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TERTIARY VOLCANIC ROCKS IN THE PEAK RANGE, CENTRAL QUEENSLAND.

by

R.G. Mollan

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'It is difficult to describe the impressions which the range of noble peaks, rising suddenly out of a comparatively level country, made upon us. We had travelled so much in monotonous forest land ... and ... the dismal scrub ... now ascending, first in fine ranges, and forming a succession of almost isolated, gigantic, conical, and dome-topped mountains, which seemed to rest with a flat unbroken base on the plain below - was spread before our delighted eyes. ... they resemble very much the chain of extinct volcanoes in Auvergne ... If water were plentiful the downs of the peak Range would be inferior to no country in the world.'

L. Leichhardt (1847) - The overland expedition from Moreton Bay to Port Essington.

TERTIARY VOLCANICS IN THE PEAK RANGE, CENTRAL QUEENSLAND

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R.G. Mollan

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SUMMARY

The volcanics in the Peak Range form part of a deeply denuded Tertiary continental volcanic province, covering about 9000 square miles, in Central Queensland. The volcanics consist of:

(a) remnants of a pile of flood basalts, up to 1800 feet thick, arranged along the central part of the Peak Range divide;

(b) basic dykes and plugs in and about the Peak Range;

(c) two groups of well-preserved protrusions, flows, and dykes of dome-forming acidic volcanics, one in the southern part of the Peak Range and the other in the northern part.

The flood basalts occupy a basinal region with an uneven floor of much older rocks (?Lower Palaeozoic to Permian) which form four fundamental structural units. The Tertiary volcanism is related to north-west trending crustal weaknesses associated with the margins of the structural units.

The flood basalts and basic dykes consist dominantly of alkalic (near undersaturated) and tholeiitic (saturated and oversaturated) olivine basalts. Tholeiite, trachyandesite and probable hawaiite are comparatively rare in the volcanic pile. Tholeiitic olivine basalt appears to be more common in the lower part of the pile. Plugs consist dominantly of analcite basanite and olivine teschenite. Phonolite forms an isolated plug east of the range.

A variety of exogenous, endogenous, and thrust domes in the southern part of the range is significantly related to a variety of acidic rock-types, including trachytes, pantellerite, and comendite. Tholoids, associated with vitric tuff, and flows in the northern part of the range,

consist of extremely acidic rhyolite with pitchstone selvages. Rare domes of peculiar 'andesitic' rocks are also present in the north. The southern group of acidic rocks, which contain fayalite, pyroxenes, and several varieties of sodic amphibole, and commonly peralkaline, whereas the northern acidic rocks, containing rare biotite, are peraluminous.

The close spatial relationships of the diverse rock-types, and their typically contrasting modes of occurrence suggest they represent a series of coeval lavas and intrusions, related to a single cycle of dominantly non-explosive volcanic activity. The association is similar to alkalic basalt associations in non-orogenic, continental and oceanic island, environments. Three basaltic magma-types, ranging from thoroughly under-saturated (basanitic) to thoroughly oversaturated (tholeiitic) compositions, are represented. A series of lavas, intermediate in composition between alkalic and tholeiitic basalts are present. The acidic rocks in the south and probable hawaiite are almost certainly the result of differentiation of the dominant alkalic basalt magma-type. The trend of rubidium/barium ratios from the basic to the acidic rocks corresponds to the trend theoretically predicted to occur in a differentiated series. Differentiation appears to have been mainly the result of fractional crystallisation; volatiles probably played a subordinate role. Phonolite was differentiated probably from the basanitic magma and tholeiite was differentiated probably from the tholeiitic basalt magma.

Rhyolite in the northern part of the range is probably the result of assimilation or remobilisation of sialic material, or the extreme differentiation of the tholeiitic basalt magma, or volatile contamination. The rhyolite is apparently related to the probable upheaval of a horst. 'Andesitic' rocks and trachyandesite are the result of either contamination or hybridisation.

SCOPE OF THESIS

This thesis attempts to elucidate several aspects of the Tertiary volcanics in the Peak Range, in particular the origin of well-preserved acid volcanic protrusions, and the origin of a series of diverse rock-types.

Initially the author became interested in the rocks of the Peak Range during the winter months of 1960 when he was a member of a Bureau of Mineral Resources geological field party engaged in mapping the Clermont 1:250,000 Sheet area, at the commencement of a survey to study the Bowen Basin. The author was responsible for mapping the Peak Range during the survey, and for reporting on the volcanics (Veevers, Randal, Mollan, & Paten, 1964). Additional field work in the Peak Range was carried out for brief periods, which totalled about six weeks, during the half-yearly field seasons, from 1961 to 1964, when the writer was engaged in the regional mapping of other parts of the Bowen Basin. During these field seasons, as an addition to his work in sedimentary geology, the writer mapped and cursorily investigated almost the entire Central Queensland Tertiary volcanic province (see Fig. 3). Part-time laboratory work commenced at the Geology Department of the Australian National University in 1963.

The author was encouraged to investigate the volcanics in a broad petrogenetic sense rather than to concentrate on specialised aspects, of which there are many.

Note on the accompanying map, Plate 1

The map presented in Plate 1 covers only the southern and central parts of the Peak Range because the geology in the northern part is complex, and could not be mapped satisfactorily in detail in the field work time that was available; the detailed geology of the northern part of the range is not of immediate consequence in relation to the main aspects of the thesis. However, apart from the detailed mapping, other aspects of the thesis embody the entire Peak Range; also, several samples from volcanics east and west of the range, outside the area mapped, have been studied (Fig. 2).

The map in Plate 1 was compiled at 1:26,000 on overlays of good quality air-photos taken by Adastra Aerial Surveys in 1952. The compilation was subsequently reduced to 1:50,000 scale and traced on a controlled base produced by the Division of National Mapping. The grid of the map is the 10,000 yard Transverse Mercator grid, Zone 7 (Australia Series).

ACKNOWLEDGEMENTS

The author is indebted to his supervisors, Dr. A.J.R. White and Dr. B.W. Chappel, for guidance in petrological aspects of the thesis. Thanks are due to Professors D.A. Brown, Dr. K.A.W. Crook, and Mr. W.B. Dallwitz for helpful discussions in the field. Dr. J.J. Veevers gave the author initial encouragement to pursue the study. Mr. J. Pennington is thanked for explaining the principles and operations of the X-ray spectrograph.

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Dr. A.J.R. White kindly read the manuscript and made helpful criticism. Mrs. N. Mollan helped with the colouring of maps and proof-reading.

INTRODUCTION

Leichhardt (1847) discovered and named the Peak Range in January, 1845, during his successful expedition from Moreton Bay to Port Essington. He named many of the peaks, which he compared, most appropriately, with the 'extinct volcanoes in Auvergne'.

The Peak Range lies between latitudes 22°30'S and 23°0'S and longitudes 147°50'E and 148°20'E in the eastern part of Central Queensland, known more specifically as the Central Highlands. The Peak Range is one of several prominent ranges in this natural region, which includes the Great Dividing and Drummond Ranges. The region ranges in elevation from about 600 feet in the lower reaches of the Mackenzie River to nearly 4000 feet in the Great Dividing Range, about 60 miles south of Springsure. The Peak Range forms a subsidiary divide within the Fitzroy River Drainage Basin, separating tributaries of the Nogoa River from tributaries of the Isaacs and Mackenzie Rivers.

The Peak Range enjoys a sub-tropical climate. The average annual rainfall is about 26 inches, which falls mostly in the summer months. The distance of 100 miles from the coast at Broad Sound influences the reliability of the annual rainfall, which varies eccentrically. The continental modification of the potential tropical climate is also felt in the high diurnal and annual temperature ranges; the summers are typically hot with temperatures frequently over 100°F, and in winter the days are warm (70° to 80°F) and the nights frequently cool to frosty.

The Peak Range area is covered mainly by heavy-textured dark soil, a weathering product of basalt. The soil supports dominantly a savannah type of vegetation, which is characterised by a cover of tall grasses and an even, widely spaced, growth of trees. Thick brigalow scrub occurs in isolated patches, whereas some areas, devoid of trees, are open grassy downs, known as the Peak Downs.

The Peak Range is 150 miles west-north-west of Rockhampton, the nearest large coastal town, and 30 miles east-north-east of Clermont, the nearest inland centre. Clermont is served by a branch railway from Emerald which lies on the inland railway from Rockhampton. Formed roads provide access from the Peak Range to Clermont, Capella, and the Pacific Highway at Lotus Creek; the Clermont-Mackay Highway passes the northern end of the Peak Range. The environs of the Peak Range are comparatively closely settled, the southern part to a marked degree. Homesteads are served by tracks; in dry weather most parts of the Peak Range are accessible in four-wheel drive vehicles, whereas in wet weather the area becomes impassable.

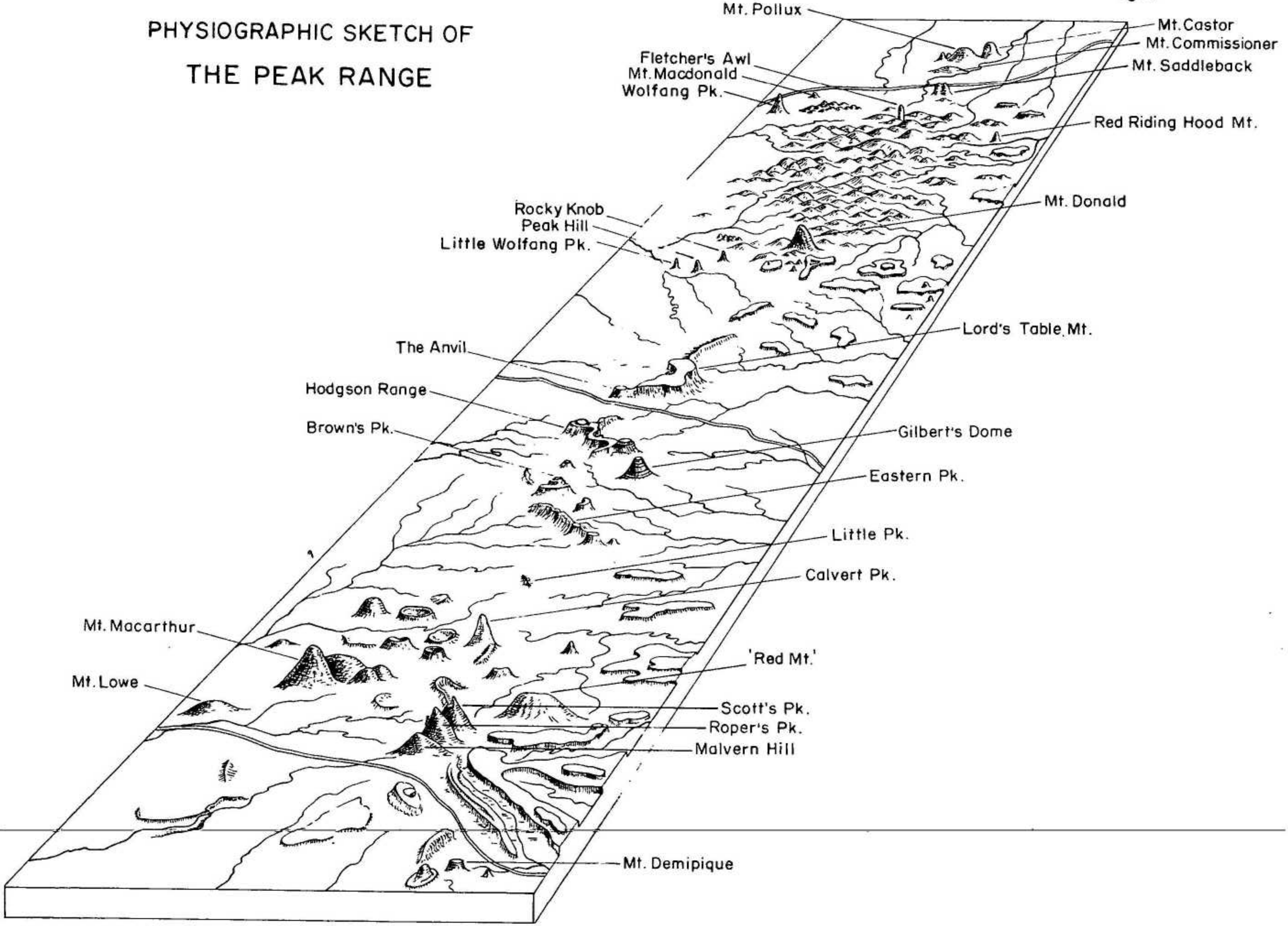
Cattle grazing is the dominant industry of the settlers; several graze sheep. Water for stock and domestic purposes is obtained partly from bores; good aquifers are found in basalt. In recent years large areas of the open downs country has been cultivated for the successful cropping of wheat, sorghum, linseed, safflower, and cotton.

PHYSIOGRAPHY

The Peak Range (Fig. 1), as its name relates, is a chain of prominent and picturesque mountains, which are separated by comparatively low, wide gaps (Plate 2). The chain of mountains extends north-westerly from Mount Demipique in the south to Mount Castor in the north. Strictly as a divide,

Fig. I.

PHYSIOGRAPHIC SKETCH OF THE PEAK RANGE



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the Peak Range terminates northwards at a point six miles S.S.E. of Mount Castor (Fig. 2), where it intersects the junction of the Drummond Range and Denham Range divides.[1]

Heights above sea level were measured by aneroid barmeter; control was provided by surveyed heights on main roads and at several trigonometrical stations. Relief in the Peak Range is about 1700 feet, from 2675 feet at Brown's Peak in the central part, to about 1000 feet at several points along the watershed in the southern part of the range. The heights of several mountains over 2000 feet above sea level include Lord's Table Mountain (2485 feet), Gilbert's Dome (2460 feet), Mount Macarthur (2425 feet), Eastern Peak (2395 feet) and a peak known locally as 'Red Mountain' (2320 feet). The heights of Scott's Peak, Roper's Peak, Calvert Peak, and Mount Donald were calculated by trigonometry to be over 2000 feet high. Many other peaks are over 1500 feet high, including Wolfang Peak (1887 feet) and Mount Castor (1864 feet).

A threefold division of the Peak Range into northern, central, and southern parts is based on regional differences in the morphology and distribution of peaks (Fig. 1). The peaks in the northern and southern parts are dominantly discrete, rocky, conical and domal, puys and pinnacles which contrast with the ridged and cupola-shaped peaks and mesas of the central part of the range. The distribution of the peaks and their relationship to the watershed of the range differs in each of the three parts. The peaks are closely clustered about the watershed in the

[1] In this report the term 'Peak Range' refers to the chain of mountains between Mount Demipique and Mount Castor.

Plate 2 Remnants of Tertiary volcanism in the central and southern parts of the Peak Range, from Campbell's Peak, 12 miles eastwards. Peaks in the right-hand half are remnants of flood basalts; peaks to the left are acid volcanic protrusions. Light areas are grassy downs on heavy-textured dark soil.

southern part, whereas in the north they are widely separated from the watershed. Peaks in the central part of the range are distinctly aligned along the watershed, and several peaks are joined by sharp-crested, sinuous ridges.

The northern part of the Peak Range consists mainly of a broad rugged upland block, between Mounts Saddleback and Donald; the block is about 2000 feet high a few miles south of Fletcher's Awl. Most of the prominent conical and domal peaks, including Mounts Castor, Pollux, Saddleback, and Donald, and Wolfang Peak are arranged around the northern, western, and southern margins of the block, which is roughly circular in plan and characterised by dendritic drainage; Fletcher's Awl forms a fine pinnacle protruding from the block (Plate 12). Most peaks protrude sharply from gently undulating downs, about 1300 feet high, which borders the block; low benches and mesas protrude from the downs east and south of the block.

The central part of the range (Plate 2) is dominated topographically by a prominent chain of ridges and ridged peaks (Hodgson Range, Eastern Peak), cupola-shaped peaks (Gilbert's Dome, Brown's Peak), and prominent mesas (Lord's Table Mountain). The peaks and ridges are set in gently undulating downs, about 1000 feet high, with low benches and mesas; the footslopes of the mountains and small ranges have graded profiles which contrast with the angled, non-graded, profiles made by the peaks in the southern and northern parts of the range.

The southern part of the range (Plate 2) consists of a cluster of closely spaced conical and domal puys, pinnacles, and short convex ridges which are set in gently undulating downs, about 1000 feet high. Dissected tableland and several prominent mesas are present immediately east of the cluster of peaks which are situated on the watershed.

The Peak Range is a subsidiary divide in the Fitzroy River drainage basin. Watercourses east of the watershed join the Isaacs and Mackenzie Rivers and watercourses west of the watershed join the Nogoa River; the Isaacs River is a tributary of the Mackenzie River whereas the Nogoa River is the name for an upper branch of the Mackenzie River.

Most creeks in the Peak Range flow only during very wet weather; several creeks are fed by springs which flow perennially during years of average rainfall. Most watercourses are choked with stream sediments which range from boulder gravel to dark silt and mud.

PREVIOUS INVESTIGATIONS

Reid (1928) briefly described the volcanics of the Peak Range. His report is mainly a topographic description of the range with a discussion of age relations between olivine basalts, trachytes, and rhyolites; several petrographic descriptions by A.K. Denmead are included in the report.

A short account of the volcanics by Brunnschweiler (1957) contains some stimulating theories about their age. Contrary to Reid's and the present author's views he considers the acid lava protrusions to be much older than the flood basalts.

Richards (1918) made a brief study of similar volcanics near Springsure, about 100 miles southwards.

STRATIGRAPHIC NOMENCLATURE

The volcanics of the Peak Range are separated, for the purposes of regional mapping, into two major units:

(1) an unnamed suite of essentially basic volcanics, which occur dominantly as flows (flood basalts), and as plugs, dykes, and sills;

(2) the Peak Range Volcanics, a suite of acidic volcanics which occur as prominent discrete bodies (protrusions), dykes, and flows; very minor occurrences of vitric tuff and phonolite are included.

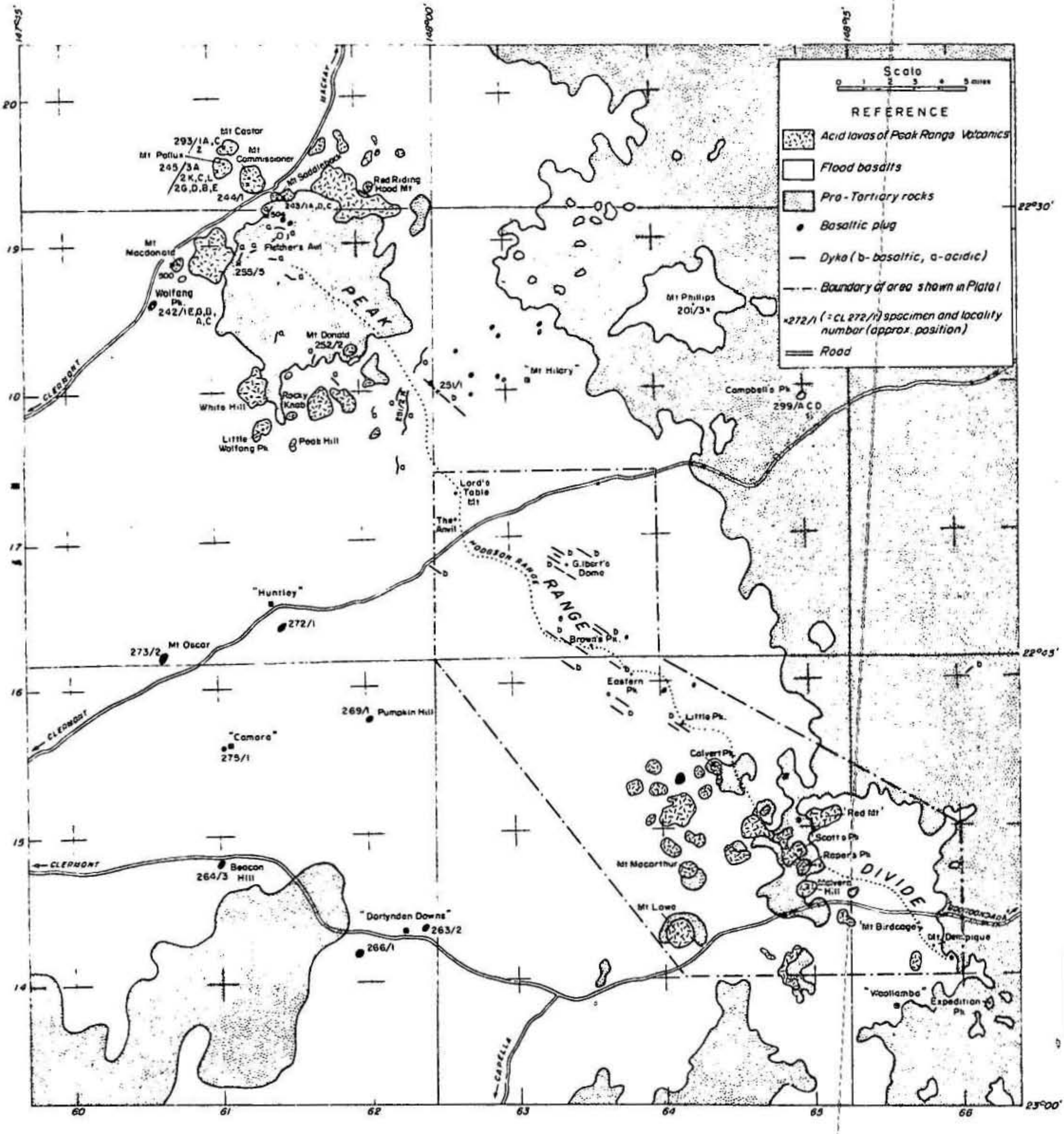
The name, Peak Range Volcanics, was proposed by the author, and approved by the Queensland Committee of Stratigraphic Nomenclature in 1961. The name has been published in Veevers, Randal, Mollan, and Paten (1964).

DISTRIBUTION AND AGE OF THE VOLCANIC ROCKS

Figure 2 shows the distribution of the volcanics in the Peak Range and its environs. The flood basalts form the chain of mountains in the central part of the Peak Range where the lava pile is about 1800 feet thick. The flood basalts are also represented in the southern and northern parts of the range, and at Mount Phillips, 12 miles east of the range by several prominent remnants, about 1000 feet thick. Much of the intervening areas between these thick remnants and much of the environs of the Peak Range are covered by a veneer and outliers of flood basalts, commonly less than 100 feet thick.

FIGURE 2.

DISTRIBUTION OF TERTIARY VOLCANICS IN THE PEAK RANGE



The Peak Range Volcanics form a cluster of mountains and hills in the southern part of the range and more widely separated mountains and hills in the northern part.

Many basaltic dykes are present in the central part of the range; several occur in the southern and northern parts. Basaltic and gabbroic plugs are present throughout the range and its environs.

The flood basalts and acid protrusions of the Peak Range Volcanics are petrogenetically related, and field evidence shows an intimate spatial relationship between the two units. The age of the two units is almost certainly confirmed as Tertiary by radiometric age determinations of basalt and trachyte specimens collected by the author from similar flood basalts and acid protrusions to the south, in the Emerald and Springsure Sheet areas; the flood basalts extend almost continuously from the Peak Range southwards through these two Sheet areas (Fig. 3). The age determinations were carried out at the Australian National University; ages range across the Oligocene-Miocene boundary (A.W. Webb, pers.comm.).

GEOLOGICAL SETTING

In this chapter, which is illustrated by Figure 3, the writer draws on regional geological concepts he acquired from active participation in regional mapping of the Bowen Basin and adjacent regions in the Clermont, Emerald, Duaringa, Springsure, and Eddystone 1:250,000 Sheet areas. The results of the mapping in the Clermont and Emerald Sheet areas are presented in two published Bureau of Mineral Resources Reports (Veevers, Randal, Mollan, and Paten, 1964, and Veevers, Mollan, Olgers, and Kirkegaard, 1964). Reports on the Duaringa, Springsure, and Eddystone Sheet areas are in preparation (Malone, Olgers, & Kirkegaard, in prep.; Mollan, Exon, & Kirkegaard, in prep.; and Mollan, Jensen, Forbes, Exon, and Gregory, in prep.) Much of the regional mapping in the Bowen Basin has been synthesised by Malone (1964). The postulated relationships between the older structural features of the region and the Tertiary volcanism, outlined in this chapter, are solely the conjectures of the present writer.

The Central Queensland Tertiary volcanic province

The volcanics of the Peak Range are part of an extensive Tertiary volcanic province in Central Queensland. The province consists of a deeply eroded sheet of flood basalts, covering about 9000 square miles. Minor interbedded pyroclastics are present in significant quantity in remnants of the volcanic pile in the Minerva Hills, 10 miles north of Springsure (Fig. 3); the Peak Range lies in the northern part of the province. Flood basalt feeders are represented by numerous basic plugs, dykes, and sills, throughout the province. Four centres of acid lava protrusion are present in the province, two in the Peak Range (in the northern and southern parts), one, 70 miles southwards in the Minerva Hills, and another, 60 miles farther southwards in the Great Dividing Range. The flood basalts interfinger with lacustrine and fluviatile sediments, northwards and eastwards.

Pre-Tertiary structure

The flood basalts and minor pyroclastics of the Central Queensland volcanic province were extruded on an uneven surface (with a relief of at least 2000 feet) of much older rocks, ranging in age from probable Lower

Palaeozoic to Cretaceous. These rocks represent several fundamental structural units, whose approximate positions are shown in Figure 3:

(1) the Anakie Inlier, a structural high, consisting of probable Lower Palaeozoic metamorphics and Devonian granite; the Nebine-Nogoa Ridge, is a buried extension of the same structural high;

(2) the Drummond Basin, a major Devonian to Lower Carboniferous downwarp;

(3) a block of Upper Devonian to Lower Carboniferous volcanics;

(4) the Bowen Basin, a major Lower Permian to Triassic downwarp which consists of the Lower Permian Denison Trough, Springsure Shelf and Comet Ridge, and the Upper Permian to Triassic Mimosa Trough;

(5) the Great Artesian Basin, a broad, Lower Jurassic to Cretaceous downwarp.

The distribution of the Tertiary volcanic products shows a distinct relationship to crustal weaknesses associated with the margins of the structural units. The regional structural grain of the area, which changes from a northerly trend in the south, to a north-westerly trend northwards is reflected by the distribution of, and lineaments within, the Tertiary volcanics.

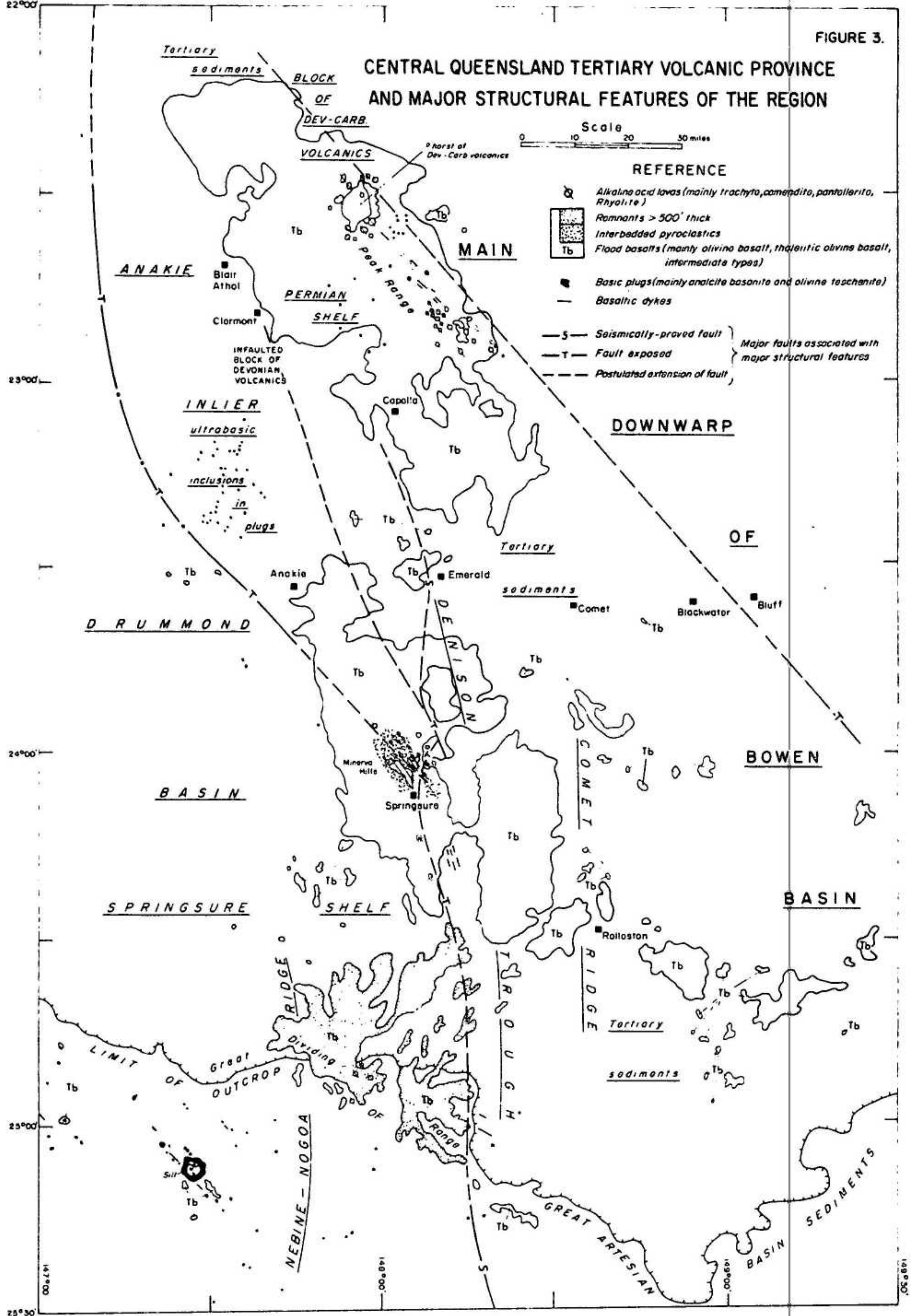
The axis of the Peak Range is postulated to lie on a major pre-Permian fault (Fig. 3). Direct evidence of weakness along the lineament is exposed in faulted Permian-Triassic rocks to the south-east. A marked north-west trending lineament in the air-photos north of the range in Upper Devonian-Lower Carboniferous rocks is probably an expression of the major fault. Acid volcanic protrusions have been emplaced round the upland block of Lower Palaeozoic to Carboniferous rocks in the northern part of the Peak Range. Permian sediments dipping at 20° off the west flank of the block confirm post-Permian uplift, and the block is tentatively regarded as a horst, uplifted during the Tertiary volcanism.

The flood basalts were extruded subaerially into shallow basinal areas that were initiated by epeirogenic movements, probably related in turn to movement along the major faults shown in Figure 3. The presence of Tertiary lacustrine and fluviatile sediments, locally over 1000 feet thick, within the basaltic province attest crustal sagging in the Tertiary. Much of the thick remnants of the flood basalt sheet lie in structurally low areas which are bounded by parts of the major faults. Isostatic crustal sagging probably progressed during the growth of the volcanic pile and the deposition of lacustrine and fluviatile sediments. Basic lavas were extruded from fissures and central conduits along the planes of the major fault zones. The localised development of highly differentiated acid lava protrusions is related to the concentration of a residua in cupolas probably related to the faults. The interbedding of basic lavas and acid pyroclastics in the Minerva Hills suggests that the process of repeated generation-differentiation of basaltic magma was synchronous with movements along the faults.

