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臺灣草嶺山鹼性玄武岩之初步研究

（節　要）

顏　滄　波

草嶺山位于新竹縣大溪鎮南約四公里之處，高出海面約三七四公尺，爲一丘陵性之山嶺。其附近地層可分爲下列諸層：

第四紀 更新世	臺地礫層	上新世	二鬮層（金瓜坑層）
	～～～（？）～～～		——斷層——
	草嶺山鹼性玄武岩熔岩流	中新世	中部夾炭層
			大寮層

二鬮層與中部夾炭層以一大逆斷層相接觸。草嶺山鹼性玄武岩覆蓋于上述兩層及大寮層之上，其與臺地礫層之關係雖不易窺見，但頗有不整合之可能。玄武岩活動時代係屬下或中更新世。

草嶺山鹼性玄武岩呈灰或暗灰色，其風化者多變爲棕色，均示斑狀構造，肉眼可見者有橄欖石，輝石等斑晶。石基均爲隱微晶質，可分爲緻密質及多孔質二種。岩石比重大致爲二•七左右。顯微鏡下觀察：斑晶有橄欖石，pigeonite，黑雲母，（斜長石，石英均罕見），構成石基之鑛物以pigeonite，橄欖石，黑雲母，長石類（正長石，灰曹長石，鉀中性長石？），白榴石，方沸石，磁鐵鑛，燐灰石，微晶，玻璃等爲主。成分鑛物之結晶次序爲 (1)斑晶橄欖石，pigeonite，黑雲母，（少量之斜長石，石英），磁鐵鑛；(2) 石基橄欖石，pigeonite，黑雲母，磁鐵鑛，燐灰石；(3) pigeonite，斜長石，白榴石；(4) 正長石；(5) 鉀中性長石，方沸石；(6) 玻璃。草嶺山鹼性玄武岩之化學成分如下：

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	灼失	總計
1.	48.32	0.34	12.68	2.95	4.92	0.18	15.42	7.45	3.60	3.46	0.58	99.90
2.	46.82	0.35	12.64	3.67	4.71	0.18	15.86	7.06	1.64	4.00	2.73	99.66

由岩石結構，組成鑛物及化學成分觀之，草嶺山鹼性玄武岩可相當于正長基玄武岩 (absarokite)，其詳細岩型可分爲：(1) 正長基玄武岩；含黑雲母正長基玄武岩。(2) 含黑雲母白榴石方沸石正長基玄武岩；含黑雲母方沸石正長基玄武岩。(3) 含黑雲母方沸石白榴石玄武岩（或正長基玄武岩）；含黑雲母白榴石方沸石玄武岩（或正長基玄武岩）。

本鹼性玄武岩時含外來捕擄岩如砂岩等，在兩者間有相互反應之顯跡。草嶺山玄武岩岩漿可能在溫度一千一百度左右之情況下噴發，流于地表。根據各種資料觀察，石基中之有色鑛物已經結晶後，草嶺山玄武岩岩漿之殘液，在地下因溫度之差異，自上而下分爲三層，上層主要由正長石所構成，中層富于正長石及白榴石，下層以白榴石及殘液爲主，而無正長石結晶。在此情形之下，上中二層先流出于地表，其次下層上昇而噴蓋于上中二層所構成之熔岩之上。

C.2

臺灣之方沸石粗粒玄武岩及方沸石橄欖灰色玄武岩

（節　　要）

顏　　滄　　波

臺灣所產鹼性火成岩，幾均屬鹼性玄武岩類，其中常含方沸石，此爲一大特徵。本岩可分爲二大類，乃方沸石粗粒玄武岩及方沸石橄欖灰色玄武岩是也。

1. 方沸石粗粒玄武岩（Analcite dolerite or Teschenite）

本岩之主要分佈地區爲臺北縣七星區，文山區，海山區及澎湖群島，多以岩盤，岩床，岩脈，熔岩流，集塊岩中之礫塊等產狀存在于新第三紀或第四紀地層中。本岩常造成單獨岩體或成普通玄武岩之分異相而出現。其岩漿活動時期可分爲下述四期：

(1) 下部夾炭層之沉積時期（下中新世）；(2) 公館凝灰岩層之沉積時期（下　中新世）；(3) 中部夾炭層沉積以後一次或一次以上之活動期（中　中新世——上新世）；(4) 第四紀礫層之沉積時期（更新世）。

臺灣產方沸石粗粒玄武岩均呈粗粒玄武岩結構，主要鑛物爲長石類（鉀長石，曹灰長石，中性長石，灰曹長石，鉀曹灰長石或中性長石？）及輝石類（輝石，含鍩輝石，pigeonite, titaniferous pigeonite, 曹輝石—輝石，曹輝石），其他鑛物由黑雲母，barkevikite, 橄欖石，方沸石，燐灰石，鐵鑛類及次生鑛物等所構成。本岩石之化學成分與方沸石粗粒玄武岩之平均成分，大同小異，無顯著差異。若與普通玄武岩之平均成分（Osann）相較則 SiO_2, MgO 及 CaO 均低，而 Na_2O 及 K_2O 略高，其他成分殆無多大高低。

臺灣產方沸石粗粒玄武岩由方沸石粗粒玄武岩質溶液固結而生成，該溶液則係普通玄武岩岩漿受分異結晶作用（Crystallization-differentiation）而生成者。

2. 方沸石橄欖灰色玄武岩（Analcite basanite）

在臺灣本島中，方沸石橄欖灰色玄武岩多發達于新竹縣關西鎮馬武督一帶，此外在澎湖群島之澎湖本島及漁翁嶼亦有此種岩石之出現。馬武督一帶之本岩石以熔岩流或集塊岩中之礫塊等產狀分佈于上部夾炭層及大埔層中，其時代係上中新世。又同類岩石亦產于枕頭山，六畜山，大山背山等地，均呈岩脈產狀，圍岩爲下部夾炭層或中部夾炭層，活動時代均未詳，但或與馬武督一帶產生該岩石之地層相同。澎湖群島所產此類岩石以熔岩流夾于第四紀砂礫及粘土層中。

方沸石橄欖灰色玄武岩之組成鑛物有長石類（鉀長石，灰曹長石，中性長石，曹灰長石）輝石類（輝石，含鍩輝石，pigeonite, titaniferous pigeonite, 紫蘇輝石，「擬紫蘇輝石」），橄欖石，方沸石，黑雲母，磁鐵鑛，燐灰石等。

臺灣產方沸石橄欖灰色玄武岩大部係由玄武岩岩漿分化而生成之產物，其分化機構與方沸石粗粒玄武岩無甚分別。又馬武督，馬福一帶之此類岩石，時含鋯石，鋼玉，紅玉，青玉，尖晶石及柘榴石（？）等鑛物。關于其成因市村毅有說明（此等鑛物均係自岩漿直接析出者），但亦有由玄武岩岩漿同化含上述諸鑛物之白雲岩質石灰岩而生成之可能。

臺南關子嶺枕頭山之石灰岩

（附 圖 三）

顏滄波　張麗旭

目　次

（一） 位置及交通

本鑛床位於臺南縣白河鎮仙草埔東南並關子嶺温泉西南各 2 公里餘，海拔約 645 公尺，構成一獨立之桌狀地，名爲枕頭山。

關子嶺西距縱貫鐵路後壁站約 15 公里，仙草埔距該站 11.5 公里，後者爲糖業公司及興南公司鑛業所之所在地。後壁及嘉義兩站與關子嶺之間各有公共汽車之便，均經白河鎮，糞箕湖及仙草埔，一日來回數次。由後壁至仙草埔，車行約需時 40 分，嘉義仙草埔間約需一小時，由此再至關子嶺僅需 15 分鐘而已。

（二） 沿　革

民國 12 年 12 月初旬關子嶺興業公司在仙草埔創辦業務所，由枕頭山北腹麒麟尾附近之民有地開採石灰岩，先以二段索道搬出仙草埔，再用輕便軌道運至後壁站，轉裝火車分售各糖廠，每逢製糖期，日銷約 20 萬毫斤。惟該灰岩所含之 MgO 爲量較多，雖可供發生 CO_2 之用，但爲蔗汁之澄淸劑並非所宜，未得與日本九州大分縣津久見所產者競爭。其後爲增進品質以圖推銷，該公司即放棄麒麟尾鑛場，重新開採碧雲寺附近之灰石，然其處境仍難克服，經營依然不振。

適二次大戰爆發，航運日益困窮，勢之所趨，各種工業原料，除非就地開發，否則無法供應。於是糖業聯合會乃計畫開採本島灰岩，首於民國 30 年由鹽水港製糖公司負責開採花蓮縣三棧溪附近之灰岩，繼於翌年復獲准枕頭山一帶（前因保安林關係未允開採）石灰岩鑛權，即在仙草埔創辦鑛業所，積極致力開發，除由枕頭山山頂至仙草埔架設索道，以及敷設牛車路之外，並由糞箕湖至新營站之間利用明治製糖軌道以利搬運，增新革舊，不遺餘力。彼時由糖聯承辦採運者計有關子嶺興業，興南，石灰興業，東興，共榮，振興六公司，日產石灰岩共達 650 公噸，尤其戰爭後期，因其

與本島中南部各處糖廠之地理關係，本省製糖用石灰岩年需 240,000 公噸之中，大半則仰之於此，是以產銷至盛。

光復之後，糖聯之舊產權一切移交糖業公司，於民國34～35兩年度，因本省糖業全盤之停頓，枕頭山灰石鑛業亦見衰微，除興南公司在麒麟尾附近繼續採掘石灰岩，就地燒灰之外，餘均停工。

至民國 36 年，爲應付將開工各糖廠之急需計，糖業公司即在烏樹林糖廠內設立鑛務科，主辦本鑛場一切事宜。當作者等前往勘查時，除趕運從前存留於仙草埔之石灰岩外，並在枕頭山西腹着手分區採石，聞於本年度內將運出 22,000 公噸。

(三) 地 形

鑛床附近爲嘉南平原與高山地帶中間之丘陵性山地，枕頭山海拔 644.8 公尺，周圍坡度峭峻，山頂平坦，構成一桌狀獨立山嶺，其西側以石灰岩之懸崖巍然聳立，俯瞰海拔不及 300 公尺之丘陵地帶，遠望之，宛如橫枕，故有其名。其南北兩面有急水溪支流白水及六重二溪，均由東向西蛇行而流，沿岸間有平坦面發育，大別可分三段，其在仙草埔附近者，海拔各爲 100, 150, 200 公尺左右。如嘉南平原東緣之平坦面海拔不過 50 公尺，乃相當於其下段，仙草埔部落及糖業公司鑛業所即位於其中段，舊巖及岩前村社即屬其上段，關子嶺部落之平坦面（海拔 310～370 公尺）亦然。凡此等平坦面均有礫石發現，顯係河成段丘之遺跡，足證地殼於最近地質時代之間歇上昇。其30～50 公尺以上之段丘崖，尤其中段被河流侵蝕殆盡，致上下兩段連接之處，阻碍交通甚巨，如仙草埔碧雲寺間之牛車路，即以仙草埔南面之段丘崖通行，尤爲困難。

總之，此地一帶丘陵，海拔最高不過 650 公尺左右，祗因於最近地質時代地殼間歇上昇，河流屢次復蘇，竟呈現複輪廻之侵蝕地形，溝壑深狹，山勢峻峭，致運輸困難。

(四) 地 質

枕頭山石灰岩係夾在砂岩與頁岩互層之間，此等地層累疊之狀，於仙草埔關子嶺間之公路東側，尤爲鮮明。此處灰岩即有上下二層，其下層位於青灰色（風化則變黃褐色）砂岩之上，厚約 2 公尺，外觀呈灰綠色，砂泥含量較多，並含生物破片甚豐，在顯微鏡下不難鑑別下列各種有孔蟲化石，故可稱之爲有孔蟲灰岩：*Amphistegina radiata* (Fichtel & Moll), *Globigerina bulloides* D'Orbigny, *G. bulloides* var. *triloba* Reuss, *Orbulina universa* D'Orbigny。

上層灰岩距下層約 150 公尺，其間多由與上述類似之砂岩組成，並夾頁岩薄層，時含灰質結核，在其下部（下層灰岩上約十數公尺之層準，Loc. 1），有下列化石發現，其中 *Phos sp.* 個體尤多：*Amusin* sp., *Pecten naganumanus* Yokoyama, *Aloides erythrodon* (Lamarck), *Phos sp.*, *Terebra sp.*, *Turricula javana* (Linné) [byorituensis Nomura], *Mitra sp.*, *Natica sp. 1*, *Ditrupa sp.*

該砂岩將與上層灰岩相接處即呈泥質，首以 10～20 公分之層厚與含有礫狀之珊瑚及彷彿 *Tridacna* 等生物破片者組成互層，層位愈上砂泥質層愈少，竟而變爲礫岩狀層與灰岩薄層所成之互層，總厚不及 20 公尺。此乃上層灰岩將尖滅之邊緣相 (Marginal facies)，由此愈南則層厚愈增，

石灰岩亦隨之愈益發育，至枕頭山一帶最厚似達 100 公尺以上。本岩多呈淡灰，淡黃或乳白色，以造礁珊瑚爲主，並含有孔蟲，石灰藻及貝殼化石。據矢部長克與半澤正四郎研究〔1, 2〕，其中有孔蟲化石有下列種類： *Operculina ammonoides* (Gronovius), *Gypsina inharens* Schultze var. *plana* Carter, *G. globulus* Reuss, *Amphistegina radiata* (Fichtel & Moll), *Rotalia calcar* D'Orbigny, *Carpenteria sp.*

此次發現之貝類化石如下（均在枕頭山西腹之崩落岩塊中）： *Antigona cfr. reticulata* (Linné), *Trochus sp.*, *Conus sp.*

上層灰岩之上概爲砂岩，砂質頁岩及頁岩之交互層，其中砂岩較爲發育，層厚時達數十公尺，嚴密言之，或可謂砂岩層與砂岩頁岩互層之反復累疊者。砂岩屬新鮮者即呈青灰色，風化則變黃褐色或褐色，岩質粗鬆，除其與頁岩組成互層者外，多爲塊狀，由麒麟尾北流之小溪一帶（上層灰岩上約 100 公尺之層準），尚有含砂岩卵石及珊瑚等生物破片而呈礫岩狀者發現。砂質頁岩或泥質砂岩均呈青灰色，多含白雲母細片，頁岩概爲青灰乃至黝灰色，時有洋葱狀構造發育。

在關子嶺公路南側之青灰色泥質砂岩中(Loc.2)有 *Cucullaea granulosa* (Jonas), *Amusium pleuronectes* (Linné), *Dentalium sp.*, *Ditrupa sp.* 等化石發現，而在枕頭山西面仙草埔與碧雲寺間之牛車路東側砂質頁岩及砂岩中 (Loc. 3, 4) 貝殼化石尤多，惟因其易於破碎，甚難採集，玆將其主要者列記於下： *Glycymeris formosana* (Yokoyama), *Ostrea sp.*, *Lopha sp.*, *Pecten (Chlamys) sp.*, *Cyclina sp.*, *Tellina prototenuilirata* Nomura, *Macoma sp.*, *Mactra sp.1* (*M. aff. veneriformis* Reeve), *Mactra sp. 2*, *Terebra sp.*, *Babylonia sp.*, *Oliva mustellina* Lamarck, *Mitra sp.*, *Batillaria multiformis* (Lischke), *Turritella bacillum* Kiener, *Natica sp. 2*, *Umbonium (Suchium) moniferum* (Lamarck), *Dallina sp.**

凡此等地層均互相整合，其一般走向爲北 30°～50° 東，向北西傾斜，傾角較急，概爲50°～60°。於麒麟尾北側爲走向約北 50° 西之斷層所切斷，斷層面北傾約 70°，由地層錯動之情形觀之，北側較南側相對下降，似屬正斷層，所謂麒麟尾斷層〔3〕即是。又在枕頭山東地層至爲擾亂，傾斜方向多與枕頭山以西相反，從前曾被認爲六重溪背斜之北延，但其所謂軸部頗可能係斷層。

至此等地層之地質時代，向無定說，或認爲海山層上部（即中新世上部）〔1, 3〕，或以爲苗栗層下部〔4, 5〕，但就上述化石觀之，其屬鮮新統幾無問題，況且其化石保存之狀態（均保留原殼），岩質以及地層累疊之情形等，與臺灣中部之卓蘭層酷似，而其含有礫岩之點，復彷彿嶺料山層之香山相〔6〕，故大體上可斷爲上部鮮新世也。

（五） 鑛層賦存之狀態

下層石灰岩於麒麟尾斷層北側延長雖有 1.5 公里餘，但其層厚僅 2 公尺左右，而且質劣，不足開採。在該斷層南側枕頭山一帶，其層位上應出露之位置，地面滿佈大小灰岩塊，大者長徑達十數公尺，甚難判斷其爲原位置之露頭抑爲轉動之岩塊，故其實際層厚無法測量。然依枕頭山東側舊

* 此一腕足動物在臺灣首次發現，由臺灣大學早坂一郎教授鑑定。又關於其他貝殼之鑑定，承臺大金子壽衛男講師指示甚多，併此誌謝。

Incline 路軌傍邊之露頭察之，此附近層厚相當膨脹，似達 20 公尺以上，而質亦較之上層幾無優劣，過去曾供製糖之用。此種灰岩塊之分佈可追至枕頭山南之牛車路石油井及天然氣噴出處附近，其間延長總有 1.3 公里。由此再南即不見之，石灰岩層於此似告尖滅。

上層灰岩於麒麟尾斷層北側之情形即如前述，下部爲泥質砂岩與含有珊瑚及彷彿 *Tridacna* 等生物破片之礫狀層所成之互層，上部爲薄灰岩及礫狀層之互層，總厚約 20 公尺，雖有良質之部份混淆，但難得均一之良石。惟本層愈南層厚愈增，品質亦愈優，在枕頭山一帶延長約 1 公里之間，最厚處似達 100 公尺以上，造成其東側之懸崖，其崩落岩塊滿佈於崖下，糖業公司現有之採石場，均以此種岩塊爲其對象。至枕頭山南端碧雲寺後面之崖，層厚復減至 30 公尺前後，其西南九股附近亦有灰岩巨塊廣佈，曾經舊糖聯開採，雖可推定其連延，惟亦以其層厚未明爲憾。

本層在六重溪北，距九股未及半公里附近完全尖滅。

總之，礦層雖有上下二層，但均爲眼球狀層，枕頭山附近適値其膨脹之處，至嘉義油田南北部地質圖所示厚灰岩層，其實乃包括二層並含其崩落岩塊之分佈地帶者也。

(六) 鑛 質

枕頭山灰岩外觀呈淡灰，淡黃或乳白色，多爲塊狀，質概堅緻，間有珊瑚構造極鮮明而多孔之部份存在。

依據民國 34 年工業研究所就松本隆一〔7〕於民國 31 年 12 月在枕頭山一帶以炸藥爆採之試料 114 個化驗之結果，則 CaO 最高 54.18%，最低 34.06%，平均 50.75%，MgO 最高 17.71%，最低 0.63%，平均 5.53%，$SiO_2+R_2O_3$ 最高 14.92%，最低 0.33%，平均 3.91%，足見其品質甚不劃一。第 2 圖即就上記 114 個之化驗結果，各算其 $CaCO_3$, $MgCO_3$ 與 $SiO_2+R_2O_3$ 之百分比後，表示於以此三成份爲頂點之三角圖表而作成者，凡百分比總數超過 100%時，均由 $CaCO_3$ 之百分比扣除其超額，而其總數不及 100%時，均將其不足額加算於 $SiO_2+R_2O_3$ 之百分比，故圖上所示 $CaCO_3$ 及 $SiO_2+R_2O_3$ 之百分比與分析數字時有 1%左右之誤差。又圖上附有 1～11 之△，特表示地質圖上附有同一數字地點之試料。由此則岩質變化之範圍不但一目了然，若與地質圖相對照，且可觀其隨地變化之甚焉。

枕頭山所產石灰岩中之 $SiO_2+R_2O_3$ 含量之平均約爲 4%，較之臺灣其他各地之石灰岩〔8〕，猶屬中庸，但其 MgO 含量平均 5.53%，除臺東縣北部一帶中新世石灰岩之外，則無匹敵者，若以和蘭製糖用灰岩之規格（SiO_2, R_2O_3 及 MgO 各 1%以下，不含 Na_2O 及 K_2O）而論，幾全不合，再以日人製糖化學專家濱口榮次郎之說（製糖用生石灰中 SiO_2, R_2O_3 及 MgO 容許存在之極量各爲 2%）爲準，則僅其約十分之一可供於此用途耳。

總之，本灰岩質甚不均，由第 2 圖察之，則 $CaCO_3$ 爲 90%以上，而 $MgCO_3$ 爲 10%以下之部份不過三分之一，專以製糖爲目的之採石，須加嚴選。作者等相信，若以肉眼及顯微鏡觀察之特徵，配合分析結果，示其變化於三角圖表上，必能顯出可使採石工人易於識別優劣之指南，惟囑糖業公司鑛務科寄送之採集標本，迄未收到，未能着手此方面之研究，至以爲憾。

（七）儲　　量

玆就實際上可採之部份，依其賦存之狀態，分區略計其儲量於次：

（1）. 枕頭山一帶上層石灰岩

延長約 900 公尺，由枕頭山西麓崩落岩塊分佈上限以上之高度平均為 100 公尺，傾斜平均 55°，故其沿層面傾斜可採深度即為 100 公尺 $\times \frac{1}{\text{Sin } 55^\circ} \doteqdot 120$ 公尺，若厚度平均以 40 公尺，比重以 2.5 計，即 $900 \times 40 \times 120 \times 2.5 = 10{,}800{,}000$ 公噸。

（2）. 枕頭山西麓之崩落岩塊

面積約 143,000 平方公尺，平均深度以 2 公尺，比重以 2.5，空隙率（為土壤所充填）以40% 計，即

$$143{,}000 \times 2 \times 2.5 \times \frac{60}{160} = 429{,}000 \text{ 公噸。}$$

由此扣除既採部份約一半則僅餘二十餘萬公噸耳。

（3）. 碧雲寺牛車路西南九股一帶

上層石灰岩層厚未明，崩落岩塊滿佈之面積約 178,000 平方公尺，按照前者計，即

$$178{,}000 \times 2 \times 2\ 5 \times \frac{60}{100} = 534{,}000 \text{ 公噸。}$$

（4）. 枕頭山北，西，南麓之崩落岩塊（抱括下層石灰岩露頭）

面積 372,000 平方公尺，深度平均以 3 公尺，其餘要素按照前二者計，即

$$372{,}000 \times 3 \times 2.5 \times \frac{60}{100} = 1{,}674{,}000 \text{ 公噸。}$$

