Lohe and McLennan, 1991).

Deformation history

The present surface of the Bathurst Batholith is considered to have been near the earth's surface without substantial overburden since early Cainozoic for the following reasons: (1) Tertiary basaltic lava flows lie nonconformably on the Bathurst Granite to the southwest of Bathurst and also lie unconformably on the country rocks just to the northeast, west and south of the Bathurst Batholith (Fig.1). (2) The Middle Shoalhaven Plain, 150 to 200 kilometres south of Bathurst, is a dissected peneplain of Ordovician strata, partly covered with Late Eocene basaltic lava flows and Early to Middle Eocene alluvial sediments. It is considered likely to date back to the Mesozoic (Ruxton & Taylor, 1982). (3) Near the Middle Shoalhaven Plain at Sassafras, a Middle Eocene basaltic lava flow overlies a plateau capping and its adjacent valleys, indicating that the early Tertiary landscape has been preserved (Young & McDougall, 1985). Pre-Cainozoic periods are the only possible times when the present surface of Bathurst Batholith was subject to certain overburden. These periods are considered to be: (1) before the uppermost part of the Bathurst Batholith was eroded preceding the formation of a nonconformity, i.e., Late Carboniferous or early Early Permian, and (2) during the time when a possible western continuation of Permian/Triassic strata of the Sydney Basin nonconformably lay on the Bathurst Batholith, i.e., Late Permian to early Cainozoic. Possibility (2) is of minor significance because the western continuation of the Sydney Basin onto the Bathurst Granite is estimated to have been much less than 1,500 metres; the sum of "about 500 metres" (=the present thickness of strata at the western edge of Sydney Basin) and "a thickness much less than 1,000 metres" (=thickness of the eroded strata in the Sydney Basin; Branagan, 1983). The thickness of sedimentary cover is estimated to have been about 300 metres maximum for the Permian and Mesozoic strata on the Ordovician to Devonian strata and a Carboniferous granite around Capertee, about 50 kilometres northeast of Bathurst (Branagan, 1972). Thus, case (1) is much more probable.

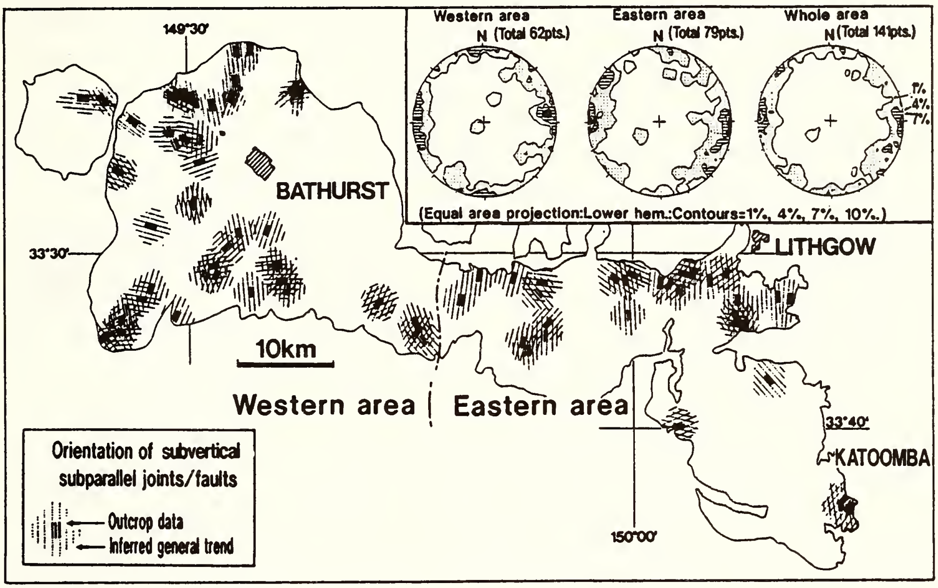


Fig.5. Distribution of subvertical subparallel joints/faults in the Bathurst Batholith. Upper right: Contoured pole density diagrams of sets of joints/faults. Each point represents the general attitude of each set.

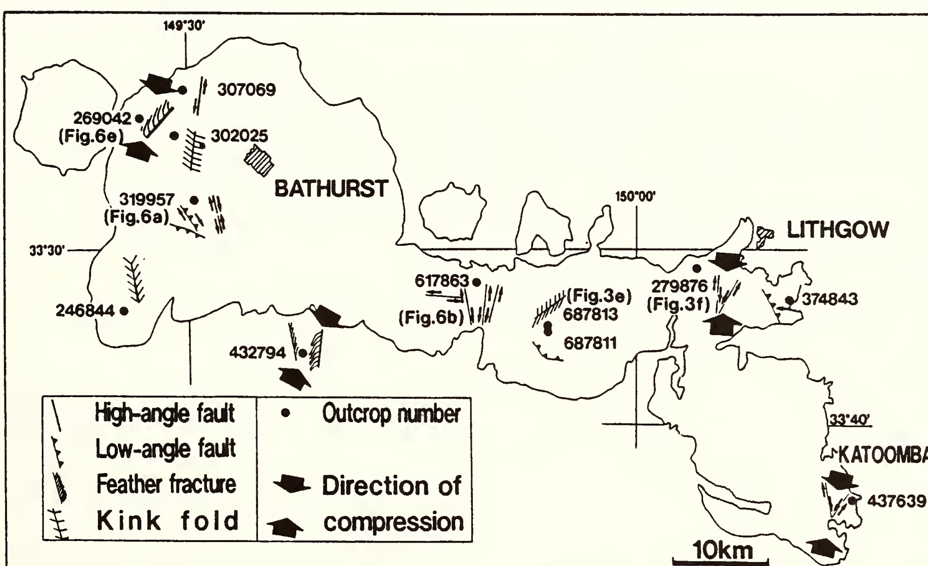


Fig.7. Locality and type of representative deformation structures of the Bathurst Granite. Faults, feather fractures, and kink folds are represented by schematical drawings. (Six numbers: grid references).