The faults along the margins of the Denison Trough and the Drummond Basin are thrust faults with no apparent transcurrent movement.

The Tertiary volcanism is possibly related to relaxation of compression along the faults.

FIGURE 3.



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PRODUCTS OF VOLCANICITY

INTRODUCTION

Apart from very minor occurrences of pyroclastics, the volcanics of the Peak Range consist of several fundamental forms of lava extrusion, shallow (lava feeder) intrusion, and lava protrusion. The extreme variation in magma composition produced, on the one hand, flood basalts and, on the other, viscid acid lava protrusions. The scarcity of pyroclastics is attributed mainly to erosion; several occurrences of pyroclastics are tentatively related to almost completely denuded tuff cones. Erosion has also stripped away large masses of the pile of flood basalts; only the mountains in the central part of the Peak Range remain to attest the immense mass of flood basalts originally extruded (Plate 2). No basaltic lava cones, or shield volcanoes have been identified. The basaltic lavas are commonly deeply weathered and poorly exposed. In contrast, the acidic lava protrusions are well preserved and well exposed.

The history of volcanic events is difficult to trace in detail with the amount of field data available. In this respect, emphasis was placed on an attempt to distinguish genetic forms in the acid lava protrusions, and to interpret some aspects of their modes of origin, in particular their histories of growth.

FLOOD BASALTS AND FOCI OF ERUPTION

Remnants of a high plateau of flood basalts consist of numerous apparently horizontal flows of basic to intermediate composition. The pile of flows has a maximum thickness of about 1800 feet at Brown's Peak (Plate 3), and a thickness over 1000 feet at several other mountains in the central and southern parts of the Peak Range, and at Mount Phillips. Water bores drilled in the downs surrounding the range have penetrated up to 300 feet of basalt. The area between these widely separated thick remnants was probably a continuous plateau of flows before erosion commenced; the plateau also probably extended several miles westwards of the range. The base of the flood basalt sheet has been observed resting at heights ranging from 900 feet to 1200 feet above sea level.

Deep weathering of many flows and the presence of scree and talus on the flanks of the mountains makes it difficult to determine the number, and individual thicknesses, of flows present. For the same reasons it is difficult to determine in detail, the succession of lava-types; only broad conclusions were reached (see Petrography). The only well-exposed and commonly fresh rocks are dark bluish, fine-grained basalts which form rocky benches and abutments in the flanks of the mountains.

The lava pile in the central part of the range consists of probably 50 flows in the uppermost 1000 feet, making the average thickness of the flows, 20 feet; several benches of hard basalt, which appear to be single flows, are individually over 50 feet high. The resistant flow capping Lord's Table Mountain and The Anvil is between 100 and 150 feet thick (Plate 4). About fifteen basalt benches are present in the pile; some form distinct ledges which can be traced round the flanks of the mountains (Plate 1). Small outcrops in the intervals between the benches reveal rotten, friable rocks which have formed soft talus resting on the bench below (Plate 4).

Plate 3 Remnants of the pile of horizontal flood basalts in the central part of the Peak Range, looking south from Gilbert's Dome. The largest remnant is Brown's Peak; Eastern Peak is in the centre of the photograph.

Plate 4 The 100 feet to 150 feet thick trachy-andesite flow capping Lord's Table Mountain and The Anvil. The flow is underlain by flood basalts - note talus.

The rocks are commonly extremely vesicular and amygdaloidal; amygdules of zeolites, and vugs of calcite and chalcedony, isolated from their host rocks by weathering, commonly occur in profusion in the talus; clay minerals occur commonly in vesicules. Some of the soft rocks are clearly deeply weathered basalts; others, commonly light grey and pinkish, probably represent intermediate lavas; some very soft non-vesicular red rocks are possibly fine-grained pyroclastics or boles. The deeply weathered flows represent quiescant intervals between volcanic phases.

Fine-grained basalts, which are commonly porphyritic, but not obtrusively so, and rarely vesicular, probably form more than two-thirds of the volcanic pile. The well-exposed dark, bluish basalts show features typical of flood basalts; in profile individual flows have a massive-textured lower part passing upwards into a platy jointed section with small vesicles; some flows show crude columnar jointing. Exposed contacts with adjacent flows are rare.

Many basaltic dykes and several plugs have been identified; probably many more are present. Most of the dykes appear to be in the central part of the range where they cut the flood basalts. The dyke swarm is aligned north-westerly; many of the dykes dip at high angles to the south-west and north-east. They are commonly less than ten feet wide, and rarely over 20 feet wide; some are prominently lenticular. Several dykes are exposed for more than half a mile; most crop out over much shorter distances. The dykes have chilled margins which are very fine-grained and finely vesicular. Platy joining, parallel to the sides, is present in the margins; thick normal jointing is present in the centre. Dykes have been observed intruding Permian sandstone east of the range; narrow zones of indurated sandstone border the intrusions.

Basaltic sills have been observed intruding shallow-dipping Permian sandstone to the east of the Peak Range. Their presence within the flood basalt pile is difficult to confirm and none have been positively identified in this environment.

Several small conical hills of well-exposed basaltic rocks in the Peak Range and its immediate environs present vent (lava feeder) plugs (Fig. 2). The hills are circular in plan, commonly between 100 yards and 300 yards in diameter; they are commonly between 200 feet and 300 feet high. The basalt commonly shows vertical and inclined polygonal columnar jointing, with columns between one and two feet across and up to 30 feet long. Several plugs lie on the trend of dykes and represent the restriction from fissure to central vent eruption. Probably many more basic plugs are present in the Peak Range but shrouding by the flood basalts, and erosion, make them difficult to identify both in the airphotos and on the ground. Similar conical plugs of gabbroic rocks are present west of the range, and a body of gabbroic rock, which probably represents a plug, is present in the southern part of the range (Plate 1).

The plugs are distinguished from the flood basalt remnants on the following grounds:

(i) they have uniform conical morphologies in contrast to the flat-topped hills of flow remnants;

(ii) they lack stratification, a prominent feature in the flow remnants (Plate 3);

(iii) well-developed columnar jointing, commonly inclined, is common, a rare feature in the flow remnants;

(iv) they are uniformly circular to slightly elliptical in plan, and commonly lie on the trend of dykes;

(v) they commonly consist of coarse teschenitic rocks.

The close spatial relationship between the thick remnants of flood basalts and the swarm of dykes in the central part of the range strongly suggests that this area was the main focus of eruption of the basaltic lavas.

ACID VOLCANIC PROTRUSIONS

Introduction

The most interesting and picturesque products of the Tertiary volcanicity in the Peak Range are numerous protrusions and dykes, and several flows and composite bodies of acid volcanics (the Peak Range Volcanics). Many of the bodies have bold, youthful morphologies, protrusions from fairly flat country.

The favorable preservation and exposure of the protrusions allows reliable inference of their original forms and histories of growth. Several distinct genetic forms are present in the Peak Range; they compare with forms studied in other much more recent and complete volcanic provinces. The landforms are related to a recent period of exhuming from a shroud of flood basalts and, possibly, pyroclastics. Evidence remains to attest that several protrusions in the northern part of the range were extruded from vents which previously erupted tuff; most of the bodies in the southern part of the range were probably not emplaced over vents of previously active volcanoes, and have an intrusive origin.

Plates 5 to 22, illustrating the acid volcanic protrusions, are presented at the end of this chapter.

Nomenclature of genetic forms

Classifications and nomenclatures have been devised by many workers for protrusion of acid volcanics. The classical writings of many authors, including Scrope on Auvergne, Daly on the Islands of Ascension, St. Helena, and Hawaii, Lacroix and Perret on Mount Pelée, and Schneider on morphological nomenclature led to the introduction of many terms which have been readily used out of context, and misapplied by later workers. In reviewing the nomenclatures and the acid volcanic bodies in the many areas from which the terms were derived, Williams (1932) selected the most appropriate terms which define forms with common, fundamentally distinct modes of origin. Williams indicated that distinctions between the different forms is arbitrary and not always clear; local environment necessarily demands a refining of the definitions. Later workers, especially Cotton (1944), have confirmed, however, that Williams' terms accentuate important fundamental differences in the modes of growth of protrusions.

The apparent high degree of preservation of the Peak Range protrusions makes it possible to postulate their original forms and demonstrate some aspects of their growth and formation. Three essentially different genetic forms of protrusions (exogenous, endogenous, and thrust domes) are distinguished; they compare essentially with the types defined by Williams (1932, p.54). The term 'thrust dome' is preferred to Williams' 'plug dome' because of the lack of unequivocal evidence indicating that these protrusions plugged a previously active vent.

The term 'protrusion' is used in a general descriptive sense (see Williams, 1932, p.51) and is not intended to imply a specific genetic form of viscid lava as used by Rittman (1962) and others.

The term 'dome' in volcanology is now generally used in reference to viscid acid lava protrusions rather than broad basaltic domes, now more satisfactorily referred to as 'shield volcanoes' (Williams, 1932, p. 54). Williams has also shown that rarely, in Daly's (1933) original sense, is the term 'endogenous' applicable to acid lava domes, most domes having an 'exogenous' component. However, the fundamental contrast in origin between the exogenous and endogenous domes in the Peak Range is sufficient to satisfy the distinction in nomenclature. Exogenous domes were formed by outward effusion of viscid lava from the tops of the growing domes, whereas endogenous domes grew by expansion from within a solidifying carapace. The terms 'cumulo-dome' and 'tholoid' are used essentially in the senses defined by Cotton (1944); 'tholoid' is reserved for endogenous domes emplaced in active vents; in the Peak Range, 'tholoids' show distinct differences to 'cumulo-domes'. Several basined and arcuate domes represent genetic modifications of the essential forms. Hybrid domes, composite protrusions, dykes, dyke-protrusions, and viscid lava flows (coulees) are also present in the Peak Range. Comparatively large masses of acidic volcanics in the northern part of the range (Fig. 2) are complexes of dykes, flows, and protrusions.

Morphology and preservation

The morphologies of the protrusions are shown in Figure 4, and in the Plates at the end of this chapter.

The domal bodies are separated into four morphological forms, distinguished by letters A, B, C, and D, on the basis of differences in flank profiles, degree of convexity, size, and outlines in plan. All are essentially smoothly convex; the flanks of the A, C, and D forms increase in plunge towards their bases, where the plunges are commonly vertical; the flanks of the domal B protrusions are slightly concave, forming graded profiles with the plain. The degree of convexity increases progressively from A to D; many of the domal A, B, and C protrusions are between $\frac{3}{4}$ mile and a mile in basal diameter; the D domes are less than half a mile across. Most domal protrusions are circular in plan; the domal A forms, and the domal C form of 'Red Mountain', are elliptical in plan.

The conical forms have much lower basal diameter to height ratios than the domal forms. The flanks plunge steeply, at up to 45°, and are vertical to overhanging at the base. In plan they are circular to slightly elliptical, with diameters ranging from $\frac{1}{2}$ mile to $\frac{3}{4}$ mile.

The bowl-shaped bodies are separated into forms A and B; the A forms have distinct depressions moulded into the crests of broad cylindrical bodies, about half a mile in diameter. The bowl-shaped B protrusions are much lower, with broader rims encompassing the depressions.

The barchan-shaped protrusions have, as the name relates, very similar morphologies to barchan sand-dunes, with steep outer walls, shallow-dipping inner flanks, the quarter moon-shaped plans.

The pinnacles, which occur only in the northern part of the range, have narrow cylindrical morphologies with highly convex crests.

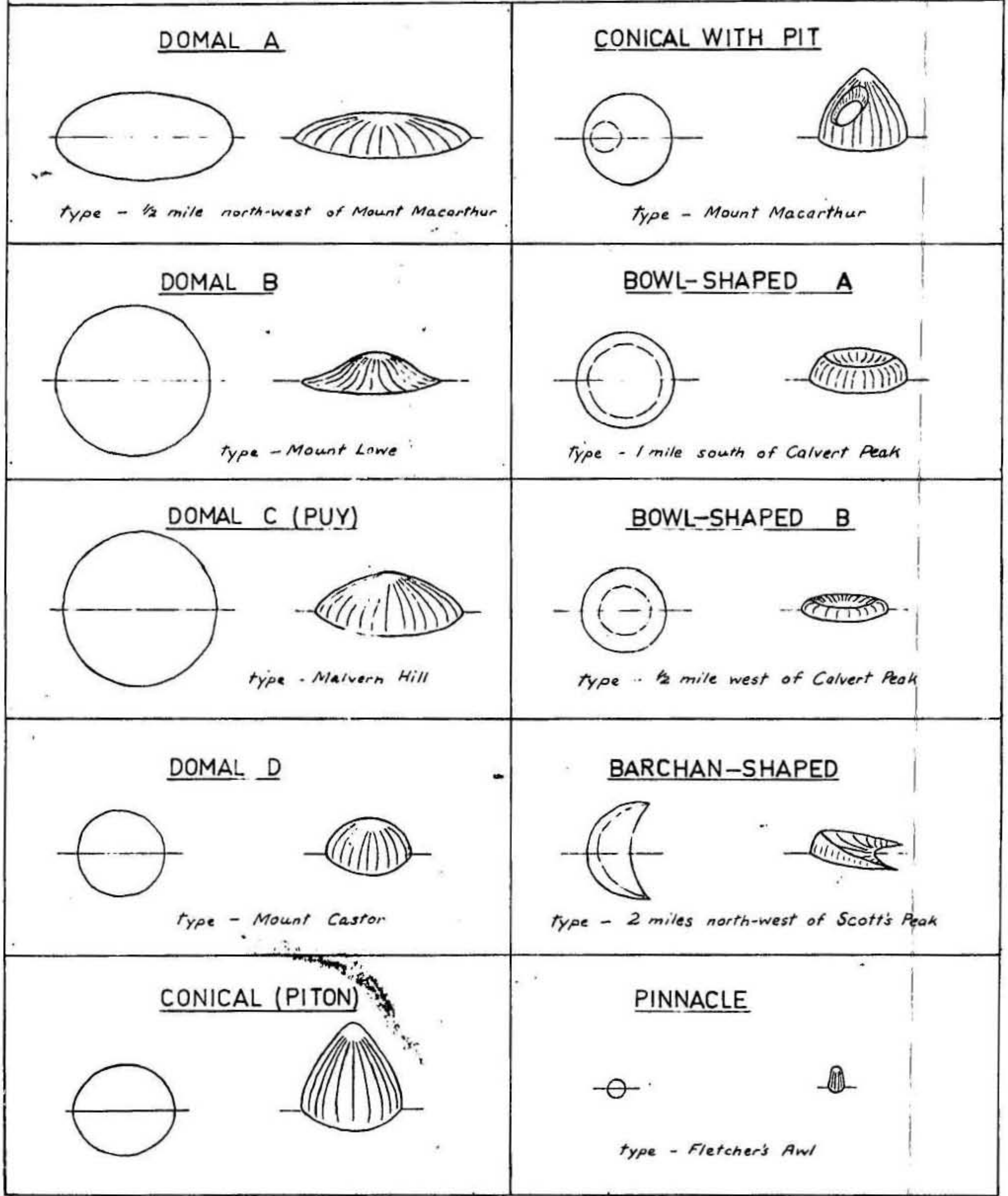
Several composite protrusions have complex morphologies; many dykes and dyke-protrusions form ridges, and flows, convex spurs, known as coulees (Cotton, 1944, p. 154).

Comparison with landforms of viscid lava protrusions in other parts of the world show that the domal (C) protrusions are similar to the 'puys' of Auvergne and the conical protrusions are like Perret's 'pitons' (Cotton, 1944, p. 175). The protrusions in the northern part of the Peak Range show fewer morphological variations than the protrusions in the south; most are domal (D) protrusions and pinnacles, with several pitons.

Figure 4

MORPHOLOGY OF ACID LAVA PROTRUSIONS IN THE PEAK RANGE

approximately to scale 1 mile = 3 centimetres



The high degree of preservation of the protrusions is related to several factors:

(i) their discrete, monolithic, massive forms;

(ii) the naturally tough, resistant character of the acid volcanics to chemical weathering and erosion;

(iii) the preferential erosion of layered, basaltic, masses and soft pyroclastics which originally formed a protective shroud - the Peak Range region is apparently in a period of rapid erosion at present so that only comparatively recently have the protrusions been totally exposed, and their lower parts exhumed.

The protrusions are only now apparently suffering destructive denudation; weathering along joints is the dominant weakening factor. The cavernous weathering of many protrusions, notably Fletcher's Awl (Plate 11) is related to chemical weathering of soft, hydrothermally-altered pockets of rock.

Genetic features

(i) Autobreccia consists of angular fragments of acid volcanic rocks commonly 'welded' by lava of similar composition. The extremely angular fragments show a wide variation in size but are commonly about pebble size. The interfragmental lava is commonly flow banded, the flow bands enclosing angular fragments. Some autobreccia consists of several generations of acid lava which has been successively brecciated and 'welded', whereas some is sheared and fractured rock which has not been 'welded' by new lava. Autobreccia is well exposed in the bare rocky flanks of many protrusions; differential weathering tends to etch the interfragmental lava (Plate 17). Zones of autobreccia roughly parallel the flanks. The zones are individually a few inches to several feet thick; several overlapping zones, separated by distinct joint planes, form a layer of autobreccia up to twenty feet thick in some protrusions.

(ii) Jointing is the most consistently prominent feature of the acid volcanic protrusions. Five sets of joints are recognised:

(a) a major set of vertical radial joints (Plate 18):

(b) a set of inclined joints which are commonly normal to the vertical radial joints (Plate 18);

(c) platy foliation, which parallels the flanks in many protrusions (Fig.5).

(d) polygonal columnar joints, which vary greatly in size and attitude (Plates 9, 13, 15, 16, 19,21);

(e) fine, irregular shear joints commonly in the margins of the protrusions (Plate 17).

Major inclined joints through the body of the Wolfgang Peak protrusion (Plate 15) appear to be unique.

(iii) Glassy selvages, and tuffs. Outcrops of dark olive green glass (pitchstone), commonly sheared and splintery, and in places porphyritic, and in others, flow-banded, are present about the bases of the protrusions of Mounts Castor, Pollux, Saddleback, and Macdonald, Wolfgang and Red Riding Hood Peaks, and about other protrusions and composite dyke-flow bodies in the northern part of the range; no glassy rocks have been found in the southern part of the range. The glassy rocks are commonly closely associated with welded lithic-vitric tuffs which also occur only in the northern part of the range.

(iv) Diapiric structures are commonly exposed in the country rocks about the protrusions in the southern part of the range. Near vertical Permian sediments were observed close to the walls of several protrusions; dips rapidly decrease to horizontal away from the protrusions, so that the zone of affected dips is rarely more than half a mile wide. An exposed contact between an overhanging slickensided northern wall of the Roper's Peak protrusion and Permian sediments, dipping away from the wall at 70°, (Plate 22) shows a complete lack of any alteration of the updomed sediments.

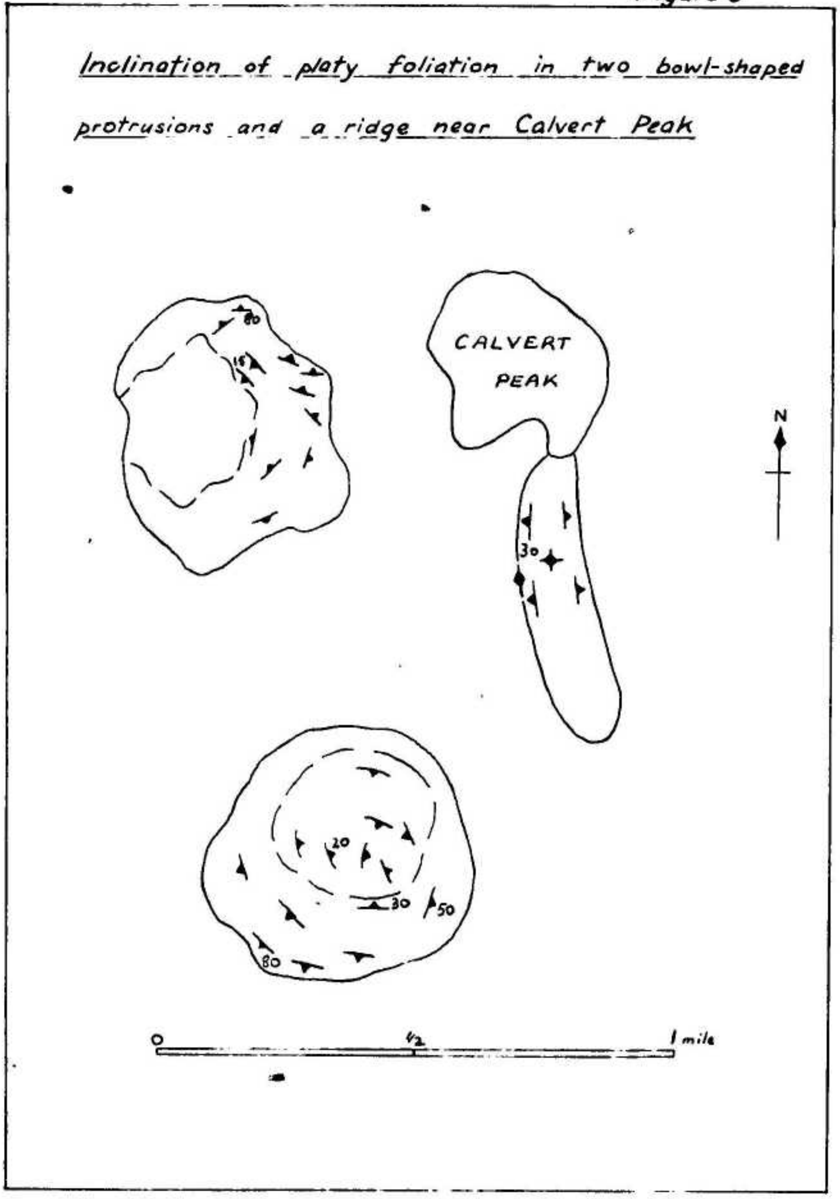
(v) Scree: the lower parts of many protrusions are shrouded in thick angular boulder scree of acid rocks (Plate 7).

(vi) Flow-banding, commonly contorted, is well developed in many protrusions. Spheroidal, concentrically-banded structures ('stone-bubbles') about $\frac{1}{2}$ inch across, are commonly associated with the flow banding. Clots and streaks of femic minerals in the light coloured acid volcanic rock of the main mass of Mount Macarthur are distinctly aligned in vertical planes, giving the rock a spotted, banded appearance.

(vii) Vesicular rock is commonly found in some protrusions in the southern part of the range, especially near the summit of the domal (B and C) and barchan-shaped bodies (Fig. 4). Coarse-grained clots of rock are commonly associated with the vesiculation.

(viii) Small caverns and pits stud the face of protrusions in the northern part of the range, a feature well-developed at Fletcher's Awl and Mount Castor (Plates 9 and 11). Large cavities are present in the domal carapaces of Mounts Castor and Saddleback (Plate 9).

Figure 5


Inclination of platy foliation in two bowl-shaped protrusions and a ridge near Calvert Peak
80
15
CALVERT PEAK
N
30
20
30
50
80
0
½
1 mile

(ix) Several <u>xenoliths</u> of basaltic rocks (one to two inches across) have been found in the main bodies of several protrusions.

<u>Origin</u>

(i) <u>General considerations</u>

Brunnschweiler's (1957) theory, based on a geomorphological argument, that the flood basalts and acid volcanic protrusions are not coeval, but belong to separate periods of volcanism, widely separated in time is discounted in the light of the following evidence:

(a) the petrologic data presented in this thesis strongly suggests that the acid volcanics represent residua derived by processes of differentiation from a basic parent magma which produced the flood basalts; despite the deep denudation of the volcanic province it is clear that the volume ratio of basic to acidic lavas was originally very large, agreeing with a single magmatic origin for the two;

(b) the presence in the Minerva Hills, to the south, (Fig. 3) of <u>interbedded</u> basic and acidic volcanics, of closely similar composition to the volcanics in the Peak Range, and the presence of acidic volcanic protrusions with the same high degree of preservation as the Peak Range protrusions;

(c) the field evidence is unfortunately equivocal; for example basalt fragments in acidic protrusions and vitric tuffs about protrusions, dykes protruding through basaltic flows, and basalt on the lower flanks of protrusions are not confirmatory of relative age relationships; the trachyandesite flow capping Lord's Table Mountain shows however that intermediate volcanics post-date the flood basalts;

(d) the viscosity of acidic lavas is so high that they normally form extremely convex extrusions and the contrast between the extensive lateral flow of low viscosity basaltic lavas is common in many volcanic provinces.

The processes of concentration of acid magma into cupolas which moved to the surface to form protrusions are related to differentiation and tectonic environment; volatiles are assumed to play an important role. Presumably the concentration of the protrusions in two localised areas indicates crustal weaknesses favorable to the formation of cupolas. Contrasts in the form of extrusion and composition of the acidic lavas in the northern and southern parts of the range is probably related to different tectonic environments. The apparent arrangement of the acidic protrusions in the north about a probable horst is significant.

(ii) Vents and diapirs

Several acid volcanic protrusions form parts of composite volcanoes, whereas other protrusions represent, probably, monogenous volcanoes. Remnants of welded vitric tuff with basalt fragments, restricted to the perimeters of several protrusions in the northern part of the range (e.g. Mounts Castor, Pollux and Saddleback, and Wolfang Peak) strongly suggest the protrusions occupy vents which previously produced tuff cones. Several small basaltic xenoliths in several protrusions without tuff remnants also suggest the presence of composite volcanoes.

Structure contours on a fossil marker bed (the clarkei-bed) in Permian strata has shown the high structural level of the beds about the southern part of the Peak Range compared with the low level of sub-horizontal beds eastwards (Veevers, Randal, Mollan, and Paten, 1964). The high structural level is related to diapiric structures in Permian sediments about many protrusions. Evidence suggests an independent, intrusive-extrusive origin for the protrusions, which are inferred to have uplifted the sediments before extruding diapirically. On the other hand, a degree of diapiric updoming can be attributed convincingly to friction between upthrust viscid lava and Permian rocks lining vents.

(iii) Modes of growth

Table 1 summarizes the features associated withthe four essentially different forms of volcanic domes, present in the Peak Range. The distinct genetic differences in the domes are inferred from a study of the preferred distribution of the features. Figure 6 illustrates the essential differences in the modes of growth of the domes. The origin of hybrid, genetically modified, and composite domes, and other forms of acidic lava extrusion are discussed.

Exogenous domes

The morphology and internal structure of the trachyte dome at Mount Lowe is consistent with the mode of lava extrusion shown in Figure 6 for exogenous domes. Extrusions of viscid trachytic lava superposed preceding extrusions by eruption from the summit of the growing dome. Convolute and undulating platy foliation in the flanks of the dome is the consequence of the flowage of viscid lava down the flanks of the dome. The growth is compared essentially with the classic theory of Scrope for the growth of

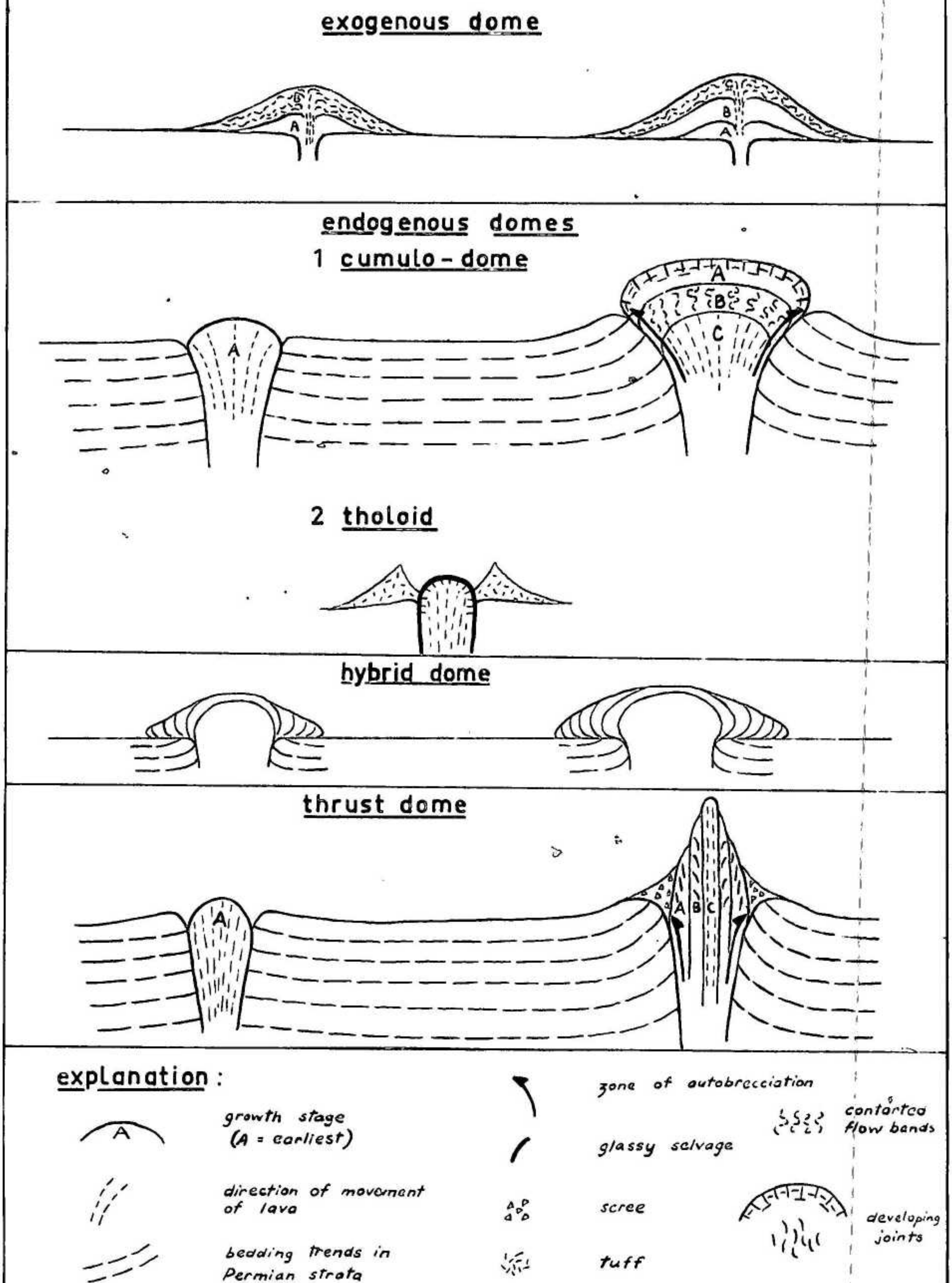
TABLE 1

Summary of features commonly associated with the four essential genetic forms of protrusions in the Peak Range

Feature	exogenous dome	endogenous domes		thrust dome
		cumulo-dome	tholoid	
dominant morphology (Fig. 4)	domal B	domal A and C (puy)	domal D, and pinnacles	conical (piton)
genetically modified forms	sunken, collapsed (Plates 5 and 8)	sunken (Plate 7)	thrust (Plate 15)	explosion pit (Plates 13 and 14)
common rock-type	trachytes	pantellerite comendite	rhyolite	pantellerite comendite
glassy selvages and associated tuff	-	-	✓	-
diapiric structures exposed in country rock	-	✓	-	✓
columnar jointing	none	poorly developed	small, straight units; horizontal at margins (Plate 9)	large, contorted units; vertical at margins (Plates 13 and 21)
other jointing characteristics	platy foliation well developed; undulating in lower flanks.	intense, planar radial and concentric	rare; 'massive' walls (Plate 11)	intense; planar, radial (Plate 18)
autobreccia	rare	'non-welded' type in patches (Plate 17)	rare, 'welded' type	'non-welded' type, superimposed zones
flow-banding	poorly developed	fairly common; mainly concentric pattern, contorted in places	well developed, straight and contorted	rare, vertical, tangential in margins
'stone-bubbles'	-	-	common	rare
cavernous, pitted faces	-	-	common (Plates 9 and 11)	rare
vesicular rock	common near summit	-	-	-
slickensides	-	✓	-	✓
overhanging faces	-	-	-	✓ (Plate 22)
definitive example	Mount Lowe	hill ½ mile N.W. of Mount Macarthur (P15)	Mount Castor (Plate 9)	Roper's Peak, (Plate 6)
distribution of forms with distinct genetic status	south (2)	south (2)	north (5)	south (4) north (1)

Figure 6

Idealised forms of viscid acid lava protrusions distinguished in the Peak Range - diagrammatic cross-sections showing postulated fundamental differences in their modes of growth



the "Mamelon Central" (Williams, 1932, pp 114-115); this steep-sided, highly convex Auvergne puy was probably formed of more viscous lava than the Mount Lowe dome with its laccolithic, low-profile form.

