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THE CAINOZOIC TO RECENT VOLCANIC ROCKS IN VICTORIA:
A REVIEW

by

D.J. ELLIS and A.K. FERGUSON

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1. Average Olivine tholeiite (Footscray and Trentham types) (Edwards, 1938, p.309, Anal. 12).

2. Average Alkali olivine basalt (Malmsburg Type) (Edwards, 1938, p.309, Anal. 11).

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PLIO-HOLOCENE VOLCANIC PROVINCE by D.J. ELLIS*

INTRODUCTION

There have been two major periods of Cainozoic volcanism in Victoria, which are known as the 'Older Volcanics' and the 'Newer Volcanics'. They can be distinguished both spatially and chemically as well as by their physiographic expression. The 'Older Volcanics' are Early Tertiary in age (Palaeocene to lower Miocene) and are silica-undersaturated alkali basalts ranging through to phonolites in composition. The 'Newer Volcanics' (upper Pliocene to Holocene) contain more silica, and range in composition from nepheline basanites to alkali basalts and minor olivine tholeiites. Trachytic differentiates are relatively uncommon.

The Newer Volcanics are distributed from Melbourne westward to the Glenelg River and are also found at Mt Gambier in South Australia (see Fig. 1). Small patches of Newer Volcanics also occur in the Eastern Highlands at Morass Creek, at Euroa, and possibly at Gelantipy, Glenmaggie, and South Buchan (Hills, 1938). The volcanic rocks form a continuous lava field of the Werribee and Western District Plains; they lie mainly on Cainozoic marine sediments, but overlap northwards onto Palaeozoic bedrock.

Many of the lava flows occupy pre-existing river valleys, in which lateral streams have since developed. In the eastern part of the Western Highlands the Newer Volcanic flows followed valleys trending north and south from the main drainage divide and thus displaced the streams laterally (Singleton & Joyce, 1969).

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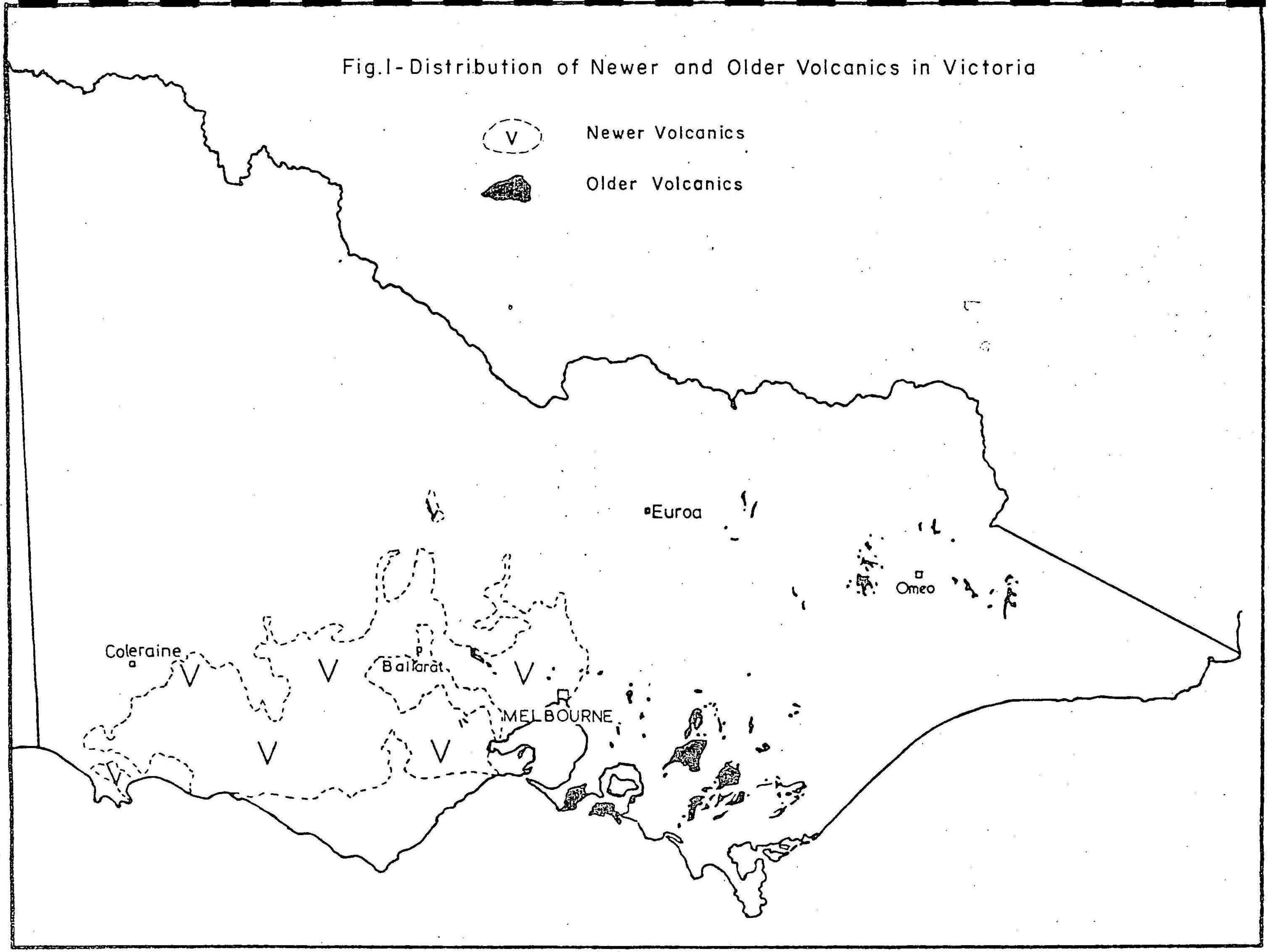