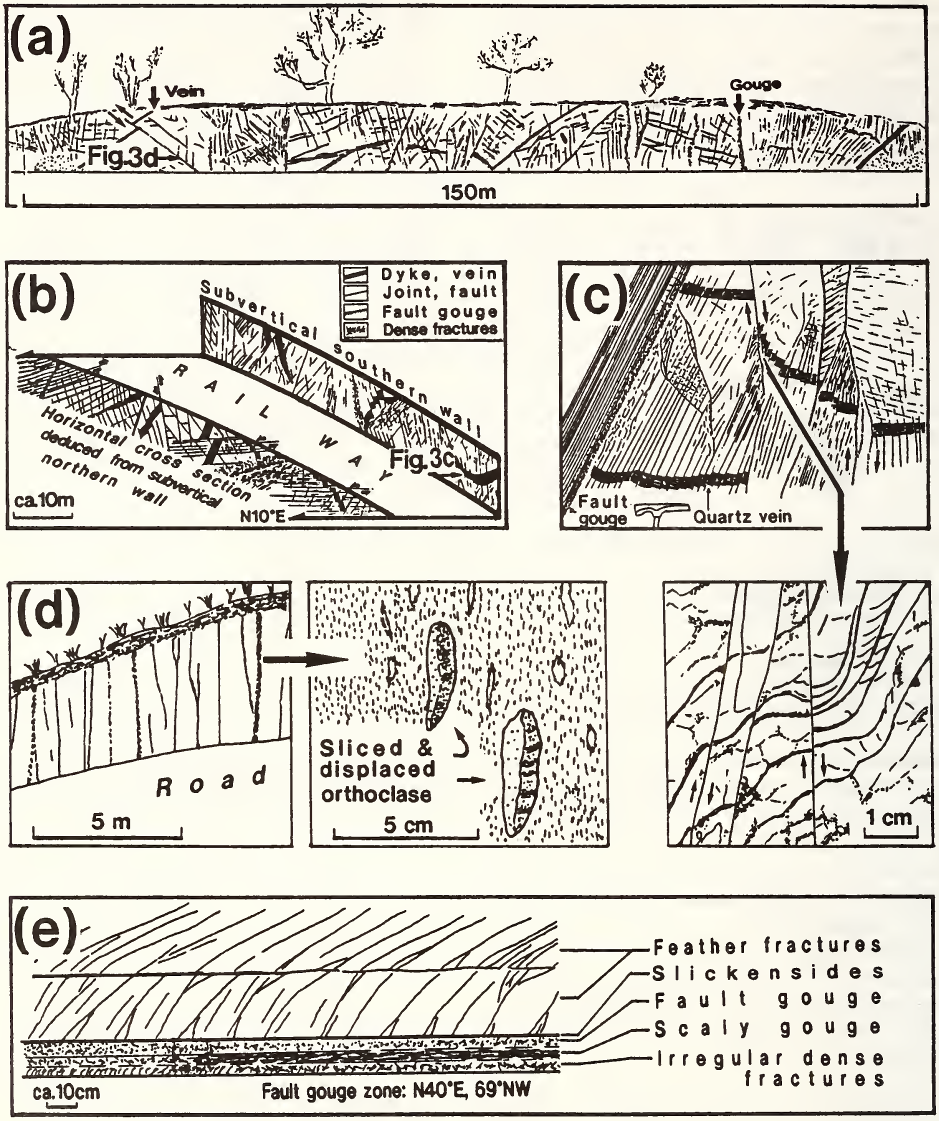
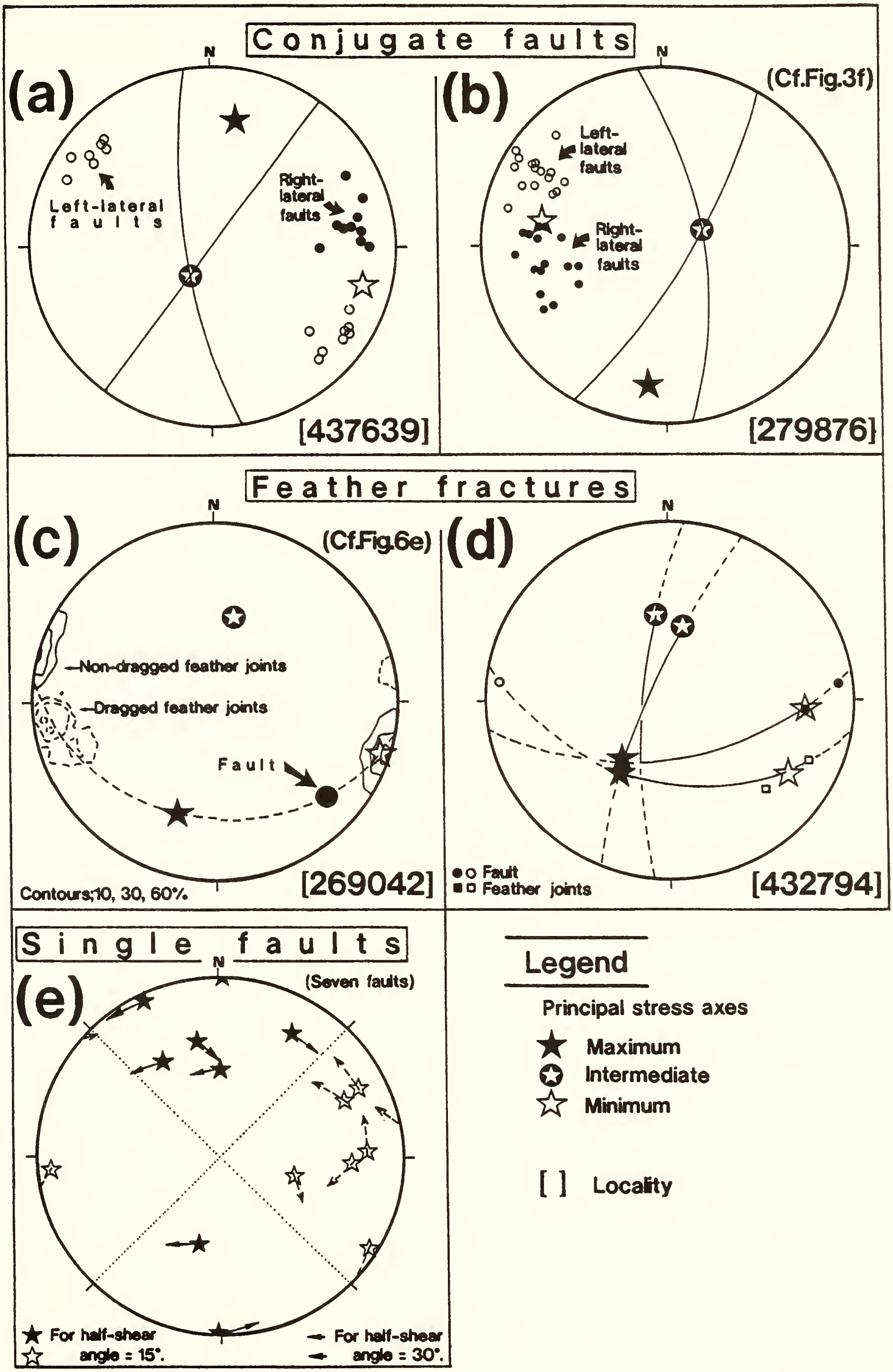


Fig.6. Sketches of intensely deformed granites.
(a) Intense brittle deformation zone made up of dense fractures of various orientations (G.R.319957: See Fig.7 for locality).
(b) Folded and displaced granite (G.R.617863: See Fig.7 for locality). Drag folding of quartz veins is well exposed on the subvertical southern wall of the railway cutting. Displaced quartz veins are well exposed on the subvertical northern wall of the railway cutting, which is shown on the plan view in the lower left of this figure.
(c) Millimetres-spaced fractures. Note displacements of quartz veins along fractures and rotation of fractures (G.R.277876, 8 kilometres west-southwest of Lithgow). Enlargement: Minor fold of densely fractured granite associated with minor fault.
(d) Sliced and displaced megacrysts of orthoclase in a gouge zone (G.R.228817, 25 kilometres southwest of Bathurst).
(e) Feather fracture, associated with a gouge zone (Plan view) (G.R.269042: See Fig.7 for locality. Wulff net in Fig.8c).

Fig.8. (Opposite Page)
Disposition of principal stress axes. (a, b, d, e: Wulff net, lower hemisphere. c: Schmidt net, lower hemisphere).
(a), (b) Deduced from conjugate faults.
(c), (d) Deduced from feather fractures.
(e) Deduced from single faults.


Conjugate faults
N
(a)
Left-lateral faults
Right-lateral faults
[437639]
(b)
(Cf.Fig.3f)
Left-lateral faults
Right-lateral faults
[279876]
Feather fractures
(c)
(Cf.Fig.6e)
Non-dragged feather joints
Dragged feather joints
Fault
Contours;10, 30, 60%
[269042]
(d)
Fault
Feather joints
[432794]
Single faults
(e)
(Seven faults)
For half-shear angle = 15°.
For half-shear angle = 30°.
Legend
Principal stress axes
Maximum
Intermediate
Minimum
[ ] Locality

Intrusion of the Bathurst Batholith is considered to have taken place at the time of deformation involving east-west shortening (Hobbs and Hopwood, 1969). This is one of the possible times for the east-west shortening responsible for low-angle thrust faults at G.R.319957 and 374843 (Fig.7), though other possibilities still remain.

As shown in some sketches (Fig.6), large strains are attained in a brittle manner in several areas. Such brittle deformation of the Bathurst Batholith is possibly related genetically to post-Late Devonian activity of the Lachlan River lineaments(Scheibner & Stevens, 1974) or is also possibly related to the early Tertiary activity of Lapstone Structural Complex at the eastern extension of the Lachlan River lineament in the Sydney Basin (Branagan and Pedram, 1990).

Comparison with other areas

A north-south compression is inferred from megakinks on the South Coast of New South Wales (Powell, 1983: Powell *et al.*, 1985), where the inferred disposition of stress axes are N-S-trending for $\sigma 1$, vertical for $\sigma 2$, and E-W for $\sigma 3$. This stress system is considered to have been responsible for the last deformation of Palaeozoic rocks on the South Coast and possibly postdating the Early Carboniferous folding event (350±Ma) (Powell, 1983) and to have antedated the oldest sediments of the Sydney Basin. Because of coincidence of stress axes dispositions and timing of deformation, the north-south compression inferred from brittle deformation structures in the Bathurst Batholith could have possibly occurred in relation to the north-south compression responsible for the formation of these megakinks.

A north-south shortening was detected in the Cann Valley Granitoids in Victoria, well south of the Bathurst Batholith, where fractures similar to those reported here are described in brittle shear zones, which "developed 310°-0° dextral brittle shear zones associated with some 020°-050° sinistral zones", and which "could be contemporaneous with the north to south compression documented in New South Wales by Powell (1984)" (Begg *et al.*, 1987). The north-south shortening characterized by this investigation is therefore not just a local feature within the Bathurst Batholith, but could possibly be part of a wider regional pattern in the Lachlan Fold Belt during Late Carboniferous or early Early Permian. The northwest to southeast shortening, which predates the north to south shortening, is detected in the Early to Middle Devonian Cann Valley Granitoids by Begg *et al.* (1987), while an east-west shortening possibly occurred in the Bathurst Batholith.

CONCLUSION

The Bathurst Batholith has been fractured densely and locally deformed intensely in a brittle manner. The most penetrative features in the batholith are subvertically-dipping subparallel fractures, many of which, through displaced markers and striations, show movements along them. Fault gouges and folds of layered structures in granites are also representative of brittle deformations. Evidence of north-south shortening is preserved and is probably related to the deformation, possibly including megakinking in the Lachlan Fold Belt, during the Late Carboniferous or early Early Permian.

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Fogs, Fossil Fuels and the Fall from Grace of St Mary's Purgatory Stone

Kenneth W. Riley

ABSTRACT. St Mary's Cathedral is used to illustrate the general deterioration of the stonework of Sydney's 19th century buildings. This deterioration is associated with the presence of sulfate salts, in which the sulfur has a range of isotopic compositions similar to that of the sulfur in the Permian coals, which were used extensively in the city. This past use meant that levels of particulate matter and sulfur dioxide in the city's atmosphere were higher than at present and over the decades, the sulfur dioxide has reacted with the external surfaces of the sandstone buildings and contributed to the decay. The past elevated levels of atmospheric pollutants from fossil fuels combustion appear also to have had some effect on the formation of fogs. In recent times, with the decrease in these pollutants, there has been a corresponding decrease in the occurrence of fogs in Sydney.

Introduction

St Mary's Cathedral can be used to illustrate the deterioration of the stone in many (if not all) of Sydney's sandstone buildings, erected in the latter half of the 19th century. The rebuilding of St Mary's commenced in 1865, after the original was destroyed by fire. Ironically, it was constructed with Hawkesbury sandstone from the Purgatory and Hell Hole sections of the Pyrmont quarry (Herman, 1956), although some of the stone may well have come from Paradise (Wallace, 1971).