The origin of a basined exogenous dome in the southern part of the range is discussed under "Modified domes". Vesicular trachyte occurs near the crests of the exogenous domes; the exogenous growth of the two domes is related to the extrusion of lava less viscour than the lava producing cumulo-domes and thrust domes; the greater mobility is due in part to the fluxioning effect of absorbed volatiles which were released on extrusion of the lava, producing vesicles.

Two domal protrusions of a peculiar 'andesitic' rock, Mount Commissioner and a low hill, two miles south-south-west of Mount Donald (Fig. 2), are tentatively inferred to be exogenous domes. The smoothly convex domes, low in profile, are circular in plan, with flanks grading into the plain. Mount Commissioner exhibits massive columnar jointing normal to the flanks.

Endogenous domes

A large, elliptically-based pantellerite dome, half a mile north-west of Mount Macarthur is the definitive example of cumulo-dome growth in the Peak Range (Plate 5). All the features associated with the dome suggest the mode of growth demonstrated in Figure 6 for cumulo-domes. The dome grey by expansion from within, under a solid or nearly solid carapace. Intense major longitudinal vertical jointing in the outer shell expresses the tension pattern in the expanding carapace. If mobile lava from the interior was allowed to extrude through these expansion cracks during growth (a feature common in some cumulo-domes, giving them a ridged, spinous, profile) it has been eroded, because the dome has a smoothly convex profile. No Permian rocks were found cropping out round the base of the dome; concentric trends, visible in the air-photos, in the soil covered plain round the dome are almost certainly the expression of trends in updomed sediments. Contorted flow banding is visible where recent rock falls have exposed the inner shell; this feature is related to movement of plastic lava restricted in free movement. Autobreccia at the margins, but not on the carapace is the result of friction between the solid walls of the expanding dome and the walls of its vent. The comparatively low profile of the dome in relation to the surrounding protrusions suggests that it did not rise very far above its vent; there is no evidence to infer origin over a previously active vent, and the dome may have been independently intrusive. Another cumulo-dome (Plate 10) is present in the southern part of the range.

Several well-preserved <u>tholoids</u>, notably Mount Castor (Plate 9), are present only in the northern part of the range. The features of these domes (Table 1) indicate a distinct form of endogenous growth in vents that previously produced tuff cones (Fig. 6). The origin of the tholoids is related to: (i) the comparatively rapid emplacement of fairly fluid acidic lava; (ii) a homogenous cooling pattern; (iii) low friction in the margins because of the comparatively low viscosity of the lava; the smaller diameters of the tholoids in relation to other domes is almost certainly related to the lack of updoming of invaded country rock, a feature typical of viscid cumulo-domes.

The low viscosity of the lava is related to a high proportion of absorbed volatiles in the lava and not necessarily to a high temperature of extrusion. The presence of volatiles is indicated by hydrothermally-altered rhyolite which is preferentially weathered, leaving cavernous rock faces (Plates 9 and 11).

The domes of Mount Saddleback and Macdonald, and Red Riding Hood Peak are tholoids; several small tholoids and dyke-tholoids (tholoids developed over vents in fissures), are present south of Mount Donald (Little Wolfang Peak, Rocky Knob, and Peak Hill) and north of Fletcher's Awl (Fig. 2). Mount Pollux, and a small dome immediately south are dyke-tholoids, emplaced over vents along the same fissure. Fletcher's Awl (Plates 11 and 12) is probably the exhumed neck of a tholoid; well-developed horizontal columnar jointing is present in its flanks.

Thrust domes

The main feature distinguishing the growth of the five thrust domes (Scott's, Roper's and Calvert Peaks, and Mounts Macarthur and Donald) is the successive upheavals of viscid lava through their axes (Fig. 6); their great heights attest this essentially vertical growth. Scott's and Roper's Peaks (Plate 6) display features consistent with the inferred mode of growth, namely:

(i) conical forms with small, smoothly convex knolls at the summit;

(ii) vertical concentric layering (a conspicuous feature in the air-photos);

(iii) contorted columnar jointing (Plate 21);

(iv) slightly overthrust slickensided faces (Plate 22);

(v) successive vertical layers of autobreccia.

The friction developed in the upward movement of viscid lava through the solidifying, but not solid, axial parts of the domes was sufficient to upheave the already solid margins; walls probably crumbled as the domes rose above the top of their vents, forming scree which protected much of the lower parts of the domes (Plate 7). Contorted columnar jointing in the inner shells (Plate 21) is a consequence of the mode of growth; vertical columnar jointing is present in the margins (Plate 13), a feature related to their upheaval in a rigid state. Pressure patterns within the domes are now revealed in intense jointing (Plate 18). Permian rocks have been dragged up into diapiric structures by friction with the upheaved solid walls of the domes. The mode of growth is slightly different from that defined by Williams (1932) for his plug domes.

Hybrid domes

Several domes in the southern part of the Peak Range are hybrids and attest Williams' statement (1932, p. 54) that 'any individual may show all three types of growth; in most cases the distinctions will be difficult ... to draw'. The origin of the twin domes a mile north of Mount Macarthur, the dome a mile south of "Gibson Downs", and the basined dome half a mile south of Calvert Peak is related essentially to cumulo-dome growth, with subsequent thrusting of viscid lava through the centre.

The domes of 'Red Mountain' and Malvern Hill are also hybrid domes, showing characteristics of endogenous and exogenous modes of growth. The domes are probably closely related to the Grand Sarcoui of Auvergne which is defined as a 'mamelon' (Cotton, 1944, p. 160). Although recent erosion has cut radial valleys into 'Red Mountain' and Malvern Hill their forms are essentially that of smoothly convex domes (Fig. 4, domal C). The well-defined concentric layering of platy foliation is a prominent feature of the 'Red Mountain' dome, a feature described by Scrope as prominent in the Grand Sarcoui. The mode of growth shown in Figure 6 is tentatively assigned to the domes; the lateral, exogenous growth of the domes is alternatively related to effusion of lava through the summits of growing cumulo-domes rather than the simultaneous upward and lateral growth indicated. Vesicular rock at the summits of the domes, and in parts of the flanks, again shows the relationship between exogeneity and volatile-fluxioned lava. Much lava, laterally displaced from the vents has been denuded.

Wolfang Peak is a hybrid dome in the sense that it represents a tholoid which has been subsequently upheaved on the south side; a vertical, smooth wall on the south face, inclined major jointing across the dome, and inclined columnar jointing on the south face, (Plates 15 and 16) are regarded as evidence of growth similar to the observed extrusion of the Mount Pelée spine.

Modified domes

Several bowl-shaped and barchan-shaped protrusions (Fig. 4) in the southern part of the range are genetically modified domes. The basining of three domes, south and west of Calvert Peak, (Plates 7 and 8) is probably the result of subsidence in the centres of the domes. Parallelism of concentric platy foliation within the depressions (Fig. 5) expresses the effect of subsidence. Daly (1925) has described similar basined domes in Ascension Island. The subsidence can be attributed to several genetic phenomena:

(i) reduction of volatile pressure in the vent during growth of the domes; or

(ii) contraction due to chilling, or

(iii) escape of lava through lateral fissures in the domes.

Basining is not restricted to a single genetic form; the dome, $1\frac{1}{2}$ miles south-west of Calvert Peak is exogenous (Plate 8), whereas the dome a mile south of the peak is an endogenous dome (Plate 7).

The low-profiled circular basinal protrusion, half a mile west of Calvert Peak (Fig. 5) is probably a sunken endogenous dome.

Several domes with forms like barchan sand dunes probably represent, (a) more complete collapse than the basined domes and, (b) protrusion of viscid lava along arcuate fissures. The prominent barchan-like dome (dome on right in Plate 5) $1\frac{1}{2}$ miles north-west of Scott's Peak apparently consists of: (i) an original exogenous quartz trachyte dome and, (ii) a subsequent extrusion of aegirine trachyte which breached the east wall of the dome and flowed eastwards. The Puy de Lassolas in Auvergne has a similar morphology and origin, a flow having breached a pyroclastic cone (Rittman, 1962, p. 123).

Three protrusions, one, immediately north-west of Scott's Peak, another, one mile north of "Lowestoft", and another two miles west of Calvert Peak probably represent domes built over arcuate fissures; viscid lava has flowed, or been directed laterally from the concave sides of the fissures. The protrusions appear like half-formed lava cones.

An off-centred crater in the west face of the thrust dome of Mount Macarthur is interpreted to represent an explosion pit (Plates 13 & 14). Fragments of the characteristic spotted pantellerite forming the dome are found in black soil downs and small hills up to half a mile from the west face of the dome. The explosion was followed by the extrusion of fayalite trachyte lava into the pit; platy foliation in the trachyte, almost filling the pit, dips steeply from its high backwall (Plate 14), suggesting the pit has the form of an inverted cone, displaced from the vertical. The explosion was almost certainly due to the release of volatile pressure. As a footnote it should be stated that the Mount Macarthur dome dispels the idea of a simple volcanic sequence in which lavas progressively become less basic; the pantellerite contains 74% SiO_2, whereas the fayalite trachyte, 60.8% SiO_2.

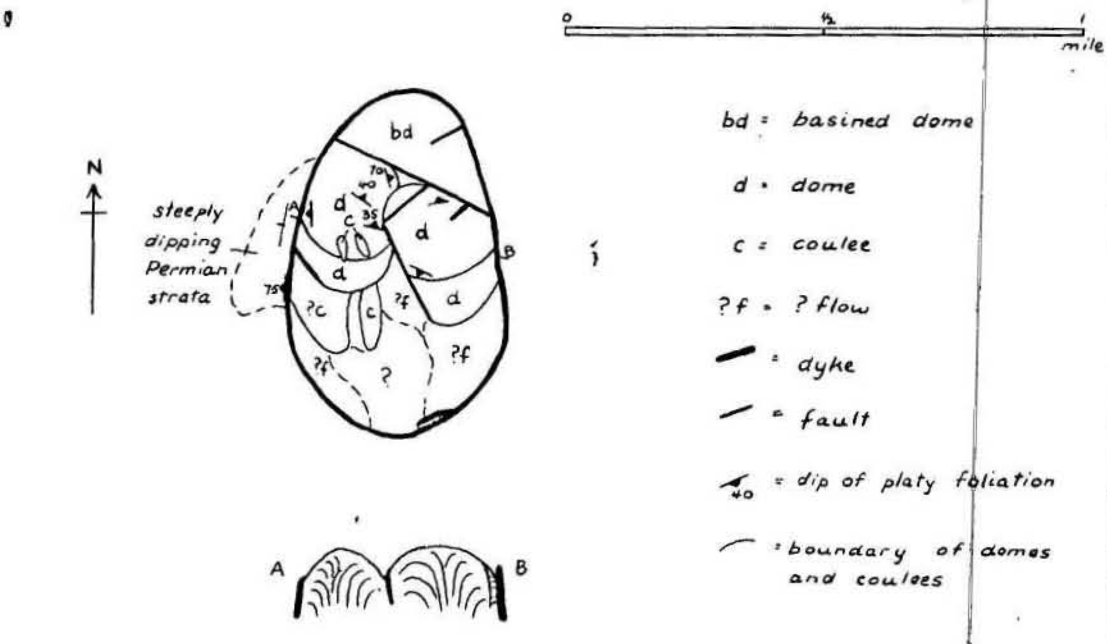
Composite protrusions

A composite protrusion, half a mile south-west of Mount Demipique (Fig. 7) consists of a sharp-crested ring dyke, oval in plan, encircling a complex of small domes and coulees (Fig. 7 and Plate 19). Several small rifts separate and intersect the domes; the rifts are related to unequal upheaval of the growing rigid body by repeated domal protrusion. The brecciated ring-dyke represents the final intrusion. The coulees appear to have been extruded on the flanks of the domes, probably from fissures in the expanding carapaces. Evidence of subaerial contraction in the skin of the viscid flows is well displayed (Plate 20).

The composite protrusion shows an important relationship to the flood basalts. The contraction features revealed on the surface of a coulee (Plate 20) almost certainly are the result of subaerial extrusion. The nearby

Figure 7

Plan of composite protrusion near Mount Demipique



Sketch-section A-B showing successive doming

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remnants of horizontal flood basalts, forming Mount Demipique and 'Mount Birdcage', are several hundreds of feet higher than the top of the protrusion. The observations infer that the flood basalts post-date the protrusion.

The slightly elliptical, low-protrusion, 2 miles west-south-west of Calvert Peak appears to represent emplacement to two semi-circular bodies along a ring fracture; a complex of small dykes and probable coulees within the ring fracture were probably subsequently emplaced along tension cracks in the country rock.

Several relatively large masses of acidic volcanics in the northern part of the range (see Fig. 2), and a mass 1½ miles north of Mount Macarthur in the southern part (Plate 1) are complexes of dykes, flows, and probably domes.

Dykes, coulees, and flows

Numerous short, commonly arcuate, dykes of acidic volcanics are present in the northern part of the Peak Range; many intrude the (?) horst of probable Lower Palaeozoic metamorphics and Devonian-Carboniferous volcanics and sediments. Fletcher's Awl is the focus of several arcuate pitchstone dykes. Many dykes are associated with complex masses of acidic volcanics (see preceding paragraph); only in the north do these dykes have pitchstone selvages. Acidic volcanic dykes are much less frequent in the southern part of the range; several, which have expanded into small domes, are present west of 'Red Mountain'.

Coulees and flows have been mentioned in the foregoing section on composite protrusions. Two trachyte ridges, one extending south from Calvert Peak (Fig. 5) and the other intersecting the "Gibson Down"-"Lowestoft" track, north-west of Scott's Peak, are probably coulees extruded from vents of the adjoining protrusions.

Phonolite plug

The phonolite protrusion of Campbell's Peak (Fig. 2) occupies a enigmatic position, in being twelve miles west of the range, and in having the form of a cylindrical plug, closely similar to basaltic plugs. Boulders of basanite with olivine nodules in scree on the flanks suggest the phonolite displaced a basaltic plug in the vent. Intruded Permian sediments are not updomed, a feature characteristic of basaltic plugs.

CONCLUSIONS

Several field features of the volcanic products in the Peak Range strongly suggest:

(i) the volcanics represent a series of petrogenetically associated lavas related to a single cycle of volcanic activity;

(ii) the association compares closely with alkalic basalt associations in continents and oceanic islands; several features compare with features of tholeiitic basalt associations;

(iii) the acidic rocks in the southern part of the range have a different petrogenetic origin to the acidic rocks in the north.

The features from which these inferences are drawn include:

(a) the close spatial relationships between a large mass flood basalts of widespread extent, on the one hand, and a small mass of dome-forming acidic lavas of restricted extent, on the other;

(b) the general absence of pyroclastics and other products of explosive activity;

(c) the lack of complex volcanoes;

(d) the presence of small basaltic plugs and a linear, as opposed to a radial, swarm of basaltic dykes;

(e) the concentration of dome-forming acidic lava bodies in a relatively small area in the southern part of the range where the country rocks are essentially flat-lying Permian sandstone and shale;

(f) the more widespread distribution, about a probable horst of ?Lower Palaeozoic to Carboniferous metamorphic, volcanic and sedimentary rocks of the acidic lava bodies in the northern part of the range;

(g) the presence of very varied assemblages of acidic rock-types and forms of acidic lava protrusion in the south;

(h) the absence of much variation in rock-type and form of acidic lava protrusions in the north;

(i) an apparently larger mass of acidic volcanics in the north compared with the mass in the south.

(j) the presence of pitchstone and tuff about protrusions only in the north.

Several general conclusions from field work about the products of volcanicity include:

(1) acidic lava protrusions, at least in the south, were extruded at several intervals during the volcanism, and a single sequence of extrusion, whereby basaltic lavas preceded eruption of acidic lavas, has not occurred;

(2) the main focus of basaltic lava eruption was in the central part of the range;

(3) acidic lava protrusions in the north were emplaced over vents which were previously active, whereas protrusions in the south are probably intrusive;

(4) volatiles have played at least a physical role in the origin of the acidic lava domes.

Plates 5 to 22

illustrating chapter on

acid volcanic protrusions

Plate 5 View west from 'Red Mountain'; barchan-shaped protrusions (collapsed domes) on the left and right, and the Mount Macarthur thrust dome in the left background. Definitive cumulo-dome to right of Mount Macarthur.

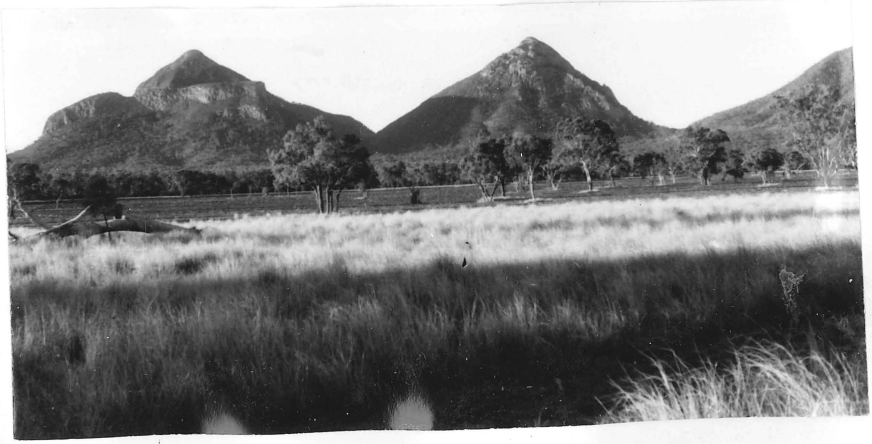

Plate 6 The thrust domes of Scott's (left) and Roper's Peaks from the south-west. The flat-topped protrusion was emplaced along an L-shaped fissure.

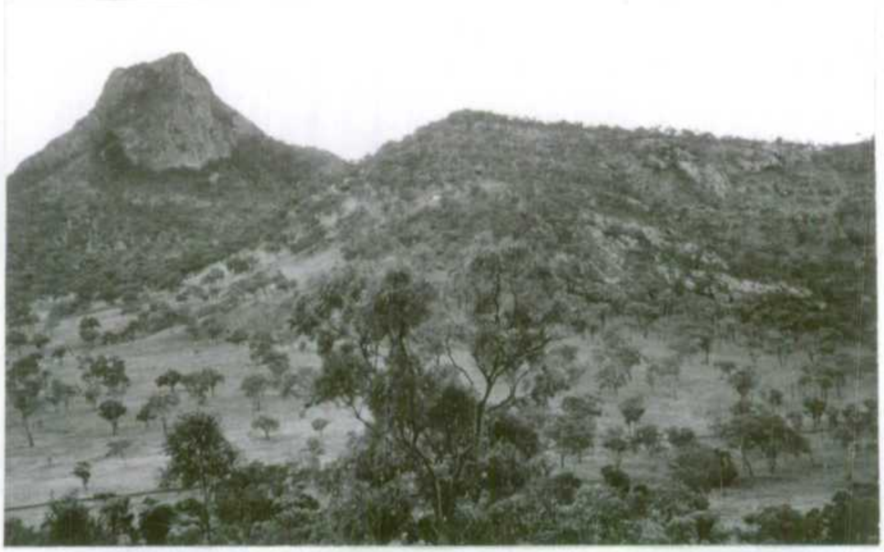

Plate 7 Calvert Peak from the south-west, with a sunken dome in the foreground. Note the thrust dome of Calvert Peak protruding typically through scree of the same rock.

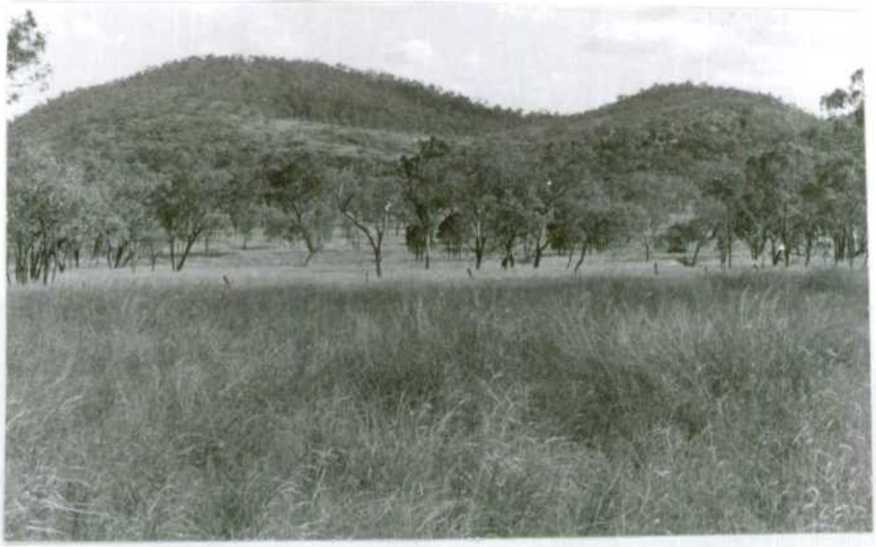

Plate 8 A sunken exogenous dome, $1\frac{1}{2}$ miles south-west of Calvert Peak.

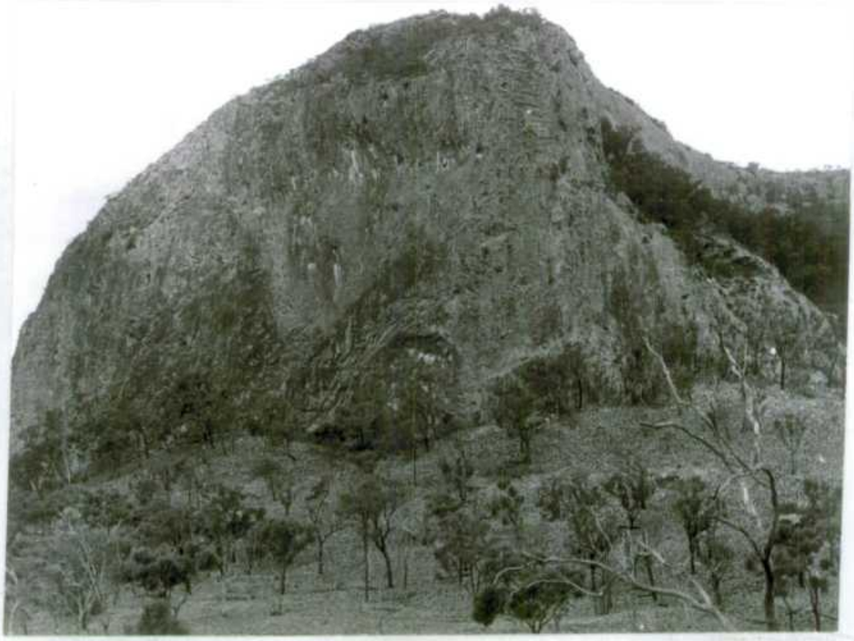

Plate 9 The south face of Mount Castor, a rhyolite tholoid; note horizontal columnar jointing. The off-centred pit is probably the result of erosion of a hydrothermally-altered, less-resistent, "pocket" of comendite - note also pits and caverns in face of protrusion.

Plate 10 A cumulo-dome of pantellerite about three miles north-west of Mount Macarthur.

Plate 11 The corroded north face of Fletcher's Awl, probably the neck of a tholoid, which has pierced Devonian-Carboniferous sediments.

Plate 12 Fletcher's Awl protruding from the upland block of Devonian-Carboniferous sediments and volcanics. The Awl is apparently the focus of several arcuate pitchstone dykes; there are no remnants of a tuff or lava cone about the protrusion.

Plate 13 Explosion pit in the west face of Mount Macarthur, a thrust dome; note vertical columnar jointing at the base.

Plate 14 Explosion pit of Mount Macarthur which is filled with fayalite trachyte; the main body of the protrusion consists of pantellerite which contains "mossy" clots of probable riebeckite, giving the rock a spotted appearance.

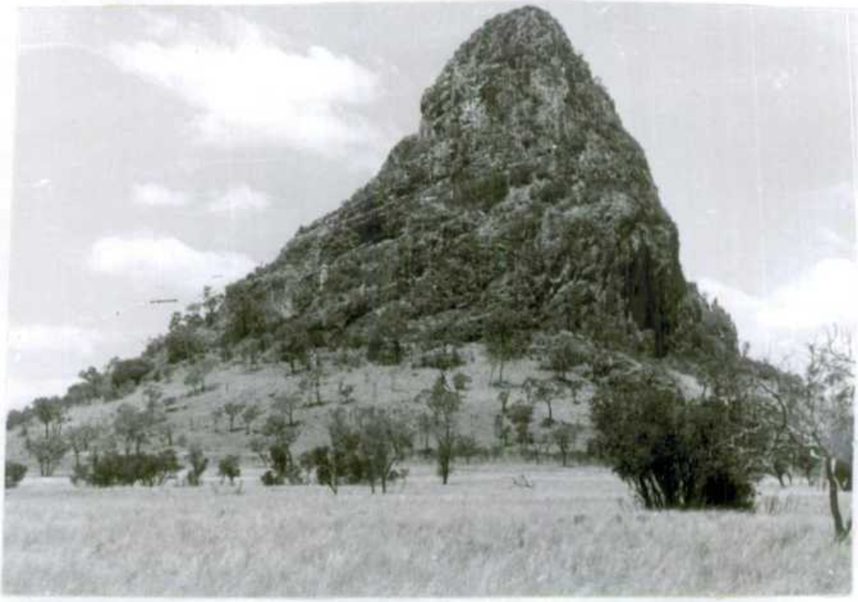

Plate 15 Wolfang Peak, a modified tholoid of rhyolite , from the west; note steep south face and inclined major jointing, dipping north; not clearly visible is vertical columnar jointing in upper half of the protrusion.

Plate 16 Inclined columnar jointing at the base of Wolfang Peak on the south face - note 'stone-bubbles' in boulder of rhyolite in foreground.

Plate 17 East face of pantellerite (?) cumulo-dome, $1\frac{1}{2}$ miles south of "Gibson Downs", showing autobreccia etched by weathering. The photograph is about ten feet across.

Plate 18 Lip of explosion pit of Mount Macarthur, showing intense jointing, normal to face of protrusion.

Plate 19 A small coulee of pantelleritic trachyte in the composite protrusion, half a mile south-west of Mount Demipique; note massive crude columnar jointing normal to face of flow.

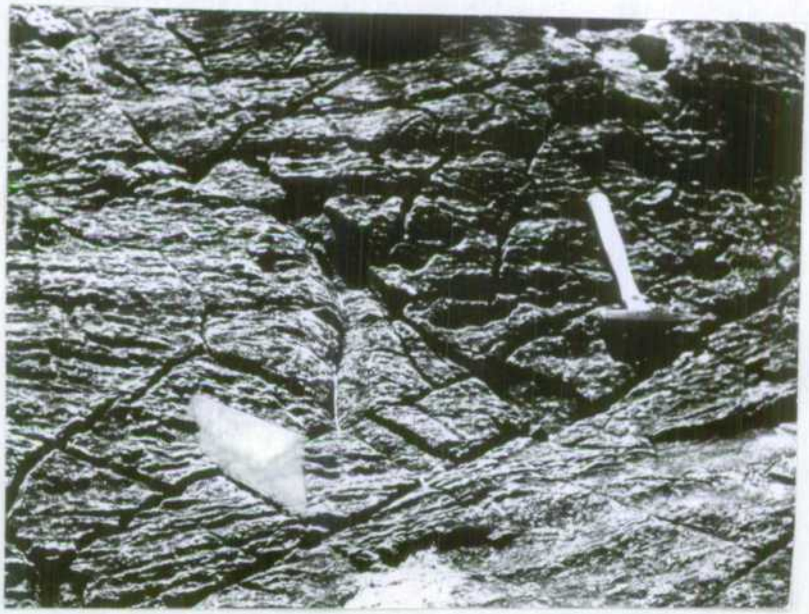

Plate 20 Subaerial contraction 'breadcrust' fractures and wrinkles on surface of the coulee shown above.

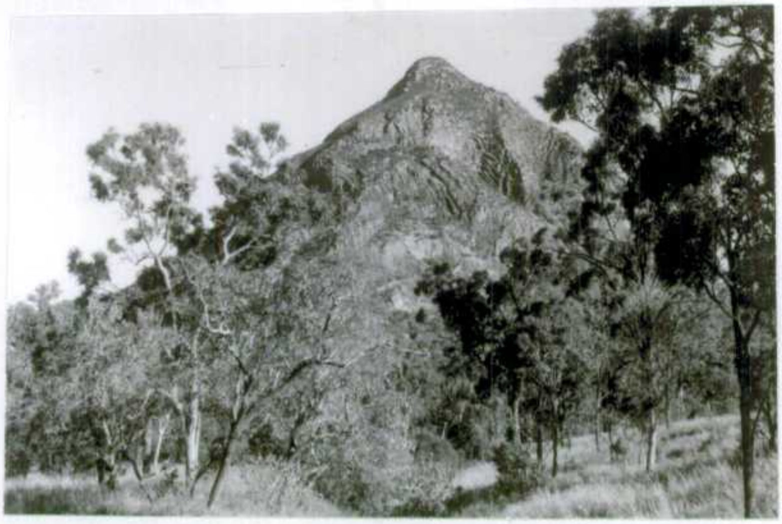

Plate 21 Contorted columnar jointing on the north face of Scott's Peak.

Plate 22 Overthrust, overhanging, smooth, slickensided wall of the north base of Roper's Peak. The wall is in contact at the base with unaltered Permian sediments which dip steeply away from the wall.