總計可採儲量約 13,000,000 公噸，將來如以機具並採掘更深之部份，可採儲量則當增加。

（八）結　　論

（1）. 枕頭山石灰岩分有上下二層，以北 30°～45° 東之走向，西北 50°～60° 之傾斜，夾在相當於卓蘭層或嶺嶺山層香山相之地層中，故其地質時代當屬鮮新世上部。

（2）. 上下二層均為眼球狀夾層，枕頭山適值其膨脹處，為本鑛床主要之部份，尤其上層石灰岩於枕頭山西側約 900 公尺之間形成 100 公尺左右之懸崖，厚度平均約 40 公尺，僅就其出露部份計，儲量約達 11,000,000 公噸。

（3）. 可採儲量至少共計 13,000,000 公噸，倘年採 250,000 公噸，則可維持 50 餘年，年採 300,000 公噸，尚可維持 40 餘年。

（4）. 目前糖業公司之採石場，均以枕頭山西麓之崩落石灰岩塊為其對象，其採掘法極其粗笨，削除土壤後，先以手鑽穿孔裝藥炸破岩塊，再以鐵鎚打碎為長徑約 20～40 公分之石塊而已。故若增加工人，擴張採石場，採量雖可增多，但該區此種灰岩崩塊可採儲量約餘 200,000 公噸，早晚須採枕頭山上層石灰岩。

（5）. 鑛場至仙草埔之間約 4 公里，專以牛車（約 80 輛）搬運，每輛載運 2.5 公噸，在秋冬涸水期間，一日雖可往復兩次，但每遇雨，道路泥濘，車行須停數日之久；夏日雨季，通行尤為

困難，搬運幾瀕杜絕。如以現狀計之，年運 70,000 公噸亦屬不易。

(6). 爲增產宜恢復枕頭山山頂之鑛場，將來一切計畫應以枕頭山上層石灰岩爲主要對象，而以枕頭山西麓及九股一帶之崩落岩塊爲副。

(7). 若修改枕頭山舊索道，並將火車軌道延至仙草埔，且利用此間撤收之輕便軌道，沿現牛車路敷設之於舊岩及碧雲寺間，以便枕頭山西麓及九股之運石，附設轉裝棧以省素手裝卸之煩，則每年 200,000 公噸之採運，當無問題，毋須另擬更大之計畫。

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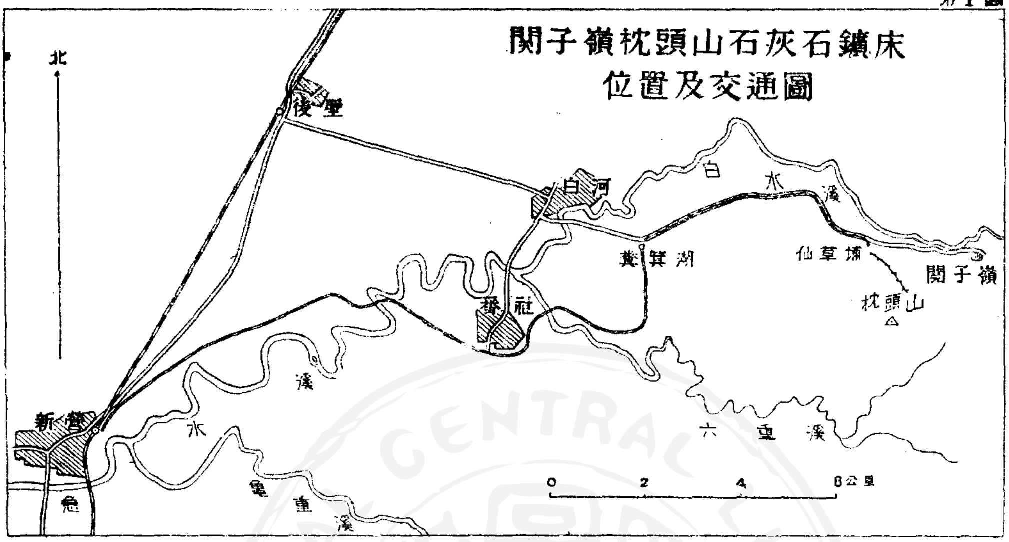
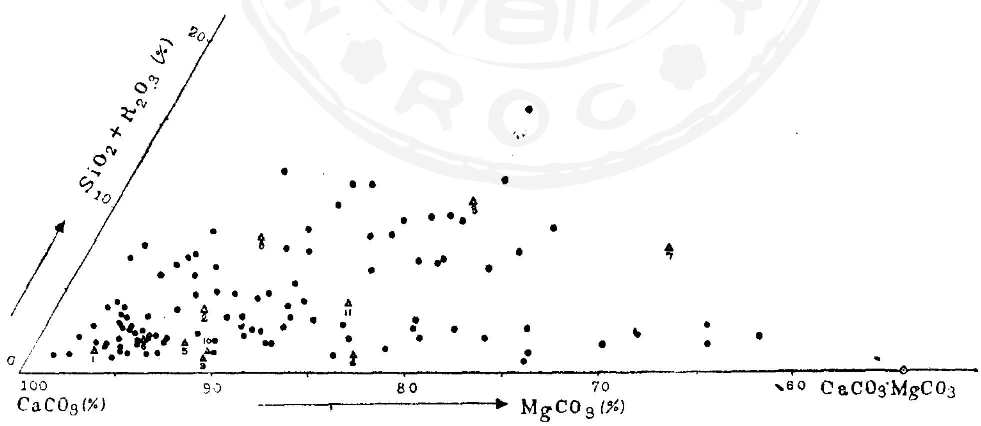
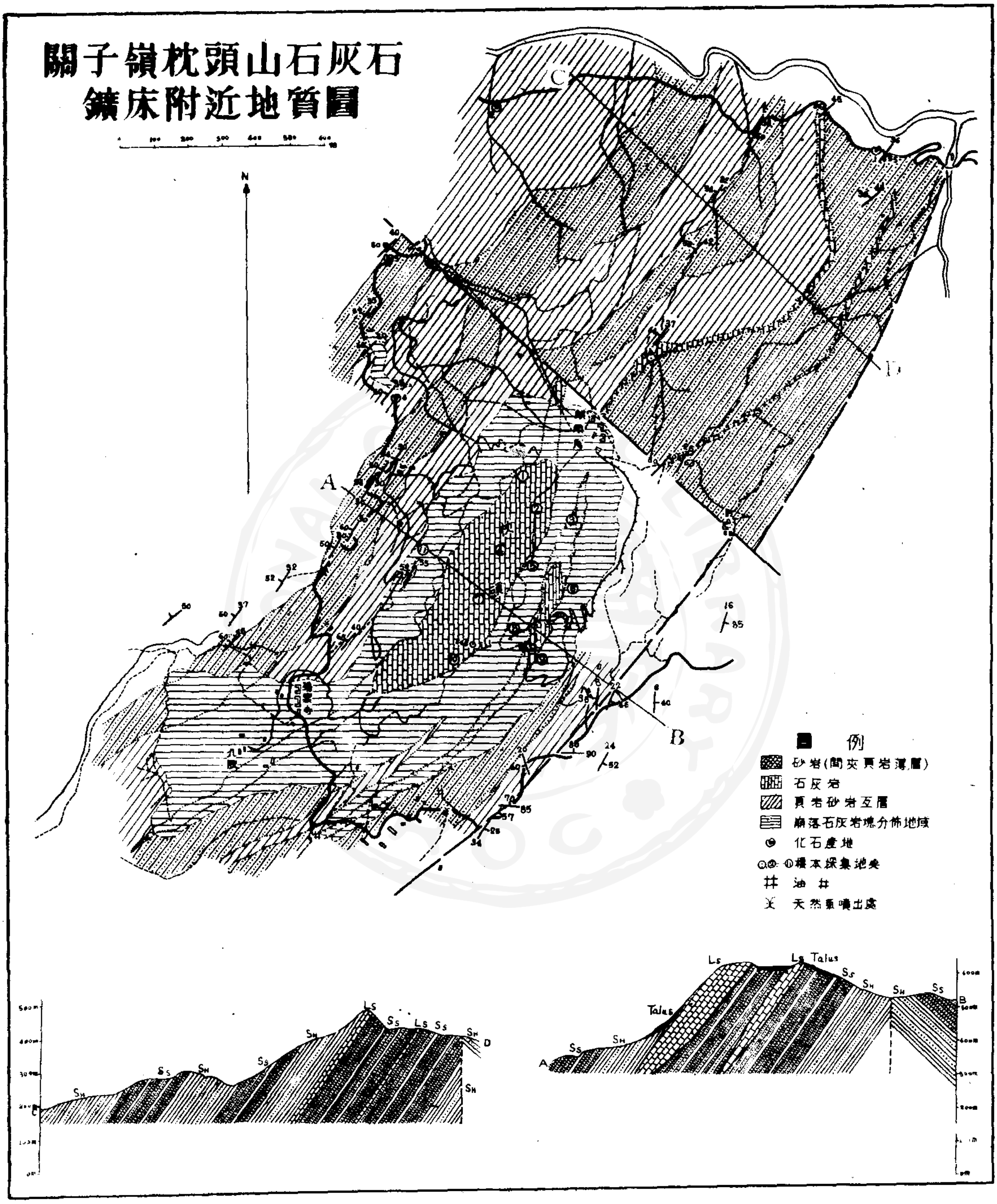
(8). 張麗旭：臺灣石灰岩之類別及其特徵，本彙報本號

第1圖





第2圖 關子嶺枕頭山石灰岩化學成份變化之範圍 (附有1~11之△特表示由地質圖附有同一數字之地點所採之標本)


關子嶺枕頭山石灰石
鑛床附近地質圖
N
A
B
C
D
圖例
砂岩(間夾頁岩薄層)
石灰岩
頁岩砂岩互層
崩落石灰岩塊分佈地域
化石產地
①②-⑪標本採集地矣
油井
天然氣噴出處
Ls
Ss
Sh
Talus

臺灣石灰岩之類別及其特徵

（附 圖 七）

張 麗 旭

目 次

（一） 臺灣石灰岩之類別

臺灣石灰岩之地質與地理分佈，較之其他各鑛範圍尤廣；就其主要鑛床而論，可由其產狀及其岩質分為下表各類：

類別		主要分佈	地質時代	特徵	
隆起珊瑚礁		高雄臺東澎湖三縣海岸及其屬島	現世	未盡變為石灰岩，多孔質。	
珊瑚石灰岩	所謂琉球石灰岩	高雄縣及臺東縣	洪積世乃至鮮新世上部	非結晶質，多呈塊狀，往往有珊瑚構造極鮮明而多孔之部份。	MgO 少，$SiO_2+R_2O_3$ 較多
	所謂 *Gypsina* 石灰岩	臺南與高雄二縣	鮮新世		MgO 及 $SiO_2+R_2O_3$ 俱多
Lepidocyclina-Miogypsina 石灰岩		臺北與新竹二縣及臺東海岸山脈	中新世	非結晶質，MgO 較少，$SiO_2+R_2O_3$ 多。	
結晶石灰岩		臺北縣東南部、花蓮與臺東二縣	始新世（一部）先第三紀？（大部）	結晶質，片理鮮明，MgO 及 $SiO_2+R_2O_3$ 均少。	

（二） 各類石灰岩之產狀與地質時代

1） <u>結晶石灰岩</u> 夾在先第三紀（？）大南澳雜岩* 及始新世粘板岩系蘇澳群之中。在大南澳雜岩中者分佈尤廣，北由大濁水溪下游南至知本溪中游，沿臺灣脊嶺山脈東側蜿蜒延展，雖非單一之石灰岩層，出沒隨地不定，且有向南逐漸尖滅之勢，但其各層層厚頗巨，時達 1,000 公尺以上。然在蘇澳群中者則反是，概為 100 公尺以下之眼球狀層，分佈至為散漫。二者均因動力變成作用變為結晶質，片理鮮明，後者往往含有 *Camerina*, *Assilina* 等化石，而在前者則未曾發現任何化石。三棧溪附近及西帽山一帶乃為前者之代表。

2） <u>*Lepidocyclina-Miogypsina* 石灰岩</u> 在臺北新竹二縣大部夾在公館凝灰岩層之中，在臺東海岸山脈則夾在都巒山層灰岩層及上原層之頁岩中，同屬中新世，概與火山碎屑岩相伴出現，層

* 地層名稱及其內容參閱張麗旭「臺灣地層之檢討」，地質論評第 13 卷，第三四合期及第五六合期， 1948.

數 1～3，各層層厚 30 公尺以下，膨縮不常，易於尖滅。此類石灰岩均非結晶質，富含 *Lepidocyclina, Miogypsina, Lithothamnium* 等化石，質量均以新竹縣赤柯山一帶之灰岩最優，臺東縣大馬及花蓮縣大港口附近之灰岩次之，其餘概不適大規模之開採。

3） 所謂 *Gypsina* 石灰岩　係 1930年矢部長克與半澤正四郎爲表示臺灣西南部各處新第三紀層中之限球狀石灰岩所稱者，原推定其時代爲中新世（海山層）上部，但除公田石灰岩或可能屬海山層上部之外，其餘似夾在相當於卓蘭層乃至頭嵙山層香山相之地層中，當屬鮮新統。各層層厚僅數公尺乃至數十公尺，含有珊瑚類 ***Amphistegina, Operculina, Rotalia, Acervulina, Gypsina, Globigerina, Orbulina, Carpenteria, Homotrema*** 等有孔蟲類，石灰藻，貝殼類之遺骸，其爲厚層者概以造礁珊瑚爲主，其成薄層者多以有孔蟲類爲主，均非結晶質，以公田及關子嶺枕頭山爲此類灰岩之代表。

4） 所謂琉球石灰岩　亦係矢部長克與半澤正四郎指高雄縣境內大崗山，小崗山，半屏山，舊城龜山，壽山，砲台山，鳳山，琉球嶼，恒春龜山，北大板埒臺地，鵞鑾鼻臺地及臺東縣附屬島嶼等海拔達 100 公尺左右乃至 350 餘公尺之隆起珊瑚石灰岩而命名者，主要由造礁珊瑚之遺骸組成，富含有孔蟲，貝類，海膽及石灰藻等類化石，概爲白色乃至灰白色之堅緻石灰岩，呈塊狀或層狀，間有珊瑚構造極鮮明而多孔之部份，層厚約 30～60 公尺，其分佈位置概在臺地與丘陵之頂部，一面造成急崖，他面形成平緩之山坡而逐漸傾沒於平地之下，其上時以礫石層蓋之。由層位學上嚴密言之，此等灰岩非屬同一單位，有一部與上述 *Gypsina* 灰岩混淆之嫌，今後必須一一加以檢討，方能確定其層位上之地位，但鑑於其地理分佈與岩質上之類似，暫以慣用之琉球石灰岩之名區別此群灰岩，以便比較。其地質時代似屬洪積世乃至鮮新世上部，以高雄壽山之灰岩爲其代表。

5） 隆起珊瑚礁　主要由造礁珊瑚集合而成，並含有貝類與有孔蟲類等之遺骸，未盡變爲石灰岩，高出海面數公尺乃至十數公尺，構成狹長之海岸段丘，或有位於段丘上面而造成段丘崖者，或有由段丘面向海面漸傾而與現生珊瑚礁相接者，顯係在最近地質時代所生成，依其岩質及其出現之高度與所謂琉球石灰岩者甚易區別。

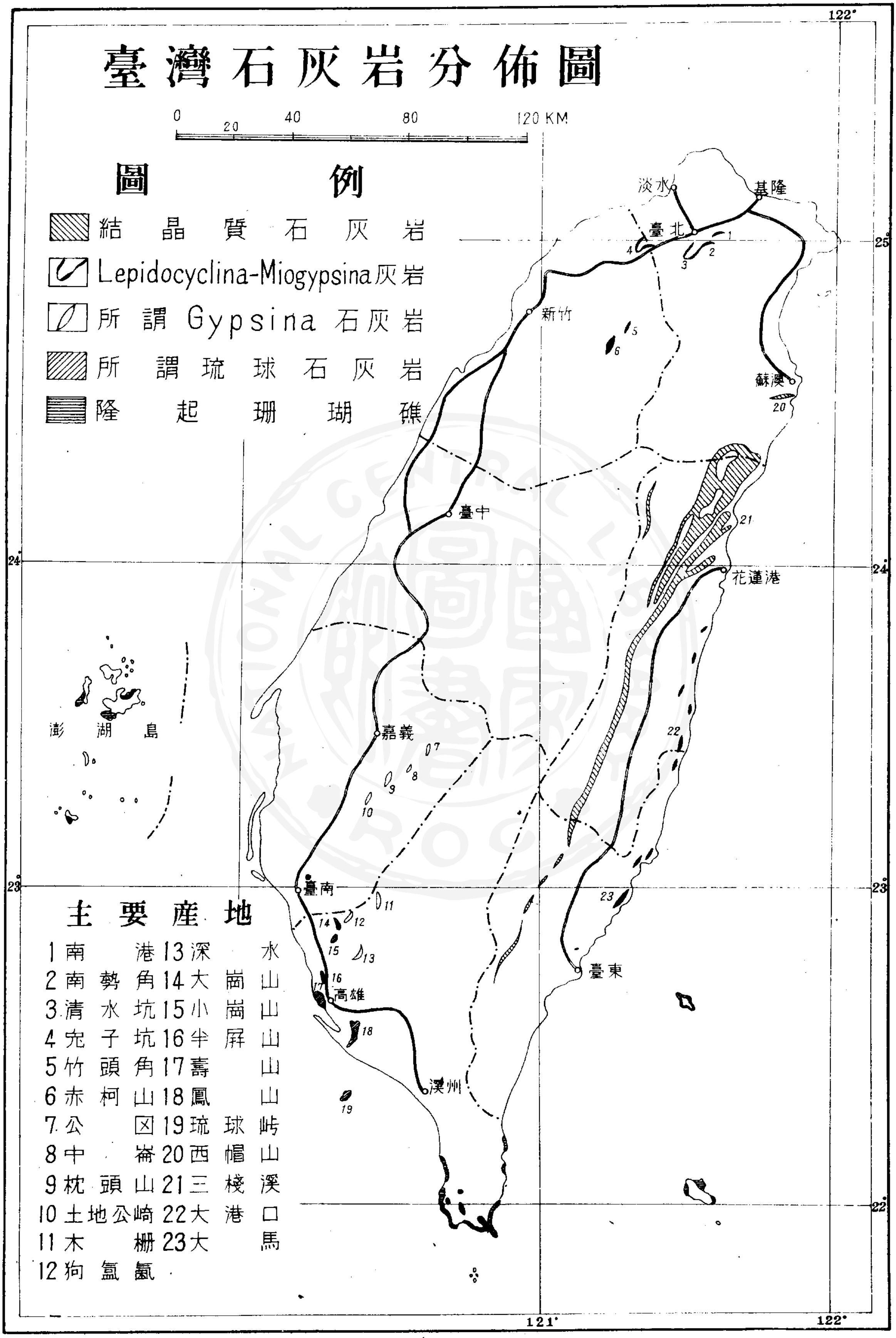
（三） 各類石灰岩之化學成份，特徵及其比較

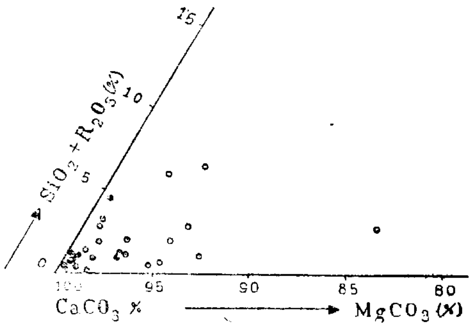
第 2～5 圖乃就各系統之石灰岩蒐集過去之分析資料，算出其 $CaCO_3$, $MgCO_3$ 及 $SiO_2+R_2O_3$ 之百分比後，表示於以此三成份爲頂點之三角圖表而作成者，凡百分比總數超過 100% 時，均由 $CaCO_3$ 之百分比扣除其超過額，而其總數不及 100% 時，均將其不足額加算於 $SiO_2+R_2O_3$，故圖上表示 $CaCO_3$ 及 $SiO_2+R_2O_3$ 之百分比與分析數字，時有 1% 左右之誤差。

由此等圖表知各類灰岩化學成份變化之範圍各異，就其一般趨向而言，結晶石灰岩之 MgO 與 $SiO_3+R_2O_3$ 含量俱少，*Lepidocyclina--Miogypsina* 石灰岩則 $SiO_2+R_2O_3$ 甚多，MgO 較少，所謂琉球石灰岩則 MgO 至少，$SiO_2+R_2O_3$ 較多，所謂 *Gypsina* 石灰岩所含之 MgO 及 $SiO_2+R_2O_3$ 爲量均巨，惟此類灰岩均依其層厚之大小及其出現層準之高低等而異其化學成份。第 6 圖即依據第 3 圖及顏滄波等之「關子嶺枕頭山之石灰岩」第 2 圖而作成者，表示此類灰岩互

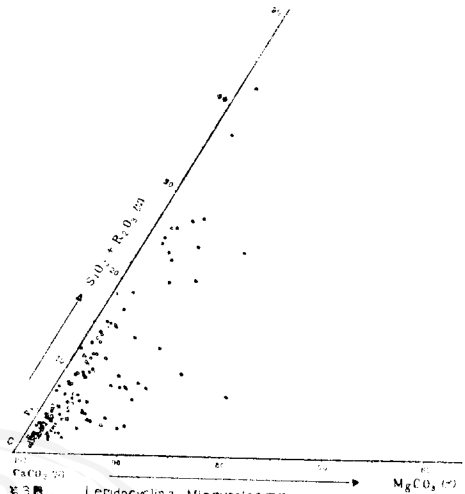
異之情形。由此觀之，枕頭山石灰岩之 MgO 含量尤高，其化學成份變化之範圍與本省其他灰岩殊異，公田灰岩之 MgO 及 $SiO_2+R_2O_3$ 成份較少，相當於枕頭山灰岩之優良部份，而與結晶灰岩及赤柯山灰岩成份近似，岩質之優爲本範疇灰岩之首，但含有微量之 Na_2O（平均不及 0.2%）爲其缺點。土地公崎及其他地方之此類灰岩均富含 $SiO_2+R_2O_3$, MgO 比較少，概與 *Lepidocyclina—Miogypsina* 灰岩(除赤柯山）相近。第 7 圖即根據第 2～6 圖而作成者，藉資比較各類灰岩化學成份之一般趨向。