Pyrmont sandstone was used in many of Sydney's buildings, and casual observation reveals that the pattern of stone decay on the Cathedral is typical of that seen on other buildings from the period.

Fall from Grace of the Purgatory Stone

The decay seen on the Purgatory and other Pyrmont stone of St Mary's Cathedral is often on the underside of external cornices, sills and archways and is associated with the deposition of salts. Rising damp at lower levels of buildings is often a cause of this deposition, but this does not produce the deterioration seen at higher levels. An example of this decay can be seen in the photographs (Figs. 1 and 2) of an archway on the eastern side of the cathedral. The photographs illustrate how the sandstone exfoliates, particularly on the undersides of

Fig. 1. Archway, eastern side of St Mary's Cathedral

overhanging stonework. Areas which are fully exposed to rain are often in very good condition; for example, the exposed carving of St Mary's face is unblemished, whereas the protected underside of surrounding stonework is badly decayed. Salt deposits are readily seen on the left-hand side of the archway. The salts, deposited in the pores of sandstone cause disruption to its structure when they crystallize (Winkler and Singer, 1972) or change in hydration (Winkler and Wilhelm, 1970). The increase in the volume of salt crystals within the pores weakens the cementing matrix and this results in the loss of sand grains or in extreme cases, pieces of stone.

Riley (1994) has reported the analyses of salts taken from St Mary's and from six other sandstone buildings in Sydney. The salts present in the stone were mainly sulfates of calcium and magnesium with minor amounts of sodium chloride and low levels of nitrate. Efflorescences present on the Australian Museum, Customs House and the Cathedral (Fig. 1) were composed of the hydrated magnesium sulfates, epsomite and hexahydrite.

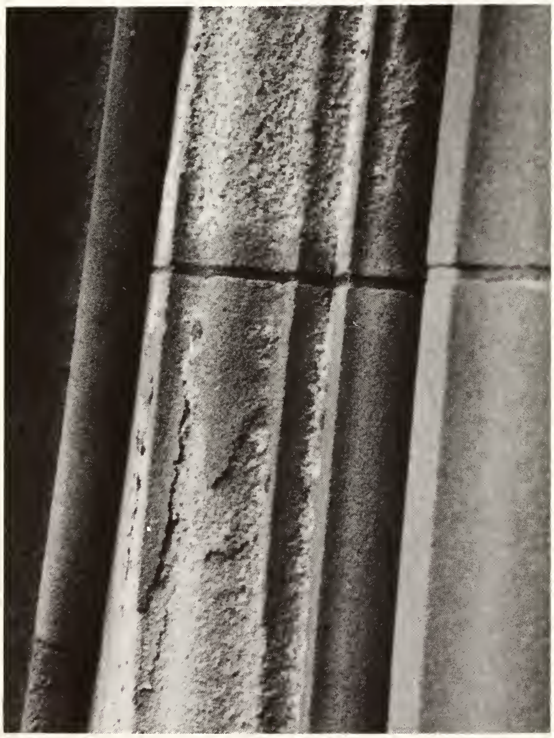

Fig. 2. Close up of efflorescence and damage

There are a number of possible sources of the sulfate in the deposits. These include the wet and dry deposition of marine sulfate, particulate sulfates (e.g. gypsum dusts from building activity) and sulfates and sulfur dioxide produced by the combustion of fossil fuels. It is also possible that the sulfates have formed from the oxidation of pyrite in the stone. However, this is unlikely as pyrite in the Hawkesbury sandstone is rare, occurring in areas where there are thick organic rich layers (Standard, 1961).

Variations in the isotopic composition of the sulfur in the sulfates can be used to indicate the source of the sulfur (Thode, 1991). Such variations are expressed as $\delta^{34}S$, the fractional differences in the isotopic ratios $^{34}S/^{32}S$ of samples relative to a standard (the Canyon Diablo troilite). Riley (1994) also reported that these values for the sulfur in the sulfates on Sydney's sandstone buildings ranged from +2.1 to +8.1‰ (Table 1). This range differs markedly from present-day marine sulfate which has a value of +21‰, and also differs from that of the sulfur in gypsum which has values ranging from +10 to +35‰ (Pilot, 1991), but is close to the values for the sulfur in the low-sulfur Permian coals of eastern Australia; the sulfur in these coals have values from -1.1 to +5.5‰ (Hunt and Smith, 1985). Smith (1992) has calculated that the sulfur emitted to the atmosphere as sulfur dioxide from coal combustion in New South Wales would have an average isotopic value of +4‰. A similar figure, +2‰ was calculated from the limited data available, for the sulfur released by the combustion of petroleum products. Overall, the sulfur emitted to the atmosphere in Sydney as a consequ-

Table 1 Isotopic Composition of Sulfates on Sydney's Sandstone Buildings

Buildings	$\delta^{34}S$ ‰ of sulfates
Australian Museum	+2.1, +3.7, +4.8
Challis House	+6.1, +8.1
Chief Secretary's Building	+3.9, +5.5
Customs House	+2.6
St Mary's Cathedral	+7.0
Town Hall	+5.9, +6.4
Great Hall, University of Sydney	+5.6

ence of the utilization of fossil fuels was estimated to have an average isotopic value of +3.6‰. This value was calculated from the tonnages of fuel used in the state, for the year, 1981-2. A similar value would apply to Sydney, although there would of course, be some variation with the amounts and origins of coal and oil used in the city over the years. The middle of the range for the sulfur in the sulfates on the city's sandstone buildings is +5‰.

Some fractionation of the sulfur isotopes does occur during the combustion of fossil fuels and subsequent deposition of the sulfates on the sandstones, particularly during the oxidation of emitted sulfur dioxide to sulfates. Buzek and Šrámek (1985) in a study of the deterioration of Prague's monuments reported that sulfate crusts have values approximately 2‰ greater than the present sulfur dioxide in that city's atmosphere. If the mechanisms involved in the formation and deposition of sulfates on Sydney's buildings are similar, then it is evident that the average isotopic value of the sulfur in the source would be less than +5‰, in the order of +3‰. There is little doubt that the sulfates are primarily derived from fossil fuel utilisation.

It has been a matter of some debate as to whether anthropogenic emissions of sulfur dioxide are a significant factor in the decay of Sydney sandstone buildings (Gibbons, pers. comm.). Certainly, in the northern hemisphere, where fuels containing high levels of sulfur have been or are utilized, there is significant stone degradation and this is directly attributable to attack by sulfur dioxide or sulfuric acid. It is apparent from the isotope measurements that to some extent, similar degradation has occurred in Sydney. Australia's indigenous fuels, both coal and crude oil are low in sulfur and presently, Sydney's atmosphere is low in sulfur dioxide; monitoring ceased in the centre of Sydney in 1987, when levels of total acid gases were well below WHO guidelines (SPCC, 1987). Unfortunately, there is no very early data on air pollution levels in Sydney, but as air pollution trends (Ferrari and Johnson, 1982) show a decline in dust deposition rates and concentrations of acid gases (primarily sulfur dioxide), it is reasonable to assume that levels of the traditional pollutants, smoke, dust and sulfur dioxide must have been higher than they are presently and it is appropriate to discuss briefly the historic sources of such pollution.

Historic Use of Fossil Fuels in Sydney

The compilation by Fraser (1983) has been used in assigning many of the relevant dates in the following brief summary of fossil fuels use in Sydney.

Coal was being used by 1797, only nine years after colonization by the British. Initially, its use was for domestic purposes. Industrial use accelerated, following the importation of the first steam engine to the colony in 1813. The historian, Bertie (1933) has described Watt's steam engine as the invention, "which caused the greatest change in the lives of the people of the world".

Interestingly, a somewhat jaundiced view of Watt's invention is taken by Elton (1989) in his novel, "Stark", in which the character, Sly Moorcock states "Ever since the first industrial revolution when James Watt boiled a kettle and invented acid rain, or whatever the hell happened, the natural, life-forming parameters of our world have been like an hour glass, getting thinner and thinner." Some poetic licence has been taken by Elton, although coal combustion does release sulfur dioxide and coal became increasingly important in Sydney, as industrialisation developed.

This was evident to Darwin who, when visiting Sydney in 1836 wrote:
"therefore so far as I can see, Australia must ultimately depend upon being the centre of commerce for the southern hemisphere, and perhaps on her future manufactories. Possessing coal, she always has the moving power at hand" (Darwin, 1839).

In the early 1830s, coal-fired steamers were replacing sailing vessels. By 1842, coal was being used to produce town gas. In 1855, the colony's first railway opened and coal-fired steam trains were run from the city. Within the city, steam trams ran from 1879 till 1900 when electrification commenced, following the completion of the city's first major public power station at White Bay. This was followed by the Pyrmont station, which commenced operation in 1904 to provide electricity to replace the gas lighting. Subsequently, all of Sydney's coal-fired power stations were located within a few kilometres of the city's centre and the last of the city's power stations, did not cease operation until 1984. Industrial activity was considerable within a few kilometres of the centre of Sydney. Paintings and photographs of early

Sydney often depict the city as one, in which there is a multitude of chimneys. The depiction by Hill in 1888 is of a city, which is "bright and clean, despite a prodigious number of smoke stacks" (Fitzgerald 1992). Photographs taken in the 1940s and 50s of areas such as Darling Harbour and Pyrmont graphically illustrate the industries and atmospheric pollution close to the centre of Sydney (Moore, 1993), (Fig. 3).

