JOURNAL AND PROCEEDINGS

OF THE

ROYAL SOCIETY
OF NEW SOUTH WALES

VOL.
91

PARTS
I - IV

1957

Edited by the Honorary Editorial Secretary

PUBLISHED BY THE SOCIETY, SCIENCE HOUSE
GLOUCESTER AND ESSEX STREETS, SYDNEY

Issued as a complete volume April 23, 1958.

Royal Society of New South Wales

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* Published October 23, 1957.
† Published December 11, 1957.

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[*] Published February 27, 1958.

[†] Published April 23, 1958.

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Royal Society of New South Wales

REPORT OF THE COUNCIL FOR THE YEAR ENDED 31st MARCH, 1957.
PRESENTED AT THE ANNUAL AND GENERAL MONTHLY MEETING OF THE SOCIETY, 3RD APRIL, 1957, IN ACCORDANCE WITH RULE XXVI.

At the end of the period under review the membership of the Society stood at 343. Twelve new members were elected during the year, but five members were lost by resignation and three names were removed from the list of members under Rule XVIII. In addition two persons were admitted as associates, these being the first in this category.

By the death of Dr. Walter Fitzmaurice Burfitt on 1st June, 1956, the Society lost its oldest member. He had been a member since 1898, and was one of the greatest benefactors of the Society. His munificence and foresight made possible the establishment of the Walter Burfitt Prize awarded by this Society, a prize which is now Australia's highest award for pure and applied research.

It is with regret that we announce also the death of Robert Desider Louis Frederick on 20th August, 1956, a member since 1943.

Nine monthly meetings were held. Details of these meetings will appear in the fourth part of Volume 90 of the *Journal and Proceedings.* The members of Council wish to express their sincere thanks to the 19 speakers at the symposia and also to the members who read their papers at the December meeting.

Annual Social Function.—Due to the incidence of the A.N.Z.A.A.S. meeting and other meetings consequent, it was found impossible to choose a suitable date for the annual social function prior to the annual meeting. The retiring Council recommends to the incoming Council that this function should be held during the year.

Awards.—The Walter Burfitt Prize, 1956, for outstanding publications in pure and applied science over the last six years was awarded to Professor J. C. Eccles, F.R.S., for his contributions to neurophysiology.

The Clarke Medal for 1957 was awarded to Miss Irene Crespin for distinguished contributions in the field of geology.

The Society's Medal, 1956, which represents the Society's appreciation of service not only to pure science but to the welfare of the Society itself, was awarded to Dr. W. R. Browne.

The James Cook Medal for 1956 was awarded to Sir Ian Clunies Ross, in recognition of his outstanding contributions to the organization of science in Australia.

The Archibald D. Olle Prize for the best original research paper by a member of the Society published in Volume 89 of the *Journal and Proceedings* was awarded to Dr. R. L. Stanton for his paper entitled " Palæozoic Rocks in the Wiseman's Creek-Burraga Area, N.S.W." This was the first occasion on which this award has been made.

The Edgeworth David Medal. There was no award made for 1956.

Liversidge Research Lecture.—The Liversidge Research Lecture, 1956, was delivered by Professor G. M. Badger on 12th July. The title of the lecture was " Recent Advances in the Chemistry of Aromatic Compounds ", and it attracted an excellent audience in the Department of Chemistry at the University of Sydney on a wet and unpleasant winter night.

Finance.—The financial position of the Society is basically sound, although the audit of the current books of account showed a slight excess of expenditure over income (£57 2s. 5d.) for the year.

The Society's share of the profits from Science House during the year was £822 1s. 9d.

The Society has again received a grant of £500 from the Government of New South Wales. The Government's continued interest in the work of the Society is much appreciated.

The Council has given serious consideration to the financial condition of the Society. Since the cost of administration has increased at a much higher rate than its income, several measures of economy have been taken, the effects of which should be apparent in the next balance sheet. Transfer of the Society's office from the ground floor to the library on the first floor of Science House not only reduces our expenses but allows visiting members to become acquainted with the extent of the library.

Rather than make a further increase in the annual subscription, Council decided to follow the lead of almost all other societies and to cease issuing the *Journal and Proceedings* as a bound volume. Members, as well as libraries, will receive the quarterly parts immediately after publication.

General.—The Council held eleven ordinary meetings. The attendance of members of Council was as follows : Mr. McCarthy, 10 ; Dr. Bosworth, 8 ; Dr. Ida Browne, 11 ; Dr. Lemberg, 8 ; Dr. Magee (on leave for two meetings), 6 ; Mr. Griffith, 11 ; Mr. Hanlon, 9 ; Mr. Donegan, 10 ; Rev. Burke-Gaffney, 11 ; Dr. Booker, 7 ; Dr. Dulhunty, 8 ; Dr. Dwyer, 4 ; Mr. Fletcher, 5 ; Mr. Harper, 10 ; Mr. Higgs, 2 ; Mr. Proud, 4 ; Prof. Taylor, 9 ; Mr. Wood, 10.

The Society was represented on the Science House Management Committee by Mr. H. A. J. Donegan and Dr. R. C. L. Bosworth ; Mr. F. R. Morrison and Mr. J. S. Proud were substitute representatives.

The President represented the Royal Society of New South Wales at the commemoration of the landing of Captain Cook at Kurnell and placed a wreath on the Banks Memorial Monument.

The President also acted as the Society's delegate at the meeting of A.N.Z.A.A.S. held at Dunedin, New Zealand, from 16th January, 1957, to 23rd January, 1957.

The President, accompanied by the Honorary Secretary, waited on His Excellency the Governor of New South Wales on 11th June. A report was given to His Excellency on the activities of the Society during the past year.

Dr. M. R. Lemberg, F.R.S., represented the Society at the opening of an exhibition of " Isotopes for Industry " on 29th January, 1957.

Section of Geology.—Mr. F. N. Hanlon was Chairman and Dr. L. J. Lawrence was Honorary Secretary. This Section met five times during the year on alternate months with the Geological Society of Australia (N.S.W. Division). The average attendance was 19.

The Library.—The amount of £120 1s. 11d. was expended on the purchase of periodicals, and an amount of £75 has been spent on binding journals in the library.

Exchange of publications is maintained with 383 societies and institutions.

For the twelve months ended 28th February the number of accessions to the library was 2,178.

To conserve space in the library, the Council decided to sell some of the duplicate copies of periodicals and some of the out-of-date engineering and medical periodicals not currently received The amount received for these was £749 8s. 6d.

The removal of the office to the first floor and the resignation of the Assistant Librarian, Mrs. E. P. Wilson, have caused some dislocation in the library services. This should soon be remedied with the appointment of a new Assistant Librarian.

Among the institutions which made use of the library through the inter-library loan scheme were : C.S.I.R.O.—Library, Canberra, and Head Office, Melbourne ; Division of Plant Industry, Canberra ; Division of Industrial Chemistry, Melbourne ; Plant and Soils Laboratory, Brisbane ; Dairy Research Section, Highett, Victoria ; Coal Research Station ; McMaster Animal Health Laboratory ; Sheep Biology Laboratory ; Division of Food Preservation ; Radio Research Board ; Division of Wool Textiles ; National Standards Laboratory : Forestry Commission of New South Wales, Division of Wood Technology ; Department of Agriculture ; Bureau of Mineral Resources ; Royal Society of New Zealand ; Cumberland County Council ; Ministry of Civil Aviation ; Collina Corporation ; Electricity Commission ; Snowy Mountains Hydro-Electric Authority ; Department of Public Health ; Sydney Hospital ; Royal North Shore Hospital ; Alfred Hospital, Melbourne ; Colonial Sugar Refining Co. Ltd. ; Waite Agricultural Research Institute ; South Australian Museum ; Sydney Technical College ; Wollongong Technical College ; N.S.W. University of Technology ; University of Sydney ; University of New England ; University of Queensland ; University of Melbourne ; Australian National University.

F. D. McCARTHY,
President.

THE ROYAL SOCIETY OF NEW SOUTH WALES.

BALANCE SHEET AS AT 28th FEBRUARY, 1957.

LIABILITIES.

1956. £		£	s.	d.	£	s.	d.
85	Australia and New Zealand Bank Ltd.—Overdraft	—			—		
18	Subscriptions Paid in Advance				27	13	4
143	Life Members' Subscription—Amount carried forward				205	19	0
	Trust and Monograph Capital Funds (detailed below)—						
	Clarke Memorial	1,876	0	6			
	Walter Burfitt Prize	1,143	14	2			
	Liversidge Bequest	686	16	3			
	Monograph Capital Fund	3,956	10	8			
	Olle Bequest	77	14	1			
7,641					7,740	15	8
23,653	ACCUMULATED FUNDS				23,528	11	1
	Contingent Liability (in connection with Perpetual Lease.)						
£31,540					£31,502	19	1

ASSETS.

1956. £		£	s.	d.	£	s.	d.
407	Cash at Bank and in Hand				385	12	0
	Investments—						
	Commonwealth Bonds and Inscribed Stock—at Face Value—held for :						
	Clarke Memorial Fund	1,800	0	0			
	Walter Burfitt Prize Fund	1,000	0	0			
	Liversidge Bequest	700	0	0			
	Monograph Capital Fund	3,000	0	0			
	General Purposes	2,460	0	0			
8,960					8,960	0	0
	Debtors for Subscriptions	120	15	0			
	Less Reserve for Bad Debts	120	15	0			
—					—		
14,835	Science House—One-third Capital Cost				14,835	4	4
6,800	Library—At Valuation				6,800	0	0
517	Furniture and Office Equipment—At Cost, *less* Depreciation				502	2	9
20	Pictures—At Cost, *less* Depreciation				19	0	0
1	Lantern—At Cost, *less* Depreciation				1	0	0
£31,540					£31,502	19	1

TRUST AND MONOGRAPH CAPITAL FUNDS.

	Clarke Memorial.			Walter Burfitt Prize.			Liversidge Bequest.			Monograph Capital Fund.			Olle Bequest.		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d
Capital at 29th February, 1956	1,800	0	0	1,000	0	0	700	0	0	3,000	0	0	—		
Revenue—															
Balance at 29th February, 1956 ..	91	19	0	121	18	5	38	17	9	852	14	7	35	4	7
Income for twelve months	59	1	0	32	16	0	22	19	1	103	16	1	42	9	6
	151	0	0	154	14	5	61	16	10	956	10	8	77	14	1
Less Expenditure ..	74	19	6	11	0	3	75	0	7	—			—		
Balance at 28th February, 1957	£76	0	6	£143	14	2	*—£13*	*3*	*9*	£956	10	8	£77	14	1

ACCUMULATED FUNDS.

	£	s.	d.	£	s.	d.
Balance at 29th February, 1956				23,652	17	6
Less—						
Increase in Reserve for Bad Debts ..	43	11	6			
Bad Debts Written Off	23	12	6			
Deficit for twelve months	57	2	5			
				124	6	5
Balance at 28th February, 1957				£23,528	11	1

The above Balance Sheet has been prepared from the Books of Account, Accounts and Vouchers of the Royal Society of New South Wales, and is a correct statement of the position of the Society's affairs on 28th February, 1957, as disclosed thereby. We have satisfied ourselves that the Society's Commonwealth Bonds and Inscribed Stock are properly held and registered.

HORLEY & HORLEY,
Per Conrad F. Horley, F.C.A. (Aust.),
Chartered Accountants (Aust.).

Prudential Building,
39 Martin Place, Sydney.
25th March, 1957.

(Sgd.) H. A. J. DONEGAN,
Honorary Treasurer.

INCOME AND EXPENDITURE ACCOUNT.

1st March, 1956, to 28th February, 1957.

1956. £					£	s.	d.
23	To Annual Social Function (Balance 1956)				6	10	6
31	,, Audit				31	10	0
104	,, Cleaning				106	0	0
29	,, Depreciation				27	8	7
44	,, Electricity				41	9	5
2	,, Entertainment Expenses				3	10	0
36	,, Insurance				38	14	3
240	,, Library Purchases and Binding				211	15	11
168	,, Miscellaneous				89	0	1
136	,, Postages and Telegrams				138	1	3
	,, Printing and Binding Journal—						
	Vol. 88—Binding	£111	0	0			
	Vol. 89—						
	Parts 2–4	856	15	3			
	Binding	129	15	6			
	Vol. 90, Part 1	233	6	3			
1,208					1,330	17	0
168	,, Printing—General				112	9	0
—	,, Removal Expenses				131	15	8
31	,, Rent—Science House Management				61	15	0
6	,, Repairs				9	19	5
—124	,, Reprints				103	15	11
1,101	,, Salaries				1,039	18	9
31	,, Telephone				31	15	9
745	,, Surplus for twelve months				—		
£3,979					£3,516	6	6

1956. £		£	s.	d.
882	By Membership Subscriptions	844	14	6
8	,, Proportion of Life Members' Subscriptions	10	10	0
—	,, Subscriptions to Journal	117	1	9
500	,, Government Subsidy	500	0	0
880	,, Science House Management—Share of Surplus	822	1	9
—	,, Rentals Received—Reception Room	99	7	11
80	,, Interest on General Investments	85	3	2
1,629	,, Sale of Periodicals *ex* Library	749	8	6
—	,, Sale of Back Numbers of Journals	230	16	6
—	,, Deficit for twelve months	57	2	5
£3,979		£3,516	6	6

ABSTRACT OF THE PROCEEDINGS

OF THE SECTION OF

GEOLOGY

Chairman : F. N. Hanlon, B.Sc.

Honorary Secretary : L. J. Lawrence, Ph.D., B.Sc.

Meetings.—Five meetings were held during the year 1956, the average attendance being 19.

March 16th :

Annual meeting. Election of office-bearers : Chairman, Mr. F. N. Hanlon ; Hon. Sec., Dr. L. J. Lawrence.

Address by Dr. T. G. Vallance, entitled " The Mineralogy of the Plagioclase Group ". Dr. Vallance illustrated by means of a series of graphs the methods of determining the various plagioclases and discussed the application of plagioclase mineralogy to the problems of depth and temperature of formation of the various igneous rocks.

May 18th :

Address by Dr. F. W. Booker, entitled " The Relationship of Geological Surveys and the State Universities in the U.S.A." Dr. Booker spoke of the close relationship that existed between geological surveys and State Universities in the U.S.A., and then showed a number of colour slides depicting university and survey buildings in America.

July 29th :

Address by Mr. F. C. Loughnan, entitled " The Place of Clay Mineralogy in the Study of Sedimentary Rocks ". Mr. Loughnan described the various modern techniques by which the clay minerals may be identified and then considered their mineralogy as an aid in the classification and correlation of argillic sediments.

September 21st :

In the absence of Dr. Phipps, who was to have addressed the Section, Dr. L. J. Lawrence delivered a short address on " The Tin and Tungsten Deposits of the New England District ". Dr. Lawrence's address was followed by a short address by Dr. L. E. Koch, who discussed various methods of assessing temperature of formation of tin and tungsten minerals.

November 16th :

Address by Mr. B. E. Balme, entitled " Fossil Spores and Regional Stratigraphy ". Mr. Balme discussed the classification of fossil spores and illustrated how they are being used as a means of stratigraphic correlation in both terrestrial and marine sediments, with special application to petroleum exploration.

Obituary

WALTER FITZMAURICE BURFITT, who died on 1st June, 1956, at the age of eighty, after a long illness, had been a member of this Society for fifty-eight years. He was born at Dubbo, N.S.W., and educated at Riverview College and later at the University of Sydney, where he had a brilliant academic career, being awarded almost every prize and scholarship for which he was eligible to compete. He graduated Bachelor of Arts in 1894, with Honours in Mathematics and First-class Honours and the University Medal in Geology. His early interest in geology, fostered by his association with Professor David, for whom he had a profound admiration, was maintained throughout his life. Entering the Faculty of Medicine, he graduated M.B. and Ch.M. in 1900, with First-class Honours and the University Medal. While doing his medical course, he also graduated Bachelor of Science in 1898.

After a year as Resident at Royal Prince Alfred Hospital, he entered private practice in Glebe, and shortly before World War I moved to Macquarie Street, to become one of Sydney's leading surgeons. For many years an honorary surgeon at Lewisham Hospital, he was Senior Honorary Surgeon and Chairman of the Honorary Staff there at the time of his retirement in 1939. He was a member of the British Medical Association, and a Foundation Fellow of the Royal Australasian College of Surgeons.

He maintained a lifelong interest in University affairs, and was Chairman of the Council of Sancta Sophia College within the University. In 1925 he made a gift of £1,000 to the University for the establishment of a scholarship to be awarded in the Faculty of Science for proficiency in Physics or Chemistry. This was but one manifestation of his practical concern for the careers of young research students.

This Society has cause for holding him in grateful remembrance. He endowed it with a gift, later supplemented by his wife to £1,000, to found the Walter Burfitt Prize for published research work. Competition for this coveted award is very keen, and some of Australia's foremost scientists have been the recipients of the prize.

In addition to his zeal for the advancement of science, Dr. Burfitt was a man of wide human sympathy and benevolence. He was also characteristically modest and retiring, and never courted but rather shunned publicity. In 1932, at the meeting at which the Burfitt Prize was being presented, he was asked to speak, and was obviously embarrassed and almost apologetic.

In 1908 he married Esmey Mann, and of their family of two sons and three daughters three have followed their father's profession.

ROBERT DESIDER LOUIS FREDERICK, who died on 20th August, 1956, was a member of the Society since 1943.

Royal Society of New South Wales

as at April 1, 1956

P Members who have contributed papers which have been published in the Society's Journal. The numerals indicate the number of such contributions.

‡ Life Members.

Elected.		
1944		Adamson, Colin Lachlan, 36 McLaren-street, North Sydney.
1938	P 2	‡Albert, Adrien, D.Sc., Ph.D. *Lond.*, B.Sc. *Syd.*, Professor of Medical Chemistry, The Australian National University, Canberra, A.C.T.
1935		‡Albert, Michael Francois, "Boomerang", Billyard-avenue, Elizabeth Bay.
1950		Alexander, Albert Ernest, B.Sc., M.A., Ph.D., Professor of Chemistry, University of Sydney.
1941		‡Alldis, Victor le Roy, Box 57, Orange, N.S.W.
1948		Anderson, Geoffrey William, B.Sc., c/o Box 30, P.O., Chatswood.
1948	P 2	Andrews, Paul Burke, B.Sc., 5 Conway-avenue, Rose Bay.
1930	P 1	Aston, Ronald Leslie, B.Sc., B.E. *Syd.*, M.Sc., Ph.D. *Cantab.*, Department of Civil Engineering and Surveying, University of Sydney. (President, 1948.)
1919	P 1	‡Aurousseau, Marcel, M.C., B.Sc., 229 Woodland-street, Balgowlah, N.S.W.
1924	P 2	Bailey, Victor Albert, M.A., D.Phil., F.A.A., Professor of Experimental Physics, University of Sydney.
1934	P 2	Baker, Stanley Charles, M.Sc., Department of Physics, Newcastle Technical College, Tighe's Hill.
1937		Baldick, Kenric James, B.Sc., 19 Beaconsfield-parade, Lindfield.
1951		Banks, Maxwell Robert, B.Sc., Department of Geology, University of Tasmania, Hobart, Tasmania.
1919		‡Bardsley, John Ralph, 29 Walton-crescent, Abbotsford.
1951		Basden, Keith Spencer, B.Sc., School of Mining and Applied Geology, N.S.W. University of Technology, Sydney.
1950		Baxter, John Philip, B.Sc., Ph.D., F.A.A., Vice-Chancellor and Professor of Chemical Engineering, N.S.W. University of Technology, Sydney.
1950		Beck, Julia Mary (Mrs.), B.Sc., 5 Hall-road, Isleworth, Middlesex, England.
1947		Beckmann, Peter, c/o Corrosion Research Unit, Department of Metallurgy, University of Cambridge, England.
1933		Bedwell, Arthur Johnson, "Wongala", Boomerang-street, Turramurra.
1926		Bentivoglio, Sydney Ernest, B.Sc.Agr., 42 Telegraph-road, Pymble.
1937	P 7	Birch, Arthur John, M.Sc., D.Phil. *Oxon.*, Professor of Organic Chemistry, University of Manchester.
1920		‡Bishop, Eldred George, 26A Wolseley-road, Mosman.
1948		Blanks, Fred Roy, B.Sc., 10 Glenwood-avenue, Coogee.
1946		Blaschke, Ernest Herbert, 6 Illistron Flats, 63 Carrabella-street, Kirribilli.
1933	P 30	Bolliger, Adolph, Ph.D., Gordon Craig Urological Research Laboratory, Department of Surgery, University of Sydney. (President, 1945.)
1956	P 2	Bolt, Bruce Alan, M.Sc., Department of Applied Mathematics, University of Sydney.
1951	P 1	Booker, Frederick William, M.Sc., Ph.D., Government Geologist, c/o Geological Survey of N.S.W., Mines Department, Sydney.
1954		Booth, Brian Douglas, Ph.D., B.Sc., 37 Highfield-road, Lindfield.
1920	P 9	‡Booth, Edgar Harold, M.C., D.Sc., 29 March-street, Bellevue Hill. (President, 1936.)
1951	P 1	Bosson, Geoffrey, M.Sc. *Lond.*, Professor of Mathematics, N.S.W. University of Technology, Sydney.
1939	P 26	Bosworth, Richard Charles Leslie, M.Sc., D.Sc. *Adel.*, Ph.D. *Cantab.*, Associate Professor, School of Physical Chemistry, N.S.W. University of Technology, Sydney. (President, 1951.)

Elected.		
1946	P 1	Breyer, Bruno, M.D., Ph.D., M.A., Department of Agricultural Chemistry, University of Sydney.
1952		Bridges, David Somerset, 19 Mt. Pleasant-avenue, Normanhurst.
1919	P 1	‡Briggs, George Henry, D.Sc., Ph.D., National Standards Laboratory of Australia, University Grounds, Sydney.
1942		Brown, Desmond J., M.Sc. *Syd.*, Ph.D. *Lond.*, D.I.C., Department of Medical Chemistry, Australian National University, Canberra, A.C.T.
1935	P 11	Browne, Ida Alison, D.Sc., " Mount Stewart ", 363 Edgecliff-road, Edgecliff. (President, 1953.)
1913	P 23	‡Browne, William Rowan, D.Sc., F.A.A., " Mount Stewart ", 363 Edgecliff-road, Edgecliff. (President, 1932.)
1952		Bryant, Raymond Alfred Arthur, M.E., Companion R.Ae.S., School of Mechanical Engineering, N.S.W. University of Technology, Sydney.
1947		Buchanan, Gregory Stewart, B.Sc., School of Physical Chemistry, Sydney Technical College.
1940		Buckley, Lindsay Arthur, B.Sc., 30 Wattle-street, Killara.
1946	P 2	Bullen, Keith Edward, M.A., Ph.D., Sc.D., F.R.S., F.A.A., Professor of Applied Mathematics, University of Sydney, Sydney.
1952	P 2	‡Burke-Gaffney, Rev. Thomas Noel, S.J., Director, Riverview College Observatory, Riverview, N.S.W.
1950		Burton, Gerald, B.Sc. *Syd.*, c/o Bureau of Mineral Resources, Canberra, A.C.T.
1955		Campbell, Ian Gavin Stuart, B.Sc., c/o Wesley College, Prahran, Victoria.
1938	P 2	‡Carey, Samuel Warren, D.Sc., Professor of Geology, University of Tasmania, Hobart, Tas.
1944		Cavill, George William Kenneth, M.Sc. *Syd.*, Ph.D. *Liverpool*, School of Organic Chemistry, N.S.W. University of Technology, Sydney.
1954		‡Chaffer, Edric Keith, 27 Warrane-road, Roseville.
1933	P 1	Chalmers, Robert Oliver, Australian Museum, College-street, Sydney.
1940		Chambers, Maxwell Clark, B.Sc., 58 Spencer-road, Killara.
1952		Chapman, Dougan Wellesley, 3 Orinoco-street, Pymble.
1953		Christie, Thelma Isabel, B.Sc., Chemistry School, N.S.W. University of Technology, Sydney.
1935	P 2	Churchward, John Gordon, B.Sc.Agr., Ph.D., 55 Belmont-road, Mosman.
1940		Cohen, Samuel Bernard, M.Sc., 74 Boundary-street, Roseville.
1940	P 2	Cole, Edward Ritchie, B.Sc., 7 Wolsten-avenue, Turramurra.
1940	P 1	Cole, Joyce Marie, B.Sc., 7 Wolsten-avenue, Turramurra.
1948		Cole, Leslie Arthur, 21 Carlisle-street, Rose Bay.
1955		Coleman, Patrick Joseph, B.Sc., Ph.D., Department of Geology, University of Sydney.
1940		Collett, Gordon, B.Sc., 27 Rogers-avenue, Haberfield.
1955		Colville, Jean Norma (Mrs.), B.Sc., 4 The Postern, Castlecrag.
1948		Cook, Cyril Lloyd, M.Sc., Ph.D., c/o Propulsion Research Laboratories, Box 1424H, G.P.O., Adelaide.
1946		Cook, Rodney Thomas, Buckley's-road, Old Toongabbie, N.S.W.
1945		Coombs, Arthur Roylance, 14 Georges River-road, Croydon.
1913	P 5	‡Coombs, F. A., Bannerman-crescent, Rosebery.
1933		Corbett, Robert Lorimer, c/o Intaglio Pty. Ltd., Box 3749, G.P.O., Sydney.
1940		Cortis-Jones, Beverly, M.Sc., 62 William-street, Roseville.
1909	P 7	‡Cotton, Leo Arthur, M.A., D.Sc., Emeritus Professor, 113 Queen's-parade East, Newport Beach. (President, 1929.)
1941	P 1	Craig, David Parker, Ph.D., Department of Theoretical Chemistry, University College, London, W.C.1, England.
1955		Crawford, Edwin John, B.E., " Lynwood ", Bungalow-avenue, Pymble.
1955		Crawford, Ian Andrew, 73 Wyadra-avenue, Manly.
1921	P 1	‡Cresswick, John Arthur, 101 Villiers-street, Rockdale.
1956		Croft, James Bernard, 228A Old Canterbury-road, Summer Hill.
1954	P 3	Crook, Keith Alan Waterhouse, B.Sc., Geology Department, University of New England, Armidale, N.S.W.
1948		Cymerman-Craig, John, Ph.D., D.I.C., B.Sc., Department of Organic Chemistry, University of Sydney.
1940		Dadour, Anthony, B.Sc., 25 Elizabeth-street, Waterloo.
1951		Darvall, Anthony Roger, M.B., B.S., D.O., 119 Marsden-street, Parramatta.
1952		Davies, George Frederick, 57 Eastern-avenue, Kingsford.
1952		Day, Alan Arthur, B.Sc. *Syd.*, Ph.D. *Cantab.*, 13 Besborough-avenue, Bexley.
1952		Debus, Elaine Joan, 62 Tarrant's-avenue, Eastwood.
1953		de Lepervanche, Beatrice Joy, 29 Collins-street, Belmore.

Elected.		
1955		Denton, Leslie A., Bunarba-road, Miranda.
1955		Denton, Norma F. (Mrs.), Bunarba-road, Miranda.
1928		Donegan, Henry Arthur James, M.Sc., 18 Hillview-street, Sans Souci.
1947		Downes, Alan Marchant, B.Sc., c/o Sheep Biology Laboratory, C.S.I.R.O., Prospect, N.S.W.
1950		Drummond, Heather Rutherford, B.Sc., 2 Gerald-avenue, Roseville.
1937	P 15	Dulhunty, John Allan, D.Sc., Department of Geology, University of Sydney. (President, 1947.)
1948		Dunlop, Bruce Thomas, B.Sc., 77 Stanhope-road, Killara.
1951		Dunn, Thomas Melanby, B.Sc., c/o William Ramsay & Ralph Forster Chemical Laboratory, University College, Gower-street, London, W.C.1., England.
1924		Dupain, George Zephirin, 15 Calvert-parade, Newport Beach.
1955		Durie, Ethel Beatrix, B.Sc., M.B., Ch.M., Institute of Medical Research, Royal North Shore Hospital, St. Leonards.
1934	P 62	Dwyer, Francis P. J., D.Sc., Professor of Organic Chemistry, The University of Pennsylvania, U.S.A.
1945		Eade, Ronald Arthur, M.Sc. *Syd.*, Ph.D. *Liverpool*, School of Organic Chemistry, N.S.W. University of Technology, Sydney.
1951		Edgar, Joyce Enid (Mrs.), B.Sc., 16 Cooper-street, Cessnock.
1950		Edgell, Henry Stewart, Ph.D. *Stanford*, c/o Iranian Oil Exploration & Producing Co., Masjid-i-Sulaiman, via Abadan, Iran.
1946	P 1	El Nashar, Beryl, B.Sc., Ph.D., 23 Morris-street, Mayfield West, 2N, N.S.W.
1934	P 2	Elkin, Adolphus Peter, M.A., Ph.D., Emeritus Professor, 15 Norwood-avenue, Lindfield. (President, 1940.)
1949		Ellison, Dorothy Jean, M.Sc., 51 Tryon-road, Lindfield.
1940		Emmerton, Henry James, B.Sc., 37 Wangoola-street, East Gordon.
1944		Erhart, John Charles, c/o "Ciba" Company, Basle, Switzerland.
1908		‡Esdaile, Edward William, 42 Hunter-street, Sydney.
1935		Evans, Silvanus Gladstone, 6 Major-street, Coogee.
1949		Everingham, Richard, 97 Hopetoun-avenue, Vaucluse.
1950		Fallon, Joseph James, 1 Coolong-road, Vaucluse.
1909	P 7	‡Fawsitt, Charles Edward, D.Sc., Ph.D., Emeritus Professor, 14A Darling Point-road, Edgecliff. (President, 1919.)
1940		Finch, Franklin Charles, B.Sc.
1940		Fisher, Robert, B.Sc., 3 Sackville-street, Maroubra.
1956		Fleischmann, Arnold Walter, 8/25 Guilfoyle-avenue, Double Bay.
1933		Fletcher, Harold Oswald, M.Sc., The Australian Museum, College-street, Sydney.
1932		Forman, Kenn P., 52 Pitt-street, Sydney.
1950		Freeman, Hans Charles, M.Sc., 43 Newcastle-street, Rose Bay.
1951		French, Oswald Raymond, 66 Nottinghill-road, Lidcombe.
1944	P 2	Friend, James Alan, M.Sc. *Syd.*, Ph.D. *Cantab.*, Department of Chemistry, University of Tasmania, Box 647C, Hobart, Tas.
1945		Furst, Hellmut Friedrich, B.D.S. *Syd.*, D.M.D. *Hamburg*, 158 Bellevue-road, Bellevue Hill.
1952		Garan, Teodar, c/o Chief Geologist, Warragamba Dam, N.S.W.
1935	P 2	Garretty, Michael Duhan, D.Sc., "Surry Lodge", Mitcham-road, Mitcham, Victoria.
1939	P 4	Gascoigne, Robert Mortimer, Ph.D. *Liverpool*, Department of Organic Chemistry, N.S.W. University of Technology, Sydney.
1942	P 6	Gibson, Neville Allan, M.Sc., Ph.D., 103 Bland-street, Ashfield.
1947		Gill, Naida Sugden, B.Sc., Ph.D., 45 Neville-street, Marrickville.
1947		‡Gill, Stuart Frederic, 45 Neville-street, Marrickville.
1948		Glasson, Kenneth Roderick, B.Sc., 70 Beecroft-road, Beecroft.
1945		Goddard, Roy Hamilton, Royal Exchange, Bridge-street, Sydney.
1953	P 2	Golding, Henry George, B.Sc. *Lond.*, M.Sc. *Syd.*, School of Mining Engineering and Applied Geology, N.S.W. University of Technology, Sydney.
1951		Goldstone, Charles Lillington, B.Agr.Sc. *N.Z.*, East Sydney Technical College, Darlinghurst.
1947		Goldsworthy, Neil Ernest, M.B., Ch.M. *Syd.*, Ph.D., 118 Ryde-road, West Pymble.
1949		Gordon, William Fraser, B.Sc., 176 Avoca-street, Randwick.
1948	P 1	Gray, Charles Alexander Menzies, B.Sc., B.E., Professor of Engineering, University of Malaya, Malaya.

Elected.		
1952		Gray, Noel Mackintosh, B.Sc. *W.A.*, 6 Twenty-fourth-street, Warragamba Dam, N.S.W.
1952		Griffin, Russell John, B.Sc., c/o Department of Mines, Sydney.
1952	P 6	Griffith, James Langford, B.A., M.Sc., School of Applied Mathematics, N.S.W. University of Technology, Sydney.
1946	P 1	Gutmann, Felix, Ph.D., N.S.W. University of Technology, Sydney.
1934		Hall, Norman Frederick Blake, M.Sc., 15A Wharf-road, Longueville.
1949		Hampton, Edward John William, 1 Hunter-street, Waratah, N.S.W.
1955		Hancock, Harry Sheffield, B.Sc., 491 New Canterbury-road, Dulwich Hill.
1940	P 15	Hanlon, Frederick Noel, B.Sc., 22 Grayling-road, Pymble. (President, 1957.)
1905	P 6	‡Harker, George, D.Sc., 89 Homebush-road, Strathfield.
1936		Harper, Arthur Frederick Alan, M.Sc., National Standards Laboratory, University Grounds, City-road, Chippendale.
1934		Harrington, Herbert Richard, 28 Bancroft-avenue, Roseville.
1948	P 6	Harris, Clive Melville, B.Sc., School of Inorganic Chemistry, N.S.W. University of Technology, Sydney.
1946		Harrison, Ernest John Jasper, B.Sc., c/o N.S.W. Geological Survey, Department of Mines, Sydney.
1954		Hasan, Syed Manzurul, M.Sc., F.G.S., c/o Bureau of Mineral Resources, P.O. Box 449, Darwin, N.T.
1956	P 1	Hawkins, Cedric Arthur, B.Sc.Agr., 11 Mitchell-street, Ermington.
1951		Heard, George Douglas, B.Sc., Queanbeyan Intermediate High School, Queanbeyan, N.S.W.
1955		Heath, Russel Alan, “ Heathcote ”, 9 Potter-avenue, Earlwood.
1919		‡Henriques, Frederick Lester, Billyard-avenue, Elizabeth Bay.
1952		Hewitt, John William, B.Sc., 31 Weatherill-street, Narrabeen.
1945		Higgs, Alan Charles, c/o Colonial Sugar Refining Co. Ltd., Building Material Division, Chatsworth House, 1-7 Bent-street, Sydney.
1938	P 4	Hill, Dorothy, D.Sc. *Qld.*, Ph.D. *Cantab.*, F.A.A., Department of Geology, University of Queensland, St. Lucia, Brisbane, Queensland.
1948	P 6	Hogarth, Julius William, B.Sc., 8 Jeanneret-avenue, Hunters Hill.
1952		Holm, Thomas John, 524 Wilson-street, Redfern.
1951		Holmes, Robert Francis, 15 Baden-street, Coogee.
1923	P 3	‡Hynes, Harold John, D.Sc.Agr., M.Sc., Assistant Director, Department of Agriculture, Box 36, G.P.O., Sydney.
1943		Iredale, Thomas, D.Sc., Chemistry Department, University of Sydney.
1942	P 1	Jaeger, John Conrad, M.A., D.Sc., F.A.A., Geophysics Department, Australian National University, Canberra, A.C.T.
1951		Jamieson, Helen Campbell, 3 Hamilton-street, Coogee.
1956		Jenkins, Thomas Benjamin Huw, B.Sc., Ph.D., c/o A.O.G. Corp., Ltd., 133 Pitt-street, Sydney.
1935	P 7	Joplin, Germaine Anne, B.A., Ph.D., D.Sc., Geophysics Department, Australian National University, Canberra, A.C.T.
1948	P 1	Jopling, Alan Victor, B.Sc., B.E.
1955	P 2	Keane, Austin, Ph.D., School of Mathematics, N.S.W. University of Technology, Sydney.
1935		Kelly, Caroline Tennant (Mrs.), Dip.Anth., “ Avila ”, 17 Heydon-avenue, Warrawee.
1924	P 1	Kenny, Edward Joseph, Under Secretary, Department of Mines, Sydney .
1948		Kimble, Frank Oswald, 31 Corongae-street, Killara.
1943		Kimble, Jean Annie, B.Sc., 383 Marrickville-road, Marrickville.
1920		‡Kirchner, William John, B.Sc., 18 Lyne-road, Cheltenham.
1948		Knight, Oscar Le Maistre, B.E., 10 Mildura-street, Killara.
1948		Koch, Leo E., Dr.Phil.Habil *Cologne*, c/o N.S.W. University of Technology, Sydney.
1939	P 3	Lambeth, Arthur James, B.Sc., “ Naranje ”, Sweethaven-road, St. John's Park, N.S.W.
1949		Lancaster, Kelvin John, M.A., B.Sc., B.Sc.Econ., London School of Economical and Political Science, Houghton-street, Aldwych, W.C.2, England.

Elected.		
1955		Lang, Thomas Arthur, M.C.E., Associate Commissioner, Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.
1951		Lawrence, Laurence James, Ph.D., School of Geology, N.S.W. University of Technology, Sydney.
1936		Leach, Stephen Laurence, B.A., B.Sc., c/o Taubman's Industries Ltd., Box 82A, P.O., North Sydney.
1947		Le Fevre, Raymond James Wood, D.Sc., Ph.D., F.A.A., Professor of Chemistry, University of Sydney.
1936	P 3	Lemberg, Max Rudolph, D.Phil., F.R.S., F.A.A., Assistant Director, Institute of Medical Research, Royal North Shore Hospital, St. Leonards. (President, 1955.)
1929	P 56	‡Lions, Francis, B.Sc., Ph.D., Department of Chemistry, University of Sydney. (President 1946–47.)
1940		Lions, Jean Elizabeth (Mrs.), B.Sc., 160 Alt-street, Haberfield.
1947		Lloyd, James Charles, B.Sc. *Syd.*, N.S.W. Geological Survey, Department of Mines, Sydney.
1940	P 1	Lockwood, William Hutton, B.Sc., c/o Institute of Medical Research, The Royal North Shore Hospital, St. Leonards.
1906		‡Loney, Charles Augustus Luxton, National Mutual Building, 350 George-street, Sydney.
1949	P 2	Loughnan, Frederick Charles, B.Sc., 11 Rosebridge-avenue, East Willoughby.
1951	P 2	Lovering, John Francis, M.Sc. *Syd.*, Ph.D. *Calif. Inst. Tech.*, Department of Geophysics, Australian National University, Canberra, A.C.T.
1950	P 1	Low, Angus Henry, M.Sc., School of Mathematics, N.S.W. University of Technology, Sydney.
1943		‡Luber, Daphne (Mrs.), B.Sc., 98 Lang-road, Centennial Park.
1945		Luber, Leonard, 80 Queen-street, Woollahra.
1948	P 2	Lyons, Lawrence Ernest, B.A., M.Sc. *Syd.*, Ph.D. *Lond.*, Chemistry Department, University of Sydney, Sydney.
1939	P 4	Maccoll, Allan, M.Sc., Department of Chemistry, University College, Gower-street, London, W.C.1.
1949		McCarthy, Frederick David, Dip.Anthr., Australian Museum, Sydney. (President 1956.)
1943		McCoy, William Kevin, c/o Mr. A. J. McCoy, 23 Victoria-road, Pennant Hills.
1950		McCullagh, Morris Behan, 23 Wallaroy-road, Edgecliff.
1949	P 2	McElroy, Clifford Turner, B.Sc., " Bithongabel ", Bedford-road, Woodford, N.S.W.
1940		McGregor, Gordon Howard, 4 Maple-avenue, Pennant Hills.
1948		McInnes, Gordon Elliott, B.Sc., Cranbrook School, Bellevue Hill.
1956	P 1	McKay, Maxwell Herbert, M.A., School of Mathematics, N.S.W. University of Technology, Sydney.
1953		McKenzie, Peter John, B.Sc., 33 Harbour-street, Mosman.
1943	P 9	McKern, Howard Hamlet Gordon, Museum of Applied Arts and Sciences, Harris-street, Broadway.
1947		McMahon, Patrick Reginald, M.Agr.Sc. *N.Z.*, Ph.D. *Leeds*, Professor of Wool Technology, N.S.W. University of Technology, Sydney.
1943		McNamara, Barbara Joyce (Mrs.), M.B., B.S., 82 Millwood-avenue, Chatswood.
1956		McPhee, Stuart Duncan, 14 Lennon-street, Gordon.
1946		McPherson, John Charters, 14 Sarnar-road, Greenwich.
1947	P 1	Magee, Charles Joseph, D.Sc.Agr. *Syd.*, M.Sc. *Wis.*, Chief Biologist, Department of Agriculture. (President 1952.)
1951		Males, Pamela Ann, 13 Gelding-street, Dulwich Hill.
1955		Mandl, Lothar Max, Dipl.Ing. *Tech. Univ. of Vienna*, Senior Technical Officer, C.S.I.R.O.
1947	P 14	Mapstone, George E., M.Sc., c/o S.A.T.M.A.R., P.O. Box 5083, Boksburg North, Transvaal, Union of South Africa.
1949		Marshall, Charles Edward, Ph.D., D.Sc., Professor of Geology, University of Sydney.
1955		Marsden, Joan Audrey, 203 West-street, Crows Nest.
1946		May, Albert, Ph.D., M.A., 94 Birriga-road, Bellevue Hill.
1935	P 1	Maze, William Harold, M.Sc., Deputy Principal, The University of Sydney.
1949		Meares, Harry John Devenish, Technical Librarian, Colonial Sugar Refining Co. Ltd., Box 483, G.P.O., Sydney.
1912		‡Meldrum, Henry John, B.A., B.Sc., 98 Sydney-road, Fairlight.
1929	P 25	Mellor, David Paver, D.Sc., Professor of Applied Chemistry, N.S.W. University of Technology, Sydney. (President, 1941.)

Elected.		
1950		Millar, Lily Maud (Mrs.), 4 Waratah House, 43 Bayswater-road, King's Cross.
1940		Millership, William, M.Sc., 18 Courallie-avenue, Pymble.
1951		Minty, Edward James, B.Sc., Cooyong-road, Terrey Hills, N.S.W.
1922	P 34	‡Morrison, Frank Richard, Director, Museum of Applied Arts and Sciences, Harris-street, Broadway, Sydney. (President 1950–51.)
1941		Morrissey, Matthew John, B.A., M.B., B.S., 46 Auburn-street, Parramatta.
1934		Mort, Francis George Arnot, 110 Green's-road, Fivedock.
1948		Mosher, Kenneth George, B.Sc., c/o Joint Coal Board, 66 King-street, Sydney.
1955		Moss, Francis John, M.B., B.S. *Melb.*, 15 Ormonde-road, Roseville Chase, N.S.W.
1944		Moye, Daniel George, B.Sc., Chief Geologist, c/o Snowy Mountains Hydro-Electric Authority, Cooma, N.S.W.
1946		Mulholland, Charles St. John, B.Sc., Assistant Under-Secretary, Department of Mines, Bridge-street, Sydney.
1915		‡Murphy, Robert Kenneth, Dr.Ing.Chem., 68 Pindari-avenue, North Mosman.
1951		Murray, James Kenneth, B.Sc., 464 William-lane, Broken Hill, N.S.W.
1950		Murray, Patrick Desmond Fitzgerald, M.A., D.Sc., F.A.A., Professor of Zoology, University of Sydney.
1930	P 7	Naylor, George Francis King, M.A., M.Sc. *Syd.*, Ph.D. *Q'ld.*, Department of Psychology and Philosophy, University of Queensland, Brisbane.
1943		‡Neuhaus, John William George, 32 Bolton-street, Guildford.
1932		Newman, Ivor Vickery, M.Sc., Ph.D., Department of Botany, University of Sydney.
1945	P 1	Noakes, Lyndon Charles, B.A., c/o Mineral Resources Bureau, Canberra, A.C.T.
1920	P 4	‡Noble, Robert Jackson, M.Sc., B.Sc.Agr., Ph.D., Under Secretary and Director, Department of Agriculture, Box 36, G.P.O., Sydney. (President, 1934.)
1947		Nordon, Peter, 60 Hampton Park, Redland, Bristol 6, England.
1940	P 26	Nyholm, Ronald Sydney, M.Sc. *Syd.*, Ph.D., D.Sc. *Lond.*, Professor of Inorganic Chemistry, London University College, Gower-street, London, W.C.1, England. (President, 1954.)
1951		‡O'Dea, Darly Robery, Box 14, P.O., Broadway.
1947		Old, Adrian Noel, B.Sc.Agr., 4 Springfield-avenue, Potts Point.
1950		Oxenford, Reginald Augustus, B.Sc., 10 Fry-street, Grafton, N.S.W.
1951	P 3	Packham, Gordon Howard, B.Sc., Department of Geology and Geophysics, University of Sydney.
1920	P 82	Penfold, Arthur Ramon, 50 Park-avenue, Roseville. (President, 1935.)
1948		Perry, Hubert Roy, B.Sc., 74 Woodbine-street, Bowral.
1956		Petersen, George, 108 Northcote-street, Naremburn.
1953	P 1	Phillips, June Rosa Pitt, B.Sc., Geology Department, University of Sydney.
1938		Phillips, Marie Elizabeth, B.Sc., PhD., *Manchester*, Soil Conservation Section, S.M.H.E.A., Cooma, 4 Morella-road, Clifton Gardens.
1935		Phillips, Orwell, 55 Darling Point-road, Edgecliff.
1946		Pinwill, Norman, B.A. *Q'ld.*, The Scots College, Bellevue Hill.
1943	P 8	Plowman, Ronald Arthur, B.Sc., Ph.D. *Lond.*, Chemistry Department, University of Queensland, Brisbane.
1919		‡Poate, Sir Hugh Raymond Guy, M.B., Ch.M. *Syd.*, 225 Macquarie-street, Sydney.
1949		Poggendorff, Walter Hans George, B.Sc.Agr., Chief, Division of Plant Industry, N.S.W. Department of Agriculture, Box 36A, G.P.O., Sydney.
1921	P 2	‡Powell, Charles Wilfrid Roberts, " Wansfell ", Kirkoswald-avenue, Mosman.
1938		Powell, John Wallis, c/o Foster, Clark (Aust.) Ltd., 17 Thirlow-street, Redfern
1927		Price, William Lindsay, B.E., B.Sc., School of Physics, Sydney Technical College, Sydney.
1956		Priddle, Raymond Arthur, B.E., 7 Rawson-crescent, Pymble.
1918	P 1	‡Priestley, Henry, M.D., Ch.M., B.Sc., 54 Fuller's-road, Chatswood. (President, 1942–43.)
1956		Prokhovnik, Simon Jacques, B.A., B.Sc. *Melb.*, School of Mathematics, N.S.W. University of Technology, Sydney.
1945		‡Proud, John Seymour, B.E., Finlay-road, Turramurra.
1935	P 3	‡Quodling, Florrie Mabel, B.Sc., Department of Geology, University of Sydney.

Elected.		
1953	P 4	Rade, Janis, M.Sc., 69A Broadway, Nedlands, Perth, W.A.
1922	P 8	Raggatt, Harold George, C.B.E., D.Sc., F.A.A., Secretary, Department of National Development, Acton, Canberra, A.C.T.
1919	P 3	‡Ranclaud, Archibald Boscawen Boyd, B.Sc., B.E., 57 William-street, Sydney.
1947		Ray, Reginald John, "Treetops", Wyong-road, Berkeley Vale.
1931	P 1	Rayner, Jack Maxwell, B.Sc., Deputy Director, Bureau of Mineral Resources, Geology and Geophysics, 485 Bourke-street, Melbourne, Vic.
1947		Reuter, Fritz Henry, Ph.D. *Berlin*, Associate Professor of Food Technology, N.S.W. University of Technology, Sydney.
1947	P 2	Ritchie, Arthur Sinclair, Department of Mineralogy and Geology, Newcastle University College, Newcastle.
1939	P 19	Ritchie, Ernest, D.Sc., Chemistry Department, University of Sydney, Sydney.
1939	P 3	Robbins, Elizabeth Marie (Mrs.), M.Sc., Waterloo-road, North Ryde.
1940		Robertson, Rutherford Ness, B.Sc. *Syd.*, Ph.D. *Cantab.*, F.A.A., Senior Plant Physiologist, C.S.I.R.O., c/o Botany Department, University of Sydney.
1949	P 10	Robertson, William Humphrey, B.Sc., c/o Sydney Observatory, Sydney.
1951		Robinson, David Hugh, 39 Molton-road, Beecroft.
1940		Rosenbaum, Sidney, 23 Strickland-avenue, Lindfield.
1948		Rosenthal-Schneider, Ilse, Ph.D., 48 Cambridge-avenue, Vaucluse.
1945		Rountree, Phyllis Margaret, D.Sc. *Melb.*, Dip.Bact. *Lond.*, Royal Prince Alfred Hospital, Sydney.

1945		Sampson, Aileen (Mrs.), 9 Knox-avenue, Epping.
1920		‡Scammell, Rupert Boswood, B.Sc. *Syd.*, 10 Buena Vista-avenue, Clifton Gardens.
1950		Searl, Robert Alexander, B.Sc., Rio Australian Exploration P/L., 20 Queen's-road, Melbourne.
1949		See, Graeme Thomas, B.Sc., School of Mining Engineering and Geology, N.S.W. University of Technology, Sydney.
1933		Selby, Edmond Jacob, Box 175D, G.P.O., Sydney.
1950		Sergeyeff, William Peter, 137 Prince's-highway, St. Peters.
1948		‡Sharp, Kenneth Raeburn, B.Sc., c/o S.M.H.E.A., Cooma, N.S.W.
1936	P 5	Sherrard, Kathleen Margaret (Mrs.), M.Sc. *Melb.*, 43 Robertson-road, Centennial Park.
1945	P 3	Simmons, Lewis Michael, B.Sc., Ph.D. *Lond.*, c/o Scots College, Victoria-road, Bellevue Hill.
1948	P 2	Simonett, David Stanley, M.Sc., Ph.D., Assistant Professor of Geography, University of Kansas, Lawrence, Kansas, U.S.A.
1943		Simpson, John Kenneth Moore, "Browie", Old Castle Hill-road, Castle Hill.
1950	P 5	Sims, Kenneth Patrick, B.Sc., 13 Onyx-road, Artarmon.
1933		Slade, George Hermon, B.Sc., "Raiatea", Oyama-avenue, Manly.
1952		Slade, Milton John, B.Sc., 10 Elizabeth-street, Raymond Terrace, N.S.W.
1940		Smith, Eric Brian Jeffcoat, D.Phil. *Oxon.*, 74 Webster-street, Nedlands, W.A.
1947	P 2	Smith-White, William Broderick, M.A. *Cantab.*, B.Sc. *Syd.*, Department of Mathematics, University of Sydney.
1919		‡Southee, Ethelbert Ambrook, O.B.E., M.A., B.Sc., B.Sc.Agr., Trelawney-street, Eastwood.
1949	P 2	Stanton, Richard Limon, Ph.D., B.Sc., 42 Hopetoun-avenue, Mosman.
1954		Stapledon, David Hiley, B.Sc., c/o Section of Geology, S.M.H.E.A., Cooma N.S.W.
1916		‡Stephen, Alfred Ernest, c/o Box 1158HH, G.P.O., Sydney.
1914		‡Stephens, Frederick G. N., F.R.C.S., M.B., Ch.M., 135 Macquarie-street, Sydney.
1948	P 5	Stevens, Neville Cecil, Ph.D., Department of Geology, University of Queensland, St. Lucia, Brisbane, Queensland.
1951	P 2	Stevens, Robert Dencil, B.Sc., Bureau of Mineral Resources, Canberra, A.C.T.
1916	P 1	‡Stone, Walter George, 26 Rosslyn-street, Bellevue Hill.
1951		Stuntz, John, B.Sc., 511 Burwood-road, Belmore.
1918		‡Sullivan, Herbert Jay, "Stonycroft", 10 Redmyre-road, Strathfield.
1919		‡Sutherland, George Fife, A.R.C.Sc. *Lond.*, 47 Clanwilliam-street, Chatswood.
1920		‡Sutton, Harvey, O.B.E., M.D., D.P.H. *Melb.*, B.Sc. *Oxon.*, "Lynton", 27 Kent-road, Rose Bay.
1941	P 2	Swanson, Thomas Baikie, M.Sc. *Adel.*, c/o Technical Service Department, I.C.I.A.N.Z., Box 1911, G.P.O., Melbourne, Victoria.
1948		Swinbourne, Ellice Simmons, 1 Raglan-street, Manly.

1954	P 5	Taylor, Griffith, D.Sc., B.E. (Min.) *Syd.*, B.A. *Cantab.*, F.A.A., Emeritus-Professor, 28 Alan-avenue, Seaforth, N.S.W. (Previous membership, 1921–1928.)

Elected.		
1915	P 3	‡Taylor, Brigadier Harold B., M.C., D.Sc., 12 Wood-street, Manly.
1955		Thew, Raymond Farly, 88 Braeside-street, Wahroonga.
1944		Thomas, Andrew David, Squadron Leader, R.A.A.F., M.Sc., 45 Greengate-road, Killara.
1952		Thomas, Penrhyn Francis, Suite 22, 3rd Floor, 49 Market-street, Sydney.
1946	P 2	Thompson, Nora (Mrs.), B.Sc., c/o Government Geologist, Lands Department, Port Moresby, Papua.
1956		Thomson, David John, B.Sc., Department of Main Roads, Parkes, N.S.W.
1955		Thorley, Geraldine Lesley, B.A., 1290 Pacific-highway, Turramurra.
1954		Tompkins, Denis Keith, B.Sc., 24 The Crescent, Lane Cove.
1940		Tow, Aubrey James, M.Sc., M.B., B.S., c/o Community Hospital, Canberra, A.C.T.
1949		Trebeck, Prosper Charles Brian, Jerilderie-street, Jerilderie.
1951		Tugby, Elise Evelyn (Mrs.), B.Sc., c/o Department of Anthropological Sociology, Australian National University, Box 4, G.P.O., Canberra, A.C.T.
1952		Ungar, Andrew, Dipl.Ing., 6 Ashley Grove, Gordon.
1949	P 1	Vallance, Thomas George, B.Sc., Ph.D., Geology Department, University of Sydney.
1953		Veevers, John James, M.Sc., Ph.D., D.I.C., Bureau of Mineral Resources, Canberra.
1921		Vicars, Robert, Marrickville Woollen Mills, Marrickville.
1935		Vickery, Joyce Winifred, M.Sc., 17 The Promenade, Cheltenham.
1933	P 7	Voisey, Alan Heywood, D.Sc., Professor of Geology and Geography, The University of New England, Armidale.
1903	P 10	‡Vonwiller, Oscar U., B.Sc., Emeritus Professor, "Silvermists", Robertson, N.S.W. (President, 1930.)
1948		Walker, Donald Francis, 13 Beauchamp-avenue, Chatswood.
1956	P 1	Walker, Patrick Hilton, B.Sc.Agr., Research Officer, C.S.I.R.O., Division of Soils, c/o School of Agriculture, University of Sydney.
1919	P 2	‡Walkom, Arthur Bache, D.Sc., 45 Nelson-road, Killara. (President, 1943–44.) (Previous membership, 1910–1913.)
1948		Ward, Judith (Mrs.), B.Sc., No. 650, c/o H.E.C., Wayatinah, Tasmania.
1913	P 5	‡Wardlaw, Hy. Sloane Halcro, D.Sc. *Syd.*, c/o Kanematsu Institute, Sydney Hospital, Macquarie Street, Sydney. (President, 1939.)
1919	P 1	‡Waterhouse, Lionel Lawry, B.E. *Syd.*, "Rarotonga", 42 Archer-street, Chatswood.
1919	P 7	‡Waterhouse, Walter L., C.M.G., M.C., D.Sc.Agr., D.I.C., F.A.A., "Hazelmere", Chelmsford-avenue, Lindfield. (President, 1937.)
1911	P 1	‡Watt, Robert Dickie, M.A., B.Sc., Emeritus Professor, "Garron Tower", 5 Gladswood Gardens, Double Bay. (President, 1925.)
1921		‡Watts, Arthur Spencer, "Araboonoo", Glebe-street, Randwick.
1954		West, Norman William, B.Sc., c/o Department of Main Roads, Sydney.
1949		Westheimer, Gerald, B.Sc., Ph.D.
1951		Whitley, Alice, Ph.D. *Lond.*, 39 Belmore-street, Burwood.
1951	P 3	Whitworth, Horace Francis, M.Sc., Mining Museum, Sydney.
1949		Williams, Benjamin, 14 Francis-street, Artarmon.
1949		Williamson, William Harold, M.Sc., 6 Hughes-avenue, Ermington.
1954		Wood, Clive Charles, B.Sc., B.E., c/o S.M.H.E.A., Cooma, N.S.W.
1936	P 14	Wood, Harley Weston, M.Sc., Government Astronomer, Sydney Observatory, Sydney. (President, 1949.)
1906	P 12	‡Woolnough, Walter George, D.Sc., 28 Calbina-road, Northbridge. (President, 1926.)
1946		Wyndham, Norman Richard, M.D., M.S. *Syd.*, F.R.C.S. *Eng.*, F.R.A.C.S., 225 Macquarie-street, Sydney.
1952		Wynn, Desmond Watkin, B.Sc., c/o Department of Mines, Sydney.

ASSOCIATES.

1956		Donegan, Elizabeth S., 18 Hillview-street, Sans Souci.
1956		Griffith, Elsie A., 9 Kanoona-street, Caringbah.

Honorary Members.

Limited to Twenty.

Elected.	
1949	Burnet, Sir Frank Macfarlane, M.D., Ph.D., F.R.S., F.A.A., Director of the Walter and Eliza Hall Research Institute, Melbourne.
1951	Fairley, Sir Neil Hamilton, C.B.E., M.D., D.Sc., F.R.S., 73 Harley-street, London, W.1.
1952	Firth, Raymond William, M.A., Ph.D., Professor of Anthropology, University of London, London School of Economics, Houghton-street, Aldwych, W.C.2, England.
1949	Florey, Sir Howard, M.B., B.S., B.Sc., M.A., Ph.D., F.R.S., Professor of Pathology, Oxford University, England.
1946	Jones, Sir Harold Spencer, M.A., D.Sc., F.R.S., Astronomer Royal, Royal Observatory, Greenwich, London, S.E.10.
1912	Martin, Sir Charles J., C.M.G., D.Sc., F.R.S., Roebuck House, Old Chesterton, Cambridge, England.
1953	O'Connell, Rev. Daniel J., S.J., D.Sc., Ph.D., F.R.A.S., Director, The Vatican Observatory, Rome, Italy.
1948	Oliphant, Marcus L., B.Sc., Ph.D., F.R.S., F.A.A., Professor of Physics, The Australian National University, Canberra, A.C.T.
1948	Robinson, Sir Robert, M.A., D.Sc., F.C.S., F.I.C., F.R.S., Professor of Chemistry, Oxford University, England.

Obituary, 1956–57.

1898. Walter Fitzmaurice Burfitt.
1943. Robert Desider Louis Frederick.

THE REV. W. B. CLARKE MEMORIAL FUND.

The Rev. W. B. Clarke Memorial Fund was inaugurated at a meeting of the Royal Society of N.S.W. in August, 1878, soon after the death of Mr. Clarke, who for nearly forty years rendered distinguished service to his adopted country, Australia, and to science in general. It was resolved to give an opportunity to the general public to express their appreciation of the character and services of the Rev. W. B. Clarke " as a learned colonist, a faithful minister of religion, and an eminent scientific man ". It was proposed that the memorial should take the form of lectures on Geology (to be known as the Clarke Memorial Lectures), which were to be free to the public, and of a medal to be given from time to time for distinguished work in the Natural Sciences done in or on the Australian Commonwealth and its territories ; the person to whom the award is made may be resident in the Australian Commonwealth or its territories, or elsewhere.

The Clarke Memorial Medal was established first, and later, as funds permitted, the Clarke Memorial Lectures have been given at intervals.

CLARKE MEMORIAL LECTURES.

The practice of publishing the lectures in the Journal began in 1936.

Delivered.
1903. " The Life and Work of the Rev. W. B. Clarke." By Professor T. W. E. David, B.A., F.R.S.
1906. " The Volcanoes of Victoria " and " The Origin of Dolomite " (two lectures). By Professor E. W. Skeats, D.Sc., F.G.S.
1907. " Geography of Australia in the Permo-Carboniferous Period " (two lectures). By Professor T. W. E. David, B.A., F.R.S.
" The Geological Relations of Oceania." By W. G. Woolnough, D.Sc.
" Problems of the Artesian Water Supply of Australia." By E. F. Pittman, A.R.S.M.
" The Permo-Carboniferous Flora and Fauna and their Relations." By W. S. Dun.
1918. " Brain Growth, Education, and Social Inefficiency." By Professor R. J. A. Berry, M.D., F.R.S.E.
1919. " Geology at the Western Front." By Professor T. W. E. David, C.M.G., D.S.O., F.R.S.
1936. " The Aeroplane in the Service of Geology." By W. G. Woolnough, D.Sc.
1937. " Some Problems of the Great Barrier Reef." By Professor H. C. Richards, D.Sc.
1938. " The Simpson Desert and its Borders." By C. T. Madigan, M.A., B.Sc., B.E., D.Sc. *Oxon.*
1939. " Pioneers of British Geology." By Sir John S. Flett, K.B.E., D.Sc., LL.D., F.R.S.
1940. " The Geologist and Sub-surface Water." By E. J. Kenny, M.Aust.I.M.M.
1941. " The Climate of Australia in Past Ages." By C. A. Sussmilch, F.G.S.
1942. " The Heroic Period of Geological Work in Australia." By E. C. Andrews, B.A.
1943. " Australia's Mineral Industry in the Present War." By H. G. Raggatt, D.Sc.
1944. " An Australian Geologist Looks at the Pacific." By W. H. Bryan, M.C., D.Sc.
1945. " Some Aspects of the Tectonics of Australia." By Professor E. S. Hills, D.Sc., Ph.D.
1946. " The Pulse of the Pacific." By Professor L. A. Cotton, M.A., D.Sc.
1947. " The Teachers of Geology in Australian Universities." By Professor H. S. Summers, D.Sc.
1948. " The Sedimentary Succession of the Bibliando Dome : Record of a Prolonged Proterozoic Ice Age." By Sir Douglas Mawson, O.B.E., F.R.S., D.Sc., B.E.
1949. " Metallogenetic Epochs and Ore Regions in Australia." By W. R. Browne, D.Sc.
1950. " The Cambrian Period in Australia." By F. W. Whitehouse, Ph.D., D.Sc. (Unpublished.)
1951. " The Ore Minerals and their Textures." By A. B. Edwards, D.Sc., Ph.D., D.I.C.
1953. " Some Problems of Tertiary Geology in Southern Australia." By M. F. Glaessner, Ph.D. *Vienna*, D.Sc. *Melb.*
1955. " Some Aspects of New South Wales Gemstones." By R. O. Chalmers, A.S.T.C.

AWARDS OF THE CLARKE MEDAL.

Established in memory of
The Revd. WILLIAM BRANWHITE CLARKE, M.A., F.R.S., F.G.S., etc.
Vice-President from 1866 *to* 1878.

The prefix * indicates the decease of the recipient.

The list of recipients from 1878, the date of the first award, to 1929 may be found in Vol. LXXXIX (for 1955).

Awarded.

1930 L. Keith Ward, B.A., B.E., D.Sc., Government Geologist, Geological Survey Office, Adelaide.
1931 *Robin John Tillyard, M.A., D.Sc., Sc.D., F.R.S., F.L.S., F.E.S., Canberra, F.C.T.
1932 *Frederick Chapman, A.L.S., F.R.S.N.Z., F.G.S., Melbourne.
1933 Walter George Woolnough, D.Sc., F.G.S., Department of the Interior, Canberra, F.C.T.
1934 *Edward Sydney Simpson, D.Sc., B.E., F.A.C.I., Carlingford, Mill Point, South Perth, W.A.
1935 *George William Card, A.R.S.M., 16 Ramsay-street, Collaroy, N.S.W.
1936 Sir Douglas Mawson, Kt., O.B.E., F.R.S., D.Sc., B.E., University of Adelaide.
1937 J. T. Jutson, B.Sc., LL.B., 9 Ivanhoe-parade, Ivanhoe, Victoria.
1938 *Professor H. C. Richards, D.Sc., The University of Queensland, Brisbane.
1939 *C. A. Sussmilch, F.G.S., F.S.T.C., 11 Appian Way, Burwood, N.S.W.
1941 *Professor Frederic Wood Jones, M.B., B.S., D.Sc., F.R.S., Anatomy Department, University of Manchester, England.
1942 William Rowan Browne, D.Sc., Reader in Geology, The University of Sydney, N.S.W.
1943 Walter Lawry Waterhouse, M.C., D.Sc.Agr., D.I.C., F.L.S., Reader in Agriculture, University of Sydney.
1944 *Professor Wilfred Eade Agar, O.B.E., M.A., D.Sc., F.R.S., University of Melbourne, Carlton, Victoria.
1945 Professor William Noel Benson, B.A., D.Sc., F.G.S., F.R.G.S., F.R.S.N.Z., F.G.S.Am., University of Otago, Dunedin, N.Z.
1946 Black, J. M., A.L.S. (*honoris causa*), Adelaide, S.A.
1947 *Hubert Lyman Clark, A.B., D.Sc., Ph.D., Hancock Foundation, U.S.C., Los Angeles, California.
1948 Walkom, Arthur Bache, D.Sc., Director, Australian Museum, Sydney.
1949 *Rupp, Rev. H. Montague, 24 Kameruka-road, Northbridge.
1950 Mackerras, Ian Murray, B.Sc., M.B., Ch.M., The Queensland Institute of Medical Research, Brisbane.
1951 Stillwell, Frank Leslie, D.Sc., C.S.I.R.O., Melbourne.
1952 Wood, Joseph G., Ph.D. *Cantab.*, D.Sc. *Adel.*, Professor of Botany, University of Adelaide, South Australia.
1953 Nicholson, A. J., D.Sc., C.S.I.R.O., Division of Entomology, Canberra.
1954 *Clarke, E. de C., M.A., Emeritus Professor of Geology, University of Western Australia.
1955 Robertson, Rutherford Ness, B.Sc. *Syd.*, Ph.D. *Cantab.*, C.S.I.R.O. Plant Physiology Unit, Sydney.
1956 *Tiegs, Oscar W., D.Sc., F.R.S., Professor of Zoology, University of Melbourne.
1957 Crespin, Irene, B.A., F.R.M.S., Bureau of Mineral Resources, Canberra, A.C.T.

AWARDS OF THE JAMES COOK MEDAL.

Bronze Medal.

Awarded for outstanding contributions to science and human welfare in and for the Southern Hemisphere.

1947 Smuts, Field-Marshal The Rt. Hon. J. C., P.C., C.H., K.C., D.T.D., LL.D., F.R.S., Chancellor, University of Capetown, South Africa.
1948 Houssay, Bernado A., Professor of Physiology, Instituto de Biologia y Medicina Experimental, Buenos Aires, Argentina.
1949 No award made.
1950 Fairley, Sir Neil Hamilton, C.B.E., M.D., D.Sc., F.R.S., 73 Harley-street, London, W.1.
1951 Gregg, Norman McAlister, M.B., B.S., 193 Macquarie-street, Sydney.
1952 Waterhouse, Walter L., M.C., D.Sc.Agr., D.I.C., F.L.S., " Hazelmere ", Chelmsford-avenue, Lindfield.
1953 Rivett, Sir David, K.C.M.G., M.A., D.Sc., F.R.S., 11 Eton Square, 474 St. Kilda-road, Melbourne, S.C.2, Victoria.
1954 Burnet, Sir Frank Macfarlane, M.D., Ph.D., F.R.S., Director, Walter and Eliza Hall Research Institute, Melbourne, Victoria.
1955 Elkin, Adolphus P., M.A., Ph.D., Professor of Anthropology, University of Sydney.
1956 Clunies Ross, Sir Ian, Kt., C.M.G., F.A.A., D.V.Sc., LL.D., D.Sc., A.R.C.V.S., Chairman, C.S.I.R.O., Melbourne.

AWARDS OF THE EDGEWORTH DAVID MEDAL.

Bronze Medal.

Awarded to Australian research workers under the age of thirty-five years, for work done mainly in Australia or its territories or contributing to the advancement of Australian Science.

Awarded.

1948 Giovanelli, R. G., M.Sc., Division of Physics, National Standards Laboratory, Sydney.
Ritchie, Ernest, M.Sc., University of Sydney, Sydney. } Joint Award.
1949 Kiely, Temple B., D.Sc.Agr., Caroline-street, East Gosford.
1950 Berndt, Ronald M., B.A., Dip.Anthr., University of Sydney.
Berndt, Catherine H., M.A., Dip.Anthr., University of Sydney. } Joint Award.
1951 Bolton, John G., B.A., C.S.I.R.O., Division of Radiophysics, Sydney.
1952 Wardrop, Alan B., Ph.D., C.S.I.R.O., Division of Forest Products, South Melbourne.
1953 No award made.
1954 Barnes, Eric Stephen, Ph.D. *Cantab.*, University of Sydney, Sydney.
1955 Womersley, Hugh B. S., M.Sc., Ph.D., Botany Department, University of Adelaide.
1956 No award made.

AWARDS OF THE SOCIETY.

Money Prize of £25.

1882 John Fraser, B.A., West Maitland, for paper entitled "The Aborigines of New South Wales."
1882 Andrew Ross, M.D., Molong, for paper entitled "Influence of the Australian climate and pastures upon the growth of wool."

The Society's Bronze Medal.

Awarded from 1884 until 1896 for published papers. The Award was revived in 1943 for scientific contributions and services to science.

1884 W. E. Abbott, Wingen, for paper entitled "Water supply in the Interior of New South Wales."
1886 S. H. Cox, F.G.S., F.C.S., Sydney, for paper entitled "The Tin deposits of New South Wales."
1887 Jonathan Seaver, F.G.S., Sydney, for paper entitled "Origin and mode of occurrence of gold-bearing veins and of the associated Minerals."
1888 Rev. J. E. Tenison-Woods, F.G.S., F.L.S., Sydney, for paper entitled "The Anatomy and Life-history of Mollusca peculiar to Australia."
1889 Thomas Whitelegge, F.R.M.S., Sydney, for paper entitled "List of the Marine and Fresh-water Invertebrate Fauna of Port Jackson and Neighbourhood."
1889 Rev. John Mathew, M.A., Coburg, Victoria, for paper entitled "The Australian Aborigines."
1891 Rev. J. Milne Curran, F.G.S., Sydney, for paper entitled "The Microscopic Structure of Australian Rocks."
1892 Alexander G. Hamilton, Public School, Mount Kembla, for paper entitled "The effect which settlement in Australia has produced upon Indigenous Vegetation."
1894 J. V. De Coque, Sydney, for paper entitled the "Timbers of New South Wales."
1894 R. H. Mathews, L.S., Parramatta, for paper entitled "The Aboriginal Rock Carvings and Paintings in New South Wales."
1895 C. J. Martin, D.Sc., M.B., F.R.S., Sydney, for paper entitled "The physiological action of the venom of the Australian black snake (*Pseudechis porphyriacus*)."
1896 Rev. J. Milne Curran, Sydney, for paper entitled "The occurrence of Precious Stones in New South Wales, with a description of the Deposits in which they are found."
1943 Edwin Cheel, Sydney, in recognition of his contributions in the field of botanical research and to the advancement of science in general.
1948 Waterhouse, Walter L., M.C., D.Sc.Agr., D.I.C., F.L.S., Sydney, in recognition of his valuable contributions in the field of agricultural research.
1949 Elkin, Adolphus P., M.A., Ph.D., Sydney, in recognition of his valuable contributions in the field of Anthropological Science.
1950 Vonwiller, Oscar U., B.Sc., F.Inst.P., Sydney, in recognition of his valuable contributions in the field of Physical Science.
1951 Penfold, Arthur Ramon, F.R.A.C.I., F.C.S., Sydney, in recognition of his valuable researches in the chemistry of Essential Oils.
1952 No award made.
1953 Walkom, Arthur Bache, D.Sc., Sydney, in recognition of his valuable contributions to Palæobotany.
1954 Mellor, David Paver, D.Sc., F.R.A.C.I., Sydney, in recognition of his valuable contributions in the field of Chemistry.
1955 Woolnough, Walter G., D.Sc., F.G.S., in recognition of his valuable contributions in the field of Geology.
1956 Browne, William Rowan, D.Sc., F.A.A., in recognition of his valuable contributions in the field of Geology.

AWARDS OF THE WALTER BURFITT PRIZE.

Bronze Medal and Money Prize of £75.

Established as the result of a generous gift to the Society by Dr. W. F. Burfitt, B.A., M.B., Ch.M., B.Sc., of Sydney, which was augmented later by a gift from Mrs. W. F. Burfitt. Awarded at intervals of three years to the worker in pure and applied science, resident in Australia or New Zealand, whose papers and other contributions published during the past six years are deemed of the highest scientific merit, account being taken only of investigations described for the first time, and carried out by the author mainly in these Dominions.

Awarded.

1929 Norman Dawson Royle, M.D., Ch.M., 185 Macquarie-street, Sydney.
1932 Charles Halliby Kellaway, M.C., M.D., M.S., F.R.C.P., The Walter and Eliza Hall Institute of Research in Pathology and Medicine, Melbourne.
1935 Victor Albert Bailey, M.A., D.Phil., Associate Professor of Physics, University of Sydney.
1938 Frank Macfarlane Burnet, M.D. *Melb.*, Ph.D. *Lond.*, The Walter and Eliza Hall Institute of Research in Pathology and Medicine, Melbourne.
1941 Frederick William Whitehouse, D.Sc., Ph.D., University of Queensland, Brisbane.
1944 Hereward Leighton Kesteven, D.Sc., M.D., c/o Allied Works Council, Melbourne.
1947 John Conrad Jaeger, M.A., D.Sc., University of Tasmania, Hobart.
1950 Martyn, David F., D.Sc. *Lond.*, F.R.S., Radio Research Board, c/o Commonwealth Observatory, Mount Stromlo, Canberra, A.C.T.
1953 Bullen, Keith E., M.A., Ph.D., F.R.S., Professor of Applied Mathematics, the University of Sydney.
1956 Eccles, John Carew, M.A., Ph.D. *Oxon.*, F.R.S., F.A.A., F.R.C.P., Professor of Physiology, Australian National University, Canberra, A.C.T.

THE ARCHIBALD D. OLLE PRIZE.

Under a bequest from the late Mrs. Olle a prize, known as the " Archibald D. Olle Prize ", will be awarded " from time to time at the discretion of the Council to the member of the Society who in any year (in its opinion) submits to the Society the best treatise, or writing, or paper, on any subject coming within the province of the Society for that year ".

1956 Stanton, Richard L., Ph.D., for his paper " The Palæozoic Rocks of the Wiseman's Creek-Burraga Area, N.S.W."

AWARDS OF LIVERSIDGE RESEARCH LECTURESHIP.

This Lectureship was established in accordance with the terms of a bequest to the Society by the late Professor Archibald Liversidge. Awarded at intervals of two years, for the purpose of encouragement of research in Chemistry. (This Journal, Vol. LXII, pp. x-xiii, 1928.)

Awarded.

1931 Harry Hey, c/o The Electrolytic Zinc Company of Australasia, Ltd., Collins Street, Melbourne.
1933 W. J. Young, D.Sc., M.Sc., University of Melbourne.
1940 G. J. Burrows, B.Sc., University of Sydney.
1942 J. S. Anderson, B.Sc., Ph.D. *Lond.*, A.R.C.S., D.I.C., University of Melbourne.
1944 F. P. Bowden, Ph.D., Sc.D., University of Cambridge, Cambridge, England.
1946 Briggs, L. H., D.Phil. *Oxon.*, D.Sc. *N.Z.*, F.N.Z.I.C., F.R.S.N.Z., Auckland University College, Auckland, N.Z.
1948 Ian Lauder, M.Sc., Ph.D., University of Queensland, Brisbane.
1950 Hedley R. Marston, F.R.S., C.S.I.R.O., Adelaide.
1952 A. L. G. Rees, D.Sc., C.S.I.R.O., Division of Industrial Chemistry, Melbourne.
1954 M. R. Lemberg, D.Phil., F.R.S., Institute of Medical Research, Royal North Shore Hospital, St. Leonards, N.S.W.
1956 G. M. Badger, D.Sc., Professor of Organic Chemistry, University of Adelaide.

PRESIDENTIAL ADDRESS

By FREDERICK D. MCCARTHY, Dip.Anthrop. (Syd.).

Delivered before the Royal Society of New South Wales, April 3, 1957.

PART I.

THE SOCIETY'S ACTIVITIES.

The past year was the ninetieth of the Royal Society of New South Wales under this title, which was bestowed on May 1st, 1866. It was an important one for the Society. Due to the economics (dealt with in our annual report) effected in the Society's accommodation and in its various activities, our financial position is now reasonably sound, and should continue to remain so in the future. To ensure that it will, members are asked to bear in mind our need for more members, and also of associate members, the latter being a new category introduced to cater for undergraduates and the wives of members. We need, too, more members from the biological and social sciences to make the Society more representative of Australian science as a whole.

A glance at the presidential addresses and annual reports of recent years will reveal how earnestly the various Councils have considered ways and means of improving the Society's financial position, its journal and its programme of meetings. The retiring Council is no exception, and it has, I feel, taken positive action in a number of ways that will be of permanent benefit to the Society. Perhaps the Society's greatest need is for additional financial assistance with the printing of its journal, but to date no permanent source of such funds has presented itself.

This year saw the introduction of a new award by the Society, the Archibald D. Olle Prize, for the best paper submitted for publication by a member of the Society. It is hoped that the idea which prompted the late Mr. Olle to finance this award, which is a money prize, will yield an increase of papers of the highest quality and also an increase in membership.

The programme at the general meetings was an intensely interesting and important one. It included symposia on electron-microscopy, radio-isotopes and radiophysics, blood-grouping and pasture developments. An address on Antarctic research, an evening devoted to the commemoration of great scientists and one to the reading of papers completed the programme. All of these subjects are of topical interest and were dealt with clearly and lucidly by authorities in their fields. While some of the meetings attracted good audiences, others were very poorly attended, and your Council feels that members generally do not support the meetings, and in doing so the speakers and the Council, as well as they should. One of the Society's important functions is to bring together scientists from different disciplines to discuss their work, and our meetings provide an excellent opportunity for this purpose.

I have great pleasure in extending my sincere congratulations to the recipients of the Society's awards for 1956. Their outstanding scientific work has been honoured by the Society with awards which now include the names of many great Australian scientists, as a perusal of the lists, two of which extend back to 1878 and 1882, of recipients will reveal. The awarding of these honours is one of the most serious, and at the same time one of the most difficult, responsibilities of your Council each year.

His Excellency the Governor, Lieutenant-General Sir John Northcott, K.C.M.G., K.C.V.G., C.B., one of the two patrons of the Society, stressed the important part that science and scientific societies are playing in the world today when he welcomed the President and Honorary Administrative Secretary to morning tea at Government House on June 11th, 1956.

This has been a year in which the many participant nations began or continued their preparations for the forthcoming Geophysical Year, and already the profound scientific results that will ultimately be revealed by this comprehensive survey are becoming apparent. It is timely to note, also, the untiring efforts of UNESCO to bring about a greater understanding of one people's problems by another, particularly of the backward and economically poor peoples of the world. In this connection we find that acculturation studies by anthropologists and sociologists are providing a mass of data that will be of the greatest value in helping such peoples towards a better future. The alleviation of their bitter struggle to live, to gain an adequate education for their children, and enlightenment for themselves, is one of the major problems UNESCO is attempting to solve.

Science has not the need nowadays to publicize itself that it had formerly. The flood of popular scientific books and of articles in newspapers and magazines, and the regular sessions devoted to science on the radio and television, are spreading widely a broad interest in and knowledge of science among the lay population. That there has been a response is evident from the support given to such media of dissemination. The large audiences which attended the section meetings and public lectures of A.N.Z.A.A.S. at Dunedin this year, and the excellent coverage in the local newspapers, form good examples of the public interest in science today. Science has, nevertheless, a task of first-class importance facing it in the need to attract to its ranks a much larger number than it does now of the young men and women leaving school. It is essential to maintain the greater proportion of scientists and technicians needed in industry and government services today. There are wonderful opportunities for the young to gain a higher education, and better facilities would appear to be one solution of the problem.

It is with the deepest regret that I record the death of Dr. Walter Fitzmaurice Burfitt, a benefactor of the Society who had a lifelong interest in science and the Society, as manifested in his munificent gifts, which made it possible to establish a highly esteemed award for original research work over a period of six years—one which has proved to be a genuine inspiration to scientific workers in both Australia and New Zealand.

My own personal thanks are tendered most warmly to the Honorary Administrative Secretary, Mr. J. Griffith, for the very efficient manner in which he has carried out the exceptionally heavy duties imposed upon him during the year ; to the Honorary Editorial Secretary, Mr. F. N. Hanlon ; to the Honorary Treasurer, Mr. H. A. J. Donegan ; and to the members of the Executive, the Council and various sub-committees for their loyal support and for their keen interest in the welfare of the Society. Vice-President Dr. Ida Browne's watchful eye on our finances and her valued assistance in many other ways during the year merit special mention. Our thanks are due also to Miss M. Ogle, Assistant Secretary, for her conscientious work during the year, and to Messrs. F. Daly and I. A. Crawford for their voluntary assistance in the reorganization of the library.

PART II.

THEORETICAL CONSIDERATIONS OF AUSTRALIAN ABORIGINAL ART.

During the past twenty years the interest of the applied and commercial artist, architect, book illustrator and the scientist in aboriginal art has increased tremendously. The motifs are now applied freely in all kinds of commercial work, and vulgar as much of this exploitation undoubtedly is, we are left with the feeling that it involves an interest in the aesthetic, apart from the scientific, values, and in the meaning of aboriginal art motifs. Although much of the art on portable objects such as weapons, utensils, ornaments and ceremonial objects, and also on the bodies of the people, is purely decorative in nature, there remains an important proportion of it that is serious and sacred when used in a ritual or ceremony. Depiction of single figures, unrelated to any others, is common in rock engravings and paintings, but in all kinds of aboriginal art—whether it be on wood, rock, the ground, body or other medium—planned compositions are featured. Thus a wide range of techniques, motifs and ideas is involved, every available medium is decorated in some areas, form is notable in weapons and design in ornaments and ceremonial objects. Aboriginal art is not a single style, concept or school, but is a mixture of a number of them. The styles we call realism and abstract are both represented. There is no denying that it is art in the true sense of the term, an art that has developed along different lines, and in a different context, to our own. Nevertheless it has been nurtured from time immemorial by religious and aesthetic inspirations and has never attained a state of free and uninhibited expression. It is timely, therefore, to discuss, more particularly in the terms of Franz Boas (1955), its variety, representative and formal modes of expression, tools and materials, form and content, and its chronological history.

The Aborigines are a semi-nomadic hunting and food gathering people who live in small local groups confined to specific territories. The men paint and incise secular objects, decorate their bodies for corroborees and ceremonies, paint and engrave on rocks. The quality of their work varies, and that of talented craftsmen stands out in collections. To the men art is an integral part of their economic, social and ritual life. To the women it is a culture element of which they stand on the fringe, their work being limited mainly to body decoration and fashioning ornaments. In Arnhem Land, for example, the men decorate baskets made by the women.

The status of the artist in aboriginal society is not a specialized one as a rule, but the old men, and the few men unable to hunt or fish through ailments, who remain in camp making weapons and the like for which they are rewarded in food and other articles (Sharp, 1934 ; Thomson, 1949), may be regarded as craft specialists, like those at Ngillipidji quarry in eastern Arnhem Land, where the men of a local group own the site and spend a great deal of their time in making and trading stone knives (Thomson, 1949) of the Leilira-type (McCarthy, Bramell and Noone, 1946). The important group of ceremonial leaders of clan and cult groups who make and decorate ritual objects, and paint sacred figures in the caves, approach most closely to specialists in tribal art as a whole. A system of hereditary craftsmen, like that of Polynesia, is not established in Australia. The art of the Aborigines, therefore, is principally an art of the men, and in its higher forms of the ritual leaders and occasional talented old individuals.

Art, like music and language, is a means of expression, of perpetuating ideas, and of educating a people about the topography, fauna and flora of their habitat and about their own history. Whether art in aboriginal culture is a product of visual or mental processes, or of an innate visual sense of form, whether it arose out of a need and desire to employ symbols in magical and religious rites, will probably never be known, and need not be debated here. It is a psychological, emotional and visual link between the social, economic, magical and ritual life of the Aborigines. It combines an aesthetic impulse or desire for expression with inspiration from all aspects of life, and illustrates well the close-knit structure of a primitive culture.

Sir Herbert Read (UNESCO, 1954) implied that environment is the principal cause of different forms of art and of the comparative skill involved among primitive peoples, stating that " a people hunting bison and reindeer across icy tundras, and retreating periodically to the shelter of caves, is bound to produce an art different from that of a people chasing kangaroos through the hot desert ". It may be pointed out that no other of the prehistoric peoples of the world who lived in a similar cold environment to the Aurignacians and Magdalenians produced a cave art of such incomparable quality ; furthermore, that only a small proportion of the Australian Aborigines chased kangaroos in the hot desert and some, in fact, never chased them at all. But Aborigines who hunted and fished and retired to rock-shelters to paint have failed to produce realistic pictures of animals as technically fine as those in France and Spain for the reasons discussed later. Environment, then, may be rejected as the primary factor in dictating the artistic quality of aboriginal art.

A much more potent factor is the possession by a people of a rich mythology and religion. On the Sepik River in New Guinea, the fascinating body of beliefs is expressed in a remarkable art of wood carving and painting, bark cloth, pottery and other media, but in central New Guinea the cultures are as bereft of art as they are of mythology and folklore. In Australia art is highly developed in areas where an inspiring body of beliefs exist, as in Arnhem Land, Kimberleys, central Australia and south-eastern Australia, and this factor would appear to me to be one of the most important ones in the development of aboriginal art.

To Professor Elkin (in McCarthy, 1956*a*) aboriginal art arises for the most part out of, and finds its meaning and significance in, the sphere of ritual and belief, combined with an aesthetic sense, and Dr. Berndt (1952*b*) regards it in the same light. The combination of an active aesthetic desire, a dynamic cultural and mythological inspiration, and an environment providing suitable rock surfaces, has both induced and enabled the Aborigines to produce a vast array of engravings and paintings in many parts of the continent. The number of paintings runs into tens of thousands in Arnhem Land alone. It is likewise patent that the above desire and inspiration have produced the wealth of ornamentation, ritual objects and body decoration characteristic of aboriginal culture.

Boas (1955) in analysing primitive art, postulated that the principle must be accepted of the fundamental sameness of mental processes in all races and in all cultural forms of the present day. To him the difference in thinking is due to the advantage bestowed on civilized people by their accumulation of written knowledge and their constant search for improvements and new ideas, as against the manner in which primitive peoples are conditioned by their culture to accept and maintain without question traditional customs and beliefs so that the logics of science are not the logics of life. Primitive man thinks in a pattern in which magic, belief and subjective causality are important factors. There are many examples of a similar mode of thinking among civilized peoples today. It is true that the aesthetic and psychological approach of aboriginal artists to their work is limited by their cultural background and setting. They thus lack the freedom of our own artists who are ever seeking new techniques and fresh ways of presenting their ideas. McElroy (1952) concluded, after applying tests to 40 Aborigines and 40 Whites, that there is little or no evidence for the existence of inter-racial good taste based upon inherited predispositions ; his results, he thinks, provide much evidence in favour of the view that the beauty of a visual object is almost entirely determined by the cultural conditioning of its perception.

The Polynesians have emphasized the formal element in their art, in which conventionalized motifs are important mythological symbols. The art of Melanesia includes areas like the Massim in which formalism prevails, and others such as the Sepik district, with an intense emotional interest in representative form and in its emphasis by various sculptural devices. In Australia, a similar contrast may be drawn in the formalism of central Australia as compared with the naturalism of the Kimberley and Cape York cave paintings and of the Sydney-Hawkesbury district engravings.

Representative Art.