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The pre-basaltic drainage is known in some detail from past mining of auriferous deposits or 'deep-leads' (Hunter, 1909; Harris & Thomas, 1934), and was comparable in pattern and gradient to the present drainage.

TECTONISM AND VOLCANIC ACTIVITY

Singleton & Joyce (1969) consider that the peaks of volcanic activity followed concurrent volcanism and minor earth movements and that the volcanic activity was initiated by a peak of tectonic activity. During the early Pliocene a general marine regression preceded volcanicity. The Highlands of Victoria were arched along an east-west axis during the Pliocene, and in southern Victoria the South Gippsland hills and the Otway Ranges were uplifted.

Post-volcanic tectonism can be found southwest of Melbourne. Movement along the Rowsley Fault has been shown to post date the extrusion of basalt near Bacchus Marsh by Fenner (1918); the basalt was dated by Aziz-ur-Rahman & McDougall (1972) at 4.03 m.y. Lavas in the ancestral Barwon and Moorabool River valleys of the Geelong area have been warped by Pliocene tectonic activity (Coulson, 1938; Bowler, 1961); and flows extending from the Anakies have been warped by the Lovely Banks Monocline at the Moorabool Viaduct (Hills, 1938).

There are no obvious relationships between the distribution of volcanic centres and the Late Cainozoic structures in the Western District of Victoria. However, in the western Highlands volcanics are concentrated in a region 80 km long and 50 km wide between Lexton and Kilmore on the west and east, and Castlemaine and Ballan on the north and south. Singleton & Joyce (1969) consider that this concentration is due to and overlaps a domal uplift of the Early Cainozoic erosion surface centred on Trentham, which is superimposed on the general arching of the Highlands.

PHYSIOGRAPHY

The Newer Volcanics are only slightly eroded, and points of eruption and surface features of lava flows are still preserved. About 450 vents have been recognized. Ollier & Joyce (1964) compiled a list of 94 named points of eruption in the Western District, and Coulson (1954) and Yates (1954) mention over 150 in the Daylesford area and farther north. Volcanoes are also mentioned by Condon (1951).

Large shield volcanoes such as are found in Queensland and northern New South Wales are absent in Victoria. The Newer Volcanics are characterized by a large number of small vents.