總之各類灰岩俱有特色，簡單列之則如上表，簡明示之則如第 7 圖。

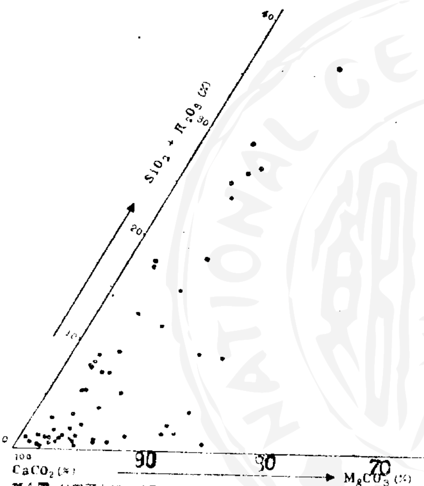

臺灣石灰岩分佈圖
0 20 40 80 120 KM
圖例
結晶質石灰岩
Lepidocyclina-Miogypsina灰岩
所謂 Gypsina 石灰岩
所謂琉球石灰岩
隆起珊瑚礁
淡水
基隆
臺北
新竹
蘇澳
臺中
花蓮港
澎湖島
嘉義
臺南
高雄
臺東
溪州
主要產地
1 南港 13 深水
2 南勢角 14 大崗山
3 清水坑 15 小崗山
4 宪子坑 16 半屏山
5 竹頭角 17 壽山
6 赤柯山 18 鳳山
7 公囝 19 琉球嶼
8 中崙 20 西帽山
9 枕頭山 21 三棧溪
10 土地公崎 22 大港口
11 木柵 23 大馬
12 狗氳氳
122°
121°
25°
24°
23°
22°



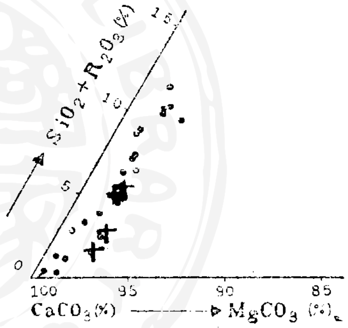
第2圖　結晶石灰岩化學成份變化之範圍
●西帽山石灰岩○三棧溪石灰岩



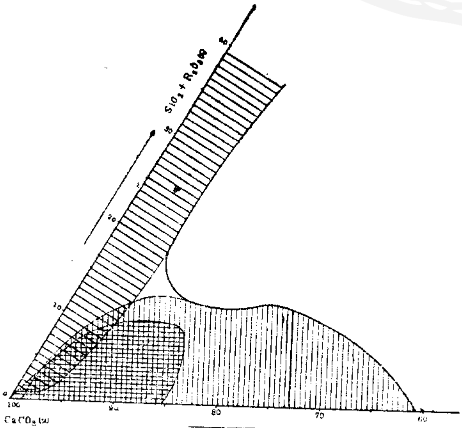
第3圖　Lepidocyclina-Miogypsina石灰岩化學成份變化之範圍
[illegible]



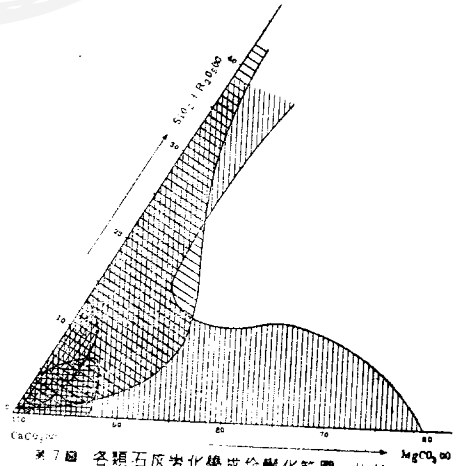
第4圖　公田及土地公崎石灰岩化學成份變化之範圍　●公田 ○土地公崎



第5圖　所謂琉球石灰岩化學成份變化之範圍
●壽山　✝大崗山及小崗山



第6圖　所謂Gypsina石灰岩化學成份變化範圍之比較
[illegible]　公田　土地公崎　一般



第7圖　各類石灰岩化學成份變化範圍之比較
結晶石灰岩　Lepidocyclina-Miogypsina 石灰岩
所謂Gypsina 石灰岩　所謂琉球石灰岩

A PRELIMINARY STUDY ON THE ALKALINE BASALT OF TSAOLINGSHAN, TACHI, SINCHU, TAIWAN

By

T. P. YEN

(With 8 Figures)

Contents

I. Introduction

Tsaolingshan[1] is situated about four kilometers south of the town Tachi,[2] Sinchuhsien.[3] It forms a gently sloping hill with a height of 374.2 m. The hill is composed entirely of the alkaline basalt. Concerning this rock, descriptions have already been written by T. Ichimura and others (1) (2) (3) (4), and geological studies in this area including the hill itself have also been made by Y. Ichikawa (1) in 1926 and by the writer (3) in 1937.

According to Ichikawa (1), the volcanic rock of this hill is similar to that occurring in the pyramidal hill, Chienshan,[4] near the town of Yingko.[5] Both belong to the category of olivine-basalt. Ichimura (4), however, pointed out that the rock is not an ordinary olivine-basalt, but is a sort of alkaline basalt. On account of its peculiar features in the megascopical, microscopical and chemical characters, the rock is likely to be considered as a new variety. It was his conclusion that without making more detailed studies, it is impossible to identify exactly the true nature of the rock.

At present the writer takes this problem into consideration again, and, as a result, it has become clear that the rock belongs to one kind of trachybasalt, the absarokite, which is first indicated by J. P. Iddings. The present paper deals briefly with the result of his preliminary studies.

As the constituent mineral grains in the groundmass of this rock are extremely fine, high-powered microscopes and several optical accessories are indispensable for detailed microscopical investigations. Unfortunately, however, owing to the ultra-fineness of the mineral grains on the one hand, and to the lack of necessary optical instruments on the other, the writer can not but leave farther observations for the future.

1 草嶺　2 大溪　3 新竹縣　4 尖山　5 鶯歌

II. Geologic Sketch

The geological formations in the district of Tsaolingshan have formerly been briefly sketched by Ichikawa (1) and the writer (2); the main features being as follows:

Quaternary	Pleistocene	1. Tableland gravel beds
		(?) Unconformity
		2. Alkaline basalt flows (Tsaoling volcanic activity)
		Unconformity
Neogene	Pliocene	3. Kinkakō beds (Niki beds of Ichikawa)
		Fault
	Miocene	4. Middle coal-bearing beds
		5. Tairyō beds

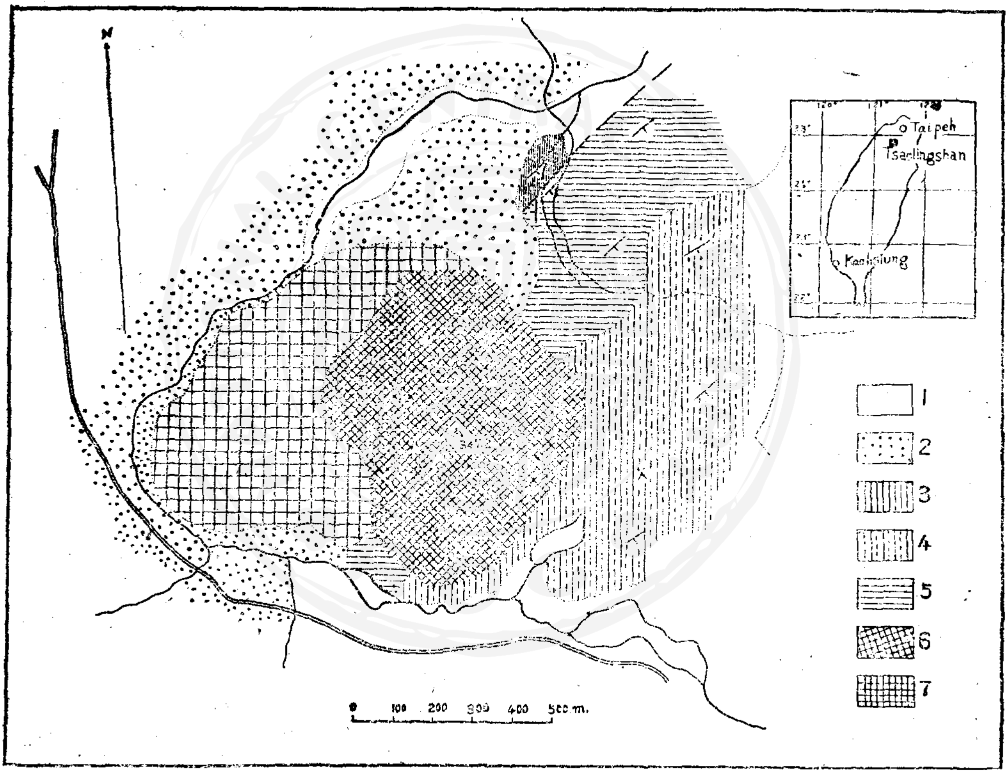


Fig. 1. Geological Map of Tsaolingshan

1. Alluvium
2. Tableland gravel beds
3. Kinkako beds
4. Middle coal-bearing beds
5. Tairyo beds
6. Principally the third type } Tsaoling
7. Principally the first and second types } alkaline basalt

Tairyō beds consist of greyish blue shale, sandstone and yellowish brown sandstone containing occasional molluscan fossils. The general strike of these strata is N40°E, dipping towards southeast at nearly 20 degrees.

Middle coal-bearing beds conformably overlie the Tairyō beds. It is composed of alternating beds of sandstone and shale, intercalating several coal seams. Two of the coal seams are workable, yielding coals with caking character. They have been working in a small mine situated about 500 m. east of the hill.

Kinkakō beds consist principally of bluish sandy shale exposing sporadically in the small valley northeast of Tsaolingshan. The strike is N 30°∼40° E, dipping southeastward at an angle of 50 degrees.

Tableland gravel beds which make up the surface of the tableland are about 200 m. above the sea level. It is composed of clay, sand and gravel, and is covered by a thin layer of lateritic soil with a thickness of one meter.

Tairyō and Kinkakō beds are brought into contact by a great reverse fault (Sinten fault), along which the strata of the two beds are more or less disturbed and crushed. The fault plane strikes northeast and dips toward southeast at a considerable low-angle.

Owing to the covering of weathered rocks and soil, it is very difficult to trace the Tsaoling volcanic body in detail, but it is quite certain that the body lies on the two beds, Tairyō and Kinkakō. Though the stratigraphical relation between the volcanic body and the Tableland gravel beds cannot be directly observed, the former perhaps does not overlie the latter, but is in an unconformable contact under the latter. That is, the deposition of the Tableland gravel beds is slightly later than the volcanic eruption. From these evidences, the age of volcanic eruption can be assumed to be middle or lower Pleistocene.

The Tsaoling volcanic body consists entirely of alkaline basalt in the occurrence of lava flows. At the southern foot of the hill, a limited exposure of agglomerate can be observed. By reason of unfavorable exposures of the rock and its aphanitic groundmass, the various rock types cannot be recognized megascopically and the detailed distribution of all those types cannot be determined in consequence too. The rock is invariably in dark grey color usually with greenish tint. It alters to brownish grey, brown and reddish brown color as a result of advancing weathering. The rock can be megascopically divided into two groups, the very porous one and the compact one; but the two usually grade into each other without any sharp boundary. The compact group may be subdivided into rough and fine facies according to the surface—apperance of the groundmass. Those which belong to the rough facies crop out chiefly in the area extending from the northern foot of the hill to the western; while those which belong to the fine facies are principally distributed on the eastern higher regions including the summit. There is a tendency that the development of porous group becomes more and more remarkable from the foot of the hill toward the summit. Based on these field data and the topographical expressions it is assumed that the Tsaoling volcanic body might be built up by at least two effusions of flow and agglomerate. There is an intimate relation between the megascopic appearance of the groundmass and the qualitative and the quantitative compositions of minerals. It would be described and discussed in full detail in the following chapter.

III. Petrography

Not long ago Ichimura (4) has briefly made a description of this alkaline basalt here discussed, but he has not identified its petrographic clan. This time more than twenty specimens of this rock (in thirty-five thin sections) collected at different parts within this igneous mass have been studied microscopically by the writer.

Megascopic Observations:—All the types show porphyritic structure, having abundant megacopic olivine phenocrysts and occasional pyroxene and biotite. The grains of olivine phenocryst often attain 2 or 3 mm. in diameter, being generally only 1 mm. or so. The groundmass of the rock is aphanitic, dense and compact. The average specific gravity of the rock is nearly 2.7 (the porous one 2.71; the porous yet somewhat weathered 2.41; the compact one 2.73).

Microscopic Observations:—All the rock types exhibit a porphyritic texture under the microscope. They contain the same phenocrysts but the groundmass varies more or less with the rock types. Olivine is the chief and abundant phenocryst. Besides, the phenocrysts are made of such minerals as pigeonite, biotite, magnetite after biotite and very rarely plagioclase and quartz. The groundmass, being fine or very fine in texture, consists principally of olivine, pigeonite, feldspars including orthoclase, plagioclase and potash-andesine (?), biotite, leucite, analcite, glass, magnetite, apatite and microlites. The groundmass, as seen in several specimens, shows fluidal texture. The characters of the various minerals will be first briefly described in the following paragraphs.

(A) *Phenocrysts:*

Olivine occurs abundantly in each type of the rock, and is euhedral to subhedral in form, having a size up to 0.6×0.2 mm. or more. Sometimes the development of cleavage is prominent. It is optically positive or negative. The axial angle (2V) is nearly 90°, ranging from (−) 2V≒87° to (+) 2V≒87°. Its chemical composition is estimated ranging from Fo 79 Fy 21 to Fo 95 Fy 5, the majority being Fo 85 Fy 15. The greatest double refraction [about $(\gamma-\alpha)$] is 0.040. Several olivine phenocrysts assume a corroded form, and some crystals are fringed by aggregates of fine pigeonite grains. In the brown and reddish brown specimens of the rock, it alters to hematite from the margin toward the center, and occasionally becomes hematite after olivine.

Pigeonite exists in each type of the rock, but is very scarce in comparison with olivine. It attains a size nearly reaching 0.3×0.03 mm., and shows subhedral form. It is colorless to light greenish yellow in color. Cleavage is very distinct and well-developed. Extinction angle Z∧C is 40°—42° and 43°—45°, commonly 41° and 44°. Sometimes the extinction angle is slightly different between the central and the outer part of the same crystal, viz., the central part is Z∧C=40°-41°, while the outer part is Z∧C=45° (according to Ichimura, the central part is Z∧C=40°; the outer part, Z∧C=42°). In other words, there is a tendency to show that the extinction angle of the central part is generally slightly smaller than that of the outer. Its axial angle (2V) is rather small, viz., 15°—20° and 30°±; very rarely it attains to 45° which marks the presence of pigeonitic augite. All are optically positive.

Biotite occurs nearly in all types of the rock. Most show their crystal outlines only, fringed by aggregates of small magnetite grains. Unaltered biotite is rather rare. The biotite has a moderate to strong pleochroism, viz., X=colorless to light yellow, Y≑Z=yellowish brown to reddish brown. Absorption is X<Y≑Z. The greatest retardation is 664 mμ, so that double refraction (γ-α) is nearly 0.034. According to Ichimura the greatest index of refraction γ is 1.622. It is optically negative and the axial angle 2V is very small (about 10°).

Plagioclase rarely occurs as phenocryst. In the thirty-five sections examined only two were found containing this mineral. There is only one crystal in each. It is twinned after the Carlsbad and the albite laws, and is turbid along the outer part. The indices of refraction of the central part are slightly higher than those of the outer. It is optically negative. The axial angle 2V is nearly 75°~80°. It corresponds somewhat to acidic bytownite or labradorite.

Quartz is very rare and is recognized in one slide only which contains a single quartz crystal. It is anhedral in form, uniaxial and optically positive.

(B) *Groundmass:*

In the Tsaoling volcanic body, the difference of rock types is principally attributed to the structure, granularity, and the kind and quantity of the mineral components of the groundmass. Here the microscopic characters of various constituent minerals of the groundmass are briefly described:

Pigeonite is found abundantly in the groundmass. It is in subhedral or anhedral form, and about 0.03 mm. in size. It is colorless or in very light greenish yellow color. The development of cleavage is distinct. The extinction angle Z∧C is 41°—42° and 44°—45°. The axial angle 2V is rather small or moderate and is often smaller than 20° or well around 30°. All are optically positive.

Olivine is less than pigeonite in quantity, and is entirely recognized as anhedral grains. Its size is nearly 0.02 mm. in diameter.

Biotite is one of the principal groundmass—minerals. It occurs in flake-like forms, having a length smaller than 0.2 mm. Its pleochroism is rather strong, viz., X=colorless~light yellow, Y≑Z=yellowish brown to reddish brown. The absorption is X<Y≑Z. Except the slight difference in shade of pleochroism, all the other optical charcters of biotite are same throughout all the speciemens. It often alters to aggregates of small magnetite grains from the outer part toward the center. This alteration is especially more distinct in those rock types that have a comparatively coarser groundmass.

Feldspars are extremely variable in quantity and granularity. They are distributed sporadically in the groundmass in the shape of patchy aggergates. In some specimens they are almost absent; while those rocks which have a coarse groundmass are especially rich in feldspars. Generally they are 0.05×0.01 mm. in size, but sometimes they attain to 0.2 mm. in length. According to the optical characters, they can be classified into three kinds. (F_1, F_2 and F_3).

F_1: Lath-shape predominat; colorless; extinction straight; elongation negative; twinning in Carlsbad law; double refraction n_2-n_1 very low, smaller than 0.006; index of refraction by immersion method is $1.515 < n_1 (\doteqdot \alpha) < 1.526$; optically negative; axial angle $2V \doteqdot 70°$. Judging from these characters, F_1 may correspond to orthoclase. Rarely severel crystals show a slightly oblique extinction, viz., $Z \wedge C$ on $(001) \doteqdot 5°$. They are perhaps anorthoclase.

F_2: Lath-shape predominant; extinction oblique; maximum extinction angle in albite twins is about 30°; twinning according to Carlsbad and albite laws; indices of refraction $n > 1.54$; double refraction, n_2-n_1, moderate, smaller than 0.009. From these characters, F_2 may be regarded corresponding to labradorite.

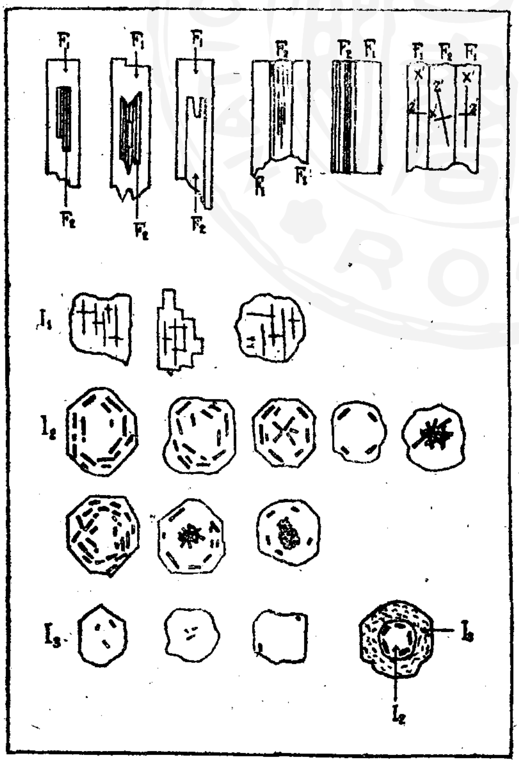


Fig. 2. Feldspars and isotropic minerals

F_3: Shows irregular form or irregularly lath-shape; extinction oblique; maximum extinction angle is about 25°; sometimes showing wavy extinction; indices of refraction n_1 and n_2 are about 1.547, and slightly higher or lower than this, namely, $\beta \doteqdot 1.54$ (the value $n_1 = 1.530 \sim 1.534$ on (010) as was measured by Ichimura is perhaps of this category); optically positive; axial angle 2V is about 50°. Judging from these characters, F_3 bears a striking resemblance to the "Potash-andesine" described by T. Tomita (5).

As to the mutual relations in occurrence among F_1, F_2 and F_3 in the groundmass, F_1 and F_2 occur together in the form of rectangular prisms, and F_3 cements the irregular spaces between F_1, F_2 and other minerals. The association of the former two is of particular interest. F_1 frequently contains minute prismatic core of F_2; and occasionally F_1 and F_2 are stuck together by twinning according to Carlsbad law. In some crystals, F_2 is sandwiched in between crystals of F_1 (Fig. 2).

Isotropic minerals are found abundantly distributed in the groudmass of Tsaoling volcanic rock, forming rounded or polyhedral crystals usually with a diameter of 0.03 mm. approximately. The quantity of them in the groundmass is in inverse proportion to that of the feldspars, that is, the former increases as the latter decreases. When there is little or no feldspar in the groundmass of the rock, these isotropic minerals are the principal constituents of the groundmass. According to these various characters especially to the index of refraction, they may be divided into three kinds, I_1, I_2 and I_3.

I_1 Assumes rounded or irregularly angular form; rectangular cleavage develops; no inclusion; index of reraction by immersion method is $n \fallingdotseq 1.490$ and $n < n$ of I_2. It appears to be analcite.