Representative, realistic or naturalistic depictions comprise the greater part of aboriginal art as a whole, not only as major motifs in rock art but as dominant subjects in a setting of cross-hatching, chevron and other line patterns, and in a dotted field, in decorative art. The principal subjects are mammals and reptiles, fish and sea mammals with some of the batrachians and birds. There are few insects, shells, invertebrates or plants portrayed in most areas. Human beings and spirits, weapons and other objects are common motifs. Generally speaking, the art reflects the fact that it is principally a male sphere and consequently the affairs and activities of the women enter very slightly into it and chiefly in so far as they are associated with the female ancestral beings. On the Forrest River some women paint Brimurer, the Rainbow-serpent, and here, too, the wife of a clan leader retouches totemic paintings during increase rites (Kaberry, 1935).

In three analyses of aboriginal rock art that I have made the results have demonstrated a wide variation in the emphasis upon the artistic value of specific subjects. A few examples will suffice. In the Sydney-Hawkesbury engravings the fish, kangaroos, wallabies, emus, shields and boomerangs are depicted more frequently than all other subjects. While the economic life is thus proved to be an important source of inspiration, it is combined with a high frequency of ancestral and ritual beings and their activities, tracks and weapons. In the paintings of this area human beings are more abundant than animals, among which the kangaroo-wallaby group and their tracks, and fish, take second place to the goannas. Among both the rock engravings and paintings such important sources of food as the wombat, possum, koala, echidna, rodents and tortoise are rare subjects, as is the dingo, and whales are unknown among the paintings. Another important point of contrast is that culture-heroes are seldom pictured in these caves, and they are rare among the cave paintings of Groote and Chasm Islands, where we find the harpooning of dolphins, turtles and dugongs by men in small canoes to be the main subjects of the artists; the animals are comparatively easy to kill by men armed with the detachable harpoon and dugout-canoe and form a major source of flesh-food, but in the Sydney-Hawkesbury district, where they are rarely shown in the rock art, the men no doubt found them difficult to spear from a frail bark canoe and consequently they were not of great importance economically. Lizards and weapons are common motifs in both localities. Whales, however, are featured among the Sydney-Hawkesbury engravings, being not infrequently stranded; they are not shown among the Groote and Chasm cave paintings, although they inhabit the seas of this area and are portrayed in the Arnhem Land bark paintings. Fish are not depicted in some coastal sites in Australia and although used as a food by inland tribes they are almost completely neglected by the latter as an art motif. Generally speaking, marine subjects are predominant in coastal areas, and animals—snakes, kangaroos, wallabies, lizards and emus principally—in the inland galleries. It is obvious that the relationship between economic and ritual subjects, as exemplified in the rock art, varies in many localities. The one may take precedence over the other in art, but the predominance of the most important economic species as art motifs within the framework of ritual is now becoming clearer as more groups of art are analysed.

The northern Kimberley tribes believe that everything edible is painted in the Wandjina caves, when in reality only a small proportion of these items is so depicted (Love, 1930).

As representative subjects, human and huge spirit beings are the dominating motifs in the Kimberley paintings and in the Sydney-Hawkesbury engravings, with them being found mythological figures like the Rainbow-Serpent and others often of curious shape, and also weapons and utensils. This complex of human, animal and spirit beings, of animals and tracks, weapons and utensils, forms a nucleus of representative art which extends from north-western Australia through the Kimberleys, Arnhem Land and the Northern Territory to parts of central Australia, and most of Victoria. The variation in subjects in the art of different parts of Australia and the many inconsistencies in different areas indicates that numerical analyses are needed from many localities and types of art to ascertain to what degree art is a reflection of local socio-economic and religious beliefs, and to make it possible to establish general principles or conclusions about this important aspect of aboriginal art.

Representative motifs occur in all kinds of aboriginal art, including body painting, but for the purposes of this discussion the cave paintings will be dealt with in detail. The amazing uniformity of style in most parts of the continent is a good example of the stability of tradition in aboriginal culture. Whether we examine the paintings and engravings in New South Wales, Queensland, Arnhem Land or Western Australia, we find the same technical devices in use for portraying various subjects. These include depicting human beings from the front with varying numbers (or none) of fingers and toes, two eyes, no mouth or nose and often no ears or neck. The head is not enlarged because of its importance in belief as it is in Melanesia and Polynesia. The arms are outstretched or upraised, but in the Kimberley Wandjina cave paintings they are held stiffly at the sides of the body. The genitals are inconspicuous in the art of some localities but of exaggerated size in other areas, notably Arnhem Land, but in the Sydney-Hawkesbury engravings the size varies according to the nature of the figure. Many variations occur in the postures of the human figures which include those seated, running, lying down, dancing, fighting and throwing weapons. The types range from the stick-men so gracefully refined in western Arnhem Land and Groote Eylandt to the huge culture-heroes of the Sydney-Hawkesbury engravings, and the stiff and poorly proportioned Wandjinas of the Kimberleys. Chronological studies of the mythology and relevant paintings throughout the continent would throw a great deal of light on the variations of styles. Macintosh's study (1951) attempts such an analysis for some southern Arnhem Land paintings.

The mammals, birds, fish, whales, dolphins and sharks are drawn in profile, each type being stylized, with a line for the mouth, one or two eyes, the outline of one limb for each pair of limbs ; fins are shown as part of the main outline of the fish. The numbers of toes and claws vary, and on the birds the wings are not shown unless in flight. Snakes are shown from the side or top view, but the lizards, frogs, turtles and tortoises are usually depicted from above. Thus the subjects are portrayed from the angle at which they are usually seen by the artists, although the poses vary widely in occasional portrayals from the basic stylized type. Examples that might be mentioned are kangaroos hopping, emus running, or both of them feeding or standing on the alert. The young is often shown in the pouch of kangaroos, and the emu may be standing beside or sitting on its eggs. Groups of old and young emus and kangaroos are common. A peculiar error in drawing kangaroos is that the hump of the great loins is often misplaced as far forward as the neck.

Stylization, however, even though it is so firmly established in aboriginal art, has not completely suppressed virtuosity. The artists are, in a sense, impressionists concerned primarily with posture and general outlines, depicted within traditional limits, but even under this restraint they have produced admirable examples of rock and other art which demonstrate a relatively high appreciation of line and mass in the best figures. Their pictures are mental images and symbols, and not representations drawn in the manner of a still-life painting.

There is a lack of any indication of body contours or tones, and of fur, feathers or scales in most of the representative art. Exceptions are feathers shown in a simple way on cave paintings in the Kimberleys and both feathers and wings on birds, by areas of dots or lines, in the bark paintings of Groote Eylandt. But the general omission of these characters elsewhere reduces considerably the artistic possibilities and scope of the artists' work. Nevertheless, although the forms are constant many individual paintings demonstrate that some artists have the skill to infuse into their work a certain amount of animation in capturing a posture or action of an animal, to the degree in some instances of producing a figure of outstanding artistic merit.

The techniques, on the whole, are simple. The painting methods display some measure of control even though much of the work is done on poor surfaces. It is difficult to determine the degree of interest of the Aboriginal artists in technique. One gains the impression from their cave and other paintings that the representation itself, the symbol, however technically deficient, is of greater importance than the method. Should this be true, it is probably the reason why their work has never risen to the great heights artistically of that of the Aurignacian and Magdalenian cave painters and engravers in the late Palæolithic period in southern France and northern Spain. The skill and knowledge of the aboriginal artists are certainly insufficient to imbue their pictures with the intense feeling and character of those of the Palæolithic artists, or with tonal variations of colour to show body contours.

Aboriginal representative art is, on the whole, child-like in its conventions. As Boas said (1955), the principles of selection in both primitive and child art are based more upon the inclusion of essential features, such as two eyes when only one should be shown, than upon a mental image of the subject. Both adopt a symbolic style in which accuracy as such is not essential because they are more intent upon including the features by which they visualize a creature or human being, an approach that Dr. Adam (1948) has called intellectual realism, than of drawing what they can see from a certain angle. There is an inconsistency in this approach inasmuch as both groups of artists will show one leg or ear when they know two of each should be shown.

FORMAL ART.

To an artist nurtured and trained in a culture in which formal art is the norm it is highly probable that the enjoyment of form is as great as that derived from representative art. In Australia the comparatively intense development of formal or geometric art is probably due to introduced ideas, not to a chronological evolution from the representative to the formal, but there must at the same time be an aesthetic interest even though the content is the more important element in the art.

In south-eastern Australia the formal designs consist of a concentric diamond set in a field of herringbone, chevron and sets of parallel lines incised at various angles. These designs illustrate well the manner in which the Aborigines set out a field and the importance of rhythmic repetition in aboriginal art. The diamond may be incised in parallel rows, or so placed that the flutings of one side form in turn one side of another concentric diamond, thus producing neat and complementary rows. It is sometimes distributed freely in no set order in the field. Where the designs are incised on cylindrical clubs, rubbings reveal that they are planned as though worked out for a flat surface. Occasionally small human or animal figures are introduced. The surfaces of the shields of this area are often divided into panels of design separated by plain bands to set off effectively the patterned panels. Each shield's surface is treated in the mass, that is, the design is taken to the edges without a marginal band or is divided into panels in a vertical, horizontal or other symmetrical arrangement. A favourite device is one in which the bands are cut in low relief through the incised pattern, thus leaving imperfect half diamonds or sets of grooves with their ends abruptly cut off. On other examples a complete design is laid out in each panel. The panels vary in length. In a symmetrical treatment of a shield's surface a short panel with a distinct design is placed between two panels each bearing the same design, which is different to the middle panel. Planned asymmetry on another shield consists of three panels of different size, each of which bears a different design. The panels are divided by bands which form a separate pattern outlining lozenges, rectangles, squares or triangles, while some of the bands are in parallel chevrons, zigzags and crosses. The plain smoothed surface of these bands blends harmoniously with the incised panels. This contrast used as a design element is well shown on the boomerangs and Lil-lil clubs of south-eastern Australia, on which linear arrangements of the design elements are common. On some specimens the intricate pattern of flowing sinuous lines, combined with straight lines, widens the scope of the artists' work. The designs are highlighted with white and red paint.

Another interesting technical device is the use of opposed and carefully arranged rectangles of concentric diamonds defined only by the punctures at the terminations of the grooves, on which reflected light produces two designs according to the angle from which it is examined. The range of cream to plum-red colourings in the fine textured and hard mulga and similar woods harmonizes perfectly with the tooled surfaces of the long boomerangs in western New South Wales.

The evenness and uniformity of the grooves, the great variety and ingenuity of the attractive patterns, demonstrate a certain mastery of technique and motor habits, a control of design which forces the admission that the finest examples of the craftsmen's work in south-eastern Australia are artistic in the true sense of the word, fashioned with a strong interest and pleasure in their aesthetic standards, quite apart from the importance of the content or significance of the art to the people. When extended into the larger surface areas of the dendroglyphs the designs become more powerful in effect with their deeper and wider grooves, but the unevenness of the work reveals a lesser control of technique.

In Western Australia the incised work on the spear-throwers, shields and ceremonial boards is comparable to that of south-eastern Australia in manual control over tools and materials, and in the mastery of planned designs in which rhythmic repetition, symmetry and asymmetry, and the use of patterns of light on opposed groups of surfaces, are characteristic features. The ingenuity and variety of designs and the wide range of ideas involved, particularly in the use of the zigzag motif on the spear-throwers, illustrate well the relatively intense aesthetic feeling and pleasure embodied in the attitude of these craftsmen to their work. This attitude in both regions has given the work that indefinable but apparent feeling of true art, even though it is on a completely different plane to that of a Chinese bronze or an African Negro sculpture.

In painting the artistic merit of the formal art is more difficult to assess, and is certainly not as high as with the representative art. In north-eastern Queensland symmetry is the basis of the large shield designs in which a boss forms the central point of a vertically or bilaterally balanced design, to achieve which the naturalistic motifs are modified and conventionalized in a variety of ways. Here, too, the patterns are deliberately planned by skilled designers. As two men paint each shield together, symmetry is a convenient principle for them to work upon. Although the surface of the corkwood shields is rough, and the application of the paint is not technically highly skilled, we must accept the blend of design, colour and symmetry as being of some artistic value in a contemporary style.

In Arnhem Land the formal elements are used as complete symbolic designs or in association with animals and other naturalistic motifs. The formal elements are numerous, being dominated by cross-hatched and parallel lines, but the technique is crude and aesthetically of little interest. The same remark applies to the dotting technique in central Australia and on Groote Eylandt. On the twined baskets of Arnhem Land the symmetrical panels each contain a similar or completely different design to one another, and are separated by strips of colours. The treatment of the surfaces is thus akin to that of south-eastern Australian decorative art.

The use of formal elements in this area is well illustrated on the bark baskets of Bathurst and Melville Islands, on which a wide range of well planned designs is painted. Again we find symmetry and the use of panels applied as important principles but asymmetry and the mass treatment of a surface are not uncommon. These baskets cannot be regarded very highly from the technical point of view but the use of colour in mass and broken style to emphasize the power of the design is so skilfully and artistically developed that the designs must be ranked in the category of art. They compare well with the abstract art of our own civilization today. There appears to be a greater freedom here in the creation and assembly of the design elements than elsewhere in Australia.

In another technique the formal element in art is also well illustrated by the ceremonial *waninga* and *natandja* totemic and historical symbols of central Australia and neighbouring areas (Spencer and Gillen, 1927). They are made of frames of sticks upon which diamond, rectangular, elongate, hexagonal and other designs are fashioned by the winding of human hair and possum-fur-string, and string decorated with feather down, on which patterns of red and white feather down and tufts of birds' feathers are made. Few of these symbols resemble the totemic object they represent, exceptions being those for yams, emu and some fruits. Some have been likened to a stretched-out animal skin, others are really derivations of the concentric diamond thread-cross (Davidson, 1951) so widespread in Oceania. The formal examples are symmetrical in principle, and the surface is treated as a whole, but their artistic value lies in the effect achieved as part of a tableau in which a decorated man is carrying or wearing one of them.

Geometric motifs among the rock engravings and paintings are not of a high artistic standard either in technique or arrangement. Perhaps such groups of paintings as the honey-ant, witchetty grub and wild plum (Spencer and Gillen, 1899) in central Australia achieve a pleasant decorative effect, but their purpose is essentially ritual and not artistic in the aesthetic sense of the term. These remarks apply also to the grooved ground drawings and to the crudely modelled "sand" figures of culture-heroes in south-eastern Australia. The Warramunga and nearby tribes in northern central Australia paint large formal designs on the ground which illustrate activities of ancestral beings in their mythology. These are traditional patterns, mostly asymmetrical in principle, but they achieve a distinctly powerful artistic effect by the beauty and colour of the designs and in their setting. There is a flowing grace about the snake designs seldom achieved in other forms of aboriginal art.

Certainly the range of art contradicts most emphatically the statement of Goldenweiser (1921) that the decorative art is quite simple, and realistic representations are apparently foreign to Australia.

SYMBOLISM.

Aboriginal art includes biological, social, ritual, geographical and astronomical subjects in which form and meaning combine to add to the aesthetic pleasure, as Boas (1955) has said of primitive art generally. Ritual objects are in the main created to represent an animal or other character or feature of a myth, such as totemic symbols in various parts of the continent, and in this instance obviously came into being to fulfil a ritual need.

Certain ceremonial objects, such as *tjuringa*, *waninga* and *natandja*, satisfy a definite need as symbols of existing beliefs and practices, and are useless for any other purpose, but where a bark container represents the type used originally by a spiritual ancestor we are dealing with an object of both practical use in everyday life and of ritual significance in ceremonies.

One of the main deficiencies in our knowledge of aboriginal art lies in the significance of many sites of rock engravings and cave paintings. Few Aborigines have made comments worth recording about the engravings (Elkin, 1949; Harney, 1951) and while we know that some of them are sacred, we cannot be certain about others. Many groups of engravings are adjacent to camp sites, and in fact most of the engravings in the interior are situated beside the most reliable waterholes in the countryside. We know that the Wandjina galleries of paintings in the Kimberleys (Elkin, 1930), the totemic galleries in central Australia (Spencer and Gillen, 1899) and some of those in south-western Arnhem Land (MacIntosh, 1952; Elkin, 1952) are still sacred to the local tribes. But the accent on ritual value varies considerably. Men, women and children camp in the rock shelters of the Oenpelli area in the wet seasons (Spencer, 1914) and all see the wealth of X-ray and other paintings on the walls and ceilings, as they do at Princess Charlotte Bay, Cape York (Hale and Tindale, 1934), in the Sydney-Hawkesbury district (McCarthy, 1948) and other localities. Thus while some galleries of paintings are sacred through totemism, or in connection with the pre-existence and re-incarnation of spirits, with ancestral beings or magic, the generalized statement that "there are some secular galleries which any person male or female may visit but the vast majority are sacred" (Elkin and Berndt, 1950) applies in some areas but not in others.

The grooved ground figures in south-eastern Australia, and the painted ones in central Australia, are sacred because they are made only in rituals, but the scratching of casual figures and tracks in the soft soil or sand is a widespread practice of both sexes of all ages. Decoration of the body, weapons, utensils and other objects follows the same pattern—some are decorated for purely artistic purposes at corroborees, others for varying ritual purposes in totemic, historical and other ceremonies. A considerable portion of the art is thus available for all of the tribe to see, and its sacredness is a question of context, not of form. There is, however, a very important group of symbols, such as the *tjuringa*, *waninga* and *natandja* of central Australia, the *rangga* of Arnhem Land, and similar objects in other areas which are made and seen only by the men initiated into particular cults or totemic groups, and which are so sacred that for a woman or uninitiated man to see them being made or used would mean death by violence or sorcery. Ground and rock art situated along the mythological pathway of an ancestral being is included in this category. Thus the significance of aboriginal art ranges from much that is casual, done by anybody, seen by everybody, to ritual art of great sacredness portrayed and used in the greatest secrecy by small groups of initiated men. Between these two extremes are designs which are sacred only in a ritual context like the geometrical or formal art of central Australia.

In Australia the relationship between symbol and meaning, or form and content, is not only with individuals but equally strong with clans or other social groups, and with the cult groups to which the designs belong, not so much to a tribe as a whole. The members of these groups react to their art designs and symbols in a consistent and unfailing manner, as part of what Boas (1955) has called expressionistic art. This attitude is typical of totemites to their totemic clan designs in central Australia, to ritual groups such as the Djunggawaul, Kunapipi and others in Arnhem Land (Berndt, 1951, 1952*a*; Warner, 1937), to the Djanba dancers of the Kimberleys, and others. Thus the real value of the art appears to lie in the content, not in the form, particularly where geometric shapes represent the natural objects used as totems. Art in aboriginal life can thus be part of a cycle beginning with the pre-existent spirit which decides the totem of the individual, and therefore the art group to which he will belong and other relationships. These bring him into touch with tribal art as a whole, with which he makes contact in many other ways. Art, like the individual and group, is part of a complex of social and economic, ritual and magical, aesthetic and mythological elements in tribal life. It is a link in the chain which is of immense benefit to society and its members. Thus the esoteric character of aboriginal art cannot be understood by an examination of specimens alone. The vital message it holds for the initiated men can only be assessed by an empirical study of the culture and its symbolism as a whole. Much of the sacred art of the Aborigines is the business of cult groups through which every member passes on initiation and comes within the category of a secret society with a group significance. On the other hand, the art employed by a rain-maker, sorcerer and in other forms of magic, or by the hunter or fisherman, is full of meaning to individuals. Thus the art exhibited widely in aboriginal life is done by a section of the men, not by all of them. Casual art in caves has a secret meaning to the men which is never revealed to the women and uninitiated.

There are exceptions to the claim (Elkin and Berndt, 1950) that the sacred significance of portable art is of a temporary nature in Australia and that the ritual value of permanent symbols painted and engraved on rocks is incidental. It is true that the *waninga*, *rangga* and similar objects are dismantled after ceremonies but the solid portions of them, like the *tjuringa*, hardwood *rangga* and Djanba sticks, are kept in secret places and are always sacred to the initiated. The sites of the Wandjina cave paintings of the Kimberleys, and those at totemic centres elsewhere, are taboo to the women and uninitiated. It is the degree of sacredness that is important. It is at its height when the rites are being performed, and the presence of the spirits is evident, when objects or designs become imbued through songs and chants in the ritual atmosphere of the spirit world. Thus the initiated men see the world about them with different eyes to the women and uninitiated because of their special knowledge of belief and art, the inside meaning as it is called, of the tribal explanation of life, of their science and logic. Designs carved and painted on weapons imbue them with a magical efficiency, but they are always permeated with the power of the secret life, otherwise the designs would serve no useful purpose, and for this reason are always sacred to the owner even though publicly displayed.

There are certain minor points of interest. The design is not named separately as such, but bears the name of a totem or hero, and a clan design is usually named after its totemic site. Similarly with ownership, a design belongs to a clan or cult group but with the bark paintings in Arnhem Land a design belongs to the man who dreams it. The meaning of one motif varies considerably. Thus concentric circles in central Australia may stand for a plant, rock, animal, spirit or ancestral being, and other things, according to the totemic design in which they are incorporated (Spencer and Gillen, 1927). In this area the elements of circles and half circles, sinuous lines, tracks and a few others are arranged in hundreds of clan patterns and they have a different meaning in each one. Thus while a motif has various meanings in one tribal art it will also have a wider range of meanings in the other localities in which it occurs. In Arnhem Land symbolism has been taken further than elsewhere in that panels of parallel and cross-hatched lines are included in the bark paintings to represent clouds from which rain is falling, pink clouds which appear after rain, waves breaking upon rocks, seaweed in the sea, and other interesting features of the landscape.

COMPOSITIONS.

In keeping with the broad artistic approach to their ceremonies, in which music, chants, dancing, acting and decoration all play their part in the performances, the Aborigines feature compositions in their art, particularly in rock engravings and paintings, and in the bark and ground drawings. These compositions illustrate activities of everyday life, particularly of the animals sought for food (McCarthy, 1939, 1941–54, 1956*b* ; Campbell, 1899). Among them the hunting of kangaroos and emus and the catching of fish and sea mammals are shown as simple groupings in many galleries throughout northern and eastern Australia, often linked together by the tracks of the animals and hunters. On Groote and Chasm islands men armed with detachable harpoons are shown catching fish, turtles, dolphins and dugongs in numerous cave paintings which exaggerate very considerably the size of the animals being caught (McCarthy, 1955). These hunting and fishing scenes are depicted sometimes as an ordinary daily event ; others are of totemic or historical ritual significance. Tiny men hunting large animals are characteristic of western Arnhem Land, in the Mimi series of paintings (UNESCO, 1954), but in the Sydney-Hawkesbury district engravings most of the hunters and animals are life-size and sometimes bigger.

At Mootwingee in western New South Wales the most important single motif among the engravings is the hunting of emus, shown in numerous compositions of tiny men, large tracks and miniature clutches of eggs (McCarthy MS). Among the paintings at this site hunts are reduced to the tracks of the hunters and of their dogs and the kangaroos. In the central Australian area of formal art similar rationalizations of hunts and ceremonies are represented in a symbolic manner with concentric circles, half circles, sinuous lines and other motifs and by emu or kangaroo tracks inside a circle. Ceremonial compositions are strikingly portrayed among the Sydney-Hawkesbury engravings (Campbell, 1899 ; McCarthy, 1941–54, 1956*b*), south-eastern Australian ground drawings, Northern Territory Lightning Brothers' cave paintings (Davidson, 1936), Kimberley *wandjinas* (Mrs. Schulz, 1956), central Australian *tjuringa* (Spencer and Gillen, 1927), and the bark paintings of Arnhem Land (McCarthy, 1956*a*). In the decorative art on the carved trees of New South Wales, the shields of south-eastern Australia and north-eastern Queensland, the spear-throwers of Western Australia and other objects are to be seen compositions of symbols which are also used in ritual art in a sacred atmosphere. It is obvious that a great deal of aboriginal art is a planned aesthetic activity, to be interpreted from the collective point of view, as a composed work of art.

Dramatic settings undoubtedly appeal to the Aboriginal artists, a fact brought out well by the perfectly arranged tableaux to be seen in the rituals of central Australia and Arnhem Land. The colour film of the central Australian totemic increase rituals of the native cat ceremonies at Watarka, taken by Dr. T. G. Strehlow, to be shown at the conclusion of this address, illustrates beautifully this concern for planned effect, in the same manner as the choreographer, musician and artist plan the compositions of our own ballets. In central Australia the painted and feathered decoration of the dancers, the siting of decorated poles combined with ground drawings, with a prevailing red and white or black and white colour scheme standing out strikingly against the grey-green vegetation or the red rocks and sand of the sacred totem centres, emphasizes the intense interest of the Aborigines in the all-over dramatic effect of a ceremony, no doubt partly to impress initiates. There is, too, the undoubted admiration felt for and appreciation of the song and dance corroborees in which some individuals excel, compositions which may travel widely, together with body decorations, to tribes which do not know the meanings of the songs or of the designs, but who are always eager to enjoy new dance-dramas of this kind.

Tools and Materials.

Boas (1955) stressed the importance of motor habits in developing the art of a primitive people and to them he attributes some of the decoration of a repetitive type. He said, further, that increasing technical skill and perfection of tools bring about changes which are determined by the general cultural history of a people. In Australia relative mastery of techniques or of the motor habits of the craftsmen has undoubtedly been a contributing factor in the development of a wide range of incised decorative art on the spear-throwers of Western Australia, the shields of south-eastern Australia, and the boomerangs of central-eastern Australia, which bear designs composed of straight and curved grooves of remarkable evenness and uniformity. Here, the technical treatment has attained a certain standard of excellence, the processes or mechanical actions of working have produced typical forms and the result may be regarded as aesthetic in its pure sense. The craftsmen in Australia have thus mastered their bone, stone and shell tools, and combined with this achievement a feeling for and pleasure in beauty that some of their products reveal in both form and decoration. In other words, they have a will to produce an aesthetic result, as Riegl (Boas, 1955) expressed it.

The aesthetic sense is revealed also in the method of working. The Aborigines are copyists to a limited degree only. In some caves the artist painting on a wall cannot help but observe and be influenced by the work of earlier generations. Thus on Groote Eylandt the paintings in several large caves represent the pictographic art of the local people from the time their ancestors occupied the island to the present day, and constitute permanent reference galleries for succeeding generations of artists. In other caves, the pictures are painted on an unused wall. Similarly, in the Sydney-Hawkesbury district, virgin rock surfaces formed the canvas of the artists for a great variety of subjects. Nevertheless, the approach of the Aborigines to their art conforms in the main to Boas' statement (1955) that the imagination of primitive artists never rises above that of the copyist, although the bark paintings of Arnhem Land form an exception to some extent in Australia. The Aborigines are critical of their tribal artists' work and pay due accord to a man whose paintings or carvings are of outstanding merit. They are especially critical of the artist who leaves out details of ritual designs, one who fails to perpetuate the traditional norm of tribal art. Poor work is unusual and the general standards of execution are usually high.

Great care is taken in painting or incising a ritual design while the sacred songs are chanted to see that the best possible job is done. I have seen a Groote Eylandt man scolded and taken away from painting a totemic design on a young boy's chest just prior to the latter's circumcision because his work was inferior and incorrect.

One of the outstanding weaknesses of aboriginal art lies in the use of pigments and paints. The artists mix and apply their colours somewhat thickly, and fine work such as the parallel lines in the X-ray paintings of western Arnhem Land is exceptional. The palæolithic artists of Europe had so deep and wide a knowledge of colours that they could mix a variety of shades and apply them in the most delicate gradations. This lack of knowledge of materials prevented the Aborigines from raising their technical standards as high as they might have done. The results certainly please them, while trade and gift exchange are added incentives to produce the best possible work within the limits of their skill and knowledge.

In the placing of their colours the Aborigines display a confidence and certainty which amounts to a relative mastery of tribal design. The colours may accentuate the curves of a spear barb and emphasize its form, or break up the long-toothed pattern of two rows of barbs. On the north-eastern Queensland shields and on the Bathurst and Melville Islands baskets contrasting colours in the mass are used with an admirable sureness of values in both symmetrical and asymmetrical designs. In south-eastern Australia red and white, or red and yellow, are added to emphasize the panels in the designs. In central Australia, Northern Territory, Arnhem Land and other places the strong appeal of colour to the aboriginal artist is evidenced by the manner of its use in rituals and on ceremonial objects. The strong contrast in their use of colour is due to their adherence to the four main colours of red, white, yellow and black.

With stone implements the Aborigines have achieved an artistic standard, or a mastery of technique, in a few types only. The biface Kimberley spear points, the uniface *pirri* and *bondi* points (McCarthy, Bramell and Noone, 1946) bear a finish far more elaborate than is necessary for utilitarian purposes. The pressure chipping technique employed demonstrates a control over material exemplified equally well in points made from bottle glass and telephone insulators in modern time as in stone. Even so, their skill does not reach that of the Solutreans nor of the American Indian stone point makers, just as that of their painters is not the equal of the Magdalenians and Aurignacians. The control of motor habits is shown to advantage on the tooled surfaces of the boomerangs of western and central New South Wales and of Western Australia, on which a stone adze-flake mounted in gum on a stick or spear-thrower is used to strike off chips of wood of even size and thickness to produce an artistically finished weapon which would be just as effective without such a surface. The parallel grooving combined with the splendid forms of many of the wooden coolamons of central and Western Australia are in the same category, demonstrating a delight in rhythmic play with a technical process. A deficiency of technique exists in the twined baskets of Arnhem Land and Cape York and the coiled baskets of south-eastern Australia, where the patterns are not interwoven like those of the American Indian and African Negro but are overstitched or painted on the baskets. The ideal standards for the form and finish of various objects are based essentially upon those developed by expert technicians of former generations as in other primitive societies (Boas, 1955), but these standards are no doubt undergoing constant change and possibly improvement. It would be interesting to check this point in Australia by a time study of old and recent specimens in museums.

The work of individual painters can be recognized in the cave paintings of Groote and Chasm Islands, and in the bark paintings of Arnhem Land generally. Some of the Groote painters work in finer lines and smaller dots than others, resulting in a loss of the power of the stronger designs. Records of the names of native artists have not been kept in other parts of Australia and it is probably impossible to check this point elsewhere.

The Aborigines possess a marked ability to handle large surfaces and to treat them in the mass or as a whole. Thus compositions in the Sydney-Hawkesbury engravings are planned and executed on flat and undulating rock surfaces 30×40, 100×30 feet and so on in size (Campbell, 1899; McCarthy, 1941–54, 1956*b*). On Chasm Island is a cave wall 40×20 feet in size which has been utilized perfectly for a frieze of large dolphins and turtles, and there are many other examples, including the ground figures on the initiation or *bora* grounds of New South Wales, and the Wandjina cave paintings in the Kimberleys (Elkin, 1930). Large surfaces on poles up to 20 feet high are handled with skill on the Jelmalandji poles and grave-posts of Arnhem Land, the carved trees of New South Wales and the *natandja* symbols of central Australia. The Aboriginal artist adapts a surface of wood, bark, rock, skin or the ground to his needs, but the question of mastery is perhaps more apparent with wood than with any other of these media.

Form is a feature of Aboriginal work, as a glance at a collection of weapons and coolamons will demonstrate. It is moulded by two factors, efficiency and weight. The natives cannot carry heavy ungainly weapons, as many of them are used as missiles, and their shape must be suited to their function. Consequently, weapons such as boomerangs, clubs, hafted adzes and axes are light, streamlined and fit into the girdle of the owner. As a rule only simple elements such as rim bindings on a basket and graduated bands on club heads are used to emphasize form. It is in the control of form in adapting it for specific purposes that a latent talent for plastic art is seen to exist among the Aborigines, but it has not been manifested, nor given the necessary cultural inspiration to develop, apart from the crude wooden and gum sculptures of Arnhem Land (Elkin and Berndt, 1950), Cape York and the northern Kimberleys.

The time factor in executing art work by the Aborigines has not been studied. Obviously the time given to such work by semi-nomadic hunters and fishermen in the wide range of habitats in Australia would vary widely, those in a fertile area being able to give more time to aesthetic interests than those living in the arid interior. Time is not an important factor in the lives of the Aborigines. In ritual art the execution of art work fits into the pattern of sacred chanting and the performance of rites, and of secular art into the pattern of economic and ritual activities. The most interesting aspect of time would be the relative amount given by members of groups in different environments to art but it is now too late to study this problem.

The effect of white contact upon aboriginal art varies. In the Kimberleys the demand for spear points has led to a marked improvement in technique. In Arnhem Land the curio demand for bark paintings has led to the production of much smaller examples than previously to speed up production, but the line work is just as carefully done as previously, although noticeable deterioration has taken place in the Groote Eylandt bark paintings in recent times. In various parts of Australia a decorative art technique involving the pressing and moving along of the sharpened end of a nail or narrow piece of iron, producing a crude meandering line pattern, was developed almost as soon as the Aborigines began to use metal tools.

Styles and Techniques.

According to Boas (1955) there are no generally valid laws that control the growth of specific art objects, but motor habits, maintained by conservatism, exert a strong influence on the development of styles because they are repeated with a confidence and pleasure based upon experience and familiarity.

A variety of styles exists within each of the major techniques of painting, engraving, modelling and sculpturing, feather-down and poker work employed by the Aborigines. Thus in cave paintings I have listed sixteen monochrome, ten bichrome and five polychrome styles employed on the continent. These are used to a greater or lesser degree on wooden objects and on the bodies of dancers and actors, on bark sheets and on the ground, but on none of these media as widely as in the cave paintings. There are six styles of rock engraving, most of them done by puncturing and pecking, due to the nature of the medium, but on wood the designs are cut, pecked or burnt-in. Styles in the other techniques are limited in nature. The 31 painting styles (McCarthy, 1955) are not restricted singly to regions in the distinctive manner of the petroglyph techniques and up to a dozen or more of them occur in the one gallery in some localities. While it cannot be shown that a chronological sequence exists from the simplest to the most advanced style of painting, it is apparent that there has been a progression from a simple group of stencil, outline and silhouette styles in south-western Australia to X-ray bichromes, and also to geometric and representative polychromes in the central and northern regions of the continent. Thus my study (1955) of the superimpositions of cave paintings on Groote and Chasm Islands revealed that some styles, including stencil, silhouette, outline and striped, date from the earliest period, as do most of the colours used, although a dark purplish-red and yellow were dominant in the earliest period followed by a tremendous surge of painting in a brighter red when the dugout canoe was introduced by the Indonesians into the local culture. This bright red continued in use till modern times.* More analytical studies of this kind are needed in other parts of Australia before general conclusions may be drawn about the sequences of styles, colours and subjects.

It is obvious that styles of a wide range form an integral part of aboriginal art. Style in itself is an aggregate of formal characteristics in either surface or plastic art. These are traditionally preserved in Australia, and it is apparent that adherence to them, as Boas pointed out (1955), limits the inventiveness and genius of an artist or craftsman. Professor Elkin (in McCarthy, 1956*a*) has stressed the importance of ritual in maintaining traditional art designs comparatively unchanged, and it is obvious that the insistence during ritual of the exact reproduction of art designs is an important factor in perpetuating them.

Local variation is an important principle in the archæology and material culture of Australia and of the economic life. As part of this complex art is subject to the same modifying factors. But art does not vary for the same technical and environmental reasons as do stone implements, wooden artifacts

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* Mountford (1954 and 1956) stated that the basic art of Arnhem Land, of which the bark paintings of Groote Eylandt are typical, consists of single and grouped figures on a plain ground. This opinion may be true of the bark paintings (the oldest of which were collected less than fifty years ago), but the real basic art of this region is that of the silhouette, outline and other cave paintings, illustrated best in the Groote and Chasm Islands caves and overlaid by more advanced and recent styles on the mainland. This basic cave art is overlaid in western Arnhem Land by the stick-figure Mimis in action poses, and the Mimis in turn by the static X-ray art. On this basis it is possible to understand why the static X-ray art is later than the moving Mimi series at Oenpelli, whereas the static and stick-figure art existed side by side in Spain in the late Palæolithic. The former art is the older one in Africa. The reason is obvious, therefore, why Mountford (1956), by ignoring the simpler static cave art of Arnhem Land, and particularly of the western portion, is unable to understand why the very advanced X-ray type should be later chronologically than the stick-figures.

or the food-getting habits of the people. The principal art regions are: (1) eastern Australia, with the Baiami-Daramulan sky-hero cults in ground figures and rock engravings and a formal geometric art on weapons ; (2) north-eastern Queensland with the totemic increase art on shields and other objects ; (3) central Australia, western New South Wales to Western Australia with the totemic and ancestral being cults illustrated in a formal geometric art ; (4) Arnhem Land with fertility cults such as the Kunapipi, Djunggawaul and others centred on human and snake ancestral beings, with increase totemism and a rich magic ; (5) Kimberleys with the Wandjina, Rainbow-serpent and increase totemic cults and art in caves ; (6) Broome with increase totemism and with interlocking key designs on weapons, sacred boards and shells ; (7) Western Australia, with rain-making and totemic hero cults with the lozenge, zigzag and other designs in a formal art style. The prevailing regional areas of art are thus linked closely with the religious complexes and the diffusion of the mythologies and rituals has brought with them new art styles and designs which have suppressed and supplanted older ones.

Local variation in aboriginal art has been the result of some interesting technical developments. In western Arnhem Land line design (typical of decorative art generally in Australia) has been accentuated and refined until the whole surface of the figures of animals in the X-ray style is covered with panels of fine and close parallel lines, painted with a feather brush to illustrate the backbone and some of the internal organs of the animal, with occasionally a young one inside the adult. In north-eastern Arnhem Land the graphic compositions of the bark paintings form another important local development.

Technically, the remarkable *mimi* art of western Arnhem Land is a local variation of outstanding merit. These graceful and animated little human figures are posed in a manner so artistically effective that in no other part of Australia has their equal been seen (except in the neighbouring Kimberleys). The stick people, as they are called, occur in many parts of the continent, including the cave paintings of the Sydney-Hawkesbury district, western New South Wales, South and central Australia, Groote and Chasm Islands. In the rock engravings at Mootwingee, western New South Wales, stick people featured in the rock engravings are shown hunting emus, carrying weapons and *waninga*-like symbols. Stick people are overlaid by the more recent X-ray love-magic and other cult art in Arnhem Land, by the ancestral spirit and totemic art in central Australia, and by the Wandjina and other art in the Kimberleys. The style has had a long history, as shown by its distribution in Australia, surviving in a crude and simple form in the south-east and becoming refined to the highest degree in the north.

The widespread custom of sticking feathers on the body appears to be an indigenous development in Australia. Dreams form an important method of creating designs in Arnhem Land, indicating a strong power of visualization during sleep, with a free play of the imagination, a characteristic feature of the magic life of the Aborigines. Climate has not affected art to any noticeable degree in Australia, where the wet and dry tropical seasons of the north, which the natives seek to maintain by rituals of which art forms an important part, contrast with the temperate four seasons of the south. During the wet season the northern natives camp and paint in rock shelters wherever available (Spencer, 1914 ; Hale and Tindale, 1934) and in the south, at least in the Sydney-Hawkesbury district (McCarthy, 1948), they adopted the same custom in the cold winter months.

DEVELOPMENT.

Another principle adopted by Boas (1955) in his study of primitive art is that each culture can be understood only as an historical growth determined by the social and geographical environment in which each people is placed and by the way in which it develops the cultural material that comes into its possession from the outside and through its own creativeness. He further points out (1955) that there is not a single region in existence in which the art style may be understood entirely as an inner growth, as an expression of the cultural life of a single tribe, and it is necessary to compare local styles with those in contiguous areas. These conclusions fit the problem of the development of aboriginal art perfectly, and are true of aboriginal culture generally, as I have pointed out in respect of archæology and material culture (McCarthy, 1940, 1953).

Just what kind of art the Aborigines had when they first came to Australia is difficult to decide. Available evidence indicates that they had a much simpler culture and fewer possessions, particularly in northern and eastern Australia, than did the recent and modern tribes known to the white man, and that their art was of a simpler nature than we know today.

The contrast in the rock engravings of southern Australia, on the other hand, illustrates this point well. The earliest known rock engravings in Australia form a sequence at Devon Downs rock shelter on the lower Murray River in South Australia, where straight grooves are incised in the Mudukian period followed by simple outlines of circles, tortoises and phallic symbols in the succeeding Murundian period. In the Sydney-Hawkesbury district the evidence to hand suggests that the outline engravings belong to the later Eloueran culture, and not to the earlier Bondian period in that area. Much of the history of aboriginal art, particularly of the rock engravings and paintings, will be explained more clearly as archæologists widen the scope of their work and excavation of prehistoric deposits is undertaken on a much wider scale.

In the meantime, the only method of analysis available is that of geographical distribution employed with so much profit in analysing Australian material culture (McCarthy, 1953), to demonstrate that many traits have been introduced and improved, and cultures as a whole have undergone considerable modification since the occupation of the country by the Aborigines. But the history of the art is a confused and difficult problem to elucidate and a number of alternatives are still open for discussion.

An initial difficulty with the formal or geometric art lies in the non-continuous distribution of most of the motifs, and the lack of any relationship between specific objects and designs. The one series of designs is not consistently associated with boomerangs or with shields or other objects throughout Australia ; instead we find that various articles forming part of a tribal material culture are all decorated with the prevailing local art designs. Boomerangs and spear-throwers are decorated in some parts of Australia and not in others. Taken separately, as Davidson has done (1939), these motifs provide an impossible riddle to solve. Taken as groups they suggest a basic connection with ancestral hero beliefs.

One group comprises the concentric diamond or rhomboid, triangle, herring-bone, chevron, sets of parallel lines and the lattice and a few other minor elements. In the Sydney-Hawkesbury district this group of formal motifs was featured on the weapons but not among the cave paintings or rock engravings, suggesting that it had not completely penetrated the culture. A more complete absorption of these motifs had taken place elsewhere in New South Wales, where they were featured on the bora initiation grounds. The presence of these concentric diamond designs on the thread-cross *waninga* of central Australia, and on the spear-throwers, sacred boards and bullroarers of Western Australia, indicates a fairly ancient existence in Australia for them as a group if they are all derived from the one origin. I have suggested previously (1940) that these designs diffused into Australia from New Guinea *via* Torres Strait, because they are so widespread in Melanesia, but their absence in Queensland and their continuous distribution from the north-west to the south-east of the continent suggest a possible line of diffusion in that direction.

Similarly, the origin of the concentric circle group of motifs appears to be indigenous at first sight if its present distribution is any guide to its origin. These motifs are featured in the decorative and ritual art in the central Australian region but a recent diffusion for them is indicated in contiguous areas where they figure in sacred art only. Concentric circles have been recorded in western Arnhem Land cave paintings, and in the Port Hedland engravings, but they are not present in the portable art of either Arnhem Land, Kimberleys or Cape York today. These areas are the channels through which the streams of introduced traits have entered Australia. They occur on the carved trees of New South Wales as an outlier or purely local development.

The concentric circle motifs are regarded as the oldest in Australia by some writers, and Professor Davidson inclines to the idea that they are indigenous, possibly a local variation of the herringbone or other formal motif. Professor Elkin has suggested (Elkin and Berndt, 1950) that the spread of rituals and doctrines associated with circumcision may have put a premium on conventional and symbolic design at the expense of symbolism, but the concentric circle motifs are spreading within the distribution of circumcision and the concentric diamond art in south-east Australia is well to the east of the circumcision area.

It could be argued that line designs form a basic element in aboriginal art, and that local preference has emphasized and popularized the concentric diamond type in some areas and the circle type in other areas, or that the diamonds, squares and circles are all variants of the one theme. This would mean that we may be dealing with groups of designs which have developed independently in different parts of Australia. From the evidence available I prefer to regard the diamond and circle series as being due to separate and distinctive outside influences.

It is now becoming apparent that an important culture complex has been diffusing in all directions from the central Australian region into northern South Australia, western New South Wales, western Queensland, Northern Territory and Western Australia. It includes the fluted non-returning boomerang and fluted containers, *tjuringa* and bullroarers with concentric circle motifs, thread-cross *waninga*, mounting of *tula* adze-flake in gum on spear-throwers and sticks, and other traits. Its full implications cannot be discussed here, but its diffusion has thrust a wedge into what appears to have been a continent-wide culture, so that now the returning boomerang, the sky-heroes and concentric diamond art occur in south-eastern Australia and Western Australia but not in the central Australian region. The concentric circle motifs are replacing the zigzag motifs in Western Australia (Davidson, 1936).

Thus the chronological development of the cultures and the replacement of one by the other in various areas in Australia complicates the problem. Perhaps the concentric diamond has been replaced in north-eastern Australia by later designs as part of more recently introduced rituals and beliefs. In a similar manner it is possible that the concentric circle motifs have been supplanted by the great Wandjina and other cults in the Kimberleys or Mother-goddess fertility and serpent cults in Arnhem Land. In both areas were the types of formal art restricted to wooden and perishable objects previously as are the zigzag and allied motifs in Western Australia today, discontinuance of their use would leave no trace of the art in their cultures. For this reason I believe that the concentric circle series was probably introduced along the north-west coast during the Bronze Age (McCarthy, 1940, 1953), prior to about A.D. 500, as these motifs are characteristic of decorative art in this metal and they spread widely in the Oceanic region, much more widely than did the making of bronze.

A point raised by the above discussion is the relationship of the concentric line art to the actual cults of which its variations now form a part. They need not necessarily have formed part of a complex of cult and art. Ancestral cults appear to be a basic element of aboriginal belief and the heroes are depicted in various ways in both representative and formal art motifs. It is possible for the concentric line motifs to have been added to the cults and blended with them. The eastern Australian evidence indicates such a possibility.

It has been shown that representative and geometric motifs occur in all art techniques employed by the Aborigines. There is no evidence in existence which suggests that the geometric art as a whole evolved from the representative. It is not possible to put together series of specimens which have at one end an animal or human figure and at the other a concentric diamond or circle, as Haddon (1895) demonstrated for scrolls in south-eastern New Guinea. The only definite relationship of this kind is that which undoubtedly exists between the snake and the zigzag in Western Australia and on central eastern Australian boomerangs. In central Australia and western Arnhem Land human figures with concentric circles as heads are painted in the caves, but there is no evidence to suggest that the concentric circles themselves represent a head without a body. The two main kinds of aboriginal art, in my opinion, had a distinct origin, and both are now integral parts of totemism and ancestral spirit cults. It would appear that the representative art had its origin in the portrayal of totemic animals for magico-religious purposes as an aid to ensure an ample supply of food and raw materials, and that the formal or geometric art has been superimposed upon the representative and ultimately became the dominant ritual art.

There is obviously a strong reason for the great development of painting in Arnhem Land, Kimberleys, Cape York and central Australia. In practically every way it is superior to that in southern areas, the colours and styles more varied, the work more advanced technically, the galleries more numerous and extensive, with a higher proportion of polychromes in the cave paintings. Similarly, in Arnhem Land the ritual paraphernalia is extraordinarily abundant and colourful, well designed and made ; there is a wealth of body designs which achieve considerable artistic effect. The bark paintings are outstanding artistic products. All of this work reveals an active aesthetic sense amongst the local Aborigines which has been stimulated in this region by the introduction of religious cults, of which their rich art forms a part. The cave paintings and engravings of Indonesia and New Guinea are comparatively simple in technique and style and cannot have provided the inspiration. But in the decorative art of these two ethnic regions is to be found a wealth of art motifs, styles and techniques similar to that of northern Australia. The art design on the bamboo pipes and lime-boxes of Celebes, which I visited in 1937, is very similar to that of north-eastern Arnhem Land and it is from the pipes, introduced by the Indonesians into the latter area, that the all-over decorative treatment of the field, with the parallel and crossed lines, has been derived in recent centuries. Thus the great flowering of art in Arnhem Land may be due to the general enrichment of culture, particularly of religious cults, which produced a dynamic and higher aesthetic standard generally, introduced by the visits for centuries past of Indonesian natives to northern Australia. It has similarly enriched the music, dances and mythology of these Aborigines.

In this discussion of aboriginal art it is pointed out that there is a consistency in method of treating surfaces throughout Australia, symmetry and rhythmic repetition being of fundamental importance, although asymmetry is a feature of some kinds of art. Art is a planned and serious aesthetic activity, finding its inspiration in mythology and in the ritual, magic, social and economic life. An outstanding feature of rock paintings and engravings in the Sydney-Hawkesbury district, and cave paintings on Groote and Chasm Islands is that species of the highest economic value as sources of food exceed all other animals as art motifs within the body of belief and ritual. The aboriginal artist possesses a clear mental picture of his subject, a sure sense of the use of colour in design, a high appreciation of form, and handles large surfaces without difficulty. The incised work displays a certain mastery of technique and materials. Aboriginal art embodies a wide range of techniques, styles and designs, in which compositions and dramatic settings are important. While the objects decorated or fashioned do not possess a high intrinsic value, their decoration comes within the category of art in its basic principles and craftsmanship. The cultural value of aboriginal art varies from casual depictions to objects and designs made and seen by men initiated into clans or cults, and designs sacred in one area may be seen by everybody outside a sacred context in other areas. The origin of the art motifs is still a controversial and confused problem, one in which local variation and development and introduced ideas have all played a part, but basic styles have persevered and survived despite the increase of surface decoration and formal art that took place.

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OBSERVATIONS ON LATERITE AND OTHER IRONSTONE SOILS IN NORTH QUEENSLAND.

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Abstract.

Four major types of laterite soils and two types of ironstone soil profiles are discussed. The relationship of the laterite soils to water table fluctuations of considerable amplitude between the wet and dry seasons, and the relation between the ironstone soils and temporary perched water tables is discussed. Some conditions under which laterite development does not occur (in conjunction with severe sheet flooding) in low-lying sites are described. The laterites appear to be of Tertiary, Pleistocene and Recent age ; the ironstone soils are post-Tertiary.

Soils containing ironstone concretions and pans are widespread in the Lower Cape York Peninsula of North Queensland. Among the most important of such soils are relict Tertiary soils mapped as Residual Lateritic Podzols and Sandplains in the Soils map of the *Atlas of Australian Resources* (1952). There also occur relict Lateritic Red Earths of comparable age. Soils of post-Tertiary development with profiles broadly similar to the relict laterite groups are also to be found. In addition there are other soils of post-Tertiary development which contain ironstone, but they differ in profile from the " laterite " soils, chiefly in the dissimilar character of the horizons beneath the zone of maximum iron accumulation. The origin of the ironstone in those soils of the above groups selected for treatment in this paper appears to be bound up with either seasonal water-table fluctuations of considerable amplitude (the laterite soils), or with temporary wet-season waterlogging above an horizon of clay accumulation (the ironstone soils).

The very general observations which form the basis of this paper were made during the course of a land use survey of the lower Peninsula, carried out by the writer in the dry seasons of 1949 and 1950. The arguments advanced are tentative. The nomenclature followed is that adopted by Stephens (1953) in the *Manual of Australian Soils*, except for four groups of soils, namely " Grey Laterite Soils ", Calcareous Grey Laterite Soils, Grey Ironstone Soils and Calcareous Grey Ironstone Soils. It is emphasized that these terms are used only in a general, descriptive, collective sense and are not proposed as new soil names.

Rainfalls in this area range from 26 inches, at Spring Creek, to the south of Mount Garnet, to over 180 inches per annum, at Tully, on the east coast. Much the greater part of the area, however—especially that portion west of the Great Dividing Range, where there are extensive lateritic remnants of the late Tertiary peneplain—has rainfalls from 26 to 40 inches a year. Only in the eastern mountains (80 to 200 inches), on the Atherton Tableland (40 to 150 inches) and along the east coast lowlands (70 to 180 inches) are much higher rainfalls noted.

Lateritic soils in the lower Peninsula are associated with three major types of land surface:

(1) Relics of the late Tertiary peneplain, which was uplifted during late Pliocene-early Pleistocene time, and variably dissected. The laterite soils occur on granites, sandstones and shales, predominantly, but not always, on the lower slopes. With the lowering of the water-table accompanying dissection they are now being truncated or dismembered to some degree. As noted above, these relict soils lie west of the Great Dividing Range and are bordered in turn to the west by the Pliocene and Pleistocene deposits of the broad plains fringing the Gulf of Carpentaria.

(2) Some lower slopes of the Pleistocene valleys incised in the Tertiary surfaces just mentioned. A Pleistocene, rather than a Recent origin, is suggested by the fact that in the Spring Creek area near Einasleigh, Recent or very late Pleistocene basalts (bombs, cones, unmodified flow walls, cavernous drainage and black soils are all typical) have in several areas lapped over the lateritic soils developed on granites in the lower slopes of the Pleistocene valleys. Included in this group are some Pleistocene river terraces and lower valley slopes of the east coast between Cairns and Tully. The parent rocks are largely granitic or schistose.

(3) The lower slopes of valleys etched in very late Pleistocene or early Recent basalts (comparable in age to those mentioned above), developed most strikingly in the high rainfall zone around Innisfail on the east coast.

The ironstone soils are associated in large part with the following erosion surfaces and deposits:

(1) The loosely consolidated sediments between Croydon and Normanton, flanking the eastern side of the Gulf of Carpentaria. These sediments are probably to be correlated with Whitehouse's (1940) Pliocene Glendower Series. The lower sites are preferred sites for ironstone-soil development.

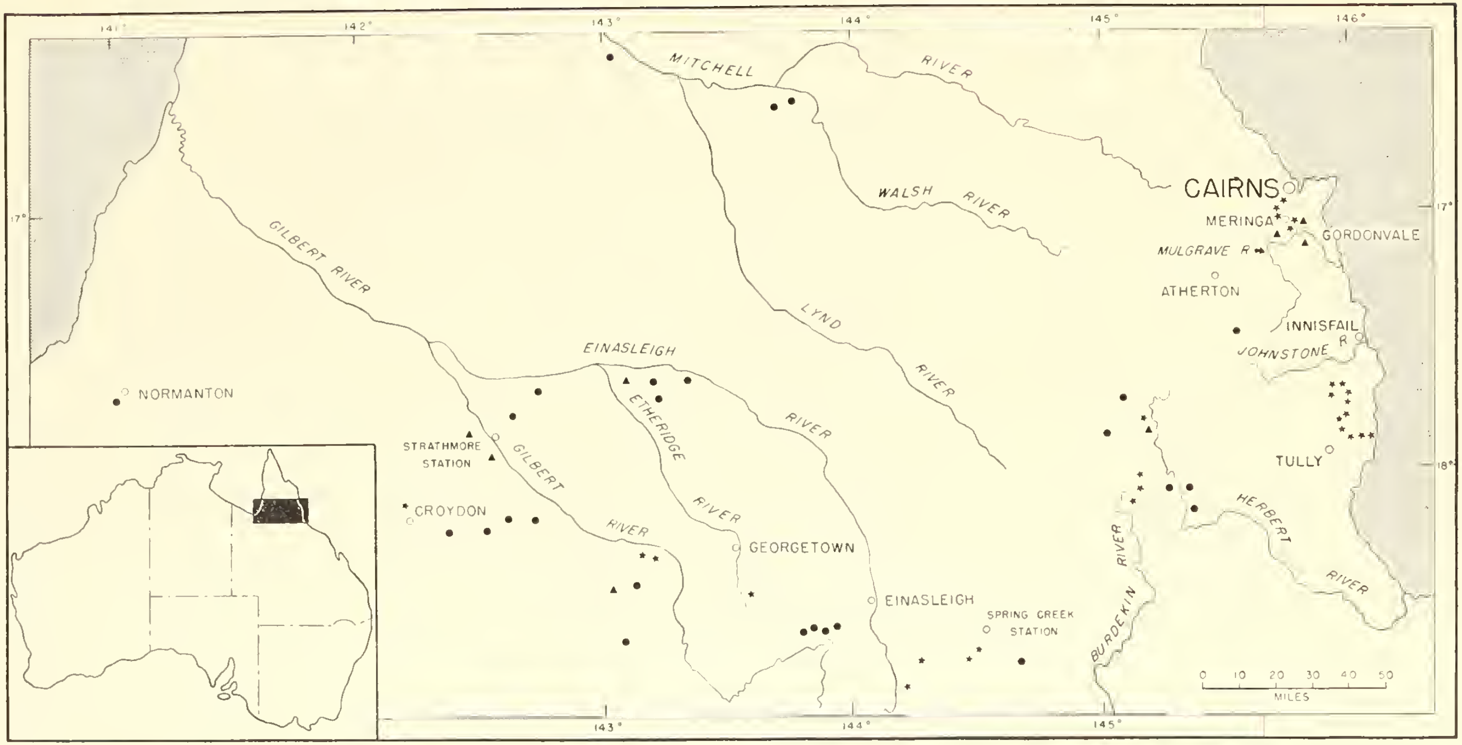
(2) Low-lying sites on Pleistocene alluvials of rivers emptying into both the Coral Sea and the Gulf of Carpentaria. Good examples are to be found along the Mulgrave River to the south of Cairns and on the Gilbert River near Strathmore Station (see Text-fig. 1).

THE LATERITE SOILS.

Four major groups of laterite soils are to be found in the lower Peninsula. They are, in decreasing order of areal extent, (i) the Grey Laterite Soils developed on both Tertiary and Pleistocene surfaces; (ii) the Lateritic Red Earths of the relict Tertiary surfaces; (iii) the Calcareous Grey Laterite Soils of the low rainfall districts around Croydon and Einasleigh, developed on granite in the lower sites of Pleistocene valleys; and (iv) the Lateritic Krasnozems on Recent basalts and on very ferruginous schists near Innisfail in the eastern lowlands. Details of each of these soils are given below, along with a typical profile for each.

(i) *Grey Laterite Soils.*

Grey Laterite Soils have developed most widely on acid rocks such as granite, sandstone, slate and schist. They have acid, grey, brownish-grey or yellowish-grey upper horizons which are light textured and usually have sesquioxidic concretions at their base. The concretions may merge into a hardpan extending into an underlying, mottled clay horizon. Extending through the mottled clay horizon may be individual pisolites, vermicular masses or vertical " pipes " of hard ironstone material. Mottling is predominantly of pale tones, yellow, orange and grey being most frequent. With increasing depth grey and even white tones become dominant, this horizon (for which Whitehouse (1940) introduced the term " pallid zone ") being overwhelmingly one of kaolinitic clays. In other parts of Australia silicification of sections of this last layer into " billy " has been recorded. Little evidence of " billy " formation was seen in north Queensland.



Text-fig. 1.—Lower Cape York Peninsula, North Queensland, giving the location of places mentioned in the text.
Location of observed and recorded laterite profiles of Tertiary age shown thus : ●
Location of observed and recorded laterite profiles of post-Tertiary age shown thus : ★
Location of ironstone soil profiles shown thus : ▲.

A typical Grey Laterite profile of Tertiary age is as follows:

The Strathmore Tertiary Profile. Developed on Mesozoic shaly sandstone near Dismal Creek on Strathmore Station. The profile is exposed at the edge of a low mesa. Present rainfall, 31 inches. Vegetation a monospecific scrub of *Melaleuca leucadendron.*

0– 5 in.	Pinkish grey fine sand; pH 5·1; clay 7%; organic carbon 0·6%; chlorides 0·003%; merging to
5– 18 in.	Yellowish grey sand; occasional iron pisolites; pH 4·9; clay 7%; chlorides 0·007%; merging to
18– 24 in.	Light yellow sand to loamy sand; pH 5·2; clay 10%; chlorides 0·007%; numerous ferruginous pisolites, increase to base, where they are cemented into
24– 48 in.	Hardpan of pisolitic laterite; yellow-brown to red-brown on fracture. Changes sharply to
48–120 in.	Cellular mottled horizon with yellow-brown to red-brown cell-walls and pipes of ironstone; grey and yellow mottled sandy clay infilling. Ironstone cells diminish with depth giving way to
120–150 in.	Greyish white pallid zone, flecked with red and yellow.
150 in.	Base of exposure.

Generally speaking, the old Tertiary soils have deeper, more strongly differentiated horizons than do those initiated during the Pleistocene. They also tend to be more acid throughout the profile, showing in particular more intense levels of acidity in the deep subsoils below the iron pans than is typical for the Pleistocene Grey Laterite Soils. The extent of each of these groups is shown on the accompanying map (Figure 2).

Comparable profiles found elsewhere in Australia include many of those described as Residual Podzols by Prescott (1944), as Lateritic Podzolic Soils by Stephens (1953) and Stewart (1954), and as Ferruginous Laterites by Hallsworth and Costin (1953).

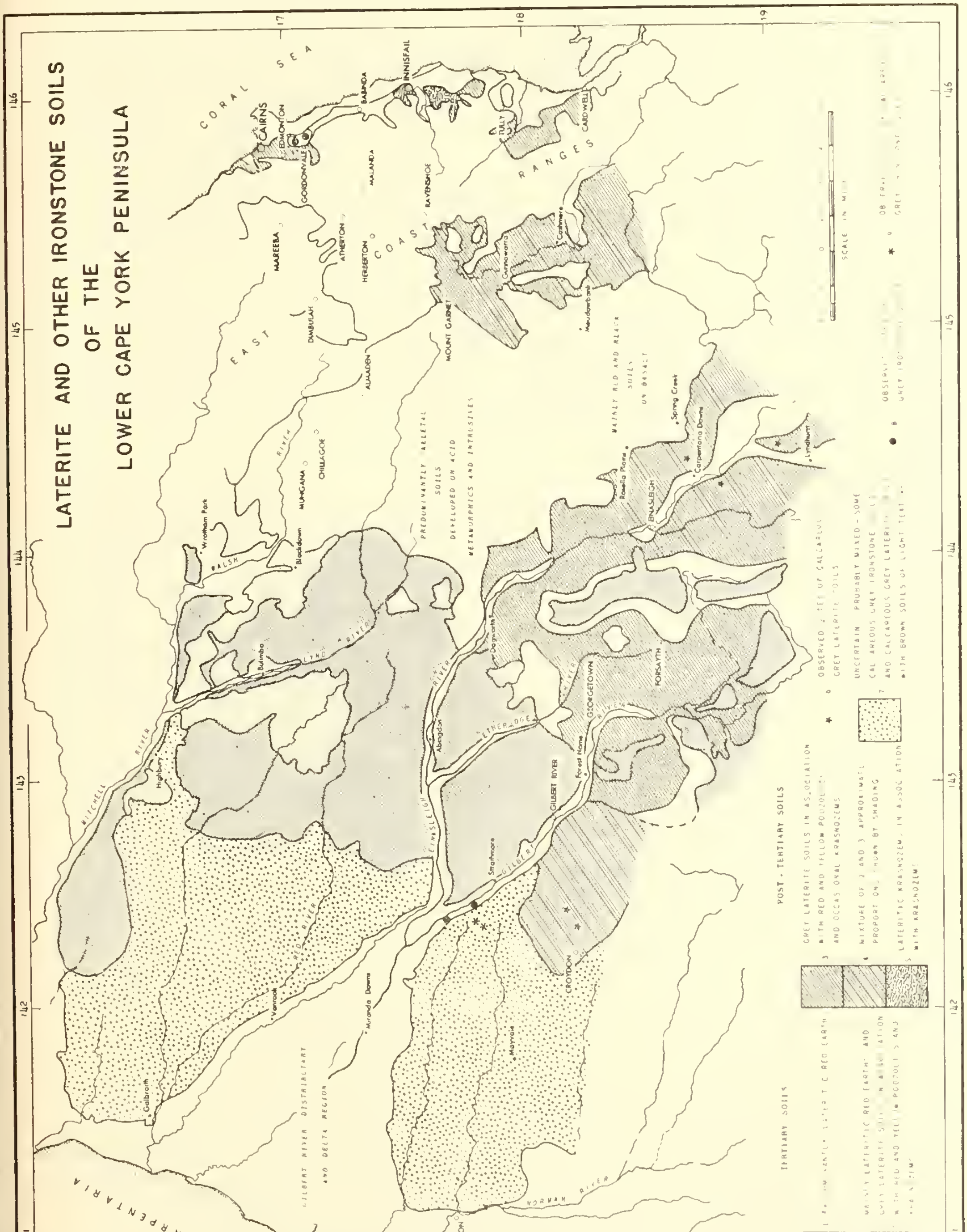
(ii) *Lateritic Red Earths.*

The Lateritic Red Earths of the lower Peninsula are overwhelmingly relict, being associated with remnants of the Tertiary land surfaces. They have developed on acid-intermediate and some acid rocks, notably shales, granodiorite, granite, ferruginous quartzites, phyllites and schists. Stephens (1953) has characterized these soils as " red to light red soils containing a horizon of laterite with mottled and pallid kaolinitic horizons beneath. The A horizon is commonly sandy to loamy in texture and darkened with a little organic matter. It passes gradually into a slightly finer textured B horizon which is usually a bright red in colour and of compact but somewhat vesicular structure. The horizon of laterite is found at various depths and it is of variable character, nodular, pisolitic, vermicular or massive. The mottled and pallid horizons beneath the laterite are variable in depth and may occasionally be missing. Frequently they contain a siliceous horizon of ' billy '." In this area they have developed on sandstones, granites and other acid to intermediate rocks.

A typical profile is recorded below.

The Mount Garnet Profile. Is developed on the upper slopes of a long 1°–2° slope on granite some 20 miles south of Mount Garnet, on the highway linking Mount Garnet to Charters Towers. Grades down slope into a Grey Laterite Soil. Tall woodland of *Eucalyptus crebra-E. dichromophloia.*

0–12 in.	Light reddish grey-brown sandy loam, with very occasional firm pisolites. Merges to
12–24 in.	Red compact loam to clay loam with numerous firm pisolites which become very hard on exposure. Merges to
24–40 in.	Lateritic mottled horizon with much irregular vermicular ironstone.
40+ in.	Decomposing granite, much weathered and with irregular ironstone masses.


LATERITE AND OTHER IRONSTONE SOILS
OF THE
LOWER CAPE YORK PENINSULA
CORAL SEA
GULF OF CARPENTARIA
EAST COAST RANGES
CAIRNS
EDMONTON
GORDONVALE
BABINDA
INNISFAIL
MALANDA
RAVENSHOE
TULLY
CARDWELL
MAREEBA
ATHERTON
HERBERTON
DIMBULAH
MOUNT GARNET
ALMADEN
CHILLAGOE
MUNGANA
Wrotham Park
Blackdown
Bulimba
Highbury
Galbraith
Vanrook
Miranda Downs
Mayvale
NORMANTON
CROYDON
Strathmore
Forest Home
GEORGETOWN
FORSAYTH
Abingdon
Dagworth
EINASLEIGH
Rosella Plains
Carpentaria Downs
Spring Creek
Lyndhurst
Cashmere
Gunnawarra
Meadowbank
MITCHELL RIVER
WALSH RIVER
LYND RIVER
RED RIVER
GILBERT RIVER
EINASLEIGH RIVER
ETHERIDGE RIVER
NORMAN RIVER
GILBERT RIVER DISTRIBUTARY AND DELTA REGION
PREDOMINANTLY SKELETAL SOILS DEVELOPED ON ACID METAMORPHICS AND INTRUSIVES
MAINLY RED AND BLACK SOILS ON BASALT
SCALE IN MILES
TERTIARY SOILS
POST - TERTIARY SOILS
GREY LATERITE SOILS IN ASSOCIATION WITH RED AND YELLOW PODZOLS AND OCCASIONAL KRASNOZEMS
MIXTURE OF 2 AND 3 APPROXIMATE PROPORTIONS SHOWN BY SHADING
LATERITIC KRASNOZEM, IN ASSOCIATION WITH KRASNOZEMS
OBSERVED ... OF CALCAREOUS GREY LATERITE SOILS
UNCERTAIN PROBABLY MIXED - SOME CALCAREOUS GREY IRONSTONE AND CALCAREOUS GREY LATERITE ... WITH BROWN SOILS OF LIGHT TEXTURE
141
142
143
144
145
146
16
17
18
19

Text-fig. 2.

(iii) *Calcareous Grey Laterite Soils.*

In the low rainfall districts of Croydon (28 inches p.a.) and on Spring Creek, Lyndhurst, and Carpentaria Downs Stations near Einasleigh (25 inches p.a.), Calcareous Grey Laterite Soils have developed at the ends of long gentle slopes on granite and granodiorite. They are all of post-Tertiary age. A typical profile is given below.

The Lyndhurst Profile. Occurs towards the end of a long $\frac{1}{2}$° slope (of two miles) on granodiorite near Bundock Creek on Lyndhurst Station. Grades upslope into a Yellow Podzolic soil. Open savannah woodland of ***Eucalyptus leptophleba-E. brownii*** vell. aff. Rainfall about 26 inches.

0–18 in.	Grey to light yellowish grey loamy sand to sandy loam.
18–36 in.	Yellow and grey reticulately mottled sandy clay with yellow-brown ironstone pisolites scattered throughout and in parts cemented into a firm hardpan.
36–70 in.	Yellow sandy clay reticulately mottled with grey with weakly developed vertical cells and pipes of ironstone.
70–96 in.	As above, with large calcium carbonate concretions up to one inch across or more.
96 in.	Decomposing granodiorite.

(iv) *Lateritic Krasnozems.*

Lateritic Krasnozems (the term follows Stephens' (1953) usage) are restricted to the lower slopes of Recent basalts,[1] mixed basalt and schist colluvial-alluvial materials, and occasional very ferruginous schists in the high rainfall areas of the east coast, notably in the Innisfail district (140 inches).

The Mena Creek Recent Profile. Typical of end-of-slope laterite development on basalt in the Mena Creek area near Innisfail. Profile through end of 2°–3° slope, cut by cane tramway. This profile has been sampled and described by Teakle (1950), and analyses carried out by the Division of Soils, C.S.I.R.O. Rainfall about 150 inches. Original cover rainforest, now cleared for sugar cane.

0– 6 in.	Disturbed by cutting.
6 in. to 4 ft.	Partly disturbed in the upper section by tram cutting. Light, brownish red light clay with occasional hard, irregular purplish-red ironstone masses up to four inches across.
4– 6 ft.	Very light brownish red light clay. Contains numerous pieces of irregular ironstone, purplish-red in colour. Tendency to cellular structure in parts, in others a weakly developed cellular structure is apparent. Merges into
6–10 ft.	Brownish red clay with large irregular, cellular ironstone masses. Merges into
10–18 ft.	Yellow grey and olive grey clay with slight segregation of iron into small irregular masses. Appears to be a weakly developed " pallid zone ".

Teakle (1950) considers that this profile is that of a " very immature laterite ".

CATENARY RELATIONSHIPS OF THE LATERITE SOILS.

The Tertiary Laterites.

In areas of dissected Tertiary laterites a varied assemblage of soils develops on the different horizons exposed by erosion, as well as on transported material derived from the laterite. No study of these derived soils was made, but in all probability they follow a pattern similar to that outlined by Stephens (1946) for southern Australia. Where the site is undisturbed the catena members depend upon the acidity of the parent materials and the degree of slope. A form of listing is adopted below (Table 1) to make the various sequences clear.

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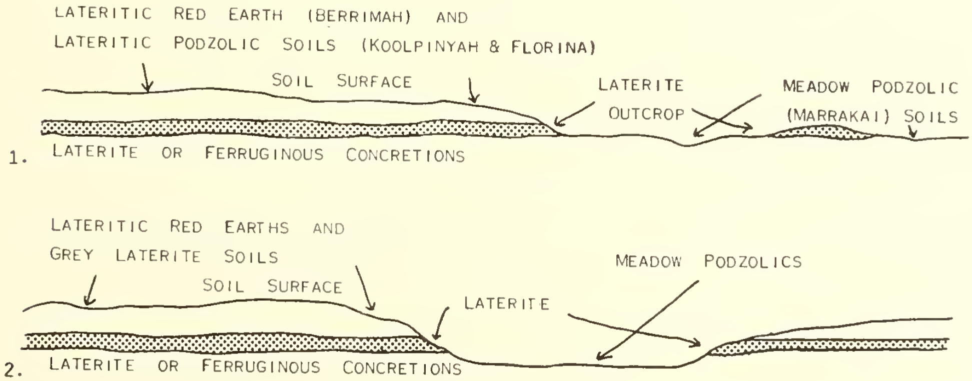
[1] Professor W. H. Bryan, University of Queensland, considers these basalts to be very late Pleistocene or early Recent in age (personal communication).

TABLE 1.

Acidity of Parent Material.	Degree of Slope.	Catenary Sequence Moving Downslope to the Right.
Acid—Intermediate shales, granodiorite, etc.	More than 1–2°.	Krasnozem—transitional—Lateritic Red Earth.
	Less than 1–2°.	Transitional Lateritic Red Earth—Lateritic Red Earth.
	Very long and gentle, less than 1°.	Transitional Lateritic Red Earth—Lateritic Red Earth—Grey Laterite Soil.
Acid sandstone, granite, etc.	More than 1–2°.	Red Podzolic—Yellow Podzolic—transitional—Grey Laterite Soil.
	Very gentle long slopes.	Red Podzolic—Yellow Podzolic—transitional—Grey Laterite Soil—Meadow Podzolic.

The last sequence listed above is of considerable interest for the light it throws on the nature of the water-table fluctuations on long very gentle slopes and may be examined further. The evidence for this sequence (namely Red Podzolic–Yellow Podzolic–transitional–Grey Laterite Soil–Meadow Podzolic) is based upon an interesting topographic succession described from the Northern Territory by Stewart (1954) and a parallel sequence in north Queensland developed on the broad, low, weakly-dissected shaly-sandstone mesas (mesa walls 15–20 feet high) between the Gilbert and Mitchell rivers to the north of Croydon. These examples are illustrated in Text-figure 3.



Text-fig. 3.—Topographic successions of laterite and meadow soils of Tertiary age in the 1. Katherine-Darwin Area (*after* Stewart, 1954) ; 2. Lower Cape York Peninsula to the north of Croydon.

Referring to the example from the Territory, Stewart notes that " in many places massive laterite outcrops around the higher margins of the Marrakai soils (described as Meadow Podzolics) of the creek flats or depressions. Apparently the ferruginous zone represents the range of fluctuation of the water-table in the wet season. In the Marrakai soil the water-table is above the surface of the soil and the soil undergoes similar pedological processes to those of the subsoils of lateritic soils. In the anaerobic conditions of the waterlogged soil iron is reduced to the ferrous form and is removed upwards from the solum. Even though flooded, the soils are very strongly leached, i.e. they must be reasonably permeable, and the water-table above soil level is apparently due to their low topographic position and the high regional wet season water-table." In general, the same topographic relations hold in the zone to the north of Croydon and Stewart's argument is applicable there also. Although these seasonally inundated soils may have been subjected to some slight post-Tertiary erosion, they probably approximate closely to the original Tertiary lowest members.

From these examples we might conclude that on very gentle long slopes on acid rocks the lowest areas subject to seasonal ponding would not tend to develop Grey Laterite Soils because the water-table fluctuations would not be of the type needed for their formation, whereas at the base of slightly steeper slopes where long-continued surface ponding is restricted they would constitute the lowest member. The areas of excessively high rainfall on the east coast provide a partial exception to this generalization for even on slopes which elsewhere would carry Grey Laterite Soils some surface ponding is common and Meadow Podzolics are often noted in such inundated zones.

The Post-Tertiary Laterites.

In the post-Tertiary laterites, as is the case with the Tertiary group, parent materials, slope and also rainfall greatly influence the course of development of the laterites and their associated soils. In Table 2 given below some general relationships are shown.

TABLE 2.

Parent Material.	Present Annual Rainfall in Inches.	Degree of Slope.	Catenary Sequence Moving Downslope to the Right.
Basalt.	40 to 140	5°+ for upper to 1–2° on lower slopes.	Krasnozems on all slopes. East coast and Atherton Tableland.
Recent Basalt and very Ferruginous Schist.	140+	As above.	Krasnozems — Yellow Brown Latosols (occasional and on basalt only)—Lateritic Krasnozems. Well developed in the Innisfail district.
Granite.	25 to 80	As above.	Krasnozem (on ferruginous schists and basic granites and in the higher rainfall areas) or Red Podzolics—Red Podzolics—Yellow Podzolics — transitional — Grey Laterite Soils. East Coast and Inland districts.
Granite and Schist.	120+ and in some favourable sites. 90+.	As above plus gentle end of slope less than 1°.	Krasnozems — Red Podzolics — Yellow Podzolics—Meadow Podzolics. East coast, especially the Tully and Innisfail areas.
Alluvial Terraces.	75+	Level to very gentle.	Krasnozem — Red Podzolics — Yellow Podzolics—Grey Laterite Soils (or in some instances Grey Ironstone Soils).

The following comments are relevant to a study of the preceding table:

(i) Generally speaking, the Pleistocene and Recent laterites have formed on steeper slopes than the Tertiary examples. They occupy a smaller proportion of the catena, and are more markedly restricted to the lower slopes.

(ii) If the present rainfall pattern is a reasonable guide to that of the Pleistocene, then it seems that laterite will form on acid rocks under considerably lower rainfalls than on basic rocks.

(iii) On basaltic parent materials Lateritic Krasnozems are found only on the lower slopes of Recent basalts in the high rainfall area around Innisfail (140+ inches p.a.), while the higher sites are characterized by Krasnozems. In several instances soils with distinct affinities with Yellow Brown Latosols were observed on sites intermediate between the Krasnozems and the Lateritic Krasnozems in the Innisfail district, but it is not known whether they are an invariable intermediate member of the catena. Elsewhere in the coastal belt where rainfalls are lower than at Innisfail, Krasnozems generally occupy all sites, including the lowest on the Recent basalts. Even on the Atherton Tableland, where rainfalls range up to 150 inches, no Lateritic Krasnozems have been observed by Teakle (1950) or the writer either on the Recent basalts in the north or on the Tertiary flows in the south. The hilly nature of the southern high rainfall zone of the Tableland and the sharp decline in rainfall (40 to 80 inches) over the more undulating and rolling lands to the north evidently has not favoured laterite development. It would appear, therefore, in north Queensland that only in undulating to rolling country where rainfalls exceed 140 inches can the persistent high water-tables needed for the formation of laterite at moderate depth be maintained on the normally free-draining Krasnozems which tend to develop over basalts at rainfall levels above about 40 inches.

(iv) Along the east coast where rainfalls are above 120 inches—and in some areas where they are as low as 90 inches per annum—laterite development is uncommon on granite and schist. This contrasts to the situation on basalt, where lateritic soils do not develop until some 140 inches are received. This contrasting situation is probably in part related to the more frequent occurrence of long very gentle slopes and flats at the base of granitic and schistose hills than is the case with the shorter and more undulating to rolling slopes on basalt. On these very gentle slopes, backed by a considerable sheet-flood catchment upslope, many low-level sites on granite and schist are waterlogged for almost the entire year and apparently do not experience water-table fluctuations of the type needed for laterite profile development. In this high rainfall area where even the dry season from July to October averages more than 16 inches sheet and imbricate rill flow of excess water is common across the gentle aprons skirting the steep hills. In such areas Meadow Podzolics, rather than Grey Laterite Soils, are the norm.

(v) The Krasnozems and Red Podzolics which are typical of all slopes over 2° on schistose alluvial-colluvial slopes to the south of Cairns (in the rainfall range 90+ inches) in some instances have lateritic ironstone and mottled and pallid horizons occurring in the very deep subsoils 15 to 25 feet or more below the surface. Fine examples of these deep horizons are exposed by deep stream gashes in the Mulgrave Valley colluvials between Meringa and Cairns; on road cuttings between Tully and Innisfail; and at Bingil Beach to the east of Tully. Whether these deep horizons are related to present-day deep water-table fluctuations or are related to earlier water-table positions—and hence are relict—the writer cannot say. However, the marked dissection of the exposure at Bingil Beach is at least suggestive of the latter possibility.

Genesis of the Laterites.

On the genesis of laterite soils in Australia there is a general consensus of opinion on the role of water-table fluctuations by which the pallid, mottled and portion at least of the ironstone horizons are developed. Stephens (1946), Whitehouse (1940), Teakle (1950) and Hallsworth and Costin (1953) have discussed the mechanism thoroughly, and the latter in particular have pointed out several possible ways in which the appropriate water-table fluctuations could arise in both tropical and sub-tropical areas, noting that water-table movements on the lower, gentle slopes of hills as well as regional water-tables on long gentle slopes could be involved in the production of laterite soils. These writers agree that—irrespective of the nature of the surface horizons—a well-developed lateritic soil contains an ironstone horizon in the subsoil, underlain in turn by a mottled and then a pallid zone, and then, in occasional instances, by a silicified horizon of " billy ". There is also agreement that during the formation of these soils the pallid zone, and to a lesser degree the mottled zone, are the site of a permanent or semi-permanent water-table, and that seasonal fluctuations in the water-table take place up to and occasionally above the level of the ironstone horizon. The development of the ironstone horizon is attributed by Teakle (1950) to deposition from iron-charged ground waters, the iron being derived " (*a*) from the surface as the leaching waters descend, (*b*) from remote places, as ground waters slowly move laterally under gravity, and (*c*) from the water saturating the pallid and mottled zone, where reducing conditions will prevail . . . (and deposition) would naturally occur at or near the fluctuating capillary fringe (of the water-table) where intermittent aeration would promote oxidation of the ferrous carbonate to ferric oxide ".

As noted in the profiles described earlier, the soil overlying, and in part included within the ironstone horizon, varies from a Krasnozem to a Red Earth, to a podzolic type soil (the Grey Laterite Soil) depending on the parent material, topographic site, rainfall and age. For the Grey Laterite Soils the development of the podzolic type surface soils may be pursued further around the question " did the podzolic type surface horizons develop contemporaneously with the deep-seated portions of the profile ? "

Prescott (1931) and Stephens (1946) consider that both surface and deep profile features developed at the same time, but Hallsworth and Costin (1953) have stated that " this does not appear to be necessary " in New South Wales. They argue that, " in so far as the Monaro and Sydney Laterites are concerned, the upper podzolized layer is more logically interpreted as having been superimposed after lateritization as an effect of a strongly podzolizing climate (during the Pleistocene) ". By implication this same argument may be applied to other areas of Australia. In the lower Peninsula the following observations suggest that contemporaneous development of the whole profile is normally the case:

(1) In the middle courses of the Einasleigh, Lynd and Etheridge Rivers are Mesozoic shaly sandstones which were strongly lateritized during the Tertiary, and were then gently warped and dissected into low mesas during and after the Kosciusko uplift of late Pliocene-early Pleistocene time. Grey Laterite Soils are now found, along with other soils, on both the mesa edges and in the interior portions of the mesas. Now, if the development of the upper grey podzolized horizon of the Grey Laterite Soils was confined to the Pleistocene, then we could reasonably expect to find considerable differences in profile between the free-draining areas at the mesa edges and the much less free-draining areas in the centres of the mesas. No such differences were observed in uneroded sites. Further, if podzolization were a Pleistocene phenomenon, then we could expect to find little difference in profile and intensity of podzolization between the various soils of the free-draining sites at the mesa edges. This is not the case,

and in fact there is a variety of soils matching those of the crests and troughs of the extremely gentle undulations of the mid-most parts of the mesas. In essence, then, the soils found on the mesas appear to reflect the pre-dissection topography and show little relation to the existing topography, which presumably was also typical of much of the Pleistocene. The writer concludes from this that, in the main, development of the surface as well as the deep profile features of the Grey Laterite Soils, antedated the Kosciusko uplift, and probably occurred at the same time.

(2) Grey Laterite Soils on granite and schist were observed in the Pleistocene valleys of the east coast, and on the lower slopes of the broad Pleistocene surfaces etched in the Tertiary upland surface at the headwaters of the Burdekin, Gilbert and Etheridge Rivers. These soils have also developed on the abandoned Pleistocene alluvials of the Mulgrave River near Cairns and on other Pleistocene terraces between Cairns and Tully. All these profiles are broadly similar to those on the mesas described above. Bearing in mind the site and time of formation differences between these groups, it is difficult to account for the development of these similar profile features through the action of two separate processes widely separated in time.

For these reasons, then, it is considered that polygenesis as a means of developing the Grey Laterite Soils is doubtful ; contemporaneous development seems much the more likely. It is suggested that the same arguments hold for the development of the Lateritic Red Earths during the Tertiary and for the Lateritic Krasnozems on Recent basalts.

This argument seems much less certain for the Calcareous Grey Laterite Soils found on granite in the Croydon and Einasleigh districts. In these low rainfall areas (28 inches or less) secondary carbonate retention may be a relatively recent imposition on laterites formed during the Pleistocene, such retention presumably following from a shift to drier conditions after the Pleistocene. In other parts of Australia there is much evidence that late Pleistocene rainfalls were higher than the present (Crocker and Wood, 1947). No clear-cut evidence to this effect is available in the lower Peninsula. However, the presence of relict areas of Indo-Malaysian flora in the headwaters of the Einasleigh River under rainfalls of about 30 inches, and the development of Tropical Black Earths on Recent basalts alongside leached red soils on earlier flows (in the same headwater zone), is at least suggestive of such a change.

With the possible exception of the low rainfall areas above there would seem to be no reason why the lateritization process is not still operative throughout the lower Peninsula, although it may perhaps be geared to a different mean water-table position compared to earlier periods. Marked water-table fluctuations occur each year with the onset and passage of the monsoon and during the wet season reducing conditions exist as close to the surface as 6 to 12 inches in many low-lying sites.

OTHER IRONSTONE SOILS.

In addition to the post-Tertiary Grey Laterite Soils and Calcareous Grey Laterite Soils and Calcareous Grey Laterite Soils occurring respectively in the high and low rainfall areas of the Peninsula, there are other ironstone soils with closely similar upper-profile features, but they lack the companion horizons of mottled and pallid kaolinitic clay and ironstone " pipes ", which are replaced by non-mottled or weakly mottled clays. The development of these non-mottled or weakly mottled clays in the place of the companion horizons implies that such water-tables as do develop in these soils are perched above an impervious clay horizon, and that there is little deeper water-table development except perhaps at levels well below the surface. Although some workers in

Australia group such profiles with the fully developed laterite containing companion horizons, the writer feels that they should be separated. Until detailed work on these soils enables more suitable terms to be devised, Grey Ironstone Soils and Calcareous Grey Ironstone Soils may be used for convenience. Typical profile data are as follows:

Grey Ironstone Soils.

Grey Ironstone Soils were observed mainly in low-lying sites on Pleistocene terraces, notably along the east coast streams under rainfalls of 75 inches or more, and also on the alluvials of the Gilbert and Mitchell Rivers where present rainfalls range from 30 to 40 inches. The writer is unsure to what extent the sites along the distributory zones of the Gilbert and Mitchell Rivers should be regarded as Pleistocene or as Recent.

The Mulgrave Profile. On the abandoned Pleistocene terrace of the Mulgrave River near Gordonvale, to the south of Cairns. Lowest portion of terrace. Originally dry sclerophyll forest of *Eucalyptus alba*, *Tristania suaveolens*, *Melaleuca leucadendron* and numerous acacias. Rainfall about 75 inches.

0–6 in.	Brownish grey sandy loam; numerous soft, earth pisolites; pH 5·6, clay 17%; silt 14%, organic carbon 3·36%, chlorides 0·01%.
6–18 in.	Light grey and light yellow grey sandy clay loam; numerous firm pisolites becoming larger with depth; pH 5·5, clay 23%, silt 14%, chlorides 0·01%.
18–30 in.	Black and yellow pisolitic rubble; discrete; firm; but not exceptionally hard where not exposed to the air. On exposure the outer surfaces become very hard and are cemented together. pH 5·1.
30–54 in.	Red scattered pisolites in a yellow clay loam; pH 5·1.
54–80 in.	Red and yellowish red sandy loam becoming sandier with depth.

The catena on these Pleistocene alluvials in the high rainfall areas consists of Krasnozems or Red Podzolic Soils in the higher areas, the former generally being found on the heavier textured alluvials; these grade downslope through Yellow Podzolics into the Grey Ironstone Soils. It is important to note that in other sites on these alluvials where the water-table fluctuations are of the appropriate type, Grey Laterite Soils occur. Clearly, then, there is considerable affinity between these two groups of lower member soils with ironstone horizons—but there is still the necessity to separate those with companion horizons from those without. Insufficient sampling was carried out to determine the associated soils in the low rainfall areas.

Calcareous Grey Ironstone Soils.

Examples of Calcareous Grey Ironstone Soils are to be found in the low rainfall area (28 to 35 inches) to the west of Croydon on unconsolidated materials probably to be correlated with Whitehouse's (1940) Pliocene Glendower Series.

The Strathmore Profile. Site seven miles west of Strathmore homestead. End of long $\frac{1}{4}$° slope. Savannah woodland of *Eucalyptus microtheca*, *E. polycarpa* and *Petalostigma pubescens*. Rainfall about 30 inches.