PETROLOGY

PETROGRAPHY

Introduction

The volcanic rocks in the Peak Range show a broad range in composition. An alkalic suite of rocks range from olivine teschenite and analcite basanite through alkalic olivine basalt and rare intermediate types (hawaiite and trachyandesite) to acidic types (trachyte, pantellerite, and comendite). A tholeiitic suite of rocks, including rare tholeiite and common tholeiitic olivine basalt, is also present; the tholeiitic rocks appear to be more common in the lower part of the volcanic pile of flood basalts. The tholeiitic and alkalic olivine basalts constitute probably over 90% of the Tertiary volcanic rocks in the Peak Range. Extremely silica-rich rhyolite and pitchstone, welded tuffs, and peculiar 'andesitic' rocks are present in the northern part of the range. Phonolite forms the isolated plug at Campbell's Peak, east of the range.

Classification and nomenclature

The essential petrographic features and other features of the rock types are summarised in Table 2.

Classification of the diverse rock-types present in the Peak Range is based on modal, normative, and chemical characteristics.

The names teschenite and basanite are used in the commonly accepted sense for basic rocks with essential modal feldspathoid or analcite; olivine teschenite differs from basanite only in having coarse, ophitic texture in contrast to the typical pilotaxitic texture of basanite. All basanites are

TABLE 2

Summary of modal and other characteristics of lava rock-types in the Peak Range

BASIC AND INTERMEDIATE VOLCANICS	associated variants	texture(s)	dominant feldspar	pyroxene(s)	olivine	other mineralogical characteristics	CIPW norm characteristics	occurrence and distribution
olivine teschenite (Plate 23)	picritic teschenite; olivine micro-teschenite	ophitic, intergranular	labradorite	titanaugite	>5%	interstitial analcite and alkali feldspar	<5% nepheline (undersaturated)	plugs, mainly west of Peak Range
analcite basanite	-	pilotaxitic	labradorite	(titan)augite	>5%	interstitial analcite (and ? feldspathoid)	>5% nepheline (undersaturated)	
alkalic olivine basalt	alkalic olivine micro-gabbro	sub-trachytic, ophitic; porphyritic types	sodic labradorite	augite	>5%	minor alkali feldspar	no nepheline; hypersthene < olivine (near-undersaturated)	dominant type
alkalic basalt	-				<5%		-	
hawaiite	-	subtrachytic	andesine	?augite	present	?alkali feldspar	-	apparently rare
trachy-andesite	-	porphyritic, glassy groundmass	oligoclase	subcalcic augite, hypersthene	minor	alkali feldspar and quartz xenocrysts, resorbed and embayed	-	flow capping Lord's Table Mountain and The Anvil
tholeiitic olivine basalt	-	ophitic, intergranular porphyritic types	sodic labradorite	subcalcic augite, minor pigeonite	>5%	intersertal brownish glass with rods of ilmenite and apatite needles	no nepheline; hypersthene > olivine (near-saturated); hypersthene + quartz (over-saturated)	sub-dominant, mainly in lower part of flood basalt pile
tholeiitic basalt	-				<5%		-	
tholeiite (Plate 24)	-	ophitic, intersertal	sodic labradorite	pigeonite, hypersthene	minor	much brownish glass	-	apparently minor; dyke and probable flow

PEAK RANGE VOLCANICS	typical colour	dominant texture(s)		dominant feldspar(s)	quartz	total femics	other mineralogical characteristics	CIPW norm characteristics	distribution
trachytes (Plate 25)	dark grey	All include porphyritic types	trachytic	anorthoclase	minor or absent	mainly >10%	mainly aegirine, some contain fayalite and ferroaugite, others? hedenbergite	acmite absent or very low (some peralkaline)	protusions, dykes and flows in southern part of Peak Range only
quartz trachyte	light grey to off-white		trachytic	anorthoclase	< 10%	<10%	several contain secondary analcite	-	
pantelleritic trachyte	medium grey-greenish grey		trachytic sub-trachytic	anorthoclase	< 10%	>10%	cossyrite, several sodic amphiboles, aegirine	-	
pantellerite (Plate 26)	light greenish		flow-banded, aplitic to subtrachytic	anorthoclase, sanidine (sodic plagioclase	>10%	>10%	brown idiomorphic hornblende (?barkevikite), cossyrite, aegirine, sodic amphiboles	>5% acmite, $Na_2O \cdot SiO_2$ peralkaline	
comendite, (Plate 27)	off-white to yellowish white		aplitic, sub-trachytic (trachytic comendite).	sanidine sodic plagioclase, quartz	>10%	<10%		<5% acmite; (peralkaline)	
rhyolite	white, pinkish - white		spherulitic, flow-banded, glassy	anorthoclase.	>10% rich	very low	biotite	corundum (peraluminous).	tholoids, flows, dykes in northern part of range only.
pitchstone	deep olive geen	glassy porphyritic, microlitic, perlitic			minor phenocrysts				selvage of protrusions in northern part of range only.
'andesitic' rock	green	allotriomorphic granular		andesine alkali feldspar	< 10%	>10%	augite, interstitial glass, zoned plagioclase	-	domes and ? flow in northern part of range only
phonolite	grey	trachytic		anorthoclase	none	< 10%	aegirine replaced by grains of magnetite; interstitial analcite.	-	plug at Campbell's Peak

analcite basanites; picritic teschenite is teschenite rich in olivine and pyroxene, and microteschenite is applied to fine-grained teschenites.

Some discussion is necessary to clarify the usage of the names alkalic (olivine) basalt, tholeiitic (olivine) basalt, and tholeiite for flood basalts in the Peak Range. The names are used in the light of discussions on the nomenclature of basalts from Hawaii by Yoder and Tilley (1962) and Macdonald and Katsura (1964). Macdonald and Katsura are of the opinion that modal and normative characteristics are not sufficiently critical in distinguishing basalt types, defined on normative characteristics by Yoder and Tilley. Macdonald and Katsura show the alkali:silica ratio to be a more reliable yardstick in defining tholeiitic from alkalic compositions, at least for the Hawaiian lavas. Six analysed basalts from the Peak Range (Table 5) show normative characteristics consistent with presence of over-saturated, near-saturated, near-undersaturated, and undersaturated basalts.[2] Three oversaturated and near-saturated basalts fall anomalously in the alkalic basalt field of Macdonald and Katsura in their alkali/silica diagram for the Hawaiian basalts; a fourth, oversaturated basalt lies in the tholeiitic basalt field; two near-undersaturated basalts lie in the alkalic basalt field. However, an unanalysed basalt with about 50% pigeonite, no

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[2]The terms oversaturated, near-saturated, near-undersaturated, and under-saturated are used in this thesis with the following senses:

oversaturated	- normative hypersthene and quartz
near-saturated	- normative hypersthene in much greater amount than normative olivine
near-undersaturated	- normative olivine in much greater amount than normative hypersthene
undersaturated	- normative olivine and nepheline.

olivine, and much glass, confirms the presence of true <u>tholeiite</u> (Plate 24) in the Peak Range. The modal characteristics of the four basalts with hypersthene and quartz in the norm are distinct from the two basalts with olivine in the norm; the modal contrast is related to oversaturated and near-saturated magmas on the one hand, and near-undersaturated magmas on the other. Thus, the oversaturated and saturated basalts are named <u>tholeiitic basalts</u> and the undersaturated basalts are named <u>alkalic basalts</u>. The presence of more than 5% modal olivine leads to tholeiitic and alkalic <u>olivine</u> basalts in accordance with Macdonald and Katsura. The distinction between basanite and alkalic olivine basalt is in the presence and absence of normative nepheline and modal analcite.

The nomenclature therefore follows the nomenclature of Macdonald and Katsura, although the definitions are necessarily based on normative and modal characteristics because of the slightly anomalous alkali:silica ratios in some oversaturated and near-saturated (tholeiitic) basalts. To deny these basalts the term 'tholeiitic' would obscure distinct modal and normative characteristics and the presence of unequivocal tholeiite rock in the Peak Range. The alkali:silica ratio anomalies is related to the presence of a complete gradation of lavas between undersaturated and oversaturated types.

The nomenclature of the unanalysed tholeiitic and alkalic basalts in the Appendix is based on comparisons with the modal characteristics of the analysed basalts; several basalts are necessarily only tentatively named. The term <u>olivine basalt</u> is used where definite tholeiitic or alkalic characteristics are not clear.

The term hawaiite is used for basalts in which the dominant modal feldspar is andesine, in accordance with Macdonald (1960).

The term benmoreite is used by Tilley and Muir (1964) to distinguish soda-rich from potash-rich (tristanite) intermediate (trachyandesite) members of the alkalic basalt association. The modal characteristics of the flow capping Lord's Table Mountain and The Anvil (plate 4) indicate that it has a composition intermediate between mugearite and trachyte. However the composition appears to be the result of either contamination or hybridisation, rather than differentiation, and the term trachyandesite is therefore preferred to benmoreite.

The nomenclature of the acidic rocks in the southern part of the Peak Range is based on their position as probable end-members in the alkalic basalt association. The acidic rocks show a gradation from trachytes through pantelleritic trachyte and quartz trachytes, to silica rich pantellerite and comendite. The arbitrary limits of modal amounts of quartz and femics, defining the names, are shown in Table 2; the limits are based on modes of similar rocks in other regions (e.g. Campbell Smith, 1931; Shand, 1943). The modal differences are also borne out by normative characteristics; in common with pantellerites and comendites elsewhere (Carmichael, 1962, shows a comparison of average analyses and norms) the pantellerite has more than 5% acmite in the norm, whereas comendite has less. Most pantellerites and pantelleritic trachytes contain cossyrite in the mode, and sodium metasilicate in the norm. Most of the acidic rocks in the south are peralkaline.

The acidic rocks in the northern part of the Peak Range are termed rhyolite because they are dominantly very silica rich, poor in femic minerals, and peraluminous. They contain biotite in contrast to comendite and pantellerite which contain sodic amphiboles and pyroxene.

The term pitchstone is used in preference to obsidian because the analysed rock (CL245/2C) contains over 3% of water.

The term phonolite is used in the generally accepted sense for a trachytic rock with analcite or feldspathoid, showing its undersaturated character.

The term 'andesitic' rock is used for rocks with andesitic affinities; their apparently anomalous position in the association is inferred in the informal name.

In the petrographic descriptions that follow, the characteristic modal features of each group of rocks are described with particular reference to analysed specimens. Notable textural and mineralogical variations in other specimens are mentioned.

Basic and intermediate rock-types

(i) Olivine teschenite and analcite basanite

Olivine teschenite and analcite basanite are comparatively rare rocks in the Peak Range, being restricted to plugs in, and west of, the range. The larger plugs, for example Mount Oscar and Pumpkin Hill (Fig. 2), more commonly consist of olivine teschenite and olivine microteschenite, whereas the smaller plugs consist mainly of analcite basanite. No flows of these rocks have been identified.

Olivine teschenite (CL269/1 Plate 23) consists of coarse phenocrysts of olivine, titanaugite, and sodic labradorite in a medium to fine-grained intergranular to ophitic groundmass of sodic labradorite, pyroxene, olivine, idiomorphic and skeletal black iron oxides and accessory acicular apatite with an intersertal mesostasis of analcite, minor alkali feldspar (sanidine and anorthoclase), and other glassy material with needles of apatite. Picritic teschenite (CL273/2), was found only in the centre of the large plug at Mount Oscar. Olivine microteschenite (CL263/2) is a finer-grained variant of olivine teschenite, relatively poor in olivine.

Analcite basanite (CL272/1) consists of essentially the same minerals as olivine teschenite. Subhedral, typically 'fresh', olivine and titanaugite phenocrysts, commonly glomeroporphyritic, are set in a pilotaxitic groundmass of labradorite with intergranular equant grains of augite, olivine, and magnetite, and interstitial analcite and alkali feldspar, with needles of apatite. In some basanite (CL264/3) pyroxene occurs in consistently much larger phenocrysts than olivine; pyroxene also occurs in large clots of fine, equant grains. Some basanite contains probable feldspathoid (?sodalite). The basanites are fine-grained rocks which are characterised by a homogeneous pattern of pits and cracks on weathered surfaces.

(ii) Alkalic olivine basalt, alkalic basalt, and alkalic olivine microgabbro

Alkalic olivine basalt and alkalic basalt form the most abundant rock-types in the Peak Range; they occur dominantly as flows, and in dykes, and possibly, plugs. Although their mineralogy is relatively simple they show textural diversity. The basalts are commonly fine-grained, dark bluish rocks with and without, clear, commonly yellowish plagioclase, and black pyroxene phenocrysts, ranging up to 20 mm long; platy foliation is a common feature. Much alkalic basalt is extremely vesicular, with ovoid and spherical amygdales of zeolite, calcite, chalcedony, and blue and white clay minerals, ranging from a few millimetres across, to the size of small pebbles. The vesicular varieties are commonly lighter in colour than the dense basalts, probably a function of alteration and less basic composition.

Alkalic olivine basalt (CL606/B) consists of small olivine (peripherally altered to bowlingite) and labradorite phenocrysts set in a groundmass consisting mainly of an ophitic intergrowth of zoned augite (mildly titaniferous) and sodic labradorite with intergranular augite, idiomorphic olivine, equidimensional magnetite, and subordinate acicular (?) ilmenite; untwinned plagioclase, with undulose extinction and zeolite (probably chabazite) form interstitial patches with intergrown apatite needles, and rare zircon. The rock shows a weak trachytic alignment of plagioclase laths. The other analysed alkalic olivine basalt (CL606/L) is essentially similar, but has a more pronounced trachytic texture, contains more porphyritic olivine, no porphyritic plagioclase, and has interstitial alkali feldspar.

In several alkalic olivine basalts the olivines have been completely pseudomorphed by iddingsite, whereas in others, bowlingite is the main alteration product. Plagioclase commonly varies between An_{45} and An_{55}[3] in

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[3]The plagioclases were determined from the values of the extinction angle $\alpha' \wedge 010$ in sections normal to the x crystallographic axis, using the curves of Rittmann and El-Hinnawi (1961).

most of the rocks. The alkalic basalts rarely contain interstitial glass; greenish-brown fibrous clay minerals are common interstitially.

The alkalic olivine microgabbro mass (?plug) in the southern part of the range (Plate 1) is essentially a coarse variant of its basaltic counterpart. The rock contains interstitial alkali feldspar and zeolite; skeletal and embayed magnetite grains are a notable feature.

(iii) Hawaiite

Several altered basaltic rocks in which the dominant plagioclase appears to be calcic andesine (An_{40-45}) are almost certainly hawaiites; rare andesine phenocrysts are present. The rocks show a prominent trachytic texture with much interstitial cloudy glassy material and fine grains of iron oxide. Olivine phenocrysts, mainly altered to iddingsite, are present in some of the rocks.

(iv) Trachyandesite

The thick flow capping Lord's Table Mountain and The Anvil (Plate 4) appears to represent a hybrid or contaminated magma which has attained the composition of benmoreite. The fairly light purplish-grey rock has a heterogeneous porphyritic appearance in hand specimen; in the base of the flow the rock shows platy foliation whereas at the top peculiar brown spheroids commonly give the rock a botryoidal surface; in thin section the spheroids have a darker glassy mesostasis than the surrounding rock. The rock at the top of the flow consists of phenocrysts (?xenocrysts, up to 5 mm long) of sanidine, anorthoclase, oligoclase, and quartz in a glassy groundmass with stumpy feldspar microlites, and small idiomorphic and anhedral crystals of zoned plagioclase, subcalcic augite, hypersthene, probable pigeonite, and fine magnetite. The phenocrysts are accompanied by groups of closely interlocking feldspar grains (?xenoliths), and 'blebs' of crystalline 'basalt'. The feldspar phenocrysts commonly have resorbed rims of varying thickness, whereas some feldspar phenocrysts show 'brain' structure and are almost completely resorbed. Quartz phenocrysts are cracked and embayed, and unaltered.

The flow, becomes thoroughly crystalline towards the base; the aphanitic mesostasis consists of an irregular mosaic of feldspars with very weak fluxion texture in places; olivine and iddingsite pseudomorphs are additional accessories; augite forms small phenocrysts. The flow almost certainly represents either a hybrid or contaminated lava whose significance is discussed in a following section.

(v) Tholeiitic olivine basalt and tholeiitic basalt

Tholeiitic olivine basalt and tholeiitic basalt together form a large part of the flood basalt pile; they are interbedded with alkalic basalt types but appear to be more frequent towards the base of the pile. In hand specimen they show textural diversity similar to the alkalic basalts; porphyritic and aphyric dark fine-grained varieties are the most common.

Tholeiitic olivine basalt (CL215/8B) is an aphyric rock with an intergranular to subophitic texture. Sodic labradorite and subcalcic augite (2V about 35^{o}) show a weak ophitic texture; sub-idiomorphic olivine, subcalcic augite with patchy shells of pigeonite, minor small pigeonite grains, and rods of ilmenite occur in intergranular spaces between labradorite laths; small patches of intersertal cloudy brown glass contain rods and fine granules of black iron oxide and apatite needles, which commonly form felted masses. Fibrolamellar brown clay forms irregular interstitial masses.

Tholeiitic olivine basalt (CL291/1C) is essentially similar but contains much more brown glass, and much interstitial calcite, in place of clay minerals; olivine also occurs as small phenocrysts. Two other analysed tholeiitic olivine basalts (CL201/3 and CL516/J) are similar; CL201/3 carries porphyritic labradorite and subcalcic augite (2V about 30°); CL516/J contains iddingsitized olivine and several zoned plagioclase crystals.

The modal characteristics of the tholeiitic basalts which appear to distinguish them from the alkalic basalts are:

(i) the occurrence of interstitial glass, commonly pigmented;

(ii) common lack of fluxion textures;

(iii) subcalcic augite and pigeonite;

(iv) rods and skeletal occurrence of black iron oxide and lack of equidimensional iron oxide.

(vi) Note on composition of olivine from alkalic and tholeiitic basalt

The β refractive indices of olivines from tholeiitic and alkalic basalts were determined with immersion oils (Table 3). Most olivine grains determined were from intergranular groundmass. The results show:

(a) the compositions are comparable with olivines commonly found in basalts (15.5%-58.5% Fayalite);

(b) the tholeiitic and alkalic basalts are not distinguished by the compositions of the olivines;

TABLE 3

Refractive Indices of olivines from alkalic and tholeiitic olivine basalts

* analysed rock

rock number	R.I. β ($\pm$.002)	% Fa
alkalic		
CL239/6D	1.699	23
CL516/A	1.710	28
CL516/D	1.683	15.5
CL516/O	1.709	28
*CL606/B	(1.747	45.5
	(1.752	48
	(1.757	50
CL606/I	1.730	37.5
*CL606/L	1.717	31.5
tholeiitic		
*CL201/3	(1.759	51
	(1.774	58.5
*CL291/1C	(1.682	15
	(1.699	23
	(1.716	31
*CL516/J	(1.728	37
	(1.737	40.5

(c) an enrichment in forsterite in distinctly porphyritic olivines (CL291/1C, CL516/D);

(d) olivines from analysed rocks contain more fayalite than the respective Mg:Mg + Fe x 100 ratios of their CIPW norms (Table 5).

(vii) Tholeiite

Tholeiite is apparently not common; only two specimens were collected. Tholeiite (CL224/2B, Plate 24) is a fine-grained, aphyric, greenish rock which consists essentially of an ophitic intergrowth of very faintly brownish-green pigeonite and labradorite with minor rods of (?) ilmenite; intersertal brownish glass carries needles of apatite and granules of iron ore; altered interstitial 'felsic' patches are also present. The pigeonite ($2V<10^o$) displays patchy zoning. The other tholeiite (CL251/1) consists of porphyritic to glomeroporphyritic hypersthene, plagioclases (andesine and labradorite), and minor olivine, in an intergranular groundmass of plagioclase, subcalcic augite, and pigeonite, with accessory skeletal and acicular black iron oxides. Interstitial patches of glassy material with needles of apatite, and calcite amygdales are present.

Acidic rock-types

Acid rock-types form the protrusions in the southern and northern parts of the range. 'Andesitic' rocks, rhyolite, and pitchstone only, occur in the northern part; all other rock-types are restricted to the southern part.

(i) Note on nomenclature of alkali feldspars, sodic pyroxene, and sodic amphiboles

The alkali feldspars in the acidic rocks belong dominantly to the anorthoclase-sanidine group (high-albite-low-sanidine series). The terms sanidine (strictly $>$ or_{37}) is used for feldspar with optic angles estimated to be less than 25° and anorthoclase (strictly $<$ or_{37}) for feldspars with optic angles greater than 25°. Some sanidine commonly has a fresh glassy appearance lacking cleavage and with irregular cracks; anorthoclase rarely shows these features. In general anorthoclase is more common in the trachytes, whereas sanidine is more common in the pantellerites and comendites. Some anorthoclase shows typical 'tartan' twinning and some sanidine, probable microperthitic exsolution lamellae (Plate 26). According to Deer, Howie, and Zussman (1963) cryptoperthites only are present in the anorthoclase-sanidine series. Sodic plagioclase (albite and oligoclase) occurs in pantellerite and comendite.

Several femic minerals, aegirine, riebeckite, arfvedsonite and barkevikite, have been recognised (on the basis of simple optics, and X-ray comparison for barkevikite, Table 4). However, other varieties of sodic amphibole are also probably present in pantelleritic trachyte and pantellerite. Cossyrite has been found in several rock-types.

(ii) Trachytes

Exogenous domes and coulees are commonly formed of dark grey, commonly porphyritic trachyte.

Aegirine trachyte (CL215/8A) consists of over 80% laths of anorthoclase arranged in a pronounced trachytic texture; the laths are about ½ mm long and commonly show Carlsbad twinning. Shred-like grains of aegirine and cossyrite fill the angular spaces between the feldspar laths; rare subhedral grains (up to 2 mm long) of aegirine, and phenocrysts of anorthoclase are present; magnetite is accessory. Patches of probable analcite appears to have a secondary habit in cavities. Aegirine shows normal pleochroic colours from deep green (α) through a lighter green (β) to a yellowish-brownish green (γ); cossyrite is pleochroic from almost black to deep reddish-brown. The femic minerals constitute over 15% of the rock.

Aegirine trachyte (CL215/5) is similar but contains no cossyrite, and less than 10% femics; extremely fine flakes and grains of aegirine are accompanied by probable riebeckite which has a 'mossy' habit and shows a very deep blue (α) through light mauve (β) to a yellowish green (γ) pleochroic scheme.

Fayalite trachyte (206/G) (Plate 25) consists of anorthoclase phenocrysts in a trachytic groundmass of anorthoclase laths with intergranular probable ferroaugite (light green), minor fayalite and black iron oxide. Small phenocrysts of buff fayalite (2V about 60°) are present. Anorthoclase phenocrysts have ragged-edged outer shells containing abundant inclusions of probable ferroaugite, cloudy apatite, and granular black iron oxide; the outer shells have higher refractive indices than the cores, probably due to higher contents of soda. The only other analysed trachyte (CL217/1A) has a similar texture; aegirine occurs in very fine grains scattered through the rock and is accompanied by similarly dispersed sodic-amphibole, cossyrite, and magnetite; much of the femic minerals have been altered to a reddish brown translucent mineral; apatite is present as distinct grains, and as needles in feldspar.

Trachyte (CL238/1) contains probable aegirine-augite (pale green, R.I.$\approx$1.85, + ve) as the dominant femic mineral; this rock is notable for porphyritic anorthoclase showing prominent fine 'tartan' twinning.

(iii) Quartz trachyte

Quartz trachyte, commonly a light grey rock, has a simple mineralogy. Over 90% of the rock consists of anorthoclase laths (showing Carlsbad twinning) arranged in a trachytic texture. Quartz ($<$10%) occurs as interstitial patches; opal is present in CL212. In many of the rocks, analcite and other fibrous zeolites are common; in CL208/2 probable analcite occurs in an anomalous position, adjacent to quartz, so that it must be regarded as secondary. Black grains (in places with reddish-brown edges) of iron oxide are persistently accessory; in several quartz trachytes small amounts of sodic femic minerals and cossyrite are present. Glomeroporphyritic anorthoclase, with outer, soda-rich shells (higher R.I.) containing fine inclusions (c.f. CL206/G, Plate 25) is present in several quartz trachytes.

(iv) Pantelleritic trachyte

Pantelleritic trachyte is essentially similar to quartz trachyte but contains greater than 10% femic minerals; in hand specimen it is a greenish grey rock, speckled with fine femic mineral grains. Very fresh pantelleritic trachytes (CL214/A and B) from the same composite protrusion contain a variety of femic minerals. Glomeroporphyritic clots of allotriomorphic saniding, showing patchy extinction, and subhedral anorthoclase are set in a groundmass of anorthoclase with two distinct habits: idiomorphic laths about $\frac{1}{2}$ mm long, with a sub-parallel arrangement, are set in a mesostasis of anorthoclase microlites and allotriomorphic grains, with interstitial quartz ($<$10%) and femic minerals. The femic minerals, which occur in angular, interstitial shreds include cossyrite, aegirine and sodic amphibole. The sodic amphibole is pleochroic in delicate translucent colours, and no deep blue colours, typical of riebeckite, are present. The pleochroic scheme which is difficult to determine because of masking by the interference colours appears to be α-greenish blue, β-greyish mauve, γ-light yellowish green, and the mineral is probably arfvedsonite; the mineral is faintly zoned and in places "welded" on aegirine.

Pantelleritic trachyte (CL203/3) consists of extremely allotriomorphic grains and ragged laths of anorthoclase forming a seriate fabric, with rare porphyritic sanidine (showing patchy extinction), interstitial quartz, and evenly distributed ragged, wispy grains and microlites of sodic amphibole, pyroxene (probably aegirine), and cossyrite. The sodic amphibole is probably arfvedsonite; its pleochroic scheme is, α-deep bluish-green, β-purplish grey, γ-light brownish yellow; its optic angle is less than 20° and it has a negative sign. Pantelleritic trachyte (CL618) also contains probable arfvedsonite.

(iv) Pantellerite

Pantellerite is typically light green with small feldspar and quartz phenocrysts. Some pantellerite is distinctly flow banded; the darker bands contain a higher proportion of femic minerals than the light bands. The only analysed pantellerite (CL206/D), from Mount Macarthur, has a distinct finely banded appearance; the bands consist of black streaks and grains of femic minerals in a light yellowish to greenish matrix. The rock contains scattered anorthoclase phenocrysts, with cloudy (resorbed) rims, and rare soda-rich plagioclase phenocrysts with shells of alkali feldspar. The phenocrysts are set in a fine allotriomorphic granular matrix of quartz, alkali feldspar (cloudy) and irregular grains (up to 3 mm across) of sodic amphibole and subordinate aegirine. The amphibole (?riebeckite) is pleochroic from deep blue through lighter indigo blue to yellowish brown; it occurs commonly with an extremely irregular 'mossy' habit.

Pantellerite (CL217/8A, Plate 26) contains sanidine with possible microperthitic exsolution lamellae; oligoclase laths are rimmed with alkali feldspar and some are ophitically enclosed in sanidine phenocrysts. Aegirine is the dominant femic mineral present.

Pantellerite (CL611, CL291/3B, CL289/1A and B) and comendite (CL221/6, CL615, and CL215/3, Plate 27) contain scattered idiomorphic phenocrysts of a brown amphibole. A concentrate (100 to 120 mesch) of the amphibole plus aegirine from rock CL611 was separated using methylene iodide; unfortunately insufficient amphibole was hand picked from the concentrate for analysis. However, comparison of the d-spacings of the amphibole from rock CL291/3B shows a close correlation with the d-spacings of barkevikite from the type locality (Barkeviksjaer, Norway) of this mineral (Table 4). The amphibole is pleochroic from light yellowish brown to deep, almost opaque, brown and rarely carries rims of probable riebeckite.

Apatite and zircon, commonly included in feldspar are present in some pantellerite; rare magnetite and acicular (?) ilmenite (CL617) are finely distributed in some pantellerite.

TABLE 4

Comparison of d-spacings in brown amphibole from the Peak Range and barkevikite from Norway

brown amphibole from pantellerite CL291/3B		barkevikite from Barkeviksjaer, Langesundsfiord, Norway	
relative I (film)	d(Å)	d(Å)	I (chart)
80	8.56	8.46	100
		4.81	13
5	4.56	4.56	6
20	3.42	3.41	10
20	3.30	3.30	26
60	3.17	3.16	85
1	3.06		
1	3.00		
1	2.82	2.82	30
60	2.75	2.73	12
15	2.61	2.61	8
15	2.55		
1	2.40	2.40	12
3	2.35	2.36	8
1	2.29		
20	2.19	2.18	8
100	2.03	2.03	7
		1.91	10
		1.89	5
5	1.70	1.70	6
		1.66	15
		1.63	7
		1.60	10
15	1.17		

(vi) Comendite

Comendite, commonly an off-white to light grey rock, differs from pantellerite in containing less than 10% femics. Comendite in the southern part of the range is distinct from rhyolite in the northern part of the range.

Comendite is typified by rock CL215/3 (Plate 27) which shows characteristics aplitic texture. Anorthoclase and sanidine phenocrysts are present; rare albite is wrapped in alkali feldspar. The analysed comendite (CL221/6) from the southern part of the range has a similar aplitic texture with irregular 'mossy' grains of riebeckite and subordinate aegirine and brown hornblende; riebeckite is rimmed by aegirine.

Rock CL615 from the southern part of the range consists of small laths and irregular grains of anorthoclase arranged with a trachytic texture in an aphaniphyric mesostasis of interlocking irregular microlites of alkali feldspar; rare flakes and microlites of riebeckite and very fine ?cossyrite, magnetite, and rare zircon are present; the rock contains slightly greater than 10% quartz and because of the close similarity to quartz trachyte is termed trachytic comendite.

(vii) Rhyolite

Rhyolite in the northern part of the range is dominantly an off-white to pinkish-white rock, ranging in texture from extremely porphyritic ('sugary') to aphyric. Flow banding and 'stone-bubbles' (lithophysae) are common. In thin section the rocks are cryptocrystalline and commonly rather cloudy; spherulitic rhyolite is present. The dominant porphyritic feldspar is 'glassy', cracked, rounded sanidine with a very low optic angle; anorthoclase and quartz phenocrysts are subordinate. Scattered biotite flakes are scattered throughout some rhyolites (CL242/1G); brown to black acicular ?iron oxide microlites are present in the analysed spherulitic rhyolite (CL293/1A).

(viii) Pitchstone

Pitchstone is a deep olive green to black, brittle, vitreous rock present as a selvage about several protrusions and dykes in the northern part of the range. Flow-banding in pitchstone is commonly contorted; intense fracturing, and an apparently associated development of perlitic structure make the rock prone to shattering.

Much pitchstone is porphyritic; phenocrysts of glassy, rounded sanidine with no cleavage occur most frequently, anorthoclase and quartz less frequently, and sodic plagioclase rarely. Flakes of biotite are scattered through some pitchstone (CL242/1E, CL243/1B). The analysed pitchstone (CL245/2C) consists of glomeroporphyritic clots of embayed, 'glassy' sanidine, oligoclase rimmed by alkali feldspar, and anorthoclase in an isotropic colourless glass (R.I. $<$ balsam) with probable hematite grains and minor zircon; the glass shows a network of commonly curved fractures.

Pitchstone (CL243/1B, CL504) is crowded with a multitude of incipient microlites and party formed, 'ghost' crystals. Pitchstone (CL242/1E) contains fragments of trachytic rock.