I_2 Shows hexagonal, octangular or rounded form in thin section; colorless; rarely with small cracks; numerous inclusions of glass. The augite and microlites are usually arranged in certain peculiar ways, that is, the two may group together and cluster at the center; or are arranged in one or more concentric zones with prismatic crystals parallel to surface of I_2; or may be radially arranged. The concentric arrangement is of the most common occurrence. In some cases I_2 is surrounded by a shell of crystals, mostly of feldspars and pigeonite, more or less parallel to the surface. The index of refraction n is smaller than the balsam, as is ascertained by the immersion method, $1.515 > n > 1.500$, i.e., nearly 1.510. Considering these characters, I_2 is very similar to leucite. Judging from the chemical composition of the rock, the presence of leucite is also quite possible.

I_3 Shows rounded or irregular form; sometimes contains small inclusions which occur sporadically; generally colorless, but sometimes in brown color; no cleavage. Index of refraction n is larger than I_2, and is nearly 1.54 (almost equivalent to balsam) or higher (the value measured by Ichimura is 1.547). Thus, it is obvious that I_3 corresponds to glass.

I_1, I_2 and I_3 often occur together and are distributed widely in the groundmass. They are usually surrounded by a shell of other minerals. In some rounded grains, the inner part is made of I_2, while the outer is composed of I_3. It indicates that these grains are crystallized in the midst of reaction between I_2 and I_3. (Fig. 2)

Magnetite found abundantly in each rock type. It is in rounded form or in octahedral shape, having a diameter of 0.015 mm. The majority of the crystals is scattered in the groundmass, but some are also found as inclusions in such minerals as biotite, olivine and pigeonite.

Apatite shows slender form, attaining 0.1×0.02 mm. in size, sometimes reaching as large as 0.5×0.2 mm. Its elongation is negative. It is brownish in color in the inner part.

Microlites are found in the isotropic minerals as inclusions or in the groundmass. They are too small to recognize their characters. The majority of them is, perhaps, made of glass, pyroxene and the like.

Rock types:—The volcanic rock constituting the main Tsaolingshan proper is pophyritic in texture with abundant phenocrysts of olivine, and rarely of pigeonite and biotite. Throughout all the rock types, there is almost no marked difference in nature of the phenocrysts; while the texture and the kinds of mineral components of the groundmass are variable according to the types of the rock. The groundmass may be divided into two kinds, fine and very fine, by the size of contained crystals. Based on the relative quantity and the kinds of mineral components of the groundmass, the rock may be classified into several types as follows:

First type (I):—Groundmass consists principally of feldspars. Isotropic minerals are almost absent or comparatively little.

Second type (II):—Groundmass consists principally of feldspars and isotropic minerals. The quantity of feldspars is nearly equal to that of isotropic minerals.

Third type (III):—Groundmass consists principally of isotropic minerals. Feldspars are comparatively scarce or almost absent. The third type may be subdivided into two subtypes as shown below:

(IIIa): Isotropic minerals are principally represented by I_2. I_1 and I_3 are comparatively rare.

(IIIb): Isotropic minerals are principally represented by I_1. I_2 and I_3 are comparatively rare.

The rock appearance, texture and granularity of groundmass of each rock type may be summarized in the following table (Table 1).

Table 1

	First type	Second type	Third type
Appearance	Rough facies	Rough facies	Fine facies
Texture	Intergranular, intersertal and partly pilotaxitic textures.	Intergranular, intersertal and partly pilotaxitic textures.	Dense, intergranular, sometimes Clathrate textures.
Granularity	Mainly fine	Fine or very fine	Principally very fine

The relation between rock types and constituent minerals is briefly tabulated below (Table 2):

Table 2. Relation between rock types and principal components of the volcanic rocks of Tsaolingshan.

Types			I	II	IIIa	IIIb
Structure		Porous	×	×	×	×
		Compact	×	×	×	×
Texture		Fine	××	××	(×)	(×)
		Very fine	(×)	×	××	××
Phenocryst		Olivine	+++	+++	+++	+++
		Pigeonite	+	+	+	+
		Biotite	(+)	+	+	+
		Plagioclase	*			*
		Quartz			*	
Groundmass		Pigeonite	+++	+++	+++	+++
		Olivine	+	+	+	+
		Biotite	(++)	++	++	++
	Feldspars	F_1 (Orthoclase)	++	++	(+)	(+)
		F_2 (Plagioclase)	+	+	(+)	(+)
		F_3 (Potash andesine?)	(+)	(+)		
	Isotropic minerals	I_1 (Analcite)	(+)	++	+	++
		I_2 (Leucite)	(+)	+(+)	++	+
		I_3 (Glass)	+	+	+	+
		Magnetite	++	++	++	++
		Apatite	+	+	+	+
		Microlite	+	+	+	+

{ ×× Type common; × present; (×) present or absent }

{ +++ Abundant; ++ common; + rare; (+) rare or absent }

*Each only one section and a single crystal

Types: I Absarokite; Biotite-bearing absarokite.
II Biotite-bearing leucite analcite absarokite; Biotite-bearing analcite absarokite.
IIIa Biotite-bearing analcite leucite basalt (or absarokite).
IIIb Biotite-bearing leucite analcite basalt (or absarokite).

The distribution of rock types: In the Tsaoling volcanic body, the main area of distribution of the first and the second types extends from the northern foot of the hill to the western; while the eastern higher part of the hill embracing the summit is principally built up of the third type. The effusive stage of the former two types is, broadly speaking, slightly earlier than the latter. This is the general tendency. However, they are, in reality, transitional to each other. All are so closely related in time of eruption that it is impossible to draw definite boundaries among them. Because the surface of the hill is almost completely covered by eluvial deposits and soil, it is very difficult to trace the distribution and to make clear the transitional relation of these rock types in the field.

IV. Chemical Composition

Two specimens of the rock in question were chemically analysed in the Geological Survey of Japan, and the results are as follows (Analytical data are quoted from the paper of Ichimura (4). (Table 3).

Table 3
Chemical composition

	T_1	T_2
SiO_2	48.32	46.82
TiO_2	0.34	0.35
Al_2O_3	12.68	12.64
Fe_2O_3	2.95	3.67
FeO	4.92	4.71
MnO	0.18	0.18
MgO	15.42	15.81
CaO	7.45	7.06
Na_2O	3.60	1.64
K_2O	3.46	4.00
Ig. loss	0.57	2.73
Total	99.90	99.66

T_1: collected from the western foot of Tsaolingshan
T_2: collected from the eastern slope of Tsaolingshan

From these chemical data, it is recognized that the rock is low in sillca and high in magnesia, potash and soda, magnesia being very rich. The abundance of magnesia can be attributed to the rich content of olivine (especially of forsterite molecule) and pigeonite in the rock. The presence of potash-feldspar, potash-bearing minerals like leucite and biotite is the main cause that the rock is high in potash content. In some specimens, soda is comparatively high; this is perhaps due rather to the abundance of soda-rich minerals like analcite among the isotropoc minerals than to the albite molecule existing in the plagioclase.

The normative minerals are calculated from the chemical composition as shown in the following (Table 4):

The above table contains several points that deserve special notice: (1) the normative orthoclase is abundant, while the normative albite and anorthite are comparatively little; the former being especially very scarce; i.e., 4.7% only; (2) in spite of the absence of modal nephelite, the normative nephelite is present in the calculation, and is even as much as 13.9% in one specimen; and (3) the normative diopside and olivine are abundant, the two combined occupying more than 40%.

The abundance of normative orthoclase is due to the presence of modal orthoclase in the groundmass. The potash is derived not only from orthoclase but also from leucite, biotite, etc., and therefore the modal orthoclase is consequently less than the normative. The fact that the normative albite and anorthite are comparatively little points to the small quantity of plagioclase in the groundmass, and, in mode, plagioclase is generally less than orthoclase. The molecular ratio of albite and anorthite in the normative plagioclase is Ab 36, An 64 and Ab 24, An 76, that is, labradorite and bytownite. In the normative calculation, there occurs nephelite which is absent in the modal. In the groundmass, however, there exists analcite which has two more silica molecules than nephelite. If analcite were put in lpace of nephelite, the chemical composition of the rock would lack silica. If the quantity of deficient silca were to be drawn out of the normative orthoclase, the normative leucite eventually would occur in the calculation. Because both analcite and leucite are present together in the modal minerals, a part of potash, alumina and silica in the normative orthoclase seems to have been derived from the modal leucite.

Table 4
Norm

			T_1		T_2
or			20.57		23.91
ab			4.72		4.72
an			8.34		15.29
ne			13.92		4.83
di	Wo	22.60	11.95	15.56	8.24
	En		9.20		6.40
	Fs		1.45		0.92
ol	Fo	24.28	20.51	26.85	23.38
	Fy		3.77		3.47
mt			4.41		5.34
il			0.61		0.76

In case we take the chemical analysis T_2, if all the normative nephelite were assumed to be analcite, its norm could be recalculated as follows: orthoclase 13.90%, anorthite 15.29%, leucite 7.85%, analcite 6.87%. In case of T_1, if the silica necessary for changing the normative nephelite into analcite were to be extracted from the normative orthoclase, then there would be leucite and kali-nephelite. Judging from the absence of kali-nephelite in the mode, the normative nephelite in T_1 is likely to be derived not only from analcite but also from such minerals as biotite, glass, etc., or a part of the normative orthoclase will be resulted from the potash-minerals. The abundance of normative diopside and olivine is in accord with the mode, and the normative chemical composition of olivine corresponds to the optical characters observed under the microscope.

From the fact that the rock of Tsaolingshan is low in silica in spite of the higher content in alkalies, it is not difficult to expect the presence of meta-alkali-alumina-silicates like leucite, analcite, etc. in the rock. Taking the presence of leucite and analcite into consideration, the norm described above may be recalculated as follows (Table 5):

V. Comparison with the Foreign Absarokites

J. P. Iddings (6) established, in 1895, a series which he named "Absarokite-Shoshonite-Banakite-Series" to a group of alkaline basalts that occur in the Yellowstone National Park of the United States. The most basic class in the series was called "Absarokite" after the name of the principal locality Absaroka Range. Its mode of occurrence is principally in the form of dike or lava flow.

The important characteristics of this most basic class, absarokite, are (1) the presence of abundant phenocrysts of olivine and augite, (2) the absence of phenocrysts of feldspar and (3) the groundmass ranges from a dark glass to an almost phanerocrystalline, light grey mass. It is often aphanitic and dark greenich grey in color. The phenocrysts are large and well defined in many cases, but are much smaller in others.

Table 5
Recalculated norm

	T_1	T_2
or	—	13.90
ab	4.72	4.72
an	8.34	15.29
lc	13.52	7.85
analcite*	19.79	6.87
(K_2O Al_2O_3)	1.18	—
di	22.60	15.56
ol	24.28	26.85
mt	4.41	5.31
it	0.61	0.76

*analcite
Na_2O Al_2O_3 $4SiO_2$

Under the microscope, the phenocrysts of olivine and augite show euhedral or subhedral form, and no phenocryst of feldspar is present. The groundmass consists principally of orthoclase, lime-soda-feldspars, olivine, augite, magnetite, apatite, brown biotite, leucite, analcite, glass, etc. The orthoclase crystals contain minute prismatic cores of lime-soda feldspars. When both orthoclase and leucite occur together in the groundmass, they are not uniformly mingled, but are clustered in groups. In some specimens brown biotite, leucite and analcite are absent. The kinds of component minerals of the groundmass and the microtexture are both variable from one specimen to the other.

Concerning the chemical composition of absarokite in Absaroka Range, Iddings stated: "Chemically absarokites are low in silica, from 46 to 52%; low in alumina, from 9 to 12%; high in magnesia, from 8 to 13%; moderatly high in alkalies, with potash higher than soda, except in one case. The molecular ratio of the alkalies to silica is 0.08 and 0.09. After the crystallization of abundant phenocrysts of olivine and augite the remainder of the magma, owing to low alumina and relatively high alkalies, was so constituted that alkali-feldspathic minerals might crystallize out, which they did or not according to the condition under which solidification took place".

From the above brief description, we know that absarokite may represent one type of trachybasalt.

The volcanic rock in Tsaolingshan bears a striking resemblance to absarokite either microscopically or chemically. That is, its phenocrysts are predominant in olivine, pigeonite, and occasionally biotite, and its groundmass is composed principally of pigeonite, orthoclase, plagioclase, potash-andesine (?), leucite, analcite, glass, magnetite, apatite, etc. Chemically it is low in silica (46.8 and 48.3%); low in alumina (12.6%); high in magnesia (15%); comparatively low in lime (7%); rich in alkalies; the molecular ratio of alkalies to silica is 0.088 and 0.118.

The comparison between the normative minerals of the rock of Tsaolingshan and those of the absarokites of the type locality as well as of other districts may be briefly summarized as follows (Tables 6–7 and Figures 3–5):

Table 6

Chemical analyses of absarokite etc.

	1	2	3	④	5	6	⑦	8	⑨	⑩	⑪	12
SiO_2	49.71	48.36	51.68	47.32	51.76	48.95	47.28	50.11	47.45	44.89	43.76	46.90
Al_2O_3	13.30	12.42	14.07	11.22	12.36	12.98	11.56	13.04	11.43	12.93	11.58	10.17
Fe_2O_3	4.41	5.25	4.71	2.91	4.88	3.63	3.52	4.58	3.22	3.31	4.39	1.22
FeO	3.37	2.48	4.57	5.81	4.60	4.68	5.71	3.94	5.78	4.35	7.57	5.17
MgO	7.96	9.36	7.72	15.96	9.57	11.73	13.17	9.27	14.60	13.71	12.97	20.98
CaO	8.03	8.65	6.65	7.11	7.14	7.66	9.20	7.63	8.18	12.95	9.64	6.20
Na_2O	1.49	1.46	2.45	1.88	1.99	2.31	2.73	1.94	2.32	1.02	3.03	1.16
K_2O	4.81	3.97	4.16	3.79	3.83	3.96	2.17	4.15	2.99	3.66	1.84	2.04
H_2O+	} 4.07	5.54	2.09	2.02	3.05	3.16	2.96	3.58	2.50	1.59	0.47	1.04
H_2O-										0.27		
TiO_2	1.57	1.18	1.08	0.75	0.47	0.49	0.88	0.96	0.81	0.95	3.41	0.41
P_2O_5	0.66	0.84	0.72	0.61	0.56	0.67	0.59	0.69	0.60	0.27	0.45	0.44
MnO	0.17	0.13	tr.	0.11	0.11	0.13	0.13	0.11	0.12			0.10
BaO	0.46	0.29		0.22						0.08		
Cr_2O_3										0.03		0.33
ZrO_2										tr.		
Ig. loss			0.13	0.18			0.18					4.38
Total	100.01	99.93	100.03	99.89	100.32	100.35	100.08			99.77	99.78	100.54

○Leucite-absarokite

	13	14	15	16	17	18	19	20
SiO_2	49.13	50.82	51.65	50.03	49.06	49.20	46.47	45.34
Al_2O_3	9.05	11.44	13.89	14.08	15.70	16.65	15.97	16.59
Fe_2O_3	3.57	0.25	2.70	2.92	5.38	4.76	5.97	5.83
FeO	5.05	8.94	4.80	6.11	6.37	5.36	4.27	4.76
MgO	17.21	14.01	11.56	10.73	6.17	4.43	5.87	5.43
CaO	5.68	8.14	4.07	7.46	8.95	7.74	10.54	11.64
Na_2O	2.01	1.79	2.99	1.46	3.11	4.54	1.69	2.93
K_2O	2.24	3.45	4.15	2.64	1.52	3.19	4.83	4.55
H_2O+	0.84		1.30		} 1.62	1.30	} 2.32	1.12
H_2O-								
TiO_2	0.42	0.59	0.55	0.61	1.36	1.68	1.33	1.30
P_2O_5	0.38	0.20	0.21	0.42	0.45	0.60	0.73	0.50
MnO	0.15	0.19	0.15	0.08	0.31	0.55	0.01	0.01
BaO	0.05	0.06	0.19	0.04				
Cr_2O_3	0.39	0.03	0.80	tr.				
ZrO_2								
Ig. loss.	3.50	0.58	1.89	3.70				
SO_3			0.19					
Total	99.87	100.49	101.09	100.29	100.00	100.00	100.00	100.00

Norms of absarokite etc.

		1	2	3	④	5	6	⑦	8	⑨	⑩	⑪	12
or		28.36	23.35	25.02	22.24	22.24	23.35	12.79	25.02	17.79	1.11	10.56	11.68
ab		12.58	12.58	20.96	9.43	16.77	9.43	16.24	16.24	12.58	—	9.43	9.96
an		15.29	15.57	14.73	11.12	13.90	13.34	13.07	14.18	11.95	19.74	12.79	16.69
ne		—	—	—	3.41	—	5.40	3.69	—	3.69	4.54	8.80	—
lc		—	—	—	—	—	—	—	—	—	16.13	—	—
di		19.69	17.50	10.74	16.27	14.26	16.06	22.88	14.82	19.79	33.20	24.97	8.79
hy		6.43	11.90	13.32	—	20.74	—	—	10.59	—	—	—	14.35
ol		3.22	2.38	2.65	28.07	—	19.63	20.13	5.31	24.10	15.84	17.99	29.42
mt		6.50	4.41	6.73	4.18	7.19	5.34	5.10	6.73	4.64	4.87	6.50	2.32
il		3.04	2.28	2.13	1.37	0.91	0.91	1.67	1.82	1.52	1.82	6.54	0.76
ap		1.68	2.02	1.68	1.34	1.34	1.68	1.34	1.68	1.34	0.67	1.34	1.01
			hem. 2.28										
F	or	50.4	45.3	41.2	52.0	42.0	50.6	30.3	45.1	42.1	5.4	32.2	30.5
	ab	22.3	24.4	34.5	22.0	31.7	20.4	38.5	29.3	29.8	—	29.0	26.0
	an	27.3	30.3	24.3	26.0	26.3	29.0	31.2	25.6	28.1	94.6	38.8	43.5
Pl	ab	45	45	59	48	47	41	55	53	51	0	43	37
	an	55	55	41	52	53	59	45	47	49	100	57	63
di	Wo	53.6	53.7	52.9	52.7	52.8	52.7	52.7	53.2	52.8	53.3	52.9	52.9
	En	45.9	46.3	40.9	39.9	40.6	39.8	39.7	43.2	39.9	42.3	41.3	41.2
	Fs	0.5	0.0	6.2	7.4	6.6	7.5	7.6	3.6	7.3	4.4	5.8	5.9
hy	En	97.9	100.0	87.0	—	87.2	—	—	92.5	—	—	—	87.1
	Fs	2.1	0.0	13.0	—	12.8	—	—	7.5	—	—	—	12.9
ol	Fo	100.0	100.0	84.5	83.2	—	81.3	82.7	92.3	83.1	88.4	86.3	86.1
	Fy	0.0	0.0	15.5	16.8	—	18.7	17.3	7.7	16.9	11.6	13.7	13.9

	13	14	15	16	17	18	19	20
or	12.79	20.02	25.02	15.57	8.90	18.90	28.36	22.80
ab	16.77	12.58	24.10	12.58	26.20	24.10	5.24	—
an	9.45	13.07	11.95	23.91	24.46	15.57	21.96	17.79
ne	—	1.42	0.57	—	—	7.67	4.83	13.35
lc	—	—	—	—	—	—	—	3.49
di	12.47	22.15	9.02	8.21	13.87	15.38	20.22	27.45

hy		20.58	—	—	27.70	11.70	—	—	—
ol		15.42	28.97	21.25	2.15	1.87	5.69	4.26	—
mt		6.03	0.46	5.34	4.18	7.89	6.73	8.82	8.35
il		0.73	0.91	1.06	1.22	2.58	3.19	2.43	2.43
ap		1.01	—	—	1.01	1.01	1.34	1.68	1.34
									Wo 0.69
F	or	32.7	43.8	41.0	29.8	14.9	32.3	51.0	56.2
	ab	43.0	27.5	39.6	24.0	44.0	41.1	9.5	—
	an	24.3	29.7	19.4	46.2	41.1	26.6	39.5	43.8
Pl	ab	64	48	67	34	52	61	19	0
	an	36	52	33	66	48	39	81	100
di	Wo	53.0	51.8	52.9	52.2	51.8	52.0	53.3	53.0
	En	41.7	33.9	39.9	36.5	33.9	35.1	44.1	40.5
	Fs	5.3	14.3	7.3	11.3	14.3	12.9	2.6	6.5
hy	En	88.4	—	—	70.7	75.0	—	—	—
	Fs	11.6	—	—	29.3	25.0	—	—	—
ol	Fo	88.1	66.2	83.7	71.6	67.4	71.4	95.3	—
	Fy	11.9	33.8	16.3	28.4	32.6	28.6	4.7	—

1 Absarokite, Cache Creek, Yellowstone National Park — Iddings
2 Absarokite, Clark's Fork River, Y. N. P. — ditto
3 Absarokite, Two Ocean Pass, Y. N. P. — ditto
4 Leucite-absarokite, Sunlight Valley, Y. N. P. — ditto
5 Absarokite, Raven Creek, Y. N. P. — ditto
6 Absarokite, Lamar River, Y. N. P. — ditto
7 Leucite-absarokite, Ishawooa Canyon, Y. N. P. — ditto
8 Absarokite, (OSANN) — Daly
9 Leucite absarokite, (OSANN) — Daly
10 Leucite absarokite, Fiordine b. Montefiscone Bolsener Gebiete, Italien. — Rosenbusch
11 Leucite absarokite, Lava des Matavuna-Vulkans von 1906, Savaii, Samoa. — Rosenbusch
12 Absarokite, Fort Ellis, 2 1/2 miles S. E. of Bozeman, Montana. — Weed and Pirsson
13 Absarokite, Beer Creek, Madison Valley, Montana — ditto
14 Absarokite, South Boulder & Antelope Creek, Montana. — ditto
15 Absarokite, Cottonwood Creek, Montana. — ditto
16 Intermediate rock between absarokite and basalt, Cottonwood Creek, Montana. — ditto
17 All basalt (including 161 basalt, 17 olivine diabase 11 melaphyre and 9 dolerite) OSANN — Daly
18 Trachydolerite (ROSENBUSCH) — ditto
19 Leucite basalt (OSANN, ROSENBUSCH) — ditto
20 Leucite basanite (OSANN, WASHINGTON) — ditto

Table 7

Tsaolingshan	Absaroka Range and Other Districts
The normative orthoclase more than the sum of the normative albite and anorthite.	The normative orthoclase equals to or less than the sum of the normative albite and anorthoclase.
Normative plagioclase: Ab36 An64 or Ab24 An76 (basic labradorite or acidic bytownite).	Normative plagioclase from Ab45 An55 to Ab55 An45 (acidic labradorite).
Normative nephelite occurs (sometimes up to 14%)	Normative nephelite, absent or present; always occurring in the leucite absarokite. (3.5~4.0%)
No normative hypersthene	Normative hypersthene, absent or present; always absent in the leucite absarokite.
Normative diopside Wo53 En41 Fs6	Normative diopside generally Wo53 En40—46 Fs7—1.
Normative olivine Fo 88-85 Fy 13-15	Normative olivine generally Fo 100—83 Fs 0-17.