0–12 in.	Ash grey very fine sandy loam; micaceous.
12–24 in.	Ash grey very fine sandy loam with occasional ferruginous pisolites.
24–48 in.	Yellow-brown clay with numerous ferruginous pisolites merging into a hardpan about 34 inches.
48–60 in.	Yellow brown clay.
60–70 in.	Yellow brown clay with calcium carbonate concretions.

These soils occupy only a small part of the catena, the Brown Soils of Light Texture (?) which occur upslope covering a much greater area. It is possible that they may have some affinities with the solodic soils described by Hallsworth, Costin and Gibbons (1953).

SUMMARY.

Soils containing ironstone concretions and pans are widespread in the lower Cape York Peninsula of north Queensland. The most common of these soils fall into two main groups:

(1) The laterite soils, characterized by subsoil iron concretions and vermicular and cellular ironstone overlying mottled and "pallid" horizons, and apparently formed by fluctuations of considerable amplitude between the wet and dry season levels of the water-table. Four major types occur: (i) Grey Laterite Soils, (ii) Lateritic Red Earths, (iii) Calcareous Grey Laterite Soils, and (iv) Lateritic Krasnozems. Formation of laterite has occurred in the Tertiary, Pleistocene and Recent. Some conditions under which laterite development does not occur (in conjunction with severe sheet flooding) in low-lying sites are described. Common catenary relationships are also given.

(2) The ironstone soils also possess horizons of ironstone concretions, but lack the deep mottled and pallid horizons which are replaced by non-mottled or slightly mottled clays. In these soils, temporary wet-season waterlogging above a clay horizon—rather than wholesale water-table fluctuations—appear to be important in developing the iron pans. Two main types occur: (i) Grey Ironstone Soils and (ii) Calcareous Grey Ironstone Soils. Both appear to be of post-Tertiary age.

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NOTE ON TEXT-FIGURE 2.

The soil boundaries given in Text-figure 2 are based upon limited reconnaissance, extended by discussions with graziers, and the use of Tri-metrogon aerial photographs (for the southern half of the area) both before and after going into the field. Useful four miles to one inch military maps were available for the Atherton, Einasleigh, Normanton and Galbraith areas. One inch to one mile military maps were used for the east coast and Atherton Tableland areas.

MAGNETIC PROPERTIES OF ROCKS.

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(Communicated by Dr. Ida A. Browne.)

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Abstract.

A critical review of the previous researches in this field has been made. The phenomenon of hysteresis in rocks, and the variation of susceptibility with magnetizing field and the magnetite content of rocks have been studied. A modified method of obtaining the hysteresis loops on the cathode-ray oscillograph has been developed. Severe scatter in the relationship between the specific susceptibility and the normative, modal and volume magnetite contents of the rocks has been observed. However, an empirical linear relationship between the specific susceptibility at a field of 8·8 oersteds and the normative magnetite content has been established.

The results, though quantitatively difficult to analyse and interpret, indicate qualitatively the ferromagnetic behaviour of rocks. This is primarily due to the presence of magnetite, though other magnetic minerals also contribute to the phenomenon.

Introduction.

Ever since the magnetic behaviour of lodestone was discovered, numerous investigators have been engaged in the determination of the magnetic properties of rocks and minerals. The volume of data accumulated over the years is so variegated and huge that, now, the study of any one of these properties has become a specialized branch. Particular significance is attached to the studies in magnetic susceptibilities because of their application in problems of geophysical exploration. The discovery of the Kursk anomaly gave an impetus to pooling up of magnetic data on rocks and minerals and resulted in a comprehensive survey by Reich (1941) and many others, of the magnetic susceptibility of various minerals.

In spite of the large range in values quoted for the susceptibility of even the same type of rocks it is now, more or less, generally agreed that the susceptibility of rock is mainly dependent on the magnetic minerals—especially magnetite—contained in the rock. However, susceptibility determinations are complicated, among others, by (i) the magnetizing field, (ii) the previous history of the rock, (iii) the grain size of magnetic particles contained in the rock, (iv) the chemical composition, and (v) petrological characteristics of the rock.

Some of these factors attracted the notice of the authors, who were primarily engaged in the detailed magnetic survey of the Sydney Basin and of the Prospect intrusion in N.S.W. An apparatus was, therefore, set up to obtain the hysteresis curves for various rock samples up to a maximum magnetizing field of 176 oersteds.

Variation of specific susceptibility of 38 rock samples in the magnetic field range of 44 to 176 oersteds has been studied. The investigations have revealed that in general the susceptibility decreases with increasing field strength. Hysteresis and the change in shape of the hysteresis loops with increasing field strength indicate the ferromagnetic behaviour, which is primarily due to the presence of magnetite in the rock.

Variation of specific susceptibility with normative magnetite content was studied for a number of samples. The studies indicate that, due to a large number of factors affecting the results, it may be hard to establish a simple relation which will have universal prediction value.

PREVIOUS RESEARCH.

Research workers like Rücker (1890), Takagi (1913), Wilson (1920–21), Barret (1932), Hallimond (1933), Nagata (1940, 1943), Werner (1945), Duffin (1946), Bruckshaw and Robertson (1948), Bruckshaw and Rao (1950) and Mooney (1952) have contributed a lot to the experimentation side as well as interpretation of susceptibility determinations of different rock types.

Rücker established that the average susceptibility of basic rocks is relatively very high.

Takagi observed that the susceptibility decreases with increasing field but in strong fields this decrease becomes less.

Various authors have attempted correlation between susceptibility and magnetic content of rocks but they have used different methods to obtain a quantitative estimate of the magnetite contained in a rock.

Nettleton and Elkins (1944) have discussed these methods with their relative merits.

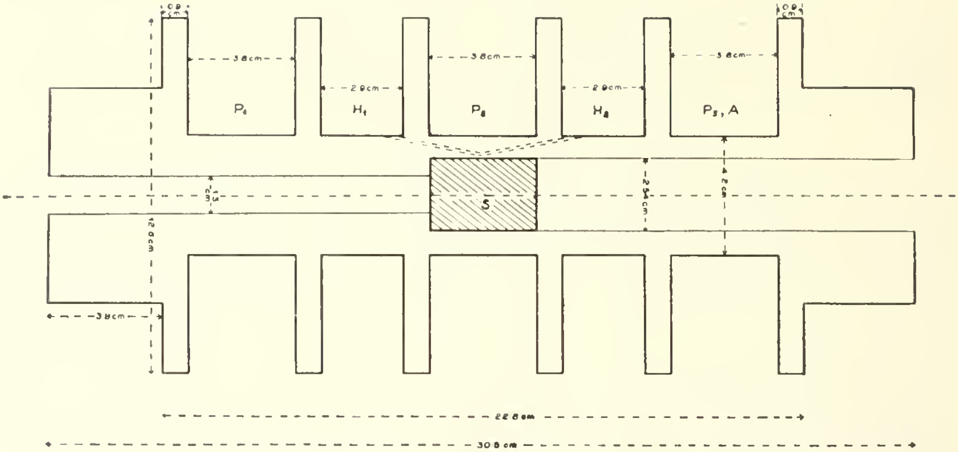
It is evident from a consideration of the work of these investigators that (i) the susceptibility values show a very considerable scattering even for the same volume percentage of magnetite, (ii) this scattering indicates definitely a large range of variation in the susceptibility of magnetite itself, (iii) the susceptibility does not decrease linearly with magnetite content at least for samples very rich in magnetite, and (iv) the failure of the assumption that the susceptibility and demagnetization factor of magnetite for a particular rock type are uniform may be the cause, in a large measure, of the large scatter observed in the data. However, it is possible to obtain certain conclusions as to the relative magnitudes of the susceptibilities encountered in different rock types. It is to be remembered that a number of factors affect the susceptibility determinations. Hence, such conclusions as can be drawn from these measurements have no more than order-of-magnitude significance. Still it is worth while attempting a correlation between such laboratory measurements and the ground and aerial magnetometric surveys.

EXPERIMENTAL TECHNIQUE.

The aim of the present investigations has been to obtain the hysteresis curves for various rock samples, in the form of cylinders, up to a maximum magnetizing field of 176 oersteds. The principle of the experimental technique is essentially the same as the one employed by Bruckshaw and Rao, with the difference that in the present case, instead of $\frac{dI}{dH}-H$ curves, the $I-H$ curves were themselves directly obtained on the oscillograph screen. An electrical circuit, which integrates the differential voltage set up in a system of three previously balanced pick-up coils, is introduced to give a vertical deflection on the oscillograph, which is directly calibrated in terms of absolute values of intensity of magnetization I.

Coil System.

The coil former consists of insulating Permali (Text-fig. 1). Six Permali discs are mounted on this former at proper places by suitably turning down the rod on a lathe at those places. The lengths have been so designed that not only the whole coil system is symmetrical about its centre, but also that when the specimen S is pushed into its limit the centre of the specimen coincides with the geometric centre of the coil system.



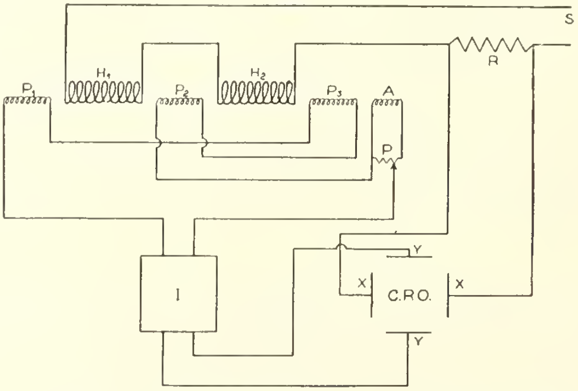
Text-fig. 1.—Section of the coil former.

H_1, H_2 form a pair of Helmholtz coils which produce an alternating average magnetic field of 88 oersteds per ampere current flowing through them. This field is nearly uniform over the area occupied by the specimen. The dimensions and other details of the coils are summarized in Table I.

Table 1.

Inner diameter of all coils= 4·2 cms.
Outside diameter of H_1, H_2=12·6 cms.

Coil.	Length in Centimetres.	Number of Turns.	Wire. S.W.G. No.	Resistance in Ohms.
H_1, H_2	2·9	857	20 En. S.C.C.	11
P_1	3·8	1835	40 D.C.C.	370
P_2	3·8	1968	40 D.C.C.	400
P_3	3·8	1805	40 D.C.C.	350



Text-fig. 2.—Schematic diagram of associated circuit.

Associated Circuit.

Text-figure 2 shows the scheme and details of the electrical connections of the associated circuit.

The Helmholtz field coils H_1, H_2 are connected in series with a resistance R and a power source S. Potential tapped from R is fed to the horizontal deflecting plates or X-plates of the cathode-ray oscillograph (C.R.O.).

The pick-up coils P_1, P_2 and P_3 are connected in series opposition, the unbalanced pick-up being further reduced by an auxiliary coil A and a potentiometer P. Voltage from these pick-up coils is fed into an integrating circuit, I, the integrated output voltage from which is applied to the vertical deflecting plates or the Y-plates.

Field Produced by the Helmholtz Coils.

Actual field produced by the coil system has been determined by three different methods :

(i) By the use of a fluxmeter.

(ii) Passing an alternating current and measuring the pick-up voltage, after feeding it to an amplifier through a 1000 to 1 transformer, by a vacuum-tube voltmeter.

(iii) Sending a direct current and determining the induced voltage.

Typical values (88·07, 88·14, 87·9 and 88·0 oersteds per ampere current), obtained from different methods, showed fair agreement among themselves.

Throughout the present work a value of 88·0 oersteds per ampere current is adopted for the field produced by the Helmholtz coils.

Balancing of Pick-up Coils.

To start with, the pick-up coils P_1, P_2 and P_3 are wound with nearly the same number of turns on each. A current of one ampere is sent through the energising coils H_1, H_2 and the voltages induced in each of the three pick-up coils consequently are measured separately with a vacuum-tube voltmeter. The sum of voltages induced in the end pick-up coils P_1 and P_3, in ideal conditions, should be equal to that induced in the central coil P_2. In practice, however, small adjustments are needed to bring about this condition. Now, keeping the turns on two coils constant, those on the third, say P_3, are so adjusted that the resultant e.m.f. from the combined system of coils is a minimum. In the final stages of this manipulation the C.R.O. is used, in place of the vacuum-tube voltmeter, for detecting the minute voltage. This adjustment could be done accurate to a turn of wire on one of the pick-up coils.

To compensate further, a few turns of 40 S.W.G. double cotton-covered wire are wound on top of P_3 to form the auxiliary coil A. This auxiliary coil is connected to a wire-wound potentiometer P, from which very small voltages could be injected to back-off the remaining out-of-balance voltage from the pick-up coils. When this balance is effected to the best, all the pick-up coils are well wrapped with cellophane paper and securely fastened.

Linearity of Oscillograph Amplifiers.

Linearity of both the X and Y amplifiers of the oscillograph is tested by injecting known voltages on to the X and Y plates separately and measuring the corresponding deflections both directly on the oscillograph screen and on photographic negatives.

Method of Obtaining the $I-H$ Curve.

Since the pick-up coils are initially balanced for nearly zero e.m.f. from their output terminals, when a current is sent through the energizing coils, without a specimen inside the coil system, a horizontal line proportional to the magnetic field is obtained on the C.R.O. screen. The introduction of a rock specimen, then, changes the induction from H to $H+4\pi I$, where I is the magnetic moment per unit volume. So, it can be seen that whatever deflection is produced on the Y-plates is due to this induction I, as the influence of H has been initially compensated. Thus a voltage proportional to $\frac{\mathrm{d}I}{\mathrm{d}t}$ is established across the terminals of the pick-up coil system. Such e.m.f. constitutes the input to the integrating circuit.

For a simple integrating circuit consisting of a condenser C and resistance R, the output voltage E_0 is given by

$$E_0=\frac{1}{CR}\int E_i\mathrm{d}t \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

where E_i is the input voltage.

Since the input voltage is proportional to $\frac{\mathrm{d}I}{\mathrm{d}t}$, it can be written down as

$$E_i\doteq P\frac{\mathrm{d}I}{\mathrm{d}t} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(ii)}$$

where P is a constant.

Therefore,

$$\int E_i\mathrm{d}t=\int P\mathrm{d}I=PI$$
$$=CRE_0.$$

Hence,

$$E_i=\frac{P}{CR}I=QI \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}$$

where $Q=\frac{P}{CR}=$a constant.

So, generally, any output voltage E_0 and hence Y_0, the corresponding deflection produced by E_0, can be written as

$$Y_0=QI_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iv)}$$

Thus it is seen that the Y-input voltage is proportional to the intensity I and the X-input to the magnetic field H; which combination gives the $I-H$ curve.

Equation (iv) affords a method of calibrating the Y-deflections directly in terms of the intensity of magnetization I.

Calibration of Vertical Deflections.

Calibration of the vertical deflections on the oscillograph screen was achieved by replacing the rock specimen by an identical current-carrying magnetic shell, which consisted of a search coil 1 in. in diameter and $1\frac{1}{2}$ in. long (same dimensions as the rock specimen) wound with 63 turns of 24 S.W.G. enamel-covered wire, on a non-magnetic bakelite former, the two ends of the wire being taken out for external connection by a single shielded wire. Vertical deflections produced on the screen of C.R.O. by passing various known currents through the search coil are measured, and knowing n and i, the combined calibration constant Q is calculated.

Determination of Hysteresis Constants.

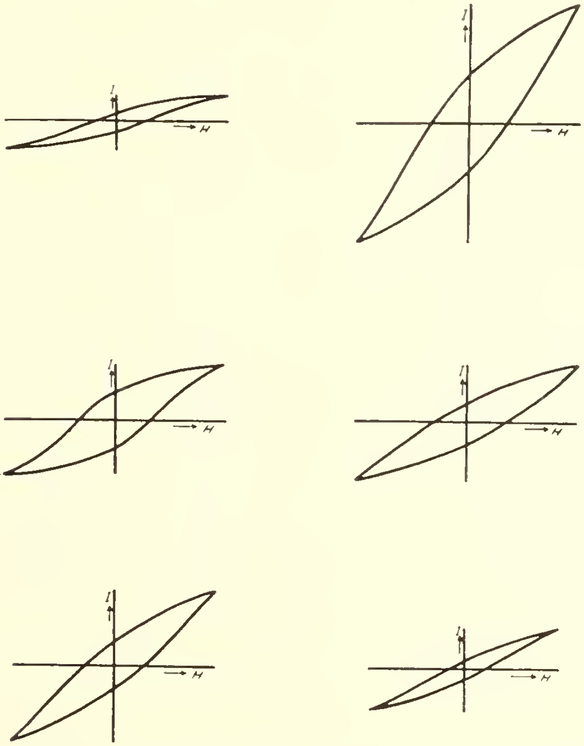
As mentioned earlier, the hysteresis curves were obtained on the C.R.O. screen. The I and H axes were obtained by disconnecting the X and Y inputs of the C.R.O. respectively.

The hysteresis curves were photographed with a 35 mm. camera and later enlarged to a suitable size. From such a picture the apparent susceptibility of the rock at any field *H* could be obtained by dividing the intensity by the field.

Variations of susceptibility and remanence with magnetic field could be studied by obtaining the hysteresis curves for various maximum magnetizing fields.

Remanence and coercivity could be directly read off as the intercepts of the curve on the vertical and horizontal axes.

A few typical hysteresis curves obtained in this investigation are shown in Text-figures 3 to 8.



Text-figs. 3 to 8.—Typical I–H curves for different rock specimens.

Experimental Results.

Calibration.

Different currents were sent through the search coil and the vertical deflections produced on the C.R.O. screen were directly measured and also photographed. Two different ranges of 1·0 mV. and 3·0 mV. on the vertical amplifier were used in these investigations. The values of the calibration constant *Q* as calculated from these observations are 1·996 for 1·0 mV. range and 0·731 for 3·0 mV. range.

Results of Rock Specimens.

Various rock specimens studied are divided into three groups. Group I consists of 13 rocks, which had been chemically analysed previously; the magnetite content of these rocks is calculated as the normative amount from these analyses. Thin sections of these rocks have been prepared during the present investigations and modal analyses carried out under a microscope to obtain the magnetite content as the ratio of the area of minerals appearing black to the total area of the section. On each section, about 100 traverses each of 12·0 mm. length were obtained to calculate the magnetite content. Group II consists of 10 rock samples from three parts of the Prospect intrusion. Group III consists of 15 specimens collected mostly from various flows in the Moss Vale-Bowral area.

A short summary of the rock types and areas of occurrence is given below.

Group I.

Specimen No.	Rock.	Area.
1	Quartz-mica diorite.	Marriott Creek, Cox's River intrusion, Little Hartley.
2	Hornblende-biotite granite.	River Lett.
3	Even-grained biotite granite.	Main Road, River Lett.
4	Monzonitic quartz diorite.	Kanimbla Creek.
5	Porphyritic biotite granite.	Bathurst Road, Hartley.
1 M	Basalt.	Robertson.
2 M	Basalt.	Camden Park.
3 M	Basalt.	Hornsby.
4 M	Olivine basalt.	Mt. Elaine, South Grafton.
5 M	Leucite basalt.	Lake Cargellico.
11 P	Dolerite (Pallioessexite).	Prospect.
12 P	Dolerite (Essexite).	Prospect.
3 B	Basalt.	Bondi.

Group II. The rocks under this group are numbered 1 P to 10 P and are all classified, except specimen 3 P, which is a shale, under the general description of Dolerite. Specimens 1 P to 3 P were collected from the South-Western quarry, while specimens 4 P to 7 P and 8 P to 10 P are from the southern and eastern faces respectively of the Emu quarry on the intrusion.

Group III.

Specimen No.	Rock.	Area.
1 K	Basalt.	Exeter.
12 17	Basalt.	Sutton Forest, "Wongonbra Estate".
21	Dolerite.	"Glenleigh Estate."
32 34	Basalt.	Bowely Estate.
36	Oligoclase basalt.	Cement Works Township.
42	Olivine basalt.	Government House, Moss Vale.
44	Labradorite basalt.	"Summerlees", Moss Vale.
45	Porphyritic basalt.	Blake's Hill.
50	Basalt.	Belanglo.
75 76	Basalt.	Allambie.
M	Dolerite.	Mittagong.
GS	Syenite.	Mt. Gibraltar.

TABLE II.

Specimen No.	Density, ρ (gms./cc.)	Susceptibility. $\chi \times 10^6$ for H (Oersteds).			
		176	132	88	44
1	2·79	100	120	130	200
2	2·66	2190	2250	2400	3800
3	2·62	650	690	800	1200
4	2·78	3740	4000	4400	6500
5	2·67	2000	2000	2200	3280
1 M	2·82	1790	1750	1720	2600
2 M	2·92	6120	6120	6120	6530
3 M	2·68	190	140	160	320
4 M	3·05	580	620	750	1290
5 M	2·90	2000	2060	2240	3200
11 P	2·98	5420	—	—	—
12 P	2·85	8180	8360	8730	12,450
3 B	2·95	5200	—	5200	6680

TABLE III.

Specimen No.	Density, ρ (gms./cc.)	Susceptibility. $\chi \times 10^6$ for H (Oersteds).			
		176	132	88	44
1 P	2·84	1680	1900	2000	3000
2 P	2·81	430	540	790	1000
3 P	2·40	90	80	—	—
4 P	3·00	3500	2850	3500	4600
5 P	2·58	1500	1500	2700	2400
6 P	2·87	4060	4360	4560	6300
7 P	2·89	2220	2360	2560	3900
8 P	2·88	6900	6800	7300	9800
9 P	2·82	3600	3000	3800	9400
10 P	2·78	3500	3550	3600	4140

TABLE IV.

Specimen No.	Density, ρ (gms./cc.)	Susceptibility. $\chi \times 10^6$ for H (Oersteds).			
		176	132	88	44
1 K	2·91	3900	4500	5150	7700
12	2·95	3800	4300	5000	7250
17	2·93	4600	5200	5900	8400
21	3·02	3100	3400	3600	5000
32	2·88	4500	4800	4800	6300
34	3·00	6300	6500	6700	9000
36	2·72	7300	7800	8700	13,250
42	3·01	450	450	500	950
44	3·04	3650	4050	4600	6700
45	2·94	6600	6900	7200	10,350
50	2·90	400	400	450	800
75	2·81	400	400	500	1000
76	2·90	700	700	900	1650
M	2·76	3450	3500	3800	5500
GS	2·54	2400	2300	2400	3550

By obtaining the hysteresis curves for four values of maximum magnetizing field, viz. 176, 132, 88 and 44 oersteds, and determining the densities of the rocks, the variation of specific susceptibility with magnetic field is studied for the specimens in the three groups. These results are summarized in Tables II, III and IV.

Values of the specific susceptibility at the maximum and minimum magnetizing fields along with those of the coercivity (H_c) and remanence at the maximum energizing field for all the specimens under investigation are summarized in Table V.

TABLE V.

Specimen No.	Susceptibility. $\chi \times 10^6$ for H (Oersteds).		Coercivity, H_c. (Oersteds.)	Remanence, $I_r \times 10^3$.
	176	44		
1	100	200	51	38
2	2190	2250	31	25
3	650	1200	26	32
4	3740	6500	23	103
5	2000	3280	26	82
1 M	1790	2600	51	119
2 M	6120	6530	41	—
3 M	190	320	62	30
4 M	580	1290	46	107
5 M	2000	3200	72	113
11 P	5420	—	68	395
12 P	8180	12,450	52	257
3 B	5200	6680	65	360
1 P	1680	3000	55	94
2 P	430	1000	46	25
3 P	90	—	—	—
4 P	3500	4600	66	223
5 P	1500	2400	43	63
6 P	4060	6300	52	318
7 P	2220	3900	43	107
8 P	6900	9800	52	189
9 P	3600	9400	58	205
10 P	3500	5140	58	376
1 K	3900	4500	69	223
12	3800	7250	54	240
17	4600	8400	58	290
21	3100	5000	56	188
32	4500	6300	70	342
34	6300	9000	58	308
36	7300	13,250	47	218
42	450	950	43	25
44	3650	6700	44	189
45	6600	10,350	54	291
50	400	800	35	13
75	400	1000	39	19
76	700	1650	47	32
M	3450	5500	38	107
GS	2400	3550	39	75

Table VI shows the χ-values at maximum and minimum magnetic fields along with the magnetite contents obtained as q_{Mt}, the normative amount from the chemical analyses, and M_{Mt}, the amount calculated from the modal analyses on thin sections. The values in the fifth column were calculated from $v = \frac{\rho}{\rho_m} \times q_{Mt}$ where a value of $5 \cdot 2$ for ρ_m—the density of magnetite—is assumed.

TABLE VI.

Specimen No.	q_{Mt}.	M_{Mt}.	ρ.	v.	$\chi \times 10^6$ for H (Oersteds).		
					176	44	8·8
1 M	4·64	2·94	2·80	2·49	1790	2600	4550
2 M	3·62	7·13	2·84	1·98	6120	6530	5400
3 M	4·41	6·65	2·82	2·39	190	320	—
4 M	3·48	2·44	3·09	2·07	580	1290	—
5 M	10·14	6·62	3·03	5·91	2000	3200	2450
1	6·03	2·48	2·84	3·29	100	200	—
2	3·48	1·49	2·74	1·84	2190	2250	3750
3	1·16	0·50	2·66	0·59	650	1200	2200
4	4·18	1·82	2·82	2·26	3740	6500	5100
5	2·78	0·63	2·70	1·45	2000	3280	3750
11 P	3·25	4·89	2·98	1·87	5420	—	—
12 P	9·28	10·57	2·99	5·34	8180	12,450	7500
3 B	4·87	3·95	2·93	2·75	5200	6680	4350

The χ-values at a low field of 8·8 oersteds calculated for certain specimens by direct measurement of the vertical deflections, are also included in the above table. They serve to show the tendency of the $(\chi - H)$ curves with a decreasing field. These values denoted by χ_0, the susceptibility at $H = 176$ denoted by χ_m, the rate of increase of susceptibility given by $R = \frac{\chi_m - \chi_0}{\chi_0}$ and the corresponding coercivity H_c values at the maximum energizing field are shown in Table VII.

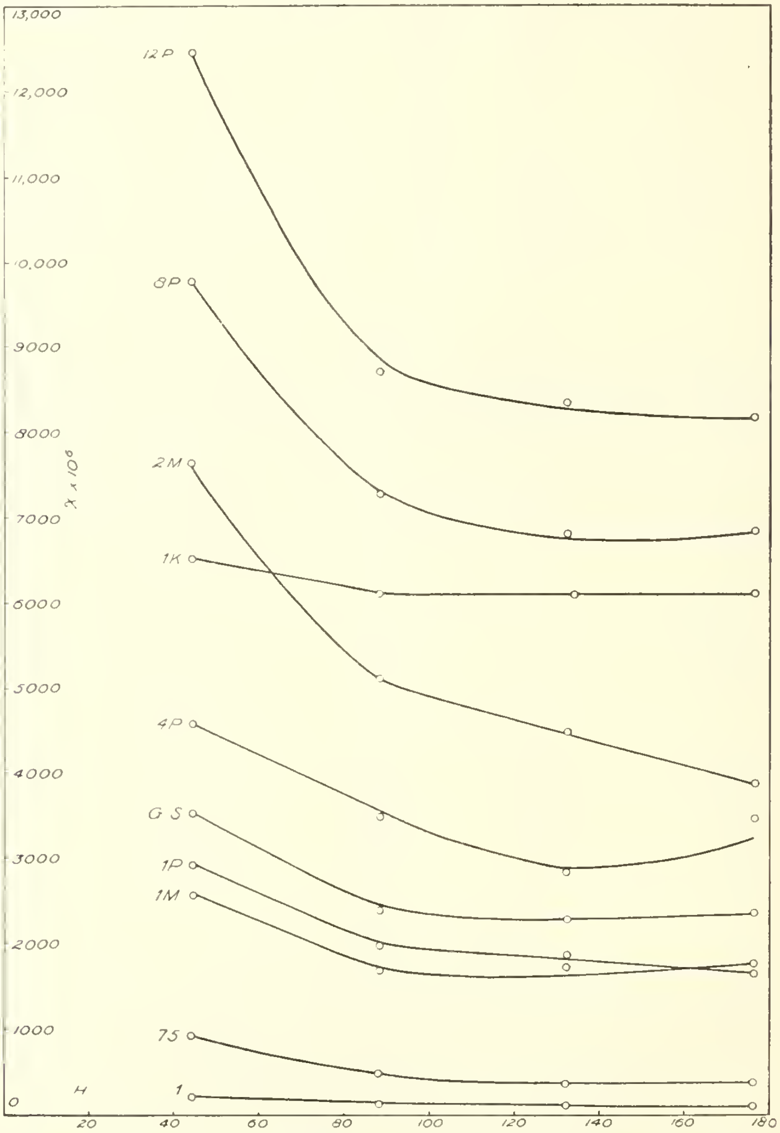
TABLE VII.

Specimen No.	$\chi_m \times 10^6$.	$\chi_0 \times 10^6$.	$R \times 10^3$.	H_c. (Oersteds).
2 M	6120	5400	133	41
12 P	8180	7500	91	52
3 B	5200	4350	195	65
8 P	6900	6400	78	52
45	6600	5800	138	54
34	6300	4750	326	58

DISCUSSION OF RESULTS.

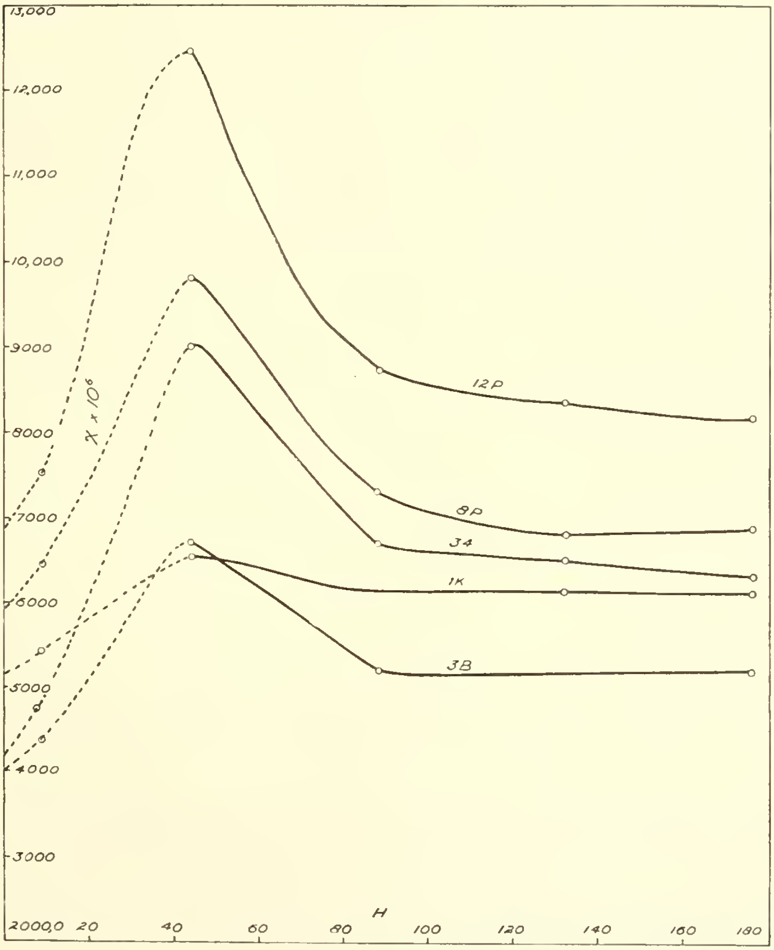
It must be emphasized, in the first place, that all results of hysteretic characteristics of rocks reported in this investigation are obtained at fields far above that of the earth. Obviously, the values quoted do not represent the natural values for the specimens. But as the experiments were conducted under similar standard conditions, the results have significance for comparison among themselves and also have an order-of-the-magnitude significance for their application to the field magnetometric studies.

The results of calibration, by replacing the rock specimen by an equivalent magnetic shell, showed a fair degree of repeatability as far as the deflections on the vertical plates of the oscillograph were concerned. A considerable amount of sensitivity is lost by the introduction of the integrating circuit as also a shunt-resistance at the Y-input terminals to eliminate the interference of harmonics on the $I - H$ curve. However, the method of calibration with a search coil was found to be quite dependable and has an added advantage of easy operation. A wide range of deflections could be calibrated by winding the coil with suitably thick wires. In the present studies, however, only two ranges of vertical amplification, viz. the 1·0 mV. and 3·0 mV. ranges, were calibrated as the deflections of all the specimens studied lay in these ranges.



Text-fig. 9.—Variation of specific susceptibility with magnetic field from 44 to 176 oersteds.

As is seen from Text-figures 3 to 8, the hysteresis loops are those of unsaturated specimens. On the assumption that the rock specimens contain disseminated spherical particles of magnetite, it can be shown theoretically that a magnetic field of about 2200 oersteds would be required for saturation of rocks. In loops of some specimens, a tendency to assume a rectangular shape or a flattening at the tips of the *I—H* curves could be visualized. This shape is more attributable to the small grain size of the ferromagnetic minerals contained in the rock than the magnetic field approaching anywhere near the saturation field. The hysteresis phenomenon is very well marked in all the specimens and, as is shown later, follows the general trend of that of ferromagnetic minerals contained in the rock, especially that of magnetite. Further, the change of shape of the hysteresis loop with changes in the magnetizing field as obtained in these investigations also resembles that of ferromagnetic materials, and thereby proves that this behaviour is due to ferromagnetic minerals contained in the rock.

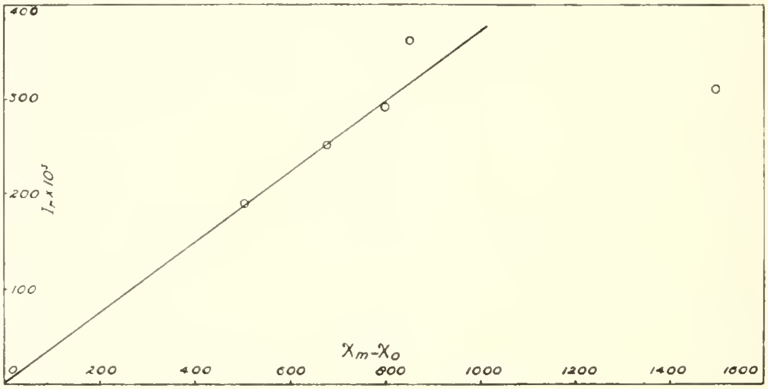


Text-fig. 10.—Variation of specific susceptibility with magnetic field from 0 to 176 oersteds.

Tables II, III and IV summarize results of variation of the specific susceptibility with the magnetic field for all specimens under the three groups; while Text-figure 9 depicts the same for a few selected samples. In spite of such a large variation among the same group of rocks, it is evident that most rocks have the same trend of variation qualitatively. Specific susceptibility increases in the same manner for most rocks, when the magnetic field is reduced from

176 to 44 oersteds. However, the rate of increase seems to differ considerably from specimen to specimen. In the two specimens 12 P and 1, for example, the variations in susceptibility in the field range of 176 to 44 oersteds are 4000 and 100×10^{-6} c.g.s. respectively. The quantum of change in susceptibility seems to agree well with the content of magnetic minerals of the rock ; the more the magnetic material, the more the change, and *vice versa*.

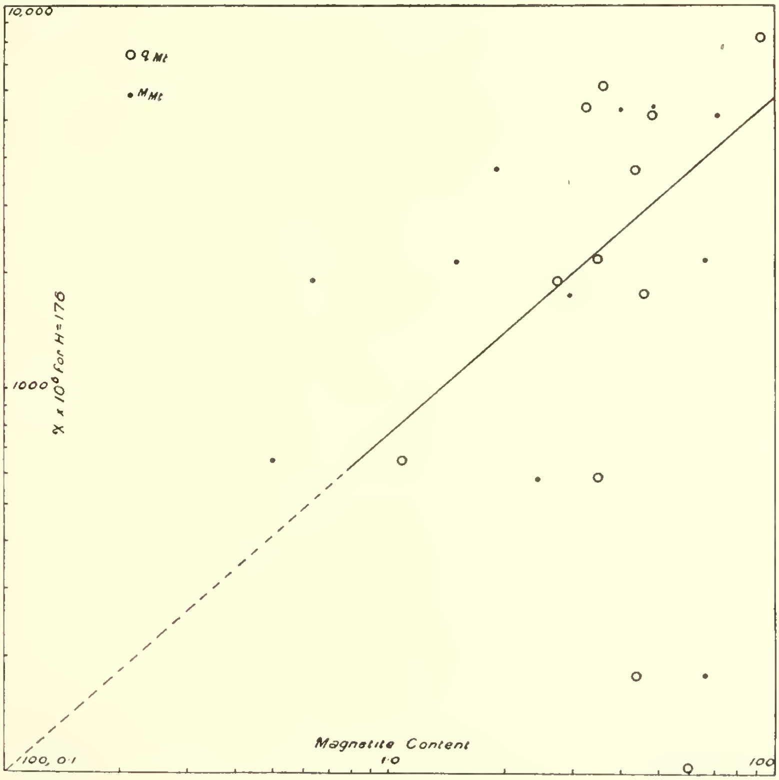
As mentioned earlier, the specific susceptibilities for a few specimens at a field of 8·8 oersteds were calculated. Text-figure 10 shows the plots of these results, together with the variation of susceptibility over the rest of the field range. The dotted lines indicate the extrapolated probable path of variation of susceptibility between 0 and 44 oersteds. It is obvious from the extrapolation that unless more data are available between 8·8 and 44 oersteds, it would not be possible definitely to locate a sharp maximum of susceptibility. However, the variations in specimens follow the same general trend, viz. an increase of susceptibility up to a field, say, of 30 to 50 oersteds, then decrease of susceptibility with further increase in magnetic field. The latter decrease is rather sharp in the initial stages, usually up to a field value of 80–100 oersteds, and then gradually becomes less with increasing fields. This type of variation bears a close resemblance to the variation of susceptibility of magnetite itself. These results confirm the observations of Takagi (1913) that the $\chi - H$ curve is " very similar to that of ferromagnetic bodies, with a quantitative difference that the field of maximum susceptibility is here much larger ".



Text-fig. 11.—Variation of remanence with rate of increase of susceptibility.

Table V shows the range of susceptibility giving the two values at maximum and minimum fields, as also the coercivity and remanence values at the minimum magnetic field. The magnitude of an enormous range of values obtainable with rock specimens is evident in this summary. Coercivity values range from 35 to 70 oersteds, while the average for most rocks may be said to lie between 45 and 50 oersteds. Most of the rock specimens are, therefore, magnetically " soft ", as has been observed by Nagata (1943), with their coercivities lying below 100 oersteds. From the results tabulated in Table VII, an idea of the relation between the rate of increase of the susceptibility R and the coercivity H_c is obtained. The six specimens, though not numerous enough to enable any reliable conclusions to be drawn, seem to agree in general with Nagata's (1953) observation that " the rate of increase in magnetic susceptibility with H becomes larger according to the increase of magnetic hardness ". In this connection the effect of grain size of the ferromagnetic minerals on the susceptibility and the coercivity has to be kept in mind and unless the shape and size of this effect on the two parameters involved is really proportionate, nothing more definite could be said about the proportionality than that it is a general trend.

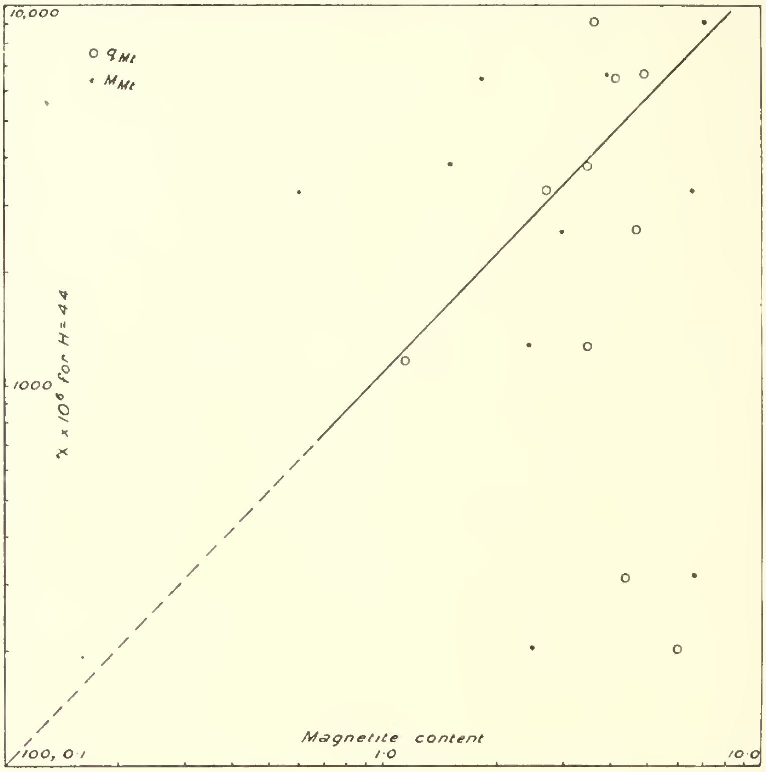
Another measure of hardness, as adopted earlier by Nagata, is the ratio of the remanent magnetization to the initial susceptibility, i.e. I_r/χ_0. If we plot this against the rate of increase of susceptibility $(\chi_m-\chi_0)/\chi_0$, the relation thus obtained needs to be a linear one. In Text-figure 11 are plotted the values of $I_r \times 10^3$ taken from Table V as the ordinates and the difference between the susceptibility at maximum field and the initial susceptibility as the abscissae.



Text-fig. 12.—Variation of specific susceptibility at 176 oersteds with normative and modal magnetite contents.

This is in effect the same as plotting the hardness factor and the rate of increase of susceptibility both multiplied by a factor χ_0. It is interesting to observe that out of the five specimens plotted nearly four seem to fall well on a straight line graph. But, as already pointed out, even from this linear relationship it may be too much of a generalization to say that the rate of increase of susceptibility varies linearly with the hardness factor, because the number of specimens involved is too few. Considerations of the effect of grain size of ferromagnetic minerals in the rock apply equally well in this case also.

Variations of specific susceptibility at various fields normative, modal and volume magnetite contents are plotted in Text-figures 12, 13 and 14. In Text-figure 12 are shown the modal and normative magnetite amounts against susceptibility at the maximum field of 176 oersteds; while in Text-figure 13 the same quantities are plotted against specific susceptibility at a field of 44 oersteds. It is seen from these two plots that the scattering of points is too large to enable any curve fitting. The lines drawn indicate the mean lines through the origin on the assumption that the largest proportion of the observed susceptibility is due to the presence of magnetite content. In Text-figure 14 the specific susceptibilities at a low field of 8·8 oersteds are plotted against the normative, modal and volume magnetite contents. A comparison of the three figures indicates a decrease in the degree of scattering of the susceptibility as the field is decreased. While realizing that the susceptibility values at earth's field differ substantially from those at even a field of 8·8 oersteds, an attempt has been made to correlate the normative magnetite content, q_{Mt}, with the susceptibility χ_0 at 8·8 oersteds. It is seen that both Slichter's relationship (1929) of $\chi_0 = 0 \cdot 3$ V. and Nagata's relationship given by equation $\chi_0 = (2 \cdot 43 \pm 0 \cdot 75) \times 10^{-2} q_{Mt}$, are not really applicable for the susceptibility values quoted here. It is doubtful whether a simple linear equation of the type proposed by either will have a universal prediction value.



Text-fig. 13.—Variation of specific susceptibility at 44 oersteds with normative and modal magnetite contents.

However, to establish an empirical relationship for these rocks, it is assumed that the specific susceptibility at 8·8 oersteds is roughly proportional to the normative amount, q_{Mt}. So we can write down

$$\chi_0 = A q_{Mt} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(v)}$$

where A is a constant given by

$$A = \frac{\Sigma \chi_0 q_{Mt}}{\Sigma q_{Mt}{}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(vi)}$$

Results of nine samples were utilized to fit into such an equation and a value of

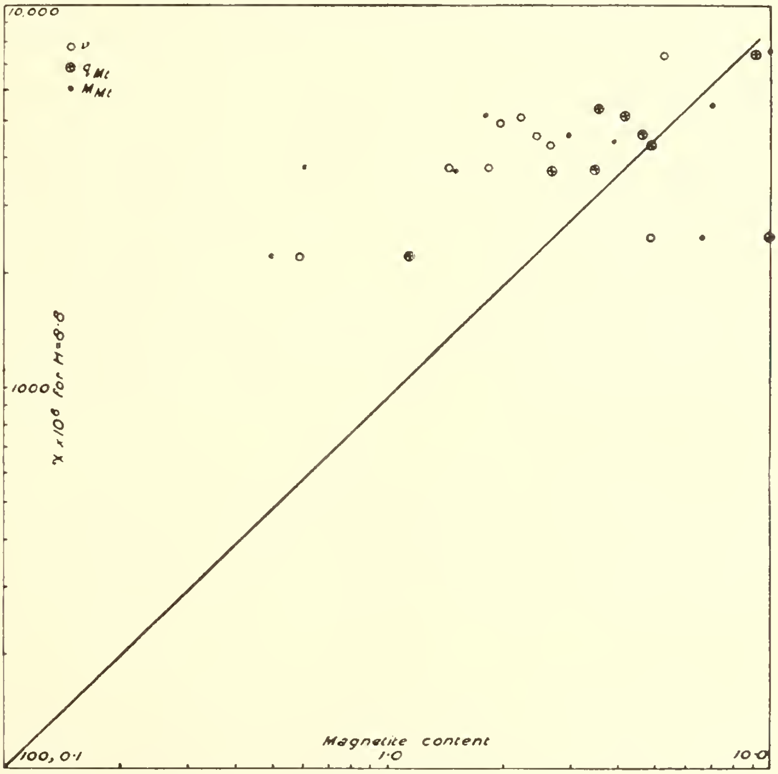
$6 \cdot 39 \times 10^{-2}$ for the constant was obtained. The error involved in such a constant is given by

$$\text{Error in } A = \pm \sqrt{\frac{r^2}{(n-1)\Sigma q_{Mt}{}^2}} \quad \ldots\ldots\ldots\ldots \text{(vii)}$$

where r is the difference between the observed value of χ_0 and the one calculated by utilizing the value of A, and n is the number of observations. The error in this case worked out to be $\pm 2 \cdot 03 \times 10^{-2}$. Hence the empirical relation may be written as

$$\chi_0 = (6 \cdot 39 \pm 2 \cdot 03) \times 10^{-2} q_{Mt} \quad \ldots\ldots\ldots\ldots\ldots \text{(viii)}$$

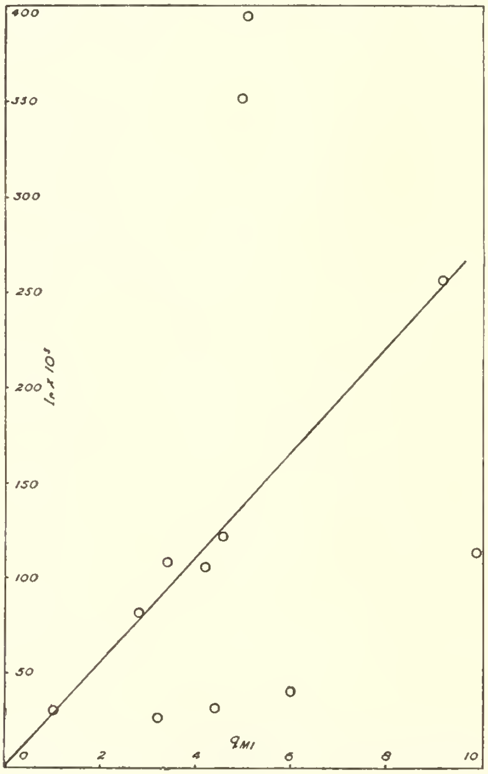
Calculating the ratios of χ_0/q_{Mt} and obtaining the mean deviation leads to a constant of $8 \cdot 3 \times 10^{-2}$ for A.



Text-fig. 14.—Variation of specific susceptibility at 8·8 oersteds with normative, modal and volume magnetite contents.

However, it is to be borne in mind that such a relation really oversimplifies the conditions existing in a rock. Apart from magnetite, rocks have generally other magnetic minerals such as ilmenite, or complex solutions of iron oxides. The effect of these is ignored in establishing a relationship of the type described above. Moreover, the magnetic history of the rock, the degree of purity of the magnetite, its grain size and its distribution within the rock specimen itself are factors which play no small part in the susceptibility considerations.

Plotting these results on logarithmic scale, though having the advantages of spreading the data more uniformly and avoiding the extreme weighting of the end-points, leads one to believe that an exponential relationship similar to the one suggested by Werner and Mooney would be more applicable. But it may be pointed out that in the latter's results, except for a few cases, the exponential constant factor is nearly unity ; also, the scattering is too large to leave any choice between a linear or an exponential relationship. Any trial at curve fitting in this case would have only an order-of-magnitude significance, and that, too, perhaps for specimens studied in a particular case. Unless exhaustive investigations are made on artificially made samples, in which known quantities of minerals are mixed to simulate as nearly as possible a known rock or rock type, it may really be very difficult to comprehend the various complex factors, which affect direct results on rock samples. In such a set of experiments on artificial samples it would be easier to isolate the individual effects and study their variation. Further, the discrepancies in the relationship between the susceptibility and the magnetite content are due, apart from the inaccuracies of determination and the variation of susceptibility values among themselves, to a considerable extent to the ambiguity in determining the magnetite content itself. The discrepancy in determinations of the magnetite could be visualized at a glance from Table VI.



Text-fig. 15.—Variation of remanence with normative magnetite.

Text-figure 15 illustrates the variation of remanence with the magnetite content. This figure, again, shows the scattering of values as much as the susceptibility. One is led to believe that the scattering is, perhaps, more due to errors in the evaluation of the magnetite content than in the determination of the hysteretic constants as the errors in the latter, if any, are believed to be rather uniform. However, it is seen that, roughly, there is a linear relationship between the remanence and the normative amount of magnetite.

CONCLUSIONS.

Summing up, the results of these investigations may be stated as

1. Variation of specific susceptibility of 38 rock specimens in the magnetic field range of 44 to 176 oersteds is studied. There is a general decrease of susceptibility with increasing field strength, the decrease being steep in the initial stages and then gradually becoming less and less.

2. Values of susceptibility determined for a few specimens at 8·8 oersteds and extrapolated to the value at the next highest field observed, produced a curve, whose shape resembles the $\chi - H$ curve of magnetite qualitatively.

3. Hysteresis and the change in shape of the hysteresis loops with increasing field strength indicate the ferromagnetic behaviour of the rocks.

4. The coercivity values indicate that most of the rocks are magnetically " soft " ; it is shown that measures of hardness given by H_c and I_r/χ_0 and their relationship with the rate of increase of susceptibility are not very trustworthy.

5. Variation of specific susceptibility with normative magnetite content was studied for 13 samples and attempts are made to establish an empirical relationship between them. It is pointed out that due to the large number of factors affecting the results, and their equally large amount of variation among rocks of the same type, it may be hard to establish a relation which will have universal prediction value.

6. All the above results, though quantitatively hard to analyse and interpret, indicate qualitatively the ferromagnetic behaviour of the rocks, and also that this ferromagnetic behaviour is primarily due to the presence of magnetite in the rock, though other magnetic minerals are also sure to contribute their share to the phenomenon.

ACKNOWLEDGMENTS.

The authors express their grateful thanks to Professor C. E. Marshall for his keen interest and encouragement throughout the progress of this work. They acknowledge the financial assistance given by the Research Committee of the University of Sydney to procure part of the equipment needed for these investigations.

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OCCULTATIONS OBSERVED AT SYDNEY OBSERVATORY DURING 1956.

By K. P. Sims, B. Sc.
(Communicated by the Government Astronomer.)

Manuscript received, February 7, 1957. Read, April 3, 1957.

The following observations of occultations were made at Sydney Observatory with the 11½-inch telescope. A tapping key was used to record the times on a chronograph. The reduction elements were computed by the method given in the Occultation Supplement to the *Nautical Almanac* for 1938 and the reduction completed by the method given there. The necessary data were taken from the *Nautical Almanac* for 1956, the Moon's right ascension and declination (hourly table) and parallax (semi-diurnal table) being interpolated therefrom. No correction was applied to the observed times for personal effect but a correction of $-0{\cdot}00152$ hour was applied before entering the ephemeris of the Moon. This corresponds to a correction of $-3''{\cdot}0$ to the Moon's mean longitude.

Table I.

Serial No.	N.Z.C. No.	Mag.	Date.	U.T.	Observer.
				h m s	
329	——	8·6	April 16	9 49 34·6	S
330	984	6·6	April 16	9 57 09·5	S
331	1381	6·3	April 19	8 56 05·2	W
332	1429	6·8	June 13	8 40 28·3	W
333	1662	6·5	June 15	9 31 34·7	S
334	2120	6·8	June 19	9 37 17·2	W
335	1968	6·9	July 15	8 54 11·2	W
336	2376	4·6	July 18	15 35 59·6	S
337	2509	6·0	July 19	15 56 45·5	S
338	1809	6·9	August 10	10 09 18·6	R
339	2307	4·1	August 14	9 01 34·0	W
340	2310	4·6	August 14	9 13 06·1	W
341	——	8·4	August 14	9 16 47·9	W
342	2330	6·3	August 14	13 59 58·0	W
343	2445	7·4	August 15	9 32 11·4	S
344	2457	6·3	August 15	13 17 30·4	W
345	2599	6·8	August 16	15 52 03·5	W
346	3093	4·5	August 20	9 43 34·2	R
347	2826	4·0	Sept. 14	12 23 12·6	W
348	2715	6·5	Nov. 7	10 11 17·3	R
349	89	6·4	Dec. 12	10 08 10·1	S

Table I gives the observational material. The serial numbers follow on from those of the previous report (Sims, 1956). The observers were H. W. Wood (W), W. H. Robertson (R) and K. P. Sims (S). In all cases the phase observed was disappearance at the dark limb. Table II gives the results of the reductions which were carried out in duplicate. The N.Z.C. numbers given are those of the *Catalog of 3539 Zodiacal Stars for the Equinox* 1950·0 (Robertson, 1940), as recorded in the *Nautical Almanac.*

TABLE II.

Serial No.	Luna-tion.	p	q	p^2	pq	q^2	$\triangle\sigma$	$p\triangle\sigma$	$q\triangle\sigma$	Coefficient of	
										$\triangle\alpha$	$\triangle\delta$
329	412	+ 97	—23	95	—22	5	—2·4	—2·3	+0·6	+13·0	—0·35
330	412	+100	+ 6	100	+ 6	0	+0·7	+0·7	0·0	+13·9	—0·06
331	412	+ 93	+38	86	+35	14	+0·2	+0·2	+0·1	+14·7	+0·05
332	414	+ 95	+31	90	+29	10	—0·8	—0·8	—0·2	+14·8	—0·04
333	414	+100	+ 3	100	+ 3	0	—1·1	—1·1	0·0	+14·1	—0·34
334	414	+ 95	—30	91	—29	9	—0·2	—0·2	+0·1	+12·4	+0·50
335	415	+ 58	—81	34	—47	66	+1·9	+1·1	—1·5	+ 4·7	—0·95
336	415	+ 96	—29	92	—28	8	—1·2	—1·2	+0·3	+13·1	—0·34
337	415	+ 84	+54	71	+45	29	—1·9	—1·6	—1·0	+11·5	+0·56
338	416	+ 98	—19	96	—19	4	+0·3	+0·3	—0·1	+12·7	—0·52
339	416	+ 62	+79	38	+49	62	—1·7	—1·1	—1·3	+ 9·7	+0·72
340	416	+100	+ 7	100	+ 7	0	—1·8	—1·8	—0·1	+14·0	—0·03
341	416	+ 98	—20	96	—20	4	+0·5	+0·5	—0·1	+13·3	—0·30
342	416	+ 39	—92	15	—36	85	+2·0	+0·8	—1·8	+ 4·4	—0·95
343	416	+ 80	+60	64	+48	36	—2·2	—1·8	—1·3	+11·3	+0·58
344	416	+ 97	—26	93	—25	7	—1·3	—1·3	+0·3	+13·5	—0·27
345	416	+ 97	+26	93	+25	7	—1·7	—1·6	—0·4	+13·2	+0·34
346	416	+ 75	—66	56	—50	44	+1·0	+0·8	—0·7	+13·6	—0·39
347	417	+ 81	+59	65	+48	35	—2·2	—1·8	—1·3	+ 9·7	+0·73
348	419	+ 83	—56	69	—46	31	+0·8	+0·7	—0·4	+12·8	—0·43
349	420	+ 97	+24	94	+23	6	—1·4	—1·4	—0·3	+12·3	+0·55

The stars involved in occultations 329 and 341 were not in the *Nautical Almanac* list ; they are Yale *25* 2364 and Yale *13* I 6660. The apparent place of 2364 was R.A. 6^h 22^m $46^s{\cdot}83$, Dec. $+21°$ $36'$ $32''{\cdot}8$, and that of 6660 was R.A. 16^h 04^m $54^s{\cdot}99$, Dec. $-20°$ $49'$ $29''{\cdot}7$.

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Sims, K. P., 1956. THIS JOURNAL, **90**, 17 ; *Sydney Observatory Papers*, No. 25.

A POLARITY REVERSAL IN THE TERTIARY VOLCANICS OF THE KURRAJONG-BILPIN DISTRICT, WITH PETROLOGICAL NOTES.

By Keith A. W. Crook.
University of New England.

Manuscript received, December 10, 1956. Read, April 3, 1957.

Abstract.

The volcanics occur as dykes, flows and necks of alkali olivine basalt containing titanomagnetite. Microscopic examination indicates the absence of ilmenite and ulvöspinel ($2FeO.TiO_2$). One 80-foot flow gives anomalies to $+1046\,\gamma$. The Merroo Neck exhibits reversal of polarity, apparently due to reversal of the geomagnetic field, and gives anomalies to $-2219\,\gamma$.

Introduction

The Kurrajong-Bilpin district (Text-fig. 1) lies some 50 miles north-west of Sydney, and consists dominantly of Triassic sandstones and shales (see Crook, 1957). Physiographically the area is part of the Blue Mountains Plateau. The Triassic sediments are horizontal, except on the east and west, where the area is bounded by easterly-facing meridional monoclines, the monocline on the east having a major fault—the Kurrajong Fault—parallel to and immediately west of it. The development of these structures post-dates the Tertiary vulcanicity and is generally referred to the Koscinsko epoch in the Plio-Pleistocene. The date of the vulcanicity is thought to be pre-Miocene, since there is no evidence of the ? Miocene laterite surface beneath the basalt flows.

Specimen numbers used throughout this paper refer to specimens and slides housed in the Museum at the Department of Geology and Geophysics, University of Sydney.

Igneous Activity.

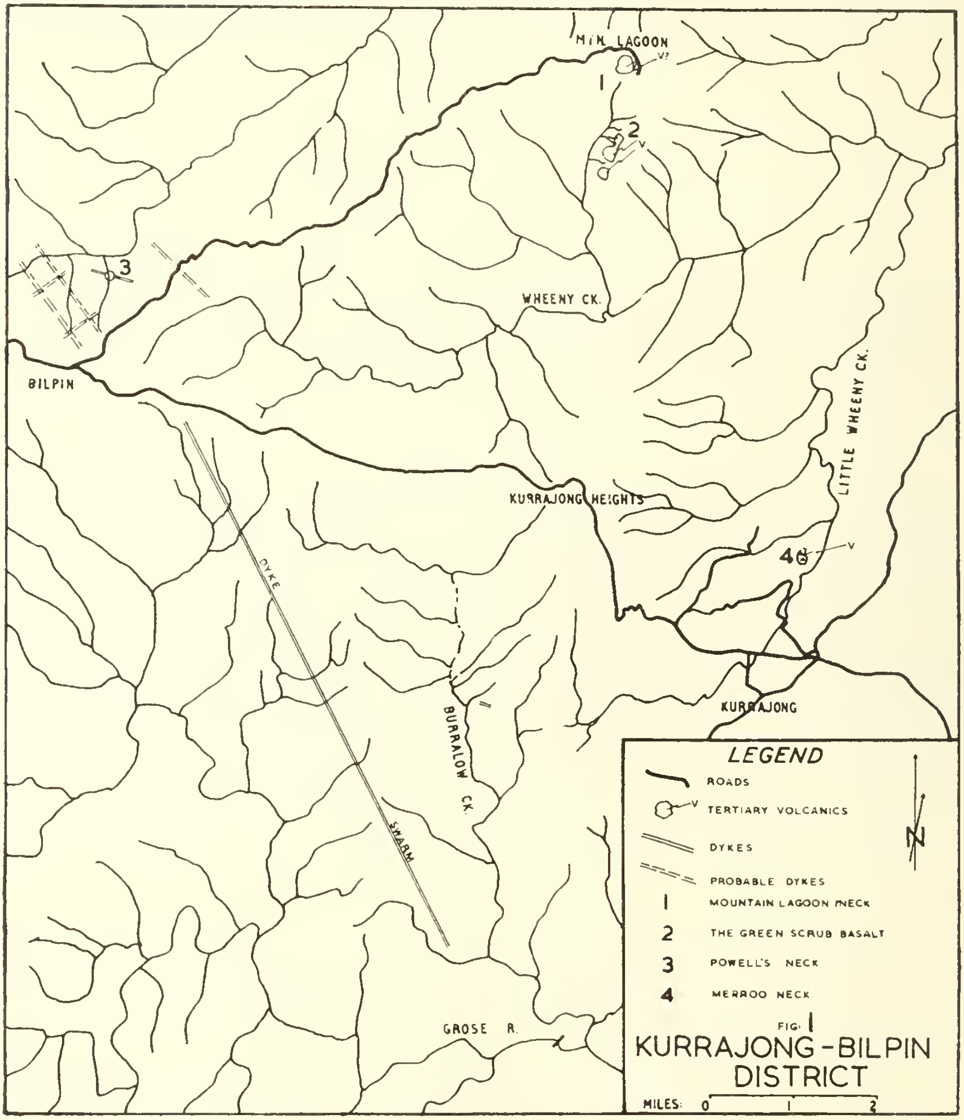
Intrusives.

Several dykes, all deeply weathered, occur in the area (Text-fig. 1). Those in the Bilpin region are apparently related to Mt. Tootie, a basalt-covered peak to the north-west. Most remarkable is the dyke swarm consisting of five dykes, the largest being five feet across. They are surrounded by a wall-like aureole of prismatized sandstone.

Powell's Neck, north of Bilpin (522636 St. Albans), noted by Carne (1908, p. 137), is a circular patch of fresh basalt about half an acre in extent overlooked by cliffs of Hawkesbury Sandstone. The soil-covered margins are marked by fragments of what is probably a weathered metamorphosed shale consisting of a box-work of limonite. It may have been derived from the Burralow Formation below.

The Merroo Neck (Willan, 1925), which is the Diamond Hill Neck of Carne (1908, p. 102), is a patch of fresh basalt breccia about an acre in extent, some 3½ miles north of Kurrajong (668568 Windsor). At its south-eastern corner are outcrops of a very weathered breccia (Text-fig. 3), probably a remnant of the shale-rich agglomerate which was associated with the vent. This material is the highest topographically in the intrusion, being on the eastern side of a hill of Ashfield Shale. On the east and north Hawkesbury Sandstone occurs.

The Mountain Lagoon is possibly situated on an intrusion. The lagoon itself is known to contain white clay to a depth of 14 feet below the floor (Mr. B. Boughton, personal communication), but this may have come from the surrounding Ashfield Shales. As the lagoon has been well filled for several years, investigation of it was not possible.



Text-fig. 1.

Extrusives.

Lying to the west of the area examined are the basalt covered peaks of Mounts Caley, Banks, Tomah, Irvine, Wilson and Tootie. A flow, which occurs south of Mountain Lagoon (630655 St. Albans), was first noted by David (1902, p. 369) and briefly described by Carne (1908, p. 122), who gave it the name " Mountain Lagoon Neck ". This term is discarded, however, in preference for " The Green Scrub Basalt " of Willan (1925), because confusion may well arise with the alleged neck on the site of The Mountain Lagoon.

Grady and Hogbin (1926), in discussing the physiography of the district, give a brief description of this basalt and the surrounding rocks. Three spurs trending westward from the high ground east of the Kurrajong Fault are covered by columnar basalt which is lower topographically than the plateau surface east of the fault, and cannot be traced over the fault line. The basalt disappears beneath talus cover as the fault is approached. Ashfield Shale, preserved under the basalt, is exposed between the spurs, but contacts are obscured.

Petrology.

The various igneous bodies are petrologically similar, and are probably comagmatic. They are all alkali olivine basalts, with the association labradorite, forsteritic olivine, titan-clinopyroxene, iron ore and interstitial analcite. A micrometric analysis (vol. percent.) of GR 98 from The Green Scrub Flow gives a composition fairly typical of these rocks :

Titan-clinopyroxene ..	41·7	Analcite	7·7
Olivine	9·8	Iron ore	5·5
Plagioclase	34·7	Alteration products ..	0·6

Texturally they tend to be trachytic, and intergranular to sub-ophitic. Phenocrysts of olivine and plagioclase are common, and titan-clinopyroxene phenocrysts occur occasionally in the Merroo Neck. The olivine contains iron ore inclusions and is frequently altered to bowlingite, or occasionally to iddingsite. The plagioclase is usually zoned and frequently corroded. Inclusions of clinopyroxene, which may form a band on the margin of the inner zone, and carbonate cores are found in feldspars from the Green Scrub Flow. Feldspars from the Merroo Neck show carbonate and iron ore inclusions, and veins and blobs of bowlingite or iddingsite. The zoning in the feldspar phenocrysts may be normal or reversed (Merroo Neck). The ground-mass feldspar is also zoned at times (Table 1).

Table 1.

Optical Properties of Plagioclases.

(Sections Cut // (010).)

Slide No.	Locality.	Habit.	Extinction Angle $X' \hat{} 001$	
			Core.	Margin.
GR 98	Green Scrub.	Phenocryst.	—30°	+7°
GR 99	,, ,,	Ground Mass.	—15°	—4°
GR 100	,, ,,	,, ,,	—25°	—3°
GR 119	Merroo Neck.	Phenocryst.	—20°	—24°
GR 120	,, ,,	,,	—20°	*ca.* —25°

The titan-clinopyroxene, which is occasionally zoned, is generally in a small euhedra, but it may occur as a felty mass associated with iron ore or as a vermicular corona about quartz xenoliths. In GR 120 the clinopyroxene occurs in clots exhibiting a semi-radial prismatic structure with granular margins.

Certain features of each igneous body are unusual, and deserve comment. The Green Scrub Flow is characterized by frequent quartz xenoliths. These may be composite grains, and show bubble trails and chlorite stringers. Quartz of this type is typical of the underlying Triassic sandstones. The xenoliths are always margined by a corona of vermicular clinopyroxene which represents "seeding" of the magma by quartz. This relationship is similar to that discussed by Stevens (1955) from the Tertiary volcanics of the Southern Highlands.

The Merroo Neck contains fragments of a pilotaxitic olivine basalt quite unlike anything encountered elsewhere in the area, and fragments of picrite. The latter contains about 40% of colourless clinopyroxene, 30% of olivine and minor plagioclase, which is similar to the types found as phenocrysts.

Powell's Neck is unusual in that it contains xenocrysts about 1 mm. in diameter of picotite, which is greenish brown with an opaque margin, and of very dark red, almost opaque chromite. An almost resorbed feldspar, with a corona of acicular clinopyroxene, suggests that xenocrysts of calcic plagioclase may also have been present.

IRON ORES.

The iron ore is without surface alteration. That from the Green Scrub Flow is of late crystallization, occurring interstitial to the feldspar, and usually to the pyroxene. Crystals may be equant and angular (0·1 mm. diameter), due to surrounding silicates; acicular (0·01 by 0·15 mm.); or skeletal (0·1 mm. diameter). Some of the skeletal crystals are text-book examples.

The iron ore in the Merroo Neck, again of late crystallization, is variable in habit. In the typical basalt it occurs exclusively as interstitial equant euhedra 0·02–0·03 mm. in diameter. The pilotaxitic basalt possesses a few large anhedral grains 1·0 by 0·5 mm. The remainder is interstitial to the feldspar as before, some as grains 0·02–0·03 in diameter, but most as a "dust" of grains 0·005 mm. or less in diameter.

In polished section iron ore and a few grains of chalcopyrite are visible. The iron ore is grey, with a brownish tint, and is isotropic or rarely faintly anisotropic. These properties, allied with the absence, after etching with HF, of exsolution lamellæ or "cloth texture" of exsolved ulvöspinel, suggest titanomagnetite, the weak anisotropism being due to lattice distortion resulting from Fe_3O_4-$FeTiO_3$ solid solutions (Edwards, 1954, p. 76). Ilmenite and ulvöspinel were not detected on microscopic examination.

Data on the iron oxide species in alkaline basalts are limited. Newhouse (1936) found only magnetite and magnetite with exsolved ilmenite in nine nepheline-basalts examined by him. Edwards (1954, p. 77) has stressed the speed at which exsolution of ilmenite can occur; it would seem that rapid cooling of the flows has prevented exsolution of $FeTiO_3$. In the absence of chemical and X-ray data, further definition of the mineral species and discussion of its magnetic properties is impossible.

Comparison of habits suggests that the titanomagnetite crystallized later in the Green Scrub Flow than in the Merroo Neck. In view of their contrasted magnetic anomalies this difference is suggestive, but the connection, if any, is obscure.

MAGNETOMETRIC SURVEYS.

Tables 2 and 3 set out data obtained from magnetometer traverses over the Green Scrub Flow and the Merroo Neck. Text-figures 2–4 illustrate the areal relationships of the anomalies. The Green Scrub Flow gives positive anomalies with an observed maximum of 1046 γ.

Their distribution (Text-fig. 2) suggests that the mass is a dissected flow. The volume percentage of iron ore (5·5%) and the thickness, about 80 feet, are sufficient to account for the anomalies. To the east the anomalies decrease due to talus cover. Indentations in the belt are due to the absence of basalt between the spurs. The Kurrajong Fault, which trends almost due north

TABLE 2.
The Green Scrub Basalt Data.

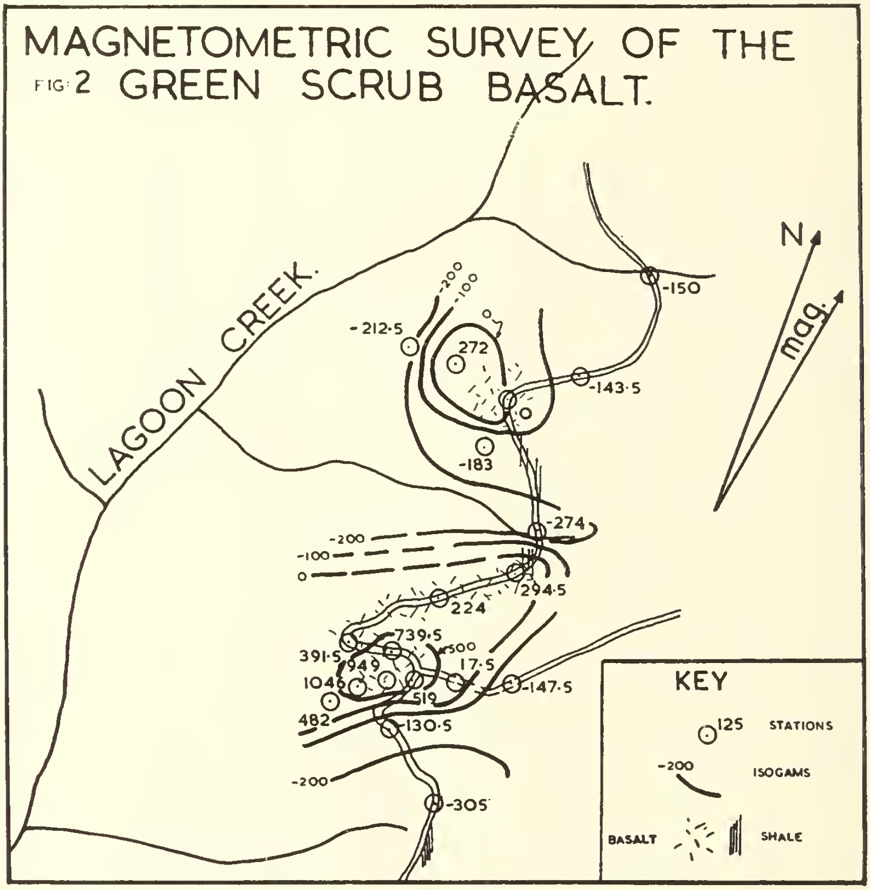
Station No.	Time, E.S.T.	Mean Scale Reading.	Reading × 30γ.	Aux. Mag. Correction.	Diurnal Correction. γ.	Local Station.	Diff. from Primary Base.
1 Base	1155	30·7	921·0	684	0	1605·0	0
2	1206	26·15	784·5	684	—7	1461·5	—143·5
3	1214	26·1	783·0	684	—12	1455·0	—150·0
4	1226	40·4	1212·0	684	—19	1877·0	272·0
5	1235	24·45	733·5	684	—25	1392·5	—212·5
6	1248	25·7	771·0	684	—33	1422·0	—183·0
1	1258	32·0	960·0	684	—39	1605·0	0
1	1348	32·9	987·0	684	—66	1605·0	0
9	1357	27·1	713·0	684	—66	1331·0	—274·0
10	1408	42·75	1282·5	684	—65	1901·5	294·5
11	1416	40·4	1212·0	684	—65	1831·0	226·0
12	1426	45·95	1378·5	684	—64	1998·5	391·5
13	1441	8·15	244·5	2163	—63	2344·5	739·5
14	1452	0·8	24·0	2163	—63	2124·0	519·0
15	1503	15·1	453·0	2163	—62	2554·0	949·0
16	1511	18·3	549·0	2163	—61	2651·0	1046·0
17	1519	—0·5	—15·0	2163	—61	2087·0	482·0
18	1535	28·35	850·5	684	—60	1474·5	—130·5
19	1544	22·55	676·5	684	—60	1300·5	—305·0
20	1556	33·25	997·5	684	—59	1622·5	17·5
21	1602	27·75	832·5	684	—59	1457·5	—147·5
1	1632	32·6	978·0	684	—57	1605·0	0

TABLE 3.
Merroo Neck Data.

Station No.	Time, E.S.T.	Mean Scale Reading.	Reading × 30γ.	Aux. Mag. Correction.	Diurnal Correction. γ.	Local Station.	Diff. from Primary Base.
3 Base	1100	+1·0	30·0	1380	0	1410·0	0
4	1115	+2·55	76·5	1380	—2·0	1454·5	34·5
5	1130	+7·35	257·5	1380	—4·0	1633·5	223·5
6	1205	+5·0	150·0	1380	—9·0	1521·0	111·0
7	1215	+0·9	27·0	1380	—10·0	1397·0	—13·0
8	1225	+1·7	51·0	1380	—12·0	1419·0	9·0
9	1235	+2·35	70·5	1380	—13·0	1437·5	27·5
10	1245	+5·45	163·5	1380	—14·0	1539·5	129·5
3	1256	+1·55	46·5	1380	—16·5	1410·0	0
11	1315	+25·6	768·0	—1561	—16·0	—809·0	—2219·0
12	1330	+39·65	1189·5	—1561	—15·5	—387·0	—1797·0
13	1345	+14·8	344·0	1380	—15·0	1709·0	299·0
14	1356	+37·55	1126·5	—1020	—14·5	92·0	—1318·0
15	1408	+23·1	693·0	—	—14·0	679·0	—731·0
16	1421	+1·45	43·5	1380	—13·5	1410·0	0
17	1430	+0·75	22·5	1380	—13·0	1389·5	20·5
18	1445	+19·45	583·5	—	—12·5	571·0	—829·0
19	1455	—1·3	—39·0	—	—12·0	—51·0	—1461·0
20	1505	+1·4	42·0	1380	—12·0	1410·0	0
21	1515	+2·85	75·5	1380	—11·5	1444·0	34·0
3	1530	+1·35	40·5	1380	—10·5	1410·0	0

through Stn. 21 (−147·5 γ), apparently truncates the basalt, since sandstone outcrops prominently east of this point. The localized nature of the anomalies would preclude a feeder situated in the fault plane, and there seems little doubt that the basalt pre-dates the faulting.

The Merroo Neck exhibits a most interesting distribution of anomalies (Text-fig. 3), and is of importance in being the first totally reverse polarized intrusion discovered in N.S.W. The anomaly pattern confirms the mass as a neck. The rise of the anomaly curve to the south (Text-fig. 4), coupled with the even slope on the north, suggests an induced positive anomaly in the south due to a southward plunge of the neck. The anomaly curve, apart from its reversal, is typical for a neck.



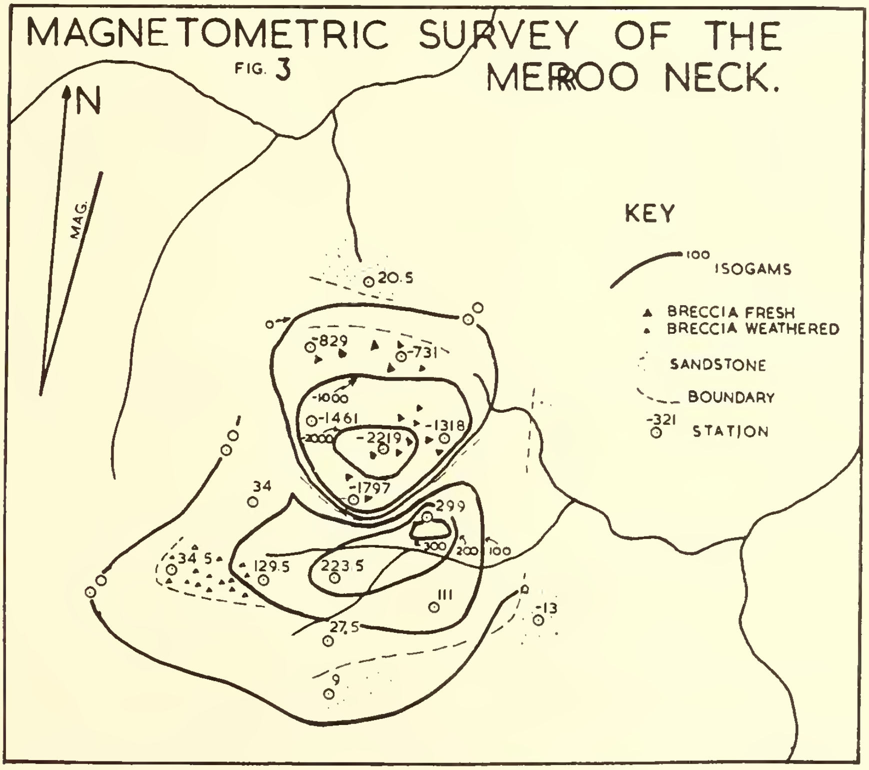
Text-fig. 2.—Scale : 7·25 ins. = 1 mile.

The residual intensity of magnetization of specimens from the mass has not been determined, one difficulty being the absence of material which is undoubtedly *in situ*. Although many fresh boulders are present, soil cover obscures their relationships. The following discussion is therefore somewhat tentative.

Discussion.

Reversals of polarity have been recorded from both overseas and in Australia, a good summary of the literature being given by Hospers (1953–54). Although published records of reversals in Australia are few, they are known from Queensland, N.S.W., and Tasmania. Jaeger and Joplin (1955) discuss reversals in the Mt. Wellington Sill. Day (in Bruckshaw, 1953) records reversals at Ginginbullen in N.S.W. and Mahmud (1955) records small magnitude reversals over the Savoy Sill in N.S.W.

Five possible causes of reversal of polarity have been suggested. Two, invoking internal influences, are (*a*) the existence in the rock of magnetic iron ores (ferrites) having two sub-lattices which can become polarized in opposite directions, giving reversal under suitable conditions; (*b*) the occurrence in the rock of two ferrites of widely different Curie Points. If present in sufficient quantity in local aggregates, the magnetization of the substance with the higher Curie Point can induce a reversal of polarity as the other mineral reaches its Curie Point. Either of these two effects may be strengthened by removal of any normally polarized material by subsequent alteration.



Text-fig. 3.—Scale: 10·1 ins. = 1 mile.

Hospers (1953–54), in dealing with reversals in Iceland, has discussed the internal mechanisms at some length and finds them an inadequate explanation for his observations. Two sub-lattice ferrites are unknown in nature, which renders the first explanation improbable. Vincenz (in Bruckshaw, 1953), in discussing the second explanation, states that concentrations of ferrite of between 40%–60% are required to produce the desired magnetic effects. Such concentrations are not common in basic intrusions. It therefore seems unlikely that either cause can be invoked to explain the reversal of the Merroo Neck.

The remaining three causes invoke external influences. Lightning strike, which may cause anomalies of very great magnitude, is generally very local in its effect. It is virtually impossible that the anomaly distribution observed can be explained by this mechanism, as the negative anomalies cover too large an area.

Bersudsky (1937), in a paper which the author has been unable to examine, suggests induction developed in fissured rocks as the cause of the high negative anomalies associated with the magnetite deposits of the Angara-Ilim region in the U.S.S.R. It is unlikely that this mechanism is operative in the case of the Merroo Neck.

There remains only reversal of the geomagnetic field. This mechanism is invoked by Bruckshaw and Robertson (1949) to explain reversals over dykes in northern England. According to Hospers (1953–54), evidence suggests that reversals occur every quarter to half million years, and have been going on since the Miocene at least.

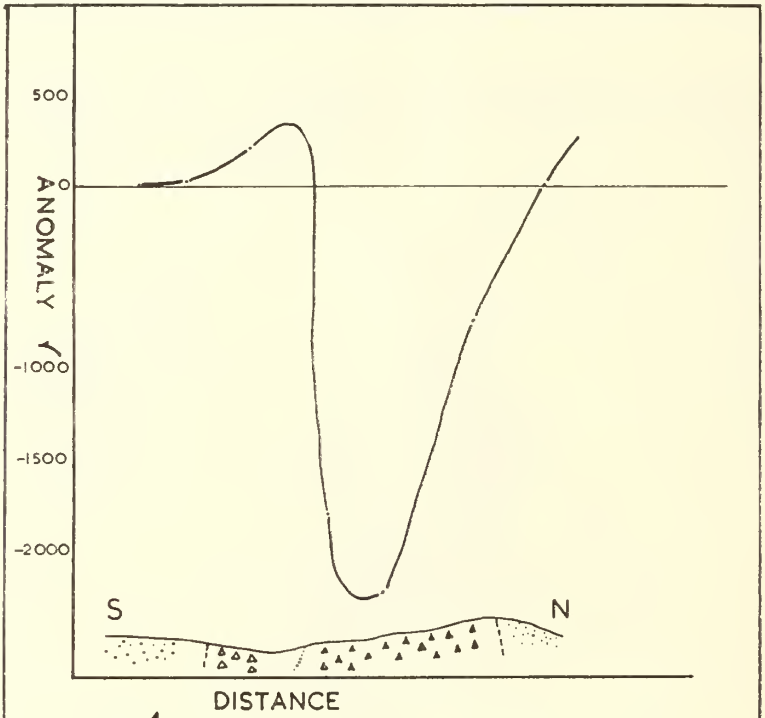


FIG. 4
ANOMALIES OVER THE MERROO NECK

Text-fig. 4.

Final judgment on the Merroo Neck must await detailed laboratory studies, but on present indications the last explanation seems most likely. It is interesting that the Green Scrub Flow is normally polarized. If reversal of the geomagnetic field does occur this flow will be of an age different from that of the Neck, although the age difference may not be great.

ACKNOWLEDGEMENTS.

The author would like to express his thanks to Messrs. B. Hobbs and J. M. Jackson for assistance with field work ; Drs. H. Narain, T. G. Vallance and J. F. G. Wilkinson for discussion and criticism ; and Mr. and Mrs. Boughton, of Mountain Lagoon, for hospitality whilst on field work.

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CORRECTION.

THE STRATIGRAPHY AND PETROLOGY OF THE NARRABEEN GROUP IN THE GROSE RIVER DISTRICT.

By K. A. W. CROOK.

THIS JOURNAL, Vol. 90, Pt. 2, p. 64.
The scale in Text-figure 1 should read "1 inch=625 feet", *not* as shown.

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A

A STUDY OF RIVER TERRACES AND SOIL DEVELOPMENT ON THE NEPEAN RIVER, N.S.W.

By P. H. Walker
and C. A. Hawkins.

Manuscript received, January 4, 1957. Read, April 3, 1957.

ABSTRACT.

A succession of eustatic-climatic terraces along the Nepean-Hawkesbury River System show a chronosequence of soils, *viz.* Lateritic soils, Solodics and Podsolics, Prairie Soils and undifferentiated alluvia. Tentative Pleistocene correlations are made.

INTRODUCTION.

This study represents a more detailed examination of part of County Cumberland which was previously covered by a broad scale soil survey.*

An attempt was made to establish the physiographic and climatic history of the area in relation to soil development. The study was carried out along the Nepean-Hawkesbury River† system between Pitt Town and Wallacia, within the Cumberland basin, 30 miles west of Sydney (Text-fig. 1). The floodplain here is the widest depositional zone along the river, approximately 100 square miles in area, and includes the agriculturally important " Hawkesbury River Flats ".

Supporting data were sought between the Sydney coastline and the western plateau region of the Blue Mountains.

PHYSIOGRAPHY.

The area lies at the foot of the Blue Mountains; it is enclosed to the north, south and west by raised sandstone plateaux at an elevation of 700 to 2,000 feet above sea level. To the east lies the low undulating shale country of the Cumberland basin, seldom rising above 300 feet.

Within the area, six formations have been defined for the purposes of discussion (Text-fig. 2). The main features of these units and their relationship to each other are discussed below.

(1) *St. Mary's Formation.* This includes the undulating country around Riverstone, Schofields and St. Mary's with hills up to 200 ft. above sea level and through which run Eastern, Rope's and South Creeks. This is an old dissected alluvial formation overlying Wianamatta shale.

(2) *Londonderry Formation.* This formation comprises the ancient deposits of river gravels, sand and boulders running sub-parallel to the present Nepean River in a broad band several miles wide. It is relatively undissected and varies in height from 50 ft. near Pitt Town to 200 ft. at Mt. Pleasant behind Cranebrook.

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* P. H. Walker, 1956. " A Soil Survey of the County of Cumberland, Sydney Region, N.S.W." N.S.W. Department of Agriculture Soil Survey Publication.

† Nepean-Hawkesbury system: south of Richmond the river is called the Nepean, and to the north, the Hawkesbury.

(3*a*) *Clarendon Formation.* This is a well-defined series of small remnants, the largest of which forms a semi-circular mass between Hawkesbury College and Rickaby's Creek. It varies in height from 40 ft. to 80 ft. and, although relatively flat, has a minor relief pattern of sand ridges and swamps. Other remnants of this formation are found behind St. Matthew's Church, Windsor, at Pitt Town village and on the western side of the Nepean at Richmond Bridge.

(3*b*) *Cranebrook Formation.* Probably contemporaneous with the Clarendon Formation is the 80 ft. terrace between Emu Plains and the Castlereagh neck. The main feature of this terrace is a number of sand-covered, boulder ridges running sub-parallel to the present Nepean course for the most part, but converging on the river at the Castlereagh neck.

Text-fig. 1.—Sketch-map of Nepean-Hawkesbury River System showing area studied.