(ix) 'Andesitic' rocks

Three separate bodies of peculiar 'andesitic' rocks occur in the northern part of the range; two bodies are apparently exogenous domes and a third (CL251/2) is probably a flow. 'Andesitic' rock (CL244/1) from Mount Commissioner is a green fine-grained rock with small feldspar phenocrysts. The rock has essentially an allotriomorphic granular texture; irregular envelopes of alkali feldspar enclose idiomorphic laths of oligoclase and andesine; some plagioclase is zoned; acicular apatite is enclosed in feldspar. Subcalcic augite and small granules of black iron oxide are intergranular, and quartz (about 5%) interstitial. The feldspars have been altered to light greenish-yellow ?clay minerals which also occur interstitially. CL251/2 is very similar; a specimen from the other dome has not been thin-sectioned but the rock looks very similar to the other two.

The origin of these unusual rocks is discussed later.

Other rocks

(i) Tuffs

Tuffs occur in the northern part of the range about several protrusions with pitchstone selvages. Some tuff bands were found sandwiched in pitchstone. A typical welded crystal-lithic-vitric tuff (CL243/1A) contains rounded fragments (1 to 2 mms) of deeply ferruginised basaltic and trachytic rocks, (?) schist, rounded and idiomorphic feldspar, pyroxene crystals, iddingsite crystals, and shard-like fragments of clear, faintly buff glass, in a cloudy glassy, flow-banded groundmass.

(ii) Phenocryst concentrate

A peculiar coarse-grained rock, consisting of loosely bound crystals of plagioclase, augite, and iddingsite pseudomorphs crops out at the summit of Gilbert's Dome. The rock is tentatively regarded as representing a concentration of phenocrysts by gas-streaming from the underlying lavas before they solidified.

(iii) Phonolite

The plug forming Campbell's Peak consists of a grey rock with a crystalline sheen, produced by the trachytic arrangement of anorthoclase laths. Acicular crystals and microlites of aegirine-augite are scattered through the rock; most of the larger crystals are replaced by fine equidimensional magnetite grains. Scattered phenocrysts of sodic plagioclase are present. Analcite (and ?feldspathoid) occurs interstitially and in irregular patches; fibrous zeolite and calcite are present in small vesicles. The rock is almost certainly a phonolite; the even distribution of interstitial analcite strongly suggests the mineral is primary.

Distribution of rock-types

Deep erosion and weathering and the insufficiency of time for a detailed systematic field study have restricted knowledge of the distribution of rock-types to several general features which are summarized as follows:

(i) basanitic and teschenitic rocks appear to occur exclusively as plugs, mainly west of the range, and in the central part of the range;

(ii) picritic teschenite, and rare olivine nodules are present in several larger plugs;

(iii) tholeiitic and alkalic olivine basalts are interbedded in the volcanic pile;

(iv) tholeiitic basalt and rare tholeiite are probably more frequent in the lower part of the volcanic pile;

(v) rare hawaiite is present in the volcanic pile which is locally capped by trachyandesite;

(vi) alkalic olivine microgabbro occurs at a low level in the southern part of the range;

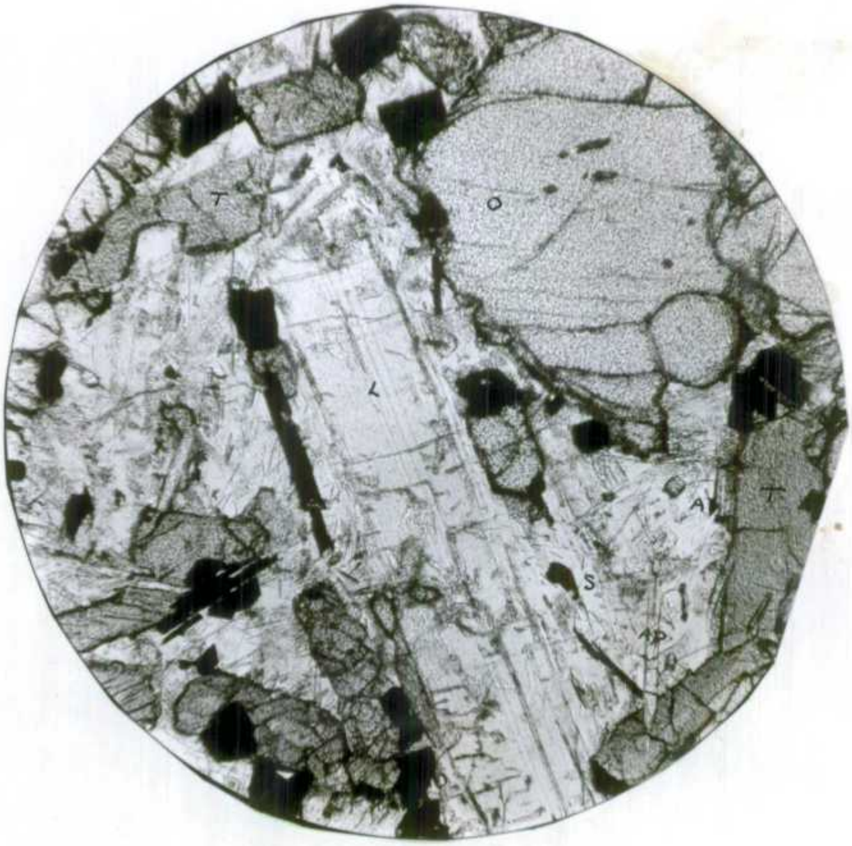
(vii) phonolite occurs as an isolated plug, surrounded by remnants of a basanitic probable flow, east of the range;

(viii) trachytes, pantellerite, and comendite occur in a cluster of protrusions in a relatively small area in the southern part of the range, whereas rhyolite associated with pitchstone and tuff, occurs in a widely separated group of protrusions and large masses, arranged in a broadly circular plan, in the northern part of the range.

Plates 23 to 27

Photomicrographs

(2 mm diameter - Plate 27 only is under crossed nicols)



<u>Plate 23</u> Olivine teschenite (CL269/1) from the plug forming Pumpkin Hill. Porphyritic olivine (O) and labradorite (L) set in sub-ophitic to intergranular groundmass of olivine, titanaugite (T), labradorite, idiomorphic magnetite and acicular ? ilmenite; intersertal patches of sanidine (S) and analcite (A) with acicular crystals and microlites of apatite (AP).

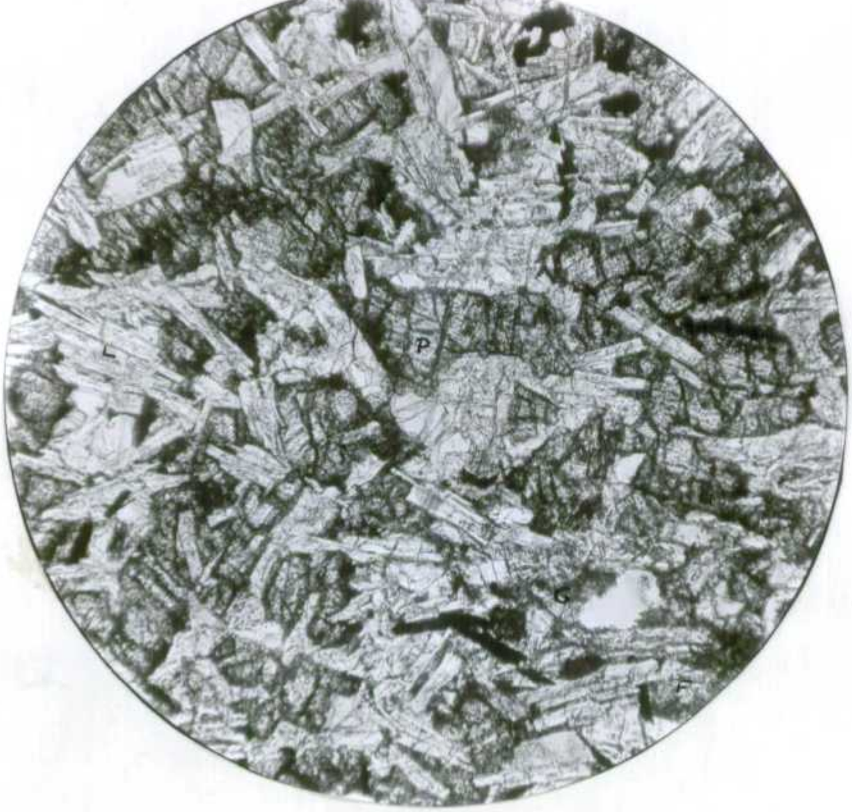
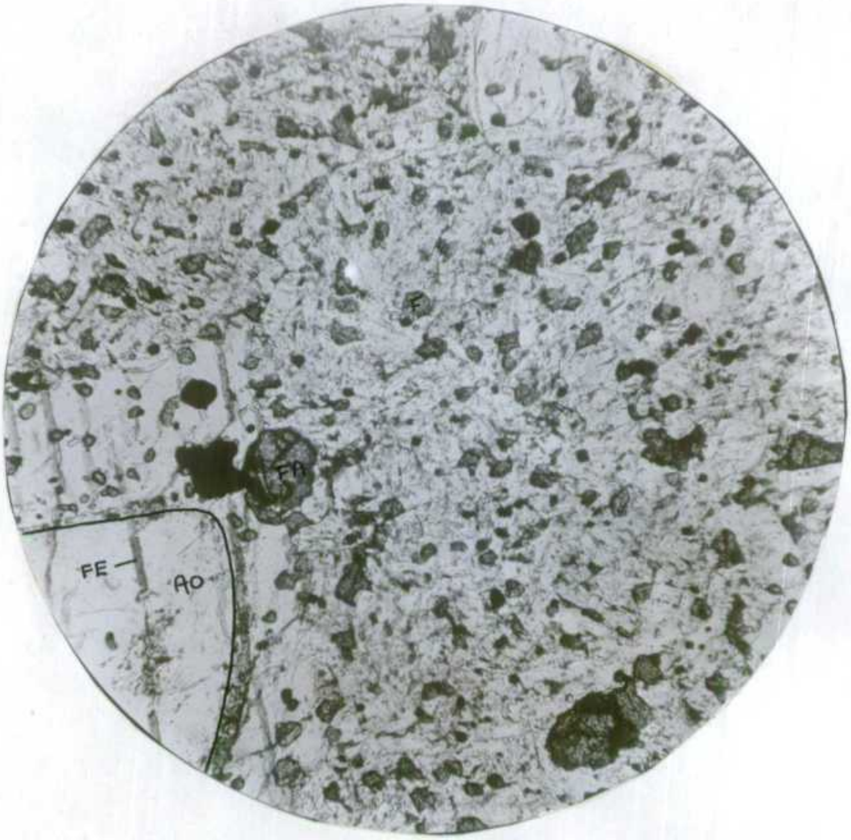


Plate 24 Aphyric tholeiite (CL224/2B) from probable flow, two miles south-east of Malvern Hill; apparently low in volcanic pile. Ophitic intergrowth of labradorite (L) and light brownish-green pigeonite (P) with minor rods of ?ilmenite; much intersertal brownish glass (G) with apatite needles and granules of black iron-ore, and altered 'felsic' patches (F); pigeonite (2V mainly $<10\%$) displays 'patchy' zoning; clear, white patches are gaps in section.



<u>Plate 25</u> Fayalite trachyte (CL206/G) from the explosion pit of Mount Macarthur. Phenocrysts of anorthoclase (AO) set in trachytic groundmass of anorthoclase laths with intergranular probable ferroaugite (light green)(F), minor fayalite and black iron-ore; three small phenocrysts of buff fayalite (2V about 60°) (FA) are shown; the anorthoclase phenocryst shown has a ragged-edged outer shell (delineated with black line) containing abundant inclusions of probable ferroaugite, cloudy apatite, and granular black iron-ore; the outer shell has a higher R.I. than the core (?due to higher soda content); light brown translucent ferruginisation (FE) delineates cleavage in the phenocryst.

Plate 26 Pantellerite (CL217/8A) from cumulo-dome, 3½ miles north-west of Mount Macarthur. Glomeroporphyritic 'patchy', (?microperthitic) sanidine (S), oligoclase (OG), quartz and probable anorthoclase (not in part of slide shown), and small aegirine phenocrysts (AE) in aplitic to weakly trachytic groundmass (showing crude banding) of cloudy sanidine, quartz, aegirine microlites, and fine black iron oxide; in the glomeroporphyritic clots plagioclase has an ophitic relationship with alkali feldspar; the alkali feldspar phenocrysts have commonly resorbed cloudy rims and plagioclase, shells of alkali feldspar; aegirine is pleochroic from yellowish green through light green to darker green; outer rims are deep green; zircon is a rare accessory as inclusions in feldspar.

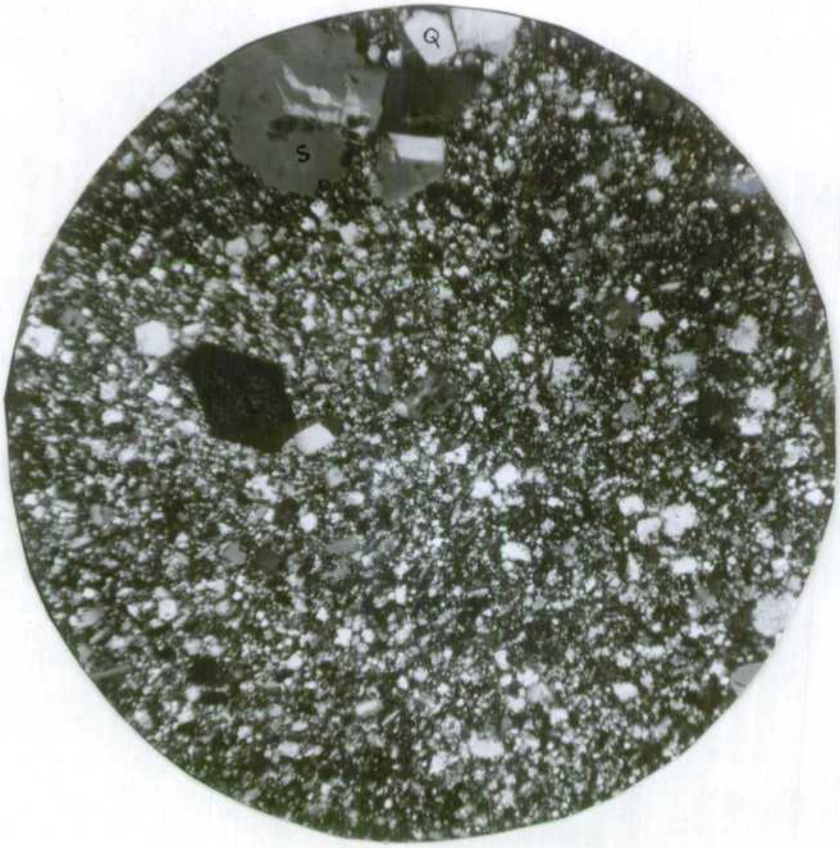


Plate 27 Comendite (CL215/3) from thrust dome of Calvert Peak. Glomeroporphyritic sanidine (S) and quartz (Q), and scattered euhedral phenocrysts of pleochroic brown amphibole (?barkevikite-see Table 4) in aplitic groundmass of sanidine (and ?anorthoclase), quartz, microlites of deep blue to light indigo soda-amphibole (probably riebeckite), and minor fine black iron-ore.

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Major elements

The major oxide analyses of eighteen lavas, together with their norms, are presented in Table 5; the localities of the rocks are given in the Appendix. The variations of seven major oxides against silica are plotted in Figure 8 (the key to the rock-type symbols is shown in Figure 12); solid lines are intended to infer the apparent trends in the content of the oxides in the same rock-types, whereas the dashed lines are intended to show, very broadly, the trends in composition throughout the series of rock-types.

The picritic teschenite (CL273/2) has a high magnesia content and low alumina, in agreement with its richness in olivine, whereas olivine microteschenite (CL263/2) is comparatively poor in olivine and shows a consequent increase in silica and alumina, and decrease in magnesia. The two analcite basanite show very similar distributions of oxides (apart from magnesia and alumina) to the picritic teschenite.

Two alkalic olivine basalts have similar compositions as basanite, apart from enrichment in silica (48%-49%). Two tholeiitic olivine basalts (CL516/J and CL201/3), within the range 50%-51% silica are poor in magnesia compared with the alkalic olivine basalts, whereas the other two tholeiitic olivine basalts contain about the same magnesia as the alkali basalts. Tholeiitic olivine basalt (CL215/8B) is notably lower in alkali content. Tholeiitic olivine basalt (CL291/1C) is notable for extremely low ferric oxide, whereas other tholeiitic olivine basalts (CL516/J and CL201/3) contain much higher ferric oxide contents. Titania contents in all the

TABLE 5

Chemical analyses and norms

Wt%	CL273/2 picritic teschenite	CL264/3 analcite basanite	CL272/1 analcite basanite	CL263/2 olivine microteschenite
SiO_2	45.5(0)	45.3(0)	45.6(0)	49.8(0)
TiO_2	1.75	2.00	1.75	1.95
Al_2O_3	10.5(0)	14.4(0)	15.6(0)	16.8(0)
Fe_2O_3	3.10	3.40	3.00	1.35
FeO	8.55	7.30	8.40	7.35
MnO	0.16	0.13	0.22	0.11
MgO	14.7(0)	9.75	6.85	5.15
CaO	9.20	8.60	9.50	8.85
Na_2O	2.70	4.15	3.30	4.40
K_2O	1.35	2.30	2.10	1.90
P_2O_5	0.57	0.89	0.69	0.62
H_2O^+	1.70	1.35	2.55	1.45
H_2O^-	0.38	0.27	0.32	0.18
CO_2	0.04	0.07	0.11	0.18
	100.2(0)	99.9(1)	99.9(9)	100.0(9)
		CIPW norms		
or	7.98	13.59	12.42	11.23
ab an	14.85) 12.54) 27.39	13.16) 13.87) 27.03	16.45) 21.55) 38.00	28.15) 20.48) 48.63
ne	4.33	11.89	6.21	4.92
di (di (he	18.75) 4.71) 23.46	14.47) 3.91) 18.38	11.18) 5.98) 17.16	9.69) 6.17) 15.86
ol (fo (fa	19.56) 6.21) 25.77	12.31) 4.21) 16.52	8.32) 5.62) 13.94	5.84) 4.70) 10.54
mt	4.49	4.93	4.35	1.95
il	3.32	3.80	3.32	3.70
ap	1.35	2.11	1.63	1.46
H_2O	2.08	1.62	2.87	1.63
CO_2	0.04	0.07	0.11	0.18
	100.21	99.94	100.00	100.10
plag. An %	46	51	57	42
Mg/Mg+Fe %	82	81	68	64
S.I.	48.4	36.2	29.0	25.6

S.I. = $MgO/FeO + Fe_2O_3 + Na_2O + K_2O + MgO \times 100$ (Solidification Index of Kuno (1959))

Wt%	CL606/B alkalic olivine basalt	CL606/L alkalic olivine basalt	CL516/J tholeiitic olivine basalt	CL201/3 tholeiitic olivine basalt
SiO_2	48.1(0)	48.8(0)	50.0(0)	50.9(0)
TiO_2	2.25	2.15	2.45	2.80
Al_2O_3	14.6(0)	15.4(0)	14.1(0)	14.9(0)
Fe_2O_3	1.85	3.35	4.10	3.70
FeO	9.35	7.90	8.00	7.00
MnO	0.14	0.13	0.16	0.09
MgO	7.30	6.20	4.30	4.25
CaO	8.15	6.80	7.05	7.75
Na_2O	3.20	4.05	3.80	3.70
K_2O	1.45	1.60	1.50	1.15
P_2O_5	0.45	0.67	0.74	0.56
H_2O^+	2.45	2.50	1.80	1.45
H_2O^-	0.75	0.55	1.80	1.70
CO_2	0.09	0.04	0.05	0.05
	100.1(3)	100.1(4)	99.8(5)	100.0(0)
		CIPW norms		
qtz	-	-	2.13	4.23
or	8.57	9.45	8.86	6.79
ab an	27.08) 48.27 21.19)	34.27) 53.39 19.12)	32.16) 49.15 16.99)	31.31) 51.96 20.65)
di (di (he	8.40) 13.31 4.91)	5.63) 8.31 2.68)	6.66) 10.76 4.10)	7.95) 11.45 3.50)
hy (en (fs	2.85) 4.76 1.91)	2.36) 3.65 1.29)	7.62) 13.00 5.38)	6.90) 10.38 3.48)
ol (fo (fa	8.01) 13.93 5.92)	7.33) 11.74 4.41)	-	-
mt	2.68	4.86	5.94	5.36
il	4.27	4.08	4.65	5.31
ap	1.06	1.59	1.75	1.32
H_2O	3.20	3.05	3.60	3.15
CO_2	0.09	0.04	0.05	0.05
	100.14	100.16	99.89	100.00
plag. % An	44	36	35	40
Mg/Mg+Fe %	66	71	65	72
S.I.	31.5	26.8	19.8	21.6

Wt%	GL606/B alkalic olivine basalt	CL606/L alkalic olivine basalt	CL516/J tholeiitic olivine basalt	CL201/3 tholeiitic olivine basalt
SiO_2	48.1(0)	48.8(0)	50.0(0)	50.9(0)
TiO_2	2.25	2.15	2.45	2.80
Al_2O_3	14.6(0)	15.4(0)	14.1(0)	14.9(0)
Fe_2O_3	1.85	3.35	4.10	3.70
FeO	9.35	7.90	8.00	7.00
MnO	0.14	0.13	0.16	0.09
MgO	7.30	6.20	4.30	4.25
CaO	8.15	6.80	7.05	7.75
Na_2O	3.20	4.05	3.80	3.70
K_2O	1.45	1.60	1.50	1.15
P_2O_5	0.45	0.67	0.74	0.56
H_2O^+	2.45	2.50	1.80	1.45
H_2O^-	0.75	0.55	1.80	1.70
CO_2	0.09	0.04	0.05	0.05
	100.1(3)	100.1(4)	99.8(5)	100.0(0)
		CIPW norms		
qtz	-	-	2.13	4.23
or	8.57	9.45	8.86	6.79
ab an	27.08 21.19 } 48.27	34.27 19.12 } 53.39	32.16 16.99 } 49.15	31.31 20.65 } 51.96
di (di (he	8.40 4.91 } 13.31	5.63 2.68 } 8.31	6.66 4.10 } 10.76	7.95 3.50 } 11.45
hy (en (fs	2.85 1.91 } 4.76	2.36 1.29 } 3.65	7.62 5.38 } 13.00	6.90 3.48 } 10.38
ol (fo (fa	8.01 5.92 } 13.93	7.33 4.41 } 11.74	-	-
mt	2.68	4.86	5.94	5.36
il	4.27	4.08	4.65	5.31
ap	1.06	1.59	1.75	1.32
H_2O	3.20	3.05	3.60	3.15
CO_2	0.09	0.04	0.05	0.05
	100.14	100.16	99.89	100.00
plag. % An	44	36	35	40
Mg/Mg+Fe %	66	71	65	72
S.I.	31.5	26.8	19.8	21.6

Wt%	CL215/8B tholeiitic olivine basalt	CL291/1C tholeiitic olivine basalt
SiO_2	49.0(0)	50.8(0)
TiO_2	1.56	1.47
Al_2O_3	14.5(0)	14.5(0)
Fe_2O_3	2.70	0.83
FeO	7.75	8.45
MnO	0.14	0.13
MgO	6.90	7.15
CaO	8.05	7.30
Na_2O	2.95	3.45
K_2O	0.46	1.05
P_2O_5	0.31	0.38
H_2O^+	1.76	1.00
H_2O^-	1.70	0.23
CO_2	2.12	2.95
	99.9(0)	99.6(9)
	CIPW norm	CIPW norm
qtz	1.81	-
or	2.72	6.21
ab an	24.96 24.97 } 49.93	29.19 20.98 } 50.17
di { di he	7.05 3.47 } 10.52	6.45 3.99 } 10.44
hy { en fs	13.91 7.84 } 21.75	11.52 8.18 } 19.70
ol { fo fa	-	2.31 1.81 } 4.12
mt	3.91	1.20
il	2.96	2.79
ap	0.72	0.88
H_2O	3.46	1.23
CO_2	2.12	2.95
	99.90	99.69
plag. % An	50	42
Mg/Mg+Fe %	70	65
S.I.	33.2	34.2

* peralkaline

Wt%	CL206/G fayalite trachyte		CL215/8A aegirine trachyte		CL217/1A* aegirine trachyte		CL215/5* aegirine trachyte	
SiO_2	60.8(0)		62.7(0)		63.9(0)		66.0(0)	
TiO_2	0.09		0.03		0.30		0.11	
Al_2O_3	16.6(0)		16.7(0)		15.9(0)		17.1(0)	
Fe_2O_3	2.74		3.79		3.80		2.07	
FeO	4.00		1.60		1.66		0.79	
MnO	0.15		0.15		0.11		0.05	
MgO	0.42		0.12		0.18		0.15	
CaO	2.52		1.37		1.17		0.36	
Na_2O	5.75		6.55		6.65		7.15	
K_2O	5.25		5.45		4.95		5.10	
P_2O_5	0.21		0.05		0.09		0.03	
H_2O^+	0.64		0.87		0.53		0.61	
H_2O^-	0.59		0.39		0.50		0.32	
CO_2	0.05		0.10		0.15		0.04	
	99.8(1)		99.8(8)		99.8(9)		99.8(8)	
	CIPW norm	op→ol+ qtz, mt→ ac	CIPW norm	op→ol+ qtz, mt→ ac	CIPW norm	op→ol+ qtz, mt→ ac	CIPW norm	op→ol+ qtz, mt→ ac
qtz	1.00	2.75	2.11	2.99	5.28	6.11	4.54	5.34
c	-	-	-	0.07	-	0.12	-	0.56
or	31.03	31.03	32.21	32.21	29.25	29.25	30.14	30.14
ab	48.65	39.66	55.42	42.98	54.23	43.79	59.56	53.70
an	3.98	8.75	0.07	6.47	-	5.22	-	1.59
ac	-	7.93	-	10.96	1.80	10.99	0.82	5.99
di {di / he}	1.16 5.04	0.29 1.79	0.64 0.10	-	0.97 0.25	-	0.81 -	-
wo	-	-	2.31	-	1.54	-	0.23	-
hy {en / fs}	0.51 2.53	-	-	-	-	-	-	-
ol {fo / fa}	-	0.64 5.03	-	0.21 2.46	-	0.32 2.13	-	0.26 1.05
mt	3.97	-	5.49	-	4.61	-	2.39	-
hm	-	-	-	-	-	-	0.14	-
il	0.17	0.17	0.06	0.06	0.57	0.57	0.21	0.21
ap	0.49	0.49	0.11	0.11	0.21	0.21	0.07	0.07
H_2O	1.23	1.23	1.26	1.26	1.03	1.03	0.93	0.93
CO_2	0.05	0.05	0.10	0.10	0.15	0.15	0.04	0.04
	99.81	99.81	99.88	99.88	99.89	99.89	99.88	99.88
plag. % An	8	18	-	12	-	11	-	3
Mg/Mg+Fe %	21	16	88	11	82	2	100	3
S.I.	2.3		0.7		1.2		1.0	

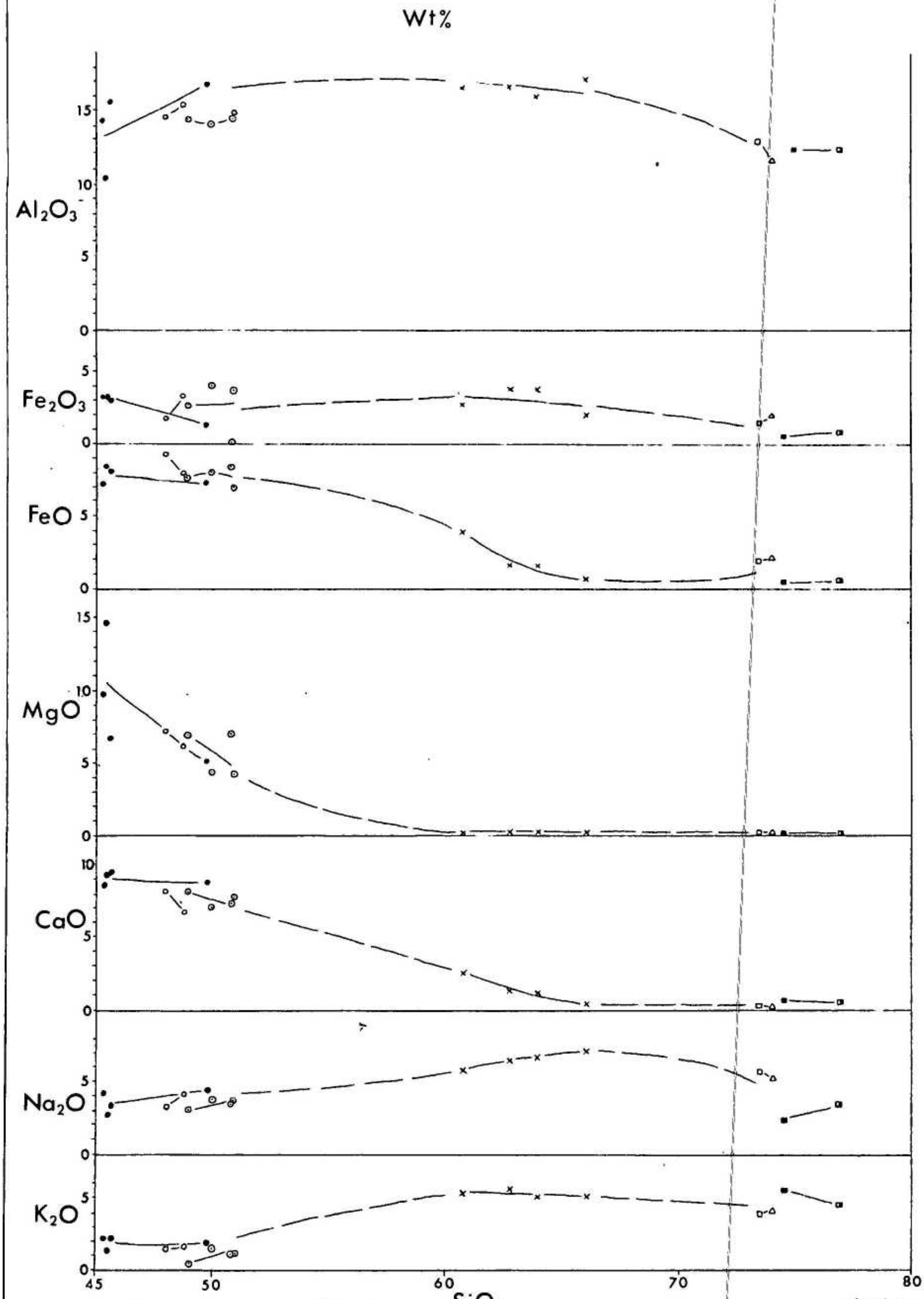
* peralkaline

Wt%	CL221/6* comendite		CL206/D* pantellerite	CL245/2C porphyritic pitchstone		CL293/1A spherulitic rhyolite	
SiO_2	73.4(0)		74.0(0)	75.5(0)		77.0(0)	
TiO_2	0.08		0.02	0.07		0.03	
Al_2O_3	12.8(0)		11.5(0)	12.3(0)		12.3(0)	
Fe_2O_3	1.44		1.98	0.48		0.79	
FeO	1.88		2.11	0.55		0.61	
MnO	0.06		0.03	0.02		0.01	
MgO	0.01		0.08	0.09		0.07	
CaO	0.22		0.16	0.58		0.45	
Na_2O	5.65		5.20	2.30		3.45	
K_2O	3.90		4.05	5.50		4.45	
P_2O_5	0.01		0.01	0.04		0.02	
H_2O^+	0.22		0.33	3.10		0.47	
H_2O^-	0.08		0.28	0.12		0.16	
CO_2	0.04		0.05	-		0.02	
	99.7(9)		99.8(0)	99.6(5)		99.8(3)	
	CIPW norm	mt→ac	CIPW norm	CIPW norm	mt→ac	CIPW norm	mt→ac
qtz	22.77	24.77	28.29	38.56	38.75	38.69	38.99
c	-	-	-	1.61	1.91	1.04	1.54
or	23.05	23.05	23.93	32.50	32.50	26.30	26.30
ab	44.13	43.08	36.61	19.46	17.89	29.19	26.60
an	-	0.56	-	2.62	2.62	2.10	2.10
ac	3.24	4.17	5.73	-	1.39	-	2.29
ns	-	-	0.21	-	-	-	-
di (di	0.01	tr	0.04	-	-	-	-
di (he	0.91	0.42	0.61				
hy (en	0.02	0.02	0.03	0.22	0.22	0.17	0.17
hy (fs	2.69	3.21	3.57	0.54	0.93	0.44	1.08
mt	0.46	-	-	0.70	-	1.15	-
il	0.15	0.15	0.04	0.13	0.13	0.05	0.05
ap	0.02	0.02	0.02	0.09	0.09	0.05	0.05
H_2O	0.30	0.30	0.61	3.22	3.22	0.63	0.63
CO_2	0.04	0.04	0.05	-	-	0.02	0.02
	99.79	99.79	99.74	99.65	99.65	99.83	99.83
S.I.	0.1		0.6	1.1		0.7	

Analysts: K.J. Heinrich and H.W. Sears (Australian Mineral Development Laboratories, Adelaide)

Figure 8

Variation diagram – SiO_2: major oxides



To accompany Record 1965/241

M(Pt)27

basaltic rocks show slight variations about 2%, with no marked changes in content from one rock-type to another.