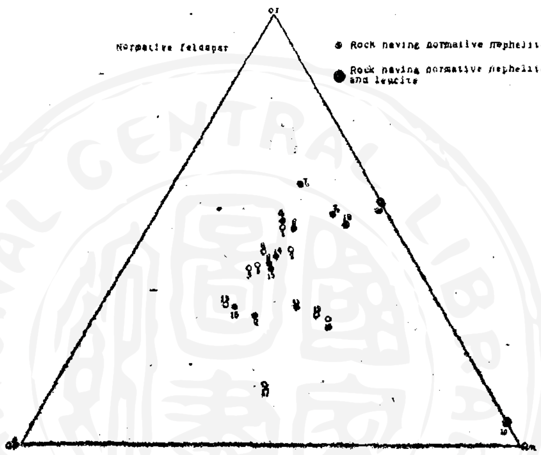


Fig. 3. Normative feldspar

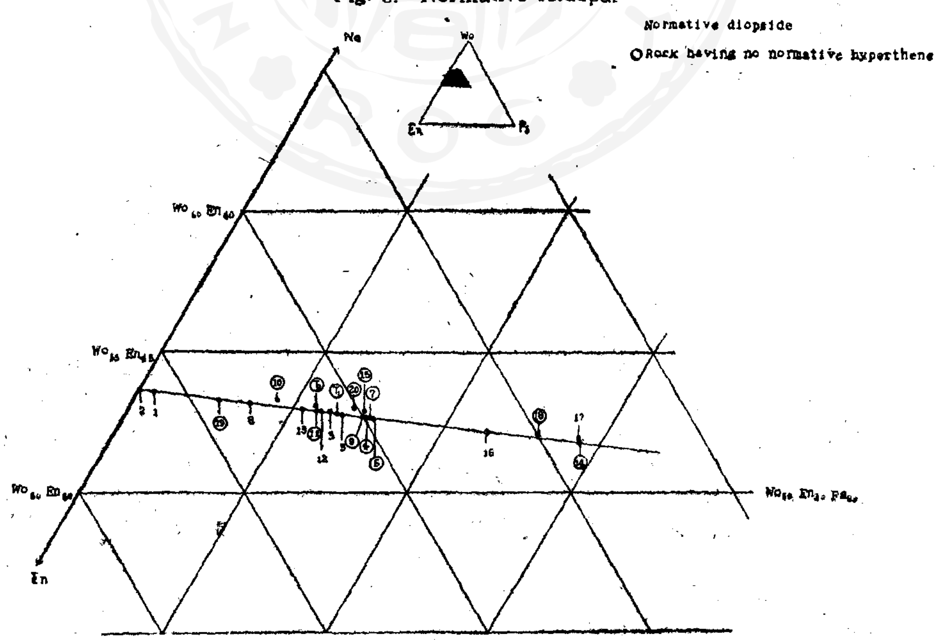


Fig. 4. Normative diopside

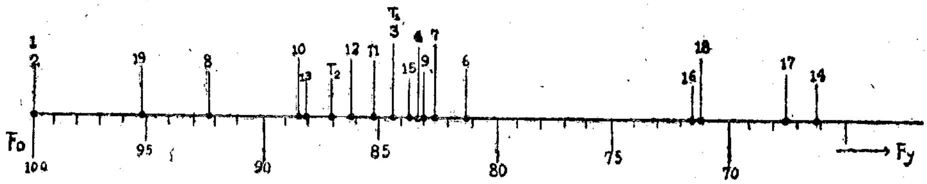


Fig. 5. Normative olivine

From the various points described above, it is obvious that the rock of Tsaolingshan belongs chiefly to the absarokite group and the main rock types are as follows:

The first type: absarokite; biotite-bearing absarokite.

The second type: biotite-bearing leucite analcite absarokite; biotite-bearing analcite absarokite.

The third type: biotite-bearing analcite leucite basalt (or absarokite).

In the provinces of alkaline rocks in Eastern Asia, several localities producing the leucite-bearing volcanic rocks have been reported up to present.

1. Vulsinitic vicoite lava of Alpong[1] in Yuling[2] Island, Korea (8).
2. Leucite (?) basalt of Sansiangtung[3], Chunanmen[4] and Wusiangtsun[5], Lungyentung[6], North Hsienching[7] Province, Korea.
3. Leucite shihlunite and anorthoclase leucite shihlunite etc. of the volcanoes of Wutalienchih[8] district, Lungchiang[9] Province, China (9) (12).
4. Leucite basanite of Ehrkoshan[10] volcano, Lungchiang Province, China (10).
5. Leucite-olivine-basalt of Chihsingshan[11] volcano, Liaoning[12] and South Hsingan[13] Province, China (11).

VI. Accidental Xenoliths in the Volcanic Rocks of Tsaolingshan

It was described by Ichimura (2) that the alkaline basalt of Tsaolingshan occasionally includes accidental xenoliths which are white in color or white color with black spots in places. They range in diameter from 5 to 30 centimeters. The accidental xenoliths consist principally of coarse sandstone rich in quartz and feldspars. Sometimes the residual magma is found injected into the interspaces between these mineral grains and consolidated. Several examples are described below.

(1) The xenolith consists of quartz and feldspar (principally orthoclase), in which a light yellow glass (representing the residual magma) fills up the interspaces or cracks of minerals. The index of refraction of the glass is about 1.54 (nearly the same as balsam). In the glass, needlelike or spherulitic microlites, aggregates of fine augite grains, analcite, etc. are recognized. The boundaries between glass

1 卵峯	2 鬱陵	3 三鄉洞	4 朱南面	5 五鄉村
6 龍岩洞	7 咸鏡	8 五大連池	9 龍江	10 二克山
11 七星山	12 遼寧	13 興安		

and quartz or orthoclase of the sandstone are generally distinct, but the latter two minerals are often turbid and cracked.

(2) In a similar xenolith, the glass, distributed in the interspaces and cracks of quartz and orthoclase, is dark brown in color, having the index of refration much lower than balsam, and sometimes showing a pearly structure. Except the microlites of olivine and augite, there are abundant crystallites of other kinds, having some such forms as trichite, skeleton crystal, globulite, scopulite, etc. in the glass.

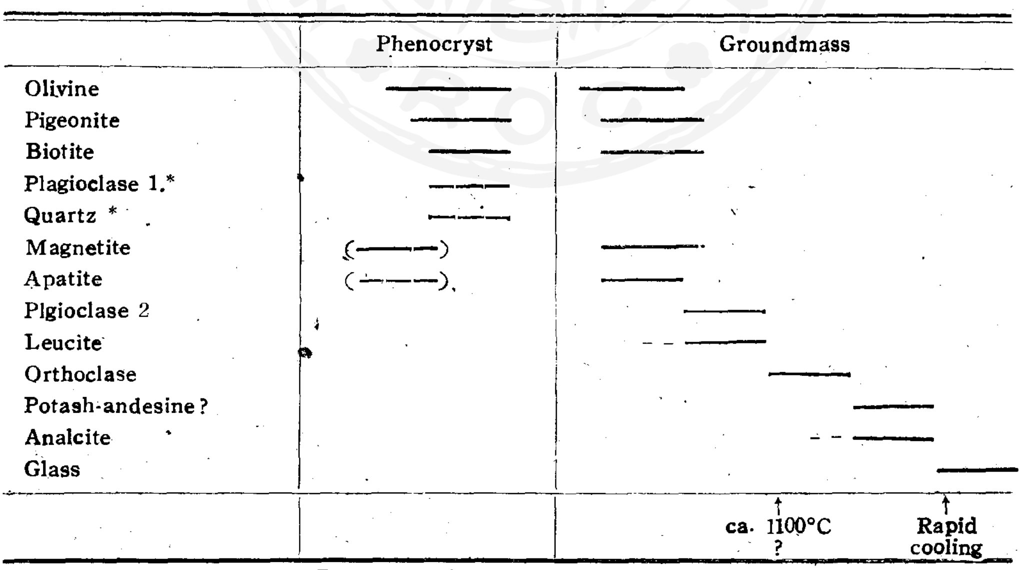
(3) A specimen shows that the lava magma, after having captured sandstone xenoliths, consolidates under the condition of mutual reaction. In consequence, the rock appears just like absarokite including abundant quartz phenocrysts (quartz grains of sandstone). Around the quartz crystals, dark brown glass develops, which has abundant microlites of augite and olivine, and crystallites; sometimes fine augite grains cluster on their surface. The lava magma consolidates as normal absarokite with phenocrysts of olivine and pigeonite, and groundmass consisting of olivine, pigeonite, orthoclase, labradorite, potash-andesine (?), glass, magnetite, etc. It has neither biotite nor leucite.

VII. Petrogenetic Consideration

Based on the microscopic observations, the sequence of crystallization of minerals in the alkaline basalt of Tsaolingshan may be assumed to be as follows (Table 8).

Table 8

Sequence of crystallization of the principal components of the rock of Tsaolingshan.



Plagioclase 1: Phenocryst, Bytownite-labradorite
Plagioclase 2: Groundmass, Labradorite
* very rare

The phenocrysts of olivine, pigeonite and biotite (very rarely plagioclase and quartz also) crystallize out first, and small magnetites crystallize at the same stage or somewhat earlier. In the course of consolidation of groundmass, olivine, pigeonite (abundantly), biotite, magnetite and apatite crystallize out in earlier stages; pigeonite, plagioclase and leucite follow them. With the lowering of temperature, orthoclase comes out. After this, potash-andesine and perhaps analcite also crystallize. Glass solidifies last. That is, the crystallization of the groundmass begins with the mafic minerals, and felsic minerals succeed them.

In the recalculated norm, the values of Ne : Kp : Si computed from the normative albite, orthoclase and leucite are as follows:—

T_1: Ne 43.3, Kp 26.7, Si 30.0

T_2: Ne 22.1, Kp 40.7, Si 37.2

If these values are plotted on the equilibrium diagram of nepheline-kalinepheline-silica-system (13), they fall within the field of leucite, denoting that the crystallization of leucite takes place earlier than that of orthoclase and analcite (Fig. 6).

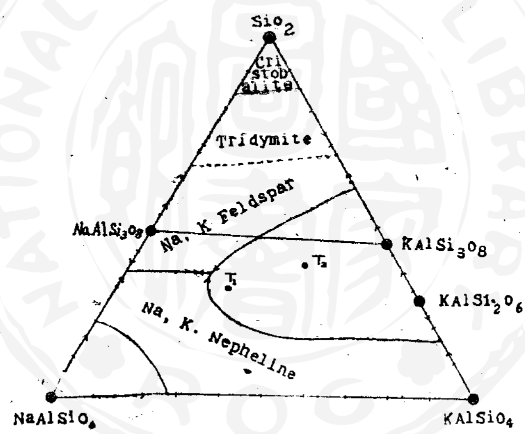


Fig. 6. Equilibrium diagram of the system, $NaAlSiO_4-KAlSiO_4-SiO_2$

The values of Le: Di: Si calculated from the normative orthoclase, leucite and diopside are as:

T_1: Lc 39.5, Py 60.5, Si 0.0; Lc 40.4, Di 59.6, Si [illegible]

T_2: Lc 50.2, Py 41.7, Si 8.1; Lc 51.5, Di 37.4, Si 10.6

They may be plotted on the leucite field or on the boundary between the fields of leucite and diopside on the equilibrium diagram of "leucite-diopside-silica system" (14). This shows that the crystallization of leucite is in the same stage as or slightly earlier than that of diopside. On the other hand, it may be observed under the microscope in several specimens that the crystallization of the latter took place earlier than the former (Fig. 7).

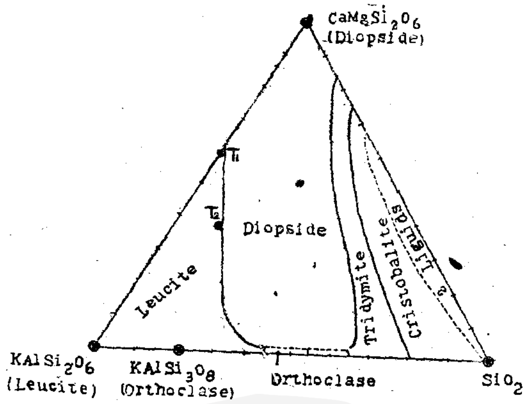


Fig. 7. Equilibrium diagram of the system, diopside–leucite–silica

The fact that no plagioclase phenocryst occurs in the alkaline basalt of Tsaoling-shan signifies that the magma is poor in lime and a greater part of lime is consumed for the formation of pyroxene, or that it is under conditions which arrest or interupt the crystallization of plagioclase. The abundance of olivine is principally due to the richness of magnesia in the magma. Magnesia, lime and ferrous oxide in the residual solution are mainly consumed for the crystallization of olivine, pigeonite, magnetite, etc. in the earlier stage; a part of alkalies constitutes biotite. In consequence, the residual solution becomes gradually richer in alkalies and poorer in silica, while alumina hardly either increases or decreases. Under these conditions, the meta-potash-alumina-silicate, leucite, crystallizes out and, with the lowering of temperature, orthoclase appears as the result of the reaction between the crystallized leucite and the residual solution. Later than or after this, from the residual solution that contains remaining potash, lime, alumina and abundant soda, potash-andesine and analcite crystallize out finally. Owing to the rapid lowering of temperature, all the remaining solution solidifies into glass.

It is possible that the temperature of the magma is very high, perhaps one thousand and several hundred degrees, before the crystallization of the groundmass. When the mafic minerals of groundmass start to crystallize, its temperature is nearly the same as the above, and the temperature, at which the formation of leucite takes place, is estimated to be higher than one thousand degrees perhaps above 1100°C. Here we may recall the experimetal data of the silicate solution of "leucite-silica system". In this system, from the solution which is very low in silica and high in $KAlSi_2O_6$, orthoclase can be produced at about 1100°C by the reaction between the already crystallized leucite and the residual solution, and the temperature is unchanged until the reaction is perfectly completed (Fig. 8).

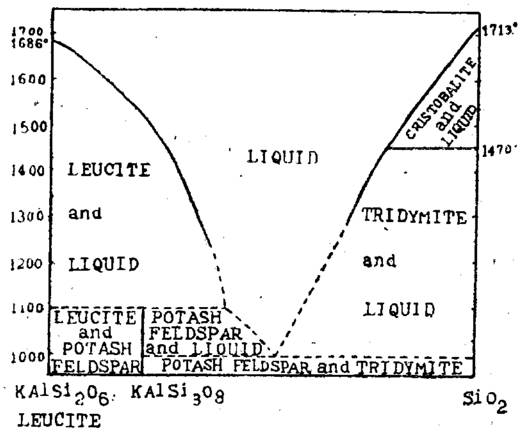


Fig. 8. Preliminary diagram of the binary system, leucite–silica.

Judging from the paragenesis of minerals in the groundmass, the volcanic rock of Tsaolingshan was consolidated under a rapid cooling condition at the temperature of about 1100°C (possibly slightly higher or lower than this). In nature the relation between the crystallization of rock minerals and the tempreature of the magma is so complex and so powerfully controlled by various factors that the experimental data of silicate solution can not be directly applied to its explanation, but they may allow us to infer the possible and probable temperature of crystallization.

At the lava lake of Kilauea, the temperature of the normal basalt flow is 1185°C; in the Vesuvius eruption of 1906, the temperature of leucite-tephrite lava ranges from 1015°C to 1040°C. In Tsaolingshan the rapid change of temperature in the lava was perhaps caused by the effusion of the residual magma. Some specimens show a fluidal structure in the groundmass.

The relation between biotite and leucite. From the various points of geological and petrological observations, it is deduced that the condition under which the volatile components included in the magma can more or less freely escape, is necessary for the crystallization of leucite from the magma. Therefore, if there were no such conditon, a part of the chemical components which are required to the formation of leucite would be consumed to crystallize biotite.

The alkaline basalt of Tsaolingshan contains abundant biotite both as phenocrysts and in the groundmass. The phenocrysts of biotite are mostly altered to aggregates of magnetite due to the reaction between the biotite and the residual solution of the groundmass. The biotite in the groundmass is unaltered and occasionally occurs with magnetite. It is generally crystallized out earlier than leucite. From these points it seems that, in earlier stages, the solution of the groundmass was under the condition that the volatile components in it could not escape freely, and in later stages, as the volatile components could freely escape, the crystallization of leucite gradually began. Judging from the fact that the quantity of biotite does not markedly differ in the porous and the compact types, the volatile components seem to have been able to freely escape from underground, i. e., before the effusion of the magma. After the effusion, the volatile components escaped vigorously and caused the formation of the porous type. That the alkaline basalt of Tsaolingshan is poor in plagioclase is perhaps due principally to the deficiency of lime, alumina and silica in the magma, and to the consumption of the larger part of lime for the formation of pigeonite.

There is no quartz present in the rock except one single crystal found in one specimen. In the igneous rock the co-existence of leucite and quartz is generally not known, but it is not an absolute rule.

As to the origin of analcite in analcite bearing basalts, both the primary and the secondary natures of origin are believed by most petrologists at persent. The possibility of the occurrence of primary analcite from a siliceous nephelite-rich liquid is suggested by Bowen's experiments. From the microscopic observation and chemical composition of the rock, the analcite in the alkaline basalt of Tsaolingshan is believed to be of primary origin.

In Tsaolingshan, each type of the rock takes the same course of solidification until the completion of the crystallization of mafic minerals of the groundmass; and simultaneously, with the formation of felsic minerals, each type starts to take the respective routine of evolution.

From the distribution of rock types, it may be deduced that, in the underground where the volatile components could escape freely, the residual magma was divided into three parts from the upper down to the lower due to the slight difference of temperature after the completion of crystallization of phenocrysts and mafic minerals in the groundmass. The upper part where the reaction between the already crystallized leucite and the residual solution has finished is composed principally of orthoclase; the middle part which was formed in the midst of reaction consists mainly of orthoclase and leucite; and the lower part is composed of leucite and the solution without orthoclase (as to the temperatures, the upper part<the middle part<the lower part). The upper and middle parts of the residual magma flowed out first; then the lower part effused out and poured mainly upon the former two.

As to the question how the alkaline basalt magma of Tsaoling volcanic body is derived from the parent magma which is perhaps basaltic in nature, the writer regrets that the data at hand are too deficient and scanty to say anything theoretical about the mechanism of derivation. He intends to take this question into consideration as the principal object of the future study. Considering the abundant occurrence of accidental xenoliths in the volcanic body, however, it may be said that selective reaction (a kind of assimilation) between the parent magma and the minerals of accidental xenoliths (perhaps mainly arkose sandstone) is at least one of the principal causes that gave birth to the alkaline basalt magma.

(April, 1948.)

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ANALCITE DOLERITE AND ANALCITE BASANITE IN TAIWAN

by

T. P. YEN

(With 4 Figures)

I. Introduction

The presence of alkaline rocks in Taiwan was First pointed out by B. Kotō [1] and Y. Deguchi [2] about fifty years ago. The former described in detail the petrography of the analcite basalt found in Penghu[1] Island in 1900. Since then, alkaline rocks have been found here and there in northern Taiwan as a result of advancing geological works. They have been described chiefly by Ichimura and others.

The greater part of the alkaline rocks hitherto made known belongs to the category of alkaline basalts, i.e. to analcite basalts represented by analcite dolerite (or teschenite) and analcite basanite. It is the most noticeable feature that the alkaline rocks of Taiwan usually have analcite as a constituent.

To clarify the relation between the alkaline basalts of Taiwan and the distribution of the alkaline effusive rocks in general, especially of the Cenozoic alkaline effusives of Eastern Asiatic and Intra-Pacific region, is an important problem in the field of igneous geology in Taiwan.

As one phase leading to the solution of the problem regarding the alkaline basalts in Taiwan, the writer intends to take the mode of distribution and the genesis of these rocks into consideration. Basaltic rocks are distributed quite widely in the northern part of Taiwan. They have been studied and compared with others geologically and petrographically by many geologists, but their chemical properties have usually been neglected up to present. Thus, we suffer from a shortage of data both for the comparative study and establishing the relation between the

1. 澎湖

chemical properties of the common basalt and the alkaline basalts.

This paper is written on the basis of several data at hand; but when new data are obtained in future, the present discussion has to be supplemented with them. For the sake of convenience, the alkaline basalts occurring in Taiwan are divided into two groups, namely, analcite dolerite (teschenite) and analcite basanite (basalt).