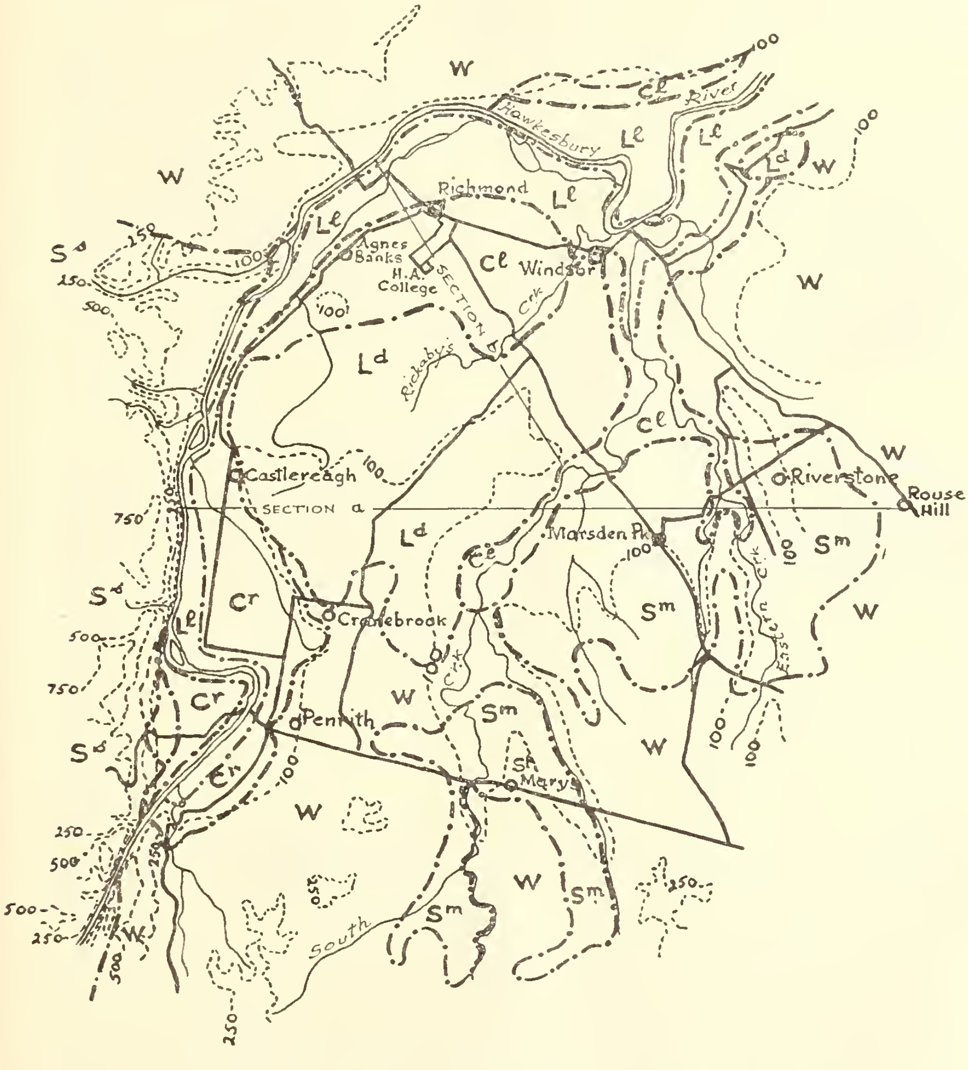
(4) *Lowlands Formation.* This is a younger terrace adjacent to the present stream course. It is probably a composite depositional unit and varies in height from 60 ft. above sea level on the north side of Castlereagh to 17–20 ft. at Pitt Town Bottoms. It is undissected, up to 1 mile wide, and characteristically has large lagoons parallel to the stream course.

(5) *Hawkesbury Formation.* This is represented by a narrow terrace, diminishing in width from 14 chains at its point of departure at Castlereagh neck to a ledge 2 chains wide at Richmond bridge.

(6) *The Present River Course.* Text-figures 3 and 4 illustrate the relationship of levels to one another and to the stream course.

Detailed Description of Units.

In this section the formations are grouped under three headings, viz. Lateritized, Podzolized and Immature Soil Formations. In addition each period of erosion and deposition or soil development is called a Stage and given a number, *i.e.* Stage I, Stage II, etc. (See Table 2).



Text-fig. 2.—Contour map showing the Six Formations studied.

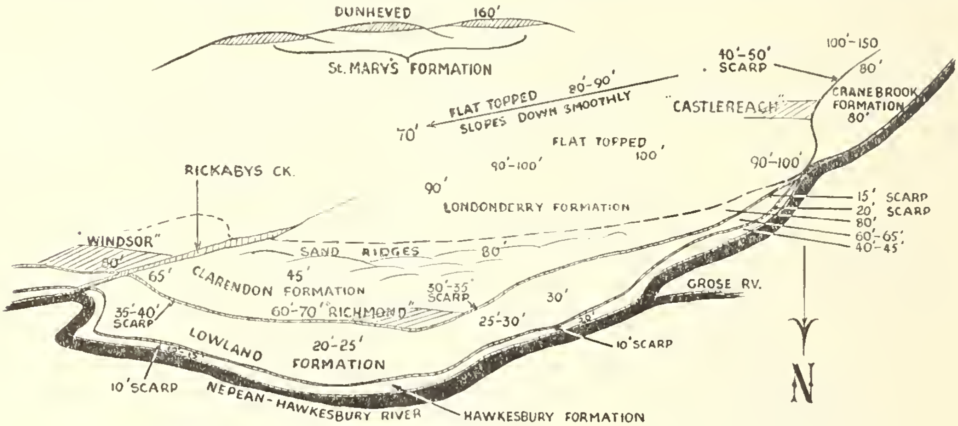
Scale : 1″=4 mls.

S^m = St. Marys.
L^d = Londonderry.
C^l = Clarendon.
C^r = Cranebrook.
Contours : ···· 100 ····
Roads : ———
Formation boundaries : —·—·—·—·
Sections in Text-fig. 4 : ——— Section *a* ———
——— Section *b* ———

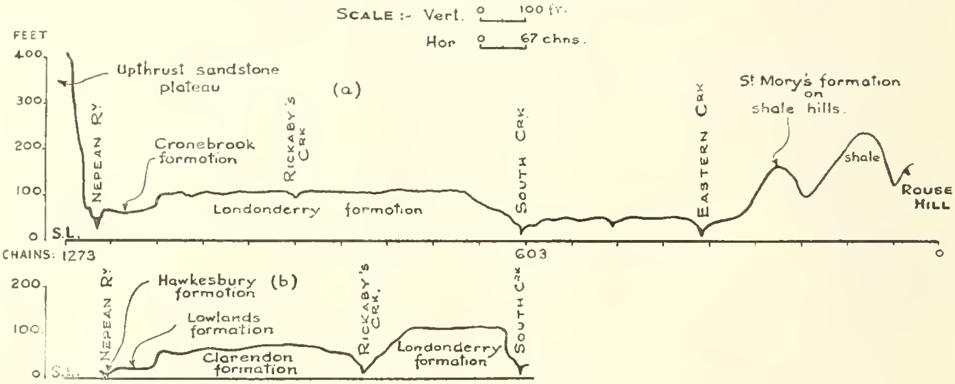
L^l = Lowlands.
H = Hawkesbury.
S^s = Hawkesbury Sandstone.
W = Wianamatta Shale.

(A) Lateritized Formations.

(1) *St. Mary's Formation.* The characteristic pattern is one of low hills capped with old alluvium and wide valleys partly filled with heavy, more recent alluvium. Laterite* remnants are found on the low hills at less than 200 ft. elevation. These are in various states of preservation from complete profiles with an indurated ironstone layer to mere remnants of the mottled or pallid zone. The process of lateritization has penetrated through the alluvium at the surface into the underlying shale often to a depth of 4–6 ft. Where the indurated zone is present, the hills are flat-topped with steep scarps overlooking the valleys.



Text-fig. 3.—A view of the Alluvial Formations of the Nepean-Hawkesbury System.



Text-fig. 4.—Cross-section from Rouse Hill to Castlereagh (*a*) with offset to Richmond (*b*).

The type location of this formation is found in a rail-cutting east of St. Mary's railway station. The depositional record is set out in the stages which are enumerated in the Chronology of Table 2. The section (Text-fig. 5) shows a shallow trough cut into the shale and filled with depositional ironstone, sand and large boulders. Weathering has penetrated through the mixed alluvium and

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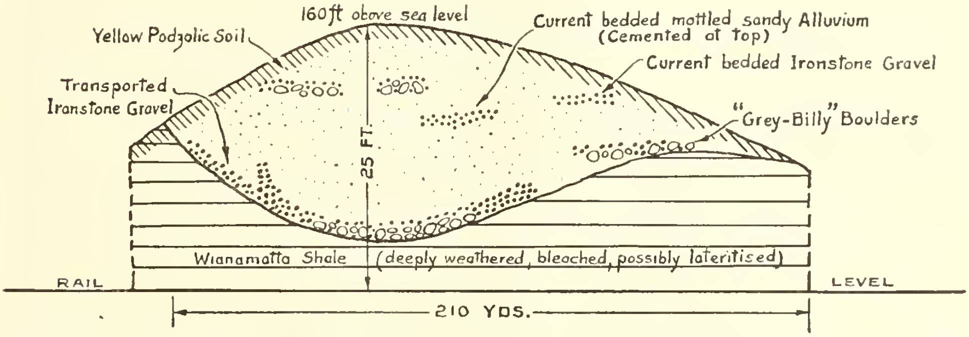
* The definition of "laterite" is that used by Hallsworth and Costin (1953), viz. that the laterite soil profile consists of indurated, mottled and pallid horizons and consequently the presence of one of these horizons suggests that there was an original laterite profile, hence the terms "laterite remnant" and "lateritization" are used.

deep into the shale. Close examination reveals at least two depositional phases : (*a*) weakly cemented, pisolitic ironstone gravel for the greater part, lining the bottom of the trough, except on the eastern side, where a single layer of large silicified ("grey billy") boulders rests directly on the shale together with the ironstone gravel, and (*b*) above this ironstone a layer, up to 15 ft. thick, of weakly cemented, reticulately mottled, current-bedded sandy alluvium which is overlain by another band of ironstone gravel with silicified boulders also weakly cemented. Finally there is a cemented, mottled red and grey sandy clay capping, which was deposited in Stage IV, subsequently lateritized (Stage V) and now has a Yellow Podzolic soil on it (Stage VIII).

The cementation of both the ironstone gravel layers, together with the deep red and white reticulate mottling of the underlying sandy layers, suggests lateritization following deposition. This rail cutting has already been described by Storrier (1951) and Hallsworth and Costin (1953) as a multiple laterite, the two ironstone layers representing successive levels of a fluctuating water table. However, on close examination the following features were observed which support the view that the ironstone gravel layers have been transported :

(i) Ironstone pisolites (gravel) are current bedded.
(ii) The ironstone layers follow the outline of the bottom of the trough.
(iii) Ironstone gravel is not a continuous horizon.



Text-fig. 5.—Diagram of St. Marys Rail Cutting showing Lateritized Alluvial Deposits in a trough in Wianamatta Shale.

The grey billy boulders mentioned in the above description are silicified and up to 24 inches in diameter. They vary in nature from quartzites to sandstones and conglomerates, but are all extremely hard and, although relatively unweathered, have a distinct bleached periphery of up to one inch. There is no evidence to suggest that they have been silicified *in situ* and their position amongst much finer sediments is anomalous, particularly as the boulders themselves are of very coarse size with no intermediate or fine grades.

It is thought that the boulders came either from a previous laterite landscape (Stage I) or material silicified by proximity to volcanic intrusions. In either case the source of the boulders was quite close to their present position, and they moved downslope by creep or slip into the stream basin at a time when ironstone gravel was being deposited.

On both shale and alluvium parent material the soils developed both on the hills and in the valleys throughout this formation are heavily textured and strongly differentiated Red and Yellow Podzolics with concretionary ironstone accumulations in the A_2 and B horizons. Curiously enough soils on the hilltops are Yellow Podzolics where the parent material is alluvium, whereas on shale parent material the hilltop soil is invariably a Red Podzolic. The occurrence of such strongly developed soils on both hilltop and valley floor suggests a considerable period of landscape stability (Stage VII).

Within the area bounded by St. Mary's Formation, the Eastern Creek deposits give some link between the dissection of the latest laterite—St. Mary's and Londonderry (Stage V)—and the present day, and for that reason are discussed here.

Around Riverstone, Eastern Creek has four levels of interest (Text-fig. 6):

1. A deposit of heavy blue-grey and reddish-grey tile-clay which is extremely fine textured and tough. This occurs at 38 ft. above sea level.
2. An upper terrace on the creek at 32 ft. above sea level.
3. A lower terrace at 28 ft. above sea level.
4. The present entrenched stream bed which was estimated to be at 10 ft. or 11 ft. above sea level.

The creek bed is cut through Wianamatta shale above which is a layer of weakly cemented ironstone gravel similar to that in the St. Mary's cutting and believed to be transported. The top of this gravel stands at 21 ft. above sea level in the creek bed and occurs again at this level under the upper terrace, and therefore appears to be a base depositional layer under the terrace system. Above this gravel are fine sandy clays and clay loams.

There are two terrace levels, and on these soil development differs. On the upper terrace the soil is a strongly differentiated Yellow Podzolic developed on a sandy clay loam parent material. The profile passes quickly from a loam to a heavy clay and then to a fine sandy clay loam by 84 inches. The A_2 is strongly bleached and tongues into the B. Ironstone accumulation in the A_2 is marked but is absent in the B horizon.

By contrast, the soil on the lower terrace shows a gradual rise in texture over a distance of 20 inches from loam to sandy clay. There is no development of a bleached horizon and no ironstone concretions in the A_2 horizon. This changes to another material at 34 inches—possibly the butt of the upper terrace.

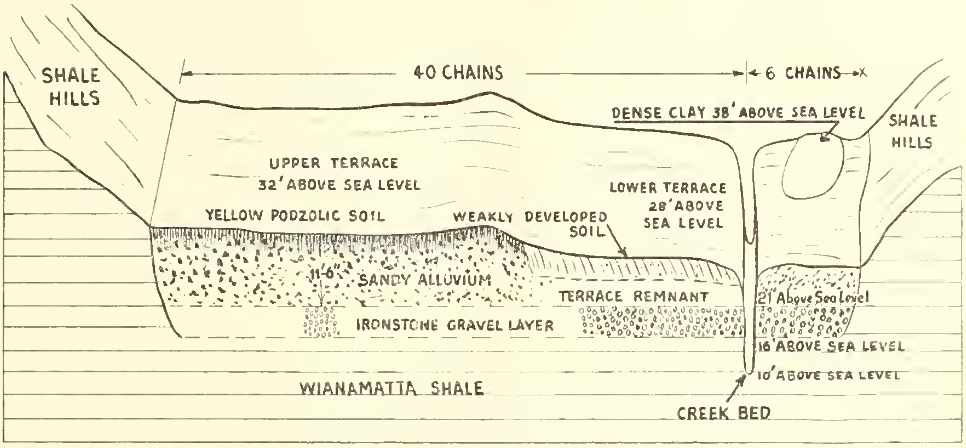
Slightly above the upper terrace level is a deposit of blue and reddish-grey tile clay. This must have been deposited from very quiet waters and may have been a swamp between the levee shoulder and the adjacent shale hills when the upper terrace was being built. It is not clear whether the terraces are climatic or eustatic; if eustatic, then they must belong to the latter part of the Pleistocene because of their low level. If they are climatic, two periods of relative aridity are suggested for terrace building since the latest laterite-forming period (see Huntington (1914)).

Sequence of Events Shown by the St. Mary's Formation and Eastern Creek Deposits.

Soil formation (Stage I).	Laterite on subdued topography under suitable climatic conditions—pre-St. Mary's.
Erosion (Stages II, III and IV).	Landscape instability, climatic and/or tectonic. Dissection of earliest laterite landscape, shallow stream beds cut; ironstone gravel from laterite deposited together with sandy alluvium and "grey billy". Two periods of more active erosion suggested by two ironstone and grey billy layers each followed by finer deposition.
Soil formation (Stage V).	Mild lateritization in the St. Mary's rail cutting.
Erosion (Stage VI).	Dissection of laterite, downcutting to much lower base level, deposition of resulting ironstone gravel in Eastern Creek bed, upper terrace built (32 ft.).

Soil formation (Stage VII).	Strongly differentiated Red and Yellow Podzolics formed on hill country—Yellow Podzolic on St. Mary's cutting and on upper Eastern Creek terrace.
Erosion and deposition (Stage XI).	Upper terrace truncated, lower Eastern Creek terrace deposited on top (28 ft.).
Soil formation (Stage XII).	Weakly differentiated Red Podzolic formed on lower terrace.
Erosion (Stage XIII).	Final stream entrenchment to 11 ft. above sea level.

(2) *Londonderry Formation.* These deposits of sands, gravels and boulders cover a much wider area than is shown as " old river gravels " on the geological map of Willan (1925). In the area studied they form a broad band several miles wide running north through Cranebrook, Windsor and Mulgrave in a direction sub-parallel to the present course of the Nepean and Hawkesbury Rivers. From Cranebrook they cross the Nepean and proceed up the Lapstone monocline almost to Glenbrook. Similar smaller deposits, no doubt of the same age, are widespread up and down the Nepean-Hawkesbury system. Near Glenbrook these deposits are over 400 ft. above sea level and have obviously been carried up by the folding which was contemporaneous with the Kosciusko uplift. East of the Nepean and south of Windsor they form a relatively undissected block tilted east and north-east.



Text-fig. 6.—Block diagram showing Section through Eastern Creek Deposits, Riverstone.

From some 200 ft. elevation at Cranebrook, the Londonderry formation slopes down to 60 ft. 1½ miles north of Marsden Park. The whole block is remarkably well preserved and flat topped. It has been cut into by the Nepean on the western side, leaving a steep 30–40 ft. scarp fronting a younger terrace, and on the south-east and east by South Creek forming a similar steep scarp. This is demonstrated in Text-figure 4.

A characteristic dense scrubby vegetation with tea-trees (*Melaleuca* spp.) and ironbark (*Eucalyptus crebra*) as the larger species distinguishes this tract from the surrounding country. For the greater part of the area a sandy cover obscures the boulders, but wherever this cover has been penetrated a bed of boulders and sand has been found beneath and sometimes another layer of sandy material occurs under the boulders. The deposits vary in thickness from 13 ft. to 40–50 ft., where observed, and overlie Wianamatta shale throughout the area. As a whole, the area has been only mildly lateritized, probably at the same time as the St. Mary's Formation, for a crust of ironstone was found at only a few places. Nevertheless the boulders show intense chemical weathering, so that while the exact form of the boulders is preserved they easily crumble to a white powder in the hand.

The sedimentary material of this formation consists mainly of large water-worn boulders up to 15 inches in diameter, set in a matrix of sand and sandy clay and, in places, current-bedded ironstone gravel. The boulders are dominantly quartzites and sandstones with some granites and porphyrites. The size of the boulders and depth of the deposits indicate the great power and duration of the streams which deposited them. The orientation of these deposits shows that they were laid down by the ancient Nepean River prior to the uplift of the Blue Mountains plateau in the Kosciusko epoch.

The soils developed on the lateritized remnants of this formation are deeply weathered and well differentiated Yellow Podzolics, having deep surface soils and heavy accumulation of concretionary ironstone in the A_2 horizon. Where part of the indurated horizon of the laterite remains, Red Podzolic soils are developed. There appears to have been little dissection of this formation about Londonderry, so that the soils are very old and show the characteristics of deep chemical weathering.

The presence of current-bedded ironstone gravel incorporated in the Londonderry sediments near Windsor indicates that existing laterites were dissected during the period of deposition. The sedimentary sequence is similar to that of the St. Mary's formation and it is suggested that the sedimentation and subsequent lateritization of these two formations was contemporaneous.

(*B*) *Podzolized Formations.*

(3*a*) *Clarendon Formation.*

The main remnant of this formation, between Hawkesbury College and Rickaby's Creek, abuts the Londonderry formation but differs from it in that there is no evidence of lateritization. It is mildly undulating with a relief pattern of sand ridges and swamps. The largest sand ridge runs in a general east-west direction through the grounds of Hawkesbury College and rises to 80 ft. above sea level at the western side fronting the Nepean. On the other hand the general terrace level falls to 40 ft. along Rickaby's Creek.

The pattern of sand ridges and swamps, so clearly seen on a detailed contour map, suggests wind distribution of the surface materials in some past period. South of Richmond, at Agnes Banks, Simonett (1950) has described a series of similar sand dunes.

An almost perpendicular scarp 30–40 ft. high separates this terrace from the younger one below. Road cuttings through the scarp show at least five layers in this formation ; in particular, the road cutting on the eastern edge of the scarp overlooking Rickaby's Creek (Text-fig. 7) illustrates this layering.

Text-figure 7 shows the following sequence :

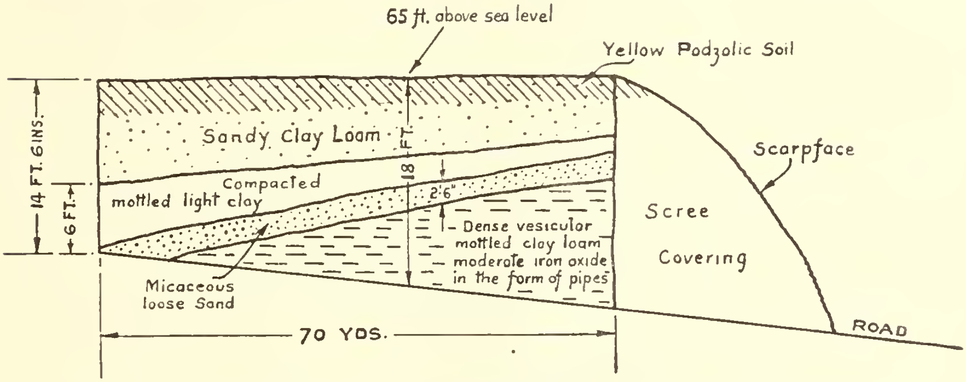
(1) A surface layer 3–10 ft. thick of loam to clay loam texture which has a strongly differentiated Yellow Podzolic soil developed on it.

(2) Remnants of a mottled, drab, compact layer which is light clay in texture, micaceous and sometimes vesicular and about 2–3 ft. thick. It appears to have been partly removed during the laying down of the surface layer.

(3) A layer of micaceous, mottled, loose sand 2–4 ft. thick which is not continuous but sometimes occurs in what were depressions in the old surface beneath. Current-bedding is evident in some exposures.

(4) A rather dense vesicular layer of fine sandy clay or clay loam which is mottled dark grey and yellowish brown. It has light to moderate amounts of iron oxide deposited in the form of vertical pipes, each with a small hollow down the centre and measuring 2–3 in. long and $\frac{1}{2}$ in. in diameter. The whole layer gives the impression of having been swampy at some period, and usually forms the lowest visible layer in the cutting down to 13–18 ft. In one case a layer of micaceous sand was found beneath this.

At least two periods of stability with lengthy periods of exposure are represented here. The first followed the deposition of dense light clay at the bottom of this cutting 10–12 ft. below the surface and was marked by considerable iron segregation giving abundant tubular ironstone. The second period of stability followed deposition of the surface layer. Between these two periods alternating fine and coarse deposition took place, but no evidence of prolonged stability was found. On Richmond aerodrome, away from the scarp, pits showed 4–5 ft. of sandy alluvium overlying water-worn boulder beds down to at least 8 ft. This is the only occurrence of boulder beds found on this terrace.



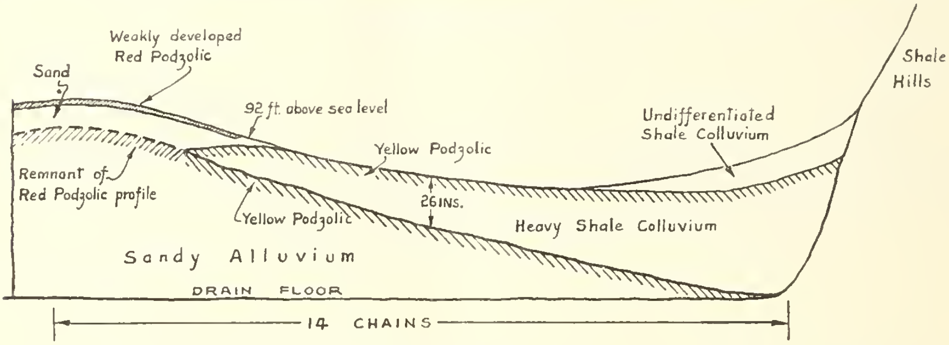
Text-fig. 7.—Diagram of Road Cutting, Richmond, through Clarendon Formation.

The soils developed on the surface layer of sands and light clays are Groundwater Podzols, Red and Yellow Podzolics and Solodics. The Red Podzolics occupy the ridges and the Yellow Podzolics the depressions. The Yellow Podzolics are strongly differentiated with a deep A horizon up to 3 ft. thick and a strongly bleached A_2. Heavy ironstone accumulation occurs in the lower part of the A and textural contrast between A and B horizons is great—often from a loam to a heavy clay. A deep A horizon is a feature of the Red Podzolics also but texture grading is much more gradual here than in the Yellow Podzolics ; bleaching in the A_2 is absent and only soft concretions of iron-cemented sand are found. The Groundwater Podzols show intense bleaching in the A_2 and an iron-organic cemented B at 30–36 in. below which is a deep zone of clay accumulation. The Solodic soils have a shallow (2 in.), extremely bleached A horizon over a deeply cracked, broadly columnar clay B horizon which has a marked predominance of sodium and magnesium on the exchange complex.

A subdivision of the Clarendon formation is possible on the basis of the degree of soil profile differentiation. The older soils are for the most part Yellow Podzolics and Groundwater Podzols, while the younger are predominantly Red Podzolics. The older soils have strongly bleached A_2 horizons and contrasting

A and B horizon textures in all topographic positions. They are found on the high sand ridge which runs through Hawkesbury Agricultural College and on similar dunes south to Agnes Banks (see Simonett (1950)). The Solodics and Yellow Podzolics on the eastern edge of the College also belong to this subdivision. The younger soils do not have well-developed texture contrast or bleached A_2 horizons except in local depressions where Yellow Podzolics occur. These are found on the western edge of Hawkesbury College and continue through Richmond to Clarendon. These subdivisions, based on the degree of soil profile development, are similar to those observed for Eastern Creek near Riverstone, and it is probable that the individual terrace systems are related.

(3*b*) *Cranebrook Formation.* This formation is separated from the Clarendon formation by the Castlereagh neck, and lies at the foot of the Londonderry scarp. The strip of alluvium, 2 miles wide, seems to have been deposited by a progressive lateral shift of the Nepean River bed towards the foot of the Lapstone monocline. The resulting sedimentary pattern consists of a series of boulder ridges running parallel to the present stream. The soils on the ridges are weakly-developed Red Podzolics showing little iron movement and no great textural differentiation.



Text-fig. 8.—Sketch of Drain Wall, Jamieson Road, Penrith, cut through Cranebrook Formation.

In the depressions well-developed Yellow Podzolics are found. The soil pattern is therefore similar to the younger subdivision of the Clarendon formation and there is little doubt that the formations are contemporaneous. South of Penrith an interesting exposure of buried soils was found on the Clarendon terrace close to the flanking shale hills (Text-fig. 8).

The oldest layer exposed is a sandy alluvium having a shoulder on the western side and a depression against the shale hills. On the shoulder a Red Podzolic soil was developed with a Yellow Podzolic in the depression. In the depression heavy shale colluvium from the adjacent shale hills overlies the sandy alluvium; on this heavy material a strongly-differentiated Yellow Podzolic was developed. Some sand from the nearby alluvial shoulder has blown over this second layer. Subsequently a further sand layer was deposited on the existing sand rise and from this sand deposit an immature Red Podzolic has been formed.

Sequence of Events shown by Clarendon and Cranebrook Deposits.

As far as can be determined by field observations, these formations are the next in chronological succession to the Londonderry formation. They represent the first material laid down subsequent to a major shift in the river course to the present river valley. In the literature this shift has been attributed partly to the major uplift of the Western Plateau, said to be part of the Late Pliocene, or Kosciusko uplift. Jensen (1911) suggests that an upbowing of the landscape, due to volcanic activity of similar age to Prospect, was the main cause of the westward shift of the river.

The Clarendon and Cranebrook formations are generally at a lower level than the Londonderry and the soils show no evidence of lateritization. The relationship between Clarendon-Cranebrook and Londonderry is similar in most respects to the relationship between the Eastern Creek terraces and the St. Mary's formation. In each case the older formations have been lateritized and subsequently dissected to varying degrees. On the dissected remnants Red and Yellow Podzolics have formed. On the other hand, the younger terrace formations are not lateritized but do show podzolic soil development and are relatively undissected. The absence of laterite on the younger formations indicates a major climatic change.

The suggested sequence of events is:

Uplift and Change in Nepean Course (Stage VI).	New stream course eroded.
Unknown time interval.	?
Depositional period (Stage VII).	Sand, followed by light clay of Clarendon level laid down.
Stability (Stage VIII).	Weathering and soil formation; older Clarendon soils (iron segregation). Podzolics and Solodics of Hawkesbury College-Agnes Banks.
Depositional period (Stage IX).	Sand and light clay material, Clarendon and Cranebrook.
Stability (Stage X).	Soil formation; Groundwater Podzols and Yellow Podzolic on alluvium on Jamieson Rd. (Text-fig. 8).
Depositional period (Stage XI).	Surface sands and loams of Clarendon.
Stability (Stage XII).	Red and Yellow Podzolics of upper Clarendon and Cranebrook. Jamieson Rd. Yellow Podzolic on colluvium. Red Podzolic on sandy alluvium.
Deposition (Stage XIII).	Sand of Jamieson Rd. cutting, alluvium against stream.
Stability (Stage XIV).	Weakly developed Red Podzolics, Jamieson Rd.

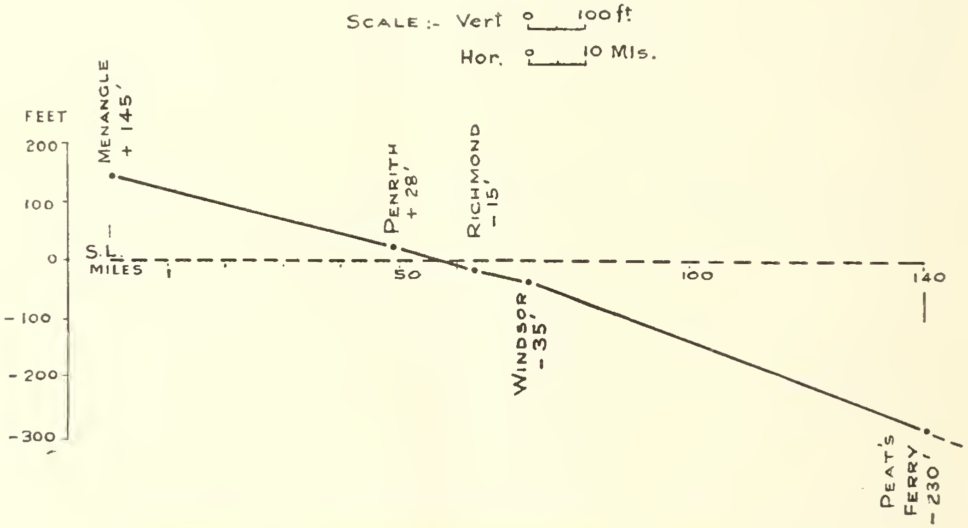
(*C*) *Immature Soil Formations.*

(4) and (5) *Lowlands and Hawkesbury Formations.* The Lowlands formation is distinguished not only by its level but also by its well-structured Prairie soils. The terrace begins on the north side of the Castlereagh neck at 65 ft. above sea level, but quickly drops to 40 ft. by Agnes Banks. A further drop to 20 ft. opposite Richmond on the north side is followed by a relatively level portion from Richmond to Pitt Town Bottoms, where it stands at 17–20 ft. above sea level (see Text-fig. 3). It is up to 1½ miles wide and consists of fine sandy sediments with little or no gravel. At approximately 8 ft. under this terrace the remnants of an older terrace are found—presumably part of the Clarendon formation.

The soils of the Lowlands formation are Prairie soils with deep organic matter penetration, good crumb structure and no texture differentiation. There has been considerable worm activity which has assisted organic matter penetration and destroyed alluvial stratification.

The Hawkesbury formation is the latest terrace against the stream course. It consists of mixed stratified sediments made up of sands, boulders, etc. From 48 ft. above sea level at the Castlereagh neck it drops to 8–10 ft. by Windsor. The sediments are strongly stratified, with no organic matter penetration and no evidence of modification due to soil-forming processes.

Not only are these two formations separated clearly from Clarendon formation by a steep scarp of 20–40 ft., but there is also a marked difference in soil profile development, denoting a long time interval.



Text-fig. 9.—Thalweg of the Nepean-Hawkesbury River Rock Bed.

(6) *The Present River Course.* The Nepean-Hawkesbury River system drains an appreciable portion of the Sydney Region. By far the greatest contribution comes from the tributaries to the south-west, which drain the upwarped dividing range running parallel to the coast. The river rises south-west of Sydney; the main arm, the Wollondilly River, joins the Cox's and sweeps down in a wide arc from the tablelands as the Warragamba River. The Nepean rises south of Picton in country of much milder relief, and is joined by the Warragamba at Wallacia. The combined stream cuts through part of the Lapstone monoclinal fold and emerges at Penrith to run along the foot of this fold and across the western edge of the Cumberland Basin. At Sackville, north of Pitt Town, it enters the Hornsby plateau, through which it meanders in a deeply incised gorge. At Wiseman's Ferry the river turns abruptly at right angles and flows east into Broken Bay.

The rock floor of the stream is 230 ft. below sea level at Peat's Ferry bridge, 14 miles from the sea, and rises to sea level between Richmond rail bridge and Castlereagh, 88 miles from the river mouth. The thalweg of the stream (Text-fig. 9), back as far as Menangle on the Nepean, shows at least three kink points. It is not known whether these changes in river grade are products of eustatic fluctuations of the sea or local subsidence. Insufficient data are available to obtain the true gradient of the rock floor between Peat's Ferry and the ocean and therefore the depth of the submerged trough at the mouth of the river. In the absence of such data it is not possible to correlate the depth of the submerged mouth with past low sea levels. However, drowned river valleys are typical of the eastern Australian coastline, and it seems more logical to propose eustatic movements than regional subsidence. Abundant evidence is available from various parts of the world, particularly in the Pacific Ocean, for sea level changes of the order of 300 ft. during the Pleistocene. [See Zeuner (1945, 1952), Stearns (1938, 1945), Tindale (1947) and Brothers (1954).]

SOME IMPLICATIONS OF THE TERRACE OBSERVATIONS.

Laterite is generally accepted as an ancient soil formation in Australia. Some workers [Prescott and Pendleton (1952), Woolnough (1927) and Hallsworth and Costin (1953)] have placed it in the Miocene; others [Whitehouse (1940), Hallsworth and Costin (1952)] regard it as Pliocene. In the area studied evidence was found of two laterite landscapes of different ages—an older pre-St. Mary's and pre-Londonderry laterite (Stage I) and the younger St. Mary's and Londonderry laterite of restricted occurrence (Stages II–V). The former supplied the current-bedded ironstone gravel which was re-cemented in the St. Mary's and Londonderry formations. The second laterite stage was confined to alluvial parent material and hence lateritization must have been restricted to low-lying areas along stream courses in this period.

In accordance with previous ideas regarding the age of laterites in Australia, the older or pre-St. Mary's laterite must be placed as Miocene or at least Pliocene in age, while the younger St. Mary's and Londonderry laterites would be Pliocene.

However, one of the major obstacles to placing these laterites in the Miocene or Pliocene is their height above sea level, particularly when the general proximity of this area to the Pacific Ocean is considered. Several workers (Zeuner, 1945; Stearns, 1945; and Brothers, 1954) have recorded sea levels as high as 550–600 ft. above the present for the Pacific Ocean and have suggested their age as the beginning of the Pleistocene. Evidence from Europe and America further suggests that Pliocene and Miocene sea levels would have been at least as high as this, and possibly higher.

Such sea levels would have inundated the whole of the Cumberland Basin up to some 300 ft. above the present levels of the St. Mary's and Londonderry laterite formations. No evidence has so far been found of such widespread drowning. This leaves two possible alternatives:

(1) Subsidence since Pliocene times has affected the whole of the Cumberland Basin, reducing its level by at least 300 ft. to bring these laterites to their present low level.

(2) Subsidence in the areas concerned has been slight or absent, so that the laterites were formed well into the Pleistocene, by which time the Pacific Ocean had progressively dropped to about 150 ft. above its present level.

On the assumption that these formations are Pleistocene it is possible to correlate all the alluvial formations with known past levels of the Pacific Ocean (see Table 1). The consequence of this alternative is that the Kosciusko uplift post-dated the mid-Pleistocene since parts of the Londonderry formation, at 110–150 ft., or mid-Pleistocene level, were carried up the monocline.

If the first alternative is accepted, the present Londonderry and St. Mary's and probably the younger landscape elevations cannot be correlated with past sea levels, and the depositional chronology will be complex.

Examination of the higher reaches of the Nepean River reveals that the Clarendon formation occurs at higher levels than between Richmond and Windsor and may be as high as 150 ft. above sea level in the vicinity of Wallacia. This results in a steeper gradient upstream from Richmond than between Richmond and Pitt Town, indicating that the upper part is of climatic origin while the downstream end, where the river bed is below sea level, has been affected by eustatic changes. Similar terrace gradients have been found for the Londonderry, Lowlands and Hawkesbury formations, indicating that they too could have been the product of the dual influence of climate and sea level. It would be expected that climatic terraces would have been built during warm-dry interglacials and interstadials, when the landscape was unstable through reduced vegetative cover, at times of high sea level. The gradient of these climatic terraces would be roughly parallel to the stream bed, to a point where inundation of the lower stream course by higher sea level would cause the terrace gradient to flatten, giving a eustatic terrace. This in fact is the typical structure of the Nepean-Hawkesbury terrace systems.

TABLE 1.

Comparison of Eustatic Levels of the Pacific.

Nepean-Hawkesbury System.	Pacific Is. Stearns (1945).	New Zealand. Brothers (1954).	Australia. Tindale (1947).
	Feet.	Feet.	Feet.
St. Mary's and Londonderry :			
110–150 feet	+150	+110–130	150
—300 feet	—300	?	
?	+100	?	105–110
Clarendon and Cranebrook :			
+40–80 feet	+ 70	+ 45– 75	65
	+ 45		
?	— 60	?	
Lowlands :			
+15–20 feet	+ 27	+ 15– 25	(29 25 ?)
?	?	—190	
Hawkesbury :			
+8–10 feet..	+ 5	+ 8– 12	5–10

Text-fig. 3 illustrates that in the Richmond-Pitt Town area younger formations occur below older formations. This could be explained as a result of intermittent uplift in the area, assuming static sea level. However, from Richmond to Broken Bay the rock bed of the river falls from sea level to —250 ft. at least, and if this were the result of subsidence, then uplift is precluded. Subsidence, on the other hand, would result in younger terraces occurring above the older, whereas at Richmond the reverse is true.

Another explanation of the terrace sequence is that it is purely climatic. This does not afford an explanation of the deep entrenchment of the lower stream course. Furthermore, it is unlikely that the terraces between Richmond and Pitt Town would have been beyond the influence of the high Pleistocene sea levels since nowhere do they rise above 90 ft.

The general succession of terrace levels between Richmond and Pitt Town, the deep entrenchment of the stream bed and the presence of kink points along its lower course can be best explained as due to progressive sea level fall with the superimposed fluctuations caused by glaciations during the Pleistocene. The upstream extensions of these terraces south of Richmond are due to climatic influence.

CHRONOLOGY.

It will be noticed in Table 2 that there are two very long periods of erosion. The first occurs between the St. Mary's and Clarendon formations, where the height difference is considerable (100 ft. at Riverstone and 50 ft. at Cranebrook), and during which there was a change from the laterite type of soil weathering to a milder type giving podzolic soils only. The second is that between the Clarendon and Lowlands formations, where the height difference (20–40 ft.) is again marked and the soil differences are great on the same type of parent material. The soil chronosequence may be summarized thus:

(*a*) St. Mary's and Londonderry Formations: Lateritic soils formed at high levels (110–150 ft.).
(*b*) Clarendon and Cranebrook Formations: (i) Dominantly Yellow Podzolic soils formed on terraces at 40–80 ft. (ii) Dominantly Red Podzolic soils formed on terraces at 40–80 ft.
(*c*) Lowlands Formation: Prairie soils formed on terraces at 30 ft.
(*d*) Hawkesbury Formation: Undifferentiated alluvial deposits as terraces at 5–8 ft.

Correlation of the terrace levels with past sea levels can only be very tentative in the absence of more data. In Table 2 an attempt has been made to relate data from the various formations and correlate these with sea levels of the past.

It is important to emphasize that whether or not the following correlations are valid, the relative chronology, as outlined, is of primary importance. It can be stated that from St. Mary's to Hawkesbury time there have been periods of vigorous stream cutting alternating with periods of aggradation and terrace building, and that these periods can be readily differentiated by a study of soils and landscape. Furthermore, such studies show beyond doubt that this is an extended time sequence covering a significant part of the geological past, and has particular bearing on Pleistocene pedological history.

SUMMARY.

A study was made of river terraces and associated landscape along part of the Nepean-Hawkesbury system. Six physiographic units were defined, representing successive stages of alluvial deposition and soil development. Proceeding from the older to the younger, these were:

(*A*) *Lateritized Formations.*

1. St. Mary's ..	Undulating country with some remnants of lateritized alluvium; Red and Yellow Podzolic soils at the surface.
2. Londonderry	Undissected river sands and gravels, lateritized; Yellow Podzolics at the surface.

(*B*) *Podzolized Formations.*

3*a*. Clarendon and 3*b*. Cranebrook.	Undissected river terraces; soils of varying ages at surface including Ground Water Podzols, Red and Yellow Podzolics and Solodics.

(*C*) *Immature Soil Formations.*

4. Lowlands ..	Undissected river terrace; Prairie soils at surface.
5. Hawkesbury	River terrace; stratified, undifferentiated sediments.
6. Present Nepean-Hawkesbury course.	

TABLE 2.
Chronology.

Stage.	State of Landscape.	Sedimentation.	Soil.	Suggested climatic conditions.	Tentative Time Scales.		
					(1) Hallsworth and Costin (1953).	(2) Nepean-Hawkesbury.	(3) Pleistocene Sea Level Correlations.
I	Stable landscape; intense lateritization.		Widespread laterite, Hornsby and National Park laterites.	Tropical.	Miocene.	Pre-St. Mary's, pre-Londonderry.	?
II	Very active erosion; dissection of laterite.	Laterite detritus, St. Mary's and part of Londonderry.		Tropical ?	Miocene-Pliocene.	Early St. Mary's and Londonderry.	Mindel-Riss Interglacial (100–150 ft. sea level).
III	Less active erosion.	Fine St. Mary's sediments.		Do.	Miocene-Pliocene.	Early St. Mary's and Londonderry.	Mindel-Riss Interglacial (100–150 ft. sea level).
IV	Increased erosion.	Laterite detritus, St. Mary's, also Londonderry.		Do.	Do.	Do.	Do.
V	Stability; mild lateritization.		St. Mary's and Londonderry laterites.	Moist, temperate.	Pliocene.	Late St. Mary's and Londonderry.	?
VI	Uplift of western plateau; change in Nepean River course; active erosion; dissection of St. Mary's laterites.	Lower Clarendon and Cranebrook sediments. Ironstone gravel, Eastern Creek.		?	Pleistocene (Orsteins).	Early Clarendon and Cranebrook.	Riss-Wurm Interglacial sea level 40–75 ft.
VII	Erosion and deposition.	Lowest sands and clays of Clarendon and Cranebrook road cuttings; upper sediments of Eastern Creek.		?	?	Early Clarendon, Cranebrook and upper Eastern Creek.	Do.
VIII	Stability.		Older Clarendon soils (iron segregation); solodics and podzolics of Hawkesbury College, Agnes Banks and the upper Podzolics of Eastern Creek. Yellow Podzolic on St. Mary's formation.	Moist, cool.	?	Early Clarendon, Cranebrook and upper Eastern Creek.	?

TABLE 2.—*Continued.*
Chronology.—Continued.

Stage.	State of Landscape.	Sedimentation.	Soil.	Suggested climatic conditions.	Tentative Time Scales.		
					(1) Hallsworth and Costin (1953).	(2) Nepean-Hawkesbury.	(3) Pleistocene Sea Level Correlations.
IX	Erosion and deposition.	Sands and clays of Clarendon road cutting — Text-fig. 7 ; lowest alluvium Jamieson Rd. — Text-fig. 8.		Warm, dry.	?	Mid-Clarendon and Cranebrook.	?
X	Stability.		Groundwater Podzols of Hawkesbury College ; Yellow Podzolic on alluvium Jamieson Rd.	Moist, cool.	Camden ortsteins, Pleistocene.	Mid-Clarendon.	Riss-Wurm Interglacial 40–75 ft.
XI	Erosion and deposition.	Surface sands and loams of Clarendon; lower Eastern Creek deposits.		Warm, dry.	?	Late Clarendon and Cranebrook ; lower Eastern Creek terrace.	Riss-Wurm Interglacial 40–75 ft.
XII	Stability.		Red and Yellow Podzolics of surface Clarendon and Cranebrook deposits; lower Eastern Creek soils. Yellow Podzolic on colluvium (Text-fig. 8), Red Podzolic on alluvium.	Moist, cool. }Jamieson Rd.		Late Clarendon.	Wurm Glacial (?).
XIII	Erosion and deposition.	Uppermost sands of Jamieson Rd. drain; alluvium against stream Jamieson Rd. ; Lowlands formation.		Warm, dry.		Early Lowlands.	Early Recent 15–20 ft.
XIV	Stability.		Weakly developed Red Podzolics and Prairie soils against stream, Jamieson Rd. ; Prairie soils of Lowlands.	Moist, cooler.		Late Lowlands.	
XV	Erosion and deposition.	Sands and gravels of Hawkesbury formation.		Warm, dry.		Early Hawkesbury.	Late Recent 5–10 ft.
XVI	Stability.		Undifferentiated sands and gravels of Hawkesbury formation.	Moist, cooler.		Present.	

From a consideration of the nature of the deposit, subsequent soil development and elevation, these formations were correlated with reported high Pleistocene levels of the Pacific Ocean. On available evidence the change from the lateritic to the non-lateritic type of weathering was dated as mid-Pleistocene.

The system was interpreted as being largely the product of alternating periods of landscape instability (erosion and deposition) and stability (soil formation). A tentative chronological table was drawn up.

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THE MINERALOGY OF THE COMMERCIAL DYKE CLAYS IN THE SYDNEY DISTRICT, N.S.W.

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With Plate I and two Text-figures.

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ABSTRACT.

Residual clays formed by the extensive leaching of Tertiary dykes in the Sydney district are predominantly kaolinitic, though illite is frequently present to the extent of 30%. The clays contain a relatively high percentage of titania, much of which occurs as distinctive leucoxene octahedra, believed to be pseudomorphous after "titaniferous magnetite". There is an association of illite with these octahedral forms of leucoxene.

INTRODUCTION.

The mineralogy of the Tertiary dyke clays occurring in the Sydney district is of interest for two reasons. Firstly, mineralogical data may enable the more effective commercial utilization of these materials; and secondly, such data may contribute to the elucidation of wider problems concerned with clay, soil and laterite genesis.

The present study arose from independent observations by both authors. One of us (F.C.L.), during a broader investigation of N.S.W. commercial clays, previously had determined the clay minerals of the Sydney deposits, whilst the other first detected and checked by X-ray diffraction methods the presence of microscopically visible leucoxene of unusual characters in some of the same dyke clays.

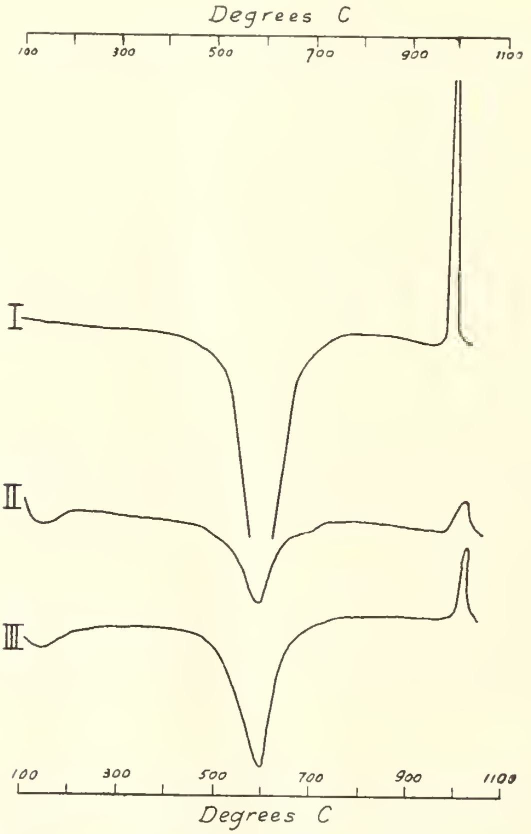
MINERALOGY AND ORIGIN OF THE DYKE CLAYS.

The commercial dyke clays of the Sydney district are located principally in the French's Forest area where they extend in a westerly trending belt from Narrabeen Lagoon to Asquith, a distance of approximately twelve miles. The dykes vary in width from a foot or two up to sixteen feet and have been worked to a depth of 40 feet or more. Some of the individual dykes comprising the system extend for several miles. Occasional short N-S trending dykes intersect the main belt.

The country rock is generally sandstone of the Hawkesbury Formation but shale lenses of the same formation occasionally form the enclosing medium.

The parent material of the clays was not observed at any point on the present survey; however, the frequent occurrence throughout the Sydney area of fine grained dolerite dykes and other intrusions of Tertiary age leaves little doubt that the parent materials of the clays were of similar composition and that the environmental conditions in the French's Forest area were favourable for the conversion to clay. The favourable conditions alluded to are the altitude of the region, the permeability of the Hawkesbury sandstone, and, contingent on these, the considerable depth to the water table. Morrison (1904) noted that the dykes intruding the Hawkesbury Formation were almost invariably weathered to considerable depth whilst those intruding the Wianamatta Group were fresh. He attributed this to differential weathering.

The clays are usually white but lack homogeneity and considerable areas are iron stained. Impregnation of the sandstone walls by iron oxides and hydroxides is common but metamorphic effects from the original dykes appear to be slight.



Text-fig. 1.—Differential Thermal curves of Dyke Clays from the Sydney Area. (I) St. Ives. (II) Belrose. (III) Narrabeen Lagoon.

Examination of samples of the dyke-clays by X-ray, thermal and chemical techniques has shown that kaolinite is the predominant clay mineral, occasionally to the exclusion of all others, but illite is frequently present and at times comprises as much as 30% of the clay mineral content.

The variability in mineral composition is evident by the differential thermal curves (Fig. 1). The sample from St. Ives is that of a well crystallized kaolinite and contrasts quite markedly with the illite-bearing kaolins from the Narrabeen Lagoon and Belrose areas.

For the formation of kaolinite from a rock of doleritic composition the complete removal from the system of the alkalies, alkaline earths and iron, together with approximately 50% of the silica is necessary. A consideration

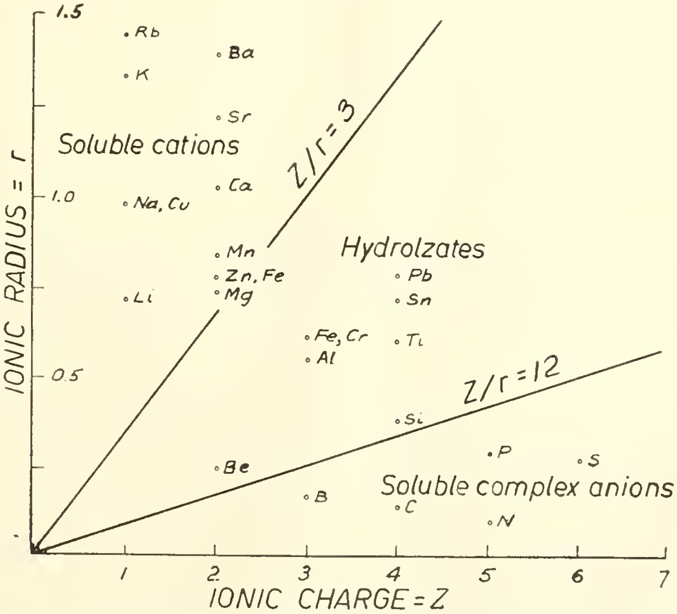
TABLE I.

Chemical Analyses of Dyke Clays and Parent Material.

	I.	II.	III.	IV.
SiO_2	43·6	49·9	43·1	42·5
Al_2O_3	37·8	29·0	34·0	15·7
Fe_2O_3	0·3	2·3	0·7	3·5
FeO..	—	—	—	—
TiO_2	3·0	5·9	5·7	1·9
MgO	—	—	—	7·2
CaO..	—	—	—	9·5
K_2O	2·7	2·3	0·7	1·8
Na_2O	—	—	—	3·1
H_2O+	9·6	9·5	12·3	2·2
H_2O-	2·6	0·3	3·0	0·6
Total ..	99·6	99·2	99·5	—
SiO_2/Al_2O_3 ..	1·15	1·72	1·27	2·70
Al_2O_3/TiO_2 ..	12·60	4·82	6·00	8·0

I. Dyke Clay—M.L. 28, Ph. Manly Cove, Co. Cumberland.
II. ,, ,, M.L. 40, ,, ,, ,, ,, ,,
III. ,, ,, Por. 341, ,, Gordon, ,, ,,
IV. Average of seven dyke rocks from the Sydney area after H. P. White and J. C. Mingaye (1904).

of the chemical analysis (Table 1) of three dyke clays and the average for seven dolerites of the Sydney district shows this trend. Goldschmidt (1937) has shown



Text-fig. 2.—Stability of the various ions as a function of the ionic potential (Z/r). After Goldschmidt, 1937.

(see Fig. 2) that the stability of the various ions in a leaching environment is a function of the ionic potential (*i.e.* the ratio of charge to radius). Consequently, of the ions occurring in the original dolerite, titanium and aluminium were the most stable and the alkalies and alkaline earths the least stable, silica occupied an intermediate position which depended on the *p*H of the leaching solutions. A spectrographic analysis (see Table 2) carried out on three dolerites and three dyke clays from the Sydney district supports Goldschmidt's findings. However, potash behaves anomalously in two of the dyke-clays and it is significant that both of these clays contain illite. Apparently the ability of potassium to enter into twelve co-ordination in the formation of the hydrous mica not only prevented its loss from the system but, further, enabled the stabilization of some of the silica by the formation of the illite—2 : 1 (silica to alumina)—lattice as opposed to the 1 : 1—lattice of kaolinite, which the leaching conditions favoured. Jackson *et alii* found illite common in the highly leached kaoline of Hawaii, some of which contained titania in excess of 30%.

TABLE 2.

Spectrographic Analysis.

Element.	I.	II.	III.	IV.	V.	VI.
Li	T	—	—	T	M	—
Na	S	S	S	T	W	W
K	M	M	M	—	M	M
Mg	V.S.	V.S.	V.S.	W	W	W
Ca	S	S	S	W	W	W
Cu	M	M	M	W	W	W
Fe	S	S	S	M	M	M
Mn	S	S	S	—	—	—
Pb	W	W	W	M	W	W
Sn	—	—	—	T	M	—
Ti	M	M	M	S	S	S
Zn	T	T	—	—	—	—

V.S., very strong ; S, strong ; M, medium ; W, weak ; T, trace.
I. Dolerite Dyke, Bondi.
II. ,, ,, Narrabeen.
III. ,, Sill, de Burgh's Bridge.
IV. Dyke clay, St. Ives.
V. ,, ,, Belrose.
VI. ,, ,, Oxford Falls.

MINERALOGICAL FORM OF THE TITANIA.

Previous references to the mineralogical form of the titania present in various clays are somewhat speculative ; thus the titania has been referred wholly or partly to the following mineral groups :

1. Doubtful titanium compounds not visible macroscopically (Goldschmidt, 1954 ; McLaughlin, 1954).
2. Anatase detected by X-ray analysis but not represented by microscopically visible particles (Brindley and Robinson, 1947 ; Nagelschmidt *et alii*, 1949 ; McLaughlin, 1955).
3. Microscopically detectable discrete crystals of various titanium minerals (Simpson, 1928 ; Carroll, 1934 ; Brindley and Robinson, 1947 ; Frederickson, 1948).

4. Microscopically visible leucoxene as rounded or angular grains or earthy or crust-like material associated with minerals of group 3 (Edwards, 1942; Frederickson, 1948; Goldman, 1955). Leucoxene varies in crystallinity and purity but usually it gives the X-ray powder pattern of rutile, anatase, brookite or sphene (Tyler and Marsden, 1938; Frederickson, 1948; Allen, 1949 and 1956; Golding, 1955.)

In the Sydney dyke-clays examined, much of the titanium occurs as microscopically visible leucoxene grains many of which exhibit well faceted but skeletal octahedral forms. The grains are dull and cream coloured in reflected light, and opaque to transmitted light but some show a pale cloudy aggregate polarization indicative of their polycrystalline (leucoxenic) constitution. The grains have similarities to the mat-surfaced grains present in some dune-sands (Golding, 1955) but differ from them in being more friable and in displaying faceted forms. The powdered leucoxene gives the X-ray pattern for anatase.

Leucoxene-rich concentrates were prepared by sieving suspensions of clay to recover the plus 50 micron material, which was then fractioned in bromoform.

The light bromoform fractions of most samples consisted of clay flakes and pellets usually peppered with small faceted leucoxenes or with blebs or plates of leucoxene. A few grains of wind-blown quartz, derived from the surrounding sandstone, also occur.

The heavy bromoform fractions of most samples consisted largely of leucoxene octahedra 0·1 to 0·2 mm. wide showing hopper or hollow faces (Figs. 1–5 and Figs. 7 and 8) or parallel growths (Fig. 6). A little attached clay, predominantly illite, was present and thin sections of the octahedra revealed triangular illite-filled centres surrounded by leucoxene, itself containing clay-filled pores. In one sample from St. Ives faceted forms were absent, the grains being ovoid, with tubular structures and pitted surfaces. It is significant that illite was not detected in this sample.

It is estimated that at least one half of the titanium shown in analyses II and III (Table 1) is present as visible leucoxene, and of this amount, about one third is present as the coarser faceted forms recovered in the heavy fraction.

ORIGIN OF THE LEUCOXENE.

While some of the leucoxene particles may have been derived from ilmenite, most grains evidently are pseudomorphs after a titaniferous mineral of octahedral habit. Such requirements for the parent crystals might be fulfilled by anatase, perovskite or " titaniferous magnetite ".

Leucoxene is known to develop during the weathering of those titaniferous minerals which also contain readily leachable ions such as iron and calcium. By growth of larger crystallites at the expense of the smaller, the leucoxene tends to build up single crystals of TiO_2 (Tyler and Marsden, 1938; Golding, 1956). The reverse process, and in particular the breakdown of single crystals of anatase to leucoxenic anatase seems unlikely.

Octahedral pseudomorphs of leucoxene believed to be after perovskite occur in certain titaniferous iron ore deposits of specialized paragenesis (Broughton and others, 1950). The presence of perovskite in the Sydney rocks, or its formation during their weathering, also appears unlikely.

The common occurrence of skeletal and titaniferous accessory iron ores in basic rock favours the third possibility. Thin sections and fragments of fresh dyke rocks from several localities in the Sydney district revealed abundant iron ore particles of a shape and size comparable to that of the smaller leucoxenes. Particles corresponding to the larger (and well faceted) leucoxenes, however, were not observed. A single black magnetic octahedron, 0·07 mm. wide, from the Peates Ridge rock showed one face with a triangular central depression, the crystal being either a hollow skeletal form or a zoned crystal in which, presumably, a corroded magnetite core is surrounded by a more titaniferous shell. Such forms, if larger, could account for some of the faceted leucoxenes observed.

In slides of coarser rocks (from Prospect) larger iron ore particles occur, and these, occasionally, show triangular reflection patterns suggesting exsolved ilmenite lamellæ lying in the octahedral planes of magnetite (Edwards, 1952). Such intergrowths however would not give rise to discrete octahedral pseudomorphs.

It is inferred that the leucoxene in the clays is derived mainly from " titaniferous magnetite " the precise characters of which are in doubt. Also it seems likely that the parent rocks of several of the clays sampled were somewhat coarser in grain size than is the case for most of the fresh rocks examined.

The weathering environment favoured the dissolution of the parent " titaniferous magnetite " with removal of the iron in the ferrous state and the hydration of the titanium to form titanic acid. Due to the presence of other ions, particularly the alkalies, in the leaching solutions, the titanic acid had limited mobility and tended to be precipitated in the gel form possibly entrapping some of the alkalies. As crystallization of the gel proceeded to form anatase, the released potash reacted with silica and alumina with the formation of illite, thus accounting for the intimate association of the two minerals.

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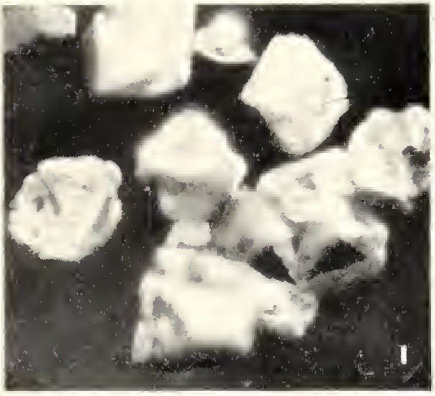
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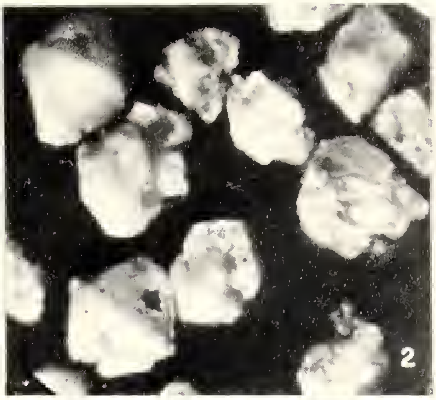
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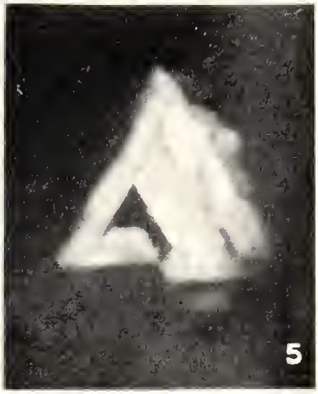
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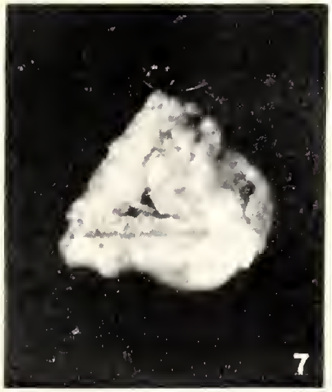
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EXPLANATION OF PLATE I.

Figures 1 and 2. Octahedral leucoxene pseudomorphs from clay at Belrose. X 80.

Figures 3 and 4. Octahedral leucoxene pseudomorphs showing hollow and stepped-in faces from clay at Belrose. X 160.

Figures 5, 7 and 8. Hollow and hopper faces in octahedral leucoxenes from clay at Oxford Falls. X 160.

Figure 6. Parallel growth speudomorphs in leucoxene from clay at St. Ives. X 160.

MINOR PLANETS OBSERVED AT SYDNEY OBSERVATORY DURING 1956.

By W. H. Robertson.

Manuscript received, June 11, 1957. Read July 4, 1957.

The following observations of minor planets were made photographically at Sydney Observatory with the 13″ standard astrograph. Observations were confined to those with southern declinations in the *Ephemerides of Minor Planets* published by the Institute of Theoretical Astronomy at Leningrad.

On each plate two exposures, separated in declination by approximately 0′·5, were taken with an interval of about 20 minutes between them. The beginnings and endings of the exposures were recorded on a chronograph with a tapping key.

Rectangular coordinates of both images of the minor planet and three reference stars were measured in direct and reversed positions of the plate on a long screw measuring machine. The usual three star dependence reduction retaining second order terms in the differences of the equatorial coordinates was used. Proper motions, when they were available, were applied to bring the star positions to the epoch of the plate. Each exposure was reduced separately in order to provide a check by comparing the difference between the two positions with the motion derived from the ephemeris. The tabulated results are means of the two positions at the average time except in cases 355, 376, 380, 401, 402, 404, 406, 427, 428, 441, 448 where each result is from only one image, due to a defect in the other exposure or a failure in timing it. No correction has been applied for aberration, light time or parallax but in Table I. are given the factors which give the parallax correction when divided by the distance. The serial numbers follow on from those of a previous paper (Robertson, 1957). The observers named in Table II. are W. H. Robertson (R), K. P. Sims (S), and H. W. Wood (W). The measurements were made by Mrs. M. Wilson who also assisted in the computation.

Table I.

1956 U.T.	Planet.	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
		h m s	° ′ ″	s	″
323 Aug. 15·69326	14 Irene	23 13 46·22	—18 46 12·5	+0·15	—2·4
324 Aug. 16·67964	14 Irene	23 13 03·69	—18 53 11·8	+0·11	—2·3
325 Aug. 23·62578	30 Urania	22 10 03·95	— 9 42 40·6	+0·13	—3·6
326 Sep. 10·53032	30 Urania	21 53 51·41	—10 51 55·7	+0·03	—3·4
327 June 25·64774	45 Eugenia	19 01 54·98	—14 39 59·4	+0·11	—2·9
328 July 19·56158	45 Eugenia	18 41 24·26	—16 00 06·8	+0·09	—2·7
329 July 24·55631	45 Eugenia	18 37 47·12	—16 19 51·2	+0·12	—2·7
330 Apr. 24·63356	53 Kalypso	15 43 10·11	—11 54 31·4	—0·03	—3·3
331 May 29·51652	53 Kalypso	15 13 11·00	—10 00 25·5	+0·04	—3·5
332 June 21·65498	54 Alexandra	19 44 30·29	—32 38 43·3	+0·01	—0·2
333 July 5·61366	54 Alexandra	19 31 26·54	—31 56 33·5	+0·03	—0·3
334 July 23·55048	54 Alexandra	19 12 40·21	—30 18 13·9	+0·02	—0·5
335 May 23·69039	104 Klymene	17 39 03·25	—25 38 44·5	+0·15	—1·4

TABLE I.—*Continued.*

1956 U.T.	Planet.	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
		h m s	° ′ ″	s	″
336 June 25·54808	104 Klymene	17 12 39·24	—25 33 30·8	+0·04	—1·2
337 July 5·64995	120 Lachesis	21 18 29·76	—21 51 03·5	—0·10	—1·9
338 July 7·66482	120 Lachesis	21 17 23·23	—21 55 06·8	+0·03	—1·8
339 July 26·60978	120 Lachesis	21 03 44·88	—22 35 46·3	+0·01	—1·7
340 Aug. 16·52916	120 Lachesis	20 46 09·16	—23 05 38·0	—0·05	—1·6
341 Apr. 24·66380	150 Nuwa	15 40 15·83	—18 18 46·5	+0·07	—2·3
342 May 2·62518	150 Nuwa	15 34 35·15	—17 53 59·5	+0·03	—2·4
343 July 5·69466	158 Koronis	20 41 51·54	—17 43 20·2	+0·13	—2·5
344 Aug. 22·51590	158 Koronis	20 04 35·12	—19 37 08·7	+0·06	—2·2
345 Aug. 27·50567	158 Koronis	20 01 56·27	—19 44 27·2	+0·08	—2·2
346 June 19·66140	170 Maria	19 41 33·17	—28 22 30·8	+0·02	—0·8
347 July 26·52607	170 Maria	19 02 46·71	—26 40 34·3	—0·01	—1·1
348 June 26·62283	209 Dido	19 39 18·00	—31 59 41·2	—0·05	—0·3
349 July 5·61366	209 Dido	19 31 36·97	—32 17 47·4	+0·03	—0·2
350 July 18·56646	209 Dido	19 19 48·02	—32 29 41·5	+0·01	—0·2
351 July 24·58642	224 Oceana	20 03 08·81	—28 30 21·9	+0·04	—0·8
352 Aug. 8·51684	224 Oceana	19 49 10·12	—28 30 13·3	—0·03	—0·8
353 Aug. 16·50360	224 Oceana	19 43 21·40	—28 18 55·9	+0·01	—0·8
354 Aug. 30·66019	264 Libussa	0 14 35·14	—14 43 25·8	+0·04	—2·9
355 Aug. 23·57253	326 Tamara	21 14 39·65	—60 10 11·4	+0·18	+3·8
356 Aug. 30·54619	326 Tamara	21 06 20·55	—58 36 27·9	+0·16	+3·6
357 Aug. 9·57951	338 Budrosa	20 59 29·06	—12 42 50·3	+0·03	—3·2
358 Aug. 23·51188	338 Budrosa	20 48 20·06	—13 10 17·2	—0·04	—3·1
359 June 18·58977	352 Gisela	18 18 48·83	—20 56 10·2	—0·04	—2·0
360 June 28·57772	352 Gisela	18 07 28·93	—20 43 12·1	+0·04	—2·0
361 June 19·59417	362 Havnia	18 09 59·98	—34 59 19·4	0·00	+0·2
362 July 18·49930	362 Havnia	17 41 12·07	—34 57 54·4	+0·02	+0·2
363 May 28·64388	396 Æolia	17 59 12·90	—22 42 56·7	—0·02	—1·7
364 June 26·55358	396 Æolia	17 34 49·56	—21 54 08·7	+0·01	—1·8
365 June 26·59410	410 Chloris	18 08 19·34	—21 59 44·3	+0·07	—1·8
366 July 19·53076	410 Chloris	17 51 27·98	—25 00 00·8	+0·11	—1·4
367 June 28·68550	433 Eros	20 50 18·10	—23 09 02·4	+0·02	—1·6
368 Aug. 9·66477	450 Brigitta	22 34 58·37	—21 42 13·7	+0·09	—1·9
369 Aug. 29·58912	450 Brigitta	22 17 48·17	—22 30 54·0	+0·06	—1·7
370 June 19·55819	451 Patientia	17 29 59·95	—21 17 20·0	—0·02	—1·9
371 July 26·49643	454 Mathesis	18 27 54·50	—32 56 33·8	—0·03	—0·1
372 July 5·64995	504 Cora	21 17 57·06	—22 22 38·8	—0·10	—1·8
373 July 7·66482	504 Cora	21 17 25·44	—22 43 09·5	—0·03	—1·7
374 July 11·69106	504 Cora	21 16 01·74	—23 25 52·0	+0·10	—1·6
375 July 18·63778	504 Cora	21 12 37·74	—24 43 31·6	—0·01	—1·4
376 July 26·66418	504 Cora	21 07 21·83	—26 15 52·2	+0·17	—1·3
377 Aug. 7·61546	504 Cora	20 57 52·69	—28 26 38·8	+0·14	—0·9
378 Aug. 8·61439	504 Cora	20 57 03·10	—28 36 43·4	+0·15	—0·9
379 Aug. 16·56280	504 Cora	20 50 40·56	—29 49 27·8	+0·06	—0·6
380 Aug. 30·52536	504 Cora	20 41 51·16	—31 19 53·1	+0·08	—0·4
381 Oct. 23·61110	511 Davida	2 41 21·92	— 8 54 41·3	+0·02	—3·7
382 Nov. 26·46070	511 Davida	2 16 01·32	— 8 46 02·0	—0·10	—3·7
383 Aug. 9·62781	528 Rezia	21 43 46·78	—32 35 27·2	+0·09	—0·2
384 Sep. 6·51329	528 Rezia	21 22 36·00	—33 23 35·4	+0·01	—0·1
385 Aug. 14·66594	532 Herculina	22 43 26·23	—25 16 39·7	+0·12	—1·4
386 Sep. 24·50702	532 Herculina	22 12 27·98	—28 57 33·0	+0·04	—0·7
387 June 18·55935	558 Carmen	17 59 02·26	—13 08 19·9	—0·07	—3·1
388 July 18·47380	558 Carmen	17 36 28·07	—14 12 02·2	—0·05	—2·9
389 Aug. 16·63618	566 Stereoskopia	22 40 16·20	—15 41 23·3	+0·04	—2·7
390 Sep. 10·55368	566 Stereoskopia	22 22 52·62	—17 28 44·3	+0·04	—2·5
391 Apr. 18·65204	572 Rebekka	15 00 31·22	— 9 50 30·2	+0·06	—3·6
392 May 16·55511	572 Rebekka	14 36 19·88	— 6 27 31·9	+0·05	—4·0
393 May 28·60870	576 Emanuela	17 15 03·31	—34 33 04·0	—0·03	+0·1
394 June 18·53044	576 Emanuela	16 54 49·60	—33 16 31·4	+0·10	—0·1

TABLE I.—*Continued.*

1956 U.T.			Planet.	R.A. (1950·0)	Dec. (1950·0)	Parallax Factors	
				h m s	° ′ ″	s	″
395	Aug.	16·60266	586 Thekla	21 48 07·01	—10 47 21·2	+0·05	—3·4
396	Mar.	22·69051	624 Hector	13 41 43·36	—27 44 56·7	+0·27	—1·4
397	May	2·53222	624 Hector	13 18 08·49	—27 03 30·0	+0·03	—1·0
398	Apr.	26·52130	640 Brambilla	12 39 33·77	—15 58 10·2	+0·03	—2·7
399	Apr.	16·69541	644 Cosima	15 42 28·61	—18 19 45·3	+0·09	—2·4
400	May	28·53006	644 Cosima	15 07 08·59	—16 12 48·3	+0·01	—2·6
401	Apr.	16·57380	672 Astarte	12 58 52·28	—19 08 00·8	+0·07	—2·2
402	Apr.	17·52338	672 Astarte	12 57 53·34	—19 05 37·0	—0·08	—2·2
403	Apr.	24·51640	704 Interamnia	12 07 31·11	—26 19 42·0	+0·07	—1·2
404	Apr.	23·68838	762 Pulcova	15 49 04·75	—37 49 23·1	+0·14	+0·5
405	Apr.	16·56028	764 Gedania	12 59 33·27	—19 15 14·6	+0·02	—2·2
406	Apr.	17·52338	764 Gedania	12 58 52·61	—19 09 28·2	—0·09	—2·2
407	June	19·53032	776 Berberica	16 47 00·98	—21 17 03·6	—0·02	—1·9
408	July	3·49932	776 Berberica	16 35 28·75	—21 59 32·7	+0·03	—1·8
409	July	24·61633	785 Zwetana	20 09 21·65	—35 50 04·0	+0·13	+0·2
410	Aug.	7·58794	785 Zwetana	19 55 17·56	—36 42 57·5	+0·21	+0·2
411	Aug.	14·50542	785 Zwetana.	19 49 39·92	—36 52 38·7	—0·02	+0·5
412	Apr.	18·65204	799 Gudula	15 00 05·69	— 9 56 46·9	+0·06	—3·6
413	Aug.	15·69326	842 Kerstin	23 11 48·94	—18 05 57·8	+0·15	—2·5
414	Sep.	3·64754	842 Kerstin	22 55 29·05	—18 23 50·6	+0·20	—2·5
415	May	29·55376	862 Franzia	15 58 12·87	—37 45 36·7	—0·02	+0·6
416	June	13·51040	862 Franzia	15 44 29·99	—36 15 00·4	0·00	+0·4
417	Aug.	27·66362	910 Anneliese	0 04 04·29	—13 01 54·5	+0·04	—3·1
418	Sep.	10·62116	910 Anneliese	23 53 15·56	—14 03 57·3	+0·05	—3·0
419	Oct.	11·54620	910 Anneliese	23 28 56·30	—15 02 16·4	+0·14	—2·9
420	Aug.	30·62999	928 Hildrun	23 37 06·39	—17 52 15·9	+0·02	—2·4
421	Oct.	11·51135	928 Hildrun	23 10 38·23	—21 44 17·4	+0·07	—1·9
422	Oct.	23·50836	966 Muschi	23 52 16·39	—21 43 57·5	+0·07	—1·9
423	Aug.	8·68709	974 Lioba	23 02 54·32	—15 04 39·3	+0·09	—2·8
424	Sep.	6·58105	974 Lioba	22 40 38·28	—18 12 32·7	+0·05	—2·4
425	Apr.	16·61404	978 Aidamina	13 59 10·58	—15 06 48·8	+0·06	—2·8
426	May	2·57508	978 Aidamina	13 48 10·45	—13 02 22·8	+0·10	—3·1
427	May	17·70891	994 Otthild	18 03 20·02	—46 29 54·5	+0·13	+1·8
428	June	13·58211	994 Otthild	17 34 48·65	—48 50 40·2	—0·01	+2·3
429	Mar.	22·62272	1000 Piazzia	12 08 44·50	—25 31 23·4	+0·25	—1·6
430	Apr.	16·51718	1000 Piazzia	11 43 52·85	—25 26 44·9	+0·06	—1·3
431	Aug.	9·57951	1006 Lagrangea	20 58 55·51	—11 39 41·6	+0·03	—3·3
432	Aug.	27·54475	1006 Lagrangea	20 42 46·86	—11 05 50·2	+0·08	—3·4
433	Sep.	3·51386	1006 Lagrangea	20 38 03·54	—10 53 04·5	+0·08	—3·4
434	Aug.	14·63844	1074 Beljawskya	22 02 08·89	—13 21 06·0	+0·12	—3·1
435	Aug.	27·58682	1074 Beljawskya	21 52 07·33	—14 13 11·3	+0·09	—3·0
436	Sep.	6·54968	1074 Beljawskya	21 44 48·98	—14 48 41·5	+0·07	—2·9
437	Aug.	9·66477	1116 Catriona	22 35 08·69	—22 33 44·0	+0·09	—1·7
438	Aug.	29·58912	1116 Catriona	22 15 53·27	—23 04 19·2	+0·06	—1·7
439	Sep.	24·68032	1140 Crimea	1 46 55·31	—10 21 20·4	+0·11	—3·5
440	Oct.	23·57095	1140 Crimea	1 21 24·84	—11 09 57·8	+0·07	—3·4
441	July	3·65840	1184 Gæa	20 30 28·56	—36 04 48·8	+0·02	+0·4
442	Aug.	7·58794	1184 Gæa	19 54 09·11	—36 07 16·9	+0·21	+0·1
443	May	16·66771	1214 Richilde	17 02 58·13	—32 23 02·0	+0·10	—0·3
444	May	29·61081	1214 Richilde	16 51 15·05	—31 40 46·3	+0·05	—0·3
445	June	13·55130	1214 Richilde	16 36 26·31	—30 22 40·6	+0·02	—0·5
446	May	17·54186	1292 Luce	14 06 25·87	—15 37 10·6	+0·09	—2·8
447	May	28·48784	1292 Luce	14 00 07·94	—14 50 10·5	+0·02	—2·8
448	Aug.	14·59515	1428 Mombasa	21 16 09·67	—26 50 06·7	+0·09	—1·1
449	Aug.	23·54360	1428 Mombasa	21 09 07·07	—28 14 46·6	+0·01	—0·8
450	Sep.	3·60020	1428 Mombasa	21 01 53·34	—29 35 24·4	+0·32	—1·3

TABLE II.

	Comparison Stars	Dependences.			
323	Yale *12* II 9741, 9768, 9770	0·13033	0·40623	0·46344	W
324	Yale *12* II 9748, 9768, 9770	0·35013	0·53184	0·11803	W
325	Yale *11* 7834, 7851, 7860	0·34677	0·38369	0·26954	S
326	Yale *11* 7767, 7770, 7777	0·32913	0·26551	0·40536	R
327	Yale *12* I 7046, 7059, 7074	0·17306	0·40538	0·42156	S
328	Yale *12* I 6896, 6901, 6918	0·17123	0·50682	0·32195	S
329	Yale *12* I 6860, 6874, 6878	0·23596	0·39753	0·36651	W
330	Yale *11* 5482, 5484, 5486	0·32726	0·22510	0·44764	S
331	Yale *16* 5325, 5326, 5333	0·39502	0·05272	0·55226	R
332	Cape *17* 10765, 10778, 10786	0·22636	0·18844	0·58520	R
333	Cape *17* 10647, 10683, 10685	0·51045	0·40273	0·08682	W
334	Cape *17* 10466, 10508, 10511	0·40972	0·26625	0·32402	W
335	Yale *14* 12113, 12121, 12132	0·28876	0·19406	0·51719	W
336	Yale *14* 11896, 11917, 11950	0·38637	0·31141	0·30222	S
337	Yale *14* 14708, 14736, *13* I 9145	0·08945	0·21634	0·69421	W
338	Yale *14* 14694, 14723, *13* I 9145	0·29063	0·08754	0·62183	W
339	Yale *14* 14577, 14587, 14604	0·29061	0·50512	0·20427	W
340	Yale *14* 14416, 14434, 14461	0·29231	0·37012	0·33758	W
341	Yale *12* II 6487, 6511, *12* I 5752	0·37530	0·30305	0·32164	S
342	Yale *12* I 5714, 5731, *12* II 6453	0·17739	0·23588	0·58673	W
343	Yale *12* I 7802, *12* II 8886, 8916	0·49541	0·12013	0·38446	W
344	Yale *13* I 8607, *12* II 8621, 8625	0·27812	0·68170	0·04018	S
345	Yale *12* II 8587, 8621, *13* I 8607	0·52913	−0·08700	0·55787	R
346	Yale *13* II 12914, 12941, 12964	0·18077	0·42259	0·39664	R
347	Yale *14* 13245, 13275, *13* II 12466	0·35861	0·44619	0·19520	W
348	Cape *17* 10727, 10738, 10743	0·24519	0·39370	0·36111	S
349	Cape *17* 10647, 10662, 10685	0·23531	0·38077	0·38392	W
350	Cape *17* 10551, 10576, 10580	0·38224	0·35362	0·26414	S
351	Yale *13* II 13199, 13204, 13248	0·35447	0·50707	0·13846	W
352	Yale *13* II 13034, 13035, 13064	0·53186	0·30097	0·16717	S
353	Yale *13* II 12959, 12961, 12985	0·23936	0·38282	0·37782	W
354	Yale *12* I 63, 74, 76	0·29035	0·32908	0·38057	R
355	L Pl. B 7221, 7230, 7238	0·30861	0·16803	0·52336	S
356	L Pl. B 7195, 7216, 7223	0·37255	0·31374	0·31371	R
357	Yale *11* 7445, 7449, 7454	0·26533	0·08424	0·65043	S
358	Yale *11* 7375, 7386, 7397	0·52976	0·19126	0·27898	S
359	Yale *13* I 7631, 7653, 7655	0·24118	0·65635	0·10247	R
360	Yale *13* I 7489, 7506, 7518	0·11381	0·42412	0·46207	S
361	Cape *17* 9763, 9775, *18* 9319	0·27231	0·35643	0·37127	R
362	Cape *17* 9394, 9432, *18* 8944	0·30640	0·30638	0·38722	S
363	Yale *14* 12336, 12371, 12394	0·24978	0·34192	0·40830	R
364	Yale *13* I 7214, 7229, *14* 12115	0·50840	0·27382	0·21777	S
365	Yale *13* I 7494, 7542, *14* 12549	0·11620	0·31215	0·57165	S
366	Yale *14* 12248, 12260, 12277	0·41465	0·34821	0·23715	S
367	Yale *14* 14461, 14483, 14496	0·46029	0·17611	0·36360	S
368	Yale *14* 15287, 15319, *13* I 9569	0·36862	0·53891	0·09246	S
369	Yale *14* 15173, 15196, 15205	0·57493	0·12751	0·29756	R
370	Yale *13* 7177, 7181, 7192	0·43964	0·21101	0·34935	R
371	Cape *17* 9983, 10008, 10017	0·25036	0·46656	0·28308	W
372	Yale *14* 14708, 14709, 14736	0·28514	0·41015	0·30470	W
373	Yale *14* 14694, 14698, 14723	0·25627	0·22348	0·52025	W
374	Yale *14* 14681, 14706, 14719	0·52000	0·07598	0·40402	R
375	Yale *14* 14658, 14660, 14680	0·19019	0·24915	0·56067	S
376	Yale *14* 14606, 14626, 14629	0·42787	0·07316	0·49897	W
377	Yale *13* II 13804, 13832, 13847	0·20421	0·51235	0·28344	S
378	Yale *13* II 13799, 13826, 13834	0·37135	0·32799	0·30066	S
379	Yale *13* II 13738, 13760, Cape *17* 11409	0·45768	0·19700	0·34531	W
380	Cape *17* 11310, 11323, 11324	0·12801	0·46605	0·40594	R
381	Yale *16* 593, 613, 617	0·23303	0·39383	0·37315	W
382	Yale *16* 490, 497, 511	0·23202	0·42591	0·34207	S
383	Cape *17* 11847, 11863, 11875	0·26731	0·44072	0·29197	S
384	Cape *17* 11674, 11675, 11708	0·20065	0·32356	0·47578	W
385	Yale *14* 15353, 15373, 15379	0·29896	0·49913	0·20190	W
386	Yale *13* II 14430, 14439, 14456	0·29324	0·21985	0·48690	S
387	Yale *11* 6128, 6136, 6152	0·23788	0·48265	0·27947	R
388	Yale *12* I 6338, 6340, 6352	0·49919	0·13989	0·36092	S

TABLE II.—*Continued.*

Comparison Stars	Dependences.			
389 Yale *12* I 8434, 8441, 8444	0·21866	0·50914	0·27220	W
390 Yale *12* I 8361, 8378, *12* II 9511	0·39337	0·21488	0·39174	R
391 Yale *16* 5260, 5270, 5275	0·32302	0·30986	0·36712	R
392 Yale *16* 5135, 5162, *17* 5181	0·42825	0·20835	0·36340	S
393 Cape *17* 9113, 9119, 9156	0·58727	0·16695	0·24578	R
394 Cape *17* 8885, 8898, 8904	0·23403	0·39747	0·36849	R
395 Yale *11* 7733, 7740, 7755	0·26605	0·37396	0·35999	W
396 Yale *13* II 8692, 8720, 8722	0·41918	0·33036	0·25046	W
397 Yale *14* 9854, 9859, 9871	0·43155	0·45162	0·11683	W
398 Yale *12* I 4851, 4868, 4873	0·29049	0·25844	0·45107	S
399 Yale *12* I 5752, *12* II 6511, 6521	0·19431	0·51329	0·29240	R
400 Yale *12* I 5574, 5586, 5587	0·32933	0·55085	0·11982	R
401 Yale *12* II 5588, 5607, 5610	0·43823	0·18362	0·37815	R
402 Yale *12* II 5588, 5607, 5610	0·75770	—0·01890	0·26120	R
403 Yale *14* 9200, 9221, 9232	0·33494	0·35368	0·31138	S
404 Cape *18* 7823, 7827, 7851	0·28019	0·26922	0·45059	S
405 Yale *12* II 5588, 5607, 5610	0·20326	0·44375	0·35299	R
406 Yale *12* II 5588, 5607, 5610	0·43310	0·21566	0·35124	R
407 Yale *13* I 6853, 6865, 6877	0·32433	0·31288	0·36279	R
408 Yale *13* I 6805, 6814, *14* 11535	0·54627	0·26923	0·18450	W
409 Cape *18* 10460, 10483, 10488	0·21956	0·24890	0·53154	W
410 Cape *18* 10333, 10334, 10347	0·53186	0·21551	0·25263	S
411 Cape *18* 10261, 10289, 10305	0·21343	0·29254	0·49403	W
412 Yale *16* 5260, 5270, 5275	0·46229	0·25060	0·28711	R
413 Yale *12* II 9741, 9751, 9770	0·23267	0·52973	0·23760	W
414 Yale *12* II 9662, 9675, 9678	0·12598	0·49002	0·38400	W
415 Cape *18* 7912, 7938, 7946	0·38298	0·52729	0·08973	R
416 Cape *18* 7771, 7797, 7810	0·31860	0·39560	0·28579	W
417 Yale *11* 8337, 13, *12* I 16	0·53869	0·05302	0·40828	R
418 Yale *12* I 8785, 8796, 8806	0·31156	0·46461	0·22382	R
419 Yale *12* I 8671, 8677, 8691	0·14305	0·49684	0·36011	R
420 Yale *12* II 9876, 9879, 9883	0·62887	0·20409	0·16704	R
421 Yale *14* 15582, 15601, *13* I 9744	0·21828	0·44856	0·33316	R
422 Yale *13* I 9940, 9950, *14* 15916	0·52062	0·25030	0·22908	W
423 Yale *12* I 8549, 8554, 8561	0·32512	0·45048	0·22440	S
424 Yale *12* II, 9586, 9590, 9608	0·36278	0·39206	0·24516	W
425 Yale *12* I 5240, 5248, 5256	0·41411	0·22022	0·36566	R
426 Yale *11* 4903, 4907, 4911	0·45487	0·34437	0·20076	W
427 Cord. D 13147, 13194, 13232	0·41181	0·24540	0·34279	S
428 Cape Ft. 16906, 16953, 17084	0·27643	0·26087	0·46270	W
429 Yale *14* 9217, 9223, 9239	0·43612	0·10750	0·45638	W
430 Yale *14* 8977, 8983, 9004	0·39572	0·22223	0·38206	R
431 Yale *11* 7429, 7459, 7460	0·32223	0·31136	0·36642	S
432 Yale *11* 7337, 7348, 7358	0·33261	0·37863	0·28876	R
433 Yale *11* 7295, 7316, 7337	0·29592	0·34392	0·36016	W
434 Yale *11* 7804, 7814, *12* I 8268	0·22872	0·34313	0·42815	W
435 Yale *12* I 8203, 8214, 8220	0·30635	0·28850	0·40515	R
436 Yale *12* I 8178, 8188, 8189	0·42565	0·30525	0·26910	W
437 Yale *14* 15286, 15315, 15319	0·21177	0·53851	0·24972	S
438 Yale *14* 15167, 15173, 15196	0·54341	0·27761	0·17899	R
439 Yale *11* 397, 403, 417	0·32606	0·29770	0·37624	S
440 Yale *11* 287, 294, 298	0·20112	0·37084	0·42804	W
441 Cape *18* 10651, 10656, 10669	0·21260	0·49343	0·29397	W
442 Cape *18* 10301, 10334, 10342	0·30101	0·29762	0·40137	S
443 Cape *17* 8972, 8977, 9008	0·51106	0·15710	0·33184	S
444 Cape *17* 8839, 8856, 8870	0·30506	0·40843	0·28651	R
445 Cape *17* 8686, 8712, 8713	0·45722	0·28680	0·25599	W
446 Yale *12* I 5278, 5286, 5297	0·18197	0·43131	0·38671	S
447 Yale *12* I 5241, 5257, 5265	0·43520	0·28278	0·28202	R
448 Yale *14* 14692, 14701, *13* II 14009	0·22208	0·33263	0·44529	W
449 Yale *13* II 13929, 13936, 13965	0·28179	0·35647	0·36173	S
450 Yale *13* II 13846, 13858, 13889	0·17066	0·32258	0·50676	W

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ORDOVICIAN CORALS FROM NEW SOUTH WALES.