For many years coal was the major fuel source used in the city, but obviously oil became more important as the use of motor vehicles increased from the 1920s. Although Australia's indigenous oil is very low in the sulfur, almost all of the oil used in the country was imported until 1970, when production from Bass Strait commenced. Significant amounts of sulfur dioxide would have been released as a consequence of using imported oil. The elevated levels of sulfur dioxide in Sydney in the early 1970s were attributed to the use of imported oil (Ferrari and Johnson, 1982).

The Occurrence of Fogs in Sydney

An increase in industrialisation in cities and the resulting air pollution, particularly smoke and particulates is often associated with an increase in the occurrence of fogs. London provides an extreme example of a once very polluted city, which was also very foggy. The monograph by Brimblecombe (1987) contains a fascinating chapter on the occurrence of fogs in London, where a decrease in pollution has resulted in a marked decrease in the incidence of fogs (see also Brimblecombe, 1982). A recent study by Eggleston et al. (1992) on trends in air pollution in England also links the decline in atmospheric pollution to the decrease in fogs. In one of the cities studied, Lincoln where levels of smoke and sulfur dioxide have decreased significantly since the 1960s, so has the incidence of fogs. Coincidentally, the 900 year old Lincoln Cathedral which was one of the cathedrals that influenced the design of St Mary's, (O'Farrell, 1971) is also suffering damage, attributed to acid precipitation from past industrial activity in that city and from nearby power stations.

The scale of pollution in early London was, of course much greater than that of Sydney. However, the changing incidence of fogs in Sydney is worthy of comment. Data from 1955 onwards is readily available from the Bureau of Meteorology. The fog days per annum for the years 1955 to 1993 have been plotted in Fig. 4. There is a general decrease in the occurrences of fogs since the mid 70s. The average for the period of time is 8.7 fog days per annum. In the first two decades, there were 12 years with a greater than average number of fog days, whereas in the latter two decades, there were only 3 years in which this had occurred.

It is apparent that, in the past twenty years in Sydney, the incidence of fogs has decreased, as have the levels of the pollutants, dust and sulfur dioxide. In Sydney, fogs are commonly radiation fogs, forming when condensation occurs in the still air, as the ground cools of a night (Bureau of Meteorology, 1991). If particulate matter or aerosols of hygroscopic salts, such as sulfates are present at high concentrations in the atmosphere, these fogs form more readily. It is doubtful whether in the absence of early pollution data, records of fog occurrences would provide an adequate indication of changing pollution levels in the city, although earlier records may confirm the existence of an overall trend.

Fig. 3. Moore's photograph - Pyrmont c. 1948

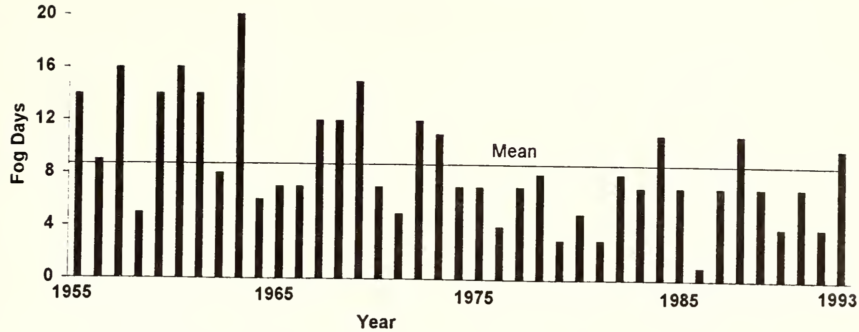

Fig. 4. Fog days in years 1955 - 1993

Conclusion

The deterioration of the stonework of St Mary's Cathedral exemplifies that of many historic sandstone buildings in Sydney. The deterioration is often associated with the deposition of sulfates, in which the sulfur has similar isotopic composition to that present in the eastern Australian coals, widely utilized within the city until quite recent times. It is apparent that the decay of the sandstone has been, in part, caused by its reaction with sulfur dioxide and sulfur acid produced from the combustion of coal and to some extent, oil and petroleum in the city.

The past utilization of coal also appears to have had some effect on the occurrence of fogs in Sydney. In recent times, these have decreased in frequency as the levels of particulate matter and sulfur dioxide have decreased in the atmosphere.

Acknowledgements

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ANNUAL DINNER ADDRESS and PRESENTATION of MEDALS,

ROYAL SOCIETY of NEW SOUTH WALES, TUESDAY 22nd MARCH 1994

His Excellency Rear Admiral Peter Sinclair, A.C., Governor of New South Wales

* Dr Armstrong Osborne - President Royal Society of NSW and Mrs Osborne
* Dr Swaine
* Distinguished Guests
* Members of Royal Society of NSW

Shirley and I are again delighted to be with Members of the Royal Society of New South Wales and their guests for this important occasion in the Society's Annual Calendar. I especially look forward to presenting shortly the Society's Awards to worthy recipients, in the knowledge that they will join a long list of distinguished Australians who have been so recognised over past decades.

The Royal Society of New South Wales can claim to be one of the oldest institutions in Australia. The Society traces its origins to the year 1821, incidentally, the same year that the Galvanometer and Electromagnet were invented, when, as a Philosophical Society, it boasted the membership of an eminent predecessor of mine, Governor Sir Thomas Brisbane, who, prior to his arrival in the colony, had been the President of the Royal Society of Edinburgh.

Governor Brisbane was not as is often claimed, Australia's first Astronomer - Captain Cook or Second Lieutenant William Dawes of the First Fleet would probably be accorded that honour. But Governor Brisbane surely played a major role in establishing the forerunner to this Society - The Philosophical Society.

In those days, New South Wales stretched right across to the present Western Australian Border, and from Cape York to Wilson's Promentary, making its area two-thirds of Australia, instead of its present one-tenth. In terms of population, however, New South Wales now has over six million inhabitants or nearly one hundred times its population in 1821.

Whilst the Society may not be as old as the First Bank (now Westpac) founded in 1817, it is older than the Sydney Morning Herald first published in 1831.

This is a fair comparison as both the `Herald' and the Society are in the business of publishing, with the Society's `Journal and Proceedings' bringing new ideas in science to many thousands of readers world wide.

An easy way to gain an appreciation of the Society's history is to take an opportunity tonight to examine the Society's leather-bound Visitor's Book, where the signatures of many significant scientists both past and present can be found.

Among those whose autograph appears is Australia's aviation pioneer Lawrence Hargrave who, exactly 100 years ago on the 12th November this year, achieved Australia's first flight using a machine heavier than air at Stanwell Park Beach, just south of Sydney. On that occasion he was assisted by one James Swaine, Grandfather of one of the Society's current Vice-Presidents.

In spite of building 36 experimental aircraft engines (of which most were powered by compressed air or steam - only three by petrol internal combustion), Hargrave was unable to construct an engine light and powerful enough to lift both itself and himself.

However, it was Hargrave who first introduced the essential principle of a successful aircraft wing, namely that a curved surface produces more lift than a flat one. Much of Hargrave's work was published in the `Journal and Proceedings' of the Society and many of his plans, models and machines, including a design for a jet engine, are still stored in Sydney.

Hargrave and the other signatories in the weighty leather-bound tome represent the History of the Society, one of a Generalist Scientific Society from which many more specialised groups, such as the Geological Society of Australia and the Institution of Engineers, have sprung over the years - but what of its future?

Science is becoming ever more specialised to the point where some are saying that "Scientists are finding out more and more about less and less, and that soon they will know everything about nothing".

A Society whose membership includes Physicists, Chemists, Engineers, Mathematicians, Medical Researchers, Geologists, Arthitects, Educators and even a Politician might therefore be seen today as somewhat unusual, and perhaps even a bit old fashioned.

But if we look at the areas where science impacts on Society today, we find that solutions rarely come from the application of a single scientific discipline, but from the work of multidisciplinary and interdisciplinary teams, which increasingly include specialists in Law and the Social Sciences.

James Barrie no doubt had his tongue in cheek when he wrote that `The only man with anything to say is the man of Science, and he can't say it!'

But the Royal Society of New South Wales does provide a forum where scientists can indeed say it - where scientists from a range of fields can meet, and whose Journal and Proceedings provides an avenue for publication of research which does not easily fit into the narrow scope of more specialised publications.

The Society's Monthly Meetings, for example the recent series on the `Sydney Environment', and its extremely important Summer Schools for Secondary Students, make science accessible and emphasise linkages between Science and Society and between the various disciplines of science themselves.

It is in bringing scientists together and in presenting a view of science as a whole to responsible members of our community, that the Royal Society of New South Wales has a significant role for the present and the future. In that I wish you well.

Thank you for your hospitality - and I now look forward to presenting on your behalf, the Society's Awards for 1993.

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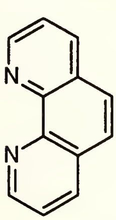
Chiral Discrimination Processes in Some Metal Chelate Systems of Biological Interest: Doctoral Thesis Abstract (Macquarie University)

Janice Rae Aldrich-Wright

This thesis reports on the design, synthesis and optical resolution of a set of chiral metal complexes which are intended to be of value for probing the comformational structures of DNA via intercalation. Optimisation of the molecular size of the parent diimine ligand was achieved by synthesis of several phen-based bidentate ligands, including the novel compound dpq, (dipyrido[6,7-d:2'3'-f]quinoxaline) and these bidentates then were incorporated into $[M(diimine)_3]^{n+}$ complexes. The effectiveness of the use of tetradentates as a means of overall shape control was investigated by synthesis of related $[M(tetradendate)(diimine)]^{n+}$complexes.