II. Analcite Dolerite or Teschenite

A. Geographical distribution

As far as is afforded by our present information, the exact representatives of analcite dolerite are known to be, distributed in Chisingchü[1] and Wenshanchü[2] of

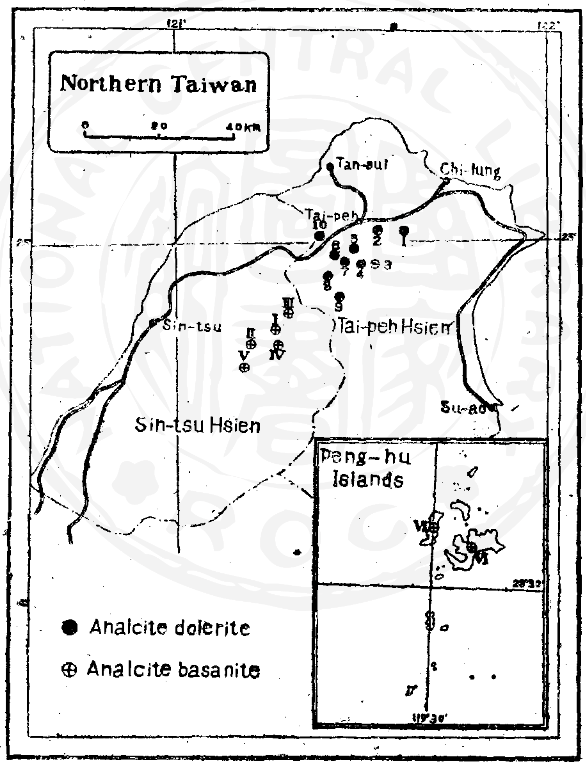


Fig. 1

1.	Luchü	6.	Neikanlinpi
2.	Shihsuitzu and Liuchangli	7.	Tsingsuikĕng
3.	Tsingtan	8.	Taliaoti
4.	Tutan	9.	Hsiungkungshan
5.	Honglululiao	10.	Poneikĕng
I.	Mawutu	IV.	Liuch'ushan
II.	Mafu	V.	Tashanpeishan
III.	Chĕntoushan	VI.	Pĕnghu

1. 七星區 2. 文山區

Taipehhsien.[1] The principal loclities are listed below:

1. Luchü[2] district (Kangkokung[3], Sitsuchēn[4], Chisingchü and Luchu, Shihtingsiang)[5]
2. Shihsuitzu[6] and Liuchangli[7] district (Shihsuitzu, Neihusiang,[8] Chisingchü and Liuchangli near Taipeh[9] city).
3. Tsingtan[10] district (Tsingtan, Sintienchen, Wenshanchü).
4. Tutan[11] district (Tutan, Sintienchen, Wenshanchü).
5. Honglululiao[12] district (Honglululiao, Chunghosiang[13], Haishanchü[14]).
6. Neikanlinpi[15] district (Neikanlinpi, Tuchengsiang[16], Haishanchü).
7. Tsingsuikeng[17] district (Tsingsuikeng, Tuchengsiang, Haishanchü).
8. Taliaoti[18] district (Taliao, Sanhsiachen, Haishanchü).
9. Hsiungkungshan[19] district (Shwangchi[20], Sanhsiachēn[21], Haishanchü).
10. Poneikeng[22] district (Poneikeng, Yingkochen[23], Haishanchü).
11. Penghu Islands (Penghuhsien).

B. Geological distribution

The geology of north-western Taiwan including regions where teschenites are found will be first briefly described here (according to Y. Ichikawa's classification, 1930 [3] [4] [5]).

Sintiku Series

Sankyō Group	Niki Beds (Utokutsu Beds of Yen)	
	Taiho Beds	
	Upper Coal-bearing Beds	

Taihoku Series

Kiirung Group	Nankō sandstone Beds	Upper Marine Fossil-bearing Beds of Taihoku Imp. Univ.
	Sōgō Beds	
	Middle Coal-bearing Beds	
	Tairyō Beds	Lower Marine Fossil-bearing Beds of Taihoku Imp. Univ.
	Kokan Tuff Beds	

Sinten Group—Lower Coal-bearing Beds

Regarding the geological age of these strara, there are generally two opinions. One of them considers the Sankyo group of Sintiku seies to be Pliocene, and the Kiirung and Sinten groups of Taihoku series, Miocene. The other ascribes all the formations described above to the Miocene. In this paper, the latter view is accepted and followed.

1. Luchü district

In the Luchü district where teschenite was first discovered in the Taiwan

---

1. 臺北縣 2. 鹿窟 3. 康諧坑 4. 汐止鎮 5. 石碇鄉
6. 濕水子 7. 六張犁 8. 內湖鄉 9. 臺北 10. 青潭
11. 塗潭 12. 橫路鹿寮 13. 中和鄉 14. 海山區 15. 內柑林埤
16. 土城鄉 17. 清水坑 18. 大寮地 19. 熊空山 20. 双溪
21. 三峽鎮 22. 坡內坑 23. 鶯歌鎮

proper and described in detail by Ichimura [6], the occurrence of the rock is recorded in the following way: "it (teschenite) is a laccolith or sill injected between alternating beds of shale and sandstone (Lower Coal-bearing Beds) which probably belong to the Miocene. The exposure is traceable about 1400 meters along its length and for 150 meters in the broadest part. The boulders derived from this igneous body are widely scattered on both sides, and the boundary of the sediments and intrusive mass is thus sometimes obscure. The northern and eastern sides form abrupt contacts with gently inclined sandstone and shale beds, being cut by two faults, while it is covered by a light grey sandstone southward. The upper sandstone is partly interstratified with thin beds of grey shale, and mostly shows a steep inclination southward, gradually passing into the thick shale zone. No further exposure of the same kind of rock is seen in this neighbourhood,…………".

2. Shihsuitzu and Liuchangli district [7]

The teschenite of this district occurs with olivine basalt and olivine dolerite, forming various boulders in the basaltic agglomerate of the so-called "Kôkan Tuff Beds".

3. Tsingtan district [8]

4. Tutan district [9]

In these two districts, the teschenite intrudes into alternating beds of grey sandstone and black shale of the Lower Coal-bearing Beds in the form of dikes and sills. The thickness of dikes and sills varies from several meters up to twenty meters. The granularity of the rock varies more or less with different localities. The most distinct character of the teschenite occurring in these districts is that it is penetrated by veinlet-like dikes and contains boulders of an alkali-syenite, and an aplitic leucocratic rock as well as a rock intermediate in type between teschenite and alkali-syenite. The teschenite is so intimately associated with these rocks that it is quite evident that they were derived from the same magma by differentiation (crystallization-differentiation). The details of the relations between the teschenite and the alkali-syenite, etc. will be dealt with in another paper.

5. Hĕnglululiao district [9]

In this district, the lenticular beds of tuff and agglomerate together with lava flows are found intercalated in alternating beds of sandstone and shale belonging to the Lower Coal-bearing Beds. Their principal composition is an olivine basalt, and the flows in part gradually pass into teschenite.

6. Neikanlinpi district. [9]

Here several dikes and sills of olivine basalt intrude into the Utokutsu beds (Niki beds of Ichikawa) consisting mainly of soft massive sandstone. A part of the olivine basalt passes into teschenite which is the youngest intrusion of the kind in Taiwan. This is a fact quite worthy of notice up to now.

Concerning the basaltic rocks distributed in the Penghu Islands, the presence of teschenite was once reported by Y. Deguchi. [2] Unfortunately, the writer has not get any chance to observe the rock specimens, so that nothing can be said about it in this paper. But if it really occurred there at all, it would probably be the youngest one in the whole province.

7. Tsingsuikeng district [11]

The teschenite occuring in this district is about 1.5 km. south of Lengsuikeng, Tuchengsiang. Except that it is known to exist in the alternating beds of sandstone and shale of the Lower Coal-bearing Beds, the detailed modes of occurrence of the rock are not clear due to unfavourable exposures. Probably it is in the form of dikes. Besides teschenite, there are also basaltic calcareous-tuff, agglomerate, and lava flows in its vicinity.

8. Taliaoti district [9]

There is an olvine basalt sill, striking NE and dipping towards NW in alternating beds of sandstone and shale of the Lower Coal bearing Beds. This sill gradually passes into teschenite in its notheastern extension. In this district, several sills, agglomerate and tuff beds are also intercalated in these beds, which, in part, may contain teschenite.

9. Hsiungkungshan district [9]

Several basaltic dikes intrude into the Middle Coal-bearing Beds and the Sôgô beds that form the southern slope of Hsiungkungshan, and two of them consist entirely of teschenite. Both have a thickness of nearly 5 m. The diabase and the teschenite which have been reported to occur at Chiachiuling[1] perhaps show the same mode of occurrence, and their boulders are abundantly found in the rivers running through this district.

10. Poneikeng district [10]

The teschenite dikes here are exposed on the ridge near Poneikeng and the banks of the upper stream of Tatsingkĕngchi[2]. They all intrude into alternating beds of sandstone and shale of the Lower Coal-bearing Beds. The rocks show dark grey color and are generally coarse-grained, but become fine and compact near the margins of the dikes.

The relations between the teschenites in the districts mentioned above and their country rocks are summarized in the following table.

1. 加九嶺 2. 大青坑溪

Table 1.

	Beds / Localities	Quaternary (Pleistocene) (?)	Miocene								
			Sankyo group			Kiilung group					Sinten gr.
			Niki Beds	Taiho Beds	Upper Coal-bearing Beds	Nanko Sandstone Beds	Sogo Beds	Middle Coal-bearing Beds	Tairyō Beds	Kokan Tuff Beds	Lower Coal-bearing Beds
1	Luchü										laccolith and sill
2	Shihsuitzu Liuchangli									boulders of agglomerate	
3	Tsingtan										dike and sill
4	Tutan										dike or sill
5	Hēnglululiao										a part of lava flow
6	Neikanlinpi		dike or sill								
7	Tsingsuikēng										sill?
8	Taliaoti										sill
9	Hsiungkungshan						← dike	→			
10	Poneikēng										dike
11	Pēnghu Islands	neck(?)									

From the above table, it is recognized that the teschenites in Taiwan do not represent a single stage, but they occur in several stages of which the following three are easily recognized:

(1) the stage when the Lower Coal-bearing Beds were depositing,

(2) the stage when the Kokan Tuff Beds were depositing, and

(3) one stage (perhaps more) after the deposition of the Middle Coal-bearing Beds. It is rather difficult at present to determine exactly when and how many times the injection took place.

The teschenite in Pénghu Islands is the youngest one in whole Taiwan. It represents the Pleistocene volcanic action in the province.

The teschenites in Taiwan occur in the forms of sills, dikes, lava flows as well as constituent boulders in agglomerates. They are found either as independent bodies or as different facies of olivine basalt. The fact that a part of the teschenite gradually passes into olivine basalt is especially important to the discussion of the genesis of teschenites in Taiwan.

C. Petrography.

The teschenites in Taiwan are more or less different in granularity and mineral constituents from place to place. In this paper, a general description is given. As to the details of each locality, respective published bibliographies are recommended to be referred to.

1. Megascopic observations.

The teschenites in Taiwan are generally compact and hard with a dark grey or greyish black color and a somewhat mottled appearance. There are several textural varieties changing gradually from coarse to fine. Some of them pass into common diabase or dolerite on the one hand, and some into common basalt on the other.

Most of the specimens are more or less weathered, usually exhibiting a light brownish grey color on the surface.

2. Microscopic observations.

Under the microscope, the teschenites show doleritic or diabasic texture, and are made principally of the following minerals:

(a) Feldspars including orthoclase (very rare), oligoclase (common), andesine (abundant), labradorite (common), potash-oligoclase (?), potash-andesine (?).
(b) Pyroxenes including common augite (rare), titaniferous augite (common), pigeonite (rare), titaniferous pigeonite (common), aegirine-augite (rare), aegirine (rare).
(c) Biotite (common).
(d) Barkevikite (rare).
(e) Olivine (common, mostly altered to secondary minerals).
(f) Analcite (common).
(g) Apatite (common).
(h) Iron ores including magnetite and ilmenite (common).
(i) Secondary minerals, mainly chlorite, calcite, natronite, sericite, zoicite, leucoxene, etc.

The granularity and the kinds and quantities of mineral constituents are more or less different from place to place even within the same locality. Because of these features the teschenites in Taiwan can be divided into several types. The teschenites that occur in Luchü, for instance, are divided into four types by Ichimura.

The characters of each principal constituent mineral are described as follows:

(a) Feldspars.

(i) Potash-feldspar (principally orthoclase). It occurs in small quantity in the specimens collected from 2. Shihsuitzu, Liuchangli and 5. Hěnglululiao. It shows lath-shape; twins on Carlsbad law; extinction straight; elongation negative; optically negative; indices of refraction n_1, n_2 smaller than 1.53.

(ii) Oligoclase. It is comparatively of common occurrence and is often found filling the interspaces of other minerals, or fringing other plagioclases. This mineral is known in the following localities.

1. Luchü: $n_2=1.543$ on (001), optically positive.
5. Hĕnglululiao.
7. Tsingsuikĕng: $n_1=1.542-$, $n_2=1.543+$ on (001).
8. Taliaoti: common.
9. Hsiungkungshan: (−) 2V≒80°.
10. Poneikĕng: $n_1=1.537+$, $n_2=1.545+$ on (001).

(iii) Andesine is the predominant plagioclase. Most of the specimens containing it commonly; shows lath-shape; twins on Carlsbad and albite laws.

1. Luchü: $n_1=1.546+$, $n_2=1.552+$ on (010).
4. Tutan: abundant
5. Hĕnglululiao: abundant
6. Neikanlinpi: abundant
7. Tsingsuikĕng: $n_1=1.551+$, $n_2=1.557+$ on (001).
8. Taliaoti: abundant
9. Hsiungkunshan: abundant, (+) 2V=75°
10. Poneikĕng: $n_1=1.519-$, $n_2=1.555$ on (010)

(iv) Labradorite is also dominant.

1. Luchü: $n_1=1.557-$, $n_2=1.562-$ on (010)
2. Shihsuitzu, Liuchangli: $n_1=1.5565$, $n_2=1.5615$ on (010)
4. Tutan: common
6. Neikanlinpi: common
9. Hsiungkunshan: common

(v) Albite. The plagioclase in the teschenite from 3. Tutan is represented almost completely by albite, and the specimens from 9. Siungkunshan contain it also.

(vi) Potash-oligoclase or andesine (?) It fills up the interspaces of other minerals, characterised by (+) 2V=50°, n≒1.54 or slightly lower than 1.54.

5. Hĕnglululiao
9. Hsiungkunshan

(b) Pyroxenes.

(i) Common augite is comparatively rare, colorless.

2. Shihsuitzu, Liuchangli: Z∧C=40°–45°
4. Tutan: Z∧C=38°, (+) 2V≒50°
5. Taliaoti: rare; Z∧C=40°–43°, (+) 2V=65°

The augite has hitherto been simply described as "common augite", but there is also the possibility that it includes pigeonite as well.

(ii) Titaniferous augite is a common mineral in the teschenite. The titaniferous augite mentioned by previous authors may perhaps include titaniferous pigeonite too. The specimens containing this mineral are found in the following:

1. Luchü: pleochroism- X=light purplish yellow, Y=light yellow or light yellowish brown, Z=light brownish violet; absorption- Z>X>Y; $Z\wedge C=40°$; (+) 2V=?; cleavage// (010); twins on (010); partly passes into aegirine or aegirine-augite.
2. Shihsuitzu, Liuchangli: pleochroism- X=light brown, Y=purplish light brown, Z=brownish light brown; $Z\wedge C=40°, 45°, 50°$; partly titaniferous pigeonite?
3. Tutan
5. Hĕnglululiao: $Z\wedge C=37°-38°$; (+) $2V \doteqdot 65°$
7. Tsingsuikeng: pleochroism- X=light purplish brown, Y=light yellowish brown, Z=light brownish violet; partly titaniferous pigeonite?
8. Taliaoti: light violet in color; $Z\wedge C=40°$; (+) $2V \doteqdot 60°$; common.
9. Hsiungkungshan: light violet in color; $Z\wedge C=43°$; (+) $2V \doteqdot 65°$.
10. Poneikĕng: pleochroism- X=light purplish brown, Y=light yellowish brown, Z=light brownish violet; absorption- Z>Y>X; $Z\wedge C=41°$.

(iii) Pigeonite is comparatively rare, colorless.

4. Tutan: $Z\wedge C=40°$; (+) $2V \doteqdot 0°$ or 30°
9. Hsiungkungshan: $Z\wedge C=40°$; (+) $2V \doteqdot 0°$ or 35°-40°

(iv) Titaniferous pigeonite is rather rare, violet or light violet in color.

5. Hĕnglululiao: $Z\wedge C=44°$; (+) $2V \doteqdot 30°-40°$
6. Neikanlinpi: $Z\wedge C=44°$ or 45°, (+) $2V \doteqdot 40°$
8. Taliaoti: $Z\wedge C=44°-45°$, (+) $2V \doteqdot 0°$ or 30°-40°, abundant

(v) Aegirine-augite most commonly occurs along the fringe of the (titaniferous) augite or the pigeonite, and sometimes as simple crystal. It is so easily weathered that it is often partly altered to certain secondary minerals. It is generally of rare occurrence.

1. Luchü: pleochroism- X=light green with bluish shade or light brownish green with bluish shade, Y=light green with brownish shade, Z=light greyish green or light brownish green; $Z\wedge C=65°$
2. Taliaoti: light green or green; $Z\wedge C=61°$; rare.
9. Hsiungkungshan: pleochroism- X=green, Y=green, Z=pale green or yellowish green; $Z\wedge C=62°$.

(vi) Aegirine is rare, either fringes aegirine-augite, or occurs as single crystal.

1. Luchü: pleochroism- X=bluish green, Y=light green, Z=yellowish brown or brownish yellow; absorption X>Y>Z; optically negative; $X\wedge C=3°$.
8. Taliaoti

(c) Biotite is found in all the specimens except that of Hsiungkungshan. Pleochroism- X=light yellow, Y=yellowish brown, Z=reddish brown or $Y \doteqdot Z$=reddish brown; (−) 2V=very small, nearly zero.

7. Tsingsuikĕng: $\beta=1.628$
10. Poneikĕng: $\beta=1.614$

(d) Barkevikite is rare.

1. Luchü: pleochroism- X=light brownish yellow, Y=reddish brown, Z=deep brown; absorption Z>Y>X; optically negative; $Z \wedge C = 5°$.
2. Tsingtan: pleochroism- X=light brownish yellow, Y=yellowish brown, Z=deep brown; $Z \wedge C$=small.
8. Taliaoti:
10. Poneikĕng: pleochroism- X=light brown, Y=light reddish brown, Z=brown; $Z \wedge C = 10°$.

(e) Olivine is present perhaps in all the specimens; mostly altered to secondary minerals by weathering:

5. Hĕnglululiao }
6. Neikanlinpi } subhedral form, (−) $2V \doteqdot 86°$.

(f) Analcite is contained in tolerable quantities in all the specimens.

(g) Apatite, slender in shape, is comparatively abundant in each specimen.

(h) Iron ores, including magnetite, ilmenite, etc., are fairly abundant.

The kinds and quantities of secondary minerals are more or less different from locality to locality according to the degree of weathering. The principal secondary minerals are chlorite, calcite, nontronite, sericite zeolites, leucoxenes, etc.

The teschenite yields more easily to weathering than the common basalt, so that it is always more or less altered where exposed. It is very difficult to obtain fresh specimens.

The mineral constituents of the teschenites collected from various districts are summarized in the following table.

Table 2.

	Localities	1				2	3	4	5	6	7	8	9	10
		Luchü												
Minerals		I	II	III	IV	Shihsuitzu Liuchangli	Tsingtan	Tutan	Hĕnglululiao	Neikanlinpi	Tsingsuikĕng	Taliaoti	Hsiungkungshan	Poneikĕng
Feldspars	Potash-feldspar					+			+					
	Albite						+						+	
	Oligoclase	+	+	+	+				+		+	+	+	+
	Andesine	+	+	+	+	+	(+)	+	+	+	+	+	+	+
	Labradorite	+	+	+	+	+	(+)	+	(+)	+	+	+	(+)	+
	Potash-oligoclase ? Potash-andesine ?								+					

Pyroxenes	Augite					+		+				+		
	Pigeonite					(+)		+					+	
	Titaniferous augite	}+	}+			}+	}+		+		}+	+	+	}+
	Titaniferous pigeonite								+	+		+		
	Aegirineaugite	+	+									+	+	(+)
	Aegirine	+	+									+		
	Biotite	+	+	+		+	+	+	+	+	+	+		+
	Barkevikite		+				+					+		+
	Olivine	+	+	+	+	+	+	+	+	+	+	+	+	+
	Analcite	+	+	+	+	+	+	+	+	+	+	+	+	+
	Apatite	+	+	+	+	+	+	+	+	+	+	+	+	+
	Iron ores	+	+	+	+	+	+	+	+	+	+	+	+	+
					Natrolite +									

D. Chemical composition

There are six chemical analyses of the teschenites collected from two localities, Luchü and Tsingtan. Since it is quite difficult to collect fresh samples, these analyses can not be deemed to be complete, although they may not deviate too much from the actual composition. The chemical analyses and norms are given in Table 3.