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With Plates II-III-IV.

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Abstract.

A coral fauna in or below the zone of *Nemagraptus pertenuis* at Cliefden Caves is the oldest so far discovered in Australia. The genera represented are *Tetradium, Billingsaria, Nyctopora, Coccoseris* and *Propora.* For these last two genera the Cliefden Caves Limestone is the earliest known appearance.

Another fauna, from the Bowan Park and Regan's Creek Limestones, contains *? Lichenaria, ? Coccoseris, Palæoporites, Propora, Heliolites* and *Eofletcheria,* with dasycladacean algæ. This may be either late Middle or Upper Ordovician, or because of the presence of *Palæoporites,* possibly Lower Silurian.

Calapoecia (first Australian record) occurs in Portion 41, Parish Boree Cabonne, near Cudal. The species is very similar to a Black River—Trenton—Richmond one from Canada.

Plasmoporella, Plasmopora and *Propora* occur in the Cargo Creek Limestone, which may be Upper Ordovician or Lower Silurian, and the Canomodine limestone, though recrystallised, appears to have a similar fauna.

The Tabulata described herein from the Orange-Cowra district of New South Wales were sent to me by Dr. N. C. Stevens, New South Wales, now of the University of Queensland, and Mr. H. O. Fletcher, Australian Museum. Rugosa were not represented in the collections. The area from which they were collected has recently been mapped by Stevens (1950*a*, *b* ; 1952 ; 1957) and his work, together with palæontological determinations by Dr. Ida Browne (1952), Mrs. Sherrard (1954) and in Stevens, 1952), Öpik (1951 and in Stevens, 1952) and Glenister (1952) has established the Ordovician age of a number of limestones previously regarded as Silurian. On the graptolite evidence assessed by Mrs. Sherrard, one at least of the rich coral faunas is of, or older than, the zone of *Nemagraptus gracilis*, and is thus older than any coral deposits known from Europe or Asia (with the possible exception of Bear Island off the north of Norway). No Australian corals have yet been found in strata equivalent to the Canadian, whence Bassler described the earliest corals, but brachiopod genera usually indicative of the Canadian have been recorded (Browne, 1952, p. 29) from the region, and we may yet hope for an Australian contribution to the problem of the origin of corals.

Cliefden Caves Limestone.—Stevens (1952) estimates this belt of limestones near Mandurama to have a maximum thickness of 2480 feet and mapped it as in general overlain by, but in places interbedded with, the Malongulli Formation of limestones and shales with graptolites of the *Nemagraptus pertenuis* zone of Sherrard (1954) *i.e.* probably of the *N. gracilis* zone. Corals occur chiefly in the lower shaly members of the Cliefden Caves Limestone, the richest beds in the lowest 50 feet, outcropping on Fossil Hill (on the south side of The Large Flat). The Fossil Hill fauna is *Tetradium cribriforme* (Etheridge), *Nyctopora stevensi* sp. nov., and *Propora mammifera* sp. nov. ; while from higher horizons within the

Cliefden Caves Limestone, we have *Billingsaria banksi* Hill, *Nyctopora ? stevensi*, *Coccoseris speleana* sp. nov. and *Propora ? mammifera*. Had the graptolites not been found, I would have considered this fauna more likely to be Trenton than older, owing to the occurrence of *Coccoseris* and *Propora*, not known elsewhere in strata older than Trenton; though it is not impossible that basal Trenton formations may be within the *Nemagraptus gracilis* zone, the graptolites probably indicate that we should extend the range of these two genera downwards.

A limestone bed in the **Malongulli Formation** between "Wonga" and Malongulli Trig. Station contains *Tetradium cribriforme*, and should not therefore be vastly different in age from the Cliefden Caves Limestone.

Bowan Park Limestone.—The coral fauna here (Por. 289, Par. Bowan, Co. Ashburnam, north of Cargo) consists of *Heliolites digitalis* sp. nov., *Propora bowanensis* sp. nov., *? Coccoseris* sp. and *Eofletcheria gracilis* sp. nob., associated with dasycladaceean algæ. Browne (1952) has considered the limestone to be Ordovician. Part of this limestone appears equivalent to part of the **Regans Creek Limestone** 3 miles south-east of Cargo mapped by Stevens (1950a), since from the latter *Propora bowanensis*, *Heliolites ? digitalis*, *Palæoporites serratus* sp. nov., *Eofletcheria gracilis* and *? Lichenaria* are known. *Palæoporites* is known elsewhere only from F_2 (=Llandovery) in Estland; *Propora* ranges upwards from the *Nemagraptus gracilis* zone through the Silurian; *Heliolites* elsewhere is not known earlier than the Lyckholm beds of the Island of Worms (=5*a*); *Eofletcheria* ranges upwards from the Chazy into the Upper Ordovician, and *Lichenaria* from the Canadian into the Trenton in North America. From their coral fauna, these limestones could thus be either Middle or Upper Ordovician or early Silurian.

Por. 41, Parish Boree Carbone, near Cudal. *Calapoecia* aff. *canadensis* ranges elsewhere from Black River into the Richmond; the New South Wales occurrence should therefore be within these limits.

Cargo Creek Limestone, south of Cargo. *Plasmoporella inflata* sp. nov., *Plasmopora cargoensis* sp. nov. and *Propora* sp. occur. *Plasmoporella* is known from 5*a*, and possibly from 5*b* in Norway and Lapland, and from the Niagaran of North America; *Plasmopora* is not known elsewhere older than the Llandovery, and extends on into the Middle Devonian. This limestone may therefore be Upper Ordovician or Lower Silurian; it has been mapped by Stevens (1950*a*).

The Canomodine Limestone, south of Cargo is much altered by compression and recrystallisation, but its two species could well be *Plasmoporella inflata* and *Plasmopora cargoensis*, so that it may be equivalent to the Cargo Creek Limestone. It also has been mapped by Stevens (1950*a*).

SYSTEMATIC DESCRIPTIONS.

Type species of genera are omitted as they have been given by Hill and Stumm in Moore, R. C., "Treatise on Invertebrate Paleontology, F. Coelenterata" (1956); and ordinal, family, subfamily or generic diagnoses are not given where these are unchanged from that treatise.

Order Tabulata Edwards and Haime, 1850.

Family **Chætetidæ** Edwards and Haime, 1850.

Subfamily **Tetradiinæ** Nicholson, 1879.

Genus **Tetradium** Dana, 1848.

Tetradium cribriforme (Etheridge). (Pl. II, figs. 1–4.)

Mitcheldeania (?) *cribriformis* Etheridge, 1909, p. 308, pls. 47, 48, limestone (Cliefden Caves Limestone, *fide* N.C.S.) in Parish of Malongulli, on the bank of the Belubula River, about 18 miles due south of the Canobolas Mountains. Middle Ordovician.

Type Specimen. Australian Museum F 13579 with thin section A.M. 817. Pl. II, figs. 1*a*–1*c*.

Diagnosis. Corallites 0·5 to 0·75 mm. in diameter and seldom dividing, in contact in short halysitoid chains.

Description. The corallum may be very large, forming masses several feet in diameter according to the original collector. It consists of slender cylindrical corallites 0·5–0·75 mm. in diameter, in which four short septa may appear, lengthening gradually till they meet at the axis, and at the same time the sides of the tube become indented at the septa, and gradually the tube divides into four, some or all of which may remain in contact or partial contact so that short angular halysitoid chains may form; there are numerous nodule- or ring-like connecting processes; in some instances these appear to place the lumina of neighbouring corallites in communication, but I cannot be sure that this is not an artefact of preservation, the walls being very thin and mostly recrystallised. The spaces between corallites were not always completely filled with mud, and clear calcite has recrystallised in the clear gaps, simulating tubules of a smaller size between the ordinary corallites, a condition which misled Etheridge into referring the species to the algal genus *Mitcheldeania*. Tabulæ have not been distinguished.

Remarks. The cribriform appearance in vertical section due to the connecting processes or rings is very characteristic. In its growth form the species approximates to that of the *T. syringoporoides* group distinguished by Bassler (1950) in North America; but in some areas of the coralla single chains of corallites in contact may be observed as in the *T. halysitoides* group; rod-like connecting processes occur in the *T. halysitoides* group in North America, but have not been described in the *T. syringoporoides group*. Both groups first appear and are dominant in the Blackriveran of North America, but one or two species live on into the Trenton, Maysville and Richmondian.

A specimen University of Queensland (F. 23212 A/B) from a limestone bed in the Malongulli Formation between "Wonga" and Malongulli Trig. Station seems identical with this species.

The possibility that the Tetradiinæ are calcareous algæ seems to deserve serious investigation.

Subfamily **Lichenariinæ** Okulitch, 1936.

Genus **Lichenaria** Winchell and Schuchert, 1895.

Lichenaria sp. (Pl. IV, fig. 22*c*, 23).

Two thin sections, University of Queensland F. 23228*B* and *C* from the Regan's Creek limestone 3 miles south-east of Cargo, of small highly domed coralla 5 mm. in diameter show corallites about 0·5 mm. wide with moderately thick walls showing no sign of septa or septal ridges, and no mural pores; tabulæ are present, but rare. They are referred to *? Lichenaria* sp., the corallites having much the same dimensions as those of *L. ramosa* Hill (1955) from the Ordovician Smelter's Limestone of Zeehan and from Ida Bay, Tasmania, but having thicker walls and no concentration of tabulæ just below the calices. Middle or Upper Ordovician.

Family **Syringophyllidæ** Počta, 1902.
Subfamily **Billingsariinæ** Okulitch, 1936.
Genus **Billingsaria** Okulitch, 1936.
Billingsaria banksi Hill. (Pl. II, figs. 5*a*, 5*b*.)

Billingsaria banksi Hill, 1955, p. 246, pl. III, fig. 40, Ida Bay, Tasmania.

Australian Museum F 46753 (with sections A.M. 6150 and 6151) from Öpik's "Large Flat" limestone (*i.e.* middle part of Cliefden Caves Limestone *fide* N.C.S.) near Mandurama has closely similar if not identical characters to the type specimen.*

Genus **Nyctopora** Nicholson, 1879.
Nyctopora stevensi, sp. nov. (Pl. II, figs. 6–8.)

Holotype. University of Queensland F 23214, Fossil Hill, Cliefden Caves, near Mandurama, New South Wales, lowest part of Cliefden Caves Limestone, Middle Ordovician.

Diagnosis. *Nyctopora* with corallites 1 mm. in diameter with crenulate walls and 16 septa (8 longer and 8 shorter) one rising from each crenulation.

Description. The corallum may be large with rounded upper surface. New corallites arise intermurally at the angles. The corallites are 1 mm. in average diameter, the mutual walls in most being crenulate with 16 more or less distinct crenulations projecting into each corallite, the inner edge of each crenulation being produced as a short septum ; these 16 may be subequal but more frequently there are 8 longer alternating with 8 shorter, closely spaced. No pores in the walls are visible, though new circular corallites at the angles are pore-like in appearance in transverse section. Tabulæ are thin, slightly domed and rather distant, about 1 mm. apart. There is considerable variation in the corallites of the holotype. Some have very thin, straight walls without signs of septa ; others show crenulations without apparent septal prolongations ; others show septal prolongations and have thicker walls ; one has a trabecular columella as in *Billingsaria* Okulitch. Individual trabeculæ cannot be distinguished in the walls or septa of the holotype and there is no appearance of spines on the axial edges of the septa.

Remarks. In the holotype a cylinder of calcite, an artefact of fossilization, is deposited as a lining to the walls. Sydney University S.U. 9288 from Fossil Hill shows a thickening and lengthening of the septa so that the common walls become almost as thick as in *Billingsaria*. S.U. 9289, doubtfully placed in *N. stevensi*, has smaller corallites, 0·78 to 0·8 mm. in average diameter, with thicker, longer septa, so that the common walls are thicker and the crenulations are less apparent : an occasional *Billingsaria*-like vertical axial trabecula is seen ; thus three specimens from Fossil Hill are all different in character : as these are the only three *Nyctopora* specimens I have from Fossil Hill, I cannot be certain whether they represent variations within one species or not.

One specimen (Aust. Mus. F 46752, with sections A.M. 6148 and 6149 on one slide) from a horizon a little higher than that of Fossil Hill (the "Large Flat" Limestone of Öpik) has corallites 1 mm. in diameter, that show thicker septa than the holotype ; one or two corallites have a columella as in *Billingsaria*.

Of the North American species figured by Bassler (1950) ours very closely resembles *N. crenulata* from the Trentonian. *Nyctopora* in North America occurs

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* "On a lithological basis, the Cliefden Caves Limestone may be divided into two members—a lower shaly limestone and an upper massive limestone. The lower member has a thickness of 480 feet on the eastern side of The Large Flat. Öpik (MS.) has suggested that this lower member may be divided, calling the lower part the Davy's Creek limestone and the upper part the Large Flat limestone". (Note by N. C. Stevens.)

rarely in the Chazy, more commonly in Black River and Trenton strata. In Europe it is rare in the 4βδ (*D. clingani* zone) Mjosa limestone and in *5a* (*D. anceps* zone).

Subfamily **Syringophyllinæ** Počta, 1902.

Genus **Calapoecia** Billings, 1865.

Calapoecia aff. canadensis Billings, 1865. (Pl. III, figs. 14*a*, 14*b*.)

Material. University of Queensland F 23224, Stevens Collection from Por. 41, Par. Boree Cabonne, Co. Ashburnham south of Cudal, New South Wales, Middle or Upper Ordovician.

The genus and species have been described in detail by Cox (1936). The genus ranges (Sinclair, 1956) from the Black River into the Richmond in North America, Arctic Canada and Greenland and from *5a* into *5b* in Norway ; it occurs in the upper *Leptæna* (Boda) Limestone of Sweden, and in the Middle Tunguska, Siberia. In Estland it is known in the Lyekholm and possibly also the Borkholm Beds. It is not known in the British Isles. *C. canadensis* has a similar range but it is not known from *5b*.

Cox's full description, being readily available, obviates any need for description of this New South Wales specimen. The 20 equal septa are sufficient to distinguish the form from the Heliolitidæ, with which it might at first be confused.

Family **Heliolitidæ** Lindström, 1876.

Subfamily **Coccoseridinæ** Kiær, 1899.

Genus **Coccoseris** Eichwald, 1855. (Hill, 1953, p. 163.)

Coccoseris speleana sp. nov. (Pl. III, figs. 13*a*, 13*b*.)

Holotype. Aust. Mus. F 46754 (with thin sections A.M. 6152 and 6153) from Öpik's " Large Flat " limestone (see footnote on p. 100), Cliefden Caves Limestone, The Large Flat, near Mandurama, New South Wales. Middle Ordovician.

Diagnosis. Growth form tabular ; tabularia 2·5 mm. diameter with axial non-septate region 1 mm. diameter containing two or three thick monacanthine trabeculæ.

Description. The corallum is flat, pancake-like, about 10 mm. high. The tabularia are about 2·5 mm. in diameter, with an outer septate zone in which the 12 septa are so thick as to be contiguous, and an inner non-septate zone about 1 mm. in diameter ; rising from the bottom of the corallite, in this axial region, are thick monacanthine trabeculæ diverging gently outwards from the axis, two or three being cut in any transverse section. The trabeculæ in the septa are seen to be directed upwards and inwards. The cœnenchyme consists of monacanthine trabeculæ so thick and contiguous as to leave no spaces ; usually 2 or more of these trabeculæ separate the septa of neigbouring corallites.

Remarks. *Coccoseris* with its characteristic thick monacanthine trabeculæ is known so far from 4βδ and *5a* in Norway ; in Tasmania the species *C. ramosa* Hill (1955, p. 249) occurs at Ida Bay.

Coccoseris sp. (Pl. IV, fig. 20.)

One specimen from University of Queensland F 23232, Bowan Park Limestone, Por. 289, Par. Bowan, with structure much obscured by silicification and staining, has corallites with aseptate regions about 0·5 mm. in diameter and a similar distance apart, with trabeculate columellæ. The cœnenchyme appears to consist of thick monacanthine trabeculæ in contact, so that the specimen is probably a *Coccoseris*. Its proportions, however, do not correspond with any known Australian species. Middle or Upper Ordovician or possibly lower Silurian.

Subfamily **Palæoporitinæ** Kiær, 1899.

Genus **Palæoporites** Kiær, 1899.

Palæoporites serratus sp. nov. (Pl. IV, fig. 24.)

Holotype. University of Queensland F 23226 from Regan's Creek limestone 3 miles south-east of Cargo, New South Wales. Middle or Upper Ordovician, or possibly Lower Silurian.

Description. The corallum is small and nodular, diameter of only specimen known being 10 mm. The tabularia are 1·5 mm. in diameter, the septate portion having a radius of 0·5 mm., so that the axial space without septa is about 0·5 mm. in diameter also ; in this axial space a trabeculate columella rises but does not fill it. A cœnchyme of one row of open tubules may be present. The septa have serrated edges due to the projection of small rod-like trabeculæ which do not appear to be arranged about single axes in the mid-plane of the septum, and thus are not parts of rhabdacanths ; they appear, however, to be directed up towards the axis of the corallites, but also to curve outwards on either side from the median plane of the septum. I have no certainty that there are spaces left through the septa as described by Kiær, but such would seem to be the case. The material is somewhat silicified and hence the structure is partly obscured. The walls of the tubuli also are serrate like the septa.

This rare genus is known so far only from Estland and New South Wales· It is referred to F_2 in Estland, now regarded as early Silurian.

Subfamily **Plasmoporinæ** Wentzel, 1895.

Genus **Propora** Edwards and Haime, 1849.

Propora mammifera sp. nov. (Pl. III, figs. 9–12.)

Holotype. S.U. 8227, Fossil Hill, Cliefden Caves, near Mandurama, New South Wales, lowest part of Cliefden Caves Limestone. Middle Ordovician.

Diagnosis. Cœnenchyme sagging between tabularia 1·5 mm. wide bounded by 12 thick monacanthine trabeculæ and 12 alternating smaller trabeculæ.

Description. The holotype corallum consists of three successive plate-like expansions each up to 10 mm. high, with tabularia about 1·5 mm. in diameter set in contact or up to 1·5 mm. apart, mostly about 0·5 mm. apart, in cœnenchyme consisting of blister-like dissepiments, the growing surfaces of the cœnenchyme sagging slightly between the tabularia ; cœnenchymal trabeculæ are rare, and seem related to the growth of new corallites. Each tabularium is defined by a more or less thick and continuous wall consisting of 12 large trabeculæ representing the 12 septa of the Heliolitidæ, and 12 intervening fibrous links (? trabeculæ), though in few cases can the count be made with precision owing to the variability in size of the trabeculæ : in some tabularia the 12 large septal trabeculæ are separated by spaces, not by fibrous links. The tabulæ are sagging, rather close, and may be incomplete.

Remarks. One other specimen of *Propora* has been found at Fossil Hill, and shows some differences from the type, so that I am uncertain whether it is a variant of the species, or a separate species. It has tabularia 1·25 mm. in average diameter set rather regularly 0·5 mm. apart, with walls consisting of 12 clearly and equally developed large septal trabeculæ which in only a few tabularia are separated by fibrous links, and these are very narrow ; cœnenchymal trabeculæ are absent, the tabulæ are domed rather than sagging, and the dissepiments of the cœnenchyme are regular and rather globose.

S.U. 9353, from the top of the Cliefden Caves Limestone under the Malongulli Formation at Trilobite Hill, Belubula River, has tabularia 2·5 mm. in diameter about 1 mm. apart, the walls consisting of 12 compound trabeculæ each thickened wedgewise, the sharp end of the wedge projecting axially, and of narrow intervening fibrous links (? trabeculæ). A vertical series of upwardly and inwardly directed trabeculæ is seen in vertical section to form the sharp end of the wedge. Vertical cœnenchymal trabeculæ are common, thinner than the 12 septa, and in some places apparently grouped to form tubuli; the tabulæ are close and very slightly domed. This may well be a species distinct from *P. mammifera*.

S.U. 9125 from the east side of The Large Flat, probably at a higher horizon than most of the other coral beds, has tabularia 1·5 to 2 mm. in diameter in contact or 0·5 mm. apart, with 12 septa thickened wedgewise and with fibrous links between them; the cœnenchyme may have tubuli in places, in others the trabeculæ are not grouped.

Propora bowanensis sp. nov. (Pls. III, IV, figs. 15, 16, 17*a*, 21, 22*a*.)

Holytype. S.U. 9350, Bowan Park, Por. 289, Par. Bowan Co. Ashburnham, north of Cargo, in algal limestone. Middle or Upper Ordovician or possibly Lower Silurian.

Diagnosis. Tabularia 0·8 mm. to 1 mm. in diameter set 0·5 mm. apart; walls with 12 septa united by fibrous links; tabulæ sagging a little.

Description. The corallum is small and nodular, 10 to 15 mm. in diameter. Tabularia are 0·75 to 1 mm. in diameter, commonly 0·8 mm., set commonly 0·5 mm. apart but occasional neighbours are in contact. In the holotype the tabularial walls consist of 12 scarcely to be distinguished septa with links of fibrous tissue, forming more or less smooth cylinders; in a second specimen in the same thin section as the holotype, the 12 septa project inwards from the walls, and the smooth appearance is lost and the septa are sharply bounded. The dissepiments of the cœnenchyme are commonly in two series between tabularia and the tabulæ may be horizontal, slightly sagging or slightly domed. No discrete trabeculæ are visible in the cœnenchyme, except where new corallites are forming.

Remarks. I was in considerable doubt whether the specimens with smooth-walled tabularia are conspecific with those with rough walls and long septa, but in the three limestones from which I have specimens, both types occur together, so I conclude that they are conspecific. These limestones are a grey algal and a yellow-brown from Bowan Park (por. 289) and a yellow-brown from Regan's Creek, 3 miles south-east of Cargo, New South Wales.

Propora sp. (Pl. IV, fig. 29*a*, 29*b*.)

Material. University of Queensland F 23244 and possibly also University of Queensland F 23258–9, Canomodine Limestone, New South Wales. Upper Ordovician or Lower Silurian.

Description. The corallum is large, the tabularia relatively small and distant being on the average 1 mm. in diameter and 1 mm. apart. The 12 moderately thick septa are joined by curved or angulate links and there may be short trabecular projections into the cœnenchyme from the septa or the links. The cœnenchyme is fine-tissued, with closely packed, small globose dissepiments and an occasional discrete trabecula. The tabulæ are gently sagging, gently domed or horizontal.

Remarks. Specimen University of Queensland F 23244 is not unlike the small nodular *Propora* from the Bowan Park Limestone (University of Queensland F 23254–6) in internal structure but its massive growth habit is very different. University of Queensland F 23258–9 are generally greatly distorted but may well be conspecific with F 23244.

Genus **Plasmoporella** Kiær, 1897, 1899.

Plasmoporella inflata sp. nov. (Pl. IV, fig. 26*a*, 26*b*, 28*a*, 28*b*.)

Holotype. University of Queensland F 23237, Cargo Creek Limestone, near top, Cargo Creek, New South Wales. Upper Ordovician or Lower Silurian.

Diagnosis. Tabularia 1·5–2 mm. in diameter and closely spaced with inflated (domed) tabulæ, and with the 12 septa commonly projecting into the cœnenchyme of small globose dissepiments.

Description. The corallum is sub-hemispherical with tabularia 1·5 to 2 mm. in diameter, the higher figure being commoner, set about 0·5 mm. apart, though some may be in contact, and others 0·75 to 1 mm. apart. The tabularial walls in the holotype are complete cylinders, composed of 12 septa projecting a little into the tabularia and in some into the cœnenchyme also, connected by curved links usually unthickenend. The cœnenchyme consists of small globose dissepiments but the short projections into it of the septa appear in sections tangential to tabularia as vertical lines dividing the dissepiments. The most notable feature of the species is, however, the general inflation or low doming of the tabulæ.

Remarks. A second specimen, identical with the holotype, occurs with it in the Cargo Creek Limestone, near the top. Several specimens from the Canomodine Limestone much distorted by compressive forces and somewhat recrystallized, could belong to this species, though there appear to be imperfect tubuli in places in their cœnenchyme, and septal projections into the cœnenchyme are fewer; the moderately domed characteristic tabulæ are present, and the diameter and spacing of the tabularia are similar.

In Norway *Plasmoporella* is found in the 5*a* Gastropod Limestone; in Southern Lapland in the Slatdal Limestone regarded by Kulling as a 5*b* equivalent. In Tasmania two species occur, one with very fine-tissued, closely packed dissepimental cœnenchyme, in limestones at the head of the Nelson River, and at Bubb's Hill, being Middle or Upper Ordovician; the other, comparable with the type species, occurs in the Chudleigh Limestone, and is probably Upper Ordovician. *Camptolithus* Lindström, regarded as a synonym of *Plasmoporella*, occurs in the Niagaran of U.S.A.

Genus **Plasmopora** Edwards and Haime, 1849.

Plasmopora cargoensis sp. nov. (Pl. IV, fig. 25, 27.)

Holotype. University of Queensland F 23238, Cargo Creek Limestone, near top, New South Wales. Upper Ordovician or Lower Silurian.

Diagnosis. Small globular or nodular coralla, tabularia 0·75 mm. set 0·5 to 0·75 mm. apart in a fine tubular cœnenchyme.

Description. The corallum is globular or nodular and small, the holotype being 20 mm. in diameter. The tabularia diverge towards the surface and are on the average about 0·75 mm. in diameter set from 0·25 to 0·75 mm. apart, more commonly the latter. Each tabularium has a more or less smoothly cylindrical wall from which very short septal spines project slightly inwards. The cœnenchyme consists of small vertical tubuli crossed by horizontal plates; 12 tubuli not different in size and shape form an aureole round each tabularium, the 12 radial partitions between them being continuous with the 12 septa. The tabulæ are horizontal and rather distant.

Remarks. *Plasmopora* is not known overseas in strata older than Llandovery, nor younger than Middle Devonian. This Cargo species is of the *P. heliolitoides* Lindström group, in which the tubuli of the aureole are not distinguished by size and shape from the remainder. Unless the aureolar tubuli are counted, the species could easily be mistaken for *Heliolites*, which, however, has more than 12 tubuli in a ring round each tabularium.

One specimen, F 23260 University of Queensland from the Canomodine Limestone has the same proportions as *P. cargoensis*, but owing to the recrystallization which has affected it, it is not possible to count the tubuli in the aureole with any certainty.

Subfamily **Heliolitinæ** Lindström, 1876.

Genus **Heliolites** Dana, 1846.

Heliolites digitalis sp. nov. (Pl. IV, fig. 18.)

Holotype. 9397 Sydney University Collection, Bowan Park Limestone, Por. 289, Par. Bowan, Co. Ashburnham north of Cargo, New South Wales. Middle or Upper Ordovician or early Silurian.

Diagnosis. Slender, fingerlike coralla with tabularia 0·5 mm. wide, about 0·75 mm. apart, in a fine tubular cœnenchyme.

Description. The coralla are slender and fingerlike, about 6 mm. in diameter and possibly branching, or with protuberances. The tabularia are small (0·5 mm. in diameter) with rather smoothly rounded walls from which 12 very small septa may project inwards; the cœnenchyme is very finely tubulate, and there are more than 12 tubuli immediately surrounding each tabularium. The tubuli are polygonal in transverse section. The tabulæ are horizontal and distant, and the dissepiments also.

Remarks. In Europe and North America *Heliolites* is not known before the Lyckholm beds of the Island of Worms (=5*a*).

A specimen University of Queensland F 23233 (Pl. III, fig. 19) from Bowan Park is encrusting, has slightly larger corallites than typical *H. digitalis*; it has also been partially silicified and is placed doubtfully in *H. digitalis*. Several corallites appear to have a columella as in *H. interstinctus*.

Family **Auloporidæ** Edwards and Haime, 1851

Genus **Eofletcheria** Bassler, 1950 (see Hill, 1954).

Eofletcheria gracilis sp. nov. (Pl. IV, figs. 17*b*, 22*b*).

Holotype. F 23253 University of Queensland Collection, Bowan Park, Por. 289, Par. Bowan, Co. Ashburnham, north of Cargo, New South Wales. Middle or Upper Ordovician or early Silurian.

Corallum of erect branches 2 to 3 mm. in diameter, with 7 to 12 corallites 0·5 to 0·75 mm. in diameter growing vertically for several mm. before opening outwards.

Description. The corallum is of erect and slender branches 2 to 3 mm. in diameter only, consisting of several (7 to 12) corallites running axially for some distance and then opening outward rather obliquely. Mutual walls between corallites are thick, $\frac{1}{3}$ to $\frac{1}{2}$ the diameter of the corallite, and are without mural pores; no septal spines have been observed. Tabulæ are distant, slightly sagging. Many of the fragments of branches are enclosed in polyzoan overgrowths.

Remarks. This is a more slenderly branching species than the Norwegian and Tasmanian representatives of the genus, which are Middle and Upper Ordovician. In addition to the type locality it occurs in the Regan's Creek Limestone 3 miles south-east of Cargo, with similar associates.

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EXPLANATION OF PLATES.

All figures enlarged by approximately 1·8 diameters.

PLATE II.

CLIEFDEN CAVES LIMESTONE, NEAR MANDURAMA—MIDDLE ORDOVICIAN.

Fig. 1.—*Tetradium cribriforme* (Etheridge), central western New South Wales. Lectotype, Australian Museum F 13579 (A.M. 817), Limestone in Parish of Malongulli, on the bank of the Belubula River, about 18 miles due south of the Canobolas Mountains. (Cliefden Cave Limestone, *fide* N.C.S.) Thin sections.

Fig. 2.—*Tetradium cribriforme* University of Queensland F 23221*b*. Fossil Hill, near Cliefden Caves from lowest 50 ft. of Limestone. Transverse section. Note corallites with four septa, near edge of figure.

Fig. 3.—*Tetradium cribriforme* University of Queensland F 23220c. Fossil Hill, near Cliefden Caves from lowest 50 ft. of Limestone. Transverse section. Note clear calcite within the matrix between corallites.

Fig. 4.—*Tetradium cribriforme* University of Queensland F 23216*b*. Fossil Hill, near Cliefden Caves from lowest 50 ft. of Limestone. Vertical section. Note connecting processes or rings.

Fig. 5*a*, *b*.—*Billingsaria banksi* Hill Aust. Mus. F 46753, "Large Flat" limestone (of Öpik); horizon above that of Fossil Hill; *a* transverse (A.M. 6150), *b* vertical (A.M. 6151) section.

Fig. 6*a*, b.—*Nyctopora stevensi* sp. nov. Holotype. University of Queensland F 23214*e*, *f*, Fossil Hill, near Cliefden Caves, from lowest 50 ft. of Limestone; *a*, transverse, *b*, vertical sections.

Fig. 7*a*, *b*.—*N. ? stevensi* Sydney University 9289. Fossil Hill, near Cliefden Caves from lowest 50 ft. of limestone; thin sections.

Fig. 8*a*, *b*.—*N. ? stevensi* Aust. Mus. F 46752, "Large Flat" limestone (of A. Öpik); horizon above that of Fossil Hill; thin sections (A.M. 6148–9).

PLATE III.

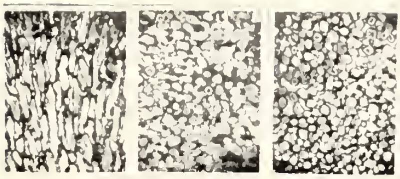
CLIEFDEN CAVES LIMESTONE, NEAR MANDURAMA—MIDDLE ORDOVICIAN.

Fig. 9*a*. *b*.—*Propora mammifera* sp. nov. Holotype, Sydney University 8227. Fossil Hill, near Cliefden Caves, from lowest 50 ft. of limestone; *a*, transverse, *b*, vertical sections.

Fig. 10*a*, *b*.—*P. mammifera* University of Queensland F 23245. Fossil Hill, near Cliefden Caves *a*, transverse, *b*, vertical sections.

Fig. 11.—*P. ? mammifera* Sydney University 9125. Eastern side of The Large Flat near Cliefden Caves probably at a higher horizon than most of the coral beds. Transverse section.

Fig. 12*a*, *b*.—*P. ? mammifera* Sydney University 9353, at top of limestone under the Malongulli Formation, Trilobite Hill, Belubula River, New South Wales *a* transverse, *b*, vertical section.



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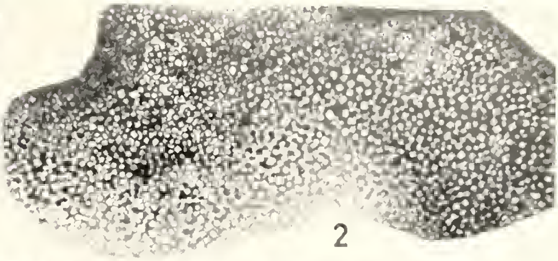

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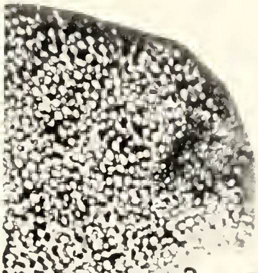

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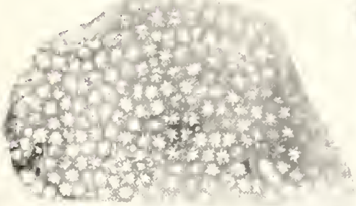

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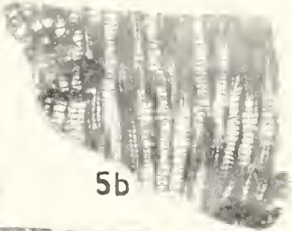

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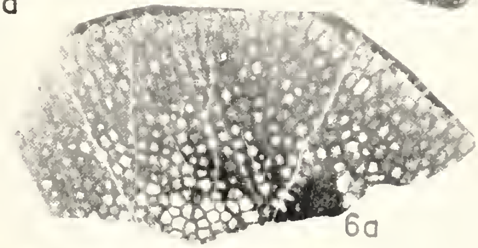

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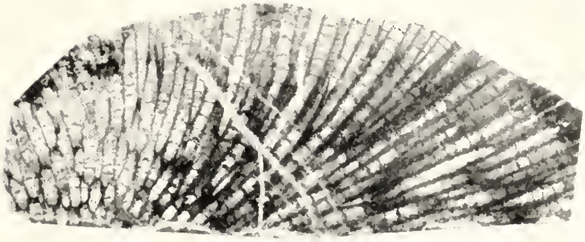

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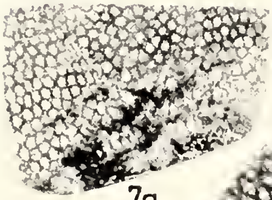

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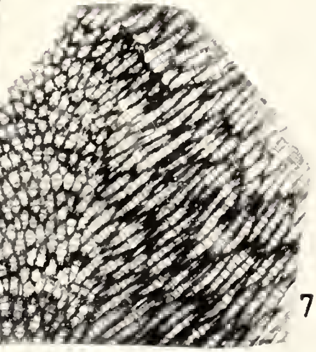

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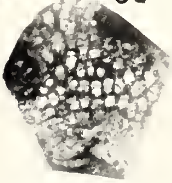

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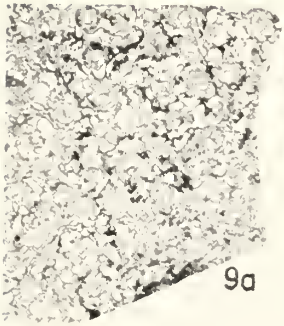
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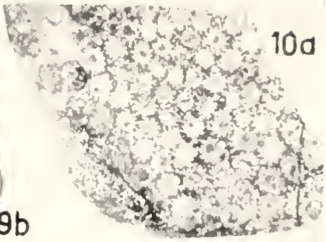
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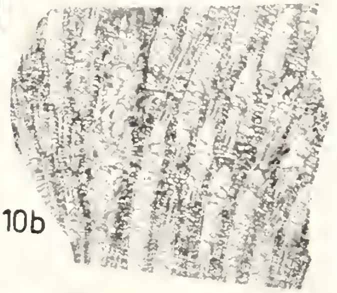
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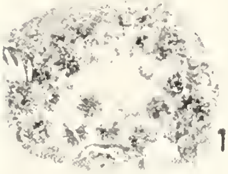
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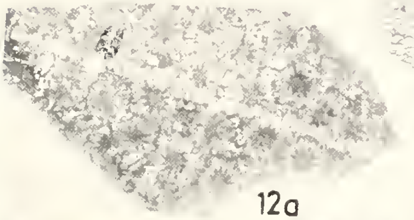
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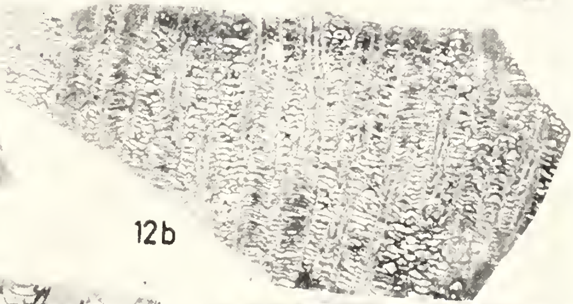
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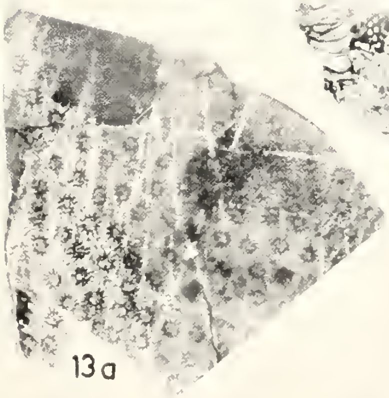
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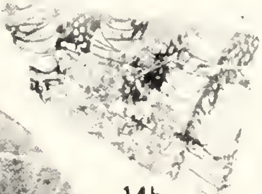
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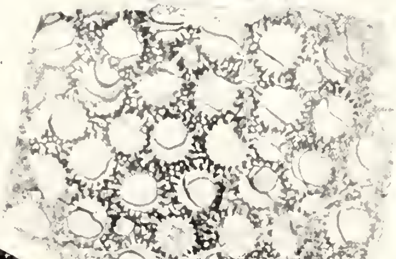
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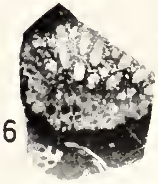
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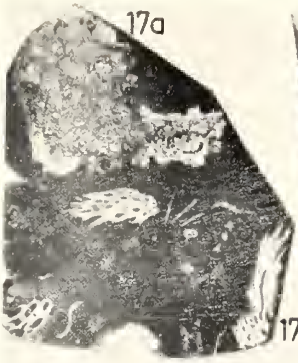
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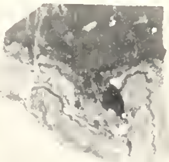

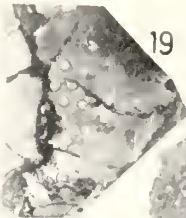
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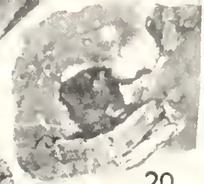
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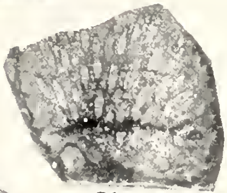
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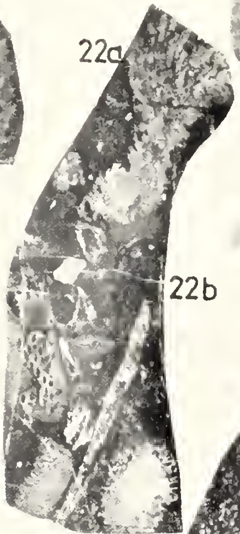
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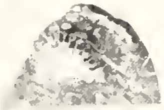
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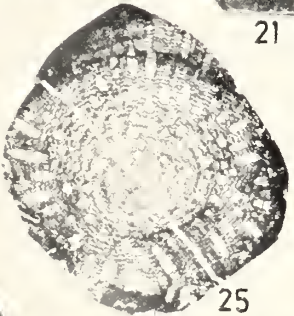
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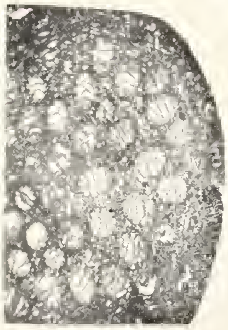
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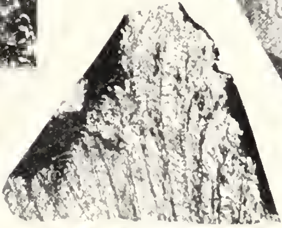
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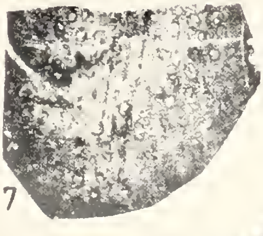
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29a

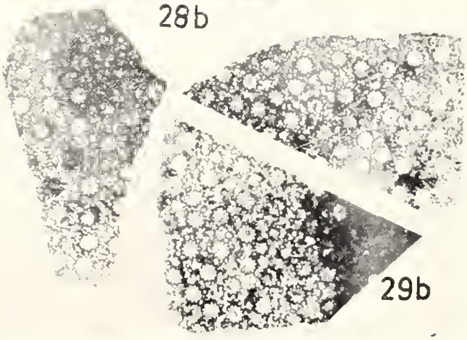
29b

Fig. 13*a*, *b*.—*Coccoseris speleana* sp. nov. Holotype, Aust. Mus. F 46754. The " Large Flat " limestone (of Öpik), horizon above that of Fossil Hill ; *a*, transverse (A.M. 6152). *b*. vertical (A.M. 6153) sections.

Por. 41.—Parish Boree Cabonne, south of Cudal. Middle or Upper Ordovician.

Fig. 14*a*, *b*.—*Calapoecia* aff. *canadensis* Billings, University of Queensland F 23224 ; *a*, transverse, *b*, vertical section.

Bowan Park Limestone, Por. 289, Par. Bowan, Middle or Upper Ordovician, or possibly early Silurian.

Fig. 15.—*Propora bowanesis* sp. nov. Holotype, Sydney University 9350. Bowan Park.

Fig. 16.—*Propora bowanenis* University of Queensland F 23252*b*. Bowan Park ; thin section.

Plate IV.

Bowan Park Limestone, Por. 289, Par. Bowan, North of Cargo—Middle or Upper Ordovician or Lower Silurian.

Fig. 17*a*.—*Propora bowanensis* sp. nov. University of Queensland F 23255*b*. Bowan Park ; thin section.

Fig. 17*b*.—*Eofletcheria gracilis* sp. nov. Holotype, University of Queensland F 23253*b*. Bowan Park ; thin sections.

Fig. 18.—*Heliolites digitalis* sp. nov. Holotype, Sydney University 9397. Bowan Park : thin section.

Fig. 19.—*Heliolites ? digitalis* sp. nov. University of Queensland F 23233. Bowan Park ; thin sections.

Fig. 20.—*? Coccoseris* sp. University of Queensland F 23232*b*. Bowan Park ; thin section.

Regan's Creek Limestone, 3 miles south-east of Cargo, New South Wales. Middle or Upper Ordovician or Lower Silurian.

Fig. 21—*Propora bowanensis* sp. nov. University of Queensland F 23227*b*. Thin section.

Fig. 22*a*.—*Propora bowanensis* sp. nov. University of Queensland F 23230*b*. Thin section.

Fig. 22*b*.—*Eofletcheria gracilis* sp. nov. University of Queensland F 23229*b*. Thin sections.

Fig. 22*c*.—*? Lichenaria* sp. University of Queensland F 23228*b*. Thin transverse section.

Fig. 23.—*? Lichenaria* sp. University of Queensland F 23228*c*. Thin vertical section.

Fig. 24.—*Palæoporites serratus* sp. nov. Holotype, University of Queensland F 23226*b*. Thin section.

Cargo Creek Limestone (near top), south of Cargo. Upper Ordovician or Lower Silurian.

Fig. 25.—*Plasmopora cargoensis* sp. nov. Holotype, University of Queensland F 23238*b*. Thin section.

Fig. 26*a*, *b*. *Plasmoporella inflata* sp. nov. Holotype, University of Queensland F 23237 ; *a*, transverse, *b*, vertical thin sections.

Canomodine Limestone, south of Cargo, Upper Ordovician or Lower Silurian.

Fig. 27.—*? Plasmopora ? cargoensis* sp. nov. University of Queensland F 23260. Thin section.

Fig. 28*a*, *b*.—*? Plasmoporella ? inflata* sp. nov. University of Queensland F 23239 ; *a*, transverse, *b*, vertical thin sections.

Fig. 29.—*Propora* sp. University of Queensland F 23244 ; *a*, transverse, *b*, vertical section.

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A

BOUNDARY STRESSES IN AN INFINITE HUB OF SPECIAL SHAPE.

By Alex Reichel.

With four Text-figures.

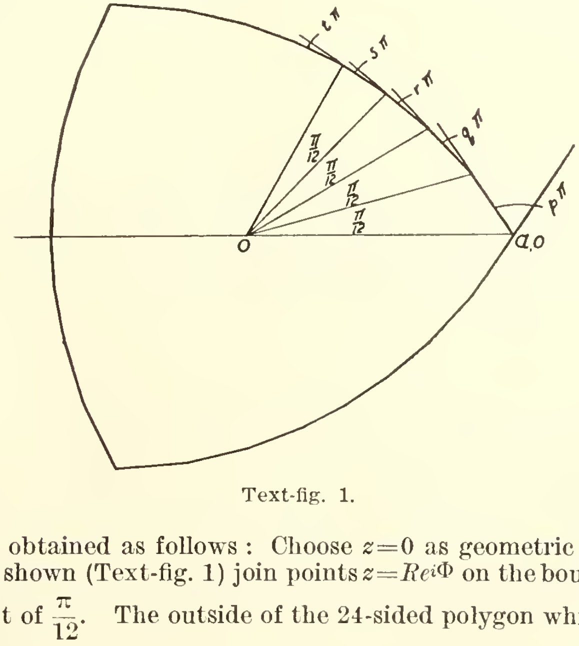
Manuscript received, June 5, 1957. Read, August 7, 1957.

Introduction.

This paper makes use of the notation and results of Muskhelishvili (1953) to find the stresses on the boundary of a hub, considered as an infinite plane with a hole in the shape of an equiangular curvilinear triangle. The stresses are caused by a moment, applied to a rigid kernel fitted into the hole. Muskhelishvili solves the fundamental problem of plane elasticity when the stresses are given on the boundary for the case of a finite region mapped on to unit circle by a polynomial. The general method used here is a modification of the above method for the case of an infinite region when the displacements are given on the boundary, and when the infinite region is mapped onto unit circle by a function of the form $z=\frac{c_0}{\zeta}+c_1\zeta+c_2\zeta^2+\dots$

The Conformal Transformation.

Each of the circular arcs forming the sides of the curvilinear triangle has the opposite corner as centre. A function of the desired form which maps the infinite region in the z-plane onto unit circle in the ζ-plane in an approximate manner can be obtained as follows: Choose $z=0$ as geometric centre, and with the orientation shown (Text-fig. 1) join points $z=Re^{i\Phi}$ on the boundary, separated by an argument of $\frac{\pi}{12}$. The outside of the 24-sided polygon which results can be



Text-fig. 1.

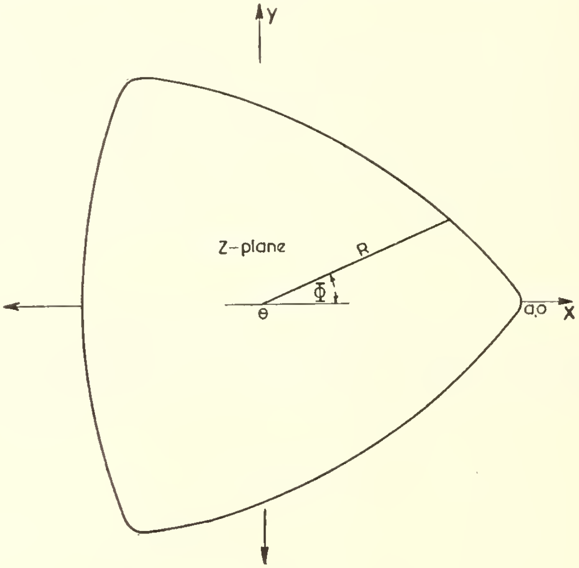
mapped on to the inside of the unit circle by the Schwarz-Christoffel formula. The sizes of the exterior angles shown are $p\pi$, $q\pi$, $r\pi$, $s\pi$, $t\pi$ where $p=0\cdot38388$, $q=0\cdot04660$, $r=0\cdot04030$, $s=0\cdot03673$, $t=0\cdot03546$ and

$$3p+6q+6r+6s+3t \doteqdot 2.$$

The Schwarz-Christoffel formula then gives

$$z=-A\int_{\zeta_0}^{\zeta}\frac{(1-x^3)^p(1+x^3)^t(1+x^6)^r(1-\sqrt{2}x^3+x^6)^q(1+\sqrt{2}x^3+x^6)^s dx}{x^2}$$

where $\zeta=\rho e^{i\theta}$ and ζ_0 is so chosen that the integral vanishes at the lower limit. A is a constant which can be used to alter the size and orientation of the hole.



Text-fig. 2.

By expanding and integrating term by term, a rapidly convergent series results. By truncating the series after five terms and choosing A so that the radius of the circumscribed circle of the hole will be a, we obtain

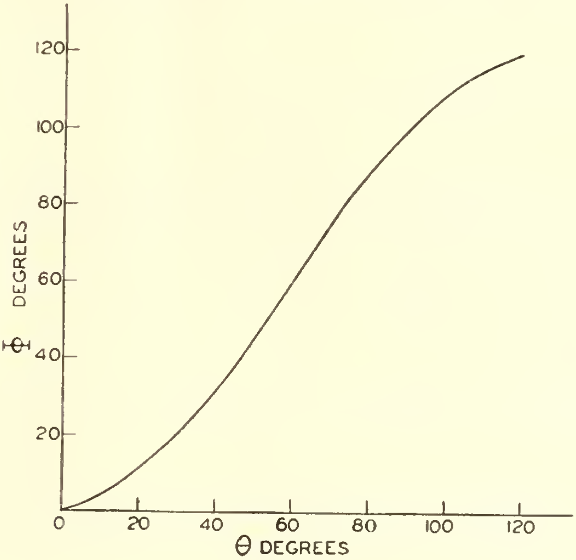
$$z=\omega(\zeta)=a\left\{\frac{0\cdot825}{\zeta}+0\cdot149\zeta^2+0\cdot017\zeta^5+0\cdot006\zeta^8+0\cdot003\zeta^{11}\right\}.$$

By plotting the curve whose parametric equations are

$$x=a\{\ \ 0\cdot825\cos\theta+0\cdot149\cos 2\theta+0\cdot017\cos 5\theta+0\cdot006\cos 8\theta+0\cdot003\cos 11\theta\}$$
$$y=a\{-0\cdot825\sin\theta+0\cdot149\sin 2\theta+0\cdot017\sin 5\theta+0\cdot006\sin 8\theta+0\cdot003\sin 11\theta\}$$

we see (Text-fig. 2) that the area mapped onto unit circle approximates the equiangular curvilinear triangle, the greatest error in R being about 3%. A rounding off of sharp corners has occurred, the radius of curvature at $\Phi=0$ (corresponding to $\theta=0$) being $0\cdot05$.

As ζ moves around unit circle anti-clockwise, z moves around the boundary of the region clockwise. The relation between angles Φ in the z-plane and angles θ in the ζ-plane are shown in Text-figure 3. Remembering the sign difference, we show positive Φ corresponding to positive θ.



Text-fig. 3.

THE BOUNDARY CONDITION.

The boundary condition for the fundamental problem of plane elasticity when the displacements on the boundary of the region are given may be represented in complex form by

$$\varkappa\varphi_1(z)-z\overline{\varphi_1'(z)}-\overline{\psi_1(z)}=2\mu(g_1+ig_2) \text{ on } L \quad \ldots\ldots\ldots \quad (1)$$

where L is the contour enclosing the region considered in the complex z-plane, $\varphi_1(z)$ and $\psi_1(z)$ are arbitrary functions arising from the solution of the bi-harmonic equation, μ is the shear modulus, and $\varkappa=3-4\sigma$ (σ being Poisson's Ratio); $g_1=g_1(s)$ and $g_2=g_2(s)$ are the given displacements of points on the contour L.

If the region in the z-plane is mapped onto unit circle in the ζ-plane by a transformation $z=\omega(\zeta)$, the boundary condition may be rewritten as

$$\varkappa\varphi(\sigma)-\frac{\omega(\sigma)}{\overline{\omega'(\sigma)}}\overline{\varphi'(\sigma)}-\overline{\psi(\sigma)}=2\mu(g_1+ig_2)=2\mu g \text{ on } \gamma \quad \ldots\ldots \quad (2)$$

where γ is unit circle in the ζ-plane and $\sigma=e^{i\theta}$; g_1 and g_2 have the same value as in (1) but are referred to the angle θ.

GENERAL METHOD OF SOLUTION.

The mapping function $z=\omega(\zeta)$ is such that $\omega'(\zeta)\neq 0$ inside or on γ. We have to find functions $\varphi(\zeta)$, $\psi(\zeta)$ satisfying (2). Since the region to be considered is an infinite region we assume that the stresses at infinity vanish. We assume also that the resultant vector of the external forces applied to the boundary of the region vanish, so that $\varphi(\zeta)$ and $\psi(\zeta)$ are holomorphic inside and on γ. The state of stress is unaltered if we assume $\varphi(0)=0$.

Taking the conjugate of (2), we have

$$\varkappa\overline{\varphi(\sigma)}-\frac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\varphi'(\sigma)-\psi(\sigma)=2\mu(g_1-ig_2)=2\mu\bar{g} \quad \ldots\ldots \quad (3)$$

Rewriting (2) in the form

$$\overline{\psi(\sigma)}=\varkappa\varphi(\sigma)-\frac{\omega(\sigma)}{\overline{\omega'(\sigma)}}\overline{\varphi'(\sigma)}-2\mu g \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

and denoting the right-hand side of (4) by $\overline{G(\sigma)}$ we note that $G(\sigma)$ represents the boundary value of a function $\psi(\zeta)$ holomorphic inside γ. The necessary and sufficient condition for this to be true is

$$\frac{1}{2\pi i}\int_\gamma \frac{\overline{G(\sigma)}}{\sigma-\zeta}d\sigma=\bar{a} \text{ for all } \zeta \text{ inside } \gamma \quad \ldots\ldots\ldots\ldots \quad (5)$$

where $\bar{a}=\overline{G(0)}=\overline{\psi(0)}$ (i.e. $a=\psi(0)$).

Thus, substituting in (5) from the right-hand side of (4) we have

$$\frac{1}{2\pi i}\int_\gamma \frac{\varkappa\varphi(\sigma)}{\sigma-\zeta}d\sigma-\frac{1}{2\pi i}\int_\gamma \frac{\omega(\sigma)}{\overline{\omega'(\sigma)}}\,\frac{\overline{\varphi'(\sigma)}}{\sigma-\zeta}d\sigma-\frac{1}{2\pi i}\int_\gamma \frac{2\mu g}{\sigma-\zeta}d\sigma=\bar{a}$$

Thus we obtain the functional equation

$$\varkappa\varphi(\zeta)-\frac{1}{2\pi i}\int_\gamma \frac{\omega(\sigma)}{\overline{\omega'(\sigma)}}\,\frac{\overline{\varphi'(\sigma)}}{\sigma-\zeta}d\sigma-\bar{a}=\frac{2\mu}{2\pi i}\int_\gamma \frac{g\,d\sigma}{\sigma-\zeta} \quad \ldots\ldots\ldots \quad (6)$$

It will be seen that (6) completely determines $\varphi(\zeta)$ as well as $\bar{a}$. Having found $\varphi(\zeta)$ we can obtain $\psi(\zeta)$ directly from (3). $\psi(\sigma)$ is the boundary value of the function $\psi(\zeta)$ holomorphic inside γ, so that

$$\psi(\zeta)=\frac{1}{2\pi i}\int_\gamma \frac{\psi(\sigma)d\sigma}{\sigma-\zeta}$$

Substituting from (3) we have

$$\psi(\zeta)=-\frac{2\mu}{2\pi i}\int_\gamma \frac{\bar{g}\,d\sigma}{\sigma-\zeta}-\frac{1}{2\pi i}\int_\gamma \frac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\,\frac{\varphi'(\sigma)}{\sigma-\zeta}d\sigma \quad \ldots\ldots \quad (7)$$

remembering that

$$\frac{\varkappa}{2\pi i}\int_\gamma \frac{\overline{\varphi(\zeta)}}{\sigma-\zeta}d\sigma=\varkappa\overline{\varphi(0)}=0.$$

SOLUTION IN THE SPECIAL CASE

The problem will be solved for the special case when the mapping function has the form

$$z=\omega(\zeta)=a\left\{\frac{0\cdot825}{\zeta}+0\cdot149\zeta^2+0\cdot017\zeta^5+0\cdot006\zeta^8+0\cdot003\zeta^{11}\right\}.$$

Towards solving (6) we note that $\dfrac{\overline{\omega(\sigma)}}{\omega'(\sigma)}$ is the boundary value of the rational function

$$\frac{\omega(\zeta)}{\overline{\omega}'\left(\dfrac{1}{\zeta}\right)}=\zeta^9\left\{\frac{0\cdot825+0\cdot149\zeta^3+0\cdot107\zeta^6+0\cdot006\zeta^9+0\cdot003\zeta^{12}}{-0\cdot825\zeta^{12}+0\cdot298\zeta^9+0\cdot085\zeta^6+0\cdot048\zeta^3+0\cdot033}\right\}$$

$$=-\{0\cdot004\zeta^9+0\cdot008\zeta^6+0\cdot024\zeta^3+0\cdot190\}+\text{terms in }\frac{1}{\zeta^3},\ \frac{1}{\zeta^6}\ .\ .\ .\ \text{etc.} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

which is holomorphic outside γ except at $\zeta=\infty$, where it has a pole of order 9.

Now $\varphi(\zeta)$ is holomorphic inside γ, so that $\overline{\varphi'(\sigma)}$ is the boundary value of $\overline{\varphi}'\left(\dfrac{1}{\zeta}\right)$, holomorphic outside γ. Hence

$\dfrac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\overline{\varphi'(\sigma)}$ is the boundary value of

$\dfrac{\omega(\zeta)}{\overline{\omega}'\left(\dfrac{1}{\zeta}\right)}\overline{\varphi}'\left(\dfrac{1}{\zeta}\right)$, holomorphic outside γ except at $\zeta=\infty$, where it has a pole of order 9.

Assuming $\varphi(\zeta)=a_1\zeta+a_2\zeta^2+.\ .\ .+a_n\zeta^n+.\ .\ .$ in $|\zeta|<1$, then

$$\overline{\varphi}'\left(\frac{1}{\zeta}\right)=\bar{a}_1+\frac{2\bar{a}_2}{\zeta}+.\ .\ .+\frac{n\bar{a}_n}{\zeta^{n-1}}+.\ .\ .\quad \text{for } |\zeta|>1.$$

Therefore, in the present case, for $|\zeta|>1$

$$\frac{\omega(\zeta)}{\overline{\omega}'\left(\dfrac{1}{\zeta}\right)}\overline{\varphi}'\left(\frac{1}{\zeta}\right)=-K_0-K_1\zeta-K_2\zeta^2-.\ .\ .-K_9\zeta^9+0\left(\frac{1}{\zeta}\right) \qquad \ldots\ldots\ (9)$$

where $K_1=0\cdot072\bar{a}_3+0\cdot048\bar{a}_6+0\cdot036\bar{a}_9$
$K_2=0\cdot048\bar{a}_2+0\cdot040\bar{a}_5+0\cdot032\bar{a}_8$
$K_3=0\cdot024\bar{a}_1+0\cdot032\bar{a}_4+0\cdot028\bar{a}_7$
$K_4=0\cdot024\bar{a}_3+0\cdot024\bar{a}_6$
$K_5=0\cdot016\bar{a}_2+0\cdot020\bar{a}_5$ $\qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (10)$
$K_6=0\cdot008\bar{a}_1+0\cdot016\bar{a}_4$
$K_7=0\cdot012\bar{a}_3$
$K_8=0\cdot008\bar{a}_2$
$K_9=0\cdot004\bar{a}_1$

Hence $\dfrac{1}{2\pi i}\displaystyle\int_\gamma \frac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\,\frac{\overline{\varphi'(\sigma)}}{\sigma-\zeta}d\sigma=-K_0-K_1\zeta-.\ .\ .-K_9\zeta^9$, so that, substituting in (6), we have

$$\varkappa\varphi(\zeta)+K_0+K_1\zeta+.\ .\ .+K_9\zeta^9-\bar{a}=\frac{2\mu}{2\pi i}\int_\gamma\frac{g\,d\sigma}{\sigma-\zeta} \qquad \ldots\ldots\ldots\ (11)$$

It is assumed that the shaft (i.e. the kernel) in the region of the hub is rigid in comparison with the hub, so that if a moment acting on the shaft causes the shaft in the region of the hub to rotate about its centre through a small angle ε, the components of displacement on the edge of the shaft will be

$$dx=-\varepsilon y,\quad dy=\varepsilon x.$$

It is further assumed that points on the hub remain in contact with the same points on the shaft after deformation as before. This will certainly be true in the case of a welded join. The displacements g_1, g_2 on the edge of the hole are then $g_1=-\varepsilon y$, $g_2=\varepsilon x$. Therefore $g=g_1+ig_2=i\varepsilon(x+iy)=i\varepsilon z=i\varepsilon\omega(\sigma)$. Thus

$$g=ia\varepsilon\left\{\frac{0\cdot825}{\sigma}+0\cdot149\sigma^2+0\cdot017\sigma^5+0\cdot006\sigma^8+0\cdot003\sigma^{11}\right\}\quad ..\ (12)$$

Now $g(\sigma)$ is the boundary value of the function $g(\zeta)$ holomorphic in $|\zeta|<1$ except at $\zeta=0$, where it has a simple pole. Thus the Cauchy Integral

$$\frac{2\mu}{2\pi i}\int_\gamma\frac{g\,d\sigma}{\sigma-\zeta}=2\mu ai\varepsilon\{0\cdot149\zeta^2+0\cdot017\zeta^5+0\cdot006\zeta^8+0\cdot003\zeta^{11}\}\quad (13)$$

Thus, equation (11) becomes

$$\begin{aligned}&\varkappa(a_1\zeta+a_2\zeta^2+\ldots+a_n\zeta^n+\ldots)+(K_0-\bar{a})+K_1\zeta+K_2\zeta^2+\ldots+K_9\zeta^9\\&\quad=2\mu ai\varepsilon\{0\cdot149\zeta^2+0\cdot017\zeta^5+0\cdot006\zeta^8+0\cdot003\zeta^{11}\}\quad \ldots\ldots\ (14)\end{aligned}$$

Comparing coefficients on both sides and substituting for K_1, K_2, . . ., K_9, we have

$$\begin{aligned}
\varkappa a_1+0\cdot072\bar{a}_3+0\cdot048\bar{a}_6+0\cdot036\bar{a}_9&=0\\
\varkappa a_2+0\cdot048\bar{a}_2+0\cdot040\bar{a}_5+0\cdot032\bar{a}_8&=2\mu ia\varepsilon\ (0\cdot149)\\
\varkappa a_3+0\cdot024\bar{a}_1+0\cdot032\bar{a}_4+0\cdot028\bar{a}_7&=0\\
\varkappa a_4+0\cdot024\bar{a}_3+0\cdot024\bar{a}_6&=0\\
\varkappa a_5+0\cdot016\bar{a}_2+0\cdot020\bar{a}_5&=2\mu ia\varepsilon\ (0\cdot017)\quad \ldots\ldots\ldots\ (15)\\
\varkappa a_6+0\cdot008\bar{a}_1+0\cdot016\bar{a}_4&=0\\
\varkappa a_7+0\cdot012\bar{a}_3&=0\\
\varkappa a_8+0\cdot008\bar{a}_2&=2\mu ia\varepsilon\ (0\cdot006)\\
\varkappa a_9+0\cdot004\bar{a}_1&=0\\
\varkappa a_{10}&=0\\
\varkappa a_{11}&=2\mu ia\varepsilon\ (0\cdot003).
\end{aligned}$$

Putting $a_1=\alpha_1+i\beta_1$, . . ., $a_n=\alpha_n+i\beta_n$ and equating real and imaginary parts we find that all α's are zero and all β's are zero except β_2, β_5, β_8, and β_{11}. Thus the only equations which concern us here are

$$\begin{aligned}
(\varkappa-0\cdot048)\beta_2-0\cdot040\beta_5-0\cdot032\beta_8&=2\mu a\varepsilon\ (0\cdot149)\\
(\varkappa-0\cdot020)\beta_5-0\cdot016\beta_2&=2\mu a\varepsilon\ (0\cdot017)\quad \ldots\ldots\ldots\ (16)\\
\varkappa\beta_8-0\cdot008\beta_2&=2\mu a\varepsilon\ (0\cdot006)\\
\varkappa\beta_{11}&=2\mu a\varepsilon\ (0\cdot003).
\end{aligned}$$

Solving (16), neglecting terms of order 10^{-5}, we have

$$\begin{aligned}
\beta_2&=2\mu a\varepsilon\left[\frac{0\cdot149\varkappa-0\cdot002}{\varkappa^2-0\cdot068\varkappa}\right]\\
\beta_5&=2\mu a\varepsilon\left[\frac{0\cdot017\varkappa+0\cdot001}{\varkappa^2-0\cdot088\varkappa+0\cdot001}\right]\quad \ldots\ldots\ldots\ldots\ (17)\\
\beta_8&=2\mu a\varepsilon\left[\frac{0\cdot006\varkappa+0\cdot001}{\varkappa^2-0\cdot068\varkappa}\right]\\
\beta_{11}&=2\mu a\varepsilon\left[\frac{0\cdot003}{\varkappa}\right]
\end{aligned}$$

and

$$\varphi(\zeta)=i[\beta_2\zeta^2+\beta_5\zeta^5+\beta_8\zeta^8+\beta_{11}\zeta^{11}]\quad \ldots\ldots\ (18)$$

and since $a_2=i\beta_2$, $a_5=i\beta_5$, etc., we have from (10)

$$\begin{aligned}K_2&=-0\cdot048i\beta_2-0\cdot040i\beta_5-0\cdot032\beta_8\\K_5&=-0\cdot016i\beta_2-0\cdot020i\beta_5\\K_8&=-0\cdot008i\beta_2,\end{aligned}$$

all other K's being zero, K_0 not being required. Hence (9) can be rewritten as follows :

In $|\zeta|>1$

$$\frac{\omega(\zeta)}{\bar{\omega}'\left(\frac{1}{\zeta}\right)}\bar{\varphi}'\left(\frac{1}{\zeta}\right)=-K_2\zeta^2-K_5\zeta^5-K_8\zeta^8+0\left(\frac{1}{\zeta}\right) \quad \ldots\ldots \quad (9')$$

Taking the conjugate of this equation we see that in $|\zeta|<1$,

$$\frac{\bar{\omega}\left(\frac{1}{\zeta}\right)}{\omega'(\zeta)}\varphi'(\zeta)=-\frac{\bar{K}_2}{\zeta^2}-\frac{\bar{K}_5}{\zeta^5}-\frac{\bar{K}_8}{\zeta^8}+\text{a Holomorphic Function} \quad .. \quad (19)$$

Considering the second integral in (7), the function $\frac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\varphi'(\sigma)$ is the boundary value of $\frac{\bar{\omega}\left(\frac{1}{\zeta}\right)}{\omega'(\zeta)}\varphi'(\zeta)$, holomorphic inside γ except $\zeta=0$, where it has a pole of order 8. Thus the Cauchy Integral

$$\frac{1}{2\pi i}\int_\gamma \frac{\overline{\omega(\sigma)}}{\omega'(\sigma)}\,\frac{\varphi'(\sigma)}{\sigma-\zeta}d\sigma=\text{the holomorphic function in (19).}$$

$$=\frac{\bar{\omega}\left(\frac{1}{\zeta}\right)}{\omega'(\zeta)}\varphi'(\zeta)+\frac{\bar{K}_2}{\zeta^2}+\frac{\bar{K}_5}{\zeta^5}+\frac{\bar{K}_8}{\zeta^8} \quad \ldots\ldots\ldots\ldots \quad (20)$$

Now, on the boundary of the hub, using (12),

$$\bar{g}=-ia\varepsilon\left\{0\cdot825\sigma+\frac{0\cdot149}{\sigma^2}+\frac{0\cdot017}{\sigma^5}+\frac{0\cdot006}{\sigma^8}+\frac{0\cdot003}{\sigma^{11}}\right\} \quad \ldots\ldots \quad (21)$$

so that

$$\frac{-2\mu}{2\pi i}\int_\gamma \frac{\bar{g}d\sigma}{\sigma-\zeta}=+2\mu ia\varepsilon\ (0\cdot825\zeta).$$

Thus equation (7) yields

$$\psi(\zeta)=2\mu ia\varepsilon\ (0\cdot825\zeta)-\frac{\bar{\omega}\left(\frac{1}{\zeta}\right)}{\omega'(\zeta)}\varphi'(\zeta)-\frac{\bar{K}_2}{\zeta^2}-\frac{\bar{K}_5}{\zeta^5}-\frac{\bar{K}_8}{\zeta^8} \quad \ldots\ldots \quad (22)$$

Relation between Moment of Applied Couple and ε.

The moment M of forces acting on the boundary of the hub about the centre will be equal and opposite to the moment of forces acting on the shaft in the vicinity of the hub about the centre. This moment is given by the real part of the change in $\chi_1(z)-z\psi_1(z)-z\bar{z}\varphi_1'(z)$ as z moves around the contour L clockwise (*cf.* Muskhelishvili's formula 33.3, in which there is a misprint), where

$$\chi_1(z)=\int\psi_1(z)dz+\text{constant.}$$

Since $\varphi(\zeta)$, $\varphi'(\zeta)$ and $\psi(\zeta)$ are holomorphic inside γ, $\varphi_1'(z)$ and $\psi_1(z)$ are holomorphic outside L, so that we need only calculate the real part of the increase in

$$\int\psi_1(z)dz=\int\psi(\zeta)\omega'(\zeta)d\zeta$$

as ζ moves around γ anti-clockwise. Thus we need the multivalued term in

$$\text{Re}\int\psi(\zeta)\omega'(\zeta)d\zeta,\ \text{i.e. in}$$

$$\text{Re}\int\left\{2\mu ia\varepsilon\ (0\cdot825)\zeta\omega'(\zeta)-\bar{\omega}\left(\frac{1}{\zeta}\right)\varphi'(\zeta)-\left(\frac{\bar{K}_2}{\zeta^2}+\frac{\bar{K}_5}{\zeta^5}+\frac{\bar{K}_8}{\zeta^8}\right)\omega'(\zeta)\right\}d\zeta.\quad ..\ (23)$$

This multivalued term is

$$\begin{aligned}\text{Re}[\{&-2\mu i\varepsilon a^2\ (0\cdot825)^2-ia\ (0\cdot298\beta_2+0\cdot085\beta_5+0\cdot048\beta_8+0\cdot033\beta_{11})\\&-a\ (0\cdot298\bar{K}_2+0\cdot085\bar{K}_5+0\cdot048\bar{K}_8)\}\ \ln\zeta]\quad \ldots\ldots\ldots\ldots\ldots\ (24)\end{aligned}$$

From (10), $\bar{K}_2=0\cdot048i\beta_2+0\cdot040i\beta_5+0\cdot032i\beta_8$
$\bar{K}_5=0\cdot016i\beta_2+0\cdot020i\beta_5$
$\bar{K}_8=0\cdot008i\beta_2.$

Substituting in (24) and simplifying, we find

$$M=2\pi\{2\mu\varepsilon a^2\,(0\cdot825)^2+a\beta_2\,(0\cdot313)+a\beta_5\,(0\cdot099)+a\beta_8\,(0\cdot058)+a\beta_{11}\,(0\cdot033)\}\quad \ldots\ldots\ldots\ldots\ldots\ (25)$$

CALCULATION OF STRESS COMPONENTS.

The components of stress in orthogonal curvilinear co-ordinates (ρ), (θ) are given by the formulæ (50.9), (50.10) in Muskhelishvili.
A rearrangement gives

$$\widehat{\rho\rho}+\widehat{\theta\theta}=4\text{Re}\left\{\frac{\varphi'(\zeta)}{\omega'(\zeta)}\right\}\quad \ldots\ldots\ldots\ldots\ldots\ldots\ (26)$$

and

$$\widehat{\theta\theta}-\widehat{\rho\rho}+2i\widehat{\rho\theta}=\frac{2\zeta^2}{\rho^2\overline{\omega'(\zeta)}}\left[\overline{\omega(\zeta)}\frac{d}{d\zeta}\left\{\frac{\varphi'(\zeta)}{\omega'(\zeta)}\right\}+\psi'(\zeta)\right].\quad \ldots\ldots\ (27)$$

When $\rho=1$, $\widehat{\rho\rho}$, $\widehat{\theta\theta}$, $\widehat{\rho\theta}$ give the normal, tangential and shear stresses on the boundary of the hub corresponding to values of θ in the ζ-plane.

Equation (26) presents no difficulty. We find, putting $\rho=1$,

$$\widehat{\rho\rho}+\widehat{\theta\theta}=\frac{4a\ (B\sin3\theta+C\sin6\theta+D\sin9\theta+E\sin12\theta)}{a^2\ (0\cdot780-0\cdot430\cos3\theta-0\cdot106\cos6\theta-0\cdot060\cos9\theta-0\cdot054\cos12\theta)}\quad \ldots\ldots\ldots\ldots\ldots\ (28)$$

where $B=1{\cdot}820\beta_2-1{\cdot}250\beta_5-0{\cdot}416\beta_8-0{\cdot}528\beta_{11}$
$C=0{\cdot}096\beta_2+4{\cdot}290\beta_5-2{\cdot}384\beta_8-0{\cdot}935\beta_{11}$
$D=0{\cdot}066\beta_2+6{\cdot}600\beta_8-3{\cdot}278\beta_{11}$
$E=9{\cdot}075\beta_{11}$.

Towards evaluating (27), we note that

$$\overline{\omega(\zeta)}\frac{d}{d\zeta}\left\{\frac{\varphi'(\zeta)}{\omega'(\zeta)}\right\}=\frac{\overline{\omega(\zeta)}\omega'(\zeta)\varphi''(\zeta)-\overline{\omega(\zeta)}\varphi'(\zeta)\omega''(\zeta)}{[\omega'(\zeta)]^2}\quad\ldots\ldots\quad(29)$$

and from the expression (22) for $\psi(\zeta)$ we find

$$\psi'(\zeta)=2\mu ia\varepsilon\ (0{\cdot}825)+\frac{2\overline{K}_2}{\zeta^3}+\frac{5\overline{K}_5}{\zeta^6}+\frac{8\overline{K}_8}{\zeta^9}-\frac{\omega'(\zeta)\dfrac{d}{d\zeta}\left\{\bar{\omega}\left(\dfrac{1}{\zeta}\right)\right\}\varphi'(\zeta)}{[\omega'(\zeta)]^2}$$
$$-\frac{\omega'(\zeta)\bar{\omega}\left(\dfrac{1}{\zeta}\right)\varphi''(\zeta)}{[\omega'(\zeta)]^2}+\frac{\bar{\omega}\left(\dfrac{1}{\zeta}\right)\varphi'(\zeta)\omega''(\zeta)}{[\omega'(\zeta)]^2}\quad\ldots\ldots\ldots\ldots\ldots\ldots\quad(30)$$

Substituting from (29) and (30) in (27) we find

$$\widehat{\theta\theta}-\widehat{\rho\rho}+2i\widehat{\rho\theta}=$$
$$\frac{2\zeta^2}{\rho^2}\left[\frac{2\mu ia\varepsilon\ (0{\cdot}825)}{\overline{\omega'(\zeta)}}+\left\{\frac{2\overline{K}_2}{\zeta^3}+\frac{5\overline{K}_5}{\zeta^6}+\frac{8\overline{K}_8}{\zeta^9}\right\}\frac{1}{\overline{\omega'(\zeta)}}+\frac{\overline{\omega(\zeta)}\varphi''(\zeta)}{\omega'(\zeta)\overline{\omega'(\zeta)}}\right.$$
$$-\frac{\overline{\omega(\zeta)}\varphi'(\zeta)\omega''(\zeta)}{\{\omega'(\zeta)\}^2\overline{\omega'(\zeta)}}-\frac{\dfrac{d}{d\zeta}\left\{\bar{\omega}\left(\dfrac{1}{\zeta}\right)\right\}\varphi'(\zeta)}{\omega'(\zeta)\overline{\omega'(\zeta)}}-\frac{\bar{\omega}\left(\dfrac{1}{\zeta}\right)\varphi''(\zeta)}{\omega'(\zeta)\overline{\omega'(\zeta)}}$$
$$\left.+\frac{\bar{\omega}\left(\dfrac{1}{\zeta}\right)\varphi'(\zeta)\omega''(\zeta)}{\{\omega'(\zeta)\}^2\overline{\omega'(\zeta)}}\right].$$

Since on the boundary of γ, $\overline{\omega(\sigma)}=\bar{\omega}\left(\dfrac{1}{\sigma}\right)$ we have, putting $\rho=1$ and $\sigma=e^{i\theta}$,

$$\widehat{\theta\theta}-\widehat{\rho\rho}+2i\widehat{\rho\theta}=\frac{2e^{2i\theta}}{\omega'(\sigma)\overline{\omega'(\sigma)}}\Bigg[2\mu ia\varepsilon\ (0{\cdot}825)\omega'(\sigma)$$
$$+\left\{\frac{2\overline{K}_2}{\sigma^3}+\frac{5\overline{K}_5}{\sigma^6}+\frac{8\overline{K}_8}{\sigma^9}\right\}\omega'(\sigma)-\frac{d}{d\sigma}\{\overline{\omega(\sigma)}\}\varphi'(\sigma)\Bigg]\quad\ldots\ldots\ldots\quad(31)$$

Substituting in (31) for $\omega'(\sigma)$, $\varphi'(\sigma)$, $\overline{K}_2$, $\overline{K}_5$, $\overline{K}_8$, etc., and separating the real and imaginary parts of each term in turn we find firstly

$$\widehat{\rho\theta}=\frac{a}{|\ \omega'(\sigma)\ |^2}[A'+B'\cos 3\theta+C'\cos 6\theta+D'\cos 9\theta+E'\cos 12\theta]\quad\ldots\quad(32)$$

where $A'=0{\cdot}635\beta_2+0{\cdot}458\beta_5+0{\cdot}403\beta_8+0{\cdot}363\beta_{11}-2\mu\varepsilon a\ (0{\cdot}681)$
$B'=-1{\cdot}516\beta_2+1{\cdot}706\beta_5+0{\cdot}896\beta_8+0{\cdot}528\beta_{11}+2\mu\varepsilon a\ (0{\cdot}246)$
$C'=0{\cdot}057\beta_2-4{\cdot}026\beta_5+2{\cdot}387\beta_8+0{\cdot}935\beta_{11}+2\mu\varepsilon a\ (0{\cdot}070)$
$D'=0{\cdot}016\beta_2+0{\cdot}003\beta_5-6{\cdot}598\beta_8+3{\cdot}278\beta_{11}+2\mu\varepsilon a\ (0{\cdot}040)$
$E'=-9{\cdot}075\beta_{11}+2\mu\varepsilon a\ (0{\cdot}027)$.

Combining the expression for $\widehat{\theta\theta}-\widehat{\rho\rho}$ from (31) with $\widehat{\theta\theta}+\widehat{\rho\rho}$ from (28), we find

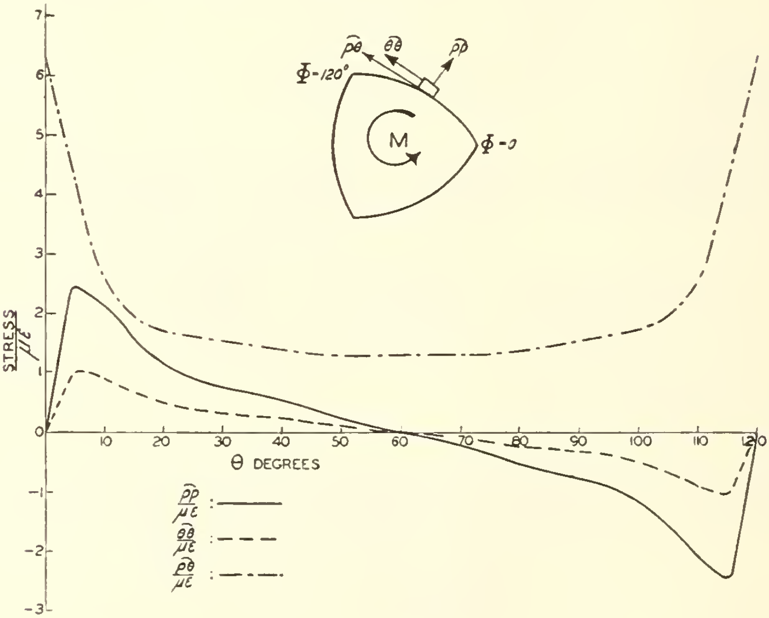
$$\widehat{\rho\rho}=\frac{a}{|\,\omega'(\sigma)\,|^2}[B'' \sin 3\theta+C'' \sin 6\theta+D'' \sin 9\theta+E'' \sin 12\theta] \quad \ldots . \ (33)$$

where $B''=1\cdot884\beta_2-1\cdot202\beta_5-0\cdot358\beta_8-0\cdot528\beta_{11}+2\mu\varepsilon a\ (0\cdot246)$
$C''=0\cdot151\beta_2+4\cdot380\beta_5-2\cdot381\beta_8-0\cdot935\beta_{11}+2\mu\varepsilon a\ (0\cdot070)$
$D''=0\cdot122\beta_2+0\cdot003\beta_5+6\cdot602\beta_8-3\cdot278\beta_{11}+2\mu\varepsilon a\ (0\cdot040)$
$E''=9\cdot075\beta_{11}+2\mu\varepsilon a\ (0\cdot027)$.

Also

$$\widehat{\theta\theta}=\frac{a}{|\omega'(\sigma)|^2}\ [B''' \sin 3\theta+C''' \sin 6\theta+D''' \sin 9\theta+E''' \sin 12\theta] \quad \ldots . \ (34$$

where $B'''=\ 5\cdot396\beta_2-\ 3\cdot798\beta_5-\ 1\cdot306\beta_8-1\cdot584\beta_{11}-2\mu\varepsilon a\ (0\cdot246)$
$C'''=\ 0\cdot233\beta_2+12\cdot780\beta_5-\ 7\cdot155\beta_8-2\cdot805\beta_{11}-2\mu\varepsilon a\ (0\cdot070)$
$D'''=\ 0\cdot142\beta_2-\ 0\cdot003\beta_5+19\cdot798\beta_8-9\cdot834\beta_{11}-2\mu\varepsilon a\ (0\cdot040)$
$E'''=27\cdot225\beta_{11}-2\mu\varepsilon a\ (0\cdot027)$.



Text-fig. 4.

Results for Special Material. Graphs.

Choosing steel as the special material, with Poisson's Ratio 0.30, we have $\varkappa=1\cdot80$. Then, from (17)

$$\begin{aligned}\beta_2\ &=2\mu a\varepsilon\ (0\cdot085)\\ \beta_5\ &=2\mu a\varepsilon\ (0\cdot010) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (35)\\ \beta_8\ &=2\mu a\varepsilon\ (0\cdot004)\\ \beta_{11}&=2\mu a\varepsilon\ (0\cdot002).\end{aligned}$$

The value of ε for a given couple with moment M is given from (25)

$$\varepsilon=\frac{M}{4\pi\mu a^2\ (0\cdot709)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (36)$$

From (32), (33), (34)

$$\widehat{\rho\theta}=\frac{-\mu\varepsilon\,(1\cdot 240-0\cdot 277\cos 3\theta-0\cdot 087\cos 6\theta-0\cdot 043\cos 9\theta-0\cdot 025\cos 12\theta)}{(0\cdot 780-0\cdot 430\cos 3\theta-0\cdot 106\cos 6\theta-0\cdot 060\cos 9\theta-0\cdot 054\cos 12\theta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (37)$$

$$\widehat{\rho\rho}=\frac{\mu\varepsilon\,(0\cdot 784\sin 3\theta+0\cdot 246\sin 6\theta+0\cdot 141\sin 9\theta+0\cdot 083\sin 12\theta)}{(0\cdot 780-0\cdot 430\cos 3\theta-0\cdot 106\cos 6\theta-0\cdot 060\cos 9\theta-0\cdot 054\cos 12\theta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (38)$$

and

$$\widehat{\theta\theta}=\frac{\mu\varepsilon\,(0\cdot 335\sin 3\theta+0\cdot 102\sin 6\theta+0\cdot 063\sin 9\theta+0\cdot 033\sin 12\theta)}{(0\cdot 780-0\cdot 430\cos 3\theta-0\cdot 106\cos 6\theta-0\cdot 060\cos 9\theta-0\cdot 054\cos 12\theta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (39)$$

The graphs of $\widehat{\rho\rho}$, $\widehat{\theta\theta}$ and $\widehat{\rho\theta}$ against θ are shown in Text-figure 4. By choosing the positive directions of $\widehat{\rho\rho}$, $\widehat{\theta\theta}$, $\widehat{\rho\theta}$ as shown we can show the stresses along the edge of the hole for values of angle Φ from 0 to 120°. The stresses are repeated on each of the other two edges. The values of Φ corresponding to the values of θ from the graphs can be obtained from Text-figure 3.

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BASIC AND ULTRABASIC ROCKS NEAR HAPPY JACKS AND TUMUT POND IN THE SNOWY MOUNTAINS OF NEW SOUTH WALES.

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With Seven Text-Figures.

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Abstract.

A number of basic and ultrabasic rocks occurring within the area drained by the Upper Tumut and Happy Jacks Rivers have been described. These include pyroxenites, hornblendites, gabbros, diorites, monzonites, lamprophyres and a number of other types occurring as minor dykes and veins.

It is believed that they are all related, and that they have been derived partly by differentiation and partly by assimilation during the Bowning Orogeny just prior to the emplacement of the granite.

It is suggested that the basic parent is an earlier intrusion of Ordovician age, possibly related to the Porphyritic Central Magma type, and that the acid parent is the (?) Silurian granite magma or partial magma.

Contents

Introduction.