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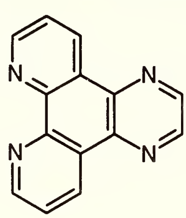
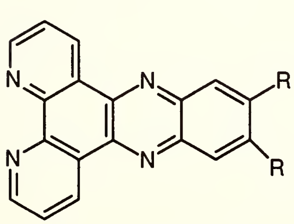


dpq



R = H = dppz
R = CH_3 = $dppzMe_2$

The crystal structure of one of these complexes, *cis*-β-$[(Ru(picenBz_2)(o\text{-}pda)](PF_6)_2$, was determined at room temperature. Crystal data: $C_{34}H_{38}N_6F_{12}P_2Ru$ is triclinic, space group P $\bar{1}$ (No.2), with a =10.129 b = 10.338, c = 19.587 Å, α = 104.42, β = 93.36, γ =92.00° and Z= 2. The structure was refined by block matrix least-squares methods to R = 0.075 for 3057 non-zero diffractometer data. Both PF_6 groups were subject to disordering with respect to their fluorine atom positions, and these have been interpreted in terms of partial occupancies. The X-ray structure, including observed torsion angles and consequent calculated coupling constants, is consistent with the NMR analysis.

Classical and chromatographic means of optical resolution of the complex products were investigated, with the aim of developing not only a method which would separate enantiomers but which also could act as a preliminary screening technique for structural probes of DNA. Resolutions using antimonyl(+)tartrate were successful for $[M(diimine)_3]^{n+}$ species when the diimine is phen or dpq. Racemic mixtures of $[Ru(bipyMe_2)_2(phen)]^{2+}$ and $[M(diimine)_3]^{n+}$ were eluted on Sephadex with enantiomeric enrichment

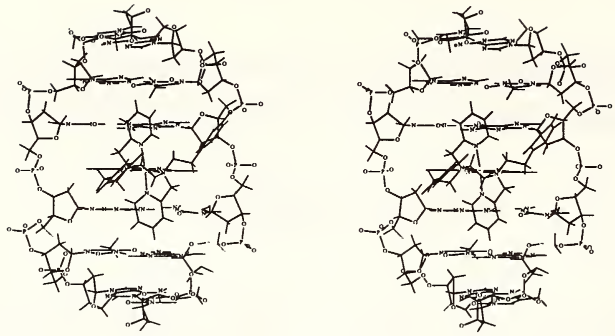


Figure 1 A computer generated stereoview of α-$[Ru(picenBz_2)(dpq)]^{2+}$complex, with dpq occupying the intercalation site of six base-pair DNA model.

of the leading and trailing fractions. The diastereomers of $[Ru(diimine)_2(aa)]^{n+}$ complexes, where the diimine is bipy or phen and aa is trp, N-Methyl-S-trp, G, asp, were resolved using μbondapak HPLC columns, eluted with an ion pairing reagent.

Chiral stationary phases were developed for HPLC applications although only one of these columns showed selectivity for the chiral metal complexes. A covalently-bound DNA stationary phase was developed and used to optically resolve $[Ru(dpq)_3]^{2+}$and $[Ru(phen)_3]^{2+}$, and confirmed that effective aromatic overlap does influence column retention times. Other immobilised-DNA stationary phases were examined, such as DNA-hydroxylapatite, cellulose-DNA column and DNA-paper. The DNA-paper proved to be an easy way of simultaneously comparing a number of metal complexes, and the R_f data correlated well with the aromatic area available for intercalation.

Computer modelling has been used extensively for the preparation of the illustrations throughout the thesis and, by adapting crystallographic data of analogous metal complexes, as a design aid in investigating the effects of structural variations on complementary fit and likely efficiency of DNA binding for the probe molecules developed (Fig 1).

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MSc Thesis Abstract:- Movement Behaviour and Structure of Groups of juvenile MULLET, *Mugil cephalus* (Linnaeus).

Stuart Fitzsimmons.

Movement behaviour and group structure of juvenile mullet, *Mugil cephalus* (Linnaeus), and obligate schooling species, was investigated for known focal individuals within small group sizes (blocks of two, three and four fish).

Plots of swimming patterns indicated two main types of movement behaviour - (a) inactive groups that covered short distances and executed few turns, and (b) active groups that covered larger distances and executed many turns. Mean swimming speeds (body -lengths/sec) and mean turning frequencies (turns/sec)both declined significantly with increasing group size, with significant differences between blocks of similar sized groups being attributed to individual variation. However, within blocks the movement behaviour of individuals was generally highly coordinated. As the size of the group increased, behavioural convergence mediated by the monitoring of companions rapidly masked individual variation and led to the characteristic uniformity of such associations.

In conjunction with mean swimming speeds, separation angles (degrees) were used to categorize groups into congregations (<0.2 BL/sec, non-polarized > 20°), shoals (>0.2 BL/sec, non-polarized >20°), and schools (>0.2 BL/sec, polarized <20°). Separation angles determined the level of polarization between individuals within groups, with polarization angles ranging from 0° (parallel orientation) to 90° (non-parallel orientation). Polarized groups of mullet were estimated to have separation angles of < 20° and non-polarized groups > 20°. Although these cut-off limits were arbitrary, groups within each category generally displayed movement behaviours quantitatively different from one another.

Polarization of individuals' headings and synchrony of their movements were generally dependent upon mean swimming speeds, with schooling behaviour generally exhibited more often by faster moving groups. As mean swimming speed decreased, groups tended to exhibit more shoaling and congregating behaviour. Focal pairs of fish within faster moving groups (>0.5 BL/sec) had significantly correlated swimming speeds and headings at lag of 0 - 1 seconds. As swimming speed decreased, lag time between correlated movements increased. In the slowest moving groups (<0.2 BL/sec), speed and heading of focal fish were not significantly correlated for lags between -5 to +5 seconds.

Distances between focal pairs (body lengths), and positional bearing (degrees) only significantly effected co-ordination of swimming speeds or headings in a small number of groups. This could be attributed to the fact that group structure did not vary significantly between blocks of similar size or for each group size. Mean interfish distance of the focal pairs varied from 0.49 to 2.1 body lengths (BL), regulated around a mean of ≈1 BL. The response fish in most instances swam at a mean position diagonally behind the focal fish, either to the left or right hand side.

A significant leader/follower relationship was observed in most groups, with the focal fish dominating the leadership for the duration of analysis. The duration of leadership did not significantly vary between groups of similar size or for each group size The duration of leadership of a single individual decreased significantly as mean swimming speeds, mean turning frequencies and separation angles increased, with group structure having no significant effect on duration of leadership.

Movement behaviour of group structure was analysed for four-fish groups within three treatments of varying physical attributes. In the tank with a structure present (clump of artificial weed), the focal pairs of individuals had mean swimming speeds significantly faster than those in the control tank and smaller tank. However, mean swimming speeds were not significantly different between groups within the smaller tank and the control tank. Groups within the smaller tank performed significantly more turns than control and structured tank groups, but mean distance travelled between turns was significantly lower. The separation angle of the focal pairs did not vary significantly between treatments or between blocks. In most blocks, mean separation angle of the focal pairs were lower compared to those of the overall group, which was attributed to the fish three and four having headings dissimilar to the focal fish. As for control groups, interfish distances and positional bearings did not significantly differ between treatments.

In summary, obligate schooling species, such as mullet, can exhibit consistent individual differences in behaviour which is considered to be the principal underlying source of variation between blocked pairs. Movement behaviour of individuals can be significantly influenced by the addition of only a single extra individual when group size is small. In nature, as small groups merge into larger associations, behavioural convergence becomes more broadly-based and the influence of particular individuals is less obvious. However, factors such as separation angle and group structure, interfish distance and positional bearing, were relatively fixed. Neither individual variation or group size had any significant effect on these parameters.

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DOCTORAL THESIS ABSTRACT : PERINATAL HYPOXIC-ISCHAEMIC ENCEPHALOPATHY: PATHOGENESIS and PHARMACOLOGICAL INTERVENTION.

William Kian Meng Tan

Perinatal hypoxic-ischaemic encephalopathy is associated with an increased risk of neurological deficits. Certain aspects of the pathogenesis of damage are still unclear. To address some of the hypotheses relating to the mechanisms of damage and recovery, chronically instrumented near-term fetal sheep were subjected to transient hypoxia-ischaemia; this procedure induces an encephalopathy showing characteristics similar to that seen in some asphyxiated term infants. Electrocorticographic (ECoG) activity was quantified with real-time spectral analysis. On-line cortical impedance was used to estimate changes in extracellular space that occur concomitantly with cytotoxic oedema and reflect cell membrane function. Histological outcome was assessed 72 hours after ischaemia.

It is not known whether postasphyxial seizures either extend damage or are an expression of existing damage. MK-801, an NMDA receptor antagonist and potent anticonvulsant (0.3 mg/kg), suppressed the epileptiform activity, delayed the onset of secondary oedema and reduced neuronal damage. These results suggest that NMDA mediated epileptiform activity that develops after a global hypoxic-ischaemic insult worsens neuronal outcome in the immature brain.

Hypoxia-ischaemia is associated with an increase in cerebral lactate levels and a decrease in tissue pH. It is not clear whether lactic acidosis worsens neuronal injury in the developing brain or is protective. Acutely induced lactic acidosis (fetal arterial lactate concentrations: 11.2 ± 1.0 mmol/l; ; pH:7.04 ± 0.06) superimposed on a 10-minute cerebral ischaemia delayed recovery of ECoG and accentuated hippocampal damage.