Table 3.
Chemical analyses of teschenite

No.	1	2	3	(1~3 av.)	4	5	6	(4~6 av.)	7	8	9	10
SiO_2	47.56	48.10	48.74	48.13	39.50	46.91	47.27	44.56	45.54	45.86	47.88	48.62
Al_2O_3	13.21	15.64	15.84	14.90	21.44	17.89	19.41	19.58	16.26	17.32	16.47	17.75
Fe_2O_3	6.65	6.80	6.90	6.78	1.99	3.18	3.98	3.05	1.69	2.10	0.43	2.92
FeO	2.98	2.78	2.82	2.86	10.06	8.96	7.76	8.93	5.30	6.74	6.82	5.14
MgO	3.59	3.80	3.85	3.75	2.09	3.23	0.92	2.08	4.48	4.57	5.20	3.32
CaO	5.04	7.77	7.88	6.90	11.28	7.99	5.69	8.32	10.78	6.90	8.54	6.75
Na_2O	4.20	2.61	2.65	3.15	4.78	4.44	5.26	4.83	4.22	4.87	3.99	5.61
K_2O	4.64	3.49	3.54	3.89	1.04	2.22	3.20	2.15	1.65	1.84	2.12	1.74
H_2O+	5.11	4.40	4.46		1.62	1.29	2.01		3.79	4.17	3.49	3.25
H_2O-	—	1.32	—		1.63	0.79	0.89		1.01	0.81	0.99	0.65
TiO_2	4.23	2.26	2.29	2.93	2.64	2.88	2.82	2.78	2.00	2.31	2.32	2.04
P_2O_5	2.21	1.66	1.68	1.85	1.57	1.00	0.41	1.00	0.45	0.60	0.41	0.75
MnO	—	tr.	—		0.11	—	—	—	2.17	1.90	2.13	1.89
Others					S 0.21 CO_2 0.05	S 0.05 CO_2 0.06	S 0.21 CO_2 0.06					
Total	99.42	100.63	100.68		100.01	100.89	99.94		99.43	100.07	100.79	100.43

No.	11	12	13	14	15	16	17	18	19	(1~19 av.)	20 (7~19 av.)
SiO_2	46.18	45.71	47.03	48.18	48.25	46.77	45.26	47.29	42.15	46.72	46.51
Al_2O_3	17.70	15.23	15.36	11.80	17.38	14.91	15.74	19.32	18.75	16.70	16.46
Fe_2O_3	4.04	2.84	3.38	9.57	4.51	7.80	2.33	6.30	4.94	4.22	4.08
FeO	5.40	6.93	7.35	5.90	5.31	4.90	7.12	1.33	7.30	5.83	5.81
MgO	3.24	8.11	5.10	6.05	2.13	2.94	5.23	6.82	3.74	4.12	4.69
CaO	8.53	7.34	8.47	7.50	6.03	6.30	8.86	9.00	9.75	7.91	8.06
Na_2O	2.62	3.96	4.32	3.46	5.81	4.97	5.01	4.13	3.34	4.22	4.33
K_2O	1.63	1.31	3.00	1.57	3.00	2.37	2.51	1.75	2.07	2.35	2.43
H_2O+	4.62	} 6.24	} 2.82	} 3.20	3.85	4.28	2.94	0.41	4.35		
H_2O-	1.32				—	0.92	0.68	0.26	4.08		
TiO_2	2.08	1.64	2.64	—	2.73	2.31	3.01	2.35	—	2.24	2.31
P_2O_5	0.50	0.47	0.73	0.49	0.65	0.29	0.90	—	0.58	0.80	0.56
MnO	2.05				0.65	0.29	0.22	1.71	—		
Others		0.73	0.47	0.71							
Total	99.91	100.51	100.67	98.65	100.64	99.90	99.81	100.67	100.07		

Norms of teschenite

No.	1	2	3	1~3 av.	4	5	6	4~6 av.	7	8	9	10
Q	—	3.54	3.54	1.32	—	—	—	—	—	—	—	—
or	27.24	20.57	20.57	22.80	6.12	12.79	18.90	12.79	9.45	10.56	12.23	10.01
ab	35.63	22.01	22.53	26.72	7.34	26.72	26.72	20.44	15.72	26.20	24.63	36.15
an	3.34	20.57	20.85	15.01	33.92	22.24	19.74	25.58	20.85	20.29	20.85	18.35
ne	—	—	—	—	17.89	5.96	9.66	10.79	10.79	7.95	5.11	5.96
di	3.46	5.40	5.40	5.62	10.19	9.25	5.19	7.74	24.39	7.79	15.39	8.50
hy	—	7.00	7.30	6.80	—	—	—	—	—	—	—	—
ol	5.18	—	—	—	9.25	9.30	4.59	7.76	6.14	13.01	9.96	5.62
mt	—	2.32	2.32	0.70	3.02	4.64	5.80	4.41	2.55	3.02	0.70	4.18
il	6.38	4.41	4.41	5.47	5.02	5.47	5.32	5.32	3.80	4.41	4.41	3.80
hm	6.72	5.28	5.28	6.40	—	—	—	—	—	—	—	[illegible]
ap	5.04	4.03	4.03	4.37	3.70	2.35	1.01	2.35	1.01	1.34	1.01	1.68
or	41	32	32		9	17	23		14	15	18	13
ab	54	36	36		49	52	53		53	57	51	63
an	5	32	32		42	31	24		33	28	31	24
Wo	(8) 17	(14) 23	(14) 24		22	21	22		38	15	27	27
En	(42) 83	(45) 77	(45) 76		23	37	21		34	44	44	51
Fs	(50) 0	(31) 0	(31) 0		55	42	57		28	41	29	22
Q	(−7.14) −2.22	(−0.44) +3.54	(−0.42) +3.54		−18.18	−8.34	−9.66		−11.34	−12.66	−8.04	−7.26

( ) convert Fe_2O_3 of hm into FeO

No.	11	12	13	14	15	16	17	18	19
Q	3.36	—	—	1.68	—	—	—	—	—
or	9.45	7.78	17.79	9.45	17.79	13.90	15.01	10.56	12.23
ab	22.01	27.25	18.34	29.34	29.34	33.01	14.67	21.48	11.00
an	31.97	19.74	13.90	11.95	12.51	11.40	12.79	28.63	30.30
ne	—	3.14	9.66	—	10.79	4.83	15.05	7.10	9.09
di	5.34	10.47	19.16	17.17	11.03	14.04	20.64	12.53	11.93
hy	8.71	—	—	11.21	—	—	—	—	—
ol	—	16.52	7.07	—	2.08	0.56	7.34	7.84	9.38
mt	5.80	4.18	4.87	13.92	6.50	9.98	3.25	2.78	7.19
il	3.80	3.04	5.02	—	5.17	4.41	5.78	4.56	—
hm	—	—	—	—	—	0.96	—	4.32	—
ap	1.34	1.34	1.68	1.34	1.34	0.67	2.02	—	1.34
or	15	13	26	18	22	20	21	13	17
al	35	55	53	58	61	62	60	47	39
an	50	32	21	24	17	18	19	40	44
Wo	20	16	34	33	41	(46) 51	35	(34) 27	24
En	58	60	44	56	39	(45) 49	44	(30) 73	40
Fs	22	24	22	11	20	(9) 0	21	(36) 0	36
Q	+3.36	−9.30	−10.86	+1.68	−9.90	(−5.04) −4.32	−15.30	(−12.60) −9.36	−10.92

1. Luchü, Sihtingsiang, Wenshanchü, Taipehhsien, Taiwan
2. ditto
3. ditto
4. Tsingtan, Sintienchēn, Wenshanchü, Taipehhsien, Taiwan
5. ditto
6. ditto
7. Mawarizawa spring, Mt. Takakusa, Shizuoka-prefecture, Japan (teschenite α type)
8. ditto ”
9. ditto ”
10. Sakamoto, Higashimasuzumura, Mt. Takakusa, Shizuoko-pref. Japan (teschenite β type)
11. ditto
12. Blackburn, Bathgate
13. Craigleith, Island, N. Berwick
14. Boguschowite, Silesia
15. Minussinsk, Siberia
16. Mapleton, Township, Maine, U. S. A.
17. Bellow water, Lugar, Scottland
18. Compo Jose, Fernandez, Uruguay
19. Blauendorf, b. Neutitschein, Östen Schlesien
20. 7∼19 average.

From the above table, it is seen that the chemical composition of the teschenites from Luchü and Tsingtan are somewhat different from each other. In the former, $K_2O > Na_2O$; in the latter, $K_2O < Na_2O$. When their components are compared with the average value of those of thirteen specimens hitherto known from various parts of the world, there is no remarkable difference. As compared with the average value of all the basalts computed by Osann, the teschenite is poorer in SiO_2, CaO, and especially in MgO, and is slightly higher in K_2O and Na_2O; the other components show neither perceptible increase nor decrease.

The norm of the teschenite of Tsingtan does not differ from the average value of the teschenite in general, but that of Luchü is characterized by containing the normative quartz, hypersthene and abundant orthoclase, but no nephelite.

E. Consideration on the genesis

(i) Expression of chemical composition

The chemical analyses of the teschenite here under discussion are those of Luchü, Tsingtan, Mt. Takakusa in the Sizuoka prefecture of Japan [17], as well as several other places in the world. The analyses are expressed by the following methods.

In the basaltic magma, two of the components, feldspar and pyroxene, play the important rôle, so that normative feldspar components (Or, Ab and An) and normative pyroxene components (Wo, En and Fs) are computed from respective chemical analyses. When normative feldspar and pyroxene are computed, silica is deficient in many specimens. Regardless of it, the normative feldspar and pyroxene are computed, but never the normative olivine and nephelite. The deficiency of silica is finally computed and shown as the negative quartz (—Q).

In the specimens from Luchü, normative hematite is present in spite of its absence in the fresh specimens. In this case, we change all Fe_2O_3 into FeO for the convenience of consideration. (As a result, the quantity of FeO in recalculated analysis is more or less larger than that in the rocks themselves.)

Thus, the calculated normative feldspar and pyroxene components are plotted on the triangular diagrams of Or-Ab-An and Wo-En-Fs.

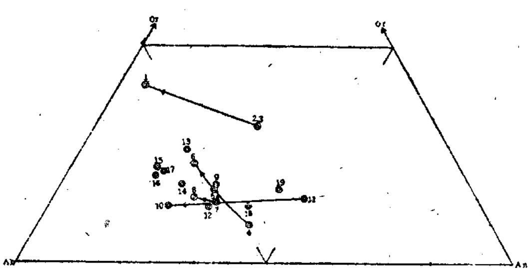


Fig. 2. Triangular diagram of Or-Ab-An

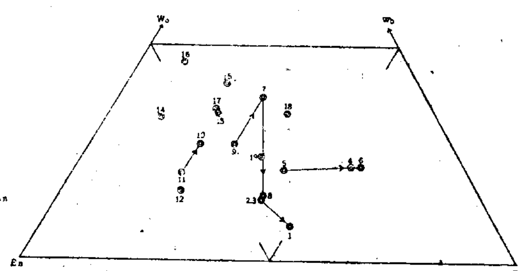


Fig. 3. Triangular diagram of Wo-En-Fs

(ii) Results

The plotted points of the normative feldspar and pyroxene components are scattered on the triangular diagrams of Or-Ab-An and Wo-En-Fs respectively. Between the normative feldspar and the normative pyroxene, there are some such relations as follows:

(a) In the rock in which the normative feldspar is comparatively rich in Or-Ab, the normative pyroxene is high in En.

(b) In the rock in which the normative feldspar is rich in Or or Ab, its normative pyroxene is high both in Wo or Fs.

This tendency is recognized also in the common basalt, but in the case of teschenite, this nature is somewhat obscured. The normative feldspar of teschenite is richer in Or-Ab, and is distributed in wider area than that of the common basalt. Also the normative pyroxene of the former ranges widely in composition than that of the latter.

From the normative feldspar and pyroxene components of the rocks in Luchü, Tsingtan and Mt. Takakusa, it is known that the feldspar component evolves from the An-rich one to the Ab-Or-rich one, and the pyroxene component has two routes of evolution, namely, one from the Di-rich one to the Fs-rich one and the other from the En-rich to the Di-rich one. These tendencies are also seen in the common basalt.

(iii) Consideration

The outline of the fractional crystallization in the common basaltic magma is first briefly reviewed here [12], [15]. Owing to the difference of the earlier-crystallized minerals in the basaltic magma, two types are recognized, namely, the one characterized by the plagioclase and olivine, and the other by calcic plagioclase and diopsidic augite, rarely by olivine. According to the condition of reaction between the earlier-crystallized minerals and solution, the component of the residual solution diverges along respective evolution-routes, and, at different stages in the course of evolution, the residual solution effuses out or intrudes into the crust and yields various kinds of basalts.

In the light of the foregoing, it is seen that the teschenite is produced in the course of the divergent evolution through the common basalt. This consideration coincides entirely with the fact that the teschenites in Taiwan and Mt. Takakusa occur always in association with olivine basalt, and often pass into the latter. In other words the teschenite is the more differentiated product of the basaltic magma than the common basalt.

The question now is how the teschenitic solution is derived from the basaltic magma producing common basalt.

There are, in general, two ways of explanation as to the various chemical components of igneous rocks. One is the contamination of magma by foreign matter; and the other is the crystallization-differentiation of magma. Viewed from the comparison of chemical components between teschenite and common basalt, the harmony between the evolution of normative feldspar and that of pyroxene, and the passage from the common basalt to the teschenite, the genesis of the major part of teschenites can well be explained by the theory of crystallization-differentiation of the basaltic magma rather than by that of the contamination of the basaltic magma with foreign matter.

According to W. Q. Kemmedy [13] and G. W. Tyrrell [14], the basaltic magma has two types, the olivine basalt magma (plateau-basalt of Tyrrell) and the tholeiite magma (flood basalt of Tyrrell). The alkaline rocks are derived from the former. But Barth [16] thinks the basaltic magma is monotypic and can yield either of the two types mentioned above in response to the reactive conditions between the earlier-crystallized minerals and solution.

In the chemical compositions, the teschenite is less in SiO_2, CaO and MgO, and slightly higher in alkalies than the common basalt. Except for these, the compositions are much the same.

Considering from these facts and various geological and mineralogical relations, it can be said that the teschenitic solution is principally more deficient in SiO_2, MgO and CaO than the common basaltic magma. As an explanation for this, the following hypothesis may be taken into account.

From the basaltic magma, calcic plagioclase and olivine or diopsidic augite crystallized in an earlier stage. While the reaction between these minerals and the solution was in progress, and the common basalt was being formed, the pyroxene was abundantly produced and took deposition or accumulation. As a result, the residual solution became less and less in SiO_2, MgO and CaO, and finally passed into the teschenitic solution. The crystallization was slower than that of the common basalt, hence doleritic texture of the teschenite was thus resulted.

Although much geological and petrographical studies have been accomplished previously, we have no chemical analysis of the common basalt in Taiwan at hand. Therefore the chemical relations between the teschenite and the common basalt can not be discussed here in detail.

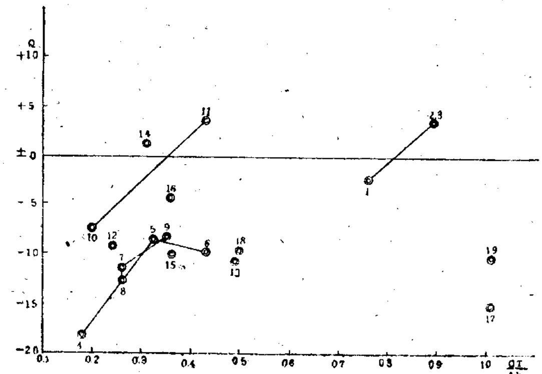


Fig. 4. The relation between quartz and $\frac{Or}{Ab}$

In the common basalt, there is a tendency that the rock having normative Or-rich-feldspar contains more normative quartz than that having normative Ab-rich feldspar. The same tendency can also be recognized in the teschenites of Tsingtan, Luchü and Mt. Takakusa. (Fig. 4). The teschenites in Tsingtan and Tutan are accompanied by the alkali-syenite (analcite syenite) and the aplitic, leucocratic rocks; and the one from the former locality was once studied by Ichimura. These may be dealt with in another paper.

III. Analcite-basanite (basalt)

A. Geographical Distribution (Fig. 1)

As far as the writer knows the occurrence of analcite basanite (basalt) in the Taiwan proper is limited entirely to Mawutu[1] and Mafu[2] districts. Besides, the same rocks are found in the Pĕnghu Island and Yüwengtao[3] (or Sisü[4]), belonging to the Penghu Group. They have been described by B. Koto in 1900. The localities where the analcite basanites are found are listed below:

1. Mawutu district (Mawutu and Chikoshan[5], Kuansichĕn[6], Sintsuhsien[7]),
2. Mafu district (Mafu, Hĕngshansiang[8], Tsutungchü[9], Sintsuhsien),
3. Chĕntoushan[10] district (Between Chiaopanshan[11] and Chĕntoushan, Tachichü[12], Sintsuhsien),
4. Liuch'ushan[13] district (Kuansichĕng, Sintsuchü, Sintsuhsien),
5. Tashanpeishan[14] district (Hĕngshansiang, Tsutungchü, Sintsuhsien),
6. Pĕnghu district (Pĕnghuhsien).

B. Geological distribution

1. Mawutu district
2. Mafu district

The geology of these districts has already been described by Ichikawa [5], Ichimura [18] and Ishizaki [20]; the latter two have paid special attention to the discussion of the strata containing the alkaline basalts. Owing to the complicated geological structure, especially due to the development of faults and abundant igneous rocks, the accurate and detailed order of succession of strata is not precisely known. But the formations containing the alkaline basalts as a whole seem to belong to the Upper Coal-bearing Beds and in part to the Taiho Beds. The strata, striking N E and dipping towards S E, consist chiefly of beds of grey sandstone, white sandstone, and coarse sandstone with subordinate shales.

Basaltic tuffs, agglomerates and lava flows are associated with these two Beds. The analcite basanite forms a member in them, and occurs either as boulders in the agglomerates or as a part of the lava flows. The most distinctive character of the basalt here is the common occurrence of olivine aggregates (each having a diameter up to 10 cm.) and augite crystals (each having about 3 cm. across). Moreover some rocks often contain zircon, corundum, sapphire, ruby, spinel, garnet (?), etc., as was studied by Ichimura [18] sometime ago.

3. Chentoushan.

1 馬武督	2 馬福	3 漁翁島	4 西嶼	5 赤柯山
6 關西鎮	7 新竹	8 橫山鄉	9 竹東區	10 枕頭山
11 角板山	12 大溪區	13 六畜山	14 大山背山	

The region extends from Chentoushan to Chiaopanshan (the name of a village, but not the hill of Chiaopanshan) and is formed of the Lower Coal-bearing Beds. The strata strike NE with a SE dip. The analcite basanite here is found intruding into these strata possibly as dikes.

4. Liuch'ushan.

The geological formation here consists of the Middle Coal-bearing Beds and the Sôgô Beds; the analcite basanite intruding into the former as dikes.

5. Tashanpeishan.

In the Middle Coal-bearing Beds and the Sôgô Beds of this district, many basaltic sills and dikes are found in association; the analcite basanite intrudes into the Middle Coal-bearing Beds as dikes.

6. Penghu Islands.

The geology and the igneous rocks of the Penghu Islands were previously studied by Y. Saito [21], Y. Deguchi [2] and B. Koto [1]. All the islands consist of basaltic flows (except Huasu[1]), and three superposing lava flows intervened by sandstone and conglomerate beds are observed above sea-level. All these flows belong to the Pleistocene (?). The lowest lava flow (the third flow) in the main island and the Yuwengtao contains associated flow of analcite basanite.

The geological age of the analcite basanite. The analcite basanites in Mawutu and Mafu districts were effused out or injected upward during the upper Miocene age when the Upper Coal-bearing Beds and the Taiho Beds were depositing; while those in the Penghu Islands were extruded in the Pleistocene (?) period. Though the age of the analcite basanites in other districts can not be determined due to their occurrence as dikes, it may perhaps be justified to ascribe them to the same age as those of Mawutu and Mafu districts, because they are found in the closely neighbouring areas.

C. Petrography

1. Mawutu district.

Ichumura (18) has already described the analcite basanite in this district together with that of Mafu. Under the microscope, the writer divides the rocks found there into two (possibly there may be more than two) types, which are temporarily called MW 1 and MW 2.

(a) MW 1 type

Megascopic observations:—The rock has a distinct porphyritic structure. It is compact with a dark grey to black color. Olivine and pyroxene are recognized. Sometimes olivine crystals form aggregates, having a diameter up to 10 cm.

Microscopic observations:—Texture porphyritic; groundmass compact with a fine texture; the phenocrysts are composed of olivine (abundant) and pyroxene (less). Olivine occurs abundantly as phenocrysts, but is rare in the groudmass.

1 花嶼.

$(-)\ 2V \fallingdotseq 85^\circ$–$86^\circ$.

Hypersthene occurs rarely as phenocrysts; elongation positive; $(-)\ 2V \fallingdotseq 70^\circ$.

Pseudohypersthene, consisting of aggregates of magnetite, augite and hypersthene, occurs rarely as pseudo-phenocrysts.

Rounded mineral-aggregates consist principally of feldspars (anorthoclase (?), oligoclase-andesine), biotite, chlorite, magnetite and analcite, and occur as pseudo-phenocrysts. These minerals are perhaps derived from the minerals or the solution rich in alkalies.

Feldspars are the principal groundmass minerals. They include andesine, labradorite and oligoclase.

Titaniferous augite is present in the groundmass; $Z \wedge C = 43^\circ$–50°, average 46°; $(+)\ 2V \fallingdotseq 50^\circ$.

Pigeonite occurs rarely as phenocryst; $Z \wedge C \fallingdotseq 40^\circ$; $(+)\ 2V \fallingdotseq 0^\circ$ or $20^\circ \pm$

Titaniferous pigeonite is common in the groundmass; $Z \wedge C = 42^\circ$–50°, average 45°; $(+)\ 2V =$ small.

Biotite occurs principally in the groundmass; showing pleochroism- X=light yellow, Y=yellowish brown, Z=reddish brown; $(-)\ 2V \fallingdotseq 0^\circ$.

Analcite fills up the interspaces among the other minerals; $n = 1.487$.

Iron ores

(b) MW 2 type

It is coarser in texture than MW 1 type, and the porphyritic structure is obscured. Under the microscope it shows equigranular texture.

Olivine is abundant, almost altered to chlorite.

Augite is rare.

Titaniferous pigeonite is abundant; $Z \wedge C = 40^\circ$–43°–45°; $(+)\ 2V \fallingdotseq 10^\circ$ or $25^\circ \pm$

Feldspars are in two kinds; the one consists of andesine-labradorite and forms lath-shape; the other shows an irregular form; $n \geq 1.54$, $(\pm)\ 2V \fallingdotseq 50^\circ$; perhaps corresponding to potash-andesine (?).

Biotite, analcite, magnetite, apatite, etc. are present in the groundmass, and their characters are the same as in MW 1.

2. Ma-fu district

The specimen in this district is the same as MW 1 type. It shows a porphyritic structure, has a fine groundmass; and contains large crystals of pyroxene besides olivine. The characters of constituent minerals are as follows:

Phenocryst olivine: $(\pm)\ 2V \fallingdotseq 85^\circ$

Pigeonite is common both in the groundmass and as phenocrysts, $Z \wedge C = 40^\circ$–43°; $(+)\ 2V =$ very small.

Pseudohypersthene consists principally of aggregates of pigeonite and magnetite.

Feldspars are the principal groundmass minerals, andesine and labradorite being the representatives.

Analcite fills up the spaces among the other minerals; n=1.489.

Iron ores.

According to Ichimura, the more important characters of the constituent minerals of the analcite basanite in Mawutu and Mafu are as follows:

Olivine: $\alpha=1.647$, $\beta=1.662$, $\gamma=1.682$; $\gamma-\alpha=0.035$; (+) 2V=81°20′.

Biotite: $\gamma=1.647$; 2V≑0°.

Analcite: n=1.487.

Titaniferous augite: weak pleochroism-X=light purplish brown, Y=light yellowish brown, Z=light brownish-purple; absorption-Z>X>Y.