Andrews (1901) briefly referred to the occurrence of norite and of syenitic diorites at Kiandra, and later Browne and Greig (1923) described the so-called norite in detail and designated it an olivine-bearing quartz-monzonite. Recent work by the Geological Survey of New South Wales (Hall and Lloyd, 1954) and by the Engineering Geology Section of the Snowy Mountains Hydro-Electric

Authority has revealed many occurrences of closely related rocks to the south of Kiandra, including ultrabasic, basic and intermediate types. Many of these have been mapped at the surface and others have been encountered in the tunnels and in the exploratory drill holes.

According to Vallance (1953) similar types occur 34 miles to the north-north-west on the same line of strike. To the east, near Cooma, and in the region north of Cooma, several small basic and ultrabasic masses are recorded (Browne, 1914 ; Joplin, 1939, 1942). These bear no close resemblance to the Snowy Mountains rocks and appear to be of Ordovician age. Basic granulites of probable Ordovician age are also recorded near Cooma and later work (Browne, 1944 and Joplin, 1943) shows that several of these masses occur to the north of Murrumbucca, and the former presence of others is suggested by the occurrence of numerous basic xenoliths in the (?) Silurian granite. N. J. Snelling, of this department, is at present engaged on a very complete study of this granite and has kindly made available several analyses of the basic xenoliths, some of which he suggests are of sedimentary origin. Recent work in the Mt. Isa-Cloncurry district of Queensland has raised the problem of distinguishing between metamorphosed basic igneous and calcsilicate rocks (Walker and Joplin in MS.) and it is indeed possible that some of the Cooma granulites are in fact highly altered banded calcareous rocks.

In the present paper an attempt is made to examine the relation between the different basic types within the Tumut Pond and Happy Jacks area and then to compare them with the other basic types recorded to the north and to the east. Their origin and their relation to the granite are also discussed in relation to the diastrophism with which they are believed to be associated.

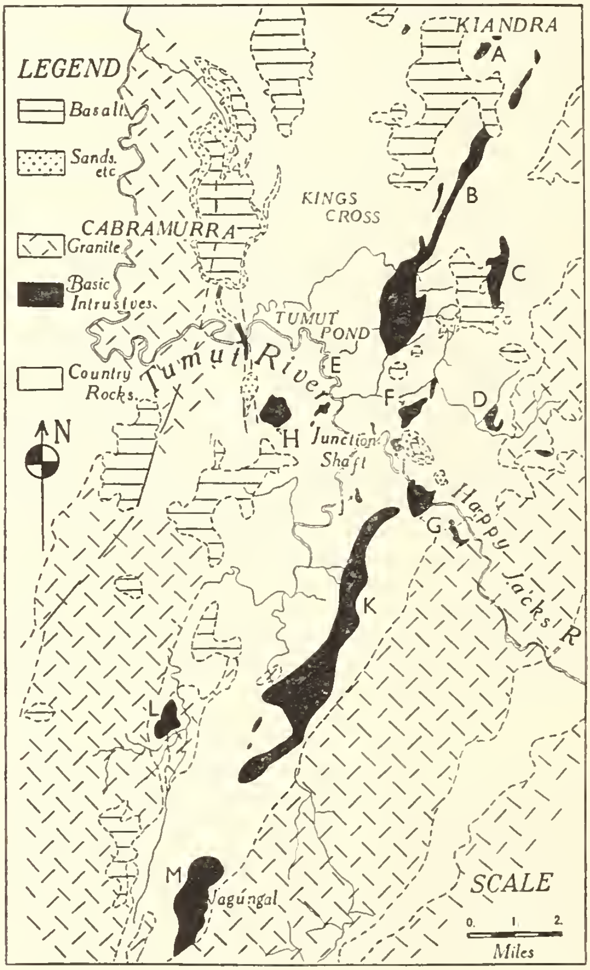
The writer would like to acknowledge her indebtedness to the Snowy Mountains Hydro-Electric Authority, and in particular to their Chief Geologist, Mr. D. G. Moye for the loan of slides, specimens and maps ; to Dr. W. R. Browne for kindly criticism and for the loan of specimens from the Kosciusko region collected by himself and by the late Sir Edgeworth David ; and to Mr. C. McElroy, of the Geological Survey of New South Wales, for the loan of specimens and for discussion on the field occurrence of the rocks in the southern part of the area. She also wishes to thank Mr. N. J. Snelling for his generosity in permitting her to use several of his unpublished analyses for the plots in Fig. 7.

2. FIELD OCCURRENCE.

Reference to Fig. 1 will show that numerous small masses of basic rock occur within the region drained by the Upper Tumut and Happy Jacks Rivers. Masses A and B were mapped by Andrews (1901) and referred to as norite and syenitic diorite respectively. Most of the other masses were mapped by Hall and Lloyd (1954) and are referred to under the collective term Jagungal-Nine Mile Complex. The larger masses are narrow elongated bodies trending approximately N. 60° E., roughly parallel to the margins of the granite. In places the basic rock is adjacent to the granite, and shows contact alteration as a result. Both within and outside the area delineated in Fig. 1, small basic dykes invade the country rocks. Some of these are possibly of Tertiary age, but many are older and closely allied to the basic types described in this paper. Dykes of lamprophyre cutting both country rocks and granite have been examined by the late Sir Edgeworth David and by Dr. W. R. Browne in the Kosciusko area, and these are briefly referred to in the petrography.

Just north of Tumut Pond, an elongated mass of serpentine trends N. 5° W., but as the strike is different and it is magmatically dissimilar to the rocks here considered, it is not discussed herein.

Although specimens from bores and tunnels and from several different outcrops have been lent by the Snowy Mountains Hydro-Electric Authority, the writer herself has examined only three outcrops in the field. Her impression is that, with but few exceptions, the different types grade one into the other and rarely show clear boundaries. Thus in the elongated mass parallel to the Tumut River, and about 2 miles south of Junction Shaft (Locality K), large patches of pyroxenite contain patches and veins of coarse hornblendite and both grade out into gabbro and finer grained dioritic types, all being intersected by veins of epidote, quartz, calcite and fine hornblende rock. Only the most detailed mapping could delimit these types, and even then junctions would probably prove indefinite and unsatisfactory.



Text-fig. 1.—Map of the Tumut Pond-Happy Jacks area showing localities of basic rocks.

In the "Diorite" quarry within the small heart-shaped mass 2 miles south-south-east of Junction Shaft (Locality G), two types predominate, a fine grained hornblendic rock cut by a lighter type with large uralitized pyroxene phenocrysts. Both are orthoclase-bearing and show affinities to the monzonite, and in places both assume a pinkish colour which appears to be due to the invasion of later solutions. The core of a bore (5193) put down though this mass shows that it consists mainly of these types and that alteration is very common. Dolerites, mica lamprophyres and porphyrites are also found in the core and probably represent small dykes or veins. As both a quarry and a bore core are available at this locality, much of the described and analysed material comes from this mass.

Most of the other masses consist predominantly of orthoclase-bearing diorites or monzonites, but the other types are commonly associated in small amount, and again the field relations are not clear, though it is possible that some order of intrusion might be established if other quarry exposures were available.

Small irregular bodies of pyroxenite and of monzonite and numerous dykes of dolerite, lamprophyre and porphyrite have been encountered in the Eucumbene-Tumut Tunnel, and a number of such dykes are exposed in the road cuttings near Junction Shaft. These, together with small veins of similar type, as well as of epidote, calcite and quartz, appear to be the only well-defined discrete injections. Veining by acid material even close to the granite is rare, though the pink coloration due to alteration may be mistaken for it in places. Except for the absence of this feature, the field relations of the basic and ultrabasic rocks show a remarkable resemblance to those of the Ach'uaine hybrids of Sutherland, Scotland (Read, 1931). Though genetically unrelated, the field occurrence is not unlike that of a group of basic rocks at Cooma (Joplin, 1939).

3. Petrography.

Pyroxenites, Hornblende-pyroxenites and Hornblendites.

Pyroxenites, hornblende-pyroxenites and hornblendites show all gradations from one into the other and are here described together.

They form small areas within some of the basic intrusions, and are commonly surrounded by and grade out into less basic types. A large mass crops out near the road about 2 miles south-south-east of Junction Shaft and a smaller irregular intrusion is found between stations 506+70 and 508+50 in the Eucumbene-Tumut Tunnel. Dr. W. R. Browne (pers. comm.) has also found pyroxenite included in granite and impregnated with tourmaline near Seaman's Hut in the Kosciusko area. It is also of interest to note that Vallance (1953) found an ultra-basic inclusion, with a chemical composition approximating to that of the pyroxenite, in the Wantabadgery granite about 30 miles north-north-west of Kiandra.

In hand specimens these rocks are dark and coarse-grained with hornblende crystals in some specimens measuring up to 15 mm. Under the microscope the pyroxenites have a fairly even grain size which may range in different specimens from 1 to 6 mm., and the fabric is from allotriomorphic granular to hypidiomorphic granular (Fig. 2*A*). The bulk of the pyroxene is pale green, optically positive witn $Z \wedge c = 54°$ and a slight polysynthetic twinning sometimes apparent. It thus appears to be diopsidic. A negative, slightly pleochroic pink pyroxene is also present in small amount. Some sections show an oblique extinction and it was suggested by Browne and Greig (1923), who found the same variety in the Kiandra monzonite, that it is a monoclinic clino-hypersthene. Both pyroxenes contain inclusions of magnetite which may grow outwards and link with schiller inclusions of the same material. Flecking with small patches of green hornblende is common and the pyroxenes are often wrapped by irregular grains (1mm.) of brown hornblende with Z=dark olive green, Y=golden yellow and X=pale yellow. Green hornblende may also form independent grains with Z=dark green, Y=olive green and X=greenish yellow, $Z<Y<X$, $Z \wedge c = 29°$.

The hornblendites consist of large interlocking grains or subidiomorphic prisms of both or either brown or green hornblende (Fig. 3*A*) and commonly occur as veins or patches in the pyroxenite or gabbro. The hornblende crystals are not infrequently up to an inch in length and Mr. C. McElroy (pers. comm.) of the Geological Survey of New South Wales reports that he has seen them at Locality K measuring up to about 5 inches in length. They alter to chlorite and epidote, and in one specimen elongated needles of epidote were noted parallel to the cleavage of the amphibole.

In a few specimens large chloritized flakes of mica occur and pseudomorphs consisting of chlorite, serpentine and iron ore suggest the former presence of a little hypersthene or olivine (see Fig. 3*A*); though no fresh olivine has been noted in these rocks, it has been detected in some of the monzonites.

TABLE I.

	I.	II.	III.
SiO_2 ..	39·49	39·97	37·33
Al_2O_3 ..	6·61	8·68	7·27
Fe_2O_3 ..	16·03	8·63	13·41
FeO ..	7·30	7·99	9·24
MgO ..	10·72	10·32	12·27
CaO ..	16·51	15·18	16·50
Na_2O ..	1·07	1·19	0·45
K_2O ..	0·25	0·74	0·03
H_2O+ ..	0·57	0·57	1·03
H_2O- ..	0·01		0·10
TiO_2 ..	1·55	4·05	1·66
P_2O_5 ..	tr.	0·10	—
MnO ..	abs.	0·19	0·07
CO_2 ..	abs.	1·15	—
FeS_2 ..	—	1·01	—
	100·11	99·77	99·63

I. *Pyroxenite,* 2 miles south-south-east of Junction Shaft (Locality K). Anal. J. K. Burnett.

II. *Yamaskite* (Hornblende Jacupirangite), Mount Yamaska, Quebec. Anal. G. A. Young. *Can. Geol. Surv. Ann. Rept.* (1904), 1906, 33. In W.T., p. 717.

III. *Pyroxenite.* Olivine Mountain, Tulameen District, British Columbia. Anal. F. M. Connor. C. Camsel, *Can. Geol. Surv. Mem.* **26**, 61, 1913. In W.T., p. 719.

Magnetite is abundant in some rocks (Fig. 2*A*) and in others almost absent. It occurs as inclusions in the ferromagnesian minerals, as independent interstitial grains and as fine aggregates of secondary origin. Commonly it is surrounded by narrow rims of brown hornblende, epidote, chlorite and sphene. Apatite and sphene are present as accessories and most rocks contain traces of much saussuritized plagioclase (Fig. 3*A*). With an increase in plagioclase the ultrabasic rocks pass into gabbros. When plagioclase is present both pyroxene and amphibole are idiomorphic against it.

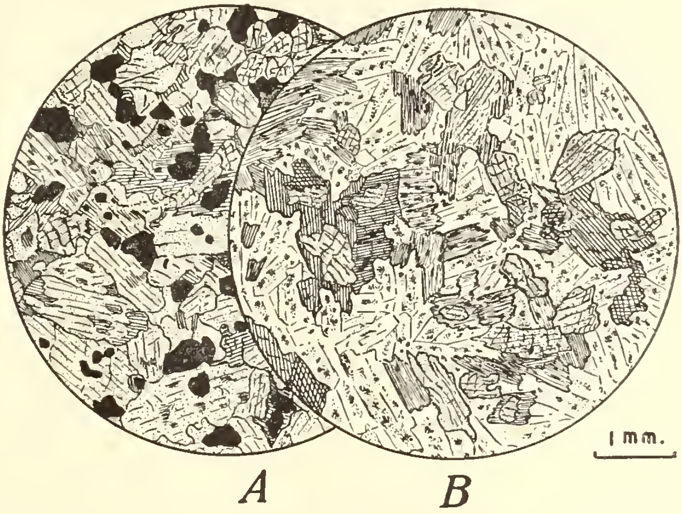
In Table 1 the chemical composition of a Pyroxenite is given, with analyses of two similar rocks for comparison.

Hornblende-Gabbros.

In handspecimen these are dark rocks of very variable grain size. They commonly have a speckled appearance due to the presence of numerous small hornblende crystals.

Under the microscope they are seen to consist of pyroxene, hornblende and plagioclase with accessory magnetite, apatite, sphene and sometimes a little quartz.

The pyroxene forms stout prisms up to 4 mm. in length, but more commonly about 0·6 mm. It is usually uralitized and surrounded by a fringe of either brown or green hornblende (Fig. 2*B*). In some specimens little or no pyroxene is present and the hornblende forms large independent poikilitic subidiomorphic prisms (Fig. 3*B*). Slight bending of the more elongated crystals has been noted. Two varieties of hornblende-gabbro occur, but there is a merging of one into the other. One contains uralitized pyroxene and shows close affinities to the pyroxenites (Fig. 2*B*) : the other, with large crystals of amphibole, shows some relation to the hornblendites (Fig.3*B*). When the latter type contains a notable quantity of green idiomorphic hornblende it passes into the hornblende-lamprophyres described below.



Text-fig. 2.

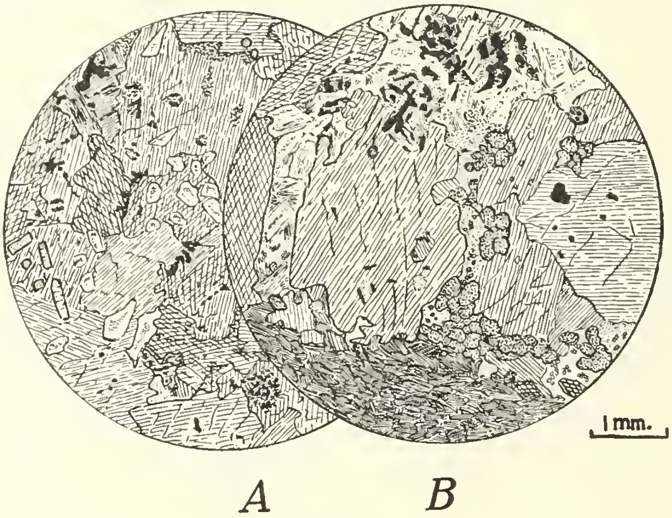
(*A*) Pyroxenite, two miles south-south-west of Junction Shaft (Locality K), showing large subidiomorphic crystals of pyroxene intergrown with magnetite and flecked by hornblende. Just above the centre of the figure pyroxene is moulded by hornblende. × 10.

(*B*) Hornblende-pyroxene-gabbro from Locality H, showing subidiomorphic prisms of pyroxene and of uralitized pyroxene, many of them moulded by brownish-green hornblende. Plagioclase forms subidiomorphic prisms and is partly moulded by hornblende ; its alteration products, mainly clinozoisite, tend to form small segregations throughout the crystals. A few grains of magnetite are also present. × 10.

Felspar occurs in irregular grains or as subidiomorphic tabular crystals or laths. The crystals are zoned with a core of labradorite ($Ab_{35}An_{65}$) and an outer margin of basic andesine ($Ab_{55}An_{45}$). Andesine also forms separate unzoned laths or small tabular crystals. Bending of twin lamellæ is present in some crystals and basic cores are commonly saussuritized. In some rocks the plagioclase is entirely altered to clinozoisite, epidote and chlorite ; in others the alteration products are not identifiable and in some cases are segregated into small patches which are flecked through the felspar (Fig. 2*B*). One specimen shows quartz replacing felspar in the form of minute droplets arranged in a regular dactylitic pattern (Joplin, 1939).

Quartz is present in most gabbros and occurs as large irregular, interstitial grains or as vein infillings. A quartz-bearing type from the core of bore 5057, about 1 mile upstream from the Tumut Pond Dam site, contains vein quartz and interstitial grains show undulose extinction while the whole rock bears evidence of strain.

Calcite occurs in the same manner as quartz and in some rocks epidote is present as vein infillings or partly or wholly replacing felspar. Chlorite is very abundant in rocks containing calcite, epidote and quartz, which have obviously suffered alteration.



Text-fig. 3.

(*A*) Hornblendite, from Locality F, showing large interlocking grains of brownish-green hornblende enclosing accessory apatite and magnetite. Small inclusions of altered olivine also occur and a number of laths of altered plagioclase are present. ×10.

(*B*) Hornblende-gabbro with vein of hornblende rock (bottom of figure), two miles south-south-east of Junction Shaft (Locality K), showing large interlocking grains of hornblende, in places moulding altered plagioclase. Clinozoisite, epidote and fibrous chlorite are abundant as alteration products of the felspar. Small pseudomorphs consisting of deep bluish-green chlorite and magnetite mark the former presence of a ferromagnesian mineral, which may have been hypersthene or olivine. Elsewhere in the slide diopsidic pyroxene, partly uralitized, is present and the rock has some affinities to the other figured gabbro (Text-fig. 2*B*). ×10.

The mode of a hornblende-pyroxene-gabbro is compared with those of three diorites in Table II.

Diorites.

In handspecimen these are medium-grained light and dark speckled rocks, in some cases indistinguishable from monzonites.

Under the microscope they are seen to consist of plagioclase, hornblende and a little quartz and magnetite. Uralitized pyroxene and much chloritized biotite have been detected in some specimens.

The plagioclase occurs as tabular crystals about 1 mm. in length, or as laths about 0·4 mm. Rare tabular phenocrysts (about 3 mm.) occur in some rocks and these types pass into the diorite-porphyrites. Plagioclase is commonly zoned, the cores being a good deal altered. The composition ranges from $Ab_{60}An_{40}$ to $Ab_{66}An_{34}$.

Green hornblende may occur as large (1 to 1·5 mm.) grains or as subidiomorphic prisms (about 1 mm.), and when pyroxene is present it is fringed by hornblende and chloritized biotite. When much idiomorphic green hornblende is present the diorite closely resembles a hornblende-lamprophyre.

Epidote and chlorite are common alteration products of the amphibole, and cores of pyroxene are pseudomorphed by chlorite, epidote and carbonates. Quartz is present in most specimens and occurs as small interstitial grains or as large irregular grains wrapping the other minerals.

In general these rocks show much alteration, and it is possible that because of this alteration small quantities of orthoclase have been overlooked and that some of them should be classified as orthoclase-bearing diorites or as altered monzonites.

TABLE II.

	Pyroxene.	Uralite.	Hornblende.	Biotite.	Plagioclase.	Quartz.	Magnetite.	Total Ferromagnesian.
1.	23	20	17	—	40	—	—	60
2.	25·4		26·1	4·3	38·4	4·3	1·5	55·8
3.	25·8		16·6	6·4	39·9	7·3	4·0	48·8
4.	8·9		10·5	11·6	53·7	13·2	1·8	31·0

1. *Hornblende gabbro.* Locality J, 1 mile south-south-east of Junction Shaft.
2–4. *Diorite.* Locality G, 2½ miles south-east of Junction Shaft.

Orthoclase-bearing Diorites and Monzonites.

In handspecimen these are medium-grained dark rocks consisting of pyroxene, hornblende, biotite, plagioclase, orthoclase and quartz. Some varieties are porphyritic and contain small phenocrysts of pyroxene discernible in handspecimen.

Under the microscope types rich in orthoclase show a distinct monzonitic fabric with idiomorphic to subidiomorphic laths of plagioclase wrapped by large irregular grains of orthoclase and quartz. The proportions of these minerals are very variable, as may be seen by reference to Table IV. The monzonite porphyry contains large crystals of pyroxene fringed with reaction borders of hornblende and biotite, and even the normal types have a slightly porphyritic appearance in that the ferromagnesian minerals tend to form clots, and these too are surrounded by reaction borders (Fig. 4*A*).

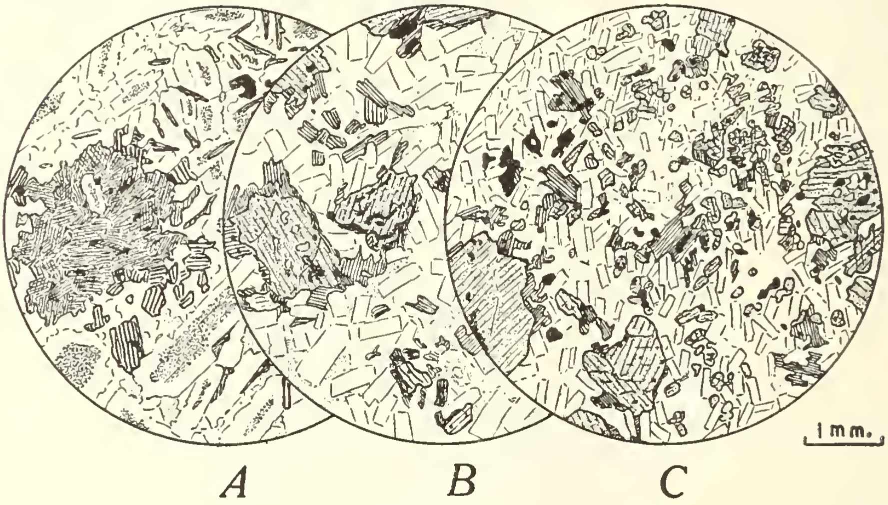
Both augite and clino-hypersthene (Browne and Greig, 1923) are present and both commonly alter to uralite. As well as fringing the pyroxene crystals and their uralitized pseudomorphs, hornblende and biotite occur as independent crystals, the latter altered to chlorite in a number of specimens. Rocks showing pink alteration in handspecimen contain little or no recognisable pyroxene, wholly chloritized biotite and partly chloritized hornblende.

Plagioclase crystals range from 2 to 0·5 mm. in length and commonly show zoning. The cores are heavily saussuritized, but when the composition can be determined it is usually labradorite. The fresh outer zone is commonly oligoclase and independent crystals of andesine also occur. In the pink altered rocks the plagioclase is altered to sericite and to kaolin and stained a deep reddish colour by hæmatite. Plagioclase has suffered greater alteration than orthoclase, though in some specimens both felspars have been much altered and it is almost impossible to make accurate micrometric measurements.

Apatite and magnetite are accessories, the latter forming small prismatic crystals or more commonly long acicular crystals up to 0·5 mm. in length.

Small crystals of altered olivine occur as inclusions in the pyroxene in many of the Kiandra rocks and at Locality H., but have not been detected elsewhere (Fig. 4, *B* and *C*).

Analyses of diorites and monzonitic rocks are given in Table III.



Text-fig. 4.

(*A*) Orthoclase-bearing diorite, from Locality I, showing prismatic crystals of plagioclase, interstitial grains of quartz and orthoclase and large crystal-aggregates of uralitized pyroxene fringed with green hornblende and biotite. Independent crystals of both hornblende and biotite also occur, the biotite being the more abundant and occurring as flat crystals giving sections the appearance of elongated flakes (compare mica-lamprophyre, Text-fig. 5*B*). × 10.

(*B*) Monzonite from Kiandra (Locality A) showing pyroxene fringed with hornblende and biotite and containing inclusions of altered olivine and plagioclase. Small stout prisms of plagioclase are moulded by orthoclase and quartz to give a monzonitic fabric. × 10.

(*C*) Monzonite porphyry from Locality H showing large crystals of pyroxene, partly fringed by biotite and containing inclusions of altered olivine, in a finer groundmass of pyroxene, biotite, orthoclase, quartz and magnetite. The groundmass shows a monzonitic fabric. × 10.

Hornblende-Lamprophyres.

These rocks occur as small dykes and veins invading country rocks and basic igneous masses, but in places the field occurrence is not clear and their petrography suggests that they may merge into either diorites or hornblende-gabbros, as has been noted in describing these two groups. In the Kosciusko area Dr. W. R. Browne has found them as dykes invading granite, and the late Sir Edgeworth David found them as dykes at Boggy Plains and on the Porcupine Ridge.

In handspecimen they are dark rocks containing small elongated crystals of hornblende in a fine groundmass.

Under the microscope it may be seen that the hornblende, whether it occurs as phenocrysts or in the groundmass, has an elongated habit (Fig. 5*A*). Certain rocks described under this heading are not strictly lamprophyres because the phenocrysts are lacking, but in every respect they resemble the groundmass of the true lamprophyres ; so that all rocks containing idiomorphic hornblende with an elongated habit are described hereunder.

In different specimens the phenocrysts may range in size from about 5 mm.×0·5 mm. to about 0·75 mm.×0·2 mm. The hornblende is brownish green with X=light brownish green, Y=olive green and Z=dark bluish green, $Z \wedge c = 24°$. The hornblende of the groundmass is the same variety and crystals measure about 0·15 mm.×0·1 mm. or even smaller in the finer grained types. The rock from Boggy Plains contains no hornblende in the groundmass, but both small stout equidimensional and elongated linear phenocrysts are present.

TABLE III.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2 ..	53·09	53·82	55·56	55·73	56·65	57·08	57·18
Al_2O_3 ..	14·53	15·59	17·97	17·65	15·80	13·62	14·13
Fe_2O_3 ..	2·49	1·55	2·01	3·12	4·78	1·30	1·90
FeO ..	6·51	6·24	4·74	3·98	4·46	6·21	5·85
MgO ..	7·64	7·12	4·21	3·55	3·98	8·07	7·00
CaO ..	7·93	6·72	6·36	6·66	7·61	7·54	7·64
Na_2O ..	2·24	3·17	2·65	2·99	1·64	2·50	2·36
K_2O ..	1·55	1·69	2·34	2·98	2·94	2·50	2·30
H_2O+ ..	1·71	1·72	0·45	1·69	0·62	0·19	0·45
H_2O- ..		0·13	0·09	0·14	0·06	0·05	0·07
TiO_2 ..	1·08	1·22	0·82	0·53	0·69	0·65	0·60
P_2O_5 ..	0·41	0·46	abs.	abs.	abs.	0·21	0·21
MnO ..	n.d.	n.d.	0·06	0·10	0·07	0·14	0·11
Co_2 ..	1·37	0·31	3·60	1·25	0·94	abs.	abs.
Etc. ..	—	—	—	—	—	0·18	0·22
	100·55	99·74	100·86	100·37	100·24	100·24	100·02
Sp. Gr. ..	2·915	2·879	—	—	—	2·937	2·927

I. *Orthoclase-bearing Diorite*, "Diorite" Quarry, Locality G. (see No. 15, Table IV). Anal. G. A. Joplin.

II. *Orthoclase-bearing Diorite.* "Diorite" Quarry, Locality G. (see No. 19, Table IV). Anal. G. A. Joplin.

III. *Altered Orthoclase-bearing Diorite* or *Monzonite*, Locality G. Bore 5193 at 248 feet (see No. 13, Table IV). Anal. J. K. Burnett.

IV. *Altered Orthoclase-bearing Diorite* or *Monzonite*, Locality G. Bore 5193 at 428 feet (see No. 8, Table IV). Anal. J. K. Burnett.

V. *Altered Orthoclase-bearing Diorite* or *Monzonite*, Locality G. Bore 5193 at 170 feet (see Nos. 9 and 10, Table IV). Anal. J. K. Burnett.

VI. *Monzonite Porphyry*, Kiandra, Locality A. Anal. W. A. Greig. Browne, W. R., and Greig, W. A., *Journ. Roy. Soc. N.S.W.*, 1923, 56, 269.

VII. *Quartz Monzonite*, Kiandra, Locality A. Anal. W. A. Greig. *Ibid.*

A specimen from the Kosciusko region contains phenocrysts of pyroxene in addition to those of hornblende.

Chlorite and epidote are common alteration products of the hornblende, and these rocks are characteristically much altered, and in some cases original phenocrysts are completely pseudomorphed.

Phenocrysts of plagioclase are uncommon, and in the rare cases when they occur the felspar is partly altered to calcite. One specimen from Locality G. contains only tabular, zoned crystals of plagioclase as phenocrysts, but the groundmass contains the characteristic elongated hornblendes and thus shows an affinity to the lamprophyre group though it might more appropriately be classed a diorite porphyrite. In the normal hornblende-lamprophyres plagioclase occurs only in the groundmass. The finer grained types contain laths or needles forming a plexus with the amphibole crystals, but in the rocks of slightly coarser texture the felspar forms small tabular crystals that measure from 0·3 to 0·75 × 0·2 mm. Much of the felspar is saussuritized and alteration to calcite is common.

TABLE IV.

Micrometric Analyses of some Snowy Mountains Rocks arranged in order of decreasing abundance of Orthoclase.

	Orthoclase.	Plagioclase.	Quartz.	Pyroxene	Hornblende.	Biotite.	Olivine.	Magnetite.	Epidote.	Total Ferro-magnesian.
1.	17·9	40·1	5·9	21·3	7·2	6·3	0·6	0·7	—	35·4
2.	14·7	44·2	5·5	22·8	5·3	6·2	Tr.	1·3	—	34·3
3.	12·4	39·3	6·7	26·7	8·0	5·1	—	1·9	—	39·8
4.	11·4	42·4	7·9	22·9	7·6	5·6	0·3	1·9	—	36·1
5.	11·2	47·6	8·6	13·6	13·8	3·6	—	1·6	—	31·0
6.	10·7	47·7	19·8	2·6	11·9	5·1	—	1·6	—	19·6
7.	9·2	52·7	12·5	—	9·0	15·1	—	0·6	—	24·1
8.	8·6	36·8	5·2	—	35·8*	5·2†‡	—	—	8·6	41·0
9.	7·6	46·1	9·8	8·8	11·9	13·2	—	2·7	—	33·9
10.	7·2	49·0	21·6	8·9	7·6	5·3	—	0·4	—	21·8
11.	7·1	52·4	7·5	9·0	9·5	11·5	—	2·6	—	30·0
12.	6·3	49·5	19·4	6·1	8·5	9·2	—	0·9	—	23·8
13.	4·7	48·7	7·6	—	28·4*	10·0†	—	0·7	—	38·4
14.	4·4	44·9	13·9	5·2	17·4	10·8	—	2·5	0·7	34·1
15.	4·3	30·5	8·9	10·3	42·7*	2·0†‡	—	1·1	—	55·0
16.	4·3	43·8	15·8	1·2	20·6	5·8	—	1·8	6·7	27·6
17.	3·7	56·3	5·6	5·0	18·5	8·4	—	2·5	—	31·9
18.	3·6	46·8	13·0	3·6	20·4	9·8	—	2·8	—	33·8
19.	1·4	54·4	5·6	29·2	1·9	5·1	—	2·3	—	36·2
20.	1·4	30·7	3·9	4·1	54·3*	5·1†‡	—	0·5	—	63·5

Note : Uralite has been counted as pyroxene when it was obviously so derived. Doubtful cases have been counted as hornblende.

* Partly chloritized.
† Wholly chloritized.
‡ Epidotized.

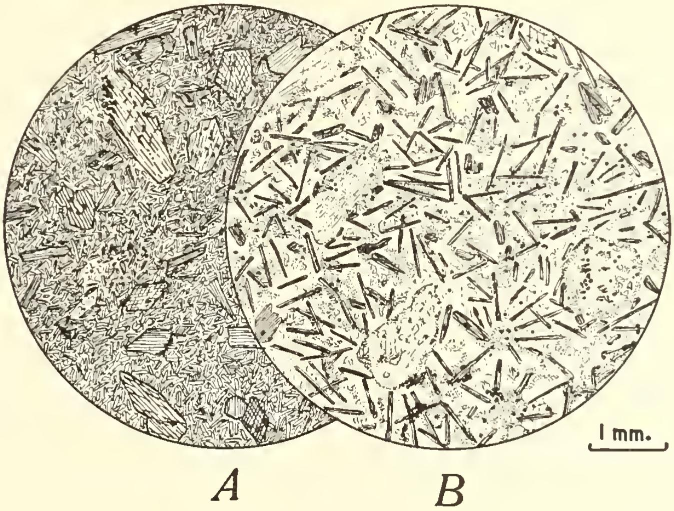
1. Kiandra (Locality A). Anal. W. R. Browne, *Journ. Roy. Soc. N.S.W.*, **56**, 1922, 261. (Anal. VII, Table III).
2–3. Kiandra, Anal. G. A. Joplin.
4. Kiandra (Locality A), Anal. G. A. Joplin.
5. Locality G. 2½ miles S.E. of Junction Shaft. Anal. G. A. Joplin.
6. Locality J. One mile S.S.E. of Junction Shaft. Anal. G. A. Joplin.
7. Locality I. One mile East of Junction Shaft. Anal. G. A. Joplin.
8. Locality G. Bore 5193 at 428 ft. (Anal. IV, Table III). Anal. G. A. Joplin.
9–10. Locality G. Bore 5193 at 170 ft. (Anal. V, Table III). Anal. G. A. Joplin.
11. Locality J. Anal. G. A. Joplin.
12. Locality G. " Diorite " Quarry. Anal. G. A. Joplin.
13. Locality G. Bore 5193 at 248 ft. (Anal. III, Table III). Anal. G. A. Joplin.
14. Locality G. Bore 5193 at 470 ft. Anal. G. A. Joplin.
15. Locality G. " Diorite " Quarry (Anal. I, Table III). Anal. G. A. Joplin.
16. Locality G. " Diorite " Quarry. Anal. G. A. Joplin.
17. Locality G. Bore 5191 at 290 fr. Anal. G. A. Joplin.
18. Locality G. Bore 5193 at 90 ft. Anal. G. A. Joplin.
19. Locality G. " Diorite " Quarry. (Anal. II, Table III). Anal. F. A. Joplin.
20. Locality I. One mile east of Junction Shaft. Anal. G. A. Joplin.

Quartz is present in most of these rocks, and many of them show a fine quartz veining. In the finer grainer types quartz is present in small fine grained aggregates (see Fig. 5*A*), and in the coarser groundmasses it occurs interstitially amongst plagioclase crystals. Except for the habit of the amphibole, the coarser groundmasses resemble fine grained quartz-diorites.

According to Iddings (1913, p. 200), such rocks are more closely related to spessartites than to camptonites on account of the larger amount of amphibole in their groundmass and of the presence of quartz.

Mica-Lamprophyre.

This rock occurs in the borehole at Locality G. and is also met with as dykes at stations 452+75 and 532+00 in the Eucumbene-Tumut Tunnel. As yet it has not been recognized as a surface outcrop in the Tumut Pond area, but the writer has examined a similar rock collected from a dyke by the late Sir Edgeworth David at Thompson's Flat, near Kosciusko, and two closely related types collected by Dr. W. R. Browne east of Boggy Plains from dykes intruding the granite.



Text-fig. 5.

(*A*) Hornblende-lamprophyre from Locality I, showing large idiomorphic phenocrysts of greenish-brown hornblende in a plexus of small idiomorphic laths of hornblende and plagioclase. Magnetite is accessory and in places small aggregates of quartz grains occur, and elsewhere this rock is veined with quartz. ×10.

(*B*) Mica-lamprophyre from Locality G, showing large phenocrysts pseudomorphed by carbonates, quartz, chlorite and magnetite, smaller phenocrysts of biotite in a groundmass of plagioclase, elongated plates of biotite, chlorite and magnetite. ×10.

The specimen from the borehole occurs at the 329-foot level and possibly represents a vein intrusive into monzonites. It is porphyritic with idiomorphic phenocrysts up to 4·5 mm. completely pseudomorphed by aggregates of carbonate, quartz, chlorite and magnetite (Fig. 5*B*) suggesting original pyroxene. In the Thompson's Flat rock a little fresh pyroxene remains as cores, though most of it is altered to uralite and chlorite with a trace of carbonate. Both of the Boggy Plains specimens contain much fresh pyroxene, though some phenocrysts are entirely altered to chlorite. One of these rocks contains a pyroxene phenocryst with a completely serpentinized inclusion suggesting the former presence of olivine. Phenocrysts in the rocks from the Eucumbene-Tumut Tunnel are also altered to chlorite, but a little carbonate is also present, the dyke at station 523+00 being the more altered and less characteristic of the group.

One of the Boggy Plains rocks contains a few altered phenocrysts of plagioclase. In the borehole specimen biotite also occurs as small phenocrysts in extremely elongated thin plates which show every gradation into the smaller flakes of the groundmass.

In this rock the groundmass has an average grain size of 0·75 mm. and consists of plagioclase, biotite, chlorite, carbonates and quartz with accessory magnetite. The Boggy Plains rocks differ from one another in regard to the groundmass. One contains almost completely chloritized flakes of biotite and is slightly more felspathic with some pyrites ; the other has an extremely fine grained groundmass consisting of plagioclase, augite and magnetite.

These rocks bear a close resemblance to kersantites—rocks that Iddings (1913, p. 199) considered to be related to the monzonites—and it is of interest to note that Harper (1919) recorded kersantite dykes in the Adelong granite some thirty miles to the north-north-west, where Vallance (1953) has described other types comparable to the basic rocks in the Snowy Mts. area. The analysis of the Adelong kersantite is plotted on the AFC diagram (Fig. 7) at point 10 and thus falls within the field of the Snowy Mts. rocks.

Mica-Porphyrites.

A vein of this material occurs at 409 feet in the borehole 5193 at Locality G. It is a porphyritic rock with a fluidal groundmass. Comparatively fresh, zoned felspar occurs as phenocrysts about 2 mm. in diameter and granular aggregates of quartz, carbonates and chlorite suggest the former presence of augite phenocrysts. The groundmass consists of plagioclase, quartz and biotite, the last delineating a well marked fluidal fabric.

Except for the presence of plagioclase phenocrysts, this rock is not unlike the mica-lamprophyre occurring 80 feet above it.

Hornblende-quartz-porphyrites.

At stations 654+00 and 649+50 in the Eucumbene-Tumut Tunnel an irregular-shaped body occurs which appears to be contact-altered and in places sheared.

It is a porphyritic rock with phenocrysts of plagioclase, quartz and an altered ferromagnesian mineral, presumably hornblende, in a very fine groundmass.

In the contact-altered rock the ferromagnesian phenocrysts consist of aggregates of criss-cross flakes of reddish brown biotite, obviously pseudomorphing an idiomorphic mineral suggesting hornblende. In the sheared rock these phenocrysts are not well defined and consist of elongated patches of chlorite and iron ores.

Quartz forms idiomorphic crystals (up to 3 mm.) slightly corroded and in the sheared rock it is granulated and strained, although some evidence of strain is also apparent in the thermally altered type.

Plagioclase forms tabular crystals up to 2·5 mm. and is slightly sericitized in the contact rock, but in the sheared specimen it is only just recognisable as an aggregate of sericite, quartz, chlorite and iron ore which merges into a groundmass consisting of the same minerals. The groundmass of the contact-altered rock forms an exceedingly fine crystalline mosaic.

Before alteration these rocks possibly showed some resemblance to the hornblende-lamprophyres, though the characteristic elongated amphibole crystals do not appear to have been present.

Dolerites.

Doleritic rocks occur in the bore 5193 at Locality G., in the bore 5057 about 1 mile upstream from the Tumut Pond dam site, and also as dykes in the Eucumbene-Tumut Tunnel. All are much altered and their identification is difficult and unsatisfactory. Furthermore, there are many individual differences between the rocks that are here grouped together. Unfortunately the present writer has not been able to examine specimens from Jagungal, but this rock has been described by Whitworth (1954) as an amphibolized dolerite with ophitic fabric and the mass is reported to be hornfelsed at the southern end where it is adjacent to the granite.

In bore 5193 these rocks occur at 140 feet and at 177 feet. The upper one consists of laths and small tabular crystals (about 0·2 mm.) of plagioclase much altered to carbonates. These appear to have been wrapped by a ferromagnesian mineral now entirely altered to chlorite with small inclusions of magnetite. Quartz is interstitial. Small (about 2·5 mm. in diameter) ellipsoidal bodies infilled with plagioclase, quartz, carbonates and radiating chlorite were possibly original amygdules or vughs. Some of these have small acicular crystals of magnetite arranged around the outer margin.

At 177 feet the rock is slightly coarser and contains a few much altered elongated crystals of mica suggesting a link with the mica-lamprophyre. This rock also contains epidote and pyrite.

Several very similar rocks occur as dykes in the Eucumbene-Tumut Tunnel. They contain a great deal of calcite and are much altered, but individual descriptions seem unnecessary.

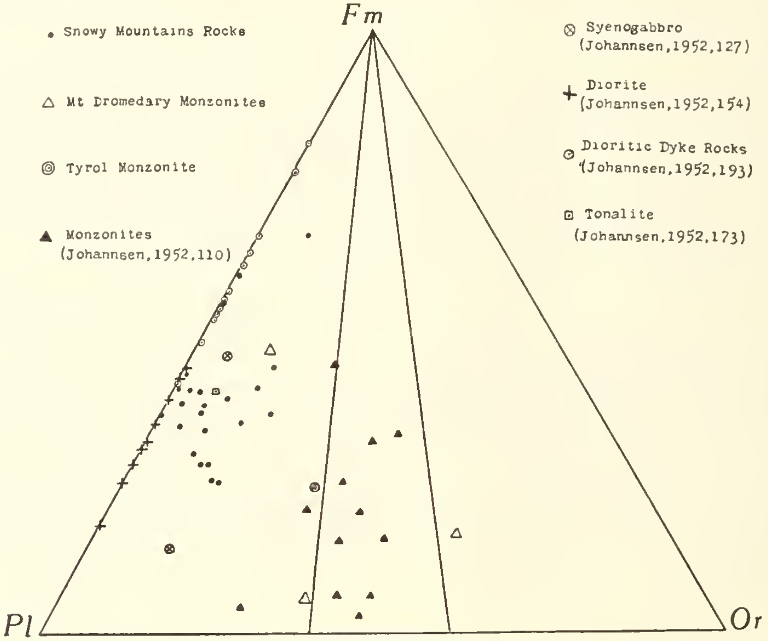
At 84 feet in bore 5057 a slightly sheared and coarser rock occurs. It contains rare phenocrysts of altered plagioclase in a subophitic groundmass consisting of heavily kaolinized plagioclase wrapped by subidiomorphic crystals of hornblende. Large grains of strained quartz are interstitial and the rock is veined by quartz and epidote.

4. NOMENCLATURE OF THE ORTHOCLASE-BEARING ROCKS.

As noted above, the Kiandra rock was originally called a norite (Andrews, 1901) and later re-named an olivine-bearing quartz monzonite (Browne and Greig, 1923). This rock contains 17·9% of orthoclase and 40·1% of plagioclase, and although it has a very distinct monzonitic fabric, it would not be regarded as a monzonite by Nockolds (1954), who considers that the ratio of the amount of potash felspar to total felspar should range within the limits of 40 and 60%, or by Iddings (1913) who lays down that the ratio of plagioclase to orthoclase should be from 5 : 3 to 3 : 5. Tyrrell (1928) considers that the amounts of plagioclase and of orthoclase should be about equal in the monzonites, and he points out that these rocks, as compared with the syenites, show an increase in ferromagnesian minerals and a more calcic plagioclase. Harker (1919), following Brøgger, defines the monzonites as a group with orthoclase and plagioclase in approximately equal proportions.

Reference to Table IV indicates that the volume percentage of orthoclase in a number of the Snowy rocks shows a wide range. These modal analyses are plotted on a triangular diagram in Fig. 6 to show the relative amounts of plagioclase, orthoclase and ferromagnesian minerals. The diagram shows that none of the Snowy Mts. rocks falls within the area prescribed as that of the monzonites by

Nockolds. Modal analyses have also been made of four specimens from the geological collections of the University of Sydney, namely, three monzonites from Mount Dromedary, N.S.W. (Brown, 1930) and one from the Tyrol. It will be noted that the Tyrol rock and one of the Dromedary rocks closely approach Nockolds' boundary, that another Dromedary specimen falls among the Snowy Mts. rocks and that the third has an excess of orthoclase and approaches the syenites. A number of modal analyses have also been taken from tables (Johannsen, 1952) and plotted, and it will be seen that the monzonites mostly fall within the area between 40 and 60% of orthoclase, whereas the Snowy Mts. rocks bear some relation to the tonalites, syenogabbros, diorites and dioritic dyke rocks.



Text-fig. 6.—Triangular diagram showing relative proportions of orthoclase, plagioclase and ferro-magnesian minerals in a number of Snowy Mountains rocks and some types from elsewhere.

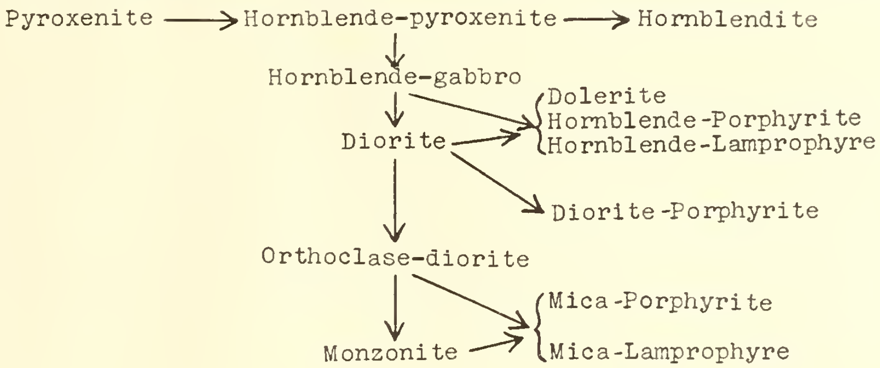
Because of the marked monzonitic fabric, of the presence of fairly basic plagioclase and of the fairly persistent presence of pyroxene, the name monzonite is retained for those types that contain readily recognizable orthoclase and a well marked monzonitic fabric. A glance at Table IV, however, will show that there is a gradation in the amount of orthoclase as well as in pyroxene, and many types rich in hornblende and poor in orthoclase might more appropriately be called orthoclase-bearing diorites.

5. Mutual Relations of the Different Rock Types.

As pointed out above, the field relations have not been examined in very much detail, but the rapid changes from one type to another suggest that large units of the more basic rocks are surrounded by the less basic, and that there are all transitions between them. In the " Diorite " quarry intrusive relations between a monzonite and an orthoclase-bearing diorite are apparent in places, but the only discrete injections are comparatively small dykes and veins.

Reference to the petrography also shows that microscope examination and modal analyses point to a gradation of one type into another ; thus the headings under which each type has been described above are only arbitrary.

The following scheme is an attempt to show these relationships as indicated by the petrography, though no direct genetic connection is necessarily implied.



It is evident that these rocks are all related in space and in time and thus they might be said to belong to a petrological province. Although the monzonites are not commonly considered as normal members of the granodiorite stem, and by some are regarded as belonging to a separate magma type, where monzonites may occur, together with latites, in a distinct petrological province (Brown, 1930 ; Hanlon, Joplin and Noakes, 1952), the literature nevertheless reveals that they are not infrequently associated with diorites and with syenites in many parts of the world. In referring to the Predazzo and Monzoni occurrence, from which the monzonites take their name, Shand (1949) pointed out that a number of rock types occur together and he discussed a hybrid origin.

6. Origin of the Basic Rocks.

The origin of the basic and ultrabasic rocks of the Tumut Pond area is a little obscure, and three possibilities suggest themselves : (1) they are original sills interbedded with the sediments and bear no relation to the contiguous granite ; (2) they are earlier differentiates of the granite magma ; (3) they are products of assimilation, one parent being granite, and the other either a basic rock or a calcareous sediment.

Reference to Fig. 1 will show that they are in very close proximity to the granite and the same relation exists further north (Vallance, 1953), so it seems that their association with the granite is not a fortuitous one, as suggested by (1).

Differentiation versus *Assimilation.*

Unfortunately the field evidence throws little light on the problem though in the " Diorite " quarry at Locality G., where good exposures are available, some intrusive relations are evident and some order of succession can be established. Elsewhere, however, and indeed in many places within this quarry, types appear to grade one into the other as though large blocks of more basic material were completely surrounded by less basic ; the petrography supports this field observation. It is also of interest to note that Vallance (1953) in describing the Adelong norite, which he compares with the Kiandra monzonite, remarks upon the presence of basic clots enriched in olivine and pyroxene that appear to be closely related to the host rocks.

Although some contacts have been observed, and a magmatic origin for at least some of these rocks is beyond dispute, the capricious distribution of the component minerals also suggests partial assimilation of solid material by a magma. Furthermore, the development of large hornblende crystals in the hornblende-pyroxenites and the segregation of such crystals to form patches of hornblendite are reminiscent of the Ach'uaine Hybrids of Sutherland (Read, 1931), and similar observations have been made among hybrid rocks by Deer (1938) and by Joplin (1939).

Many of these rocks, particularly the monzonites, show excellent examples of a discontinuous reaction-series, and in fact the Kiandra rock was used for many years in the Department of Geology, University of Sydney, as an illustration of Bowen's Reaction Principle. Bowen (1922 *a* and *b*) discussed this principle with reference both to differentiation and to reaction between acid magma and solid basic material. In a normal differentiation series it would be unusual for a complete sequence of discontinuous reaction minerals to be present in a single specimen, yet such is the case in many of the monzonites. If this took place during differentiation, it would suggest great and sudden variations of temperature during cooling, whereas it could be regarded as fairly normal in the case of solid material that was undergoing both mechanical and chemical assimilation in an acid magma.

Zoned plagioclase, though present in most rocks, is not the continuous type that might be expected in a differentiation series. A rapidly fluctuating temperature might explain this too, but it would not explain the fact that a plagioclase of intermediate composition normally surrounds the zoned crystals. Such an arrangement, on the other hand, can be explained readily by assimilation. The basic, somewhat altered cores of labradorite represent the original felspar of the basic parent, the fresh oligoclase rims represent the phase which is being deposited by the magma at the time of incorporation of the basic material, and the surrounding andesine has formed as a result of some assimilation and has been deposited later from a basified magma.

Although a monzonitic fabric may develop during the course of crystallization from a differentiating magma, it is a fabric that might well be expected in a rock of hybrid origin, especially when the amount of orthoclase and of quartz shows such marked variation. Further reference to Table IV will show that although it has been arranged in order of decreasing orthoclase, there is no corresponding regular gradation in the volume percentages of other minerals ; this again is a departure from a normal differentiation series.

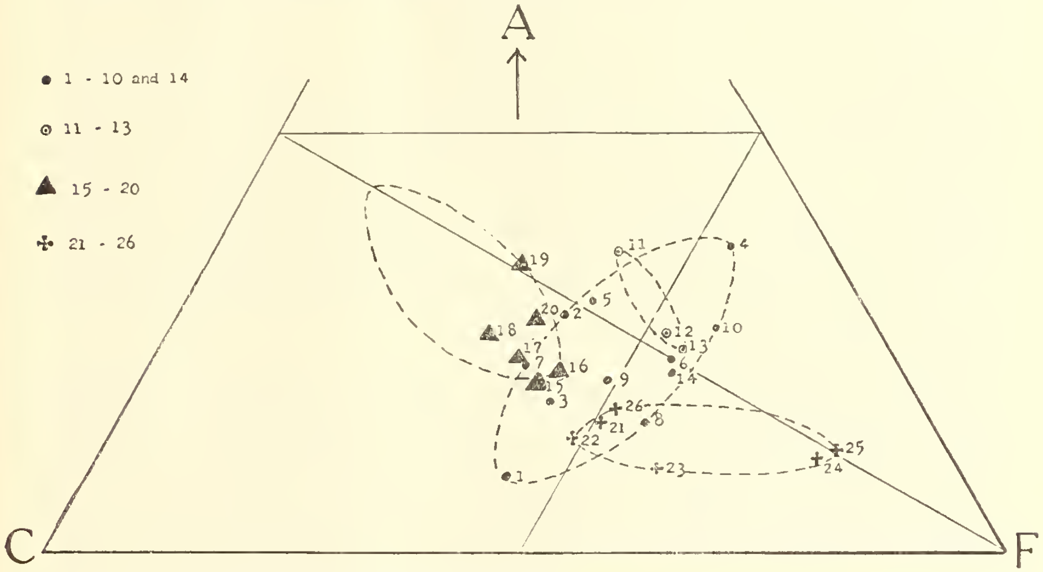
In Table II three modal analyses of diorites and one of hornblende-gabbro are compared. Unfortunately this is an insufficient number of analyses upon which to base conclusions regarding origin, but it is evident that the volume percentages show some regular gradation, and there appears to be more evidence of differentiation here than among the orthoclase-bearing types in Table IV. Diorites of doubtful origin have been found among the Ach'uaine Hybrids and Read (1931) has pointed out that they have some resemblances to the intermediate type of Ach'uaine Hybrid and are probably related. Although the origin of the Snowy Mts. diorites is also doubtful, they are most certainly related both to the ultrabasic rocks and to the monzonites.

Thus the weight of evidence seems to favour assimilation rather than differentiation for the origin of these rocks, and if such is the case then the nature of the basic parent must now be considered.

Nature of the Basic Parent.

As indicated above (p. 121), two types of basic magma appear to have antedated the granite at Cooma. One, related to a norite, has given rise to ultrabasic types and is itself metasomatized by the granite (Browne, 1914 ;

Joplin, 1939, 1942), and the other, a basic granulite, appears to have affinities to the Porphyritic Central Magma type, and is found only as inclusions within the granite (Joplin, 1942); furthermore, recent work (Walker and Joplin in MS.) suggests that some of these basic granulites may be of sedimentary origin. Although neither of these types is known to crop out in the Tumut Pond–Happy Jacks area, either may occur among the deeper-seated rocks and must be considered as a possible parent of the hybrids.



Text-fig. 7.—AFC diagram showing fields for Porphyritic Central Magma type, magnesia-rich amphibolites at Cooma and Snowy Mts. and Adelong rocks.

1. Pyroxenite, Locality K.
2. Altered monzonite, Locality G.
3. Orthoclase-bearing diorite, Locality G.
4. Altered monzonite, Locality G.
5. Altered monzonite, Locality G.
6. Orthoclase-bearing diorite or monzonite, Locality G.
7. Quartz-bearing olivine-monzonite, Kiandra, Locality A.
8. Monzonite-Porphyry, Kiandra, Locality A.
9. Norite, Adelong.
10. Kersantite, Adelong.
11. Pyroxene-granulite, Hume Weir, Albury.
12. Altered basic rock, Hume Weir, Albury.
13. "Trachytic" rock, Albury.
14. Xenolith in equilibrium with granite, Murrumbucca.
15. Basic xenolith, Murrumbucca.
16. Hornblende-granulite, Cooma.
17. Amphibolite, Adelong area.
18. Hornblende-pyroxene granulite, Cooma.
19. Basic xenolith, Murrumbucca.
20. Basic xenolith, Murrumbucca.
21. Coarse phase of heterogeneous amphibolite, Cooma.
22. Amphibolite (relict gabbro), Cooma.
23. Fine-grained granoblastic amphibolite, Cooma.
24. Ultrabasic inclusion, Adelong area.
25. Tremolite-chlorite schist, Cooma.
26. Fine phase of heterogeneous amphibolite.

Again there is little doubt that the hybrids are very closely associated with the pyroxenite, which appears to have a magmatic origin since a mass of it occurs as a small irregular intrusion with sound contacts at stations 506+70 to 508+50 in the Eucumbene-Tumut Tunnel. Thus this too must be considered in a discussion on the ancestry of the hybrids.

It was shown on an AFC diagram (Joplin, 1942) that the basic rocks at Cooma fall into two well-defined separate fields. These have been re-plotted in Fig. 7, and the field for the magnesia-rich type extended to include two ultrabasic rocks, one from the Cooma area and one from Wantabadgery to the north-north-west (Vallance, 1953). Basic rocks from the Snowy Mts. region, from the Adelong area 34 miles north, and from the Albury district about 150 miles west, are also plotted, as well as several xenoliths from the Silurian granite north of Cooma. It is clear that these occupy a separate field which is distinct from the other two, but which slightly overlaps them. It was suggested (Joplin, 1946) that the three basic rocks from Albury might compare with the pyroxene-granulites of Cooma, but it is now apparent that they fall into a smaller separate field and resemble the Snowy Mts. types more closely than the Porphyritic Central Magma type with which they were originally compared.

Points 15 and 19 are the plots of basic xenoliths in the Silurian granite on Murrumbucca Creek, north of Cooma, and it is obvious that they are related to the granulites, whereas point 14, which is a xenolith in almost complete equilibrium with the granite, occupies a position in the same field as the Snowy Mts. basic rocks. If it can be assumed that this xenolith had an original composition similar to those represented by points 15 and 19, then it can be suggested that the Snowy Mts. basic rocks have arisen from a magma much hybridized by the incorporation of material similar to the Cooma granulites and possibly related to the Porphyritic Central Magma type or to a highly metamorphosed calcareous rock. Unfortunately the identity of the xenolith (point 14) is uncertain, so this inference cannot be made with any confidence.

Point 1 represents the analysis of a pyroxenite with which these rocks are undoubtedly associated in the field. It falls within the area arbitrarily delineated for this group of rocks, and appears to differ widely from the two ultrabasic rocks 24 and 25, which are associated with the more magnesia-rich type of magma. The fact that this ultrabasic rock contains greater C and A relative to F on the AFC diagram suggests that it represents a distinct ultrabasic magma, that it is an ultrabasic differentiate of the Porphyritic Central Magma type, that it is a differentiate of some other magma unknown in the Cooma area, or that it is a metasomatized calcareous rock. Unfortunately there is no means of solving this problem, but two observations are pertinent, namely, the relatively small amount of pyroxenite and the suggestive positions of points 14, 15 and 19 on the AFC diagram. The limited amount of pyroxenite and its persistent association with the other basic rocks strengthen the view that it is a differentiate rather than a separate ultrabasic magma, whilst its position on the diagram relative to those of the three xenoliths, and its close field relation to the gabbros, lend slight support to the view that it is a differentiate of the Porphyritic Central Magma type.

Although hornblende is present in most of the rocks described in this paper, it is noteworthy that pyroxene is a prominent mineral, and that much of the hornblende is either pseudomorphing or moulded on to original pyroxene. Pyroxene is the typical ferromagnesian mineral of the basic extrusives and of the intrusives associated with the stable areas of the crust, while hornblende is more common in the granitic complexes of the geosynclines, where hornblendites are typically developed and where pyroxenites are rare. For this reason the writer has some hesitation in suggesting that the pyroxenite is genetically related to the Silurian granite. On the other hand, pyroxenites are not unknown as associates of the Porphyritic Central Magma, a magma characterized by the presence of pyroxene. The essential minerals of rocks belonging to the Porphyritic Central Magma type are basic plagioclase, augite and iron ores. This magma is distinguished by the early separation of basic felspar, thus the normal basic differentiate is an anorthosite, though veins of pyroxenite are recorded in the Great Eucrite Ring-dyke of Ardnamurchan (Richey and Thomas, 1930). There is some evidence that such a magma gave rise to small sills or flows in the Cooma area, so it is not unreasonable to assume that a series of slightly larger differentiated sills occurred at some depth below the present level of erosion in the Snowy Mts. area.

The Hybridization Process.

In a few places the basic rocks have been altered by the granite and, with the exception of the lamprophyres, there is little doubt that they antedate most of the granites in the Snowy Mts. area. Furthermore, their marginal disposition to the (?) Silurian granite suggests that they are related to it and probably belong to the same orogeny.

If a hybrid origin is postulated the granite is the likely acid parent, and assimilation must have taken place at a deep level before the emplacement of the granite at the present level of erosion. If such an assumption be made, then at this level the granite magma, or partial magma, would have sufficient energy to completely assimilate deep-seated basic rocks consisting of pyroxenites and gabbro by a process of reaction. Thus a basified acid magma, containing fragments with which it was in complete equilibrium, might be emplaced at higher levels as a diorite. It is probable that larger fragments, which had failed to attain equilibrium, would also travel upwards with this magma and occur within it as partly resorbed xenoliths of pyroxenite or gabbro.

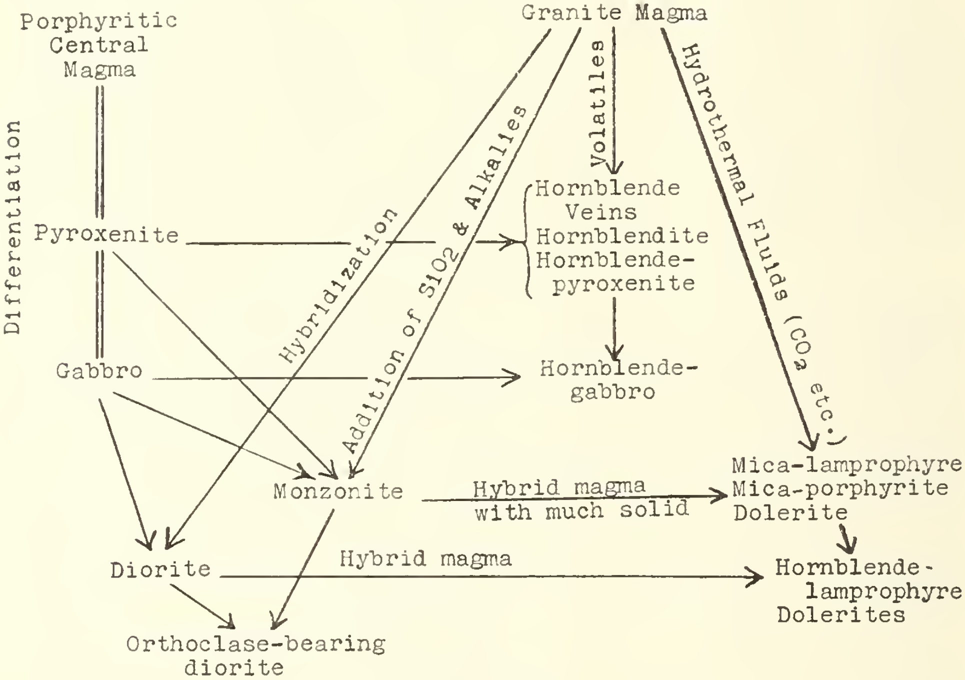
Possibly at a higher level and a slightly later stage, other sills of the gabbro and pyroxenite were invaded by solutions containing silica and alkalies arising in advance of the main granite intrusion, and these would produce both orthoclase-mica-diorites and monzonites. At this higher level the energy, and possibly the time, was insufficient to bring about complete equilibrium, and thus there is a more complete discontinuous reaction-series exhibited by these rocks than by the diorites that formed at a deeper level. Nevertheless, there was still sufficient energy to bring about a fairly complete mechanical disintegration, and sufficient liquid phase for the material to move upward as a mobile mass to be injected at the present level of erosion.

It seems likely that the rise of the granite followed closely upon that of the monzonite, and that accompanying volatiles were responsible for the formation of large hornblende crystals *in situ* among rocks of appropriate composition, thus forming hornblendites and hornblende-gabbros.

Shortly afterwards, when the granite and basic hybrids that had been emplaced at the present level of erosion were essentially solid, there was a discrete injection of small dykes and veins of lamprophyre, porphyrite and dolerite. These are highly altered rocks, and it is obvious that carbon dioxide played an important rôle in their formation. It seems likely that they were derived from a deeper level of hybrid magma and subjected to hydrothermal action at the end stage of the consolidation of the granite after emplacement.

Reference to Table III shows that two of the altered orthoclase-diorites or monzonites (Anal. IV, V) contain higher potash than the two fresh monzonites (Anal. VI and VII), yet if the corresponding modes be compared (Table IV, Nos. 8, 9, 10, 2 and 1), it will be seen that the orthoclase and biotite content is much lower in the altered rocks and in fact bears no relation to the amount of potash present. It may be further noted that the altered rocks contain lower silica and higher alumina as compared with the fresh monzonites, and though this may be due to alteration it seems more likely that the altered rocks were more closely allied to the orthoclase-diorites and originally may have been more basic than those analysed (Table III, I and II), there being an addition of silica and of potash at a late stage, which caused sericitization of the felspar and some silicification. A decrease in the amount of magnesia may imply a movement of chlorite-bearing solutions, and the increase of ferric iron relative to ferrous iron further suggests alteration. In the field the pink rock shows an intrusive front against the orthoclase-diorites, and it seems fairly obvious that this is brought about by an invasion of hydrothermal solutions that have not only brought in potash and silica, but have brought about alteration and movement of many of the components of the rock. This possibly took place during the last stage of the cooling history of the granite, and perhaps slightly later than or approximately at the same time as the discrete injections.

This study is not sufficiently detailed to permit further elaboration of these processes, and these suggestions are put forward only as a tentative explanation of the origin of this interesting and complex group of rocks. An attempt is made to indicate their origin schematically below.



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ON A FORMULA OF THE CONVOLUTION TYPE RELATED TO HANKEL TRANSFORMS.

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Summary.

Assuming that the Hankel transform is defined by

$$\bar{f}(u)=T_\nu[f(x)]=\int_0^\infty xJ_\nu(xu)f(x)dx$$

the formula

$$T_\nu\left[\frac{2^{-\nu}x^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\infty\int_0^\pi\frac{f(w)g(s)s^{\nu+1}\sin^{2\nu}\alpha}{w^\nu}d\alpha ds\right]$$
$$=u^{-\nu}\bar{f}(u)\bar{g}(u)$$

with $w^2=x^2+s^2-2xs\cos\alpha$, $w\geqq 0$ is discussed.

Incidentally, the formula

$$T_\nu^{-1}[u^{-\nu}J_\nu(us)\bar{f}(u)]=\frac{2^{-\nu}s^\nu x^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\infty\frac{f(w)}{w^\nu}\sin^{2\nu}\alpha d\alpha$$

is derived.

I

The n-dimensional Fourier Transform of a function $f_0(x_1, \ldots, x_n)$ is defined by

$$f_1(\xi_n, \ldots, \xi_n)\equiv F_n[f_0(x_1, \ldots, x_n)]$$
$$=\frac{1}{(2\pi)^{\frac{1}{2}n}}\int_{-\infty}^\infty\ldots\int_{-\infty}^\infty e^{i(\xi\cdot\eta)}f_0(x_1, \ldots, x_n)dx_1, \ldots, dx_n, \quad \ldots (1.1)$$

where $\xi\cdot\eta$ signifies the dot product of the vectors $(\xi_1, \ldots, \xi_n)$ and $(x_1, \ldots, x_n)$.

The inversion formula for this transform is

$$f_0(x_1, \ldots, x_n)\equiv F_n^{-1}[f_1(\xi_1, \ldots, \xi_n)]$$
$$=\frac{1}{(2\pi)^{\frac{1}{2}n}}\int_{-\infty}^\infty\ldots\int_{-\infty}^\infty e^{-i(\xi\cdot\eta)}f_1(\xi_1, \ldots, \xi_n)d\xi_1, \ldots, d\xi_n. \quad \ldots (1.2)$$

It is well known that if $f_0(x_1, \ldots, x_n)\equiv f_0(r)$ where

$$r^2=x_1^2+\ldots+x_n^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (1.3)$$

then the equation (1.1) reduces to

$$\rho^{\frac{1}{2}n-1}f_1(\rho)=\int_0^\infty rJ_{\frac{1}{2}n-1}(\rho r)[r^{\frac{1}{2}n-1}f_0(r)]dr \quad \ldots\ldots\ldots (1.4)$$

where $f_1(\rho)\equiv f_1(\xi_1, \ldots, \xi_n)$ and

$$\rho^2=\xi_1^2+\ldots+\xi_n^2. \qquad \ldots\ldots\ldots\ldots \quad (1.5)$$

With this modification, equation (1.2) reduces to

$$r^{\frac{1}{2}n-1}f_0(r)=\int_0^\infty \rho J_{\frac{1}{2}n-1}(\rho r)[\rho^{\frac{1}{2}n-1}f_1(\rho)]d\rho \qquad \ldots\ldots \quad (1.6)$$

The convolution formula connected with the transform (1.1) is

$$F_n\left[\frac{1}{(2\pi)^{\frac{1}{2}n}}\int_{-\infty}^\infty \cdots \int_{-\infty}^\infty f_0(x_1-y_1, \ldots, x_n-y_n)g_0(y_1, \ldots, y_n)dy_1, \ldots, dy_n\right]$$
$$=f_1(\xi_1, \ldots, \xi_n)g_1(\xi_1, \ldots, \xi_n). \qquad \ldots\ldots\ldots\ldots \quad (1.7)$$

If $f_0(x_1, \ldots, x_n)\equiv f_0(r)$ and $g_0(x_1, \ldots, x_n)\equiv g_0(r)$, this equation reduces to

$$F_n\left[\frac{2^{1-\frac{1}{2}n}}{\Gamma(\frac{1}{2})\Gamma(\frac{1}{2}n-\frac{1}{2})}\int_0^\infty \int_0^\pi f_0(W)g_0(s)s^{n-1}\sin^{n-2}\alpha\, d\alpha ds\right]$$
$$=f_1(\rho)g_1(\rho) \qquad \ldots\ldots\ldots\ldots \quad (1.8)$$

where $W^2=r^2+s^2-2rs\cos\alpha$.

We now make the substitutions

$$r^{\frac{1}{2}n-1}f_0(r)=f(r), \qquad r^{\frac{1}{2}n-1}g_0(r)=g(r)$$
$$\rho^{\frac{1}{2}n-1}f_1(\rho)=\bar{f}(\rho), \qquad \rho^{\frac{1}{2}n-1}g_1(\rho)=\bar{g}(\rho)$$
$$n=2\nu+2,\ r=x,\ \rho=u,$$

and obtain

$$\bar{f}(u)=\int_0^\infty xJ_\nu(ux)f(x)dx$$
$$\equiv T_\nu[f(x)], \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.9a)$$

$$f(x)=\int_0^\infty uJ_\nu(ux)\bar{f}(u)du$$
$$\equiv T_\nu^{-1}[\bar{f}(u)], \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.9b)$$

and

$$T_\nu\left[\frac{2^{-\nu}x^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\infty \int_0^\pi \frac{f(w)g(s)s^{\nu+1}\sin^{2\nu}\alpha}{w^\nu}d\alpha ds\right]$$
$$=u^{-\nu}\bar{f}(u)\bar{g}(x) \qquad \ldots\ldots\ldots\ldots \quad (1.10a)$$

where $w^2=x^2+s^2-2xs\cos\alpha$.

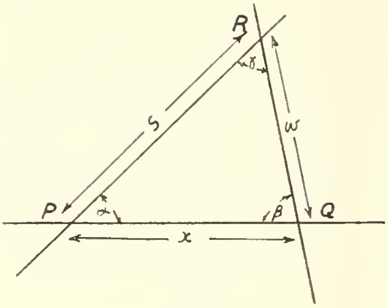
Equation (1.10a) can be interpreted as either

$$\frac{2^{-\nu}}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\infty x^{1+\nu}J^\nu(xu)dx\int_0^\infty \int_0^\pi \frac{f(w)g(s)s^{\nu+1}\sin^{2\nu}\alpha}{w^\nu}d\alpha ds$$
$$=u^{-\nu}\bar{f}(u)\bar{g}(u). \qquad \ldots\ldots\ldots\ldots \quad (1.10b)$$

or as

$$\int_0^\infty u^{1-\nu}\bar{f}(u)\bar{g}(u)J_\nu(xu)du$$
$$=\frac{2^{-\nu}x^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\infty \int_0^\pi \frac{f(w)g(s)s^{\nu+1}\sin^{2\nu}\alpha}{w^\nu}d\alpha ds \qquad \ldots\ldots\ldots \quad (1.10c)$$

Referring to the diagram



which needs no description, it is easily seen that the equation (1.10a) may be written in the symmetrical form

$$u^{-\nu}\bar{f}(u)\bar{g}(u)=T_\nu\left[\frac{2^{-\nu}x^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_A f(w)g(s)\sin^\nu\alpha\,\sin^\nu\beta\, dA\right] \quad .. \; (1.10d)$$

where the integral is taken over the upper half plane.

The formal work of this section suggests that formulæ (1.10) hold only for $\nu=\frac{1}{2}n-1$ (n=an integer $\geqq 1$). We will prove two cases in which the equations hold for all $\nu>-\frac{1}{2}$.

2

Suppose that $x^{\frac{1}{2}}f(x)$ and $x^{\frac{1}{2}}g(x)$ belong to $L^2(0, \infty)$, then it is well known that $u^{\frac{1}{2}}\bar{f}(u)$ and $u^{\frac{1}{2}}\bar{g}(u)$ belong to $L^2(0, \infty)$ where the integrals in equations (1.9a) and (1.9b) are to be understood to be mean-square integrals. In particular

$$f(x)=\underset{p\to\infty}{\text{l.i.m.}}\int_0^p uJ_\nu(xu)\bar{f}(u)du.$$

The Parseval formula for this transform takes the form

$$\int_0^\infty xf(x)g(x)dx=\int_0^\infty u\bar{f}(u)\bar{g}(u)du. \quad \ldots\ldots\ldots\ldots \; (2.1)$$

If

$$g(x)=x^\nu,\ 0<x<\eta$$
$$0,\quad \eta<x$$

then

$$\bar{g}(u)=u^{-1}\eta^{\nu+1}J_{\nu+1}(u\eta).$$

Substituting these values for $g(x)$ and $\bar{g}(u)$ in equation (2.1), we obtain

$$\int_0^\eta x^{\nu+1}f(x)dx=\eta^{\nu+1}\int_0^\infty J_{\nu+1}(u\eta)\bar{f}(u)du, \quad \ldots . \; (2.2)$$

which leads to

$$f(x)=\frac{1}{x^{\nu+1}}\frac{d}{dx}\left[x^{\nu+1}\int_0^\infty J_{\nu+1}(ux)\bar{f}(u)du\right] \quad \ldots\ldots\ldots\ldots \; (2.3)$$

(The integral on the right is an L^1-integral and the equation holds almost everywhere for $\nu>-\frac{1}{2}$.)

We now find a formula for $T_\nu^{-1}[u^{-\nu}J^{\nu}(us)\bar{f}(u)]$, $s>0$ and $\nu>-\frac{1}{2}$.

Since $u^{-\nu}J_\nu(us)$ is bounded, $u^{\frac{1}{2}-\nu}J_\nu(us)\bar{f}(u)$ belongs to $L^2(0,\infty)$ whenever $u^{\frac{1}{2}}\bar{f}(u)$ belongs to $L^2(0,\infty)$.

Using Watson, p. 397 (16) (somewhat modified), we find that

$$I\equiv\int_0^\infty u^{-\nu}J_\nu(us)J_{\nu+1}(ux)\bar{f}(u)du$$
$$=\frac{2^{-\nu}x^\nu s^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\infty\int_0^\pi\frac{J_{\nu+1}(uw)(x-s\cos\alpha)\sin^{2\nu}\alpha\bar{f}(u)}{w^{\nu+1}}d\alpha du$$

where again $w^2=x^2+s^2-2xs\cos\alpha$.

Observing that when $x\neq s$, $w\geqq|x-s|$ and when $x=s$, $w=2x\sin\frac{1}{2}\alpha$, we can show that the integral converges absolutely, which allows the order of integration to be interchanged. Thus

$$I=\frac{2^{-\nu}x^\nu s^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\pi\frac{(x-s\cos\alpha)\sin^{2\nu}\alpha}{w^{\nu+1}}d\alpha\int_0^\infty J_{\nu+1}(uw)\bar{f}(u)du$$
$$=\frac{2^{-\nu}x^\nu s^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\pi\frac{(x-s\cos\alpha)\sin^{2\nu}\alpha}{w^{2\nu+2}}d\alpha\int_0^w y^{\nu+1}f(y)dy$$

(from equation (2.2)).

Then

$$\frac{d}{dx}[x^{\nu+1}I]=\frac{2^{-\nu}s^\nu x^{2\nu}}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\pi\left[-\left\{\frac{(2\nu+1)s\sin^{2\nu}\alpha\cos\alpha}{w^{2\nu+2}}+\frac{(2\nu+2)xs^2\sin^{2\nu+2}\alpha}{w^{2\nu+4}}\right\}\right.$$
$$\left.\int_0^w y^{\nu+1}f(y)dy-\frac{xs^2\sin^{2\nu+2}\alpha}{w^{\nu+2}}f(w)+\frac{x\sin^{2\nu}\alpha}{w^\nu}f(w)\right]d\alpha$$

(In order to justify the differentiation under the integral sign we observe that $f(w)$ belongs to $L^1(a,b)$ for finite a and b, and then use the properties of w, just quoted, in conjunction with McShane, p. 217, Coroll. 39.2.)

$$=\frac{2^{-\nu}s^\nu x^{2\nu}}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\pi\left[-\frac{d}{d\alpha}\left\{\frac{s\sin^{2\nu+1}\alpha}{w^{2\nu+2}}\int_0^w y^{\nu+1}f(y)dy\right\}+\frac{x\sin^{2\nu}\alpha}{w^\nu}f(w)\right]d\alpha$$
$$=\frac{2^{-\nu}s^\nu x^{2\nu+1}}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\pi\frac{f(w)}{w^\nu}\sin^{2\nu}\alpha d\alpha.$$

Then equation (2.3) shows that

$$T_\nu^{-1}[u^{-\nu}J_\nu(us)\bar{f}(u)]$$
$$=\frac{2^{-\nu}s^\nu x^\nu}{\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})}\int_0^\pi\frac{f(w)}{w^\nu}\sin^{2\nu}\alpha d\alpha. \quad \ldots\ldots\ldots\ldots (2.4)$$

We now replace $\bar{f}(u)$ in equation (2.1) by $u^{-\nu}J_\nu(us)\bar{f}(u)$ and obtain

$$\int_0^\infty\int_0^\pi\frac{s^\nu x^{\nu+1}f(w)g(x)\sin^{2\nu}\alpha}{2^\nu\Gamma(\frac{1}{2})\Gamma(\nu+\frac{1}{2})w^\nu}d\alpha dx$$
$$=\int_0^\infty uJ_\nu(us)[u^{-\nu}\bar{f}(u)\bar{g}(u)]du.$$

(the last integral being an L^1-integral).

Interchanging x and s leads to

$$\int_0^\infty \int_0^\pi \frac{x^\nu s^{\nu+1} f(w) g(s) \sin^{2\nu} \alpha}{2^\nu \Gamma(\frac{1}{2}) \Gamma(\nu+\frac{1}{2}) w^\nu} d\alpha ds$$

$$= \int_0^\infty u J_\nu(ux) [u^{-\nu} \bar{f}(u) \bar{g}(u)] du. \quad \ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

We have thus proved that equation (1.10*c*) holds if $x^{\frac{1}{2}} f(x)$ and $x^{\frac{1}{2}} g(x)$ belong to $L^2(0, \infty)$, the integrals being L^1-integrals.

3

In this section, we will show that equation (1.10*b*) holds if $x^{\frac{1}{2}} f(x)$, $x^{\frac{1}{2}} g(x)$ and $x^{\nu+1} g(x)$ belong to $L^1(0, \infty)$.

The transform in this case is defined by

$$T_\nu[f(x)] = \int_0^\infty x J_\nu(ux) f(x) dx. \quad \ldots\ldots\ldots\ldots \quad (3.1)$$

Writing $2^{-\nu} h(x) / \Gamma(\frac{1}{2}) \Gamma(\nu+\frac{1}{2})$ for the right side of equation (1.10*c*), we will prove that $x^{\frac{1}{2}} h(x)$ belongs to $L^1(0, \infty)$.

Now

$$\int_0^\infty \int_0^\pi x^{\frac{1}{2}+\nu} s^{\nu+1} w^{-\nu} \mid f(w) \mid\mid g(s) \mid \sin^{2\nu} \alpha d\alpha dx$$

$$= s^{\nu+1} \mid g(s) \mid \int_0^\infty \int_0^\pi \mid f(w) \mid \sin^{\nu-\frac{1}{2}} \gamma \sin^{\nu+\frac{1}{2}} \alpha \, w^{-\frac{1}{2}} x d\alpha dx$$

$$= s^{\nu+1} \mid g(s) \mid \int_0^\infty \int_0^\pi \mid f(w) \mid \sin^{\nu-\frac{1}{2}} \gamma \sin^{\nu+\frac{1}{2}} \alpha \, w^{\frac{1}{2}} d\gamma dw$$

(changing the origin of co-ordinates from P to Q, see figure)

$$\leqq C s^{\nu+1} \mid g(s) \mid \int_0^\infty w^{\frac{1}{2}} \mid f(w) \mid dw$$

where $C = \int_0^\pi \sin^{\nu-\frac{1}{2}} \gamma d\gamma$.

Thus

$$\int_0^\infty \int_0^\infty \int_0^\pi x^{\frac{1}{2}+\nu} s^{\nu+1} w^{-\nu} \mid f(w) \mid\mid g(s) \mid \sin^{2\nu} \alpha d\alpha dx ds$$

$$\leqq C \int_0^\infty s^{\nu+1} \mid g(s) \mid ds \int_0^\infty w^{\frac{1}{2}} \mid f(w) \mid dw.$$

This indicates that the integral on the left of the last inequality converges absolutely. We may then change the order of integration to obtain the required result.

Now

$$\int_0^\infty \int_0^\infty \int_0^\pi x^{\nu+1} J_\nu(xu) s^{\nu+1} w^{-\nu} f(w) g(s) \sin^{2\nu} \alpha d\alpha ds dx$$

$$= \int_0^\infty s^{\nu+1} g(s) ds \int_0^\infty \int_0^\pi x^{\nu+1} J_\nu(xu) w^{-\nu} f(w) \sin^{2\nu} \alpha d\alpha dx \quad \ldots\ldots \quad (3.2)$$

(by absolute convergence)

$$=\int_0^\infty s^{\nu+1}g(s)ds\int_0^\infty\int_0^\pi x^{-\nu}w^{\nu+1}J_\nu(xu)\sin^{2\nu}\gamma f(w)d\gamma dw$$

(changing the origin from P to Q).

$$=2^\nu\Gamma(\nu+\tfrac{1}{2})\Gamma(\tfrac{1}{2})u^{-\nu}\int_0^\infty wJ_\nu(uw)f(w)dw\int_0^\infty sJ_\nu(us)g(s)ds$$

(recalling that $x^2=s^2+w^2-2sw\cos\gamma$ and using Watson, p. 367 (16))

$$=2^\nu\Gamma(\nu+\tfrac{1}{2})\Gamma(\tfrac{1}{2})u^{-\nu}\bar{f}(u)\bar{g}(u). \quad\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Then comparing equations (3.2) and (3.3), we see that equation (1.10*b*) holds under the conditions stated at the beginning of this section.

4

In this section, we note two interesting applications for the case $\nu=0$. In this case the equation (1.10*a*) reduces to

$$T_0^{-1}[\bar{f}(u)\bar{g}(u)]=\frac{1}{\pi}\int_0^\infty\int_0^\pi f(w)g(s)d\alpha ds \quad\ldots\ldots\ldots\ldots \quad (4.1)$$

From Watson, p. 485 (5), we find

$$T_0\left[\frac{1}{x^2+k^2}\right]=K_0(uk). \quad\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

Thus

$$\int_0^\infty uJ_0(ux)[K_0(uk)]^2du=\frac{1}{\pi}\int_0^\infty\int_0^\pi\frac{sd\alpha ds}{(s^2+k^2)(x^2+s^2-2xs\cos\alpha+k^2)}$$

$$=\int_0^\infty\frac{sds}{(s^2+k^2)[(s^2+x^2+k^2)^2-4x^2s^2]^{\frac{1}{2}}}$$

$$=\frac{1}{2x(x^2+4k^2)^{\frac{1}{2}}}\left[\sinh^{-1}\frac{x}{2k}\left(\frac{x^2+3k^2}{k^2}\right)+\sinh^{-1}\frac{x}{2k}\right]$$

$$=\frac{1}{x(x^2+4k^2)^{\frac{1}{2}}}\sinh^{-1}\frac{x}{2k}$$

(compare with Erdelyi, p. 16 (32), where this result appears in a different form).

Consider the equation

$$\frac{d^2y}{dx^2}+\frac{1}{x}\frac{dy}{dx}-k^2y=f(x) \quad\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Assuming that $f(x)$ is a suitable function, we take the T_0-transform of equation (4.3) and obtain

$$-u^2\bar{y}-k^2\bar{y}=\bar{f}(u)$$

where $T_0[y(x)]=\bar{y}(u)$. Thus

$$\bar{y}(u)=-\frac{1}{u^2+k^2}\bar{f}(u).$$

Then referring to equations (4.1) and (4.2) we find the particular solution

$$y(x) = -\frac{1}{\pi}\int_0^\infty\int_0^\pi K_0(kw)f(s)d\alpha ds$$

of equation (4.3). This leads to the "general" solution of the equation in the form

$$y(x) = AI_0(kx) + BK_0(kx) - \frac{1}{\pi}\int_0^\infty\int_0^\pi K_0(kw)f(s)d\alpha ds.$$

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THE GEOCHEMICAL BEHAVIOUR OF ELEMENTS IN METEORITES.

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With four Text-figures.

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ABSTRACT.

The geochemical behaviour of selected elements is discussed relative to their observed distributions between the silicate, sulphide and metal phases of stony-iron meteorites. Furthermore, the observed distribution of certain elements in iron meteorites is discussed relative to the behaviour of these elements during the crystallization of an iron-nickel melt forming the core of the parent meteorite body.

INTRODUCTION.

In 1937, Goldschmidt suggested an empirical geochemical classification of the elements into three groups—siderophile, chalcophile and lithophile—depending on whether the elements tended to concentrate in either metal, sulphide, or oxide+silicate phases, respectively. As a basis for his classification, Goldschmidt used the data available on the observed distributions between the metal, sulphide and silicate slag phases forming in metallurgical processes as well as data on the distributions of elements in iron meteorites, troilite (Fe S) from both stony and iron meteorites, and the silicate portion of the stony meteorites. Many of the data on distributions in meteorites which were available to him are now considered to be of rather dubious reliability. Furthermore, it now seems most unlikely that the silicate, sulphide and metal phases of chondritic stony meteorites were ever in equilibrium with regard to the distribution of trace elements, since all indications are that these meteorites are essentially consolidated aggregates of all three phases (Lovering, 1957, *b* & *c*). It is not surprising, then, that Goldschmidt's geochemical classification of the elements (see Goldschmidt, 1954) has not always accorded with the behaviour of elements predicted from their thermodynamic and atomistic properties.

The only primary meteorites known in which silicate (+oxide), sulphide (+phosphide) and metal phases exist and in which the distribution of elements can be taken as representing equilibrium distributions at temperatures of up to 2000° K and of between 10^4 and 10^5 atmospheres are the stony-iron meteorites (Lovering, 1957*b*). Of these the pallasites are by far the most common (70 per cent. of the total number) and are composed of olivine crystals (of composition about forsterite 80 : fayalite 20) and very minor oxide (magnetite and probably chromite) phases embedded in a base of iron-nickel alloy (about 11 per cent. nickel) with troilite (FeS) and some schreibersite (Fe_3P). Olivine and metal each make up about 50 per cent. by weight, while troilite and schreibersite together make up about 1 per cent. From observed phase relationships and from data given by Perry (1944), the order of crystallization is probably olivine, metal, troilite and schreibersite. Recent work by Goldberg, Uchiyama and Brown (1951), Patterson, Tilton and Inghram (1955), Lovering, Nichiporuk, Chodos and Brown (1957), and Lovering (1957, *a* & *c*) has provided analytical data for the silicate, sulphide and metal phases of pallasite meteorites from which the geochemical behaviour of the elements Mg, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Ga, Ge, Pb, can be determined.