Four trachytes, ranging between 61% and 66% silica, show regular variations in their contents of most oxides with increasing silica content. Magnesia is consistently very low and calcium oxide decreases regularly with increasing silica content. The trachytes contain appreciably higher contents of alkalis than all other rock-types, and slightly higher alumina than the basaltic and extremely acidic rocks. Three aegirine trachytes are characterised by an appreciable excess of ferric oxide over ferrous oxide whereas fayalite trachyte contains less ferric oxide than ferrous oxide; the four rocks are not altered.

Pantellerite and comendite from the southern part of the range, with 73%-74% silica, are relatively lower in most other oxides than the trachytes; the content of total iron oxides is about the same as the aegirine trachytes.

Rhyolite and pitchstone from the northern part of the range show several distinct compositional differences to the comendite and pantellerite from the south. The rhyolite (CL293/1A) is considerably richer in silica; both rhyolite and pitchstone have an excess of potash over soda, in contrast to all other analysed rocks, in which soda is dominant. Iron is lower, and calcium shows a slight increase, compared with the southern comendite and pantellerite. All the acidic rocks from the southern part of the range, except fayalite trachyte (CL206/G) and aegirine trachyte (CL215/8A)[4] are

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[4]CL215/8A is almost peralkaline; the lack of peralkalinity is probably due to an analytical error.

peralkaline i.e. there is a molecular excess of alkalis over alumina) in contrast to the rhyolite and pitchstone from the north which are not peralkaline, but peraluminous.

Norms

Definitive normative characteristics of the different rock-types have been mentioned in the section on classification and nomenclature of the rocks (Table 2). The norms of the undersaturated teschenites and basanites are approximately analogous with their modal characteristics; modal analcite is represented by normative nepheline. Ilmenite appears to be a very minor mineral in the rocks, whereas 3% is present in their norms indicating high titanium contents in the clinopyroxenes. The alkali basalts show near-undersaturated characteristics, low in normative hypersthene compared with olivine. The tholeiitic olivine basalts are near-saturated (CL291/1C) and over-saturated (CL215/8B, CL516/J, and CL201/3) with very high amounts of normative hypersthene and low amounts of normative quartz. These characteristics must be related to interstitial glass and subcalcic augite in the rocks, because no hypersthene and quartz is present.

Two norms were calculated for each of the trachytes; orthopyroxene and magnetite in the CIPW norms were converted respectively to olivine plus quartz, and acmite. The modification of the CIPW norms were converted respectively to olivine plus quartz, and acmite. The modification of the CIPW norm gives a closer approximation to the mode, with acmite represented by ferroaugite in CL206/G, and aegirine in the other trachytes; also the CIPW norm takes no account of the fact that fayalite can co-exist with quartz; fayalite, however is present in the mode of only CL206/G.

The calcium forming wollastonite in the CIPW norms of the three aegirine trachytes forms anorthite in the modified norms and alumina is resultantly in excess, leaving normative corundum. The high Fe_2O_3:FeO ratio in aegirine trachyte (CL215/5) is expressed in the presence of normative hematite.

Comendite and pantellerite (CL206/D, which has no magnetite in the CIPW norm) contain acmite in the CIPW norm, and pantellerite contains sodium metasilicate (ns), showing its high peralkalinity. Rhyolite and pitchstone from the northern part of the range do not contain acmite in the CIPW norm; other differences are the presence of normative anorthite and corundum.

The peralkalinity factor (Mol. $(Na_2O + K_2O)/Al_2O_3$) of the acidic rocks ranges from 1.01 in CL215/5 to 1.12 in CL206/D, showing a steady increase with increasing silica content.

Trace elements

Concentrations of rubidium, strontium, and barium were determined in a representative series of fifteen rocks (Table 6), of which nine are analysed rocks (Table 5). The rubidium concentrations are based on an isotope dilution value of 210 ppm for the standard G-1, determined at the Australian National University by Dr. W. Compston and Mr. M. Vernon. This value gives 22 $\pm$ 0.5 ppm of ribidium for the standard W-1, determined at the Australian National University by the unpublished method of Dr. K. Norrish (C.S.I.R.O., Adelaide), compared with an isotope dilution value of 22 ppm of rubidium in W-1. The strontium concentrations are based on an isotope dilution value of 247 ppm for G-1, and using Dr. Norrish's X-ray fluorescence method, 186 $\pm$ 1 ppm for W-1. The barium

TABLE 6

Concentrations (p.p.m.) of Rb, Sr, & Ba

* analysed rocks

	Rb	K/Rb	Sr	Ba	Ba/Rb
CL263/2* (olivine microteschenite)	31	503	766	419	13.5
CL264/3* (analcite basanite)	50	380	1022	561	11.2
CL606/L* (alkalic olivine basalt)	35	378	797	506	14.5
CL608 (?alkalic olivine basalt)	32		734	451	14.1
CL610/A (alkalic olivine basalt)	19		382	271	14.3
CL215/8B* (tholeiitic olivine basalt)	12	317	417	225	18.8
CL291/1C* (tholeiitic olivine basalt)	25	347	433	306	12.2
CL607 (tholeiitic olivine basalt)	10		307	130	13.0
CL614 (tholeiitic basalt)	18		347	172	9.6
CL215/5* (aegirine trachyte)	266	158	6	3	0.01
CL215/8A* (aegirine trachyte)	193	227	13	47	0.24
CL611 (pantellerite)	500		-	-	-
CL221/6* (comendite)	759	42	-	-	-
CL293/1A* (spherulitic rhyolite)	463	78	5	12	0.03
CL615 (trachytic comendite)	293		2	-	-

These results were obtained by X-ray spectrography, using a method kindly made available by Dr. K. Norrish of the C.S.I.R.O., Adelaide.

TABLE 7

Concentrations (p.p.m.) of Rb, Sr, Yt, Zr, Nb

* analysed rock
+ also in Table 6

Arranged in order of increasing acidity downwards

rock number	Rb	Yt	Zr	Nb	Sr
CL616 (=CL217/1A*) (aegirine trachyte)	150	70	900	80	All below limit of detection (40 p.p.m.)
CL609/B (aegirine trachyte)	160	120	1050	70	
CL612/A (pantelleritic trachyte)	150	60	1120	70	
CL618 (pantelleritic trachyte)	370	185	1730	145	
CL617 (pantellerite)	475	105	2640	320	
CL611+ (pantellerite)	490	230	3450	370	
CL619 (pantellerite)	620	300	4770	420	
CL615+ (trachytic comendite)	290	50	930	140	

These results were determined by X-ray fluorescence spectroscopy by Dr. N.C. Stevens, (Department of Geology, University of Queensland).

concentrations are based on 1225 ppm in G-1 (Fleischer and Stevens, 1962) which gives a value of 210 ± 5 ppm for W-1 using Dr. Norrish's method, compared with a value of 225 ppm for W-1, suggested as the best value by Fleischer and Stevens (1962). Concentrations of rubidium, strontium, yttrium, zirconium, and niobium were determined in eight acidic lavas (Table 7), of which one is an analysed rock (Table 5) and two were determined independently for rubidium, strontium, and barium (Table 6). In Tables 6 and 7 the rocks are arranged approximately so that in descending order they increase in acidity.

The following trends are evident:

(i) rubidium increases, and strontium and barium decrease, with increasing acidity;

(ii) strontium, rubidium, and barium are mainly more highly concentrated in basanite, teschenite, and alkalic basalt than tholeiitic basalt;

(iii) rubidium, zirconium, yttrium, and niobium are much more highly concentrated in pantellerite and pantelleritic trachyte than trachyte and comendite.

Significance of trace element distribution

Taylor and Heier (1960) have pointed out several reasons why the Ba/Rb ratio offers the best guide to fractionation processes. The reasons stated are that the two elements are 'readily determined, with good precision and accuracy; they form bonds with about the same amount of ionic character; they are close enough in size to K so that they enter the lattice readily; Ba possesses a double charge to cause it to enter the early fractions, and

Rb is just large enough to be slightly enriched in the later fractions'.

Taylor and Heier have shown that the later members of alkali feldspars in a fractionated series have low Ba/Rb ratios compared with early crystallised members. The Ba/Rb ratios in Table 6 show the expected trend, with very low values in the acidic rocks compared with the basic rocks.

The K/Rb ratios for the analysed rocks in Table 6 are fairly uniform about 350 in the basic rocks but an uneven enrichment of rubidium in the acidic rocks gives eccentric variations in the K/Rb ratios. This feature is in agreement with observations of Taylor and Heier (1960) on Norwegian granites, in which there is an enrichment of rubidium in pegmatites.

Concentrations of rubidium, yttrium, zirconium, and niobium show a rapid increase in rocks ranging from aegirine trachyte to pantellerite. The trachytic-comendite (CL615) is closer to quartz trachyte than comendite in texture and composition, containing slightly more than 10% modal quartz; it is notably impoverished in femic minerals. Broadly, the increase in concentration of the trace elements appears to parallel increase in acidity. Butler and Smith (1962) have noted that niobium increases notably in concentration with the appearance of riebeckite. Although pantelleritic trachyte (CL618), pantellerite (CL617 and CL611) and trachytic-comendite (CL615) are the only rocks in Table 7 containing sodic amphibole and show a marked increase in niobium concentration, very fine-grained pantellerite (CL619) appears to contain only aegirine (30%) and no sodic amphibole, and yet contains the highest concentration of niobium. This pantellerite contains also very high concentration of the other trace elements. The three pantellerites contain appreciably higher concentrations of the four elements than the [illegible] concentrations of the elements determined by Butler and Smith (1962) in pantellerites, comendites, and trachytes in other parts of the world. The concentration of niobium in all the rocks in Table 7 are appreciably higher than concentrations of the elements quoted by Butler and Smith (1962) in acidic derivatives of tholeiitic rocks.

The high concentrations of zirconium, niobium, and the rare earth elements in peralkaline rocks has been attributed to volatiles by Sørensen (1960).

DISCUSSION

Aspects of the origin of the volcanic rocks are discussed in terms of a unified petrogenetic sequel in the following sections. However, several mineralogical and chemical features are discussed here in relation to possible petrogenetic trends and effects.

The volcanics show a variation from 45% to 77% silica; conspicuous gaps without analysed representatives occur between 51% and 61% silica and between 66% and 73% silica. The silica contents of tholeiite, hawaiitic basalt, and trachyandesite would almost certainly fall in the first gap, and the latter gap would be occupied by quartz trachyte and pantelleritic trachyte. It is confidently inferred that the province contains a complete range of rocks from thoroughly undersaturated to thoroughly oversaturated types.

The compositions of picritic teschenite and olivine microteschenite are significant when considered in relationship to the composition of the two analcite basanites. The rapidly cooled fine-grained analcite basanites are closely similar in composition and are therefore inferred to represent a basaltic magma-type of the Peak Range province. The picritic teschenite and the olivine microteschenite represent the same magma-type, which was modified by fractional crystallisation under slow cooling conditions (expressed in the coarse texture of the rocks). The two rocks represent the complementary effects of fractionation, picritic teschenite being enriched in the early crystallising minerals and olivine microteschenite being impoverished in the same.

Allied to the constant variation in silica content is the presence of a range of pyroxenes. Titanaugite is dominant in basanite and teschenite, augite in alkalic basalt (some contains mildly titaniferous augite), subcalcic augite and minor pigeonite in tholeiitic basalt, pigeonite and hypersthene in tholeiite, ferroaugite in fayalite trachyte, probable hedenbergite in trachyte, and aegirine in trachyte and pantellerite.

The preferential distribution of titanaugite in the basanitic and teschenitic rocks is apparently not related to higher contents of titanium (Table 5) although two tholeiitic basalts (CL291/1C and CL215/8B) do show a slight diminution in titanium content. The presence of ilmenite in excess of magnetite in the tholeiitic basalts indicates the preferred habit of titanium in these rocks. Wilkinson (1957) has shown that the later formed pyroxenes in the teschenite of the Black Jack Sill are poorer in titanium, so the titanaugites of the basanitic and teschenitic rocks in the Peak Range probably represent pyroxenes crystallising at an earlier stage in cooling than the pyroxenes in the alkalic and tholeiitic basalts. Thus, titanium in the tholeiitic rocks is inferred to have precipitated as ilmenite before the crystallisation of pyroxene. This is emphasised in the ophitic and intergranular fabrics of the tholeiitic rocks. The comparative delay in the precipitation of subcalcic pyroxene in the tholeiitic rocks is due to a lower temperature of crystallisation thanaugite. Titanium is effectively fractionated by the earlier crystallisation of ilmenite. This effect is possibly related to the fairly high fayalite contents of olivines in alkalic and tholeiitic basalts; the formation of ilmenite in preference to magnetite left more iron for olivine.

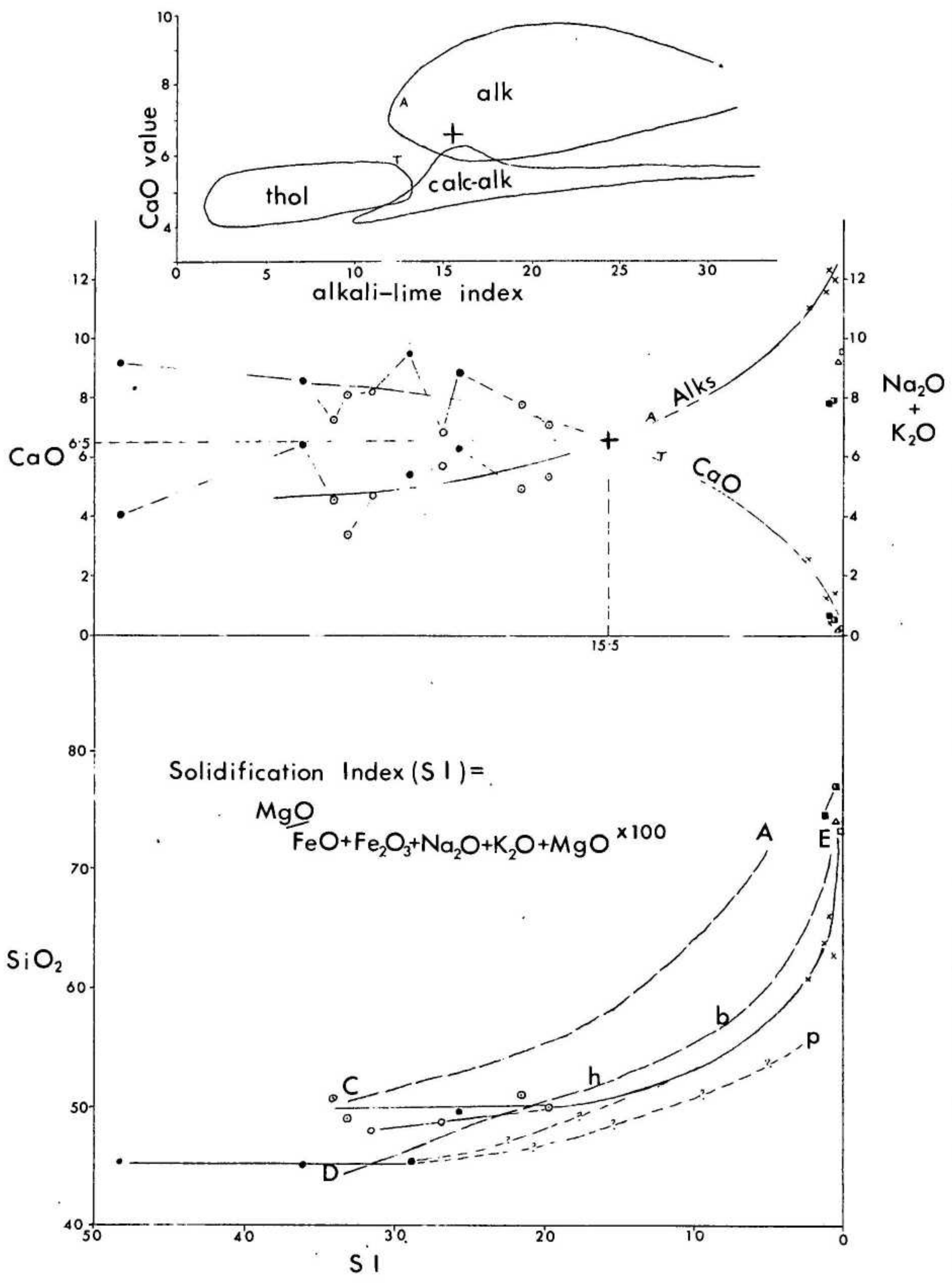
The dominant subcalcic augite in two tholeiitic basalts (CL215/8B and CL291/1C) would be more acutely expressed in their norms if the high contents of CO_2 were converted into calcium carbonate. The conversion would effect a closer analogy with the mode, as the rocks contain much interstitial calcite.

Mineralogical differences between the fayalite trachyte (CL206/G) and the three aegirine trachytes appear to support inferences drawn by Carmichael (1962) on the relevance of the system $FeO-Fe_2O_3-SiO_2-Na_2O.SiO_2$ to coexisting femic minerals in pantellerites. Carmichael holds that because the system 'contains two oxidation states of iron, it is to be expected that the partial pressure of oxygen prevailing at the time of crystallisation ... will influence the assemblage of the ferromagnesian minerals that precipitate'. The four trachytes appear to be compatible with the suggestions made by Carmichael for pantellerites that 'increase of the partial pressure of oxygen in the pantelleritic liquids may increase the amount of precipitating pyroxene and also its content of soda and it may also increase the amount of magnetite and possibly ilmenite at the expense of fayalite and cossyrite'. Thus, the presence of fayalite and ferroaugite in CL206/G is accompanied by an excess of FeO over Fe_2O_3 whereas the other trachytes contain aegirine and an excess of Fe_2O_3 over FeO. Carmichael has noted that fayalite is apparently never associated with aegirine in pantellerite.

The different assemblages of sodic amphiboles, aegirine, cossyrite, and iron oxides found in the acidic rocks are probably related to complex variations in the partial pressure of oxygen and composition during crystallisation.

Figure 9

SI:SiO_2 diagram and alkali-lime index



To accompany Record 1965/241

M(Pt)28

VARIATION DIAGRAMS

The volcanics in the Peak Range present a complex petrogenetic problem. Field evidence and petrographic and petrochemical evidence strongly suggest that the diverse rock-types are associated in a single volcanic cycle. In presenting several variation diagrams an attempt is made by comparisons with other provinces to further strengthen this suggestion and to suggest possible lines of petrogenetic evolution of the volcanism. The rock associations in the provinces with which the Peak Range is compared in the diagrams presented have been shown by experimental and petrological studies to have been derived primarily by differentiation. The main agent of differentiation has in turn been inferred to be crystal fractionation. Variation diagrams have been devised to highlight the degree of fractionation in a series of associated rocks; several of these diagrams are used here. The key to the rock-type symbols used in the variation diagrams is in Figure 12.

Solidification index and alkali-lime index diagrams

Kuno (1959) devised the solidification index as a measure of the amount of residual liquid in a rock. The degree to which associated volcanics show a steady diminution in the solidification index is an indication of their degree of fractionation. Figure 9 shows silica plotted against the solidification indices. The line CA represents the trend of the average silica and SI values of aphyric rocks from the Izu-Hakone pigeonitic rock series plotted from figures in Kuno (1959); the rock-types range from basalt to dacite. The line DE represents the trend of rocks from the Circum-Japan Sea alkali province from analyses of Tomita, quoted in Kuno

(1959); the rock-types range from limburgite-basanitoid to comendite. Several inferences shown by lines in the diagram can be drawn regarding the plots of the rocks from the Peak Range:

(i) the spread of the basaltic rocks suggests the presence of three basaltic magma-types, producing in turn the basanite-teschenite rocks, the alkalic basalts, and the tholeiitic basalts;

(ii) the alkalic and tholeiitic basaltic rocks appear to form a transitional series of lavas between the pigeonitic basalts and alkali basalts of the Japan provinces; with increasing SI values the trends of the tholeiitic and alkalic basalts converge, on the Circum-Japan Sea alkali province trend;

(iii) the trend of the basanite-teschenite magma-type with increasing SI is not obvious with the analyses available; the plot of the olivine microteschenite among the alkalic-tholeiitic basalt suggests that the trend is towards the same trend as the basalts; alternatively the basanite-teschenite magma may have locally fractionated to produce the phonolite at Campbell's Peak, which is hypothetically plotted at 'p'; evidence has already been discussed showing local fractionation features in the teschenites, a feature emphasised in the SI:SiO_2 plot by thw wide separation of the picritic teschenite and the olivine microteschenite;

(iv) the letters 'h' and 'b' represent the positions of 'trachy-andesitic basalt' and 'trachy-andesite' from the Circum-Japan Sea province; hawaiitic basalt and trachyandesite in the Peak Range probably have about the same compositions respectively as the two rocks;

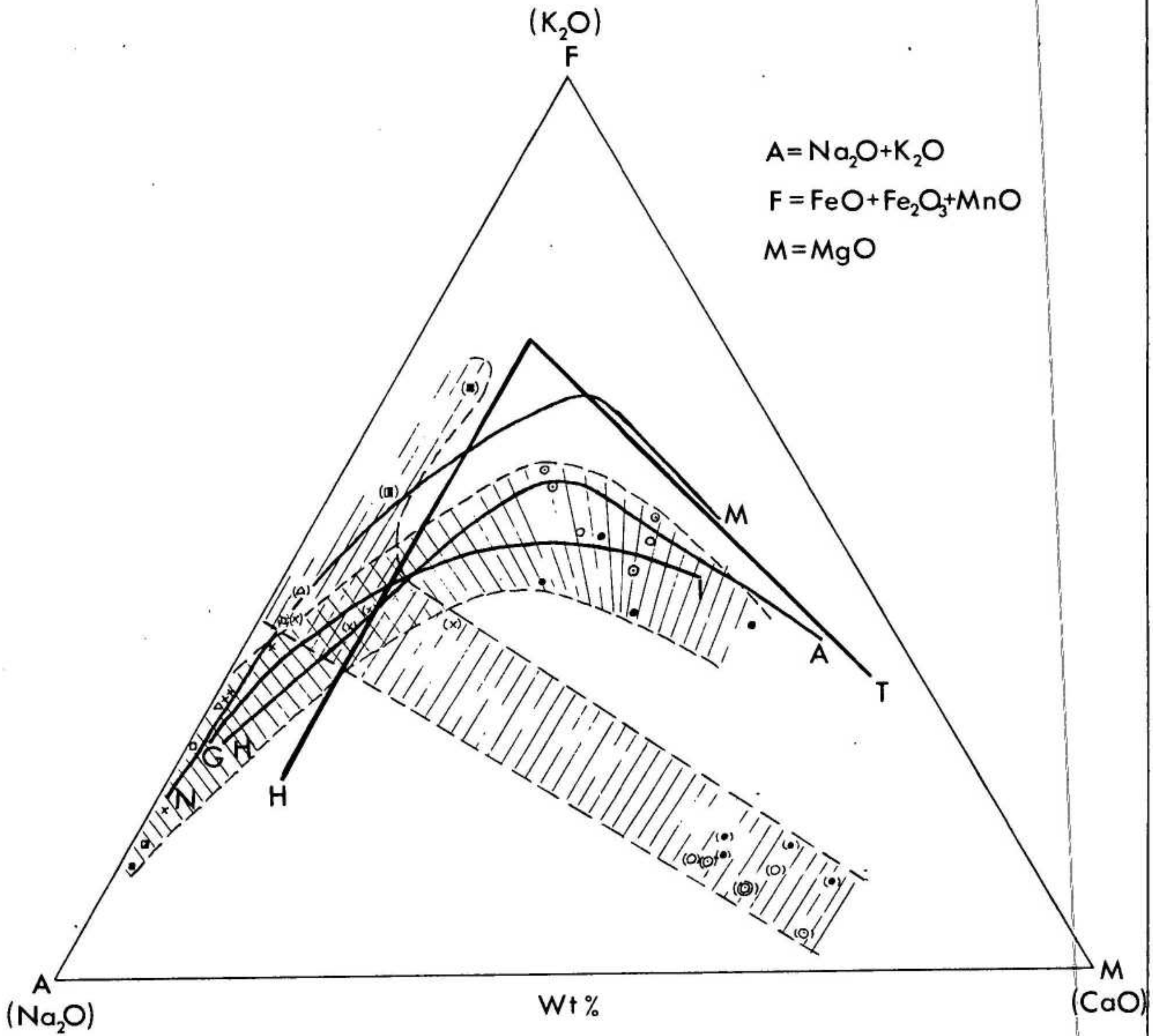
(v) the positions of the trachytes shown an earlier stage of fractionation than the comendite and pantellerite from the southern part of the range;

(vi) the rhyolite and pitchstone specimens from the northern part of the range are slightly displaced from the trend through the trachytes, comendite and pantellerite; the higher SI of the pitchstone than the rhyolite agrees with the implications of fractionation in the diagram.

The contents of total alkalis and calcium oxide in all the rocks are plotted separately against SI in the same diagram (Fig. 9). Smooth average curves drawn through the points of all the basaltic rocks and the trachytes intersect at a point with an SI value of 15.5; this is the alkali-lime index of Kuno (1959), and serves to show the fractionation stage of the basalt to trachyte rock suite. Kuno has plotted alkali-lime index values against the corresponding CaO values for many separate provinces and the fields of the different associations are shown (thol+tholeiitic, alk+alkalic, calc-alk+calc-alkali). The plot of the Peak Range basalt-trachyte association falls in the lower part of the alkalic field. Similar plots are shown for the basanite-teschenite to trachyte rocks (A) and for the tholeiitic basalts to rhyolite and pitchstone from the northern part of the range (T). Plots for different combinations of basaltic and acidic rock-type groups lie either in the alkalic field or between the tholeiitic and alkalic fields. There are insufficient analyses to draw reliable inferences from these plots. However, the close position of T to Kuno's tholeiitic field suggests that the rhyolite and pitchstone from the northern part of the range are related more to a tholeiitic, rather than an alkalic trend. It is also evident that the province as a whole shows more prominent alkalic than tholeiitic affinities.