Plagioclase: andesine-labradorite.

Magnetite: octahedral or granular form.

Picotite: anhedral form.

3. Chĕntoushan

The appearance and constituent minerals of the analcite basanite in this region are similar to those of MW 2.

Olivine: almost altered to chlorite.

Pigeonite: Z∧C=40°; (+) 2V=very small.

Feldspars: andesine-labradorite.

Biotite: pleochroism-X=light brown, Y≑Z=reddish brown; (−) 2V≑0°.

Analcite, magnetite, apatite, etc. are the same as in MW 2.

4. Luch'ushan

The rock in this region is also similar to MW 2.

Olivine: almost altered to chlorite, etc.

Pigeonite: Z∧C=42°-43°; (+) 2V=very small.

Feldspars: andesine and labradorite; the latter is somewhat more freqent than the former.

Biotite: abundant; pleochroism-X=light yellowish brown, Y≑Z=dark brown; (−) 2V≑0°.

Analcite.

Magnetite.

This rock sometimes contains xenoliths which consist of chlorite, chalcedony, calcite, plagioclase, etc. Brownish glass with scattered biotite usually fringes the xenoliths.

5. Tashanpeishan

The analcite basanite is similar to MW2 type, and shows more or less porphyritic structure, having olivine as the chief phenocrysts. The main constituent minerals are as follows:

Olivine: (−) 2V≑85°.

Titaniferous augite: Z∧C=40°-43°; (+) 2V≑70°.

Feldspars: oligoclase, andesine, labradorite and little potash-andesine (?) (n≧1.54;

(+) 2V≒50°.)

Analcite: abundant

Magnetite.

Apatite.

6. Pĕnghu district

(a) Penghu Island (the main island of the Penghu group)

Hattori, Kôno and Rin [19] have all described the analcite basanite found in this island. The more important features of the constituent minerals are given as follows.

Plagioclase: $n_1=1.557$, $n_2=1.564$ on (001); $n_2-n_1=0.007$; acidic labradorite.

Titaniferous augite: $Z \wedge C=-50°$.

Olivine

Analcite: $n=1.486$.

Magnetite

Apatite

(b) Yüwengtao

The analcite basalt in this island was studied by Kotô [1]. The specimens from Sisü were studied under the microscope by the writer, and the results are outlined below.

The rock is dark grey to black in color, compact, medium-grained; shows more or less pophyritic texture; contains no plagioclase phenocrysts.

Phenocrysts:—

Olivine: (−) 2V≒85°–86°, 90°, (+) 2V≒88.

Titaniferous pigeonite: $Z \wedge C=40°$; (+) 2V≒30°–40°.

Titaniferous augite: $Z \wedge C=40°$; (+) 2V≒65°–70°.

Hypersthene: rare.

Groundmass:—

Plagioclase: labradorite, andesine and oligoclase.

Analcite

Magnetite

Apatite

The modes of occurrence and the constituent minerals of the analcite basanites from the localities mentioned above are tabulated below.

Table 4.

Localities / Occurrence, Minerals, etc.	Mawutu		Mafu	Chĕng-toushan	Liuchu-shan	Tashan Peishan	Pĕnghu Islands	
	MW1	MW2					Penghu	Yüweng
Mode of occurrence	lava flow or boulders of agglomerate		»	dike?	dike	dike	lava flow	
Structure	Porphy-ritic	equig-ranular	Porphy-ritic	equi-gran.	equi-gran.	(por-phy.)		(por-phyr.)

Occurrence, Minerals, etc. \ Localities		Mawutu		Mafu	Cheng-toushan	Liuchu-shan	Tashan Peishan	Penghu Islands	
		MW 1	MW 2					Penghu	Yüweng
Texture		fine	medium	fine	medium	medium	medium		medium
Feldspars	K-feldspar	(+)	+				+		
	Oligoclase	(+)					+		+
	Andesine	+	+	+	+	+	+		+
	Labradorite	+	+	+	+	+	+	+	+
Pyroxenes	Augite		(+)						
	Titaniferous augite						+	+	+
	Pigeonite	+		+	+	+			
	Titaniferous pigeonite	+	+						+
	Hypersthene	(+)							(+)
	Pseudohypersthene	(+)		(+)					+
	Olivine	+	+	+	+	+	+	+	+
	Analcite	+	+	+	+	+	+	+	+
	Biotite	+	+		+	+			
	Magnetite	+	+	+	+	+	+	+	+
	Apatite	+	+	+	+	+	+	+	+

+ present (+) rare

D. Chemical composition

There are four chemical analyses of the analcite basanites in Taiwan. Three of the specimens were collected from Mawutu and one of the specimens, from Penghu Island. These chemical analyses and the norms calculated therefrom are tabulated here.

Table 5

Chemical analyses of analcite basanite

No.	1	2	3	4	5	6	7	8	9	10
SiO_2	41.92	42.94	47.42	43.46	40.81	41.10	43.77	44.85	45.59	46.54
Al_2O_3	12.70	13.90	13.88	14.24	13.08	14.82	13.04	12.55	12.98	12.63
Fe_2O_3	6.39	1.32	3.83	3.60	6.40	2.35	2.96	3.33	4.97	3.41
FeO	8.13	8.12	8.26	8.64	7.20	10.38	6.14	5.30	4.70	5.29
MgO	12.01	12.79	8.76	8.66	10.03	9.43	12.91	10.27	8.36	10.09
CaO	9.97	9.29	9.13	8.80	10.12	10.56	11.47	8.32	11.90	8.00
Na_2O	3.90	2.97	3.55	3.78	2.43	3.94	3.19	4.77	4.53	5.11
K_2O	0.48	1.56	1.44	1.07	0.31	1.28	0.79	0.72	1.04	1.64

H_2O+		3.16			3.97	2.31	2.58	2.01	3.91 3.40	2.35
H_2O-					0.82	0.39	0.63	0.95	0.51	0.25
TiO_2	0.81	3.11	0.72	2.43	3.96	3.20	1.08	5.07	1.32	3.98
P_2O_5		1.05		0.08	0.88	0.19	1.42	1.17	0.91	0.91
MnO	0.21	tr.	0.18	0.19	0.07	0.14	0.18	0.07	0.14	—
Ig. loss	3.11		2.60							
Total	99.63	100.71	99.57		99.93	100.50	100.16	99.60	99.87	100.25

Norms of analcite basanite

No.	1	2	3	4	5	6	7	8	9	10
or	2.78	9.45	8.34	6.67	1.67	7.78	4.45	3.89	6.1	9.45
ab	8.38	10.48	20.44	15.20	20.44	—	13.10	28.82	18.9	24.63
an	15.85	19.74	17.74	18.35	23.91	17.24	18.90	11.12	12.2	7.23
ne	13.35	7.95	5.11	9.09	—	18.18	7.38	5.94	10.2	9.94
di	26.81	15.28	1.89	20.33	16.08	28.55	22.94	17.71	30.0	20.98
ol	18.49	24.27	16.12	15.12	11.46	15.59	20.46	12.18	6.5	11.12
mt	9.28	1.86	5.57	5.34	9.28	3.25	4.41	2.55	7.2	4.87
il	1.52	5.93	1.37	4.56	7.45	6.08	2.13	9.58	2.5	7.60
ap		2.69			2.02		3.36	2.69	1.9	2.02
					hy 3.23			hm 1.60		

1. Mawutu, Kwangsihchēn, Sintsuhsien, Taiwan (Ichimura)
2. ditto (")
3. ditto (")
4. Pēnghu island, Pēnghuhsien, Taiwan (Kono)
5. Rathjordan, Limerick, Irland. (Rosenbusch)
6. Fernhill, New-South Wales (")
7. Lungtun, Chienchingpehtao, Korea (Tomita)
8. Scano Mte. Ferru, Sardinien (Rosenbusch)
9. Basin, Colorado, U. S. A. (")
10. Bonarva, Sardinien (")

Among these rocks, Mawutu 3, according to Ichimura [18], belongs to the olivine basalt. Judging from its analysis, however, it seems to be an intermediate type between olivine basalt and analcite basanite.

There is hardly any difference between the chemical analyses of the analcite basanites (or basalts) in Taiwan and those in foreign countries. They are, in a word, similar to one another. The analcite basanite is poorer in SiO_2 and Al_2O_3, but richer in FeO, MgO and CaO (especially in MgO) by comparing its chemical composition with that of the common basalt. Besides, no marked difference is found as regard to the other constituents.

The abundance of magnesia is due to the presence of abundant olivine (rich in forsterite molecule) phenocrysts or aggregates in these rocks.

Except for the slight quantitative difference in silica, there is a remarkable resemblance between the composition of Mawutu 3 and that of Pênghu island 4. Under the microscope, both show similar characters except that the former has less analcite than the latter. The disparity in quantity of analcite seems to be the principal cause of this slight quantitative difference of silica in these rocks.

It must be noticed that some analcite basanites of Mawutu and Mafu districts contain such minerals as zircon, corundum, sapphire, ruby, spinel and garnets (?). A tolerable quantity of zircon is quite of special importance.

E. Consideration on the genesis.

There are several important geological-petrological facts concerning the alkaline rocks under discussion. They are:

1. that the analcite basanite occurs often with the common basalt in the same activity-stage,
2. that the boulders in agglomerates have both analcite basanite and olivine basalt,
3. that there is a rock type intermediate between the analcite basanite and the common basalt; in other words, the analcite basanite passes gradually into the common basalt.

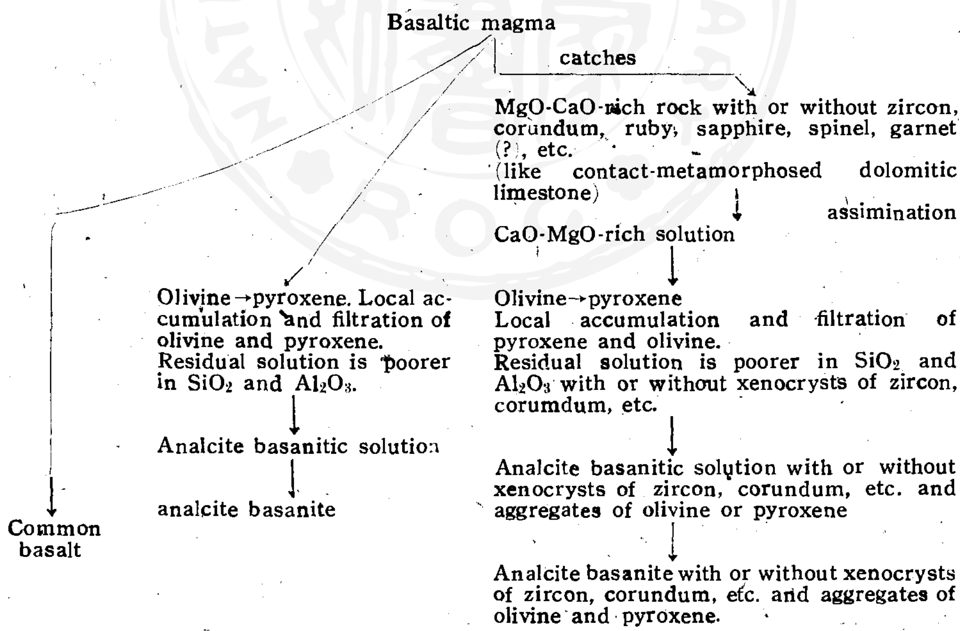
From these facts, it may be assumed that a part of the andlcite basanites in Taiwan was derived from the common basalt by the crystallization-differentiation of the common basalt magma. And the mechanism of the differentiation can be explained by the same principle as that for the analcite dolerite or the teschenite.

Unfortunately, the specimens of this kind contain so much phenocrysts (even olivine or augite aggregates) that their chemical analyses can not be directly used for the chemical consideration of details of the mechanism of the generation and their relation with the common basalt. In future, not only the common basalt but also the rocks of this kind containing no or very little phenocrysts must be studied chemically. It is indispensable for the study of the alkaline basaltic rocks in Taiwan.

As mentioned above, the analcite basanites in Mawutu and Mafu districts contain in part such minerals as zircon, corundnm, ruby, sapphire, spinel, garnet (?), etc. with abundant olivine aggregates and large crystals of pyroxene. Concerning the occurrence of these minerals Ichimura [18] once studied and concluded that: "Zircon is likely to have been crystallized at the earliest stage of consolidation of the basaltic magma. There is also an evidence that colorless zircon and olivine masses were comtemporaneously formed. In this case the magma seems to have been of abnormal type, as is indicated by the frequent occurrence of olivine masses in the basaltic rocks under consideration. Corundum can be supposed to have been crystallized in such an abnormal magma, in which an excess of alumina was also present." He considered that zircon and corundum were directly crystallized out from the magma. There is a fact that zircon and corundum are sparingly present in basic rocks, so his consideration may imply one possible case.

On the other hand, the genesis of the rock bearing these minerals may also be explained by the contamination with foreign rocks in the basaltic magma. If magnesia-lime-rich rocks were caught and assimilated in the basaltic magma, the magma would be rich in magnesia and lime, and have crystallized out abundant olivine and pyroxene in the earliest stage. The residual solution would then be poor in silica and alumina, and would gradually pass into the composition of analcite basanite. If the magnesia-lime-rich rocks contained such minerals as zircon, corundum ruby, sapphire, spinel, garnet (?), etc. as in the case of the metamorphosed dolomitic limestone, these minerals would not be dissolved and would remain unchanged after assimilation. In other words, these minerals are considered as xenocrysts and not to be directly crystallized from the magma. The generation of the analcite basanites in Mawutu and Mafu districts may be explained by the crystallization-differentiation of the basaltic magma with or without contamination.

The outline of the generation of analcite basanite and common basalt from the basaltic magma may be schematically represented in the table below.



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THE KWANTZULING LIMESTONE*

(Summary).

By

T. P. YEN and LI-SHO CHANG*.

(With 1 Plate and 2 Figures)

(1) The Kwantzuling limestone now being quarried for the use of the sugar industry is located 12.5 km E by S of the Houpi and 15 km E by N of the Hsinying railway station. The limestone forms an isolated, flat-topped peak called Chêntoushan, which is about 646 m above sea level and looks like a pillow from a distant view.

(2) For transportation of the limestone, a branch railway runs from Hsinying to Fênchihu and is connected by a light railway with Hsients'aopu, where the mine office is situated (Fig. 1).

(3) The limestone forms two lenticular layers. The lower one is conformably underlain by a formation of dark bluish grey sandstones (mostly changed to yellowish brown colour by weathering) and overlain by a sequence of similar sandstones about 150 m thick, often intercalating or blending into thin shaly beds of bluish grey colour. The upper one overlying this sequence of rocks is overlain in turn by alternating beds of looser, brownish grey coloured, micaceous, muddy sandstones and dark bluish grey shales, the former being by far prevalent.

(4) In general, these strata strike N30°-50°E, dipping 50°-60° to NW. The fossil species listed in the Chinese text are found either in the limestones or in the beds between and above them. Not only the particular species, but also their state of preservation, together with the lithological characters, lead the authors to conclude that the strata containing these fossils are of Upper Pliocene age rather than of Upper Miocene or Lower Pliocene age as previously considered. They perhaps may be correlated to the Takuran formation even if partly to the Hsiangshan facies of the Tokazan formation.

(5) The limestones in consideration are traceable for a distance of about 3 km as indicated on the geological map attached. On the road from Hsients'aopu to Kwantzuling, where both the two limestone layers are about to thin out, the lower layer is presented as a greenish grey coloured, sandy limestone measuring only 2 m or so in thickness, composed chiefly of foraminifer remains and other organic fragments; whereas the upper layer exhibits a marginal facies, that is an alternation zone not exceeding 20 m, where various grey shaded limestones alternate at intervals of up to

*Investigated by T. P. Yen and Li-Sho Chang, and written for publication by the latte r.

20 cm with intraformational-conglomeratic shales containing fragments of coral and Tridacna-like organisms in the upper part, and the latter alternate in the same manner with shales without such fragments in the lower part. Although both layers swell gradually southwards with an increase in purity, they are likely not to be worthy of exploitation for a distance of about 1.5 km from the above-mentioned road to the Chilinwei fault. At Chêntoushan they attain the maximum in thickness. Not only the roof of the peak is entirely occupied by outcrops and shattered debris of limestones, but also the slopes and the immediate surroundings of the peak are extensively covered by tali of limestones and some of them have been already worked since twenty years ago. In all probability, the upper layer, forming a precipitious cliff on the western side of the peak about 1 km long, amounts to a maximum thickness of more than 100 m and the lower layer amounts to more than 20 m, though the exposures for both layers are not so complete as to admit more precise estimations. Both layers gradually pinch again southwards. The lower layer thins out entirely at the adjacent SW foot of Chêntoushan and the upper layer measuring about 30 m in thickness at the southwestern cliff of the peak seems to continue several hundred metres beyond Chiukû, as evidenced by the zonal distribution of the limestone blocks, which sometimes attain a diameter exceeding some ten meters and seem very likely to be either outcrops or shatterd masses in situ. In this district the limestone blocks have also been worked once some years ago. Both limestone layers have been mapped together with the talus deposits as a thick lens on the geological map of the Chiai oil-field by H. Rokkaku.

(6) The limestones are essentially built of reef corals, non-crystalline, varying from grey shades to milky white in colour, generally massive, but sometimes showing porous coral structures on weathered surfaces.

(7) The chemical compositions of the limestones collected by R. Matsumoto in the Chêntoushan district are plotted on the ternary diagram (Fig. 2). The exceedingly high content of MgO and the wide range of variations in chemical compositon are the most unfavourable factors against the usage of the Kwantzuling limestone for the sugar industry so that for this purpose careful selection is required. Strictly speaking, only one third is perhaps profitable for use.

(8) The upper limestone layer is estimated to contain at least about 11,000,000 metric tons at Chêntoushan, and the available amount of limestone talus is estimated at about 2,500,000 tons altogether.

(9) The present yearly demand of the sugar industry in Taiwan is about 100,000 tons of limestone and could not be over 250,000 tons in the near future. Therefore the limestone at Kwantzuling is enough to supply 250,000 tons per year for more than 50 years, and 300,000 tons per year for more than 40 years.

LIMESTONE GROUPS IN TAIWAN AND THEIR CHARACTERISTICS

(Summary)

By

LI-SHO CHANG*

(With 7 Figures)

Although distribution of limestones in Taiwan is geologically and geographically rather wide, they may be grouped as in the following table according to their mode of occurrence and their lithological characters.

<table>
<tr><th colspan="2">Group</th><th>Main Distribution</th><th>Geological Age</th><th colspan="2">Characteristics</th></tr>
<tr><td colspan="2">Raised Coral Reef</td><td>Coasts of Kaohsiung, Taitung and Penghu Districts</td><td>Holocene</td><td colspan="2">With fresh coral structures and very porous</td></tr>
<tr><td rowspan="2">Coralline Limestone</td><td>The so-called Riukiu Ls.</td><td>Kaohsiung and Taitung Districts</td><td>Pleistocene to Upper Pliocene</td><td rowspan="2">Non-crystalline, mostly massive, but sometimes showing porous coral structures.</td><td>Poor in MgO, but rather rich in $SiO_2+R_2O_3$</td></tr>
<tr><td>The so-called Gypsina Ls.</td><td>Kaohsiung and Tainan Districts</td><td>Pliocene</td><td>Rich in MgO and $SiO_2+R_2O_3$</td></tr>
<tr><td colspan="2">Lepidocyclina-Miogypsina Limestone</td><td>Taipeh and Sinchu Districts and the eastern flank of the Eastern Costal Range</td><td>Miocene</td><td colspan="2">Non-crystalline, MgO poor, $SiO_2+R_2O_3$ abundant</td></tr>
<tr><td colspan="2">Crystalline Limestone</td><td>Southeastern part of the Taipeh District and the eastern flank of the Backbone Range</td><td>Partly Eocene, but mostly of unknown age</td><td colspan="2">Crystalline and schistose, MgO and $SiO_2+R_2O_3$ poor</td></tr>
</table>

Figure 1 shows the general distribution of each group and figures 2~5 denote the chemical compositions of the crystalline, the Lepidocyclina-Miogypsina, the Gypsina and the Riukiu limestone groups respectively plotted on ternary diagrams.

In spite of the close similarity in physical and chemical properties within each group, the so-called Gypsina limestones differ greatly from one another in the chemical compositions and appear to possess on the ternary diagram a variation field similar to that of the Lepidocylina-Miogysina group, except that the Kwantzuling limestone, which is excluded from figure 4 and is indicated independantly in figure 2 of the preceeding paper, has a peculiar variation field owing to the exceedingly high MgO content. The individual variation fields of the three representatives of this group are given in figure 6 and a general one is constructed therefrom for this group.

*Formerly R. Choh.

For comparison, the general variation fields of these four groups are drawn together in figure 7 based on figures 2–6.

Postscript

Recently a new name, Older Reef Limestone, was proposed by I. Hayasaka, C. C. Lin and T. P. Yen(1) for the so-called Riukiu Limestone, and a local name, Kaohsiung Limestone, was proposed by P. F. Chen(2) for that developing in the vicinities of Kaohsiung city. While I. Hayasaka and others put the Older Reef Limestone into Pleistocene and consider it to be contemporaneous with the Tableland Gravel, P. F. Chen regards the Kaohsiung Limestone, conformably underlain by the Byoritzu beds (in a wide sense), to be Pliocene in age.

In his previous paper,(3) the writer has pointed out that the so-called Riukiu Limestone is partly correlated to the Hsiangshan facies of the Tokazan formation and for that reason must be re-studied from a tectonical point of view. According to him, every limestone conformable to the Hsiangshan facies of the Tokazan formation must be distinguished from the Riukiu Limestone and the application of the name "Riukiu Limestone" must be confined to those limestones that are unconformably underlain by the Tokazan formation.

The so-called Gypsina limestones and most of the so-called Riukiu limestones are but lenticular bodies intercalated in various horizons of the Pliocene formations in southern Taiwan, though most of them are similarly built mainly of reef-coral remains. Therefore, it seems quite meaningless to the writer to propose any new group name for the two, unless the stratigraphical position of each lens is explained, and it is better, by far, to give a local name to every lens stratigraphically well defined.

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