Treatment strategies against hypoxic-ischaemic injury in the perinatal period are limited. The effectiveness of GM1, a glycosphingolipid which is an endogenous component of plasma membrane, was evaluated. GM1 (30 mg/kg), started 2 hours before a severe insult, improved recovery of acute cortical oedema and ECoG activity and reduced neuronal loss without compromising arterial blood pressure or metabolic status.

Three 10-minute episodes of reversible cerebral ischaemia, repeated at 1 hour interval, can markedly sensitise the fetal brain to neuronal loss. The same dose of GM1 given immediately after the first insult counteracts this sensitisation and protects against subsequent insults through stabilisation of membrane function. These results demonstrate the potential of GM1 as a strategy to protect the CNS of distressed fetuses at risk of hypoxic-ischaemic injuries.

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MASTERS THESIS ABSTRACT

Intake of organochlorines from the breastmilk of Victorian women.

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Organochlorines have been distributed throughout the environment. Many organochlorines are pesticides and some are industrial pollutants. Due to their high lipophilicity, toxicity in particular animal species and ability to bioaccumulate in animals, the use of these chemicals has been restricted. Mobilisation of fat tissue by weight loss or breastfeeding allows stored organochlorines to re-enter the blood stream. Excretion of organochlorines in breastmilk is a significant way for women to reduce their body burden. Unfortunately, in the process breastmilk can transfer organochlorines from mother to child.

The purpose of this project was to estimate infants' daily intake of organochlorines from breastmilk and to trace the elimination patterns of these compounds from the mothers.

Each infant was test-weighed over twenty-four hours to provide an accurate milk intake. The entire content from one breast was collected at the midmorning feed. Three collections occurred for each mother at intervals of a month. The lipophilic material was extracted from the milk and the organochlorines were separated by gel permeation chromatography. The organochlorine extract was analysed by selected ion monitoring on a gas chromatograph-mass spectrometer (GC-MS).

The lipid content of milk varies dramatically and this factor influences the concentration of organochlorines in breastmilk. The determination of the levels of organochlorines present on a milk-fat basis accounts for changes in lipid composition. The amount of milk an infant drinks daily varies from mother to mother. To determine reliable intakes of organochlorines it is essential to measure the amount of milk consumed by each infant.

Residues of *p,p'*-DDE, *p,p'*-DDT, dieldrin, aldrin, α, β, γ, δ-HCH, HCB, oxychlordane, *trans*-nonachlor, heptachlor epoxide and PCBs were detected. There was widespread contamination of breastmilk with *p,p'*-DDT and its metabolite *p,p'*-DDE, HCB, PCBs, oxychlordane and HCHs, with *p,p'*-DDT and HCB being found in nearly all samples. A number of infants received daily intakes of *p,p'*-DDT, heptachlor epoxide, total chlordane, dieldrin and PCBs above the acceptable daily intakes (ADIs). Generally, the levels of organochlorines detected in the breastmilk represents no danger to the infant.

The main human source of organochlorines is probably foodstuffs. There was no significant difference between the concentrations of organochlorines found in breastmilk from the two regions studied. The use of termiticides in houses was not associated with the level of organochlorines found in breastmilk. Over the period of lactation a general downward trend in concentration of organochlorines was observed, with levels of *p,p'*-DDE decreasing significantly. The concentrations of *p,p'*-DDT and dieldrin in human milk have decreased in Victoria, whilst levels of HCB and PCBs have increased. The byproducts of some chlorinated industrial processes and the disposal of PCB-containing products are possibly increasing the environmental burden of these organochlorines.

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BIOGRAPHICAL MEMOIRS

JOHN ALLAN DULHUNTY - 1911-1994

John Dulhunty died in Queanbeyan on 7 April, 1994, in his eighty fourth year. A descendant of a family that pioneered inland New South Wales in the 1820s, and proud of his long Australian heritage, John was a legend in the Department of Geology and Geophysics at the University of Sydney, where he continued to work and enjoy life with his many University colleagues until his enforced move south in 1993. Son of John J. Dulhunty of Merriwa, John was born on 1 April, 1911.

He was sent by his father to Cranbrook School in Sydney, but preferred the country life and soon returned to the family property on the Cudgegong River. However he had gained something from his chemistry teacher, devising and building a still to provide fuel for running equipment in a shearing shed, using oil shale which he found cropping out in the river bank. Some years later he returned to Sydney, had some private tuition and matriculated to the University of Sydney where he graduated in 1938 with a Bachelor of Science degree with First Class Honours in Economic Geology. John's first paper, written while still an undergraduate, was, not surprisingly, on oil shale.

He was awarded the Deas Thompson Scholarship for Mineralogy in 1938, held a Linnean Macleay Fellowship from 1940 to 1944, and a Senior Commonwealth Research Fellowship from 1945 to 1949. His research culminated in the completion of his Doctor of Science thesis on the Classification and Origin of New South Wales torbanites in 1946.

In the period between 1934 and 1968 he produced more than thirty papers on the fossil fuels. His experimental work on the formation of coal, and the various metamorphic processes which caused changes in rank of coal,were carried out in the Department of Geology, in equipment designed and built by himself and colleagues with whatever material came to hand. The classic papers were published particularly in the early years of World War II, in Australian journals (particularly the Royal and Linnean Societies of New South Wales), so did not reach the wider international readership till some years later. However John's expertise was certainly appreciated by the Australian authorities, and during the war he was involved in considerable practical, as well as fundamental, research, including the production of methane gas from the Balmain Colliery shaft, and distillation of oil from various oil shale deposits. Immediately following the cessation of hostilities in Europe John was sent as a member of a British delegation to Germany to examine its coal research facilities. About this time he also became involved in a related, but neglected field of research, palynogy, in which he published several important basic Australian papers (including one with his wife Roma {née Johnson}, who he had married on 17 May, 1941). This work was later taken up by his research students.

His love for the landscape is illustrated by the many papers he wrote on "physiography". These concentrated, at first, on the region where he grew up, the northwestern edge of the Sydney Basin, and include his Clarke Memorial Lecture to the Society in 1964, where he dealt with the Permian glaciation that played such an important part in shaping that landscape. In the 1960s John saw the opportunity to refine some of his physiographic and stratigraphic work by becoming involved in dating the enigmatic igneous rocks on the northwestern edge of the Sydney Basin. This successful work saw him sort out out a number of long-term problems, in collaboration with other scholars, his most recent paper on this topic appearing in July 1992.

In 1951 he was appointed to a Senior Lectureship in Geology in the University of Sydney, and in 1957 promoted to Reader. He was Acting Head of the Department of Geology and Geophysics on three occasions, during 1955, 1961 (when the Department moved to the present Edgeworth David Building) and again in 1967.

After his official retirement in 1973, John undertook a most ambitious programme of research. With his wife Roma he carried out a series of arduous expeditions to Lake Eyre (which they had first visited in 1950), to document thc major sequence of wet-dry cycles of sedimentological and geomorphological change in the lake. This resulted in a number of important research papers to scientific journals, especially those of the Royal Societies of South Australia and New South Wales. Many of John's fine colour photos also adorned the three books written by Roma about their adventures in the Lake Eyre region. Characteristically, when major publishers weren't interested and their original publisher had ceased operation John and Roma published the final volume themselves in 1986.

John had a long, faithful and active association with the local scientific bodies, publishing most of his work in the Royal and Linnean Societies of New South Wales, and then in the Geological Society of Australia's journals. He was President of the Royal Society in 1947, and acted as councillor and advisor on publications at various times. He received the Society's medal for service to Science in 1970. In 1976 the Society published the proceedings of a 75th celebratory Conference held in the Department of Geology and Geophysics. The Edgeworth David Society symposium in 1992, appropriately on Australian Landscapes and economic implications, also recorded the appreciation of his colleagues for his scientific work. John was President of the Geological Society in 1964-65, after a stint as Chairman of the New South Wales Division. In all these activities he worked assiduously for the benefit of the science he loved and for the members of these Societies.

In the late 1960s John had a long bout of sickness, which he fought off with characteristic toughness, continuing to teach and research under difficult conditions. In recent years the onset of emphysima made the climbing of hills difficult, and the regretful abandonment of fieldwork. This coincided with the sudden decline in the health of his wife, Roma and, sadly, her death late in 1990.

Of a total of eighty six papers and articles, more than thirty appeared in Society publications.

Generations of students benefited from contact with John Dulhunty. His unfailing courtesy (students were addressed from their first lecture as "ladies and gentlemen"), his stimulating and entertaining lectures, his wise counsel and administrative expertise gained him affection, respect and admiration.

John was not without his eccentricities, and I suspect he played up to expectations at times. A great love was a 1930s Rolls Royce that he nursed with great care. But as a colleague recently remarked, it was the only Rolls that he had ever seen the owner touching up with pot and paint brush. However, with John's practical skills you would probably never notice!

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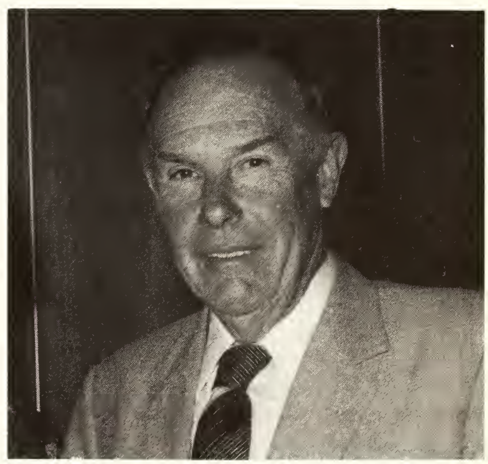
D.F.B.