Figure 10

F-M-A diagram



FMA (and CaO-Na$_2$O-K$_2$O) diagram

The FMA diagram (Fig. 10) is combined with a plot of Na$_2$-K$_2$O-CaO. The shaded areas represent the fields of the Peak Range rocks; the bracketed symbols are in the Na$_2$O-K$_2$O-CaO plot. Heavy lines represent the following trends in the FMA plot:

NG - Thingmuli tholeiitic province (Carmichael, 1964)

GI - Gough Island (Le Maitre, 1962)

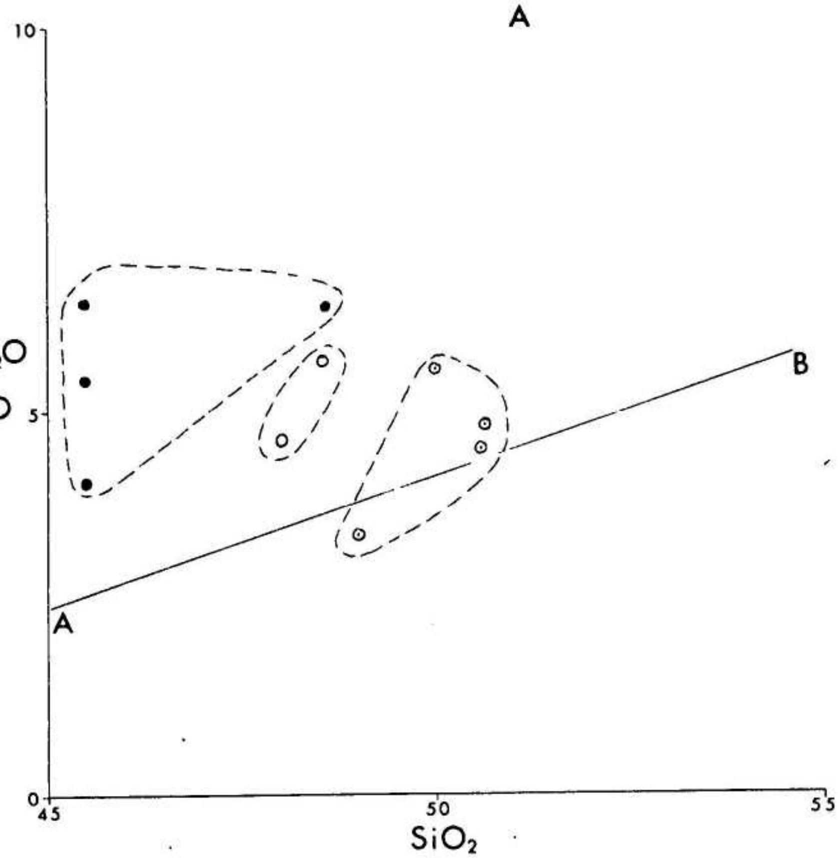
HA - Hawaiian alkalic rocks)
) (Macdonald and Katsura, 1964)
HT - Hawaiian tholeiitic rocks)

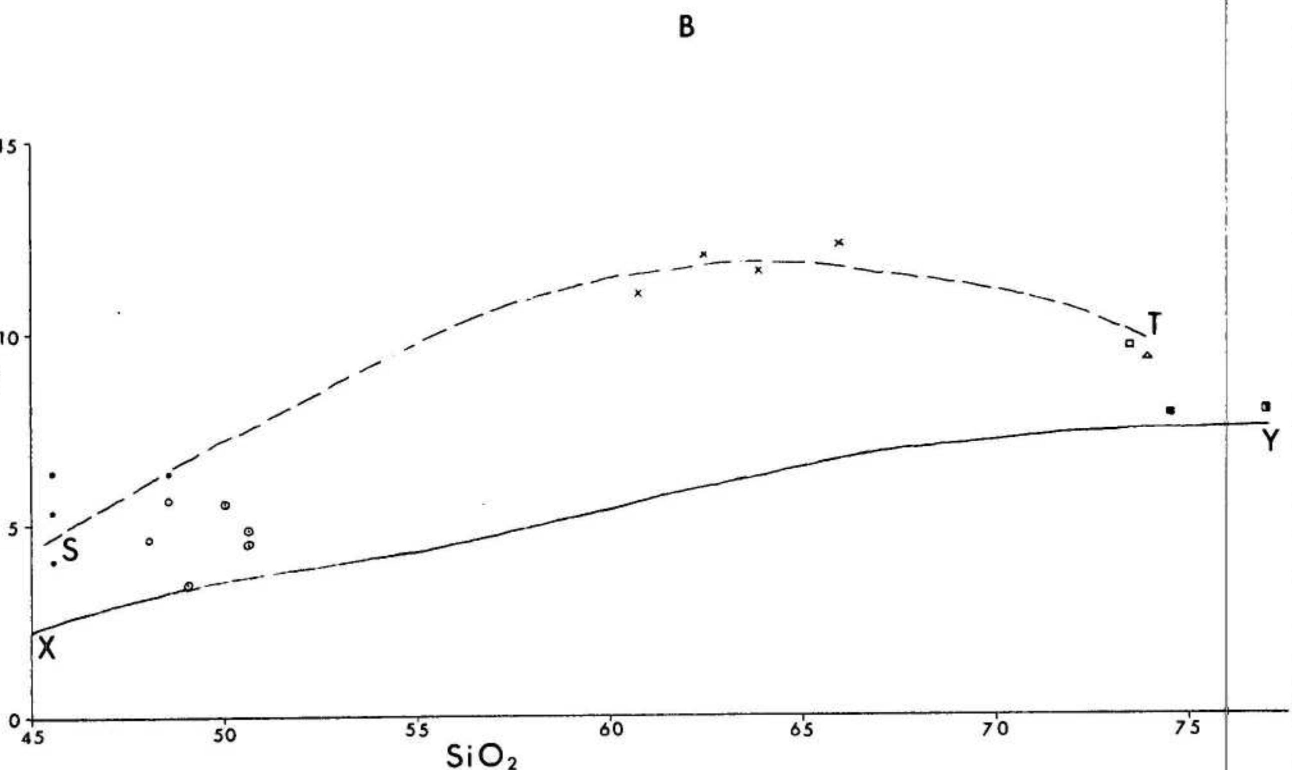
When all the plots of the basaltic rocks are considered a definite alkalic quality is apparent. The spread of points suggests the presence of more than one basaltic magma-type; the diagram also supports the inferences drawn from the SI:SiO$_2$ diagram regarding the possible subsequent pattern of differentiation of the basaltic magmas.

The Na$_2$O-K$_2$O-CaO diagram shows a similar trend to many differentiated volcanic provinces; two points of interest are the distinct grouping of the basaltic and acidic rocks and the anomalous positions of the rhyolite and pitchstone in relation to the other acidic rocks.

Figure 11

Alkali-silica diagrams





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Alkali-silica diagrams

The alkali-silica diagram (Fig. 11A), shows:

(i) a definite separation of the three basaltic rock-types;

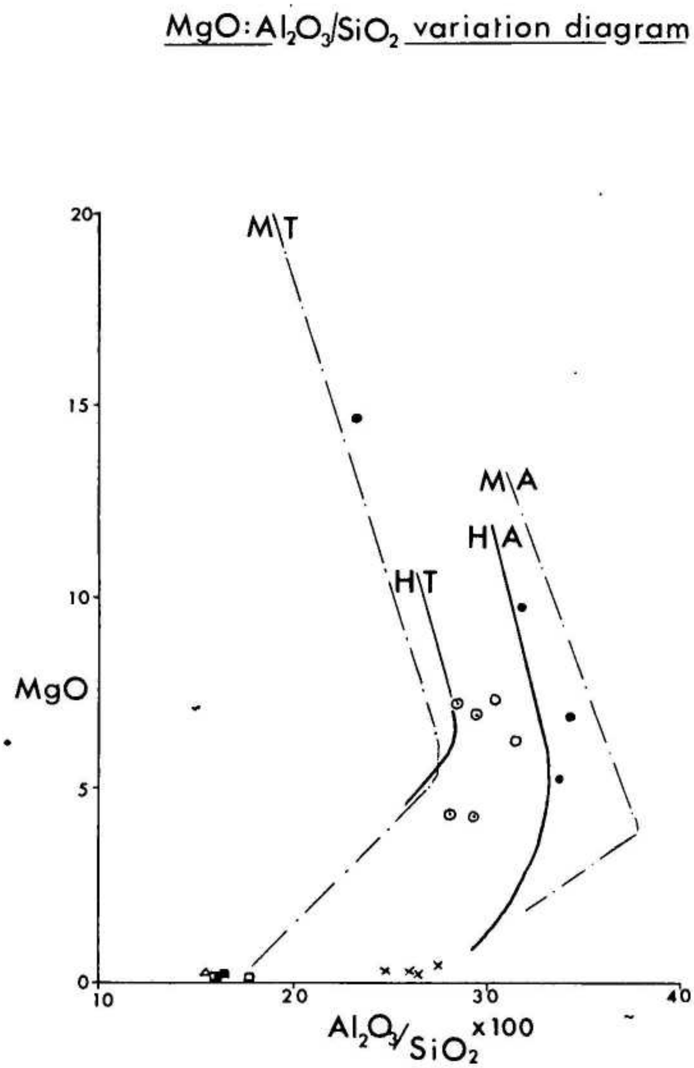
(ii) slightly anomalous positions of three tholeiitic basalts in relationship to the line A - B which separates the tholeiitic and alkali basalts of Hawaii, adapted from Macdonald and Katsura (1964) and Tilley (1950); this feature supports the inferences drawn from the SI:SiO_2 diagram, that the more acidic tholeiitic basalts show alkalic affinities.

The alkali-silica diagram (Fig.11B) shows the plot of all the rocks; the line X-Y, adapted from Kuno (1959), separates the tholeiitic series of rocks from the Izu-Hakone region in Japan from the alkalic series of the Circum-Japan Sea region. The diagram is significant in showing:

(i) a close similarity of trend in the Peak Range rocks with the trend in the Circum-Japan Sea rocks, expressed by the line S-T, which is adapted as the average curve of numerous rocks plotted in the diagram by Kuno (1959):

(ii) the displacement towards the line X-Y of the pitchstone and rhyolite from the northern part of the range.

Figure 12



key to rock-type symbols:

- • {olivine teschenite / analcite basanite
- ○ alkalic olivine basalt
- ⊙ tholeiitic " "
- × trachyte
- △ pantellerite
- □ comendite
- ◘ rhyol'te
- ■ pitchstone

$MgO:Al_2O_3/SiO_2$ diagram

The variation diagram devised by Murata (1960), in which magnesia is plotted against the alumina:silica ratio (Fig. 12) is an indication of differentiation; the diagram shows similar features to the other diagrams in that:

(i) the basaltic lavas show a pervasion across the field between the trends of the alkalic and tholeiitic rocks of Hawaii (lines HA and HT) and the trends of averages of alkalic and tholeiitic rocks (lines MA and MT); the lines HA and HT are adapted from Yoder and Tilley (1962) and lines MA and MT from Murata (1960);

(ii) the trachytes lie on the fractionation trends of the alkalic basalts of Hawaii whereas the more acidic rocks lie on the trend of the tholeiitic rocks.

Summary of trends

The variation diagrams show several significant features related to rock-type association:

(i) the basaltic rocks show a spread in composition;

(ii) similar basaltic rock-types show a linear arrangement in parallel with the linear arrangement of the other basaltic rock-types in some diagrams; the parallel spacing of similar rock-types in the diagrams is also parallel with the directions indicative of differentiation;

(iii) in general all the analysed tholeiitic rocks show alkalic affinities; two tholeiitic olivine basalts (CL291/1C and CL215/8B) with less saturated characteristics (lower normative quartz) than the other two tholeiitic basalts show the closest affinity to tholeiitic trends in other provinces;

(iv) the two thoroughly oversaturated tholeiitic basalts, and the alkalic basalts show close affinity to alkalic trends in other provinces;

(v) the basanites and teschenites show the highest degrees of separation in lines parallel to the inferred trends of differentiation; they show a strong alkalic trend;

(vi) the basanite-teschenite trend is well separated from the alkalic basalt and tholeiitic basalt trends which are not so distinctly separated; the presence of a series of basalts ranging from tholeiitic to alkalic compositions is commonly found in basaltic provinces (Green and Poldervaart, 1955);

(vii) most of the acidic rocks lie close to alkalic basalt association trends; the rhyolite and pitchstone specimens from the northern part of the range show displacement from these trends in several variation diagrams.

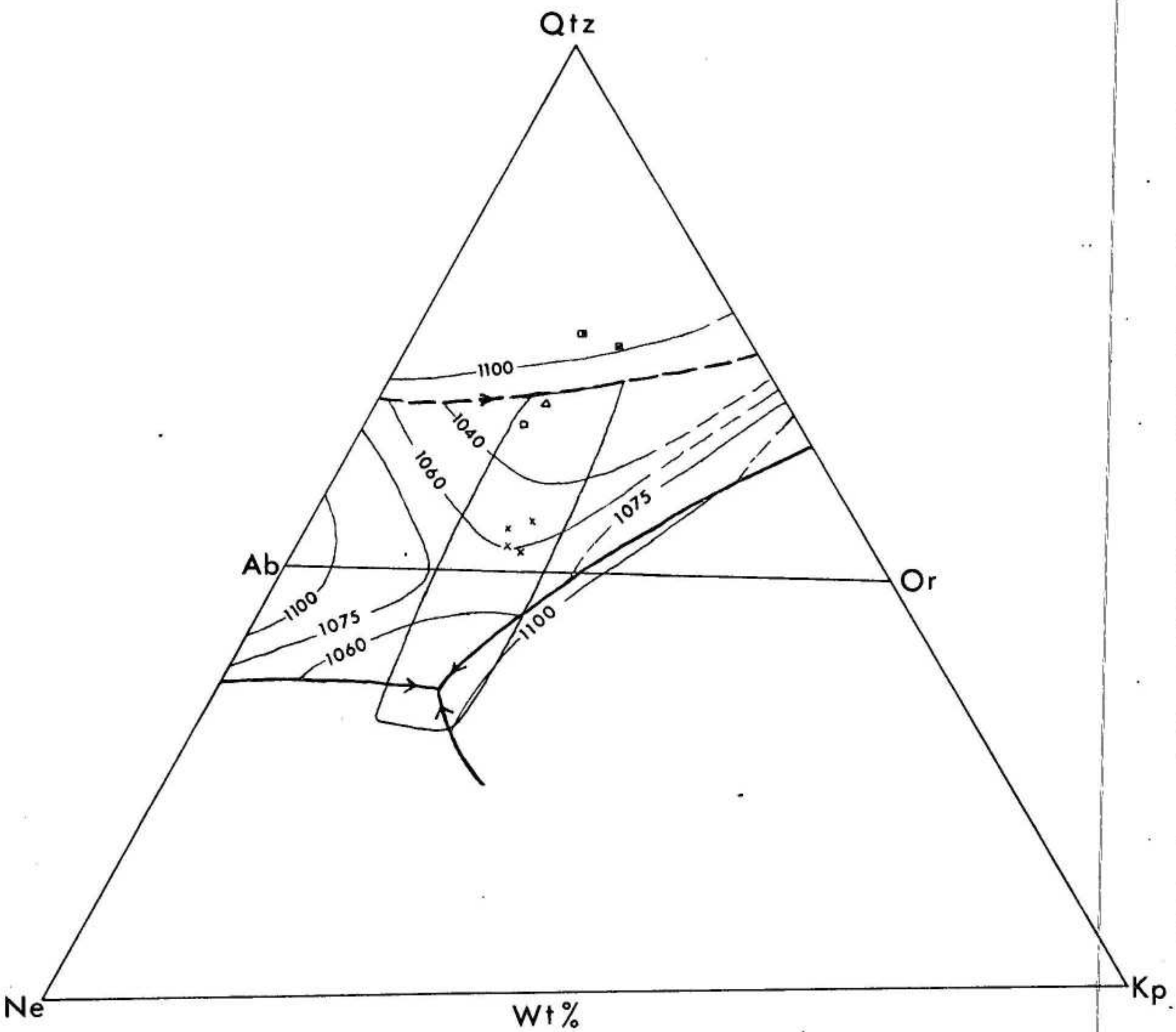
Variations in the acidic rocks

The analysed acidic rocks of the southern part of the Peak Range include fayalite trachyte, three aegirine trachytes, pantellerite and comendite; the rocks are characterised by an excess of soda over potash; apart from the fayalite trachyte and one of the aegirine trachytes (CL215/8A) all the rocks are peralkaline. In contrast, pitchstone and rhyolite from the northern part of the range carry an excess of potash over soda and are peraluminous. The peralkaline rocks from the southern part of the range belong to the 'agpaitic series' as defined by Carmichael (1962).

Bailey and Schairer (1962, 1964a and 1964b) have pointed out that petrogeny's residua system ($NaAlSiO_4$-$KAlSiO_4$-SiO_2) is not strictly a residua

Figure 13

Plot of acidic rocks in Qtz-Ne-Kp system



system for peralkaline and peraluminous rocks. Plotting the recalculated normative contents of orthoclase, albite, and quartz of peralkaline and peraluminous rocks in this system and in the orthoclase-albite-quartz system, does not take into account the soda in acmite and sodium metasilicate of peralkaline rocks and alumina in normative corundum of peraluminous rocks. The two well-known systems can therefore be used only to show at least rleative features of the Peak Range peralkaline and peraluminous acidic rocks (Figs. 13 and 14); only tentative conclusions can be drawn. (It should be noted that Chayes and Mētais (1964) have recently suggested an alternative to the standard normative calculation to cope with the alkali balance in peralkaline rocks).

The acidic rocks all contain more than 80% of total orthoclase, albite, and quartz in the CIPW norm. It is interesting to note that in the modified norms (Table 5) of three trachytes (CL206/G, CL215/8A, CL217/1A), with magnetite converted to acmite and orthopyroxene to olivine plus quartz, the total orthoclase, albite, and quartz is less than 80%. As already pointed out the modified norms are closer to the modes of the rocks and thus more soda, than indicated by the CIPW norm, is actually combined in acmite.

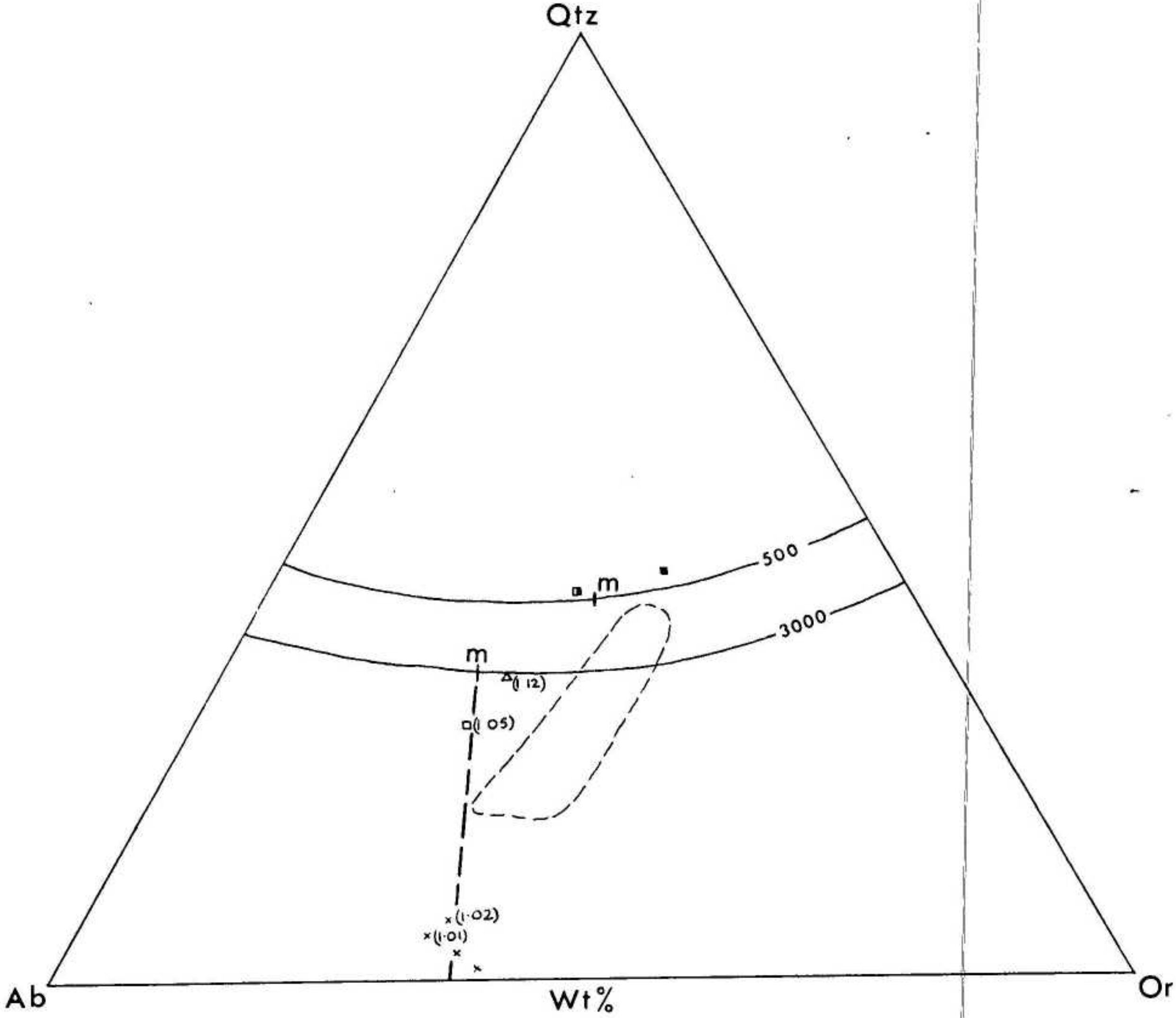
The plot of the rocks in the $NaAlSiO_4$-$KAlSiO_4$-SiO_2 system (Fig. 13, after Schairer, 1950) show two significant features:

(i) all the rocks, except pitchstone and rhyolite fall in the upper part of the residua trough of Bowen (1937);

(ii) the rocks show a trend in relationship to temperature gradients in the system; fayalite trachyte lies on the higher temperature side of the 1060°C isotherm, whereas the aegirine trachytes plot progressively at lower

Figure 14

<u>Plot of acidic rocks in Qtz-Or-Ab system</u>



temperatures; comendite (CL221/6) plots on the lower temperature side of the $1040^{o}C$ isotherm and pantellerite (CL206/D) plots at a lower temperature, close to the tridymite-feldspar join.

The rocks are also plotted in an enlargement of the orthoclase-albite-quartz system (Fig. 14). The field boundaries at 500 and 3000 kg/cm^2 water-vapour pressure are plotted, and the minima on the curves are shown by 'm' and the heavy broken line represents the experimental thermal 'valley' (Tuttle and Bowen, 1958). The field outlined represents the plots of comendites and pantellerites from Pantelleria, adapted from Carmichael (1962). Figures in brackets are the molecular ratios of $(Na_2O+K_2O)/Al_2O_3$ in the peralkaline rocks. Significant features of the diagram are:

(i) the rocks show much less distortion from the experimental thermal 'valley' than the Pantellerian rocks;

(ii) the rocks have lower degrees of peralkalinity compared with the Pantellerian rocks which range from 1.20 to 1.80 in molecular ratios of $(Na_2O+K_2O)/Al_2O_3$ (Carmichael, 1962);

(iii) the peraluminous rhyolite and pitchstone from the northern part of the range are displaced from the thermal 'valley' in the same sense as peralkaline rocks.

In the light of Bailey's and Schairer's recent observations only tentative suggestions regarding the petrogenetic implications of the plots of acidic rocks in the two diagrams can be made:

(i) the acidic rocks from the southern part of the range appear to represent highly fractionated oversaturated residua;

(ii) the rocks show a trend in which increasing fractionation is accompanied by increasing peralkalinity;

(iii) rhyolite and pitchstone from the northern part of the range are possibly related to either modification of the fractionation trend which produced comendite and pantellerite in the south, or they belong to a different trend.

PETROGENESIS

The data presented strongly suggests that the Tertiary volcanic rocks in the Peak Range have an associated coeval origin. The diversity in rock-types is apparently due mainly to differentiation by fractionation of one or more basaltic magma-types. Acidic and some intermediate rocks in the northern part of the Peak Range, are anomalous to the alkalic basalt association represented by the bulk of the rocks. These rocks are probably the result of assimilation and hybridisation rather than the result of different trends in differentiation.

The alkalic basalt association

The complementary association in the Peak Range of a large volume of flood basalts, and a much smaller volume of intermediate rocks and dome-forming acidic lavas, combined with the almost complete absence of pyroclastics and other products of explosive activity is typical of alkalic basalt associations (see Conclusions to Products of Volcanicity). Furthermore, the presence of relatively high total alkali contents in most of the rocks, with an excess of soda over potash, is typical of the same association. The close association of basalts ranging from thoroughly undersaturated types (basanite) to thoroughly oversaturated types (tholeiite) is not atypical in non-orogenic regions where the alkalic basalt association is prevelant, Hawaii presenting a classical example. The extreme differentiation of alkalic basalt to comendite in the Peak Range is possibly related to the continental, rather than oceanic environment; acidic volcanic rocks appear to be rare in oceanic islands.

Parent magma

The origin of differences in composition in basaltic magma-types is sought in the partial melting of sub-crustal ultrabasic material under differing physico-chemical conditions (Yoder and Tilley,1962) on the one hand, and in the partial melting of ultrabasic material of different compositions at different depths (Kuno, 1960). However, Yoder and Tilley have pointed out that Kuno's conclusions defer the ultimate problem to the origin of the compositional variations in the source material with depth.

O'Hara (1965) suggests that if basaltic magma is accepted to represent primarily residual liquids of fractionation processes at depth then the variations in basaltic magma-types should be related to a 'continuous series of evolutionary changes' in their ascent to the surface. The continuous changes, expressed in variations in rock-types, depend on 'where partial melting occurred, and the rate at which the liquids move towards the surface relative to the rate of cooling'. O'Hara's scheme provides a satisfactory hypothesis for the derivation of the diverse rock-types in the Peak Range and the presence of three basaltic magma-types (basanite-teschenite, alkalic basalt, tholeiitic basalt) Partial melting in a specific low pressure regime can produce tholeiitic and alkalic basalts, according to the points at which the movement of magma to the surface is interrupted. Thus, immediate extraction of liquids from a partial melting source of magma will produce tholeiitic lavas, whereas an interruption in the extraction of liquids produces alkalic basalts; the basanitic magma is probably related to a more prolonged interruption than that producing alkalic basalt. A further delay in the movement of the alkalic basalt magma to the surface produces, by fractionation, intermediate, acidic, and phonolitic lavas. Thus, O'Hara states, 'whether a province is biased towards tholeiitic or alkaline products will depend upon tectonic conditions, which decide whether the majority of liquids are brought to the surface relatively quickly or in a manner involving delays at the site of magma generation, or on their way to the surface'. If O'Hara's model is accepted then the presence of several intervals of acidic lava extrusion during the Peak Range volcanism suggest that repeated tectonic movements in the region were related to the generation of new batches of parental magma.

Differentiation

Several lines of evidence have shown that the acidic rocks of the southern part of the range meet the requirements of fractionated residua from the alkalic basalt magma type. Several features, suggesting that fractional crystallization, was the main process of differentiation, include:

(i) the local enrichment and impoverished of early crystallising components in slowly-cooled teschenite;

(ii) interstitial alkali feldspar, the main component of the acidic rocks, is present in some teschenite, basanite, and alkalic basalt;

(iii) the basaltic rocks representing similar magma-types show trends in composition, consistent with the trends expected by fractional crystallisation.

(iv) the trend of the rubidium/barium ratios from the basic to acid rocks is comparable with the trends in fractionated plutonic bodies, and corresponds to the trend theoretically predicted to occur in a fractionated series;

(v) trends in variation diagrams are similar to trends in composition of rocks in alkalic basalt associations of other regions, where the rocks have been demonstrated to represent intervals in fractionated layered plutonic bodies;

(vi) the acidic rocks show the trend expected of fractionated residual liquids, in that increasing acidity is compatible with lower temperatures of crystallisation.

The role of volatiles, as agents of differentiation, is inferred by the extreme concentrations of 'volatile' trace elements and low temperature constituents in the acidic rocks and the low concentrations of the same in the basic rocks. Field evidence has shown that the expulsion of the extremely viscous acidic magma has been accompanied by volatiles. The evidence supports the concept of 'gas-streaming' (Shand, 1943) in which liquid salic constituents in a solidifying basaltic crystal mush have been expelled by rising gases.

Peralkalinity, and oversaturated and undersaturated residua

The origin of peralkaline liquids is one of petrogeny's problems which has recently been investigated with experimental work in the 'peralkaline residua system', Na_2O-Al_2O_3-Fe_2O_3-SiO_2 by Bailey and Schairer (in press); the same authors have already published preliminary results on their investigations in the system (Bailey and Schairer, 1964b). They have shown that peralkaline oversaturated residua are present in the system, indicating that rocks of similar composition (pantellerite and comendite) represent residual liquids. The same authors have shown that the early precipitation of potash-rich feldspars effectively fractionates alumina, leaving a peralkaline liquid (the "orthoclase effect").

The temperature col about the orthoclase-albite join in the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2 (Fig. 13) has been regarded as significant in determining the composition of residua. The position of early differentiates in relation to the col invariably determines the oversaturated or undersaturated character of all the later residua in a volcanic association. The Peak Range residua follow the oversaturated trend (Fig. 13). Bailey and Schairer (1964b) have suggested fractionation mechanisms for the transition from undersaturated to oversaturated compositions and vice versa. However, the isolated position of the phonolite plug does not suggest that either of these transitions has taken place in the Peak Range. The plug is surrounded by debris of basanite and it therefore regarded as representing local differentiation of basanitic magma to undersaturated residua (Fig. 9). Furthermore, the absence of basanite or teschenite close to the trachyte, pantellerite, and comendite protrusions in the southern part of the range suggests that the basanitic magma has not produced oversaturated differentiates.

<u>The acidic rocks in the northern part of the range</u>

The rhyolites and pitchstones in the northern part of the range are different in many ways to the acidic rocks in the south. Differences in forms of occurrence and setting have been outlined in the "Conclusions" to the chapter on "Products of volcanicity". Petrological differences to the acidic rocks in the south are now summarized:

(i) the rocks are all rhyolites and pitchstones, very rich in silica (74% to 77%);

(ii) they are peraluminous;

(iii) they have an excess of potash over soda;

(iv) they are extremely poor in femic constituents and contain biotite;

(v) rhyolite (CL293/1A) contains significant traces of strontium and barium;

(vi) rhyolite and pitchstone plot in significantly different positions to comendite and pantellerite from the south in some variation diagrams;

(vii) the lavas were apparently less viscous than the southern acidic lavas.

The acidic rocks in the southern group of protrusions show many characteristics associated with differentiation from an alkalic basalt magma. A different origin must be sought for the anomalous acidic rocks of the north. Four effects, possibly related to their origin, are discussed.

(1) Assimilation

The rocks possibly represent normal differentiated residua of alkalic basalt magma which have been contaminated by the assimilation of low-temperature melting sialic material.

(2) Remobilisation by partial melting of sialic material

A more extreme hypothesis than assimilation is the possible effect of partial low-temperature melting of salic components in crustal material by the action of rising magma, highly charged with volatiles.

These two hypothesis are supported by:

(a) the apparent association of the extrusion of the acidic lavas with the uplift of a horst;

(b) the presence of quartz schists and Devonian-Carboniferous volcanics (some acidic) in the horst;

(c) fragments of dioritic rocks in the scree of Mount Castor;

(d) evidence of explosive and volatile activity;

(e) a comparably large bulk of the acidic volcanics;

(f) the inferred low temperature of fusion of the highly acidic liquid.

(3) Volatile contamination

Extreme volatile activity possibly contaminated normal alkalic basalt residua.

(4) Tholeiitic derivatives

The rocks possibly represent differentiates of the tholeiitic magma-type. Pitchstone is commonly associated with tholeiitic derivatives (e.g. Iceland and Arran). Furthermore, in two variation diagrams (Figs. 9 and 11), the rhyolite and pitchstone specimens show closer affinity to compared tholeiitic trends.

The origin of the anomalous rocks was possibly the result of two or more of these phenomena.

'Andesitic' rocks and trachyandesite

The peculiar 'andesitic' rocks in the northern part of the range, and trachyandesite at Lord's Table Mountain represent either hybrids or contaminated lavas.

The botryoidal texture in parts of the trachyandesit flow and the presence of embayed quartz xenocrysts, 'blebs' of basaltic rock, and resorbed alkali feldspar xenocrysts suggest the rock is the result of mixing of basaltic and acidic lavas. Hybrid rocks of similar composition are present in Otago, New Zeland (Benson, 1941).

On the other hand the trachyandesite is closely similar to trachyandesite from the Gisborne district of Victoria, described by Edwards (1940), and figured in Joplin (1964). Edwards states that the trachyandesite presents 'the apparent anomaly of a "tholeiitic process of differentiation" superposed on the normal (trachytic) process of differentiation'. The anomaly he relates to 'local assimilation of the invaded sediments'.

The 'andesitic' rocks appear to be more homogenous in texture and composition than the trachyandesite. Their close spatial association with the rhyolites suggests they have a similar origin, and this is unlikely to be hybridisation for the rhyolites. The unusual petrography of the 'andesitic' rocks suggests they are the result of contamination of tholeiitic basalt magma by salic constituents.

The problem of the intermediate rock-type deficiency

Chayes (1963) has thrown doubt on the theory of magmatic differentiation for the oceanic basalt-trachyte association. The implications of Chayes' argument affects a large part of petrogenetic thinking. He has shown that, within the limitations imposed primarily by selective sampling and analysing, statistically there is a prominent definiency of rocks in the compositional range between basalt and trachyte in the association; the point has earlier been suggested by Daly (1925) and others. The bimodal frequency distribution of rocks in the association is emphasised in statistical plots made by Chayes of the values of SiO_2, CaO, and the Thornton-Tuttle differentiation index (normative quartz + orthoclase + albite + leucite + nepheline, Thornton and Tuttles, 1960). Chayes has demonstrated theoretically that fractional crystallisation of a basaltic magma would not be expected to produce the bimodal frequency, but rather a gradual diminution in frequency from basalt to trachyte.