A measure of the lithophilic *versus* chalcophilic behaviour of an element in these meteorites is given by the massaction constant, C_1, for the reaction

$$\text{M Silicate} + \text{FeS} \rightleftharpoons \text{MS} + \text{Fe Silicate}$$

where M is any metal and from which

$$C_1 = \frac{(\text{M})_{\text{Sulphide}}(\text{Fe})_{\text{Silicate}}}{(\text{Fe})_{\text{Sulphide}}(\text{M})_{\text{Silicate}}}.$$

Thus elements for which C_1 is >1 have stronger chalcophilic tendencies in this environment while elements for which C_1 is <1 have stronger lithophilic tendencies.

Table I.

Trace-element Distribution Between Olivine (Silicate), Troilite (Sulphide) and Metal Phases of Pallasites and the Geochemical Behaviour of Some Elements in Meteorites.

Element.	Concentration (ppm) in the Constituent Phases of Pallasites.			$C_1 = \frac{(M)_s(Fe)_{si}}{(Fe)_s(M)_{si}}$	$C_2 = \frac{(M)_m(Fe)_s}{(Fe)_m(M)_s}$	Geochemical Behaviour.	
	Olivine.*	Troilite.†	Metal.‡			Gold-schmidt (1954).	This Work (based on C_1 and C_2).
Mg	27·8%	∼0·003%	—	0·00002	—	L	*L*>C>S
Ti	25	∼2	<1	0·012	<0·4	L, (C)	*L*>C>S
V	15	10	<1	0·097	<0·07	C, L	*L*>C>S
Cr	150	1100	∼2	1·1	<0·002	C, L	*C*, *L*>S
Mn	1900	320	<5	0·025	0·011	C, L	*L*>C>S
Fe	9·3%	63·6%	88·5%	1	1	S, C	L, C, S
Co	35	160	5500	0·67	25	S, [(L)]	*S*>L>C
Ni	0·025%	0·6%	11·0%	3·5	13	S, [(L)]	*S*>C>L
Cu	4	700	200	26	0·21	C	*C*>S, L
Ga	<2	∼0·4§	18	>0·03	32	C, (L)	*S*>C, L
Ge	<20	8	40	>0·06	3·6	S	*S*>C, L
Pb	<10	∼15¶	∼0·37¶	>0·2	0·018	C, (S)	*C*>S, L

* Data from Lovering (1957*b* and *c*).

† Data from Lovering (1957*b*) unless otherwise stated.

‡ Data from Lovering *et al.* (1957) unless otherwise stated.
L = Lithophile ; C = Chalcophile ; S = Siderophile.

§ Troilite from Iron Meteorites [Goldberg *et al.* (1951)].

¶ Phases from Iron meteorites [Patterson *et al.* (1955)].
C>(C)>[(C)].

A measure of the chalcophilic *versus* siderophilic behaviour of an element in these meteorites is given by the mass-action constant, C_2, for the reaction

$$\text{MS} + \text{Fe} \rightleftharpoons \text{M} + \text{FeS}$$

from which

$$C_2 = \frac{(\text{M})_{\text{Metal}}(\text{Fe})_{\text{Sulphide}}}{(\text{Fe})_{\text{Metal}}(\text{M})_{\text{Sulphide}}}.$$

Elements for which C_2 is >1 have stronger siderophilic tendencies in this enrivonment while those for which C_2 is <1 have stronger chalcophilic tendencies.

The geochemical behaviour of the elements as listed in Table I has been calculated from the relative values of C_1 and C_2. Goldschmidt's (1954) geochemical classification is also included in Table I.

In Part I of this paper an attempt is made to explain the observed geochemical behaviour of the elements in meteorites from both thermodynamic and atomistic viewpoints. Part II is concerned with the behaviour of certain siderophilic elements during the crystallization of the metal core of the parent meteorite body from which the various iron meteorites have originated (Lovering, 1957*a*).

PART I.

THE GEOCHEMICAL BEHAVIOUR OF ELEMENTS IN PALLASITE METEORITES.

THERMODYNAMIC APPROACH.

The distribution of elements between the three phases is governed by reactions of the type :

$$\mathrm{M} + \mathrm{Fe}\ \text{silicate} \rightleftharpoons \mathrm{M}\ \text{silicate} + \mathrm{Fe}$$

$$\mathrm{M} + \mathrm{Fe}\ \text{sulphide} \rightleftharpoons \mathrm{M}\ \text{sulphide} + \mathrm{Fe}.$$

TABLE II.

Standard Free Energy of Formation (ΔF°) of Some Oxides and Sulphides, After Rankama and Sahama (1950) *and Goldschmidt* (1954).
(*kg. cal. per gm. Atom Oxygen/Sulphur at 25° C*).

	$-\Delta F^\circ$		$-\Delta F^\circ$		$-\Delta F^\circ$
MgO	136·4	ZnO	76·3	ZnS	40·4
Al_2O_3	125·6	SnO	60·8	FeS	23·4
V_2O_3	103·7	FeO	59·6	PbS	22·7
TiO_2	102·5	NiO	51·7	NiS	21·3
MnO	91·3	PbO	45·1	CoS	21·1
Cr_2O_3	84·5	Cu_2O	29·5	Cu_2S	19·2
Ga_2O_3	78·3	In_2O_3	7·3	CuS	11·7
				Ag_2S	8·7

Thus a knowledge of the free energies of the various metal silicates and metal sulphides, in relation to those of iron silicate and iron sulphide, would enable predictions to be made of the geochemical behaviour of the elements.

Unfortunately, few free energy data are available for metal silicates and free energy data for the metal oxides are generally used instead. Goldschmidt (1954) and others have stated that the following general relationships hold :

$$\text{Lithophile elements } -\Delta F^\circ_{\text{element oxide}} > -\Delta F^\circ_{\mathrm{FeO}}$$

$$\text{Chalcophile elements } -\Delta F^\circ_{\text{element sulphide}} \geqslant -\Delta F^\circ_{\mathrm{FeS}}$$

$$\text{Siderophile elements } -\Delta F^\circ_{\text{element sulphide}} < -\Delta F^\circ_{\mathrm{FeS}}$$

where $\Delta F^\circ_{\text{element oxide/sulphide}}$ is the standard free energy of formation of element oxide/sulphide per gram atom of oxygen/sulphur.

From Table II it is apparent that the free energy data do not explain the observed behaviour of all the elements. For example, Ga, Zn and Cr should be lithophilic, but their observed behaviour would indicate they are either chalcophilic or siderophilic. Similarly, Cu, Pb and Ag should be strongly siderophilic but all are actually chalcophilic. Rankama and Sahama (1950) have suggested that the anomalous behaviour of Ga and Zn may be due to their distribution being not controlled by the thermodynamic properties of their pure compounds (because of their low concentrations and subsequent inability to form pure compounds) " but by the energy balances connected with the corresponding isomorphic substitutions."

Most workers have pointed out that discrepancies between observed and calculated behaviour of elements from free energy data are only an approximation since metal oxide rather than metal silicate data have been used. The present writer would like to suggest that an even greater source of error lies in the use of free energy data for metal oxides and sulphides in which the metal is present in an oxidation state which is different from that in which it occurs in the meteorite environment. Thus it is important to establish in which oxidation states the elements are most likely to occur in the environment in which the pallasite meteorites crystallized.

Oxidation Potentials and the Oxidation States of Elements in the Meteorite Environment.

In aqueous solutions, oxidation/reduction potentials may be used to indicate the stable oxidation state of an element relative to that environment. Although it is recognized that oxidation potentials are not unreservedly applicable, in the absence of other data they probably can be used to provide some information concerning the stable oxidation states of elements in the ionic and metal melts of the meteorite environment. In order to take some account of the change in environment from aqueous solution to the ionic and metal melts of the meteorite environment, it will be arbitrarily assumed that oxidation potentials for likely reactions must differ by $\pm 0 \cdot 2$ volts from the oxidation potential of the limiting reaction which is taken to be characteristic of the particular environment under discussion.

The history of pallasites is such (Lovering, 1957*b*) that two stages in their crystallization are clear, and each must be considered separately when discussing the distribution of elements between the metal, sulphide and silicate phases during crystallization.

Stage 1: At temperatures around 2000° K and pressures about 10^4–10^5 atmospheres (Lovering, 1957*b*), olivine crystals became enmeshed in a melt of iron-nickel metal in which sulphur and phosphorus were also distributed. The elements present in this system would then distribute themselves between the silicate phase and the metal+sulphide phase. Metals migrating into the silicate environment would form cations whose oxidation states were controlled by the oxidation potential (E_0) of the reaction

$$Fe^{2+} = Fe^{3+} + e \qquad E^0 = 0 \cdot 771 \text{ volts.}$$

From the assumptions made above, the stable oxidation state for any metal in the silicate phase is given by the form on the left-hand side of reactions for which the oxidation potentials are greater than $1 \cdot 0$ volts and on the right-hand side for reactions for which E_0 are less than $0 \cdot 6$ volts. For reactions with E_0 values between $0 \cdot 6$ and $1 \cdot 0$ volts, it is not possible to differentiate between the two lowest oxidation states given in these reactions. The E_0 values of a number of oxidation reactions of interest to this discussion are given in Table III.

Similarly, the stable oxidation states within the iron metal+sulphide melt will be controlled by the E_0 value for the reaction:

$$Fe + S^{=} = FeS + 2e \qquad E_0 = -1 \cdot 00 \text{ volts.}$$

Using these data, the stable oxidation states for certain elements in the two phases can be calculated and have been listed in Table IV.

The information in Table IV may be used to a limited extent to explain the observed geochemical behaviour of elements in meteorites. For example,

TABLE III.

Oxidation Potentials of Some Reactions of Geochemical Interest.
(Data from Latimer, 1938).

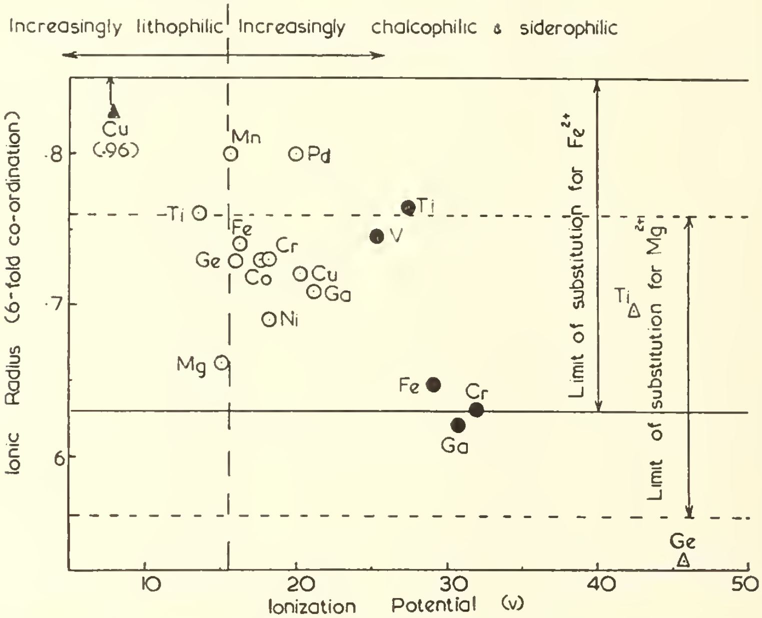
	E° (volts)
$Co^{2+} = Co^{3+} + e$	1·842
$Pb^{2+} = Pb^{4+} + 2e$	1·7
$Au = Au^{+} + e$	1·68
$Mn^{2+} = Mn^{3+} + e$	1·52
$Au = Au^{3+} + 3e$	1·42
$Au^{2+} = Au^{3+} + e$	>1·29
$Au^{+} = Au^{2+} + e$	<1·29
$Fe^{2+} = Fe^{3+} + e$	0·771
$Cu = Cu^{+} + e$	0·522
$Cu = Cu^{2+} + 2e$	0·3448
$Cu^{+} = Cu^{2+} + e$	0·167
$H_2 = 2H^{+} + 2e$	0·00
$Fe = Fe^{3+} + 3e$	—0·036
$Pb = Pb^{2+} + 2e$	—0·126
$V^{2+} = V^{3+} + e$	—0·20
$Ni = Ni^{2+} + 2e$	—0·250
$Co = Co^{2+} + 2e$	—0·277
$Ti^{2+} = Ti^{3+} + e$	—0·37
$Cr^{2+} = Cr^{3+} + e$	—0·41
$Fe = Fe^{2+} + 2e$	—0·44
$Ga = Ga^{2+} + 2e$	—0·45
$Ga = Ga^{3+} + 3e$	—0·52
$Ga^{2+} = Ga^{3+} + e$	—0·65
$Cr = Cr^{3+} + 3e$	—0·71
$Cr = Cr^{2+} + 2e$	—0·86
$S^{=} + Fe = FeS + 2e$	—1·00
$Mn = Mn^{2+} + 2e$	—1·05
$V = V^{2+} + 2e$	—1·5±0·3
$Ti = Ti^{2+} + 2e$	—1·75
$Mg = Mg^{2+} + 2e$	—2·34

TABLE IV.

Stable Oxidation States within Various Phases during the Crystallization of the Pallasite Meteorites.

Stage I.		Stage II.	
Silicate.	Iron + Sulphide Melt.	Metal.	Sulphide (FeS)
Au	Au	Au	Au
Ga^{3+}	Ga	(Ga)(Ga^{2+})	Ga
Co^{2+}	Co	(Co)(Co^{2+})	Co
(Cu)(Cu^{2+})	Cu	Cu	Cu
Cr^{3+}	(Cr)(Cr^{2+})	(Cr^{2+})(Cr^{3+})	(Cr)(Cr^{2+})
Mn^{2+}	(Mn)(Mn^{2+})	Mn^{2+}	(Mn)(Mn^{2+})
Ti^{3+}	Ti^{2+}	(Ti^{2+})(Ti^{3+})	Ti^{2+}
V^{3+}	V^{2+}	V^{2+}	V^{2+}
Mg^{2+}	Mg^{2+}	Mg^{2+}	Mg^{2+}
Ni^{2+}	Ni	(Ni)(Ni^{2+})	Ni
Pb^{2+}	Pb	Pb	Pb

cations which can replace either Fe^{2+} or Mg^{2+} cations in the olivine lattice could be lithophilic in their geochemical behaviour. The main criterion which replacing cations should satisfy is the well-known generalisation of Goldschmidt that their ionic radii should not exceed about 15 per cent. of the radius of either Fe^{2+} or Mg^{2+} ions. The relationship of the size of a number of cations to the size of Fe^{2+} and Mg^{2+} cations is illustrated in Figure 1.



Text-fig. 1.—The relationship of ionic radius and ionization potential for a number of cations.

Monovalent (full triangles); divalent (open circles); trivalent (full circles); tetravalent (open triangles).

Some off-scale cations: Pb^{2+}: $r=1·20$, $I=15·05$.
V^{2+} : $r=0·88$, $I=14·2$.
Si^{4+} : $r=0·53$, $I=45·7$.

Returning to specific examples of behaviour of elements in the silicate environment in meteorites, gold is present in the zero oxidation state and is consequently *not* likely to be a lithophilic element. On the face of the available evidence at this point Ga, Cr, Ti, V, Mn, Co, Cu and Ni may all possibly be lithophilic elements. Both Ga^{3+} and Cr^{3+} may *capture* a Mg^{2+} site in the olivine lattice, while Ti^{3+} and V^{3+} may *capture* an Fe^{2+} site. Similarly, Mn^{2+} may be *camouflaged* in an Fe^{2+} site, as may Co^{2+}, Cu^{2+} or Ni^{2+} in either Fe^{2+} or Mg^{2+} sites. However, Ringwood (1956) has recently shown on other grounds that nickel appears to enter common olivine at the expense of iron rather than magnesium.

Stage 2: With further cooling of the metal+sulphide melt, two distinct and immiscible phases—metal phase and FeS phase (troilite)—separate out. The elements which were concentrated in the metal+sulphide melt during stage 1 must now distribute themselves between these two separate phases. Within the Fe S phase, the stable oxidation states of the elements will be governed by the oxidation potential range of $\pm 0·2$ volts about E_0 for the reaction

$$Fe + S^{=} = FeS + 2e \qquad E_0 = -1·00 \text{ volts}$$

as previously given. Within the metal phase, the stable oxidation states will be governed by the oxidation potential range of $\pm 0 \cdot 2$ volts about E_0 for the reaction

$$Fe = Fe^{2+} + 2e \qquad E_0 = -0 \cdot 44 \text{ volts.}$$

The most likely stable oxidation states of certain elements in both metal and Fe S phases are listed in Table IV.

When cations of the elements Au, Ga, Co, Cu, Ni, Pb in oxidation states greater than zero enter the metal+sulphide melt, they are immediately reduced to the metallic state (oxidation state zero) and thus could well be siderophilic elements. On the other hand, both Ti and Mg can exist only in the +2 oxidation state in the same environment, and thus both might be either chalcophilic or lithophilic elements. The data for Cr and Mn are not so conclusive, since both zero and +2 oxidation states may well be stable in this environment.

Even more conclusive evidence concerning the geochemical behaviour of certain elements arises from an inspection of their stable oxidation states in both the metal and sulphide phases. For example, Ga, Co and Ni may possibly occur in either the zero or the +2 oxidation states in the metal phase, but only the zero state is possible in the FeS phase; consequently, all three should be siderophilic elements, as has been observed to be the case. Also, Cr, Mn, Ti, V and Mg exist in oxidation states other than O in the metal phase; thus these elements should *not* show siderophilic characteristics. This is in agreement with their observed behaviour (Table I). However, Cu and Pb should exist as native metals in both metal and FeS phases, and thus should show siderophilic tendencies. From Table I it appears that both Cu and Pb are more likely to be chalcophilic than lithophilic in character. In the case of Pb, the explanation may be due to the large size of the Pb atom (12-fold co-ordination radius 1·746Å) compared to the size of the Fe atom (1·260Å) which it should replace during crystallization of the metal phase. The Pb may originally have concentrated in the metal+sulphide melt relative to the silicate phase, but as the metal crystallized before the sulphide phase, the Pb was rejected from the crystallized metal phase and forced to concentrate in the still molten FeS melt. Such an explanation would not apply to Cu, whose radius (1·17Å) is essentially identical with that of Fe.

The geochemical behaviour of the elements in the pallasite meteorites is not completely explained by oxidation potentials, but some indication is given of stable oxidation states within the various phases of the pallasite meteorite environment.

Ionization Potentials and the Geochemical Behaviour of Elements in Pallasite Meteorites.

It has long been recognized that since the type of bonding characteristic of the silicate, sulphide and metal phases is significantly different, then the measured tendencies of elements to form certain bond types should be valuable in providing a theoretical basis for the geochemical behaviour of the elements in these various phases.

Lithophilic-Chalcophilic Tendencies.

We will confine our attention first to relative distributions between metal/non-metal compounds (*i.e.* the silicate and sulphide phases). There is general agreement that bonds in sulphide minerals are dominantly non-ionic (*i.e.* covalent), and that in silicates, metal/non-metal bonds might be described as " approximately half covalent and half ionic " (Ahrens, 1953). Thus elements which tend to form metal/non-metal compounds which are predominantly covalent should tend to be chalcophilic, while those which form metal/non-metal compounds with ionic characteristics should tend to be lithophilic.

TABLE V.

Ionization Potentials and Ionic Radii for Some 1^+, 2^+, 3^+ and 4^+ Cations.

(Data from Ahrens, 1952, 1953, or Calculated from his Data).

a. Univalent Cations.

	Li^{+}	Ti^{+}	Zn^{+}	Ag^{+}	Cu^{+}	Au^{+}
I (volts)	5·4	6·1	$\sim$6	7·57	7·7	9·22
Radius (Å)	0·68	1·47	$>$0·74	1·26	0·96	1·37

b. Medium-sized Divalent cations (0·6—0·85Å).

	Ti^{2+}	Mg^{2+}	Mn^{2+}	Ge^{2+}	Fe^{2+}	Co^{2+}
I (volts)	13·6	15·03	15·64	15·93	16·24	17·4
Radius (Å)	$>$0·76	0·66	0·80	0·73	0·74	0·73

b. (continued)

	Zn^{2+}	Cr^{2+}	Ni^{2+}	Pd^{2+}	Cu^{2+}	Ga^{2+}
I (volts)	18·0	$\sim$18	18·3	19·9	20·28	20·51
Radius (Å)	0·74	$\sim$0·73	0·69	0·80	0·72	0·71

c. Large Divalent Cations (0·85–1·35 Å).

	Ba^{2+}	Ca^{2+}	V^{2+}	Sn^{2+}	Pb^{2+}
I (volts)	10·0	11·9	14·2	14·6	15·05
Radius (Å)	1·34	0·99	0·88	0·93	1·20

d. Trivalent Cations.

	Sc^{3+}	V^{3+}	Al^{3+}	Fe^{3+}	Ga^{3+}	Cr^{3+}
I (volts)	24·75	$\sim$26·5	28·4	30·6	30·7	$\sim$32·1
Radius (Å)	0·81	0·74	0·51	0·64	0·62	0·63

e. Tetravalent Cations.

	Pb^{4+}	Sn^{4+}	Ti^{4+}	Si^{4+}	Ge^{4+}	V^{4+}
I (volts)	39	40·70	43·24	45·1	45·7	$\sim$48·5
Radius (Å)	0·84	0·71	0·68	0·42	0·53	0·63

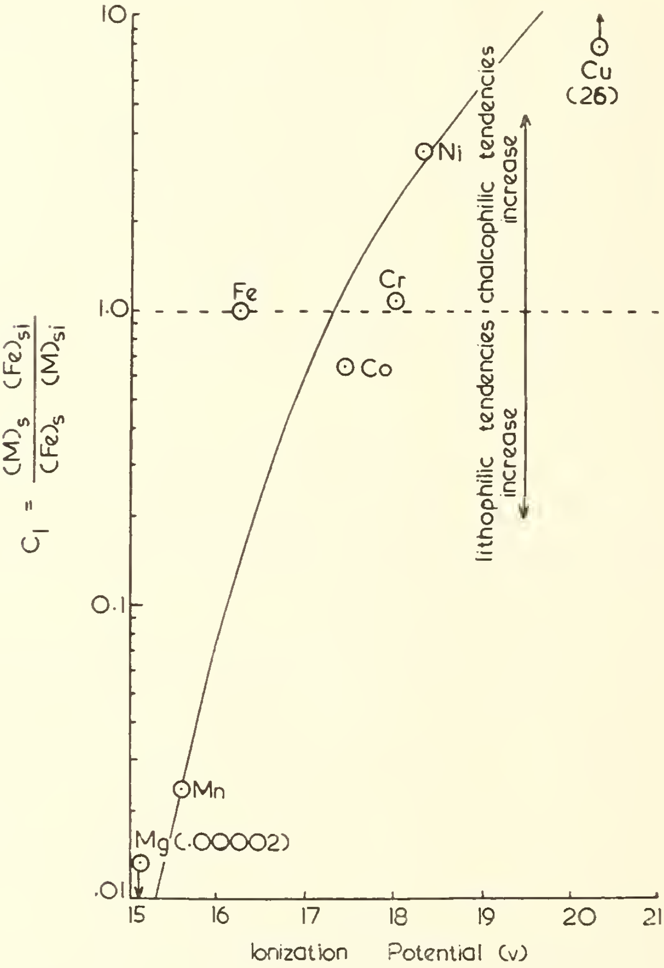
In an attempt to predict the type of metal/non-metal compounds which the various elements would form, Ahrens (1953) has abandoned the classical covalent approach to bond formation and with it the use of Pauling's (1948) electronegativities to indicate bond type in favour of an " ionic approach to bond formation ". From Ahrens' point of view, the formation of a bond passes through three main stages ; first, that of initiation of the reaction ; second, an intermediate or transitory " free-ion " stage ; and third, equilibrium. The important stage, as far as the geochemical behaviour is concerned, is that in which virtually free cations and anions are formed. In this stage *anion affinity* has been defined as the power of a free cation to attract anions. Ahrens used ionization potentials (*i.e.* last-stage ionization potentials for $M^{(n-1)+} \rightarrow M^{n+} + e$) to *indicate* anion affinity. He pointed out that anion affinity is related to such properties as *polarizing power*, *ionic potential* and *field strength* which have been defined by other authors, but that none of these take into consideration variable screening of the nucleus by ions of different electronic configuration. In the final stage, coulombic attraction between cation and anion draws them together to give an equilibrium product. If the anion affinity (*i.e.* ionization potential, *I*) is small, the metal/non-metal bond will be largely ionic ; if anion affinity is large, the bond will be largely covalent. The degree of covalent character may be regarded as the degree with which the anion has its negative charged distribution drawn towards the cation (*i.e.* the degree of polarizability of the anion in the field of the cation).

Ahrens has discussed the geochemical distribution of elements between sulphide and oxide (rather than silicate) phases. The S^{2-} anion is much more easily polarized than the O^{2-} cation, so that metal-sulphur bonds have a greater covalent character than metal-oxygen bonds. Thus for ions of the same valence and similar size, those with the highest ionization potentials should show the greatest tendency to form covalent bonds with sulphur and thus to concentrate in the sulphide phase (*i.e.* be chalcophilic).

The sulphide phase in the pallasites is FeS and the highest stable oxidation state in which the elements under discussion can occur in FeS has been shown before to be +2. Thus we will restrict this discussion to the behaviour of those elements whose divalent cations are of similar size to the Fe^{2+} ion and can replace it in the FeS structure. Ahrens (1953) has previously stated that an I value greater than about 15·5 v. is required before the element tends to preferentially enter the sulphide phase. In the meteorites the lithophilic versus chalcophilic character of a cation of similar size and valence to that of Fe^{2+} will depend on its I value relative to that of Fe^{2+} (*i.e.* 16·2 v.). Elements whose divalent cations have I values considerably greater than 16·2 v. should be chacophilic in behaviour, while those with I values considerably lower than 16·2 v. should be lithophilic. It would seem to be a fair assumption that cations whose I values were within ±0·5 v. of the I value of Fe^{2+} might be either chalcophilic or siderophilic. Increasing I value relative to Fe^{2+} should correspond to increasing chalcophilic character for the elements and decreasing I value should correspond to increasing lithophilic character. From Figure 2 it would appear that in general this relationship does hold, at least insofar as Cu, Ni, Cr, Co, Mn and Mg are concerned, but Ti seems to be less lithophilic than its I value would suggest. Precise values of C_1, which is the measure of the lithophilic-chacophilic behaviour of an element, for Ga and Ge are not available, but their I values would suggest that Ga should be relatively strongly chalcophilic, while Ge could be either chalcophilic or lithophilic. The behaviour of V and Pb is complicated by the fact that their divalent cations are significantly larger than Fe^{2+}, but just taking into account their I values, then both V and Pb should be lithophilic. The available data would indicate that V is indeed strongly lithophilic, while Pb is almost certainly chalcophilic.

Chalcophilic-Siderophilic Behaviour.

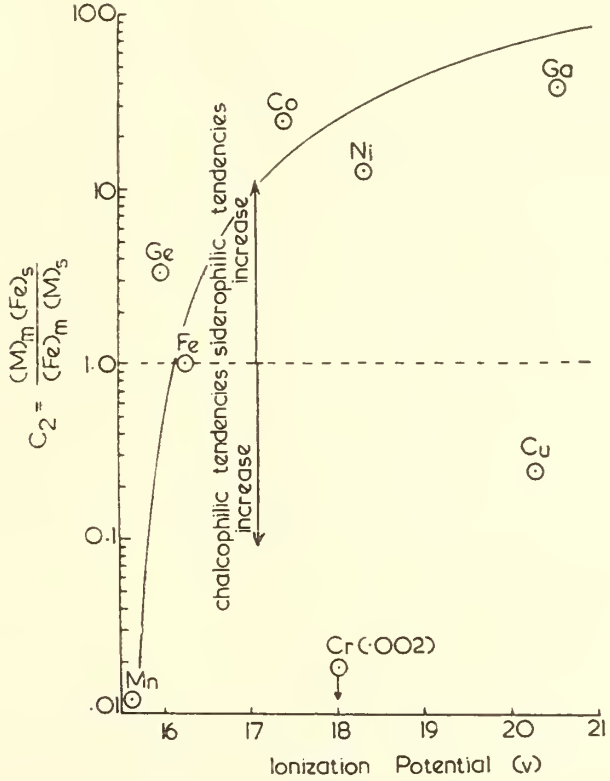
Ahrens (1953) has stated that for all valence groups, extremely high I values for a cation would indicate that the outer valence electrons are tightly held. As a result, these elements are reluctant to enter into chemical combination and elements with very high I values should *tend* to remain native. However, an inspection of the data in table V will show that this is only partly true. Thus Ahrens' statement probably represents an over-emphasis of one parameter. With regard to the chalcophilic-siderophilic behaviour of certain elements in



Text-fig. 2.—Lithophilic-chalcophilic behaviour of certain divalent cations of comparable size (0·6–0·85 Å.) as a function of their ionization potentials.

Notes : Some off-scale cations of comparable size are Ti (C_1 : 0·012, I : 13·6 v), Ga (C_1>0·03, I : 20·51 v) and Ge (C_1>0·06, I : 15·93 v) while V (C_1 : 0·097, I : 14·2 v) and Pb (C_1>0·2, I : 15·05 v) are significantly larger cations also off-scale.

meteorites, let us again refer to the ionization potentials of their divalent cations relative to that of Fe^{2+}. As has been assumed in the lithophilic-chalcophilic discussion, cations whose I values are within $\pm 0 \cdot 5$ v. of Fe^{2+} may be either chalcophilic or siderophilic relative to Fe. Then cations whose I values are greater than about 16·7 v. should be siderophilic, with greater siderophilic tendencies as the I value increases. Similarly, cations whose I values are increasingly less than about 15·7 v. should be increasingly chalcophilic.



Text-fig. 3.—Chalcophilic-siderophilic behaviour of certain divalent cations of comparable size (0·6–0·85 Å.) as a function of their ionization potentials.

Notes: Ti (C_2: $<0 \cdot 4$, I: 13·6 v) is an off-scale cation of comparable size while V (C_2: $<0 \cdot 07$, I: 14·2 v) and Pb (C_2: 0·018, I: 15·05 v) are significantly larger cations also off-scale.

From Figure 3 it would appear that the elements Ga, Ni, Co, Ge, Mn, and perhaps also Mg and Ti, do follow the predicted trend, although Cu and Cr are apparently well off the curve. The significantly larger size of the divalent V and Pb cations might be expected to introduce complications, but their I values would suggest they should be non-siderophilic, as has been observed to be the case (Table I).

All in all, ionization potentials are of considerable use in predicting the geochemical behaviour of elements, provided that their oxidation states are known.

PART II.

BEHAVIOUR OF ELEMENTS DURING THE CRYSTALLIZATION OF IRON METEORITES.

In a previous work (Lovering, 1957*a*) it has been shown that the observed nickel contents of iron meteorites are consistent with their having differentiated by a process akin to fractional crystallization from an originally homogenous melt of about 11% nickel. For nickel the distribution coefficient, k, given by the ratio

$$\left(\frac{\text{nickel concentration in solid phase}}{\text{nickel concentration in remaining melt}}\right)$$

is about 0·5, so that the first formed crystals of iron-nickel alloy have the lowest nickel contents. As crystallization proceeds, the nickel content of the solid phase gradually increases. From analytical data recorded by Goldberg *et al.* (1951) and Lovering *et al.* (1957), it would seem that certain other siderophilic elements (*e.g.* Co, Cu, Pd, Au) behave in a similar manner to nickel and have distribution coefficients <1. On the other hand, analytical data for Ga and Ge (Lovering *et al.*, 1957) would indicate that k values for these elements are considerably greater than 1, so that the first formed solid phase has a very high Ga and Ge concentration while the last solid phase to crystallize is very much impoverished in both elements. There is also some evidence that unlike Co, Cu, Pd and Au, both Ga and Ge do not vary smoothly when compared to the nickel content of the alloy but seem to concentrate in three or even four distinct levels. Some possible reasons for this unusual behaviour will form the subject of another work which is at present in preparation. The purpose of this discussion is to attempt to explain the tendency of certain elements to concentrate in the solid phase relative to the liquid phase (*i.e.* elements with $k>1$), and other elements to concentrate in the liquid phase relative to the solid phase (*i.e.* $k<1$) during the crystallization of the metal iron melt.

Solid Solutions in Metals.

According to Darken and Gurry (1953), the following factors control the extent of primary solid solution in metals :

Size factor : primary solid solution is seriously hindered whenever the disparity in atomic radii exceeds 15 per cent. In this discussion we are dealing with fractionation of elements between the metal melt and the face-centred cubic (γ-phase) iron-nickel solid which crystallizes first. Thus the 12-fold co-ordination radii of the elements should be used.

Electronegativities : metallic elements with electronegativities within $\pm 0 \cdot 4$ electronegativity units of the substituted element have maximum solid solubility (*i.e.* >5 atoms per cent.) in that element.

Electronegativities may also be used to predict the behaviour of a trace-element during the crystallization of a melt. For instance, Ringwood (1955) studied the distribution of elements during the crystallization of silicate magmas. He pointed out the general weakening effect of increased covalent bonding in a compound and used electronegativities (*i.e.* the power of an atom to attract electrons) to determine the extent of covalent relative to ionic bonding in a compound. The greater the difference in electronegativity of two atoms which are bonded together, the more ionic (*i.e.* stronger) the bond will become. Ringwood was able to propose that whenever diadochy in a crystal is possible between two elements possessing appreciably different electronegativities, the element with the lower electronegativity will be preferentially incorporated because it forms a stronger and more ionic bond than the other. A difference of 0·1 or more in electronegativities is necessary before this rule has a significant effect on diadochic substitutions.

Given Pauling's (1948) concept of metallic bonds as essentially resonating covalent bonds and Ahrens' (1953) ionic approach to covalent bond formation described previously, then it is felt that the application of Ringwood's dictum, concerning electronegativities of elements and their behaviour in the crystallization of silicate melts, to the crystallization of metallic melts has certain justification. Thus, considering the iron metal melt in the meteorite environment, elements with electronegativities less than that of Fe will be preferentially incorporated in the early crystallizing solid phases and should decrease in concentration in the solid phase as crystallization proceeds. Those elements whose electronegativities are greater than Fe will tend to remain in the melt and should gradually increase in concentration in the solid phase which separates as crystallization proceeds.

TABLE VI.

Metallic Valencies and 12-*fold Co-ordination Radii* (*after Pauling, in Darken and Gurry,* 1953) *of Certain Elements and Their Electronegativities.*

Element.	Metallic Valence.	12-fold Co-ordination Radius (Å)	Metallic electronegativity (X)	Selected Value of Electronegativity (Gordy and Thomas, 1956).
Cr	6	1·267	2·24	1·4(2)*
Fe	5·78	1·260	2·30	1·7(2)
Co	6	1·252	2·37	1·7
Ni	6	1·244	2·38	1·8
Cu	5·44	1·276	2·20	2·0(2)
Ga	3·44	1·408	1·61	1·5
Ge	4	1·366	1·77	1·8
Pd	6	1·373	2·20	2·0
Au	5·44	1·439	2·00	2·3

* Figure in brackets is valence state to which the selected electronegativity value refers.

We may look upon those elements with smaller electronegativities as forming metallic bonds (or resonating covalent bonds, in the sense of Pauling) with Fe in which the "ionic character" is greater than those with higher electronegativities. These bonds will be stronger and consequently will be more stable in the relatively high temperature environment in which the first crystals form.

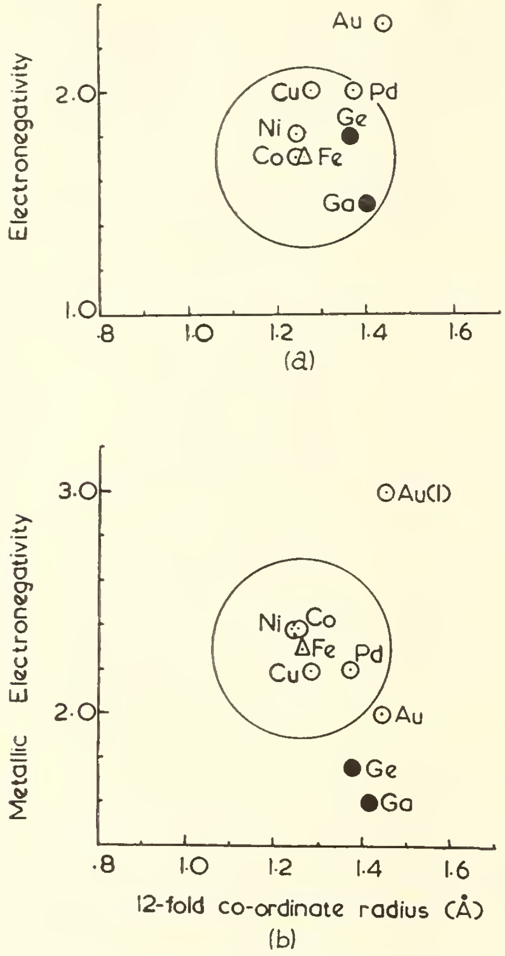
Thus a knowledge of the metallic radius and the electronegativity of an element (Table VI) relative to Fe should be sufficient to determine whether that element (1) has unlimited substitution of Fe, and (2) is concentrated in either the solid or liquid phase as crystallization proceeds.

From the information plotted in Figure 4*a*, the following conclusions may be drawn :

(i) all metals plotted (except Au) should have maximum solubility in iron ;
(ii) Cu, Pd and Au should be concentrated in late-forming solid phase ;
(iii) Ga should be enriched in early-forming solid phase relative to the melt ;
(iv) behaviour of Ni, Ge and Co cannot be predicted as electronegativities of these elements lie between ±0·1 electronegativity units of Fe.

This would certainly explain the qualitative behaviour of Cu, Pd, Au and Ga, but it does not explain the behaviour of Ge.

With regard to the behaviour of gallium, it is interesting to point out that Petit and Nachtrieb (1956) found that liquid gallium is more metallic in character than the solid phase, suggesting that gallium should tend to concentrate in the solid phase crystallizing from a metal melt, as has been observed from the analytical data.



Text-fig. 4.—The behaviour of certain elements in the metallic phase of iron meteorites as related to their metallic radii and (*a*) electronegativities (Gordy and Thomas, 1956), (*b*) metallic electronegativities (this work).
Notes: Elements increasing with nickel (open circles); elements decreasing with nickel and showing "quantized" distribution (full circles). Elements with maximum (>5 atoms per cent.) substitution for Fe lie inside the large circle.

Metallic Electronegativities.

Gordy (1946) has derived an equation which expresses the electronegativity (x) of a neutral atom as a function of the number of electrons (n) in the incompletely filled (valence) shell and the single-bond covalent radius (r) of the atom:

$$x=0\cdot31\left(\frac{n+1}{r}\right)+0\cdot50 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Darken and Gurry (1953) have pointed out that more significant values for the electronegativities of Class I elements (the true metals) are given if Pauling's metallic valences (n^1) are used in place of the term n in Gordy's equation (1). The electronegativity value so defined will be called here the *metallic electronegativity*, and has been calculated for a number of elements (Table VI).

If we now plot the metallic radii and metallic electronegativities of some elements (Figure 4*b*), the following conclusions may be drawn :

(*a*) all metals plotted, except Au, Ge and Ga, should have maximum solubility in iron.

(*b*) Au, Ge and Ga should be enriched in first-formed crystals.

(*c*) behaviour of Ni, Co, Cu, Pd cannot predicted.

The behaviour of elements Ga, Ge, outside the area of maximum solubility is explained on this basis. With regard to gold, Darken and Gurry (1953) have shown that the behaviour is best explained by using an electronegativity value based on the unit valence state. Using this new value, the tendency should be for gold to concentrate in the melt, as has been observed.

SUMMARY.

The geochemical behaviour of certain elements (Mg, Ti, V, Cr, Mn, Co, Ni, Cu, Ga, Ge, Pb) relative to their distributions between the silicate (olivine), sulphide (troilite) and metal phases of pallasitic stony-iron meteorites has been determined from new data. Oxidation potentials are used to indicate the most likely oxidation states of the elements in the various phases. Ionization potentials of the divalent cations are used to indicate their anion affinity relative to Fe^{2+} and consequently to explain their relative lithophilic-chalcophilic-siderophilic tendencies.

The distribution of Ga, Ge, Co, Pd, Cu and Au in iron meteorites is discussed as a function of the behaviour of these elements during the crystallization of an iron-nickel melt forming the core of the parent meteorite body. *Metallic electronegativities* (x) for each of these elements, relative to X_{Fe}, are used to prediet whether an element is concentrated in the solid or the liquid phase as crystallization of the melt proceeds. The metallic electronegativity of a metal is calculated from a modified version of Gordy's (1946) equation in which $x=0{\cdot}31\ [(n^1+1)/r]+0{\cdot}50$ where

n^1=Pauling's metallic valence, and

r=the 12-fold co-ordination radius for the element.

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CLARKE MEMORIAL LECTURE*

FURTHER REMARKS ON THE SEDIMENTARY FORMATIONS OF NEW SOUTH WALES.

By Alan H. Voisey, D.Sc.
Department of Geology, University of New England, Armidale, N.S.W.

With six Tables.

Abstract.

Work done on the sedimentary formations of N.S.W. since 1947 is discussed and the rocks are arranged according to the Australian Code of Stratigraphical Nomenclature. A bibliography of publications on N.S.W. stratigraphy since the publication of T. W. E. David's "Geology of the Commonwealth of Australia" in 1950 is given, and the contributions made are organized into tables showing the recognized formations and groups defined up till the end of 1956.

Contents.

Introduction.

I feel that I can pay no better tribute to the Reverend W. B. Clarke, in whose memory I am delivering this lecture tonight, than by discussing "the sedimentary formations of New South Wales". For nearly forty years this great man, aptly called "the Father of Australian Geology", laboured upon them single-handed with little or no equipment save those articles which, I maintain, are still the most important which a geologist can possess, namely, a pair of strong boots, a hammer and a haversack. For longer journeys—and he made many of them—he had to rely upon the horse.

I propose tonight to deal very briefly with the progress of research since Clarke started his work, then to discuss the advances we have made in the last decade, and finally, to suggest what progress we might make in the future.

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* Delivered to the Royal Society of New South Wales, July 30, 1957.

HISTORY OF STRATIGRAPHICAL INVESTIGATIONS.

It is convenient to consider the history of stratigraphical investigations in this State in three main periods :

The first might be said to extend from 1839 to 1878, as it was during this time that the Rev. W. B. Clarke carried out the work which he discussed in his book " Remarks on Sedimentary Formations of New South Wales ", 4th Ed., 1878.

The second, from 1879 to 1946, was dominated by the work and influence of Professor Sir T. W. E. David and later by Dr. W. R. Browne. Advances made were included in " The Geology of the Commonwealth of Australia ", 1950.

The additions to our knowledge which took place during the third period, from 1947 to 1957, will be my main concern tonight.

It is quite clear that Clarke paved the way for later work by his careful determinations of the order of superposition of the strata, which he saw as he travelled through the State.

He was essentially a field geologist, who placed more value upon his own observations than upon the views of the palæontologists such as McCoy, to whom he submitted the fossils which he collected for identification. In spite of understandable differences of opinion, he received much aid and encouragement from some of his famous contemporaries, namely, Sir Roderick Murchison, Professor Adam Sedgwick, Professor L. G. de Koninck, Dr. O. Feistmantel, W. Lonsdale and J. W. Salter. He brought together the records of the early explorers, P. E. de Strzelecki, T. L. Mitchell and L. Leichhardt, and visitors in the persons of J. B. Dana and J. B. Jukes.

Following the identification of many of the 4,000 specimens he sent to the Woodwardian Museum, Cambridge, he was able to effect broad correlations between the sedimentary formations of N.S.W. and overseas sequences.

During the second period rapid building took place on Clarke's solid foundations. In the bibliographies of " The Geology of the Commonwealth " some fifty persons are listed as contributing to the geology of New South Wales. Most of the early work was done by T. W. E. David, W. G. Woolnough and W. N. Benson, through the University ; and by C. S. Wilkinson, E. F. Pittman, J. E. Carne, J. B. Jaquet, R. Etheridge, Junr., and W. S. Dun, through the New South Wales Geological Survey. They were later joined by L. A. Cotton, W. R. Browne, A. B. Walkom, L. L. Waterhouse, G. D. Osborne and I. A. Brown at the University ; E. C. Andrews, L. F. Harper, L. J. Jones, E. J. Kenny, A. C. Lloyd, H. G. Raggatt and C. J. Mulholland in the Survey ; and C. A. Sussmilch at the Technical College.

Some contributions were also included in the book from those who might be regarded as belonging to the third period : G. A. Joplin, K. Sherrard, F. Booker, S. W. Carey, J. A. Dulhunty, J. Crockford, F. Hanlon, and myself.

" The Geology of the Commonwealth " brought together the stratigraphical work done in Australia ; the sedimentary formations were organized into " series " and " stages " and intra-continental correlations were made ; fossil zones were recognized and more detailed correlations with overseas sequences were suggested.

The third period, commencing in 1947, the last year from which W. R. Browne was able to collect material for the book, is characterized by the attempt to introduce an Australian Code of Stratigraphical Nomenclature in order to control the subdivision and naming of the rocks. Because of the increasing number of sequences being described there arose the need for separate " rock " terms as distinct from the time-rock terms " series " and " stage ", which were coming more and more into use in a dual sense.

The move initiated by Glaessner, Raggatt, Teichert and Thomas in 1948 and discussed at a number of meetings (see Raggatt, 1950, 1953) led to the acceptance of the code, the latest statement of which was published in the *Australian Journal of Science* in February, 1956 (Raggatt, 1956). Rock sequences are now divided into " groups ", " formations " and " members ".

The terms " series " and " stage " are applied only in a time-rock sense corresponding with the time-terms " epoch " and " age ", and should preferably be of world-wide application. They may have intra-continental validity, where correlation on a wider basis is difficult or impracticable.

There is as yet no universal acceptance of time or time-rock terms of world-wide application. W. R. Browne (1949) pointed out that in Australia the major subdivisions on the whole have been standardized on the European scale and that it is undesirable to change them. Nevertheless, it has been the custom in New South Wales to use a number of our own time and time-rock terms—the most common being the division of the Permian into Lower Marine, Lower Coal, Upper Marine and Upper Coal, and of the Carboniferous into Burindi (Lower and Upper) and Kuttung (Lower and Upper).

Other series and stage names as originally given in relation to certain sequences, such as those in the Cumberland Basin, Yass and Tamworth districts, have not been widely used elsewhere, largely because of doubts about correlation. The term Lambian has been used to imply a particular facies, but has also assumed a time-rock significance.

There is much to be said for the adoption of local time and time-rock terms, if only to cover the period of uncertainty about inter-continental correlations. The question as to whether they should be State-wide or Australia-wide is one which can really only be decided by usage. In New South Wales we seem to be making use of the Victorian Ordovician stage names of Bolindian, Eastonian, Gisbornian, and so on. Queensland names of Bunya and Neranleigh-Fernvale for some unfossiliferous Palæozoic (?) beds common to both States are frequently used.

The practice which the code insists must be discontinued is the employment of the time-rock terms " series " and " stage " for rock sequences, as was done prior to its acceptance. Illustrative of what would now be regarded as their misuse is my own work on the North Coast. I introduced the names Boonanghi Series and Kullatine Series for strata supposedly of Burindi and Kuttung age, because I was not sure of their exact limits in time. Had I been doing the work since the code was introduced, I would have called them the Boonanghi Beds and Kullatine Beds until I had defined a number of formations, after which they would have been organized into the Boonanghi and Kullatine groups (Voisey, 1934).

While I do not now advocate any changes in our system of nomenclature, I desire to express the view that we might be better advised to continue to use our own time and time-rock terms until we are satisfied that the palæontologists have established close correlations with overseas standard series and stages. It should be in order to speak of the Dalwood and Macleay groups of sedimentary rock as being of Lower Marine age. This might be preferable to using the Russian terms, Artinskian and Sakmarian, at the present time.

The division and description of rock sequences using the code has become the prime task of stratigraphers during the last decade.

The Geological Survey of New South Wales, led by Dr. F. W. Booker, has paid particular attention to the Coal-measures during this period, F. Hanlon (1947–48) being concerned with the North-west Coal-field, E. O. Rayner (1949) with the Western Coal-field, and F. Hanlon (1956) and C. E. McElroy (1957) with the Southern Coal-field.

Workers outside the survey have been relatively few, but N. C. Stevens (1948–1956), G. H. Packham (1953, 1954), R. L. Stanton (1955), J. Phillips (1955) and G. F. Joklik (1950) have described Lower and Middle Palæozoic formations in the Central-western areas of the State. G. D. Osborne (1950) gave a comprehensive account of the Carboniferous rocks, and F. C. Loughlan (1954) subdivided the Permian strata of the Gloucester Trough. G. D. Osborne (1948), J. F. Lovering (1953, 1954) and K. A. W. Crook (1956) have discussed the Triassic sequences.

Much progress has been made in the study of the palæontology of the formations by I. Crespin (1955) (Foraminifera), D. Hill (1954*a*, 1957) (corals), K. Sherrard (1949, 1951, 1953) (graptolites), J. Crockford (1947, 1948, 1951) (Bryozoa), K. Campbell (1955, 1956, 1957) (brachiopods), H. O. Fletcher (1950) (molluscs and trilobites), C. Teichert and B. F. Glenister (1952, 1953) (cephalopods), E. F. Riek (1954*a*, 1954*b*) (insects) and R. T. Wade (1953) (fishes).

I shall now proceed to a discussion of the recent stratigraphical contributions and to show by means of tables the correlations, both inter- and intra-continental, which have been made.

THE SEDIMENTARY FORMATIONS.

Pre-Cambrian.

Pre-Cambrian beds outcrop in the Barrier Ranges. They are not known to occur in the eastern portion of New South Wales, although big thicknesses of unfossiliferous sediments, which may be older than Ordovician, are present.

Ordovician.

Black banded slates, siltstones, cherts and calcareous deposits in association with tuffs, breccias, andesitic conglomerates and andesite lavas have been found to contain Ordovician fossils. K. M. Sherrard (1953, p. 73) listed a number of graptolites, showing that representatives of the English Arenig, Llandeilo and Caradoc series are present. She herself mapped and described Upper Ordovician sediments from the Nanima-Bedulluck District but did not name any formations (Sherrard, 1951).

N. C. Stevens (1952–1956) mapped Ordovician rocks in the central-west and showed that some limestones, formerly considered to be of Silurian age, contain a fauna which includes Bryozoa, stromatoporoids, Brachiopoda, Mollusca and corals, as well as graptolites. I. A. Brown (1952) deduced an Ordovician age from the brachiopods, and D. Hill (1955) recognized the coral fauna as being high in the Ordovician. Upper Ordovician graptolites were identified by K. Sherrard. Stevens, in addition to naming the formations as shown in Table A, pointed out that some of the lavas were characterized by pillow-structure and albitization, which suggest submarine origin, and that overlying shallow-water limestones may have developed on a ridge of volcanic material, associated perhaps with a rising, median geanticline. Greywackes were laid down probably in deep water in a region of more rapid subsidence east of the limestones.

From the Wiseman's Creek-Burraga area Stanton (1955) described under the heading of Triangle Group, a thickness of approximately 10,000 feet of " low grade metamorphic products of predominant shales, greywackes, isolated chert lenses and very minor tuffaceous bands ". He did not name any formations. The Rockley Volcanics, overlying the Triangle Group, consist almost entirely of regionally metamorphosed andesitic pyroclastics, but with occasional flows or sills, and reach a thickness of approximately 5,000 feet near Rockley.

Vallance (1953*a*, p. 96), in dealing with the metamorphism of sedimentary rocks in the Wantabadgery-Adelong-Tumbarumba District, noted that no successful attempt had been made to subdivide the sediments, probably Upper

TABLE A.
ORDOVICIAN.

CLIEFDEN CAVES. Stevens (1956).	CANOMODINE. Stevens (1956).	BOWAN PARK. Stevens (1956).	WISEMAN'S CREEK-BURRAGA. Stanton (1955).	CANBERRA. Öpik (1954).	QUEANBEYAN. Phillips (1955).	VICTORIAN STAGES.	EUROPEAN STAGES.
	Millambri	Malachi's Hill					
	Formation.	Formation.					Ashgillian.
Angullong Tuff.	— ? — ? — ?	— ? — ? —	Rockley Volcanics.			Bolindian.	
	Cargo Creek	Bowan Park,					
	and	Barton					
	Canomodine	and	— ? — ? — ? —				Caradocian.
	Limestones.	Regan's Creek		Acton Shale.	Acton Shale.	Eastonian.	
		Limestones.					
Cliefden Caves							
Limestone.			Triangle Group.				
						Gisbornian.	
Walli Andesite.	Cargo Andesite.	Cargo Andesite.		Pittman	Muriarra		Llandeilian.
				Formation.	Formation.	Darriwilian.	
							Llanvirnian.
						Yapeenian.	
						Castlemainian.	
				— — ? — ? —	— ? — ? —	Chewtonian.	Arenigian.
				Black Mountain	Black Mountain	Bendigonian.	
				Sandstone ?	Sandstone ?		
						Lancefieldian.	
							Tremadocian.

Ordovician in age. He considered that the assemblage of shales and subgreywackes appeared to be fairly typical of what one might expect of sediments deposited near the axial region of a miogeosyncline.

In the Australian Capital Territory, according to Öpik (1954, p. 135), the Black Mountain Sandstone (Pittman, 1911), at least 1,500 feet thick, is older than Middle Ordovician. The overlying Pittman Formation is a rhythmic sequence 700 feet thick of sandstones, micaceous sandy shales, mudstones, black argillaceous shales and radiolarites containing graptolites, conodonts, rare brachiopods and sponges. The succeeding Acton Shale is 200 feet thick.

J. Phillips (1955), from the adjacent area of Queanbeyan in New South Wales, defined the Muriarra Formation and correlated it with the Pittman Formation.

A number of reports by officers of the N.S.W. Geological Survey, notably L. R. Hall and C. L. Adamson, refer to slates, phyllites, quartzites, schists and cherty shales in the southern part of the State. Fairbridge (1953, P. III, 13–14), from the vicinity of Kiandra and Adaminaby, described a eugeosynclinal sequence of sediments possibly some 40,000 feet in thickness. Geologists of the Bureau of Mineral Resources and the Snowy Mountains Hydro-Electric Authority have carried out extensive investigations of the geology of the Snowy Mountains area, but little information has yet been published.

As noted in many publications unfossiliferous phyllitic rocks, apparently of great thickness, outcrop on both the South and North Coasts of New South Wales, continuing into Queensland. In 1934 I gave the name Nambucca Series to beds occurring typically at Nambucca Heads and correlated them with the Bunya Phyllites of Queensland (Voisey, 1934, p. 335). They will, in future, be referred to as the Nambucca Beds in accordance with the code.

The broad general picture of Ordovician times resulting from a consideration of the beds described is that of a depositional area consisting of two main depressions in the ocean floor, that to the west being a miogeosyncline (Kay, 1950) and that to the east a deep eugeosyncline.

Between the two lay a region where ridges and troughs gave rise to mixed shelly and graptolite facies, greywackes and limestones occurring in close proximity to one another.

Silurian.

As a result of his ardent collecting Clarke established the presence of Silurian rocks in N.S.W., and a list of fossils of that age identified by de Koninck is quoted by Clarke (1878, p. 12 and Appendix XIV).

I. A. Brown and K. M. Sherrard (1951) correlated the beds of the Yass-Bowning area with the Wenlock and Lower Ludlow of England on the basis of the graptolite identifications. In 1954 I. A. Browne described the area of deposition as " a broad, generally shallow sea-way, probably dotted with islands and archipelagoes, with which were associated coral reefs and beach deposits ". She noted that the greater part, if not the whole of the Silurian sequence, was developed in the neighbourhood of Yass and estimated the total thickness of Silurian beds as 8,300 feet.

G. A. Joplin (1952), in a useful summary of the Wellington-Molong-Orange-Canowindra region, arranged previous work in accordance with the code of stratigraphical nomenclature, dividing the Silurian sequence into :

(i) The Manildra Formation consisting of cherts, shales, tuffs and limestone with porphyries.

(ii) The Nanima Formation of limestones, andesite flows, pyroclastics and intrusives.

(iii) The Gamboola Formation of limestones and shales.

Stevens and Packham (1952), from Four Mile Creek, south-west of Orange, defined the Panuara Formation with the Bridge Creek Limestone Member at the base. From the graptolite assemblage, which included *Monograptus gregarius*, *M. exiguus* and *M. dubius*, they concluded that the formation comprised the equivalents of the Lower Llandovery, Upper Llandovery, Wenlock and Lower Ludlow Series of Great Britain. They pointed out that the Bridge Creek Limestone was the first in Australia for which a basal Silurian age had been proved. They suggested that it might extend downwards into the Ordovician. The overlying unfossiliferous Wallace Shale may be either Upper Silurian or Lower Devonian. The same authors described the occurrence of the Panuara Formation in the Spring and Quarry Creeks area, noting that Joplin (1952) had included it in the Gamboola Formation, regarded as Lower Silurian (Packham and Stevens, 1954). They called the fossiliferous limestone at the base the Quarry Creek Limestone Member.

From the Australian Capital Territory A. A. Öpik defined the formations of a Silurian sequence as shown in Table B. He noted that it was from the Yarralumla Formation that Clarke (1878) collected a number of the fossils which were described by de Koninck (1876–1877).

Phillips (1955) described over 1,000 feet of similar beds from the Queanbeyan area.

As to structural relations Öpik (1954, p. 138) recognized the unconformity between the Camp Hill Sandstone and the Ordovician Black Mountain Sandstone, and Phillips (1955, p. 120) recorded the former's disconformable relations with the Upper Ordovician Acton Shale. Öpik regarded the Yarralumla Formation as being folded before the Mount Painter Porphyry was intruded in Lower Ludlow time. The Ainslie Volcanics, believed to be Lower Devonian, are unconformably resting on the eroded surfaces of Silurian rocks.

Sherrard (1951, p. 69) described sandstones, quartzites, limestones and mudstones in the Nanima-Bedulluck District, correlating the fossil zones with the English Ludlow and Wenlock. Formation names were not given.

The Wiseman's Creek-Burraga rocks, probably all of Silurian age, were divided by Stanton (1955) into :

(i) Burraga Group (4,500 ft.) of greywackes, shales and andesitic tuffs.

(ii) Kildrummie Group (6,000 ft.) of limestones and shales.

(iii) Campbell's Group of Shales, greywackes and conglomerates.

No formation names have yet been given.

The Silurian sequence at Cobar, previously mapped by E. C. Andrews, was divided by G. F. Joklik (1950) as shown in Table B. He described the Cobar Group as comprising shore-line deposits showing frequent change of facies and with contemporaneous vulcanism. Vulcanicity continued into the Upper Silurian, the products being associated with radiolarian cherts and limestones.

In north-eastern New South Wales many observations have been made upon the Woolomin and Fitzroy beds, which are possibly Silurian. A. Spry (1953, 1955) mentioned polymictic breccias, greywackes, sub-greywackes, quartzites, jaspers, biotite hornfelses, calc-silicate hornfelses and basic lavas as belonging to the Woolomin Group.

J. W. Whiting (1950) recorded Silurian fossils from an isolated outcrop of limestone near Jackadgery. This discovery suggests that the jaspers and quartzites of Woolomin type in the locality are also of Silurian age but field relationships do not appear to be clear enough to establish the matter beyond doubt.

TABLE B.
SILURIAN.

COBAR. Joklik (1950).	WISEMAN'S CREEK-BURRAGA. Stanton (1955).	FOUR MILE CREEK. Stevens and Packham (1952).	WELLINGTON-CANOWINDRA. Joplin (1952).	QUEANBEYAN. Phillips (1955).	CANBERRA. Öpik (1954).	YASS. I. A. Browne (1954).	N.S.W. SERIES. David (1950).	EUROPEAN SERIES.
Mallee Tank Group. Rookery Limestone. Undifferentiated Sediments. Weltie Chert.	Burraga Group.	Wallace Shale.	Manildra Formation.			Hume Series Shales, sandstones and Conglomerates. Upper Trilobite Bed Shale, conglomerate and Sandstone. Middle Trilobite Bed. Black Bog Shales. Hume Limestone. =Lower Trilobite Bed. Barrandella Shales. Bowspring Limestone. Laidlaw Series.		Upper Ludlow.
— —?— — —?— —	- - ? - - ? - -				Red Hill Group. Yarralumla Formation.		Hume Series.	Lower Ludlow.
C.S.A. Group.	Kildrummie Group.		— — — — — Nanima Formation.		Deakin Volcanics.			
— — ? — — ? —		Panuara Formation.		Morley Formation.	Fairbairn Group. Mahon Formation. Molonglo River Formation. Molonglo Sandstone. Molonglo Ford Hornfels.	Yass Series.	- - - - - - - Yass Series.	Wenlock.
Cobar Group. Nurri Formation. Sandstone.			— — — — —	— — — —	Mt. Pleasant Rhyolite. St. John's Beds.	Douro Series.	- - - - - - -	— — —
Slate.	- - ? = ? - - Campbell's Group.		Gamboola Formation.	Brun Shale. — — — — — Bouchon Beds.	Canberra Group. City Hill Shale. Riverside Formation. Turner Shale. State Circle Shale.	Bango Series. Hawkins Series.	Bango Series.	
		— — — — — Bridge Creek Limestone Member.		Camp Hill Sandstone.	Camp Hill Sandstone.	—?—?—?— - Mundoonan Sandstone.		Llandovery.

As was the case with the Ordovician sediments, it is apparent that there were two different types of deposition area, possibly miogeosynclinal to the west and eugeosynclinal to the east. The actual positions of the troughs were not quite the same, as evidenced by the unconformities which have been recognized.

Devonian.

Clarke (1878, p. 17), following the determination of the age of fossils sent overseas by him, was able to show that Devonian rocks were well represented in N.S.W. He wrote (p. 21) : " . . . it may be well to mention that there seems to be in parts of the Western Districts an exhibition of rocks which resemble in various ways the conglomerates of the Old Red Sandstone of Europe ; such overlie the marine Upper Silurian beds in the neighbourhood of Wellington and are known to contain *Lepidodendra*."

Subsequent work in the Wellington District and southward through Molong to Canowindra was summarized by G. A. Joplin (1952), who listed the Devonian sequence as follows :

Upper Devonian.

Catombal Formation—consisting of conglomerates, quartzites and red shales.

Lower to Middle Devonian.

Garra Beds, consisting of rhythmically bedded limestones and shales. Rhyolites.

Further work may eventually lead to the division of the Garra Beds into at least two formations.

Packham (1953), in describing *Hadrophyllum wellingtonense* from the Garra Beds, noted that closely related species from south-east Asia came from a position about the Lower-Middle Devonian boundary.

Slight unconformities have been recognized, one between Silurian and Lower Devonian, and another between rocks of Middle and Upper Devonian age.

I. A. Browne (1954), from Clarke's collecting-ground of Taemas and Cavan, noted a thickness of at least 2,500 feet of rhyolites, andesites and tuffs, which she had earlier called the Black Range Series (Brown, 1940), followed by 2,000 feet of Middle Devonian fossiliferous limestone and clastic sediments. These were called the Murrumbidgee Beds by C. A. Sussmilch (1914) and the Taemas Series by David (1950).

A. A. Öpik (1954, p. 46) recorded the presence of the Ainslie Volcanics and Narrabundah Ashstone from the Australian Capital Territory.

Stevens and Packham (1952) divided the beds of Four-Mile Creek south-west of Orange into :

Black Rock Sandstone.
Bulls' Camp Rhyolite.
Wallace Shale.

The Wallace Shale, which is apparently conformable with the brown shales of the Silurian Panuara Formation, occurs also in the Spring and Quarry Creeks area.

Benson (1912–1917) dealt very fully with the Devonian rocks of the Great Serpentine Belt Area between Warialda and Nundle, and I. A. Brown added to our knowledge by her careful work around Attunga (1942) and by her submission of fossils to D. Hill, who described them and showed that the Nemingha limestone was probably Lower Devonian in age (Hill, 1942*a*).

TABLE C.
DEVONIAN.

MURRUMBIDGEE. I. A. Browne (1954).	CANBERRA. Öpik (1954).	FOUR MILE CREEK. Stevens and Packham (1952).	WELLINGTON-MOLONG. Joplin *et al.* (1952).	TAMWORTH. Voisey (Revised from Benson).	TAMWORTH. David (1950).	EUROPEAN STAGES.
				Manilla Group.		
	Unnamed Quartzite.				Barraba	
		Black Rock Sandstone.	Catombal Formation.	Barraba Mudstone.		Famennian.
					Series.	
	Manar Porphyry.					Frasnian.
				Baldwin Formation.		
				Tamworth Group.		
					Tamworth	
				Moore Creek Limestone.		
					Series.	Givetian.
Taemas Series.						
Upper Limestone.						
Fine Tuffs.				Sulcor Limestone.		
Lower Limestone.						
			Garra			Couvinian.
Black Range Series.	Narrabundah Ashstone.		Beds.			
				Nemingha Limestone.		Coblentzian.
Tuffs.						
Rhyolites.	Ainslie Volcanics.	Bulls' Camp Rhyolite.	Rhyolite.			
						Gedlnnian.

Further work on the Devonian rocks, particularly during the last five years, has made it desirable to name the sequence in terms of the stratigraphic code.

The Lower and Middle Devonian sequence, which was called the Tamworth Series by Benson (1913*a*), should now be called the Tamworth Group, as Benson (1913–1917) described a number of rock units which may be regarded as having formation status. Among these are the Moore Creek Limestone, Loomberah Limestone, Nemingha Limestone, Silver Gully Agglomerate and Nemingha Red Breccia. It is expected that work at present proceeding in the Nundle, Tamworth and Attunga districts will soon yield a comprehensive picture of the sequence.

As shown in another publication the overlying portion of the Devonian succession, called by Benson (1913*a*) the Baldwin Agglomerate, is made up of a variety of rocks of which coarse beds are only a minor, if conspicuous, part. It is proposed to name it the Baldwin Formation. Near Manilla the sudden change from coarse beds to mudstones is so well marked that it shows up physiographically and is an easily mapped junction. The Barraba Mudstone is acceptable as a formation name and is taken to include all the strata up to the base of the Burindi Group. Both formations, which contain similar sedimentary types but in different proportions, are included in the Manilla Group.

Osborne, Jopling and Lancaster (1948) described the sediments around Timor, east of Murrurundi, including the Timor Limestone, 760 feet thick. These beds appear to be southern continuations of the Tamworth and Manilla groups.

While there are certain similarities in the faunas and lithology of the Middle Devonian sediments between the Murrumbidgee and Tamworth provinces, there are big differences in the deposits of Upper Devonian rocks in the western and north-eastern portions of the State. Undoubtedly very different conditions prevailed, as already explained by I. A. Brown (1932, p. 329).

Carboniferous.

The main contributions to our knowledge of Carboniferous stratigraphy since 1947 were made by G. D. Osborne (1949, 1950), who discussed the occurrence of ignimbrites in the Hunter-Karuah District and dealt very fully with the structural evolution of the Hunter-Manning-Myall Province. He described a number of sequences, but did not assemble his earlier work in the terms of the code of stratigraphic nomenclature.

The individual Carboniferous strata between Raymond Terrace and Gunnedah have been mapped in some detail but no one has yet published any list of formations and groups. This will shortly be done for the Rangari-Wean area west of Manilla by B. Engel and K. Williams.

In spite of all the work carried out difficulties in nomenclature are still great. They arose originally from the introduction of the name Kuttung Series for rocks in the Hunter Valley, thought to correspond with the Rocky Creek Conglomerates of Benson (1913), by David and Sussmilch (1919). The Wallarobba Conglomerates did not correspond with the basal Rocky Creek Conglomerates as Benson, Dun and Browne had previously agreed was a possibility, but were much lower in the succession (Benson, Dun and Browne, 1920, p. 287).

Carey and Browne (1938), recognizing this overlap, suggested the nomenclature which has been used ever since.

Terrestrial.	*Marine.*
Upper Kuttung Series.	——
Lower Kuttung Series.	Upper Burindi Series.
——	Lower Burindi Series.

They stated (pp. 592–593): " The names Kuttung and Burindi are so well known and entrenched in Australian geological literature that it seems inadvisable to change them; the former name too has always connoted terrestrial and the latter marine deposition and this significance is preserved in the modified nomenclature."

Although they recognized the presence of some marine intercalations in the Lower Kuttung, these have since been found also in Upper Kuttung beds in a number of places (see Voisey, 1939*a*, p. 247; Scott, 1947, p. 229; Osborne, 1950, pp. 12–13). It would seem, therefore, that there is little reason now to place much emphasis on the suggestion that the Kuttung beds are terrestrial. There was, however, a notable change in the nature of the sedimentation in most areas at the end of Lower Burindi time.

When asked to write an article on the Gondwana System in New South Wales for the 19th International Geological Congress in Algiers in 1952, I thought it better, in the absence of other rock names, to use the term " group " instead of " series " for divisions of the Carboniferous sequence, and so described the Upper Kuttung, Lower Kuttung, Upper Burindi and Lower Burindi groups.

The names Burindi and Kuttung have therefore been used in both the rock and time-rock sense, and also to indicate differences in facies. Because of the inclusion of the words " upper " and " lower ", they do not conform to the code as rock-terms but would still be acceptable as time-rock-terms. The suggestion is made that they be so retained for the present.

Rock terms for the various formations will be decided upon by future workers, and the names of Kuttung and Burindi may be used in some way, preferably in the areas where they were originally defined.

More satisfactory progress has been made in the palæontology of the formations, and more secure correlations with European and North American sequences have already emerged. Crockford (1947), after a study of the bryozoan faunas from the Lower Burindi mudstones, suggested a correlation with the Osagean of North America and, hence, with the Tournaisian of Europe. Work done on the brachiopods and corals from the northern end of the Werrie Basin by Campbell (1957) has confirmed an Upper Tournaisian age for the higher parts of the Lower Burindi mudstones in that area.

Previously Delépine (1941) had suggested an Upper Tournaisian age for a goniatite assemblage from the lower part of the Burindi mudstones in the same vicinity previously regarded by Brown as Lower Tournaisian (Carey, 1937, p. 353). The evidence of the brachiopods suggests that the age determined by Delépine is too young, and further support comes from a partial reassessment of the goniatite evidence by Miller and Collinson (1951). The closest affinities of these faunas appear to be with those of North America, though there remain clear connections with Western Europe and North Africa also.

The bryozoans from the marine intercalations in the Lower Kuttung at Rouchel Brook (Crockford, 1948, 1951) are very similar to those from the upper part of the Lower Burindi mudstone. However, the *Phricodothyris* described from this locality by Campbell (1951) is quite distinctive.

The so-called *Productus barringtonensis* from beds in the Gloucester Trough mapped by me as Upper Burindi (Voisey, 1940) is now known to belong to the genus *Marginirugus*, which in North America is restricted to a horizon near the Tournaisian-Visean boundary. The form was known only from the lower North Coast of New South Wales, until Traves (1955) recorded that the genus was recognized by Öpik from the Septimus Limestone in Western Australia. This suggests that the coarse sedimentation of the Lower Kuttung-Upper Burindi type may have commenced earlier in the Gloucester area than in the Werrie Basin.

TABLE D.
CARBONIFEROUS.
Showing Changes in Nomenclature of the Carboniferous Formations.

ROCKY CREEK. Benson (1913).	HUNTER RIVER. David and Sussmilch (1919).	CLARENCETOWN-PATERSON. Osborne (1922).	CURRABUBULA. Carey (1937).	YESSABAH. Voisey (1934).	N.S.W. Voisey (1952).	N.S.W. SERIES. Carey and Browne (1938).	EUROPEAN STAGES.
Rocky Creek Conglomerates.	Kuttung Series.	Kuttung Series.	Upper Kuttung Series.	Kullatine Series.	Upper Kuttung Group.	Upper Kuttung Series.	Moscovian.
	Glacial Beds.	Glacial Stage.					Namurian.
Burindi Series.	Mt. Johnstone Beds.	Volcanic Stage.	Lower Kuttung Series.	— ? — — ? — — —	Lower Kuttung Group.	Lower Kuttung Series.	Viséan.
	Martin's Creek Beds.			Boonanghi Series.	= Upper Burindi Group.	= Upper Burindi Series.	
	Wallarobba Beds.	Basal Stage.					
	Burindi Series.	Burindi Series.	Burindi Series.		Lower Burindi Group.	Lower Burindi Series.	Tournaisian.

The only recent work on faunas higher in the Carboniferous is that of Crockford (1948, 1951), who concluded that a cryptostomate bryozoan fauna from a horizon mapped by Osborne (1950) in the upper glacials of the Upper Kuttung was closely comparable with that of the Neerkol Series of Queensland. Hence, a correlation with the Moscovian was suggested. Maxwell (1951) made reference to Neerkol brachiopods in the Upper Burindi of Gloucester, Bramble Bay and the Emu Creek Series of Drake.

We are thus well on the way towards establishing very close correlations with the Carboniferous rocks of North America and Europe, and it is apparent that only by the continuation of this detailed palæontological work shall we be able to define our series here in the terms agreed to by European and American geologists.

A discussion of the palæogeography of Carboniferous times has been given elsewhere (Voisey, 1945 and 1957).

Permian.

Clarke (1878, p. 66) divided the Hunter River sequence into

Upper Coal Measures.
Upper Marine Beds.
Lower Coal Measures.
Lower Marine Beds.

While advocating a Palæozoic age for them, he stated (1878, p. 36) that even in 1861 he had been willing to admit that, though some of the coal appeared to belong to the true Carboniferous epoch, some might belong to the Permian, as was suggested by Mr. Dana.

Controversy regarding the actual Carboniferous-Permian boundary was to continue for nearly 80 years longer. That it is not yet over is evidenced by D. Hill's closing remarks in her review of Permian stratigraphy. She states (1954*b*, p. 104) " It is possible, then, that in Australia also the *Glossopteris* flora may have entered in the Stephanian and the tendency apparent since 1951 to take the base of the Australian Permian down to include all beds with the *Glossopteris* flora may prove to have been ill-inspired ".

The Geological Survey of New South Wales, following a great deal of work on the coalfields, subdivided the Hunter River sequence in terms of the code (as indicated in the Table E). The major changes are the substitution of the names " Dalwood Group " and " Maitland Group " for " Upper Marine Series " and " Lower Marine Series " on the grounds that " Upper Marine " and " Lower Marine " are not place names (Hill, 1954*b*, p. 93).

Hanlon, Joplin and Noakes (1953) also reorganized the nomenclature of the Illawarra District (see Table E).

Hanlon (1947–48 ; see Hill, 1954*b*, pp. 93–94) has named the formations he had previously described from the North-western Coalfield, and Loughnan (1954) has recognized a number of formations in the Gloucester Trough. C. T. McElroy (1957), after a detailed examination of the sediments of the Southern Coal-field, described them as well-sorted sandstones and discussed the heavy mineral assemblages.

E. K. Sturmfels (1950) recorded *Glossopteris* and *Noeggerathiopsis* from the Oaklands-Coorabin Coalfield and noted that I. Crespin had identified *Hyperamminoides* cf. *aucula* Parr and *Ammodiscus* cf. *milletianus* Chapman.

The Permian sediments in the Ashford Coalfield were examined by H. B. Owen and G. M. Burton (1954), and detailed sections were listed, but the sequence was not divided into formations and groups.

TABLE E.
PERMIAN.

ILLAWARRA. Hanlon, Joplin and Noakes (1953).	HUNTER RIVER. N.S.W. Geol. Surv., in Hill (1954*b*).	NORTH-WEST COALFIELD. Hanlon, in Hill (1954*b*).	GLOUCESTER COALFIELD. Loughnan (1954).	MANNING RIVER. Voisey.	MACLEAY RIVER. Voisey.	BOOROOK-DRAKE. Voisey.	N.S.W. SERIES. David (1950).	RUSSIAN STAGES.
Illawarra Coal Measures.	Newcastle Coal Measures. Tomago Coal Measures.	Black Jack Formation.					Upper Coal Measures.	
Tappitallee Mountain Tuff. Berkley Latite. Minnamurra Latite. Gerringong Volcanics. Cambewarra Latite. Saddleback Latite. Broughton Tuff. Shoalhaven Group. Berry Shale. Nowra Sandstone. Wandrawandian Siltstone.	Maitland Group. Mulbring Formation. Branxton Sub-Group. Muree Formation. Belford Formation. Elderslie Formation.	Gladstone Formation. Porcupine Formation.	Broad Gully Formation. Spring Creek Conglomerate.			Boorook Group. Gilgurry Mudstone. Cataract River Formation.	Upper Marine Series.	Tartarian. Kazanian. Kungurian.
Clyde Coal Measures.	Greta Coal Measures.	Werris Creek Coal Measures.	The Craven Coal Measures.				Lower Coal Measures.	Artinskian.
	Dalwood Group. Farley Formation. Rutherford Formation. Allandale Formation. Lochinvar Formation.	Werrie Basalts. Temi Group.	Ward's River Conglomerate. The Avon Coal Measures. Dewrang Formation.	Manning Group. Colraine Mudstone. Cedar Party Limestone. Kimbriki Formation.	Macleay Group. Warbro Formation. Yessabah Limestone. Tait's Creek Formation.	Cheviot Hills Group. Girard Pyroclastics. Drake Volcanics.	Lower Marine Series.	Sakmarian.

In order to bring my own work on the North Coast (Voisey, 1934–1950) into line with the code and to correlate the beds with those of the Hunter River District, I suggest the following scheme, which will be discussed in another publication.

Hunter River.	Manning River.	Macleay River.
Dalwood Group	*Manning Group*	*Macleay Group*
Farley Formation	Colraine Mudstone	Warbro Formation
Rutherford Formation		
Allandale Formation	Cedar Party Limestone	Yessabah Limestone
Lochinvar Formation	Kimbriki Formation	Tait's Creek Formation

The rocks of the Boorook-Drake area in the County of Buller are also being renamed as follows :

Boorook Group.

Gilgurry Mudstone	1000 ft.
Cataract River Formation	810 ft.

Cheviot Hills Group.
Girard Pyroclastics.
Drake Volcanics.

The Plumbago Creek Series (Voisey, 1936*b*, p. 162 ; 1939*c*), which in future will become the Plumbago Creek Beds, was recently re-examined and found to contain definite Permian fossils. These were identified by K. S. W. Campbell as follows : *Anidanthus springsurensis* Booker, *Strophalosia* cf. *preovalis* Maxwell, *Terrakea* sp., *Aviculopecten* sp., *Stenopora* sp., *Fenestella* sp. and *Polypora* sp. These occur in rocks exposed in a gully about a mile north-west of the limekilns on the Tabulam-Pretty Gully Road. Because of the intervening granite intruding the beds, their relations with the Boorook and Cheviot Hills groups have not been determined, but the fossils indicate that they should be low in the section.

Permian sedimentary formations are probably much more widespread in north-eastern N.S.W. than has previously been supposed. They occur at least at intervals in a belt running from the vicinity of Mt. Jasper in the watershed of the Hastings River through the Mooraback area, where in Limestone Creek limestones are exposed. They appear again in rugged country around Hall's Peak, where they are associated with flows of rhyolite and andesite.

Permian fossils were found in a limestone boulder in the neighbourhood of Jeogla, 33 miles east of Armidale, by W. Anderson (R. Etheridge, Junr., 1888 ; Andrews, 1908). They were found *in situ* a few years ago by Mr. Maurice Wyndham in Oaky Creek and in a number of other places to the north. An extensive occurrence near the Devil's Chimney in the gorge of Kangaroo Creek, Aberfoyle, is said to have been visited by Professor David nearly 60 years ago.

Fossils identified by H. O. Fletcher from Jeogla include *Linoproductus cora* var. *farleyensis* (Eth.), *Spirifer* cf. *duodecimcostata* McCoy, *Spirifer stokesi* Koninck, *Spirifer vespertilio* Sowerby, *Dielasma sacculum* var. *hastata* (Sowerby), *Pleurotomaria morrisiana* McCoy, *Conularia levigata* Morris.

The beds around the Oaky Creek Dam Site were mapped by E. J. Harrison (1949, p. 70).

Because of the intense folding and faulting in New England it is very difficult to separate the various formations, and it is thought that much of the rock hitherto regarded as being Lower Palæozoic and resembling the Brisbane Metamorphics, will turn out to be Upper Palæozoic.

Triassic.

It was Clarke who named the sandstones around Sydney the Hawkesbury Sandstones, and the shales above them the Wianamatta Beds (1878, p. 70). These names have been retained in the revised form of the Triassic sequence as given by Hanlon, Osborne and Raggatt in 1953. Table F shows the details of the recently accepted nomenclature. Osborne (1948), in an excellent review of the stratigraphy of the Sydney Basin, brought together earlier work, illustrating his treatment by means of a number of measured sections. He also dealt with the nature of the sediments and their structures and discussed the possible environments under which they were formed.

Lovering (1954) subdivided the Wianamatta Group, and Crook (1956) detailed the formations of the Narrabeen Group outcropping in the Grose River District, applying the principles set out by Packham (1954) in the classification of the sediments and discussing the depositional conditions.

J. Rade (1953, p. 153 ; 1954*a*, p. 42) gave the name Gunnee Beds to grey, gritty sandstones with shales 100 feet thick in the Delungra area (Portion 42, Ph. Gunnee) recording from them *Thinnfeldia odontopteroides* (Morris), *T. lancifolia* (Morris), *T. feistmanteli* (Johnston), *Johnstonia coriacea* (Johnston) and *Stenopteris elongata* (Carruthers). He pointed out that available bore-logs indicated that the Triassic sediments thinned out quickly towards the west. Triassic beds are known to outcrop southward towards Gunnedah around the eastern margin of the Artesian Basin. Some well-preserved plant remains were shown to me recently by Mr. C. R. McWilliams on his property " Greylands ", near Turrawan, in beds immediately overlying the Permian Coal Measures.

Jurassic.

Rade (1954*a*, 1954*b*) described some of the Jurassic rocks in the Warialda and Coonamble areas assigning to some of them a Walloon age, but did not apply any formation names.

Wade (1953) described some Jurassic fishes from N.S.W. but did not give details of their stratigraphical occurrence.

There is a great deal of work to be done on the beds of the Clarence Basin and the Jurassic sediments fringing the Artesian Basin. It is not possible at present to give any list of the formations.

Cretaceous.

Rade (1954*a*, 1954*b*) referred to the Cretaceous sediments in the Artesian Basin in New South Wales. Crespin (1955) listed the Lower Cretaceous foraminifera derived from bores in northern New South Wales, mentioning 102 genera and species, most of them arenaceous forms. She suggested that the assemblages indicated deposition in a near-shore, shallow, brackish-water environment.

Tertiary.

Little has been written of Tertiary sediments in the past decade, but names have been given to a number of lava flows and pyroclastic rocks, notably by Hanlon, Joplin and Noakes (1954) for the Illawarra District and by Crook and McGarity (1955) for the Minynon Falls District.

TABLE F.
TRIASSIC.

SYDNEY BASIN. Lovering (1954).	COLO-GROSE. Crook (1956).	NARRABEEN-WYONG. Hanlon-Osborne-Raggatt (1953).	SOUTH COAST. Hanlon-Osborne-Raggatt (1953) ; Hanlon (1956).	NEW SOUTH WALES SERIES. David (1950).	EUROPEAN STAGES.
Wianamatta Group. Camden Sub-Group. Prudhoe Shale. Picton Formation. Razorback Sandstone. Annan Shale. Pott's Hill Sandstone. Liverpool Sub-Group. Bringelly Shale. Minchinbury Sandstone. Ashfield Shale.	Wianamatta Group. Bringelly Shale. Minchinbury Sandstone. Ashfield Shale.			Wianamatta Series.	Rhaetic. Keuper.
Hawkesbury Sandstone. Passage Beds. Massive Orthoquartzite.	Hawkesbury Sandstone.	Hawkesbury Sandstone.	Hawkesbury Sandstone. Undola Sandstone Member.	Hawkesbury Series.	Upper Bunter.
Narrabeen Group.	Narrabeen Group. Burralow Formation (with Tabarag Sandstone Member).	Narrabeen Group. Gosford Formation. Mangrove Sandstone Member. Ourimbah Sandstone Member. Wyong Sandstone Member.	Narrabeen Group. Gosford Formation.	Narrabeen Series.	Lower Bunter.
		Clifton Sub-Group. Collaroy Claystone.	Clifton Sub-Group. Bald Hill Claystone.		
	Grose Sandstone.	Tuggerah Formation.	Bulgo Greywacke. Stanwell Park Claystone.		
		Munmorah Conglomerate.	Scarborough Greywacke.		
			Wombarra Shale. Otford Greywacke Member.		
	Caley Formation.		Coalcliff Greywacke.		

Pleistocene.

Vallance (1953*b*) described the finding of varved clays in the valley of Trapyard Creek in the Kosciusko district by W. R. Browne and D. G. Moye. This was the first record of Pleistocene varved glacial deposits in New South Wales.

THE FUTURE.

An examination of our knowledge of the sedimentary formations of New South Wales reveals that there are many gaps. These occur primarily because there have been so few workers. Even those who are most interested actually spend comparatively short periods in the field. I feel that as a group none of us should feel satisfied with the collective effort in the last ten years. It is true to say that a large part of the work has been done by University staff and students. Because of the necessity for such investigations to yield tangible results, there has been a conscious selection of areas known to be mappable and to contain a variety of interesting rocks.

Officers of the N.S.W. Geological Survey have been dealing principally with coal-bearing areas, so far as stratigraphical work is concerned. Others have studied fracture-patterns and aspects of ore deposition, and have not been able to spend time on stratigraphical work.

As a result of the selection of areas for special reasons we find that we know a great deal about the lacustrine and shelf deposits. The miogeosynclinal and exogeosynclinal areas of the Central West and the coal-fields have been well studied. We know relatively little about the eugeosynclinal deposits, apart from scrappy notes in a large number of reports.

While we have been struggling to find what rocks actually exist in New South Wales, big advances in the study of sedimentary formations have been made overseas, particularly in America, because of their importance in the search for oil. Even there work has been much more concentrated upon continental and miogeosynclinal areas than upon the contents of the eugeosynclines. In Australia, we have been particularly handicapped by the comparative scarcity of sub-surface information. Unless the search for oil is successful and work on sedimentary formations is encouraged, we do not stand much chance of rectifying this position.

One must hope that it will be possible to expand the personnel and facilities of the State Geological Survey, so that it will be able to embark on a programme of systematic mapping in co-operation with the Commonwealth Bureau of Mineral Resources. In the United States there exists close liaison not only between the U.S. Geological Survey and the state surveys, but also between both and the Universities. The procedure adopted in both the United States and Canada, whereby some members of the University staffs work with the Surveys during vacations, and conversely certain survey officers are invited to spend some time in the Universities, has a lot to recommend it. The use of University students by the Surveys during vacations is a step in the right direction.

Very little mapping has yet been done in this State from aerial photographs, but their use in the future should greatly expedite the completion of map sheets and add to their accuracy. The efficient functioning of the Survey Service of the Australian Military Forces at Victoria Barracks and the Air Photo Library of the N.S.W. Department of Lands, to both of which all members of my department are heavily indebted, should now make this possible.

Apart from the economic necessity in relation to our resources of coal, petroleum and the non-metals, the regional mapping of the State is a necessary basis for all other geological investigations.

As pointed out by Krumbein and Sloss (1951, p. 4), there are two principal aspects of stratigraphy, one physical relating to the rocks and their characteristics, and the other involving the study of palæontology. Through the former we proceed to lithological correlation and sedimentary tectonics, and through the latter to the study of organic evolution. From both we determine the history of an area and build up the palæogeography.

Recent papers show that the palæontologists are becoming more precise in their work, thus enabling us to make closer correlations with overseas sequences in the manner attempted by Clarke.

On the other hand, we have a tremendous amount of sedimentary petrology ahead of us. Rock names given in the past have usually been those determined in the field, and when one attempts to use the data for environmental studies the shortcomings are most noticeable.

The kind of work being carried out by Packham (1954), Lovering (1954), Crook (1954, 1956) and McElroy (1957) is a necessary part of our stratigraphical investigations, and must be done before any really reliable data on sedimentary facies and sedimentary tectonics can be assembled. Not only must agreement be reached on rock classification, but details of sedimentary structures, as indicated by Packham (1954), must be recorded.

The future should see much more accurate mapping, more sedimentary petrology and a continuation of the good work being done in palæontology.

An absorbing story is contained in the sedimentary formations of New South Wales and we, like Rev. W. B. Clarke, must seek by diligence and perseverance to read it.