Kenneth John Brown, 1925 - 1994

Ken Brown passed away on the 13th July 1994. Ken was born at Campsie on the 9th of January 1925 and received his secondary education at Sydney Technical High School. He went on to tertiary education at Sydney Technical College, where, on 31st December 1947, he was awarded Associateship of the College having completed the Diploma Course in Industrial Chemistry and Chemical Engineering. The following year, on the 29th of November 1948, he was admitted as an Associate of the Royal Australian Chemical Institute. Ten years later, on the 31st of December 1958, he was awarded the Certificate of the

Management Certificate Course at the Sydney Technical College. In 1955 Ken had been appointed a Research Chemist with the firm of Johnson & Johnson, with which company he remained for the next 26 years, becoming Supervisor of the Cotton Department.

A few years before this appointment he was married to Dorothy Anthon from Moss Vale. Both Dorothy and Ken had a great interest in craftsmanship relating to jewellery: Dorothy developed, amongst many other accomplishments, a great skill as a goldsmith and silversmith, whilst, as a complement to this, Ken became very well versed in the science & practice of gemmology. In November 1966 he passed the examination in the Theory and Practice of Gemmology and was awarded the Diploma of the Gemmological Association of Australia. Just three years later, on the 19th November 1969, he was awarded the Diploma of the Gemmological Association of Great Britain, whose examination he had taken in the previous June.

Ken had many other interests, including cricket and atheletics in his younger days, later becoming an amateur specialist and enthusiast on Peugot cars. He and Dorothy travelled extensively both in Australia and overseas, an activity which included the expert appreciation and collection of gemstones and jewellery. Ken and Dorothy resided in Gymea, NSW.

Ken joined the Royal Society of New South Wales in 1963.

G.W.K.F.

Robert Mortimer Gascoigne, 1918 - 1994

Dr. Robert Mortimer Gascoigne died in April, 1994. He was born on the 16th March, 1918 and spent his early years in Wyong, New South Wales. He joined the Royal Society of New South Wales as a student member in 1939 and became a Life Member in 1978. He published four papers in the Journal and Proceedings. After graduating BSc and MSc in organic chemistry at the University of Sydney, Bob Gascoigne volunteered for war service and was sent to New Guinea. His early research was on anti-malarial drugs, a subject which was related to his stay in New Guinea. Later he was awarded an ICI Fellowship to do research at the University of Liverpool where he gained a PhD. He returned to a lectureship at the Sydney Technical College and later moved to Kensington as a member of the staff of the Chemistry Department at the University of New South Wales. His main research was on natural products related to Australian plants, including detailed studies of tetracyclic triterpenses. Although his scientific work was highly regarded, Bob had special interests in the history and philosophy of science and he transferred to that department, where he remained until his retirement in 1977 as a Senior Lecturer.

Bob Gascoigne was one of a special band of scientists, albeit few in number, who have worked successfully in the interdisciplinary field of science and philosophy. Amongst his most prestigious publications, the recently published "The History of the Creation" is surely his magnum opus. In this book he shows that our contemporary knowledge of the history of the universe and of life is highly-consistent with a theologically-informed historical conception of the fundamental Judeo-Christian doctrine of creation. He said that this book "deals with, or touches upon-some might say, dabbles in-almost every main branch of natural science as well as anthropology, psychology, philosophy and theology, not to mention some excursions into the history of science". Surely there is a need for a book concerning modern scientific knowledge about evolution in the context of a historical understanding of the fundamental Judeo-Christian doctrine of creation.

In keeping with his usual humility, Bob Gascoigne stated that "I hope that this attempt will stimulate or provoke others to do better". Bob was a strong family man and his widow, two sons, three daughters and eight grandchildren will miss him greatly. He achieved many of the aims of the Royal Society of New South Wales by marrying various branches of science with history and philosophy. He was a thinker with a strong sense of integrity and wisdom. Vale Bob Gascoigne, scholar and scientist.

Books published by Dr. R.M. Gascoigne:

Historical Catalogue of Scientists and Scientific Books from the Earliest Times to the Close of the 19th Century. 1984, 1174 pp.

A Historical Catalogue of Scientific Periodicals 1665-1900 with a Survey of their Development. 1985, 205 pp.

A Chronology of the History of Science 1450 to 1900. 1987, 585 pp.

The History of the Creation. 1993, 326 pp.

D.J.S.

Phyllis Margaret Rountree

On the 27th July last Australia lost one of its great bacteriologists, Dr. Phyllis Margaret Rountree, who died at the age of 83. She was born at Hamilton, Victoria, and had a highly successful career in science at Melbourne University, leading to the degree of DSc. She joined the Waite Research Institute in Adelaide, originally intending to follow agricultural science, but soon was attracted to the Walter and Eliza Hall Institute in Melbourne and from there went to the School of Hygiene in London, having developed an interest in bacteriology. There she achieved a Diploma in Bacteriology. After war service in England and Australia she was attracted in 1994 to a research position at the Royal Prince Alfred Hospital, Sydney, where she quickly established her international reputation by primary research on staphylococcal bacteriophages. The University of Sydney conferred on her an honorary Doctorate of Science for this work. She retired in 1971 and continued to live in Paddington, Sydney. She joined this Society in 1945, and served on the Council in 1957-58, later declining an offer of nomination as president.

Beverly Cortis-Jones

Beverly Cortis-Jones, MSc (Syd), of Mt. Keira Wollongong, passed away on 12 June, 1994. He became a member of the Society in 1940. A research chemist, he worked with a London Hospital group in the late 1940s on hormone studies, and joining the Colonial Sugar Refining Company in Sydney, became deeply involved in sugar-cane technology. He achieved patents for a type of salicylic acid (1952, jointly with a late eminent member of the Society, Dr Richard Bosworth), purification of cane-sugar syrups (1966) and retardation of colour development in raw sugar (1970). He was 81 years of age.

Simon James Prokhovnik

Simon James Prokhovnik, BA, MSc(Melb), of Birchgrove, Sydney, passed away on 20 June 1994. A member of the Society since 1956, he contributed four papers to the Journal and Proceedings. His special field was relativity, and for many years he was on the academic staff of the School of Mathematics at the University of New South Wales. His deeply thoughtful and engagingly quiet manner will be missed by many friends.

Sir Frederick White

With great regret we record the passing of Sir Frederick White, KBE, FAA, FRS. He was elected an Honorary Member of the Society in 1973 and during his residency in Canberra took an active interest in the Society's affairs. Born in New Zealand, he quickly showed strong aptitude for physics and graduated MSc from Victoria University College, Wellington and PhD from Cambridge University, England. He lectured in physics at King's College, London from 1931 to 1936 (publishing a standard work of the time on Electromagnetic Waves), and returned to New Zealand as professor of physics at Canterbury University College, Christchurch from 1937 to 1942. During 1941 he also acted as chairman of the Radiophysics Advisory Board and was seconded to the Australian Council of Scientific and Industrial Research. He crossed the Tasman Sea permanently in 1942 to take up the position of chief of the Division of Radiophysics of the CSIR, holding this post during the remainder of the Second World War in a time of intensive work on radar and allied projects. From 1949 to 1957 he was Chief Executive Officer, from 1957 to 1959 he was Deputy Chairman, and from 1959 to 1970 he was Chairman of the CSIRO. This last period was one of tremendous growth in the Organisation when it established its international scientific status. He was created a Knight Commander of the British Empire in 1962, was elected FRS in 1966 and FAA in 1960, as well as receiving many other honours. In recent years he retired from Canberra to Brighton, Victoria. Sir Frederick died on 17 August, 1944 aged 89 years.

Journal and Proceedings, Royal Society of New South Wales, Vol.127, pp 169-170, 1994
ISSN 0035-9173/020169- 02 $4.oo/1

INDEX TO VOLUME 127

Abstract of Proceedings, 1994, 73

Abstracts of Theses
ALDRICH-WRIGHT, J.R., 155
BAXTER, Rohan A., 63
BILLS, Peter J.. 65
TAN, William Kian Meng, 158
FITZSIMMONS, Stuart, 157
KAYNAK, Akif, 62
PARKINSON, Murray L., 67
PICKERING, Catherine M., 61
QUINSEY, P.M., 159
ROBERTS, Maureen B., 64
WOODWARD, Roslyn, 69
ZHU, Jin., 66

Annual Dinner 22nd March 1994
Address by Patron of the Royal Society of NSW His Excellency Rear-Admiral Peter Sinclair A.C. Governor of New South Wales, 153

Awards, citations, 80

Barker, J.S.F., From *Buzzatti* to Buffaloes Excursions into Genetic Variation. 3rd Walter Poggendorff Memorial Lecture, 1993, 23

Bibliography of the Reverend W.B. Clarke (1798 - 1878) "Father of the Australian Geology", Michael K. Organ, 85

Biographical Memoirs, 82

Biotechnology
Genetic Variation, 23

Breccia Filled Diatreme in Permian Illawarra Coal Measures and Triassic Strata, Kandos, New South Wales, Dove, Andrew and Lee, Graham, 39

Brittle Deformation of the Bathurst Batholith: A coeval behaviour with megakinking in the Lachlan Fold Belt, southeastern Australia. Kazuo Kasaka, 135