One of the main objections to Chayes' argument is the unreliability of sampling, for various reasons, to yield a frequency of specimens relative to the abundances of exposed rock-types. This is particularly relevant to any inferences which might be drawn at present regarding the frequency distribution of intermediate rock-types in the Peak Range. It has already been concluded that hawaiite is probably present. The doubt about the definite identification of this rock-type is due to deep alteration. Lateral sampling of the flows in the central and southern parts of the range is fairly representative (Plate 1) but a natural preference in vertical sampling was for less altered flows. However it cannot be assumed that weathering or any other alteration process has preferentially attacked intermediate rock-types. Trachyandesite is an unsuitable rock to consider in the present context because of its origin probably by hybridisation or contamination.

Chayes has related his argument only to the oceanic island basalt-trachyte associations, where lack of sial diminishes other petrogenetic implications. Some of the rocks in the Peak Range have been tentatively related to sialic contamination and syntexis. However Chayes' argument should be considered in relation to the Peak Range because of the apparent scarcity of intermediate rocks in the range, and because of the apparently similar gradational trends of the Peak Range basalt - 'normal' acidic rock association and the basalt-trachyte association of the oceanic islands.

Conclusions

The Tertiary volcanics in the Peak Range represents a complex volcanic cycle. The region has a dominant petrological affinity to alkalic basalt associations occurring in non-orogenic, continental and oceanic island, environments. Variations in conditions at the source of generation of parental magmas has probably produced the variations in the compositions of the basaltic lavas; three basaltic magma-types are represented in the basanites and teschenites (undersaturated), the alkalic (near-undersaturated) basalts, and the tholeiitic (saturated and oversaturated) basalts. The alkalic basalts are dominant; differentiation, primarily by fractionation, has produced intermediate (hawaiitic) lavas and acidic peralkaline end-products at several intervals during the volcanic cycle. Basanite appears to have locally differentiated to phonolite. Tholeiitic basalt has probably differentiated locally to tholeiite. Very silica rich peraluminous rhyolite, associated with vitric tuff and pitchstone, is probably related to assimilation or remobilisation of sialic crustal material rather than differentiation from a tholeiitic magma or modification of normal alkalic residua by volatiles. Several occurrences of unusual intermediate rocks are related to either local contamination of basaltic lavas or hybridisation.

REFERENCES

BAILEY, D.K., and SCHAIRER, J.F., 1962 - Peralkaline residual liquids: Some petrogenetic considerations. Carnegie Inst. Washington Year Book, 61, 95-96.

BAILEY, D.K., and SCHAIRER, J.F., 1964a - Feldspar-liquid equilibria in peralkaline liquids - the orthoclase effect. Amer.J.Sci., 262 (10), 1198-1206.

BAILEY, D.K., and SCHAIRER, J.F., 1964b - The peralkaline residua system: Na_2O-Al_2O_3-Fe_2O_3-SiO_2. Carnegie Inst. Washington Year Book, 63, 74-79.

BAILEY, D.K., and SCHAIRER, J.F., in press - The system Na_2O-Al_2O_3-Fe_2O_3-SiO_2 at 1 atm and the petrogenesis of alkaline rocks. J. Petrol.

BENSON, W.N., 1941 - Cainozoic petrographic provinces in New Zealand and their residual magmas. Amer.J.Sci., 239, 537-552.

BOWEN, N.L., 1937 - Recent high-temperature research on silicates and its significance in igneous geology. Amer.J.Sci., 33 (193), 1-21.

BRUNNSCHWEILER, R.O., 1957 - Final Report on Authority to Prospect for Petroleum No. 16P, Bowen Basin, Queensland. Santos Ltd Adelaide (unpubl. rep.)

BUTLER, J.R., and SMITH, A.Z., 1962 - Zirconium, niobium, and certain other trace elements in some alkali igneous rocks. Geochim.coshmoch. Acta, 26, 945-954.

CARMICHAEL, I.S.E., 1962 - Pantelleritic liquids and their phenocrysts. Miner.Mag., 33, 86-113.

CARMICHAEL, I.S.E., 1964 - The petrology of Thingmuli, a Tertiary volcano in Eastern Iceland. J.Petrol., 5(3), 435-460.

CHAYES, F., 1963 - Relative abundance of intermediate members of the oceanic basalt-trachyte association. J.geophys.Res., 68(5), 1519-1534

CHAYES, F., and MÉTAIS, D., 1964 - On the relation between suite of CIPW and Barth-Niggli Norms. Carnegie Inst. Washington Year Book, 63, 193-195.

COTTON, C.A., 1944 - Volcanoes as landscape forms. Whitcombe and Tombs, Christchurch.

DALY, R.A., 1925 - The Geology of Ascension Island. Proc.Amer.Acad.Arts Sci., 60 (1), 3-80.

DALY, R.A., 1933 - Igneous rocks and the depths of the earth. 2nd edition. McGraw-Hill, N.Y.

DEER, W.A., HOWIE, R.A., and ZUSSMAN, J., 1963 - Rock forming minerals, volume 4. Longmans, Green, London.

EDWARDS, A.B., 1940 - The Cainozoic volcanic rocks of the Gisborne district, Victoria. Proc.Roy.Soc.Vic., 52 (2), 281-311.

FLEISCHER, M., and STEVENS, R.E., 1962 - Summary of new data on rock samples G-1 and W-1. Geochim.cosmoch.Acta, 26, 525-543.

GREEN, J., & POLDERVAART, A., 1955 - Some basaltic provinces. Geochim. cosmoch.Acta, 7, 177-188.

JOPLIN, G.A., 1964 - A petrography of Australian igneous rocks. Angus and Robertson, Sydney.

KUNO, H., 1959 - Origin of Cenozoic petrographic provinces of Japan and surrounding areas. Bull.volc., 2nd ser., 20, 37-76.

KUNO, H., 1960 - High alumina basalt. J.Petrol., 1 (2), 121-145.

LEICHHARDT, L., 1847 - The overland expedition from Moreton Bay to Port Essington. Boone, London.

LE MAITRE, R.W., 1962 - Petrology of volcanic rocks, Gough Island, South Atlantic. Bull.geol.Soc.Amer., 73, 1309-1340.

MACDONALD, G.A., 1960 - Dissimilarity of continental and oceanic rock types. J. Petrol., 1 (2), 172-177.

MACDONALD, G.A., and KATSURA, T., 1964 - Chemical composition of Hawaiian lavas. J. Petrol., 5 (1), 82-133.

MALONE, E.J., 1964 - Depositional evolution of the Bowen Basin. J.geol.Soc. Aust., 11 (2), 263-282.

MALONE, E.J., OLGERS, F.O., and KIRKEGAARD, A.G., in prep. - The geology of the Duaringa and St. Lawrence 1:250,000 Sheet areas, Queensland. Bur.Min.Resour.Aust.Rep.

MOLLAN, R.G., EXON, N.F., and KIRKEGAARD, A.G., in prep. - The geology of the Springsure 1:250,000 Sheet area, Queensland. Bur.Min.Resour. Aust.Rep.

MOLLAN, R.G., JENSEN, A.R., FORBES, V.R., EXON, N.F., and GREGORY, C.M., in prep. - The geology of the Eddystone and Taroom 1:250,000 Sheet areas, and of the western part of the Mundubbera 1:250,000 Sheet area, Queensland. Bur.Min.Resour.Aust.Rep.

O'HARA, M.J., 1965 - Primary magmas and the origin of basalts. Scot.J. Geol., 1 (1), 19-40.

REID, J.H., 1928 - The Isaacs River Permo-Carboniferous Coal Basin. Qld Govt Min.J., 29, 192-197.

RICHARDS, H.C., 1918 - The volcanic rocks of Springsure, Central Queensland. Proc.Roy.Soc.Qld, 30, 179-198.

RITTMANN, A., 1962 - Volcanoes and their activity. Wiley, N.Y.

RITTMANN, A., and EL-HINNAWI, E.E., 1961 - The application of the zonal method for the distinction between low and high temperature plagioclase feldspars. Schweiz.Min.Petr.Mitt., 41, 41-48.

SCHAIRER, J.F., 1950 - The alkali feldspar join in the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2. J.Geol., 58, 512-517.

SHAND, S.J., 1943 - Eruptive rocks, 2nd edition. Murby, London.

SMITH, W. CAMPBELL, 1931 - A classification of some rhyolites, trachytes, and phonolites from part of Kenya Colony, with a note on some associated basaltic rocks. Quart.J.geol.Soc.Lond., 87, 212-258.

SORENSEN, H., 1960 - On the agpaitic rocks. Int.geol.Cong., 21st Sess., 13.

TAYLOR, S.R., and HEIER, K.S., 1960 - The petrological significance of trace element variations in alkali feldspars. Int.geol.Cong., 21st Sess., 14.

THORNTON, C.P., and TUTTLE, O.F., 1960 - Chemistry of igneous rocks, 1, Differentiation index. Amer.J.Sci., 258, 664-684.

TILLEY, C.E., 1950 - Some aspects of magmatic evolution. Quart.J.geol. Soc.Lond., 106, 37-62.

TILLEY, C.E., and MUIR, I.D., 1964 - Intermediate members of the oceanic basalt-trachyte association. Geol.Foren.Stockh.Förh., 85, 434-443.

TUTTLE, O.F. and BOWEN, N.L., 1958 - Origin of the granite in the light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O. Mem.geol.Soc.Amer., 74.

VEEVERS, J.J., MOLLAN, R.G., OLGERS, F.O., and KIRKEGAARD, A.G., 1964 - The geology of the Emerald 1:250,000 Sheet area, Queensland. Bur. Min. Resour. Aust. Rep., 68.

VEEVERS, J.J., RANDAL, M.A., MOLLAN, R.G., and PATEN, R.J., 1964 - The geology of the Clermont 1:250,000 Sheet area, Queensland. Bur. Min. Resour. Aust., 66.

WILKINSON, J.F.G., 1957 - The clinopyroxene of a differentiated teschenite sill near Gunnedah, New South Wales. Geol. Mag., 94, 123-134.

WILLIAMS, H., 1932 - The history and character of volcanic domes. Univ. Calif. Publ. Bull. Dep. geol. Sci., 21 (5), 51-146.

YODER, H.S., Jr., and TILLEY, C.E., 1962 - Origin of basalt magmas: An experimental study of natural and synthetic rock systems. J. Petrol., 3, 342-532.

APPENDIX

THIN-SECTIONED ROCK SPECIMENS OF THE TERTIARY VOLCANICS IN THE PEAK RANGE

(In each group of rocks those from the southern and central parts of the range are placed first)

⊛ full silicate analysis + Rb, Sr, Ba analysis

* full silicate analysis only

O Rb, Sr, Ba analysis only

\+ indicates shown in Fig. 2, others located in Plate 1

ROCK NUMBER	SLIDES		ROCK TYPE	FORM OF OCCURRENCE	LOCALITY (Grid reference, 10,000yd. Transverse Mercator, Zone 7, Australia Series, Clermont 1:250,000 Sheet area)
	B.M.R. Regd. No(s).	Un-numbered			
CL273/2*	7043		olivine teschenite	plug	Mount Oscar (60601599)+
	7024		picritic teschenite		
CL263/2⊛	7012		olivine micro-teschenite	plug	One mile E.N.E. of "Dorlynden Downs" (62351435)+
CL266/1	7025		olivine micro-teschenite	plug	1½ miles W.S.W. of "Dorlynden Downs" (61901418)+
CL269/1	7011		olivine teschenite	plug	Pumpkin Hill (62001576)+
CL275/1	7026		olivine teschenite	plug	Small hill at "Camara" (61011560)+
CL264/3⊛	7007		analcite basanite	plug	Beacon Hill (60981482)+
CL272/1*	7008		analcite basanite	plug	Hill, ½ mile south of "Huntley" (61401640)+
CL281/2	7022		(?) analcite basanite	plug	Mount Faulkner (57632080) (outside area of Fig. 2)

CL620		2	alkalic olivine micro-gabbro	?plug	$1^1/3$ miles W.S.W. Calvert Peak, on Capella road. (64121529)
CL238/6A	7041		alkalic olivine basalt	flow	Southern slopes of Eastern Peak. (63771603)
CL239/6B	7040		alkalic olivine basalt	flow	Northern slopes of Gilbert's Dome. (63431679)
CL239/6C	7050		alkalic olivine basalt	flow	Northern slopes of Gilbert's Dome. (63441680).
CL239/6E	7039		alkalic olivine basalt	flow	Northern slopes of Gilbert's Dome. (63431682).
CL239/6F	6277		?alkalic olivine basalt	dyke (border)	Northern slopes of Gilbert's Dome. (63421680).
CL240/1	6273		alkalic olivine basalt	dyke	Lower east flank of Brown's Peak (63651633).
CL516/A		1	alkalic olivine basalt	flow	S.E. end of Hodgson Range (63101700)
CL606/B*		2	alkalic olivine basalt	flow	Base of 'Mount Birdcage' on south side. (65691422)
CL606/B'		1	?alkalic olivine basalt	flow	South ridge of 'Mount Birdcage'. (65681422)
CL606/L®		1	alkalic olivine basalt	flow	Southern slopes of 'Mount Birdcage'. (65681429).

CL608[O]		1	?alkalic olivine basalt	flow	$1\frac{1}{2}$ miles S.E. of Malvern Hill, on north flank of small hill. (65211443)
CL610/A[O]		1	?alkalic olivine basalt	flow	Base of hill one mile east of Roper's Peak. (65121477)
CL610/B*		1	alkalic olivine basalt	flow	Hill, one mile east of Roper's Peak. (65161478).
CL610/C		1	alkalic olivine basalt	flow	Hill, one mile east of Roper's Peak. (65171478)
CL622		1	alkalic olivine basalt	flow	Bench, $1\frac{1}{4}$ miles north of Calvert Peak on Capella road. (64371564).
CL623/E		1	alkalic [illegible]e basalt	flow	Hill, $1^{1}/3$ miles east of Eastern Peak. (64011603).
CL516/D		1	alkalic iddingsi-tized olivine basalt	flow	S.E. end of Hodgson Range. (63111699).
CL516/L		1	?alkalic iddingsi-tized olivine basalt	flow	S.E. end of Hodgson Range. (63121696).
CL516/O		1	?alkalic iddingsi-tized olivine basalt	flow	S.E. end of Hodgson Range. (63121695).
CL606/G		1	alkalic iddingsi-tized olivine basalt	flow	South ridge of 'Mount Birdcage'. (65681425)
CL242/1C	6265		altered ?alkalic ?olivine basalt	flow	Base of Wolfang Peak, south-west side. (60601862)+

CL245/2B	6244		altered ?alkalic ?olivine basalt	?flow	West footslopes of Mount Pollux. (61051950)+
CL606/G'		1	iddingsi-tized olivine basalt	flow	South ridge of 'Mount Birdcage'. (65681425)
CL606/I		1	iddingsi-tized olivine basalt	flow	South ridge of 'Mount Birdcage'. (65671427).
CL606/I'		1	iddingsi-tized olivine basalt	flow	South ridge of 'Mount Birdcage'. (65671427)
CL606/K		1	iddingsi-tized olivine basalt	flow	South ridge of 'Mount Birdcage'. (65671428)
CL606/M		1	iddingsi-tized olivine basalt	flow	Near top of 'Mount Birdcage'. (65681430)
CL224/2A	6236		altered basalt (zeoli-tised)	dyke	2 miles S.E. of Malvern Hill. (65281437)
CL239/6D		1	altered basalt	flow	Northern slopes of Gilbert's Dome. (63431681)
CL240/2	6263		altered (?hawaii-tic) basalt	flow	Top of Brown's Peak (63571626)
CL241/2A	6243 6253	1	trachyand-esite	flow	Top of Lord's Table Mountain (62631736)

CL241/2B	6225		trachyandes-ite	flow	Base of flow capping Lord's Table Mountain. (62651732)
CL215/8B⊗	7038		tholeiitic olivine basalt	flow	$\frac{1}{2}$ mile S.S.W. of Calvert Peak. (64311531)
CL220/6A	7004		tholeiitic olivine basalt	flow	Lower east flank of Malvern Hill. (65071458)
CL291/1C⊛	6267	1	tholeiitic olivine basalt	flow	About 2 miles W.N.W. of Scott's Peak. (64621495)
CL516/J*		1	tholeiitic olivine basalt	flow	South-east end of Hodgson Range. (63111697)
CL607^{0}		1	tholeiitic olivine basalt	dyke	Ridge, 1$\frac{1}{4}$ miles S.E. of Malvern Hill. (65211445)
CL614^{0}		1	tholeiitic olivine basalt	flow	Bench, one mile east of 'Red Mountain'. (65281515)
CL623/B		1	?tholeiitic olivine basalt	flow	Hill, $1^{1}/3$ miles east of Eastern Peak. (64031603)
CL201/3*	7053	1	tholeiitic olivine basalt	flow	Southern slopes of Mount Phillips. (64401848)+
CL516/F		1	tholeiitic basalt	flow	S.E. end of Hodgson Range. (63111698)
CL516/K		1	tholeiitic basalt	flow	S.E. end of Hodgson Range. (63121696)
CL621		1	tholeiitic basalt	flow	Bench, one mile north of Calvert Peak. (64351561)

CL613		1	tholeiitic basalt	flow	$1\frac{1}{2}$ miles east of 'Red Mountain'. (65391513).
CL245/2E	6233		tholeiitic basalt	?flow or fragment out of ?agglom-erate.	West footslopes of Mount Pollux. (61051950)+
CL224/2B	6240		tholeiite	flow (?dyke)	2 miles S.E. of Malvern Hill. (65271436)
CL251/1	7031		tholeiite	dyke	About 4 miles west of "Mount Hilary". (62551797)+
CL244/1	6260		'andesitic' rock	dome	Mount Commissioner (61301940)+
CL251/2	7006		'andesitic' rock	?flow	About 6 miles west of "Mount Hilary". (62301789)+
CL206/G*	5709 6248	3	fayalite trachyte	flow filling explosion pit in thrust dome	In pit of Mount Macarthur. (64161474)
CL215/5⊛	7034		aegirine trachyte	?sunken dome	North face of low hill, $\frac{1}{2}$ mile west of Calvert Peak. (64271543)
CL215/8A⊛	7029	1	aegirine trachyte	dyke or coulee associ-ated with protru-sion	In creek cutting ridge extending south from Calvert Peak. (64361535).

CL217/1A*	6276	1	aegirine trachyte	dyke or coulee associated with protrusion	1 mile N.W. of Scott's Peak where "Lowestoft" road crosses creek. (64731495).
CL225/5	6227		aegirine trachyte	coulee or dyke	3 miles S.E. of "Wilmor Downs". (64811407)
CL238/1	7037		?hedenbergite trachyte	?collapsed dome	North face of hill, 2 miles west of Calvert Peak. (63981542).
CL609/B		1	aegirine trachyte	sunken dome	Hill 1½ miles S.E. of Malvern Hill. (65211441)
CL299/A	7014		phonolite	plug	Campbell's Peak (65001790)+
CL299/C	7033		phonolite	plug	Campbell's Peak (65001790)+
CL299/D	7056		phonolite	plug	Campbell's Peak. (65001790)+
CL208/2	6269	1	(zeolitised) quartz trachyte	dyke in composite protrusion	Ridge, 2 miles N.N.W. of Mount Macarthur. (64061506)
CL211/A	7009		quartz trachyte	sunken dome	Hill, one mile south of Calvert Peak. (64271522)
CL211/B	7010		quartz trachyte	sunken dome	Hill, one mile south of Calvert Peak. (64271523)
CL212	5713		quartz trachyte	broad dyke	Ridge, 2 miles S.E. of "Wilmor Downs". (64661419)
CL288/1	7005		quartz trachyte	small dome	Small hill, ½ mile N.W. of Mount Macarthur. (64051479)
CL291/1A	6234		(zeolitised) quartz trachyte	collapsed dome	South flank of hill, 2 miles north of "Lowestoft" (64621497)

CL291/2	6245 6264		(zeoliti-sed) quartz trachyte	protrusion (barchan-shaped)	Hill, about one mile north of "Lowestoft". (64571481)
CL292/1	7054		quartz trachyte	dyke of composite protrusion	Ridge, 2½ miles north of Mount Macarthur. (64081516)
CL203/3	6268		pantell-eritic trachyte	?autointr-usion into dome	West flank of 'Red Mountain' (65031508).
CL203/5	5711		pantell-eritic trachyte	?autointr-usion into dome	West flank of 'Red Mountain' (65031506).
CL203/4B	6255 7042		pantell-eritic trachyte	large dome	West flank of 'Red Mountain' (65051504).
CL612/A		2	pantell-eritic trachyte	large dome	East flank of 'Red Mountain (65211509).
CL210/2	7035		pantell-eritic trachyte	sunken dome	Hill, 2½ miles north of Mount Macarthur (64211418).
CL618		1	pantell-eritic trachyte	sunken dome	Hill, 2½ miles north of Mount Macarthur (64161521)
CL214/A	7020		pantell-eritic trachyte	ring dyke of compo-site protrusion	Hill, about 2 miles N.N.E. of "Woollamba" (65691409)
CL214/B	7051		pantell-eritic trachyte	coulee in composite protrusion	Hill, about 2 miles N.N.E. of "Woollamba" (656[illegible]14[illegible]
CL290/1	7030		pantell-eritic trachyte	small dome on dyke	Small hill, ½ mile west of 'Red Mountain' (64931509).

CL204	6228		pantell-erite	thrust dome	North side of Scott's Peak. (64941492)
CL205	6271		pantell-erite	cumulo-dome	North flank of hill, ½ mile N.W. of Mount Macarthur. (64071492)
CL205/1	5712		pantell-erite	cumulo-dome	West flank of hill, ½ mile N.W of Mount Macarthur. (64011489)
CL619		1	pantell-erite	cumulo-dome	North flank of hill, ½ mile N.W. of Mount Macarthur. (64061493)
CL206/A	6274		pantell-erite	thrust dome	Mount Macarthur, west face. (64121476).
CL206/B	7023		pantell-erite	thrust dome	Mount Macarthur, west face. (64121474).
CL206/C	7028		pantell-erite	thrust dome	Mount Macarthur, west face. (64121474)
CL206/D*	5710 6270		pantell-erite	thrust dome	Mount Macarthur, west face. (64131474)
CL206/E	7015		pantell-erite	thrust dome	Mount Macarthur, west face (rim of pit) (64141474)
CL206/F	6266		pantell-erite	thrust dome	Mount Macarthur, west face (inside rim of pit) (64151474)
CL209/A	6251		pantell-erite	cumulo-dome	South face of hill about 3 miles N.N.W. of Mount Macarthur. (63851524)
CL209/B	6238		pantell-erite	cumulo-dome	South face of hill about 3 miles N.N.W. of Mount Macarthur. (63861524)
CL209/C	7049		pantell-erite	cumulo-dome	South face of hill about 3 miles N.N.W. of Mount Macarthur. (63871524)

CL289/1A	7059		pantell-erite	dome	Hill, one mile south of "Gibson Downs". (64761514)
CL289/1B	7032		pantell-erite	dome	Hill, one mile south of "Gibson Downs". (64761513)
CL291/3B	6272		pantell-erite	?dyke	West face of flat-topped hill between Roper's and Scott's Peaks. (64821480)
CL292/2	7055 6275		pantell-erite	?dyke or composite protrusion	About 3½ miles N. of Mount Macarthur, immediately south of "Gibson Downs" turn-off. (64071511)
CL292/4A	6249		pantell-erite	?sunken dome	¼ mile west of "Gibson Downs" turn-off. (64051525)
CL292/4B	6231		pantell-erite	?sunken dome	¼ mile west of "Gibson Downs" turn-off. (64051527)
CL517/8A		1	pantell-erite	cumulo-dome	North face of hill, three miles N.N.W. of Mount Macarthur. (63871531)
CL611[0]		1	pantell-erite	thrust dome	East face of Scott's Peak. (64961489)
CL617		1	pantell-erite	dome	Hill, ½ mile east of "Gibson Downs". (64831539)
CL207	6259		comendite	dome	West of twin peaks, about one mile north of Mount Macarthur. (64171492)
CL215/3	7016 (no specimen)		comendite	thrust dome	West face of Calvert Peak (64341543)
CL220/5	7021		trachytic comendite	float, probably from Malvern Hill dome	½ mile east of Malvern Hill (65131459)

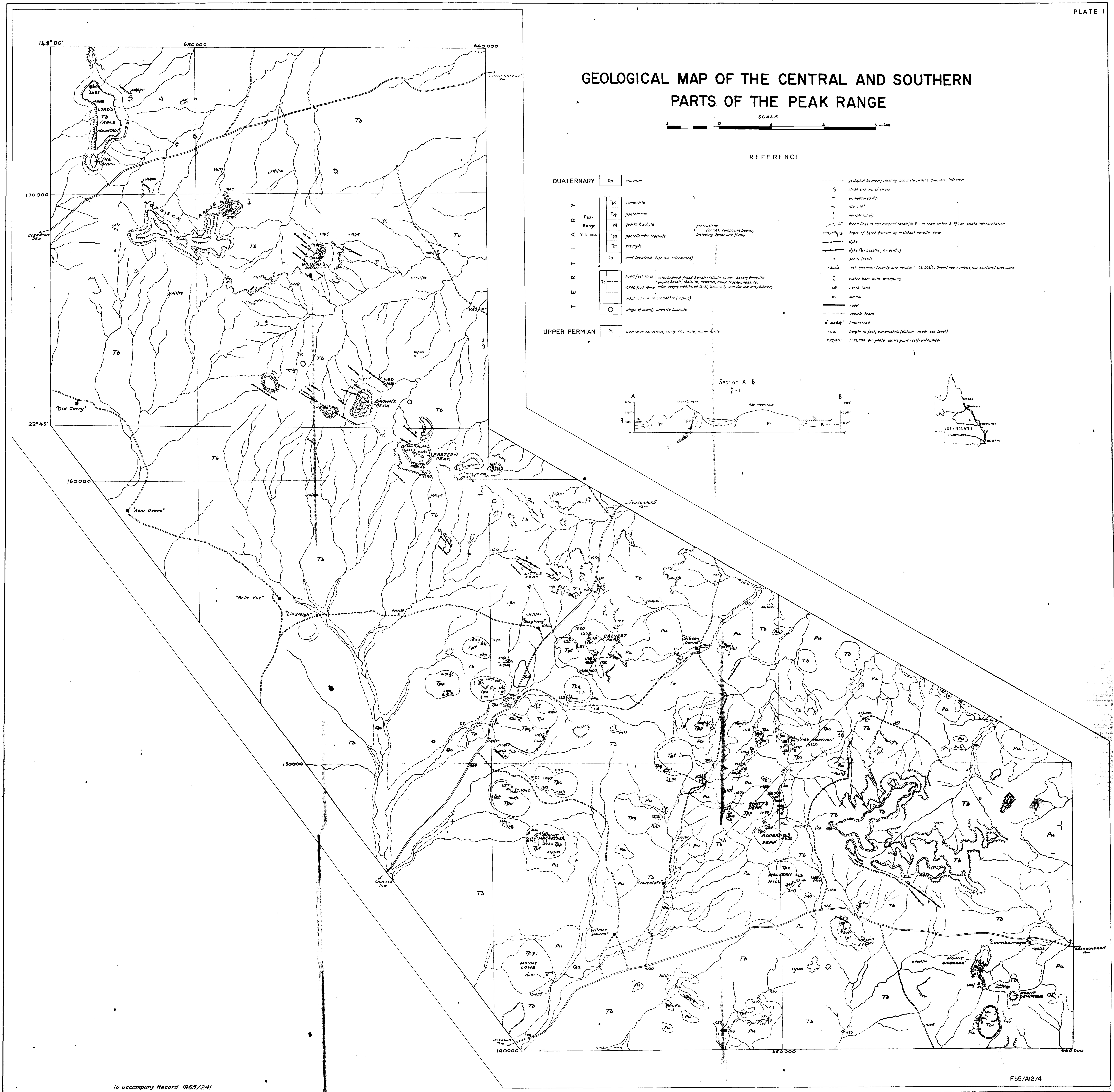
CL221/6⊕	7018		comendite	thrust dome	East face of Roper's Peak (65001475)
CL221/6A	7019		comendite autobreccia	[redacted]	East face of Roper's Peak (65011473)
CL615^{0}		1	trachytic comendite	dome	East face of Malvern Hill (65051460)
CL289/2	7017		comendite	dome	East of twin peaks about one mile north of Mount Macarthur. (64221490)
CL242/1A	6256		rhyolite	dome	Wolfang Peak, south face. (60601862)+
CL242/1B	7048		rhyolite	dome	Wolfang Peak, south face. (60601862)+
CL242/1G	6258		rhyolite	dome	Wolfang Peak, south face. (60601862)+
CL243/1C	6229		rhyolite	tholoid	Mount Saddleback-east face (61471930)+
CL245/2D	6252		rhyolite	dyke-tholoid	Mount Pollux, southern end, near small knoll. (61051950)+
CL245/2L	6247		spherulitic rhyolite	dyke-tholoid	Mount Pollux, southern end, near small knoll. (61051950)+
CL245/2G	7050		altered spherulitic glassy rhyolite	?flow or dyke closely associated with protrusion	South end of Mount Pollux, near small knoll. (61051950)+
CL252/2	7036		rhyolite	thrust dome	Mount Donald, west face. (61951830)+
CL255/5	6230		rhyolite	?dyke	Ridge, 2 miles S.W. of Fletcher's Awl. (61201890)+
CL293/1A⊕	6257 7044		spherulitic rhyolite	tholoid	West slopes of Mount Castor (61101963)+

CL293/1C	7045		rhyolite autobreccia	tholoid	West slopes of Mount Castor (61101963)+
CL293/2	6237		rhyolite rhyolite	protrusion	Small knoll immediately west of Mount Castor. (61101963)+
CL242/1E	6235	1	porphyri-tic pitchstone	dome	Wolfang Peak - south face. (60601862)+
CL243/1B	7052		porphyri-tic microlitic pitchstone	margin of tholoid	Mount Saddleback, east face. (61471930)+
CL245/2C*	6232		porphyri-tic pitchstone	margin of dyke-tholoid	Mount Pollux, southern end, near small knoll. (61051950)+
CL245/3A		1	porphyri-tic pitchstone	margin of dyke-tholoid	Mount Pollux - southern end near small knoll. (61051950)+
CL504		1	microlitic pitchstone	dyke	Ridge, ½ mile south of Mount Saddleback. (61401920)+
CL239/6A	6226		?phenocryst concentrate	?phenocryst concentrate on top of lava pile	Topmost bed of Gilbert's Dome. (63421678)
CL243/1A	7013		welded crystal-lithic-vitric tuff	remnant of tuff ring.	Mount Saddleback, east face. (61471930)+

CL245/2K	6241		welded crystal-lithic-vitric tuff	remnant of tuff ring.	Mount Pollux - southern end. (61051950)+
CL500		1	lithic-vitric ?tuff	remnant of tuff cone.	Mount Macdonald, west face. (60771895)+

PLATE I

GEOLOGICAL MAP OF THE CENTRAL AND SOUTHERN PARTS OF THE PEAK RANGE



To accompany Record 1965/241

F55/A12/4