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ADDENDUM TO MY PAPER "ON WEBER TRANSFORMS."

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Manuscript received, November 13, 1957. Read, December 4, 1957.

Referring to my paper with the above title (Griffith, 1956), Professor R. P. Boas, Jnr., has pointed out (Boas, 1957) to me that the arbitrary smallness of $\int_0^\eta$ on line 7, page 247, is not by any means obvious, particularly in view of equation (2.3) on page 236.

This last objection is removed by writing " $s=u>0$ " in place of " $s=u$ " in the enunciation of Theorem W.

Now recalling that $|\alpha^{\frac{1}{2}}J_\nu(\alpha)|$ has a finite upper bound M_1 for $\alpha>0$, that $|\alpha^{\frac{1}{2}}Y_\nu(\alpha)|$ has a finite upper bound $M_{2,\nu}(\alpha_0)$ for $\alpha>\alpha_0>0$, that $Q_\nu(\alpha)>0$ for $\alpha>0$, that $|J_\nu(\alpha)|\leqq Q_\nu(\alpha)$ and that $|Y_\nu(\alpha)|\leqq Q_\nu(\alpha)$, we see that the only terms on lines 4 and 5 of page 247 which appear to give trouble are those involving $Y_{\nu+1}(\lambda s)$ and $Y_\nu(\lambda s)$.

It will suffice for our conclusions if we prove that

$$S_1\equiv\lambda^{\frac{1}{2}}s^{3/2}J_\nu(as)Y_{\nu+1}(\lambda s)/Q_\nu(as)$$

and

$$S_2\equiv\lambda^{\frac{1}{2}}s^{\frac{1}{2}}J_\nu(as)Y_\nu(as)/Q_\nu(as)$$

are bounded for all $\lambda\geqq a$ and $0<s<\eta<u$.

Writing $\alpha=\lambda s$, we obtain

$$S_1=\frac{\alpha^{3/2}J_\nu(a\alpha/\lambda)Y_{\nu+1}(\alpha)}{\lambda Q_\nu(a\alpha/\lambda)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$=s\alpha^{\frac{1}{2}}Y_{\nu+1}(\alpha)\frac{J_\nu(a\alpha/\lambda)}{Q_\nu(a\alpha/\lambda)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Now taking $\nu>0$ and referring to the asymptotic estimates in the neighbourhood of the origin, we see that we can choose an α_0, so that when $0<\alpha<\alpha_0$, $|Y_{\nu+1}(\alpha)|$ and $Q_\nu(\alpha)$ are monotonic decreasing and $J_\nu(\alpha)$ is monotonic increasing. Thus equation (1) gives

$$|S_1|<\frac{\alpha_0^{\frac{1}{2}}}{\lambda}\ \frac{\alpha J_\nu(\alpha)\,|Y_{\nu+1}(\alpha)|}{Q_\nu(\alpha_0)}$$

and, since the right side is bounded, S_1 is bounded for $0<\alpha<\alpha_0$.

Now, after the choice of α_0, we see that equation (2) shows that $|S_1|<\eta M_{2,\nu+1}(\alpha_0)$ for $\alpha>\alpha_0$.

So we have proved that S_1 is uniformly bounded if $0<s<\eta<u$ when $\nu>0$.

Only a slight modification in the above proof is required for $\nu=0$, and a similar method may be applied to show that S_2 is also uniformly bounded.

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R. P. Boas, Jnr., 1957. Review of above paper. *Math. Reviews*, **18** (6), p. 481.

ON THE ZEROS OF A CERTAIN FUNCTION INVOLVING BESSEL FUNCTIONS.

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With two Text-figures.

Manuscript received, November 11, 1957. Read, December 4, 1957.

In a paper published some time ago (Griffith, 1957) I stated, without proof, some facts concerning the distribution of the zeros of

$$w(z,\,C,\,\nu)\equiv w(z)\equiv zH^{(1)}_{\nu+1}(z)-CH^{(1)}_{\nu}(z),\quad \nu\geqq 0,\qquad \ldots\ldots\quad (1)^*$$

where C is a *real* constant. The results quoted were sufficient for the needs of the paper. I submit in what follows an analysis of the zeros of $w(z)$ for $-\frac{1}{2}\pi\leqq\arg z\leqq\frac{3}{2}\pi$, which will include a statement of, and a proof of, the previous assertions. It will be obvious that our conclusions can be modified trivially to give information concerning the zeros of $zK_{\nu+1}(z)-CK_{\nu}(z)$ in the region $-\pi<\arg z<\pi$.

Suppose that $z_0=re^{i\alpha}$, $-\frac{1}{2}\pi\leqq\alpha\leqq\frac{1}{2}\pi$ is a zero of $w(z)$. Then writing $\bar{z}=re^{-i\alpha}$, we see that

$$z_0H^{(1)}_{\nu+1}(z_0)-CH^{(1)}_{\nu}(z_0)=0$$

and

$$\bar{z}_0H^{(2)}_{\nu+1}(\bar{z}_0)-CH^{(2)}_{\nu}(\bar{z}_0)=0$$

Then by Erdélyi (1953, p. 80, (43)) we obtain

$$-\bar{z}_0e^{i\pi(\nu+1)}H^{(1)}_{\nu+1}(\bar{z}_0e^{i\pi})+Ce^{i\pi\nu}H^{(1)}_{\nu}(\bar{z}_0e^{i\pi})=0$$

that is

$$(\bar{z}_0e^{i\pi})H^{(1)}_{\nu+1}(\bar{z}_0e^{i\pi})-CH^{(1)}_{\nu}(\bar{z}e^{i\pi})=0$$

Since the order of these equations may be reversed, we observe that the *zeros of* w(z) *are symmetrically placed with regard to the imaginary axis.*

We now show that *if a multiple zero of* w(z) *occurs, it must lie on one of the axes.*

Banerjee has proved that $H^{(1)}_{\nu+1}(z)$ and $H^{(1)}_{\nu}(z)$ have no common zero (quoted in Erdélyi, 1953, p. 62). Thus it immediately follows that no zero of $H^{(1)}_{\nu}(z)$ will coincide with a zero of $w(z)$.

Now $w(z)$ may be written in either of the forms

$$w(z)=zH^{(1)}_{\nu+1}(z)-CH^{(1)}_{\nu}(z)\qquad\ldots\ldots\ldots\ldots\ldots\ldots\ldots\quad (2a)$$

or

$$w(z)=-zH^{(1)}_{\nu-1}(z)+(2\nu-C)H^{(1)}_{\nu}(z)\qquad\ldots\ldots\ldots\ldots\quad (2b)$$

(Watson, 1953, p. 74).

---

[*] The Bessel Functions $J_\nu(z)$, $Y_\nu(z)$, $H^{(1)}_\nu(z)$, $H^{(2)}_\nu(z)$, $I_\nu(z)$ and $K_\nu(z)$ used in this paper are those defined by Watson (1953, pp. 40, 64, 73, 77 and 78). We will write $w(z)$ whenever it is not necessary to specify C and ν.

Now, if $w(z)$ has a multiple zero, z_0, then z_0 is a zero of both $z^\nu w(z)$ and $d[z^\nu w(z)]/dz$. Thus

$$z_0^\nu[-z_0H_{\nu-1}^{(1)}(z_0)+(2\nu-C)H_\nu^{(1)}(z_0)]=0$$

and

$$z_0^\nu[z_0H_\nu^{(1)}(z_0)-CH_{\nu-1}^{(1)}(z_0)]=0$$

(Watson, 1953, p. 74).

Then eliminating $\mathrm{H}_{\nu-1}^{(1)}(z_0)$ from these two equations, we have

$$z_0^\nu[z_0^2+C(C-2\nu)]H_\nu^{(1)}(z_0)=0.$$

If we delete the branch point from our consideration and recall that $H_\nu^{(1)}(z_0)\neq 0$, we see that $z_0^2+C(C-2\nu)=0$.

Now C and ν are real, and we see that this proves our assertion.

To obtain many of our results we write

$$w(z)=zH_\nu^{(1)}(z)\zeta(z),$$

where

$$\zeta(z)=\frac{H_{\nu+1}^{(1)}(z)}{H_\nu^{(1)}(z)}-\frac{C}{z}, \qquad \dots\dots\dots\dots\dots\dots \quad (3)$$

and examine the change in arg $\zeta(z)$ as z passes around certain contours.

Thus, account must be taken of the zeros of $H_\nu^{(1)}(z)$. Combining information supplied in Erdélyi (1953, p. 62) and Watson (1953, p. 511), we obtain

A. (*a*) $H_\nu^{(1)}(z)$ has no zeros if $0\leqq \arg z<\pi$.

(*b*) If $\nu-\frac{1}{2}$ is an even integer $2k$, then $H_\nu^{(1)}(z)$ has k zeros in each of the regions $-\frac{1}{2}\pi<\arg z<0$ and $\pi<\arg z<\frac{3}{2}\pi$.

(*c*) If $\nu-\frac{1}{2}$ is an odd integer $2k-1$, then $H_\nu^{(1)}(z)$ has $k-1$ zeros in each of the regions $-\frac{1}{2}\pi<\arg z<0$ and $\pi<\arg z<\frac{3}{2}\pi$ and a single zero on the negative imaginary axis.

(*d*) If $\nu-\frac{1}{2}$ is not an integer and $2k$ is the nearest even integer, then $H_\nu^{(1)}(z)$ has k zeros in each of regions $-\frac{1}{2}\pi<\arg z<0$ and $\pi<\arg z<\frac{3}{2}\pi$.

Analysis of the case $C=2\nu$ is somewhat trivial. Here we find that

$$w(z)=-zH_{\nu-1}^{(1)}(z) \qquad \dots\dots\dots\dots\dots\dots \quad (4)$$

Thus if $C=2\nu$, *all the zeros of* $\mathrm{H}_{\nu-1}^{(1)}(\mathrm{z})$ *are zeros of* $\mathrm{w}(\mathrm{z})$. Further, by examining the behaviour of $w(z)$ in the neighbourhood of the origin, it will be found that $\mathrm{w}(0, 2\nu, \nu)=0$ *only for* $0<\nu<2$.

It is only in this special case that the origin is a zero of $w(z, C, \nu)$, since if $C\neq 2\nu$ we find that

$$w(z)\sim\begin{cases} i\pi^{-1}[C\log z-2][1+o(1)], & \nu=0 \\ i\pi^{-1}[\Gamma(\nu)2^\nu z^{-\nu}][2\nu-C][1+o(1)], & \nu\neq 0 \end{cases}$$

as $|z|\to 0$.

We tabulate first some of the formulæ to be used later. To obtain these we use Erdélyi (1953), p. 4 (4), (5) ; p. 5 (15) ; p. 8 (32) ; p. 80, (35), (39)(, (42) ; and p. 85 (1).

$$\frac{H_{\nu+1}^{(1)}(z)}{H_\nu^{(1)}(z)}\sim i[1+O(|z|^{-1})] \qquad \dots\dots\dots\dots\dots \quad (5)$$

as $|z| \to \infty$;

$$\zeta(z) \sim \begin{cases} \left[\dfrac{2}{z \log z} - \dfrac{C}{z}\right][1+o(1)], & \nu=0 \\ \dfrac{2\nu - C}{z}[1+o(1)], & \nu \neq 0 \end{cases} \qquad \text{............} \quad (6)$$

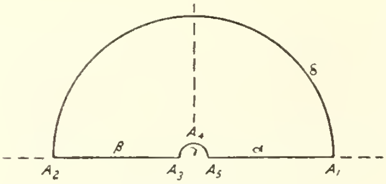
as $|z| \to 0$;

when $z=x>0$

$$\frac{H^{(1)}_{\nu+1}(z)}{H^{(1)}_{\nu}(z)} = \frac{J_{\nu+1}(x)J_\nu(x)+Y_{\nu+1}(x)Y_\nu(x)-2i(\pi x)^{-1}}{[J_\nu(x)]^2+[Y_\nu(x)]^2}; \qquad \text{......} \quad (7)$$

when $z=re^{i\pi}$, $r>0$

$$\frac{H^{(1)}_{\nu+1}(z)}{H^{(1)}_{\nu}(z)} = \frac{-J_{\nu+1}(r)J_\nu(r)-Y_{\nu+1}(r)Y_\nu(r)-2i(\pi r)^{-1}}{[J_\nu(r)]^2+[Y_\nu(r)]^2} \qquad \text{......} \quad (8)$$



Text-fig. 1.

when $x=te^{\frac{1}{2}\pi i}$, $t>0$

$$w(z)=(\tfrac{1}{2}\pi i)^{-1}e^{-\frac{1}{2}\nu\pi i}[tK_{\nu+1}(t)-CK_\nu(t)]; \qquad \text{............} \quad (9)$$

when $z=ue^{-\frac{1}{2}\pi i}$, $u>0$

$$\frac{H^{(1)}_{\nu+1}(z)}{H^{(1)}_{\nu}(z)} = \frac{\pi \cos \nu\pi \,.\, u^{-1}-iP}{Q} \qquad \text{......................} \quad (10)$$

where

$$P=\{\pi^2 I_{\nu+1}(u)I_\nu(u)-K_{\nu+1}(u)K_\nu(u)\}+\pi \sin \nu\pi\{I_{\nu+1}(u)K_\nu(u)-I_\nu(u)K_{\nu+1}(u)\}$$

and

$$Q=[\pi I_\nu(u)+\sin \nu\pi K_\nu(u)]^2+\cos^2 \nu\pi[K_\nu(u)]^2.$$

Since we have completed the case $C=2\nu$, we will assume in what follows that $C\neq 2\nu$. Since C/z is real on the real axis, equations (7) and (8) show that $\zeta(z)$ does not vanish on the real axis. Thus w(z) *does not have a zero on the real axis.* Similarly, since C/z is imaginary on the negative imaginary axis, equation (10) shows that if $\cos \nu\pi \neq 0$ (i.e. $\nu-\frac{1}{2}$ does not equal an integer), $w(z)$ does not have a zero on the negative real axis.

We now determine the number of zeros above the real axis by examining the increase of arg $\zeta(z)$ as z passes around the contour in Figure 1.

It will be assumed that the large semicircle δ (with centre the origin) is sufficiently large for the estimate (5) to be valid and the small semicircle γ to be small enough for the estimate (6) to hold.

It is then easy to see that the values of arg $\zeta(z)$ are given by the following table.

	$C<2\nu$	$C>2\nu$
A_1	$-\frac{1}{2}\pi$	$-\frac{1}{2}\pi$
A_2	$-\frac{1}{2}\pi$	$-\frac{1}{2}\pi$
A_3	$-\pi$	0
A_4	$-\frac{1}{2}\pi$	$\frac{1}{2}\pi$
A_5	0	π
A_1	$-\frac{1}{2}\pi$	$\frac{3}{2}\pi$

The increase in arg $\zeta(z)$ is zero if $C<2\nu$ and is 2π if $C>2\nu$. Thus, referring back to A(a) above and recalling the symmetry of the zeros, we conclude that

If $C<2\nu$, $w(z)$ *has no zero above the real axis.*

If $C>2\nu$, $w(z)$ *has one and only one zero above the real axis. This is a simple zero, which lies on the positive imaginary axis.*

In view of equation (9), we see that we have proved incidently a rather obvious result which we will need later, *viz.*: $tK_{\nu+1}(t)-CK_\nu(t)$ *has one and only one real positive zero if* $C>2\nu$ *and no real positive zero if* $C<2\nu$.

Now the recurrence formulæ (Watson, 1953, p. 79) show that

$$tK_{\nu+1}(t)-CK_\nu(t)=tK_{\nu-1}(t)-(C-2\nu)K_\nu(t).$$

If we sketch the graphs of $tK_{\nu-1}(t)$ and $(C-2\nu)K_\nu(t)$ it is immediately obvious that as $C-2\nu$ increases from 0 to ∞, the zero moves from the origin to ∞. The asymptotic formulæ for the Bessel functions show that for large C the zero approximates to $C-\nu-\frac{1}{2}$.

We now proceed to determine the distribution of the zeros of $w(z)$, which lie below the real axis.

We first assume that $\nu-\frac{1}{2}$ is not an integer. Thus $\cos\nu\pi\neq0$, and so $w(z)$ will have no zeros on the negative imaginary axis.

Keeping Figure 1 in mind, the description of Figure 2 is obvious (See page 194).

As z passes around the contour in Figure 2, the values of arg $\zeta(z)$ are given by the following table:

	$C<2\nu$		$C>2\nu$
	$\cos\nu\pi>0$	$\cos\nu\pi<0$	
A_6	$-\frac{1}{2}\pi$	$-\frac{1}{2}\pi$	$-\frac{1}{2}\pi$
A_1 ..	$-\frac{1}{2}\pi$	$-\frac{1}{2}\pi$	$-\frac{1}{2}\pi$
A_5	0	0	$-\pi$
A_7	$\frac{1}{2}\pi$	$\frac{1}{2}\pi$	$-\frac{1}{2}\pi$
A_6	$-\frac{1}{2}\pi$	$\frac{3}{2}\pi$	$-\frac{1}{2}\pi$

Thus arg $\zeta(z)$ is unchanged except when $C<2\nu$ and $\cos\nu\pi<0$; in which case the increase is 2π. So if $C<2\nu$ and $\cos\nu\pi<0$, the number of zeros of $w(z)$ in $-\frac{1}{2}\pi<\arg z<0$ is one more than the number of zeros of $H_\nu^{(1)}(z)$ in that region. Otherwise the number of zeros of $w(z)$ and $H_\nu^{(1)}(z)$ in $-\frac{1}{2}\pi<\arg z<0$ is the same.

Then referring back to A(d) we obtain

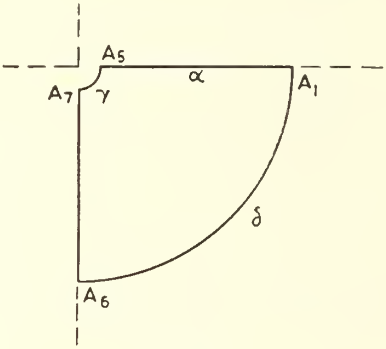
If $\mathrm{C}>2\nu$, *then* w(z) *has* k *zeros in* $-\frac{1}{2}\pi<\arg z<0$ (*and in* $\pi<\arg z<\frac{3}{2}\pi$) *provided* $2\mathrm{k}-\frac{1}{2}<\nu<2\mathrm{k}+\frac{1}{2}$ *or* $2\mathrm{k}+\frac{1}{2}<\nu<2\mathrm{k}+1\frac{1}{2}$.

If $\mathrm{C}<2\nu$, *then* w(z) *has* k *zeros in* $-\frac{1}{2}\pi<\arg z<0$ (*and in* $\pi<\arg z<\frac{3}{2}\pi$) *provided* $2\mathrm{k}-1\frac{1}{2}<\nu<2\mathrm{k}-\frac{1}{2}$ *or* $2\mathrm{k}-\frac{1}{2}<\nu<2\mathrm{k}+\frac{1}{2}$.

We now assume that $\nu-\frac{1}{2}=n$ (n, an integer). Thus $\cos\nu\pi=0$.

We cannot use a method similar to that used above, since there may be zeros on the negative imaginary axis.

Using Erdélyi (1953), p. 78 (90) to determine the explicit expansion for $w(z, C, n+\frac{1}{2})$, we observe that it may be expressed as the product of a factor which has no finite zero and a polynomial of degree $n+1$.



Text-fig. 2.

Thus $w(z)$ must have $n+1$ zeros. If $C>2\nu$, one only of these must lie above the real axis, and if $C<2\nu$, then all must lie below the real axis. If we determine the number of zeros which lie on the axis, the remainder will be symmetrically placed on either side.

We write $z=ue^{i\pi}$, $u>0$ and use Erdélyi (1953), p. 5 (15) and p. 80 (45) and Watson (1953), p. 79 to put $w(z)$ in the following forms:
if $\nu-\frac{1}{2}=2k$ (k an integer)

$$w(z)=2\pi^{-1}e^{-(k+\frac{1}{4})\pi i}p(u) \quad \ldots\ldots\ldots\ldots\ldots \quad (11a)$$

with

$$p(u)=[uK_{\nu+1}(u)-CK_{\nu}(u)]-\pi[uI_{\nu+1}(u)+CI_{\nu}(u)] \quad \ldots\ldots \quad (11b)$$

$$=[uK_{\nu-1}(u)-(C-2\nu)K_{\nu}(u)]-\pi[uI_{\nu-1}(u)+(C-2\nu)I_{\nu}(u)]\,.\,. \quad (11c)$$

and if $\nu-\frac{1}{2}=2k-1$ (k an integer)

$$w(z)=-2\pi^{-1}e^{-(k+\frac{1}{4})\pi i}q(u) \quad \ldots\ldots\ldots\ldots \quad (12a)$$

with

$$q(u)=[uK_{\nu+1}(u)-CK_{\nu}(u)]+\pi[uI_{\nu+1}(u)+CI_{\nu}(u)] \quad \ldots\ldots\ldots\ldots \quad (12b)$$

$$=[uK_{\nu-1}(u)-(C-2\nu)K_{\nu}(u)]+\pi[uI_{\nu-1}(u)+(C-2\nu)I_{\nu}(u)]. \quad (12c)$$

Thus to find the zeros of $w(z)$ on the negative imaginary axis of z, we need only consider the zeros of $p(u)$ and $q(u)$ for positive u.

It will be seen that it is necessary to treat the cases $\nu-\frac{1}{2}$ and $\nu=1\frac{1}{2}$ separately.

With $\nu=\frac{1}{2}$, we have

$$w(z, C, \tfrac{1}{2})=-(\tfrac{1}{2}\pi z)^{-\frac{1}{2}}e^{iz}[z-i(C-1)]$$

with its only zero at $i(C-1)$.

When $\nu=1\frac{1}{2}$,

$$w(z, C, 1\tfrac{1}{2})=i(\tfrac{1}{2}\pi z^3)^{-\frac{1}{2}}e^{iz}[z^2+iz(3-C)-(3-C)]$$

and the explicit formula for the zeros may be written as

$$z_0=-i\tfrac{1}{2}(3-C)\pm\tfrac{1}{2}(3-C)^{\frac{1}{2}}(1+C)^{\frac{1}{2}}.$$

Except that there is a zero at the origin when $C=3$ $(=2\nu)$, this indicates a typical result of the case $\nu=2k-\frac{1}{2}$. We have:

when $C<-1$, there are two negative imaginary zeros;
when $C=-1$, there is a double imaginary zero (at $z_0=-2i$);
when $-1<C<3$, there are no zeros in the imaginary axis;
when $C>3$, there are two imaginary zeros, one positive and one negative.

We now assume that $0\leqq C<2\nu$, $\nu\geqq 2\frac{1}{2}$. Then $uI_{\nu+1}(u)+CI_\nu(u)$ is obviously strictly monotonic, increasing from 0 to ∞, for increasing from 0 to ∞. Our previous work shows that $uK_{\nu+1}(u)-CK_\nu(u)$ will have no zeros and never become negative. Thus $q(u)$ will have no zeros.

Using Watson (1953, p. 70), we find that

$$uK_{\nu+1}(u)-CK_\nu(u)=uK_{\nu-1}(u)+(2\nu-C)K_\nu(u)$$

and that

$$\frac{d}{du}[uK_{\nu-1}(u)]=-[uK_\nu(u)-\nu K_{\nu-1}(u)]$$

which has no zeros for $\nu<2(\nu-1)$. Thus $uK_{\nu+1}(u)-CK_\nu(u)$ is strictly monotonic decreasing to zero.

Thus $p(u)$ has one and only one zero.

We now assume that $C>2\nu$, $\nu\geqq 2\frac{1}{2}$, and consider

$$u^\nu[uK_{\nu+1}(u)-CK_\nu(u)]\equiv s(u)\equiv r(v)$$

as a function of $v=u^2$. Then

$$\frac{dr}{dv}=-2u^{\nu-1}[uK_\nu(u)-CK_{\nu-1}(u)]$$

and

$$\frac{d^2r}{dv^2}=4u^{\nu-2}[uK_{\nu-1}(u)-CK_{\nu-2}(u)].$$

So, obviously, r, dr/dv and d^2r/dv^2 each have one and only one (simple) zero. Then, keeping the asymptotic expressions for the Bessel functions in view, we observe that the graph of $y=r(v)$ starts at a point on the negative y-axis, increases steadily, and after cutting the v-axis passes through a maximum. It then decreases to an inflexional point, at which it changes from being concave downwards to being convex downwards and then finally approaches the v-axis from above.

Since $u^\nu[uI_{\nu+1}(u)+CI_\nu(u)]$ (as a function of v) is monotonic increasing from zero, it easily follows that $q(u)$ has one and only one zero, but that $p(u)$ may have no zero, a double zero or two zeros, but no more than two zeros.

Now sketching the graphs of $u[K_{\nu-1}(u)-\pi I_{\nu-1}(u)]$ and $(C-2\nu)[K_\nu(u)+\pi I_\nu(u)]$, it will be seen that as $C-2\nu$ increases from zero, one of the zeros of $p(u)$ will increase from zero, while the other will decrease from the zero of $K_{\nu-1}(u)-\pi I_{\nu-1}(u)$ to a common value $u_1(\nu)$[*] with corresponding $C=C_1(\nu)$.

---

[*] We have written $u_1(\nu)$ and $C_1(\nu)$ to emphasize the fact that these values are dependent on ν.

For $C>C_1(\nu)$, there will be no zero on the negative imaginary axis.

Now at (u_1, C_1) we observe that $u^\nu p(u)$ and its derivative will have a common zero. Thus

$$[u_1K_{\nu-1}(u_1)-(C_1-2\nu)K_\nu(u_1)]-\pi[u_1I_{\nu-1}(u_1)+(C_1-2\nu)I_\nu(u_1)]=0$$

and

$$[-u_1K_\nu(u_1)+C_1K_{\nu-1}(u_1)]-\pi[u_1I_\nu(u_1)+C_1I_{\nu-1}(u_1)]=0.$$

Eliminating $K_\nu(u_1)$ and $I_\nu(u_1)$ from these equations, we find that

$$[u_1^2-C_1(C_1-2\nu)][K_{\nu-1}(u_1)-\pi I_{\nu-1}(u_1)]=0,$$

in which the second factor is not zero. Thus (u_1, C_1) can be found from the point of intersection of

$$u^2-C(C-2\nu)=0 \quad \dots\dots\dots\dots\dots\dots \quad (13)$$

and

$$C=\frac{u[K_{\nu+1}(u)-\pi I_{\nu+1}(u)]}{K_\nu(u)+\pi I_\nu(u)} \quad \dots\dots\dots\dots\dots \quad (14)$$

We now assume that $C<0$. We may use a method similar to that just given. We will then find that $p(u)$ has one and only one zero, while $q(u)$ may have no zero, a double zero or two zeros.

As C increases from $-\infty$, then one zero of $q(u)$ will decrease from $+\infty$, while the other will increase from the single zero of $K_\nu(u)-\pi I_\nu(u)$ until they coincide at $u_2(\nu)$ with $C=C_2(\nu)$. As C increases further, there will be no zero until C passes 2ν. There will then be one zero (as shown above).

The values of $u_2(\nu)$ and $C_2(\nu)$ can be found from the point of intersection of (13) and

$$C=\frac{u[K_{\nu+1}(u)+\pi I_{\nu+1}(u)]}{K_\nu(u)-\pi I_\nu(u)} \quad \dots\dots\dots\dots\dots\dots \quad (15)$$

Collecting the results, we now summarize.

Omitting the cases $\nu=\frac{1}{2}$ and $\nu=1\frac{1}{2}$, which have been discussed above, the distribution of the zeros of $w(z)$ when $\nu-\frac{1}{2}=n$ (n an integer) is given by the following table.

		Negative Imaginary Axis.	Positive Imaginary Axis.	Regions. $-\frac{1}{2}\pi<\arg z<0$ $\pi<\arg z<\frac{3}{2}\pi$
$\nu=2k+\frac{1}{2}$	$C<2\nu$ ..	1	0	k
	$2\nu<C\leqq C_1(\nu)$ ..	2	1	$k-1$
	$C>C_1(\nu)$ ..	0	1	k
$\nu=2k-\frac{1}{2}$	$C\leqq C_2(\nu)<0$ ..	2	0	$k-1$
	$C_2(\nu)<C<2\nu$ ..	0	0	k
	$C>2\nu$ ..	1	1	$k-1$

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TAPIOLITE AND THE TRI-RUTILE STRUCTURE.

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With Plate V and two Text-figures.

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ABSTRACT.

A twinned tapiolite from Strelley, Western Australia, is recorded. X-ray powder-data is given for rutile, strüverite and three tapiolites; the tri-rutile structure is discussed.

A crystal from the Pilbara district, Western Australia, was presented to the Department of Geology and Geophysics, University of Sydney, some years ago. It was considered to be tantalite, but proved to be tapiolite, and as this tetragonal iron tantalate is rare, a short description of the specimen will be given. It was found at Strelley, lat. 20° 30′ S., long. 118° 55′ E., in the Pilbara district, where a wealth of rare minerals has been provided by granite pegmatites; many, including tapiolite, were described by Simpson (1917).

This Strelley crystal of 133 grammes weight and specific gravity of 7·60 is illustrated by photographs (Plate V, Figs. 1 and 2). Goniometric measurement and projection showed that the face planes developed belong to the forms a, {100}; n, {230} and p, $\begin{matrix}\{111\}\ \text{Nordenskiöld,}\\ \{113\}\ \text{Goldschmidt}\end{matrix}$ of a holosymmetric tetragonal crystal. The apparent absence of symmetry is due to extension parallel to the edge between adjacent pyramids, *i.e.* elongation $\begin{matrix}[\bar{1}01]\ \text{N.}\\ [\bar{3}01]\ \text{G.}\end{matrix}$ and twinning on $\begin{matrix}(\bar{1}0\bar{1})\ \text{N.}\\ (\bar{1}0\bar{3})\ \text{G.}\end{matrix}$ For many years this twin masked the identity of tapiolites in which it occurred; such crystals were called skogbolite, and listed with orthorhombic species. Actually, distortion resulting from the elongation $\begin{matrix}[\bar{1}01]\ \text{N.}\\ [\bar{3}01]\ \text{G.}\end{matrix}$ combined with the "Skogbole" twin is a characteristic feature of tapiolite, columbian and other rutiles.

A direct comparison may be made between the crystal (Plate V, Fig. 2) and the stereographic projection of it on a plane normal to the twin and composition plane (Text-fig. 1). The 230 form is partly suppressed, but the orthorhombic disposition of the other face poles is obvious.

Crystal angle measurements made with a contact goniometer were within a degree of the following recorded values (Simpson, 1917).

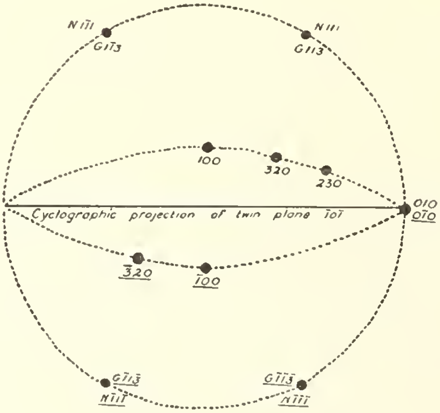
	010^230	33° 41½′
	100^111	61° 30′
N.	111^1$\bar{1}$1	57° 00′
G.	113^1$\bar{1}$3	
	100^$\bar{1}$00	65° 46′
	100^0$\bar{1}$0	90° 00′

The conventional phi and rho angle table for forms present is

		φ	ρ
a.	100	90° 00′	90° 00′
n.	230	33° 41½′	90° 00′
p.	111 N. 113 G.	45° 00′	42° 26′

(Porter *et al.*, 1951).

Double indexing of the zone axis, the twin plane and the form p will be noted. Nordenskiöld chose p, the prevalent *hkl* form, as a parametral plane and derived an a : c ratio, 1 : 0·6464, very close to the ratio for rutile, which is 1 : 0·644. Both crystals are dihexagonal dipyramidal, 4/m 2/m 2/m, and may show the same form development with almost identical interfacial angles, and the asymmetric elongation and twinning.



Text-fig. 1.

The structure of rutile was determined by Vegard (1916), and later by Huggins (1926). The data are, Space Group P 4/m n m ; a_0 4·58, c_0 2·95 ; $a_0 : c_0 = 1 : 0{\cdot}644$; cell contents, Ti_2O_4.

Goldschmidt (1926) made a structure determination of " mossite " from near Moss, Norway. This was a tapiolite in which the proportions of Ta_2O_5 and Cb_2O_5 by weight were approximately 52% and 31% respectively. The name mossite is reserved for crystals with a Cb_2O_5 content exceeding that of Ta_2O_5 (Palache *et al.*, 1944). The space group is P 4/m n m ; cell dimensions a_0 4·711, c_0 9·12 ; cell contents $Fe_2\ (TaCb)_4O_{12}$ and the $a_0 : c_0$ ratio 1 : 1·936, *i.e.* 1 : 0·645 × 3. The unit cell may be considered as a vertical stack of three rutile cells, a unit which suggests the name tri-rutile for this tapiolite structure. The metal positions are identical for rutile and tapiolite ; the geometrical distribution of Fe and (Ta, Cb) on titanium sites is the ordered arrangement shown in Text-fig. 2.

The tri-rutile structure requires a parametral plane with angle constants, phi 45°, rho *ca.* 69° 58′, and new miller indices for forms other than planes in zone [001]. The transformation formula from Nordenskiöld to Goldschmidt being 100/010/003. The pyramid {113} is very prominent on tapiolite crystals, almost invariably present, and may even occur as a closed form, but the parametral plane is never developed. This anomaly prompted the investigation of the tapiolite structure.

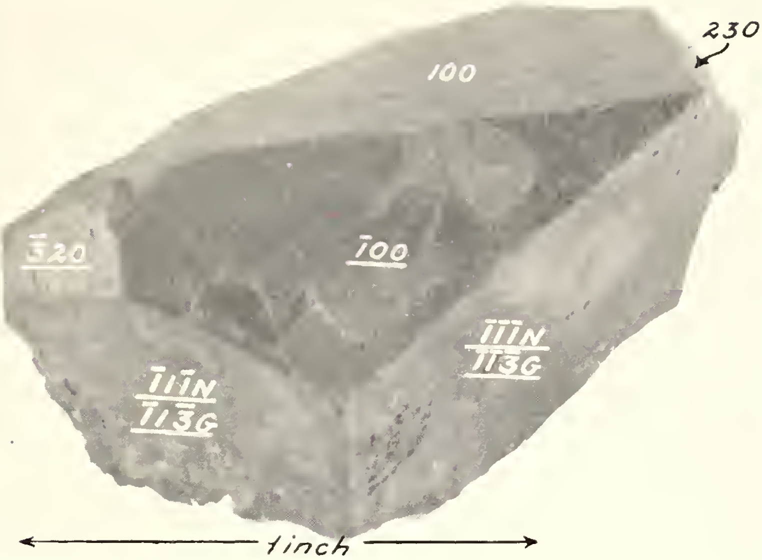


Fig. 1.

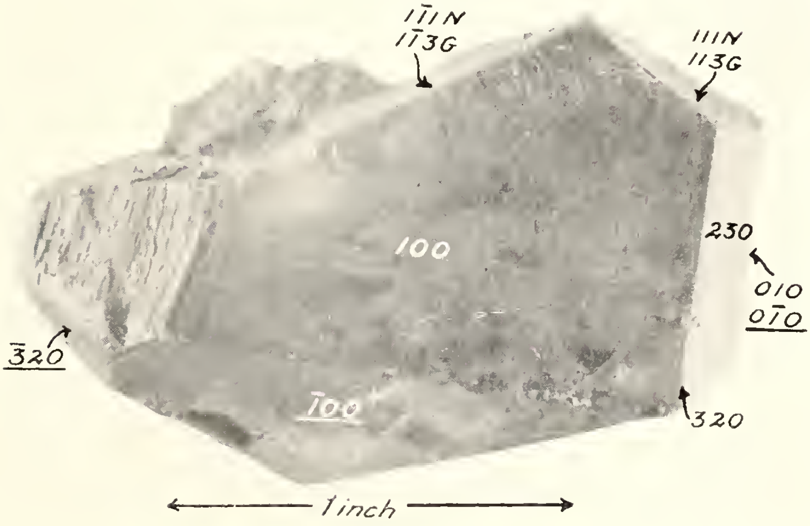
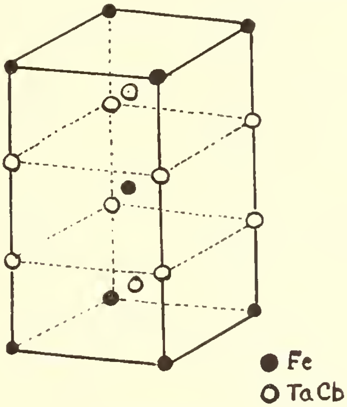


Fig. 2.

Twinned tapiolite from Strelley, Pilbara District, Western Australia.

Powder photographs were made of rutile, strüverite and three tapiolites. The rutile was an acicular, wine-brown crystal from Hartford Co., Maryland, and the strüverite, tantalian rutile from the province of Tangafeno, Madagascar (Harvard Geological Museum specimen No. 80080). This material included a good equant 4 cm. crystal of strüverite showing the forms a, {100} and p, {111} and the distortion which is present in the Strelley crystal. The tapiolites chosen were from the following localities: Skogbole, Finland (Museum of Natural History, New York, Specimen No. 14488); Tabba Tabba Creek, Pilbara district, Western Australia (Museum of Natural History, New York, Specimen No. 24491), and Strelley, Western Australia, portion of the crystal described in this paper.

Photographs were made with the Straumanis technique on a camera of radius 5·73 cm., using nickel-filtered CuKα radiation. Intensities were estimated visually. Lattice plane spacings have been indexed and are listed in Table I, which includes published X-ray data for a strüverite, three tapiolites and the tri-rutile substances, ordoñezite, $ZnSb_2O_6$, artificial $ZnSb_2O_6$ and byströmerite, $MgSb_2O_6$, all of which had been investigated with copper radiation, except the strüverite of column 3, for which iron had been used.



Text-fig. 2.

Powder photographs of the strüverite and tapiolites were made from heat-treated specimens as well as from the natural mineral. Material was heated in evacuated silica tubes for one hour at 1200° C., and then cooled slowly to room temperature. When half-millimetre spheres were being prepared, it was noticed that heat-treated tapiolite powder was russet brown in colour, while the original powder was nearly black. Strüverite was unaffected by the heat treatment, and the two films of its powder were identical. All specimens for powder photography were tested for radioactivity by Dr. Day of the Department of Geology and Geophysics, University of Sydney; none was detected.

The powder patterns of rutile, strüverite and tapiolite resemble each other closely. If attention is fixed on the more prominent arcs in the low angle region of the films, lateral shift will be observed before the Bragg angle reaches 45°. The shift indicates an expansion of the lattice of rutile to accommodate larger ions. The table of d spacings lists miller indices for rutile and tri-rutile in columns 1 and 14 respectively. The d_{110} spacing shows an increase from 3·23 Å. in rutile through 3·27 Å. in strüverite to 3·33 Å. in tapiolite. d_{200}, which for rutile is 2·28 Å., for strüverite becomes 2·31 Å., and for tapiolite 2·36 Å., correlating with a reduction in scale of the powder patterns. Actually the larger spacings such as d_{110} are not sufficiently reliable for detailed study on

TABLE I.

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, Byströmerite and Tapiolite.

New Powder Data are marked with an asterisk.

Abbreviations: NI = plane not indexed; v.st. = very strong; m = medium; w = weak; H = observed in heat-treated material. In column 1, I = ilmenite. In column 14, M = microlite. C = columbite phase.

1	2		3		4		5		6		7		8		9		10		11		12		13		14
hkl. (Rutile Lattice.)	Rutile. Hartford, M.D., U.S.A.		Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		$ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		Tapiolite. (No. 14488 Museum Nat. History, New York.) Skogbole, Finland.		Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		*hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
																			5	5·75	5	5·83			M
							10	4·58			40	4·63	10	4·60	vw	4·52			20	4·61	5	4·55	10	4·65	100
							20	4·11			70	4·19	10	4·21	w	4·14			20	4·17	30	4·16	20	4·19	101
			20	3·87NI													40	3·67	5	3·68	5	3·65			C ?
			40	3·59NI																					
110	90	3·23	80	3·25	100	3·27	90	3·26	v.st.	3·30	100	3·32	90	3·34	v.st.	3·32	80	3·33	100	3·33	90	3·32	90	3·38	110
																					3	3·10			C ?
																			vvw		10	2·97	5	2·96	M
																	40	2·85	5	2·83	5	2·83	5	2·84	
1			40	2·76	2	2·71																			

TABLE I.—*Continued.*

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, Byströmerite and Tapiolite.—Continued.

1 *hkl.* (Rutile Lattice.)	2 Rutile. Hartford, M.D., U.S.A.		3 Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		4 Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		5 Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		6 $ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		7 Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		8 Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		9 Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		10 Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		11 Tapiolite. (No. 14488 Museum Nat. History, New York.) Skogbole, Finland.		12 Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		13 Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		14 *hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
							10	2·65	w	2·69	30	2·69	10	2·71	w	2·69			5	2·69	10	2·68	10	2·69	112
101	60	2·47	70	2·50	70	2·50	80	2·55	st	2·58	90	2·57	80	2·58	v.st	2·55	80	2·57	90	2·57	90	2·56	90	2·56	103
200	10	2·28	40	2·32	40	2·31	40	2·31	m	2·33	50	2·34	50	2·37	st	2·36	60	2·37	40	2·36	50	2·365	40	2·36	200
111	40	2·17	40	2·20	40	2·20	20	2·23	w	2·24	20	2·25	20	2·26	vw	2·25	20	2·26	10	2·26	10	2·26	10	2·26	113
210	10	2·04	20	2·07	10	2·06	20	2·07	w	2·08	30	2·08			vw	2·10	20	2·11	5	2·10	10	2·10	5	2·10	210 202
							20	2·02	w	2·03	30	2·04	10	2·06	w	2·06			5	2·07	20	2·05	5	2·06	211
																	60	1·94	3	1·93	5	1·92	2	1·92	212
							10	1·90	m	1·89							20	1·86	2	1·88H	2	1·89H			114
I			40	1·88	5	1·88																			
																					10	1·82	5	1·84	M
211	100	1·68	100	1·70	90	1·70	100	1·72	v.st	1·72	90	1·73	100	1·74	v.st	1·74	100	1·75	100	1·74	100	1·74	100	1·74	213

TABLE I.—*Continued.*

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, *Byströmerite and Tapiolite.*—Continued.

1	2		3		4		5		6		7		8		9		10		11		12		13		14
hkl. (Rutile Lattice.)	Rutile. Hartford, M.D., U.S.A.		Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		$ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		Tapiolite. (No. 14488 Museum Nat. History, New York.) Skogbole, Finland.		Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		*hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
									vw	1·71											5	1·71	5	1·70	105
220	50	1·62	60	1·64	40	1·64	50	1·64	st	1·64	40	1·65	70	1·68	st	1·68	60	1·68	50	1·67	50	1·67	50	1·67	220
									vw	1·63											5	1·65			204
			20	1·51					vw	1·55					w	1·57	40	1·56	2	1·57	5	1·57	3	1·57	222
002	30	1·47	40	1·49	20	1·49	30	1·54	st	1·54	20	1·54	30	1·53	m	1·535	40	1·54	20	1·54	20	1·53	20	1·53	006
310	30	1·45	50	1·47	30	1·465	50	1·47	st	1·52	40	1·48	60	1·50	st	1·501	60	1·501	40	1·50	50	1·50	50	1·50	310
															vw	1·428	40	1·43	2	1·42H	10	1·42H	5	1·42H	312
301	60	1·355	70	1·37	50	1·37	60	1·38	st	1·38			50	1·39	st	1·406	70	1·41	60	1·404	60	1·403	50	1·405	303 +215 +116
112	30	1·342	60	1·36	30	1·36	40	1·39	st	1·39					st	1·395			60	1·39H	50	1·39H	40	1·39H	116H
311	4	1·30															20	1·34							313
															w	1·300			2	1·30H	5	1·30H	2	1·30H	321

TABLE I.—*Cqntinued.*

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, Byströmerite and Tapiolite.—Continued.

1	2		3		4		5		6		7		8		9		10		11		12		13		14
hkl. (Rutile Lattice.)	Rutile. Hartford, M.D., U.S.A.		Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		$ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		Tapiolite. (No. 14488 Museum Nat. History, New York.) Skogbole, Finland.		Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		*hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
202	7	1·24	40	1·26	20	1·255	30	1·28	m	1·28	10	1·28	30	1·29	m	1·287	40	1·29	20	1·295	30	1·286	20	1·29	206
							10	1·24		1·24											5	1·25H			314
212	3	1·19																							
321	30	1·17	70	1·18	40	1·18	60	1·19	st	1·19	30	1·19	50	1·21	st	1·209	60	1·21	50	1·210	60	1·210	50	1·210	323
400	20	1·147	60	1·16	50	1·161									w	1·186	40	1·19	20	1·186	20	1·186	20	1·186	400
410	4	1·13																							
222	40	1·09	70	1·11	40	1·115									m	1·136	60	1·14	30	1·135	30	1·133	40	1·134	226
																			30	1·132H	40	1·130H	30	1·133H	226H
330	20	1·081	60	1·09	30	1·093									m	1·120	40	1·121	20	1·117	20	1·118	20	1·118	330

TABLE I.—*Continued.*

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, Byströmerite and Tapiolite.—Continued.

1	2		3		4		5		6		7		8		9		10		11		12		13		14
hkl. (Rutile Lattice.)	Rutile. Hartford, M.D., U.S.A.		Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		$ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		Tapiolite. (No. 14488 Museum Nat. History New York.) Skogbole, Finland.		Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		*hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
411	20	1·042	70	1·05	30	1·055									st	1·08	70	1·08	40	1·078	40	1·077	30	1·078	413
312	20	1·034	60	1·04	30	1·048									st	1·073			50	1·072H	50	1·073	30	1·073H	316
420	10	1·026			20	1·036									m	1·063	40	1·06	20	1·061	30	1·061	20	1·061	420
															vw	1·035			2	1·033H	5	1·034	2	1·034H	
421	4	0·990															40	1·01							
103	10	0·961			10	0·977									m	1·001			30	1·001H	40	1·001	10	1·000H	109
113	2	0·942													vw	0·965NI					8	0·977H	2	0·978H	119
																			5	0·963	5	0·963	2	0·963	
															vw	0·950									
															vw	0·946									
402	20	0·905			20	0·918									st	0·940			20	0·941	20	0·941	20	0·942	406

TABLE I.—*Continued.*

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, Byströmerite and Tapiolite.—Continued.

1	2		3		4		5		6		7		8		9		10		11		12		13		14
hkl. (Rutile Lattice.)	Rutile. Hartford, M.D., U.S.A.		Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		$ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		Tapiolite. (No. 14488 Museum Nat. History, New York.) Skogbole, Finland.		Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		*hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
510	20	0·898			30	0·901									st	0·930			20	0·931	20	0·931	20	0·932	510
																			10	0·927	10	0·926	20	0·925	219
213	40	0·889			30	0·890									st	0·923			50	0·921H	40	0·922H	30	0·922H	219H
															w	0·914			2	0·912	5	0·914	2	0·914	512
431 + 501	30	0·876			20	0·885									st	0·908			40	0·908	50	0·908	40	0·908	503 + 433
332	30	0·874													st	0·905			40	0·906	30	0·905	30	0·906	336
422	20	0·844			20	0·854									m	0·874			30	0·874	30	0·874	30	0·875	426
303	20	0·829			30	0·840									m	0·860			20	0·859H	30	0·860	50	0·860	309
521	40	0·819			40	0·829									m	0·849			50	0·849	60	0·848	40	0·848	523
440	8	0·813													w	0·841			20	0·842	20	0·840	10	0·841	440

TABLE I.—*Continued.*

Comparative Table of Lattice Plane Spacings in Rutile, Strüverite, Ordoñezite, $ZnSb_2O_6$, Byströmerite and Tapiolite.—Continued.

1	2		3		4		5		6		7		8		9		10		11		12		13		14
hkl. (Rutile Lattice.)	Rutile. Hartford, M.D., U.S.A.		Strüverite (A.S.T.M. Index). River Sebantun Salak, Federated Malay States. (Not indexed.)		Strüverite (No. 80080 Harvard Museum). Tongafeno, Madagascar.		Ordoñezite. $ZnSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		$ZnSb_2O_6$ (Artificial). (*Am. Min.*, 1955, Vol. 40, p. 66.)		Byströmerite. $MgSb_2O_6$ (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. Chanteloube, France. (*Am. Min.*, 1955, Vol. 40, p. 66.)		Tapiolite. (Not indexed.) (*Bull. Soc. Min. France*, Vol. 78, 1–3, p. 137, 1955.)		Tapiolite. (A.S.T.M. Index.) Skogbole, Finland. (Not indexed.)		Tapiolite. (No. 14488 Museum Nat. History, New York.) Skogbole, Finland.		Tapiolite. (No. 24491 Museum Nat. History, New York.) Tabba Tabba, W. Australia.		Tapiolite. (A.122 Dept. Geol. and Geophysics, Uni. Sydney.) Strelley, W. Australia.		*hkl.* Tri-Rutile Lattice.
hkl.	I.	d.*	I.	d.	I.	d.*	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.	I.	d.*	I.	d.*	I.	d.*	*hkl.*
530					10	0·797									m	0·815			20	0·816	30	0·815	20	0·815	530
																			20	0·811		0·810	40	0·809	443
															m	0·809			40	0·810H	50	0·809H	50	0·808H	443H
323					30	0·791													2	0·803H	10	0·803H	6	0·803H	329
																			30	0·799	50	0·798	40	0·798	516
															m	0·797			60	0·797	50	0·797H	50	0·797H	516H
															m	0·795			10	0·793	30	0·793	10	0·793	525

account of the rapid variation in d values with slight changes in small glancing angles.

Planes of the tri-rutile structure where $l=0$ or $3n$, where n is an integer, are common to both lattices and produce the distinctive lines of the powder patterns; in other words, the rutile lattice is dominant. All *okl* reflections are restricted by the space group to those with $k+l=2n$.

Extremely feeble but significant arcs appear on powder photographs of tapiolites. They may be better developed in one tapiolite than another, and are most distinct in films of heat-treated specimens. When indexed, they prove the existence of a tri-rutile structure. The planes are: 101, 112, 202, 211, 114, 105, 204, 222, 312, 215, 314 and 525.

Powder films of heat-treated specimens, in addition to giving evidence of the tri-rutile structure, prove that marked contraction takes place in the c axis length on heat treatment, apparently a steric effect of geometrical packing.

Extraneous lines in tapiolite patterns probably belong to a columbite phase and to microlite. These arcs are identified by the C and M respectively, in column 14. Columbite, the orthorhombic paramorph of tapiolite, is frequently intergrown with, and associated with, tapiolite (Meizner, 1951; Permingeat, 1955). Microlite is recognized as an alteration product of tapiolite. The formula may be written $A_2B_2O_6$ with A=Na, Ca, K, Mg, Fe^2, Mn^2, Sn^3, Pb ? +rare earths. B=Cb, Ta, Ti, Sn ?, Fe^3, W ? (Palache *et al.*, 1944), which indicates that the structure tolerates a great deal of replacement. Rosén and Westgren (1938) showed that there was close resemblance between microlite and a roméite-atapite group of minerals which had been studied by Machatschki (1930). Spacings calculated for faint extraneous lines in the tapiolite photographs correspond to those giving the most intense reflections of the roméite pattern. It is not suggested that the antimony compound is present, but rather some related tantalian substance. Recently compounds of the general formula $A_2B_2O_7$ have been examined (Gasperin, 1955); they included $Sn_2Ta_2O_7$, $Pb_2Sb_2O_7$ and $Ca_2Ta_2O_7$ and were placed in the koppite-type series of oxides of the pyrochlore-microlite group.

Very weak lines in the strüverite photographs which cannot be indexed are possibly due to ilmenite, an exsolution product of some rutiles, such lines are indicated in column 1 of the table by the letter I.

The formula for strüverite is $Fe^2_x(TaCb)_{2x}Ti_{(1-3x)}O_2$, where the maximum value for x is $0 \cdot 2$ (Palache *et al.*, 1948).

For the value $x=0 \cdot 2$ the formula may be written $Fe^2(TaCb)_2O_6 2TiO_2$; one part tapiolite and two parts rutile. Strüverite may be indexed as rutile, *i.e.* there is statistical distribution of Fe^2, Ta, Cb and Ti on the metal sites of a rutile lattice which expands to accommodate the larger ions. Cell dimensions determined for rutile are a_0 4·584, c_0 2·94, and for strüverite a_0 4·63, c_0 2·999.

Discussion of the Tri-rutile Structure.

Strüverite, with a mono-rutile structure, is in part tapiolite in composition. Morphologically the minerals may be identical. Study of chemical analyses shows there is departure from theoretical composition and strict stoichiometric proportions in both. The question arises as to whether the tri-rutile structure is essential in tapiolite or whether a disordered state may be natural. Interesting information on this point has been gained by reference to other researches.

The tri-rutile structure has been determined for artificial $ZnSb_2O_6$ (Bystrom *et al.*, 1942), byströmerite, $MgSb_2O_6$ (Mason *et al.*, 1952) and ordoñezite, $ZnSb_2O_6$ (Switzer *et al.*, 1955).

In byströmerite the superlattice lines are relatively strong. The mineral has not been found crystallized, so whether the well-developed superlattice has any effect on morphology is not known. Ordoñezite, however, occurs as simple crystals in which three forms only are developed : {001}, {110} and {011}. The {011} has a rho value *ca.* 63°, which directs attention to the long c of tri-rutile. So far as the author is aware no tapiolites have been described in which this *okl* form is the only pyramid present. When Bystrom, Hok and Mason (1942) published X-ray data on the tri-rutile structure of $ZnSb_2O_6$ they gave lattice constants for the isostructural substances $MgTa_2O_6$, $CoTa_2O_6$ and $NiTa_2O_6$ also. During experiments a " mono-rutile " was produced when $MnSb_2O_6 7H_2O$ was heated for four hours at 800° C., and a chromium antimony oxide also appeared to be " mono-rutile ", but the X-ray photographs were not regarded as entirely satisfactory.

Brandt (1944) carried out research on ABO_4 compounds : Cr, Fe and Rb columbates, Al, Cr, Fe, Rb antimonates and Cu, Fe and Rh tantalates. All were found to have mono-rutile structures. Cell dimensions determined for the iron tantalate were a_0 4·672 ; c_0 3·042, very similar to rutile. The other isostructural substances had parameters close to these values. No tri-rutile structures were found, but when iron antimonate was being prepared a tri-rutile, $FeSb_2O_6$, appeared when oxides were heated for one day at 1130° C.

Hutchison (1955), in a report on optical studies of tantalum minerals, stated that X-ray precession photographs of tapiolite from Ross Lake, N.W. Territory, Canada, showed that the mineral had a rutile structure, not a tri-rutile one. No X-ray data were given in this paper.

It would seem from experimental and other evidence that tapiolite may or may not show a superlattice structure. The opinion is expressed that natural crystals are at first mono-rutile, with statistical distribution of ions of different valence over the metal sites, if necessary with lattice defects, and that this structure may persist indefinitely, or be replaced after a time in part of the crystal mosaic by the ordered tri-rutile ion assemblage.

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THE MANILLA SYNCLINE AND ASSOCIATED FAULTS

ALAN H. VOISEY, D.Sc.

With Plate VI.

Manuscript received, November 19, 1957. Read, December 4, 1957.

ABSTRACT.

The Manilla Syncline and Namoi Fault are recognized and described, together with many faults, some causing schuppen-structure in the western portion of the Hunter-Bowen Orogenic Belt in north-eastern N.S.W. The Baldwin Formation and the Barraba Mudstone are regarded as constituting the Manilla Group of sedimentary rocks.

The Manilla Syncline is a dominant structural feature recognizable for some fifteen miles to the north of Manilla, New South Wales. In his comprehensive description of the geology of the Western Slopes Benson (1917*a*, p. 250) mentioned that there was a synclinal structure in this vicinity, but did not emphasize its importance. The writer feels that it warrants special attention in view of its position in the tectonic pattern now emerging from more detailed study of the Upper Palæozoic orogenic movements in north-eastern New South Wales.

This paper deals also with the structures in the rocks of Benson's Near Western and Middle Western zones, and the map (Plate VI) includes parts of the Eastern Zone and the Serpentine Line.

The area shown was mapped in the field, use being made of aerial photographs supplied by the Department of Lands, N.S.W.

STRATIGRAPHY.

Names used with reference to rock units in the following discussion are substantially those of Benson (1912, 1913*a*), but in order to conform with the Australian Code of Stratigraphic Nomenclature (Raggatt, 1956), and in anticipation of work soon to be published, some slight modifications have been made.

The pre-Devonian rocks east of the Serpentine Line, called Woolomin Series by Benson (1912, p. 100), will be referred to as the Woolomin Group (Spry, 1953, p. 129).

The Lower to Middle Devonian radiolarian claystones, cherts, limestones, tuffs and breccias, which were called the Tamworth Series by Benson (1913*a*, p. 495), will be designated the Tamworth Group. They include the Moore Creek Limestone (Benson, 1915, p. 541) and the Tamworth Common Cherts, the last-named being generally referred to as the Tamworth Cherts and thus shown on the map (Plate VI).

The Barraba Mudstone and underlying Baldwin Formation, regarded as Upper Devonian, constitute the Manilla Group. This departure from the inclusion of both Baldwin and Barraba sediments in the Barraba Series (Benson, 1915, p. 577) is made because the most satisfactory mappable boundary in the Manilla-Bingara belt is that between these two formations. Their upper and lower limits are by no means as easily recognized. As Benson's names are so well established for the particular portions of the sequence they have been retained.

The term " formation " is preferred to " agglomerate " for the Baldwin portion because it consists of a number of different kinds of rock. The so-called " agglomerate " grades into breccias and finer-grained sediments, which Benson called tuffs, but which would now be better described as greywackes in the sense of Pettijohn (1957). The degree to which they have been derived from volcanic material has yet to be determined.

Attempts were made to measure stratigraphical sections through the sequence at various places but the extensive faulting has rendered it virtually impossible to obtain reliable figures.

The thickness of three thousand feet for the Baldwin Formation estimated by Benson (1913*a*, p. 495) seems to be a reasonable one. Two thousand one hundred feet were measured by the writer by means of a traverse made over Pyramid Hill. Of this about 10% could be described as breccia or " agglomerate ", 30% as greywacke and 60% as mudstone.

About two thousand feet of Barraba Mudstone overlying the Baldwin Formation are represented in the area mapped. There are a number of breccia and greywacke beds in the mudstone sequence, mainly in the higher parts of it, but the total percentages are much less than in the Baldwin Formation.

Benson (1913*a*, p. 503) defined the Burindi Series and later mentioned the presence among Burindi mudstones of crinoidal limestones and conglomerates south of Crow Mountain. These beds and others exposed by Borah and Spring creeks are included in the Burindi Group, which will not be differentiated into Upper and Lower parts in this paper.

STRUCTURAL GEOLOGY.

The area shown on the map (Plate VI) was chosen to portray the Manilla Syncline, which had been an object of interest to the writer for a number of years because of the excellent physiographical expression arising through the contrasting resistances to erosion of the Baldwin Formation and the overlying Barraba Mudstone. It was extended to include the Serpentine Line and the Black Mountain Fault.

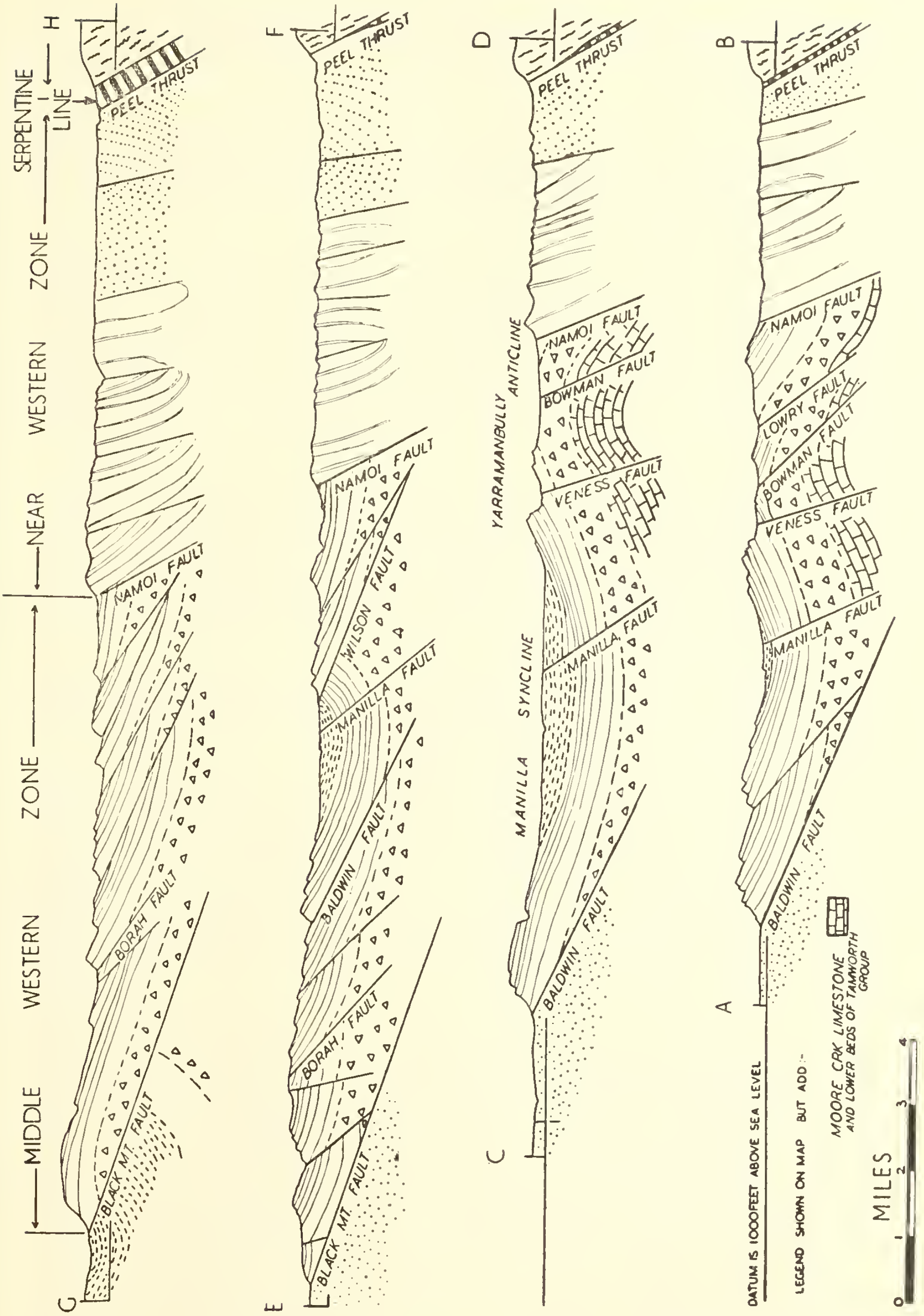
For some twelve miles to the north-north-west of Manilla the railway and road to Barraba traverse the wide, relatively flat, valley of the Manilla River. This has been carved out of the soft Barraba Mudstone, which occupies the axial region of the fold. On both sides of the valley hills rise steeply, forming conspicuous cuestas. The effect is made more marked because of the sudden change from the mudstone to hard arenaceous material forming the topmost bed of the Baldwin Formation, from which it has been stripped by erosion.

The syncline is best seen at its southern end from points along the Somerton-Manilla and the Tamworth-Manilla roads. Good views, looking south down the axis, may be had from the Barraba-Manilla Road north of Upper Manilla.

The structure closes in the south but is destroyed at its northern end by thrusting from the east, as shown on the map (Plate VI) and by means of sections (text-figure 1).

The Yarramanbully Anticline lying to the east of the Manilla Syncline is extensively fractured, the principal breaks being the Veness, Bowman and Lowry Faults. It pitches to the north, and the strata of the Tamworth Group appear in the central zone.

It has not been thought necessary to name all the faults, but only the principal ones. Benson (1917*a*, p. 253) had previously discussed the Black Mountain and Baldwin faults and the Serpentine Line, which was later called the Peel Thrust (Carey and Browne, 1938, p. 605). To these may be added the Fleming, Namoi, Lowry, Bowman, Veness, Wilson and Borah faults.


H
SERPENTINE LINE
NEAR WESTERN ZONE
MIDDLE WESTERN ZONE
PEEL THRUST
NAMOI FAULT
BORAH FAULT
BLACK MT. FAULT
G
F
PEEL THRUST
NAMOI FAULT
WILSON FAULT
MANILLA FAULT
BALDWIN FAULT
BORAH FAULT
BLACK MT. FAULT
E
D
PEEL THRUST
YARRAMANBULLY ANTICLINE
NAMOI FAULT
BOWMAN FAULT
VENESS FAULT
MANILLA SYNCLINE
MANILLA FAULT
BALDWIN FAULT
C
B
PEEL THRUST
NAMOI FAULT
LOWRY FAULT
BOWMAN FAULT
VENESS FAULT
MANILLA FAULT
BALDWIN FAULT
A
DATUM IS 1000FEET ABOVE SEA LEVEL
LEGEND SHOWN ON MAP BUT ADD:-
MOORE CRK LIMESTONE AND LOWER BEDS OF TAMWORTH GROUP
MILES
0
1
2
3
4

Text-fig. 1.

Greywacke bands in the Barraba Mudstone outcropping to the west of the Black Mountain Fault are folded into a south-pitching syncline.

It is convenient to use Benson's tectonic divisions in describing the structures.

(i) *The Eastern Zone.* The strata of the Woolomin Group jaspers, cherts and phyllites lying to the east of the Serpentine Line are invariably tightly folded and shattered and have experienced slight dynamic metamorphism. They are extensively silicified and, at present, there is no consensus of opinion regarding their method of formation.

(ii) *The Serpentine Line.* The Peel Thrust is not a single fracture but a complex system of faults, probably with a very large aggregate displacement. Some lateral as well as vertical movements are certainly involved. There is always a very well marked change in the rock types across this line. An interesting feature is the presence of slivers and lenses of rocks of different ages in the shattered zone. Serpentinite occupies a number of the fractures along the Line. No observations additional to those of Benson were made on the ultrabasic rock.

(iii) *The Near Western Zone.* Benson (1917*a*, p. 238) took this zone as extending from the Serpentine Line to Pyramid Hill, but the writer prefers to take it as occupying the belt between the Line and the Namoi Fault. This is a very important fracture, which separates the steeply dipping, isoclinally folded beds from the more gently dipping ones in the Yarramanbully Anticline and the Manilla Syncline. The fault traverses the whole of the area mapped and was followed for several miles northward. It undoubtedly continues for a considerable distance to the south.

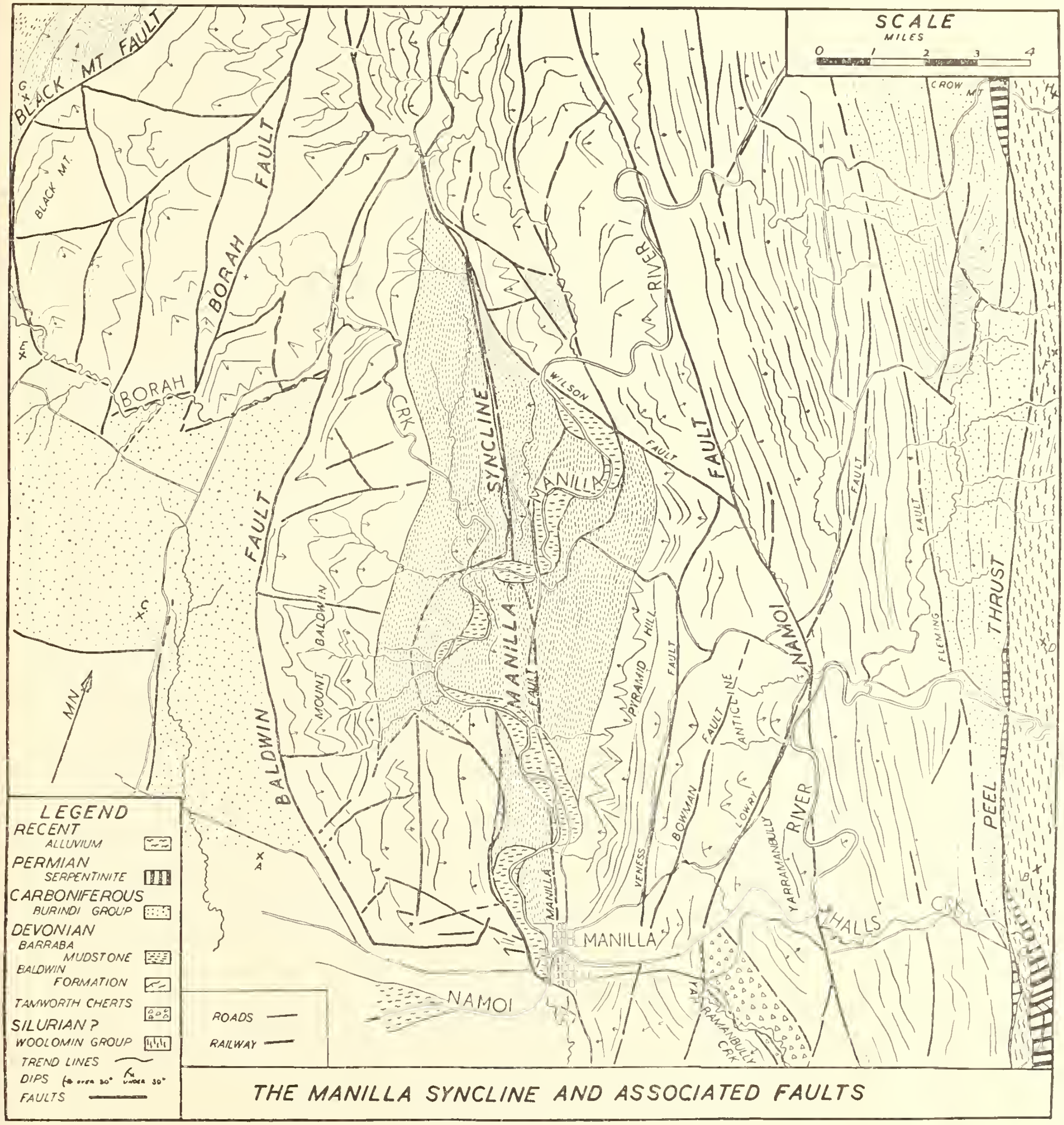
A wedge of Burindi rocks lies adjacent to the Line all along the eastern portion of the area. Within the wedge there appears to be a broken syncline pitching to the north. Another major break, the Fleming Fault, separates these beds from the Manilla Group strata to the west.

Except for an occasional westerly dip of 70° or more. the strata in the isoclinal zone are vertical or dip steeply to the east. Strike-faulting is probably more prevalent than could be shown on the map. Because of the lack of marker beds it was not possible to determine the extent of the repetition of the beds. It was difficult also to ascertain which portions of the belt were Baldwin and which were composed of Barraba beds. Benson (1917, Plate XIX) regarded most of them as belonging to the Barraba Mudstone, but the writer, because of his observation of so many greywacke beds, is inclined to think that the strata for the most part are the equivalents of those he has placed in the Baldwin Formation.

(iv) *The Middle Western Zone.* This zone is taken to extend from the Namoi Fault to the Baldwin and Black Mountain Faults and includes the Manilla Syncline and Yarramanbully Anticline. The dips in this zone are generally below 30°, in contrast to those exceeding 60° in the Near Western Zone. This difference has had a marked effect upon the physiography, which is characterized by numerous well-developed cuestas wherever the Baldwin strata outcrop. Parallel lines of low hog-backs are typical of the Near Western Zone. On the aerial photographs these patterns are equally distinct, changing across the Namoi Fault from a series of parallel lines on the east to groups of zig-zags on the west.

The Lowry, Bowman and Veness faults appear to be closely related to the Yarramanbully Anticline. This structure can be recognized by the changed dip directions of the beds. Benson (1917*a*, Plate XIX) showed much of the Parish of Veness as consisting of Tamworth strata. These seem to occupy much of the

Journal Royal Society of N.S.W., Vol. XCI, 1957, Plate VI



THE MANILLA SYNCLINE AND ASSOCIATED FAULTS

low ground, but, as they could not be defined with certainty and separated in the field, they are not indicated on the writer's map (Plate VI). In view of the very similar lithology throughout the whole sequence from Burindi to the Tamworth beds, it is extraordinarily difficult to decide to which of these groups any isolated outcrop of rock belongs.

The Manilla Syncline pitches to the north near Manilla. It is broken along its axis by the Manilla Fault, which may be recognized, particularly in the vicinity of Upper Manilla, where it displaces some of the coarse beds of the Barraba Mudstone.

The Wilson Fault, which cuts obliquely across the Syncline, is most probably a thrust. It has brought the strata, which might well have formed part of the eastern limb of the Yarramanbully Anticline, so far to the west that they have become almost continuous with those in the western limb of the Manilla Syncline. The thrust flake is broken by a number of minor fractures. It seems to have moved from the north-north-east towards the south-south-west. A succession of faults, probably most or all of them dipping to the east, has broken the beds of the northern part of the area into a series of small blocks of easterly-dipping Baldwin strata. Benson (1917*a*, p. 255) wrote of it as "schuppen" faulting, which he suggested took place at approximately the same time as the intrusion of the ultra-basic rocks.

Benson mapped the great Baldwin and Black Mountain faults and estimated a throw of 2,000 feet for the latter. The Baldwin Fault, which brings Baldwin rocks into contact with those of the Burindi, is of comparable size. Both of them are more likely to be great thrusts than vertical faults as indicated by Benson on his sections (1917*a*, p. 254).

While simple compression is probably the main cause of the Manilla structures, there appear to have been some torsional movements during the process. The Yarramanbully Anticline pitches to the north; the beds on the north-north-east side of the Wilson Fault appear to have moved from north-north-east to south-south-west, and there seems to have been some rotation of blocks in the Black Mountain area. Moreover, it can be observed in the Nundle district and elsewhere that the Peel Thrust dips steeply to the east. The Fleming, Namoi and some other faults, which run almost in straight lines, also appear to have high dips. It seems possible that some of them could be grouped with the high-angle shears of Carey and Osborne (1938, p. 202, fig. 3).

It is suggested here that in the early stages of the compression the area was thrown into a number of folds, those in the west being gentle and those on the east having steeply dipping limbs. Continued pressure produced tight folding accompanied by some strike faulting in the eastern belts and fracturing of the folds to the west. Increasing intensity led to major fracturing and differential movements of various parts of the whole orogenic belt with consequential torsion between these parts. (See sections in text-figure.)

ACKNOWLEDGEMENTS.

My thanks are due to the N.S.W. Dept. of Lands for supplying the Aerial Photographs and to the Commonwealth Research Grant for expenses involved in carrying out work in the field.

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ABSTRACT OF PROCEEDINGS.

3rd April, 1957.

The combined Annual General Meeting and the seven hundred and twenty-eighth General Monthly Meeting was held in the Hall of Science House, Sydney, at 7.45 p.m.

The President, Mr. F. D. McCarthy, was in the chair. Seventy members and visitors were present.

The death was announced of Robert D. L. Frederick, a member since 1943.

John Craig Cameron was elected a member of the Society.

The following awards of the Society were announced :

The Society's Medal for 1956 : Dr. W. R. Browne.
The Walter Burfitt Prize for 1956 : Prof. J. C. Eccles, F.R.S.
Tho James Cook Medal for 1956 : Sir Ian Clunies Ross.
The Clarke Medal for 1957 : Miss Irene Crespin.
The Edgeworth David Medal for 1956 : No award.
The Archibald D. Olle Prize : Dr. R. L. Stanton.

The Annual Report of the Council and the Financial Statement were presented and adopted.

Messrs. Horley and Horley were re-elected as Auditors to the Society for 1957–1958.

The resignations from membership of the Society of Phyllis M. Nicol and Hedley A. Mallaby were announced.

The names of R. M. Jones and E. E. Malone were removed from the List of Members in accordance with Rule XVIII.

The following accessions have been entered in tho library catalogue : parts of periodicals, 54 ; purchased parts, 39.

The following papers were read by title only : " Observations on Laterite and Other Ironstone Soils in North Queensland ", by D. S. Simonett ; " Magnetic Properties of Rocks ", by H. Narain and V. B. Rao ; " Occultations Observed at Sydney Observatory during 1956 ", by K. P. Sims ; " A Polarity Reversal in the Tertiary Volcanics of the Kurrajong-Bilpin District, with Petrological Notes ", by K. A. W. Crook ; " A Study of River Terraces and Soil Development on the Nepean River, N.S.W.", by P. H. Walker and C. A. Hawkins.

Office-bearers for 1957–1958 were elected as follow :

President.—F. N. Hanlon, B.Sc.

Vice-Presidents.—Rev. T. N. Burke-Gaffney, S.J. ; H. A. J. Donegan, M.Sc. ; F. D. McCarthy, Dip.Anthr. ; C. J. Magee, D.Sc.Agr., M.Sc.

Hon. Secretaries.—Ida A. Browne, D.Sc. ; J. L. Griffith, B.A., M.Sc.

Hon. Treasurer.—F. W. Booker, Ph.D.

Members of Council.—G. Bosson, M.Sc. ; G. W. K. Cavill, M.Sc., Ph.D. ; J. A. Dulhunty, D.Sc. ; A. F. A. Harper, M.Sc. ; D. P. Mellor, D.Sc. ; W. H. G. Poggendorff, B.Sc.Agr. ; Phyllis M. Rountree, D.Sc., Dip.Bact. ; G. Taylor, D.Sc. B.E. (Mining), B.A., F.A.A. ; H. F. Whitworth, M.Sc. ; H. Wood, M.Sc.

The retiring President, Mr. F. D. McCarthy, delivered his Presidential Address, entitled " Theoretical Considerations of Australian Aboriginal Art ".

By courtesy of Dr. T. G. H. Strehlow and the Film Director of the Department of the Interior the colour film " The Native Cat Ceremonies at Watarka " was shown.

At the conclusion of the meeting the retiring President welcomed Mr. F. N. Hanlon to the Presidential Chair.

1*st May*, 1957.

The seven hundred and twenty-ninth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Twenty-two members and visitors were present.

Charles Mark Groden was elected a member of the Society.

The following paper was read by title only : " The Mineralogy of the Commercial Dyke Clays in the Sydney District, N.S.W.", by F. C. Loughnan and H. G. Golding.

Mr. H. W. Wood, Government Astronomer, gave an address entitled " An Astronomical Tour of England and Ireland ".

5th June, 1957.

The seven hundred and thirtieth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Forty-eight members and visitors were present.

William Ernest Baker was elected a member of the Society.

Professor K. E. Bullen, F.R.S., F.A.A., delivered an address entitled "The Geophysical Year".

3rd July, 1957.

The seven hundred and thirty-first General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Sixty-eight members and visitors were present.

Alex Reichel was elected a member of the Society.

It was announced that Dr. R. J. Noble, Under Secretary, Department of Agriculture, Sydney, and a member of the Society since 1920, had been honoured by Her Majesty, Queen Elizabeth II, with a C.B.E. It was also announced that the Clarke Memorial Lecture, entitled "Further Remarks on Sedimentary Formations in New South Wales", would be delivered by Professor A. H. Voisey, Geology Department, University of New England, on 30th July, 1957.

The following papers were read by title only: "Minor Planets Observed at Sydney Observatory during 1956", by W. H. Robertson; "Ordovician Corals from New South Wales", by Dorothy Hill, F.A.A.

The evening was devoted to a symposium on "Biological Effects of Radiation", and the following addresses were given: "Radiation Hazards—Physical Aspects", by Mr. B. W. Scott, State Bureau of Physical Services, Royal Prince Alfred Hospital; "The Effects of Ionizing Radiations on Living Animal Tissues", by Dr. L. E. Atkinson, Department of Medical Physics, St. Vincent's Hospital; "Present Day Radiation Hazards to Man", by Dr. E. George, Department of Medical Physics, St. Vincent's Hospital.

7th August, 1957.

The seven hundred and thirty-second General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

Rev. T. N. Burke-Gaffney, Vice-President, was in the chair. Fifty-three members and visitors were present.

The Chairman announced the death of Orwell Phillips on 28th July, 1957, a member since 1935.

It was announced that the following awards were being made available by the Nuffield Foundation Dominion Travelling Fellowships Board: Medicine, 2; Natural Sciences, 2; Humanities, 1; Social Sciences, 1. It was also announced that the South-East Asia Treaty Organization is offering, during 1957–1958, research fellowships to scholars of SEATO countries.

Notice of motion by the Council that the following alteration be made to the wording of Rule IX: ". . . An absentee member is a member not resident in either New South Wales or the Australian Capital Territory", to replace ". . . An absentee member is a member who is resident outside New South Wales".

On behalf of A.N.Z.A.A.S. the presentation of the Mueller Medal was made to Emeritus Professor A. P. Elkin.

The following papers were read by title only: "Boundary Stresses in an Infinite Hub of Special Shape", by A. Reichel; "Basic and Ultrabasic Rocks near Happy Jacks and Tumut Pond in the Snowy Mountains of New South Wales", by G. A. Joplin; "On a Formula of the Convolution Type Related to Hankel Transforms", by J. L. Griffith.

The evening was devoted to a symposium on "Principles of Television", and the following addresses were given: "An Outline of the Method of Operation of a Television System", by Mr. W. H. Arnold, Lecturer in Electrical Engineering, N.S.W. University of Technology; "Non-Entertainment Television", by Mr. C. W. Gidley, Liaison Officer, Amalgamated Wireless (Aust.) Ltd.; "Producing a Television Show", by Mr. L. A. Major, Production and Programme Manager, ATN Channel 7.

4th September, 1957.

The seven hundred and thirty-third General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Eighteen members were present.

The Chairman announced the death of George Harker on 15th August, 1957, a member since 1905.

The following papers were presented: "Minor Planets Observed at Sydney Observatory during 1956", by W. H. Robertson; "The Mineralogy of the Commercial Dyke Clays in the Sydney District, N.S.W.", by F. C. Loughnan and H. G. Golding; "A Study of River Terraces and Soil Development on the Nepean River, N.S.W.", by P. H. Walker and C. A. Hawkins; "Ordovician Corals from New South Wales", by Dorothy Hill, F.A.A.; "Boundary Stresses in an Infinite Hub of a Special Shape", by A. Reichel; "On a Formula of the Convolution Type Related to Hankel Transforms", by J. L. Griffith.

2nd October, 1957.

The seven hundred and thirty-fourth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Thirty-six members and visitors were present.

Herbert Gordon Roberts was elected a member of the Society.

The President moved the following motion—Alteration of wording of Rule IX: "An absentee member is a member not resident in either New South Wales or the Australian Capital Territory", to replace "An absentee member is a member who is resident outside New South Wales". A vote was taken, with twenty-six members voting for the motion, against—nil. It was announced that the motion would be submitted for confirmation at the next General Monthly Meeting.

The following paper was read by title only: "The Geochemical Behaviour of Elements in Meteorites", by J. F. Lovering.

The evening was devoted to a symposium on "Beach Sands of Australia", and the following addresses were given: "Growth and Development of the Beach Sands Industry", by Mr. E. J. Harrison, Senior Geologist, Department of Mines, N.S.W.; "Mining Methods and Restoration Procedure on Beach Sands Leases", by Mr. B. A. Hadley, Senior Inspector of Mines, Department of Mines, N.S.W.

6th November, 1957.

The seven hundred and thirty-fifth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Fifteen members were present.

The following resignation was received: Professor Alan J. Birch.

The evening was devoted to a Commemoration of Great Scientists, and the following addresses were given: "Alfred Binet and Mental Measurement", by Mr. A. G. Hammer, Department of Psychology, University of Sydney; "Karl Pearson—Founder of a Science", by Professor G. Bosson, School of Mathematics, N.S.W. University of Technology; "Ronald Ross and Mosquito Day—The Conquest of Malaria", by Professor Harvey Sutton, O.B.E.

4th December, 1957.

The seven hundred and thirty-sixth General Monthly Meeting was held in the Hall of Science House, Gloucester Street, Sydney, at 7.45 p.m.

The President, Mr. F. N. Hanlon, was in the chair. Sixty-four members and visitors were present.

The following were elected members of the Society: Brian Edward Clancy, U. Hla, Frank Leechman and Barry S. Thornton.

The following names were removed from the list of members in accordance with Rule IX: G. H. Burton, R. Everingham, L. Luber and W. P. Sergeyeff.

The motion by the Council (alteration of wording of Rule IX), carried at the October General Monthly Meeting, was confirmed: "An absentee member is a member not resident either in New South Wales or the Australian Capital Territory", to replace "An absentee member is a member who is resident outside New South Wales".

The following papers were read by title only: "Addendum to my paper 'On Weber Transforms'", by J. L. Griffith; "The Zeros of a Certain Function Involving Bessel Functions", by J. L. Griffith; "Tapiolite and the Tri-rutile Structure", by Florrie M. Quodling; "The Manilla Syncline and Associated Faults", by A. H. Voisey.

The evening was devoted to a seminar on "Artificial Satellites", and the following addresses were given: "Radio Methods of Tracking Artificial Satellites", by Dr. D. L. Hollway, C.S.I.R.O. Division of Electrotechnology; "The Scientific Uses of Artificial Satellites", by Mr. C. A. Shain, C.S.I.R.O., Division of Radiophysics; "The Motion of Artificial Satellites", by Mr. H. W. Wood, Government Astronomer, Sydney Observatory.

NOTICE.

The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity, it was resuscitated in 1850, under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales"; in 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, it assumed its present title, and was incorporated by Act of the Parliament of New South Wales in 1881.

FORM OF BEQUEST.

I bequeath the sum of £ to the Royal Society of New South Wales, Incorporated by Act of the Parliament of New South Wales in 1881, and I declare that the receipt of the Treasurer for the time being of the said Corporation shall be an effectual discharge for the said Bequest, which I direct to be paid within calendar months after my decease, without any reduction whatsoever, whether on account of Legacy Duty thereon or otherwise, out of such part of my estate as may be lawfully applied for that purpose.

[*Those persons who feel disposed to benefit the Royal Society of New South Wales by Legacies are recommended to instruct their Solicitors to adopt the above Form of Bequest.*]

TO AUTHORS.

Particulars regarding the preparation of manuscripts of papers for publication in the Society's Journal are to be found in the "Guide to Authors", which is obtainable on application to the Honorary Secretaries of the Society.

The previous volumes and separate parts of the *Journal and Proceedings* may be obtained at the Society's Rooms.

The Library and Reading Room of the Society at Science House, Gloucester and Essex Streets, Sydney, is available for the use of members on week-days, 10 a.m. to 12 noon and 2 p.m. to 4 p.m.

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The Royal Society of New South Wales originated in 1821 as the "Philosophical Society of Australasia"; after an interval of inactivity, it was resuscitated in 1850, under the name of the "Australian Philosophical Society", by which title it was known until 1856, when the name was changed to the "Philosophical Society of New South Wales"; in 1866, by the sanction of Her Most Gracious Majesty Queen Victoria, it assumed its present title, and was incorporated by Act of the Parliament of New South Wales in 1881.

FORM OF BEQUEST.

I bequeath the sum of £ to the Royal Society of New South Wales, Incorporated by Act of the Parliament of New South Wales in 1881, and I declare that the receipt of the Treasurer for the time being of the said Corporation shall be an effectual discharge for the said Bequest, which I direct to be paid within calendar months after my decease, without any reduction whatsoever, whether on account of Legacy Duty thereon or otherwise, out of such part of my estate as may be lawfully applied for that purpose.

[*Those persons who feel disposed to benefit the Royal Society of New South Wales by Legacies are recommended to instruct their Solicitors to adopt the above Form of Bequest.*]

TO AUTHORS.

Particulars regarding the preparation of manuscripts of papers for publication in the Society's Journal are to be found in the "Guide to Authors", which is obtainable on application to the Honorary Secretaries of the Society.

The previous volumes and separate parts of the *Journal and Proceedings* may be obtained at the Society's Rooms.

The Library and Reading Room of the Society at Science House, Gloucester and Essex Streets, Sydney, is available for the use of members on week-days, 10 a.m. to 12 noon and 2 p.m. to 4 p.m.

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