Brown, Kenneth John, Obituary, 165

Building
Cement Stabilised Earth Bricks, 33

Carrington, Richard, Obituary, 83

Caves, Cement, Bats and Tourists: Karst Science and Limestone Resource Management in Australia, R.A.L. Osborne, Presidential Address 1994, 1

Cement stabilised pressed Earth Bricks with low cement contents. Strength of, K.A. Heathcote and R. Piper, 33

Chappell, B.W., Lachlan and New England:- Fold Belts of Contrasting Magmatic and Tectonic Development. 47th Clarke Memorial Lecture, 1993, 47

Clarke Medal 1993, 80

Clarke Memorial Lecture, 1993, 47

Clarke, W.B. (1798 - 1878). Bibliography of the Reverand, Michael K. Organ, 85

Contents Vol. 127 1/2 and 3/4,

Council Report 1993 - 1994, 71

Curtis-Jones, Beverly, Obituary, 167

Davies, George Frederick, Obituary, 82

Dove, Andrew and Lee, Graham, Breccia Filled Diatreme in Permian Illawarra Coal Measures and Triassic Strata, Kandos, N.S.W., 39

Dulhunty, John Allan, Obituary, 161

Edgeworth David Medal 1993, 80

Financial Statement 1993, 75

Fogs, Fossil Fuels and the Fall from Grace of St. Mary's Purgatory Stone. Kenneth W. Riley, 147

From *Buzzattii* to Buffaloes - Excursion into Genetic Variation, J.S.F. Barker, 3rd Walter Poggendorff Memorial Lecture, 1993, 23

Gascoigne, Robert Mortimer, Obituary, 166

Geology
Bibliography of the Rev. W.B. Clarke, 85
Brittle Deformation, Bathurst Batholith, 135
Degeneration of Sandstone stone work, 147
Diatreme, Kandos NSW, 39
Kröhnkite, Broken Hill NSW, 31
Lachlan and New England, Magmatic Development, 47
Limestone, 1

Governor of New South Wales, and Patron of the Society, His Excellency Rear-Admiral Peter Sinclair, AC Address, Annual Dinner March 1994, 153

Grigg, Gordon C., Clarke Medal 1993, 80

Heathcote, K.A. and Piper, R., Strength of Cement Stabilised Pressed Earth Bricks with low Cement Contents, 33

Kosaka, Kazuo, Brittle Deformation of the Bathurst Batholith:- A coeval behaviour with megakinking in the Lachlan Fold Belt, southeastern Australia, 135

Lachlan and New England:- Fold Belts of Contrasting Magmatic and Tectonic Development. 47th Clarke Memorial Lecture, 1993, 47

Lawrence, L.J. Stocksick, C.M. and Williams, P.A., An Occurrance of Kröhnkite at Broken Hill, NSW, 31

Lee, Graham, Dove, Andrew and, Breccia Filled Diatreme in Permian Illawarra Coal Measures and Triassic Strata, Kandos, NSW, 39

New South Wales
- Brittle Deformation, Bathurst Batholith, 135
- Degeneration of Sandstone Stonework, 147
- Diatreme, Kandos NSW, 39
- Kröhnkite, Broken Hill, NSW, 31
- Lachlan and New England, Magmatic Development, 47
- Limestone, 1

Organ, Michael K., Bibliography of the Reverend W.B. Clarke (1798 - 1878). "Father of Australian Geology", 85

Osborne, R.A.L., Caves, Cement, Bats and Tourists:- Karst Science and Limestone Resource Management in Australia. Presidential Address 1994, 1

Piper, R., Heathcote, K.A. and, Strength of Cement Stabilised Pressed Earth Bricks with Low Cement Contents, 33

Poggendorff Memorial Lecture 1993, 23

Presidential Address 1994, 1

Prokownik, Simon James Obituary, 167

Riley, Kenneth W., Fogs, Fossil Fuels and the Fall from Grace of St. Mary's Purgatory Stone, 147

Rowntree, Phyllis Margaret, Obituary, 167

Royale, Harold George, The Royal Society of New South Wales Medal 1993, 81

Royal Society of New South Wales Medal, 1993, 81

Skerritt, John Howard, Edgeworth David Medal, 1993, 80

Stocksiek, C.M. and Williams, P.A.. Lawrence, L.J., An Occurrance of Kröhnkite at Broken Hill, N.S.W., 31

Strength of Cement Stabilised Pressed Earth Bricks with Low Cement Contents, Heathcote, K.A. and Piper, R., 33

Williams, P.A.. Lawrence, L.J., Stocksiek, C.M. and, An Occurrence of Kronkite at Broken Hill, N.S.W., 31

White, Sir Frederick, Obituary, 167

JOURNAL AND PROCEEDINGS

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CONTENTS

VOLUME 127,

Parts 1 and 2

OSBORNE, R.A.L.
Caves, Cement, Bats and Tourists: Karst Science and Limestone Resource Management in Australia. (Presidential Address 1994) 1

BARKER, J.S.F.
From *Buzzatti* to Buffaloes - Excursions into Genetic Variation (3rd Walter Poggendorff Memorial Lecture, 1993). 23

LAWRENCE, L.J.,STOCKSIEK, C.M. and WILLIAMS, P.A.
An Occurrence of Kröhnkite at Broken Hill, N.S.W. 31

HEATHCOTE, K.A. and PIPER R.
Strength of Cement Stabilised Pressed Earth Bricks with Low Cement Contents 33

DOVE, Andrew and LEE, Graham
Breccia Filled Diatreme in Permian Illawarra Coal Measures and Triassic Strate, Kandos, New South Wales 39

CHAPPELL, B.W.,
Lachlan and New England: Fold Belts of Contrasting Magmatic and tectonic Development (47th Clarke Memorial Lecture, 1993). 47

ABSTRACTS OF THESES:-

PICKERING, Catherine M.: Reproductive Ecology of Five Species of Australian Alpine *Ranunculus*. 61

KAYNAK, Akif: A Study of Conducting Polyrrole Films in the Microwave Region 62

BAXTER, Rohan A.: Representation Issues in Genetic Algorithm Function Optimization 63

ROBERTS, Maureen B.: The Diamond Path: A Study of Individuation in the Works of John Keats. 64

BILLS, Peter J.: Barotropic Depth-Averaged and Three-Dimensional Tidal Programs For Shallow Seas 65

ZHU, Jin: Tannin Toxicity Studies in Mice and Sheep 66

PARKINSON, Murray L. Multi-Frequency MF/Lower HF Ocean Radar Studies of Wind-Wave Trasients 67

WOODWARD, Roslyn 'It's so Strange when you stay Sick': The Challenge of Chronic Fatigue Syndrome 69

COUNCIL REPORT, 1993-1994
Report 71
Abstract of Proceedings 73
Summer School Photo 74
Financial Statement 75
Awards 80
Biographic Memoirs 82

Date of Publication:
June 1994

Parts 3 and 4

ORGAN, M.K.
Bibliography of the Reverend W.B. Clarke (1798 - 1878) "Father of Australian Geology" 85

KOSAKA, Kazuo
Brittle Deformation of the Bathurst Batholith: A coeval behaviour with megakinking in the Lachlan Fold Belt, Southeastern Australia 135

RILEY, Kenneth W.
Fogs, Fossil Fuels and the Fall from Grace of St. Mary's Purgatory Stone 147

ADDRESS by HIS EXCELLENCY REAR-ADMIRAL PETER SINCLAIR, A.C.,
Governor of New South Wales, Annual Dinner 1994 153

ABSTRACTS OF THESES:-

ALDRICH-WRIGHT, J.R.: Chiral Discrimination Processes in some Metal Chelate Systems of Biological Interest 155

FITZSIMMONS, Stuart: Movement Behaviour and Structure of Groups of juvenile Mullet, *Mugil cephalus* (Linnaeus) 157

TAN, William Kian Meng: Perinatal Hypoxic-Ischaemic Encephalopathy: Pathogenesis and Pharmacological Intervention 158

QUINSEY, P.M.: Intake of Organochlorines from the breast milk of Victorian Women 159

BIOGRAPHICAL MEMOIRS 161

INDEX to VOLUME 127 169

DATE of PUBLICATION:
Vol. 127 Parts 3-4: December 1994

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CONTENTS

VOLUME 127, Parts 3 and 4.

ORGAN, M.K.
Bibliography of the Reverend W.B. Clarke (1798-1878) "Father of Australian Geology" 85

KOSAKA, Kazuo
Brittle Deformation of the Bathurst Batholith: A coeval behaviour with megakinking in the Lachlan Fold Belt, Southeastern Australia 135

RILEY, Kenneth W.
Fogs, Fossil Fuels and the Fall from Grace of St. Mary's Purgatory Stone 147

ADDRESS by HIS EXCELLENCY REAR-ADMIRAL PETER SINCLAIR, AC, Governor of New South Wales, Annual Dinner 1994 153

ABSTRACTS OF THESES:-

ALDRICH-WRIGHT, J.R.: Chiral Discrimination Processes in some Metal Chelate Systems of Biological Interest 155

FITZSIMMONS, Stuart: Movement Behaviour and Structure of Groups of juvenile Mullet, *Mugil cephalus* (Linnaeus) 157

TAN, William Kian Meng: Perinatal Hypoxic-Ischaemic Encephalopathy: Pathogenesis and Pharmacological Intervention 158

QUINSEY, P.M.: Intake of Organochlorines from the breast milk of Victorian Women 159

BIOGRAPHICAL MEMOIRS 161

INDEX to VOLUME 127 169

DATE of PUBLICATION:
Vol. 127 Parts 3-4: December 1994