The eruptive centres have been studied by Skeats & James (1937), Ollier & Joyce (1964), Ollier (1967), and many others (see Bibliography). Several types of vents have been recognized:

a) Lava volcanoes such as Mt Hydewell, Mt Hamilton, and Hanging Rock. Singleton & Joyce (1964) distinguish four different types: lava shields, lava discs, lava cones, and lava domes.

b) Scoria cones, formed by the accumulation of pyroclastic material in steep-sided hills, form the most striking physiographic features in much of the Newer Volcanics, particularly in the Camperdown area of the Western District, where scoria cones such as Mt Porndon, Mt Leura, and Mt Noorat occur. Many contain rock and mineral inclusions derived from the upper mantle. Very few are higher than 150 m. Mt Elephant, about 250 m, is the highest and most are less than 100 m high.

c) Some 34 tuff rings were recognized in the Newer Volcanics by Singleton & Joyce (1969): they are concentrated in the region between Warrnambool and Colac. They consist of annular accumulations of bedded ash and fragmentary material ranging from 15 to nearly 150 m in height, surrounding a crater 500 m to more than 3 km across. Many of these craters are occupied by lakes, e.g. Lake Bullenmerri, Lake Purrumbete, and Tower Hill.

The 'tuffs' are well bedded; beds range from thin lamellae to about 30 cm. The structure of some tuff rings has been studied by Marshall (1967). The tuff contains abundant fresh palagonite, and many deposits contain a variable but high proportion of Cainozoic sediment (Singleton & Joyce, 1969). The tuff at Mt Porndon, however, contains less than 10 percent of country rock, the bulk of the country rock being composed of rounded quartz grains and carbonate material (Ellis et al., 1971).

The formation of the tuff rings has been ascribed to the entry of groundwater into the volcanic system (Ollier & Joyce, 1964; Gill, 1967); Singleton & Joyce (1969) proposed a four-stage model:

(i) Formation of the initial vent with or without lava flow.

(ii) Waning of initial activity and withdrawal of lava down the vent. Groundwater enters the system when the pressure in the vent falls below that of the aquifer, and causes violent explosions as a result of which sedimentary and lapilli ejectamenta accumulate in the form of a tuff ring surrounding the area of steam emission, e.g., Lake Purrumbete and Lake Bullenmerri.

(iii) Renewed volcanic activity in which nested scoria cones are formed, e.g. Tower Hill.

(iv) Prolonged volcanic activity after which the tuff ring is buried under a scoria cone, e.g. Mt Noorat. Singleton & Joyce (1969) believe that the concentration of tuff rings in the Warrnambool-Colac region corresponds to the 'axis' of a broad downwarp in the Cainozoic sediments in which groundwater would be concentrated.

ISOTOPIC DATES

Until recently much of the data on the relative ages of the lavas have been based on geomorphological, stratigraphical, and palaentological studies (Hills, 1938; Ollier & Joyce, 1964). McDougall et al. (1966) dated 12 samples of the Newer Volcanics by the K-Ar method and obtained ages ranging from 4.5 $\pm$ 0.15 m.y. to 0.57 $\pm$ 0.03 m.y., and recently Aziz-ur-Rahman & McDougall (1972) dated an additional 15 samples that gave ages ranging from 4.21 $\pm$ 0.03 m.y. to 1.62 $\pm$ 0.03 m.y. A basalt near Hamilton was dated at 4.35 $\pm$ 0.01 m.y. by Turnbull et al. (1965). The Tower Hill eruption is estimated by radiocarbon dating to be approximately 5500 to 6000 years old (Gill, 1971).

The isotopic dating has shown that although volcanism generally migrated westward from the Older Volcanics, mainly east of Melbourne, to the Newer Volcanics west of Melbourne, no further apparent migration occurred: volcanism covered the entire province of the Newer Volcanics during upper Pliocene to Recent times, the most recent eruptive centres being along the southern margin of the lava plains.

PETROLOGY

Rock types range chemically from trachybasalt through nepheline-basanite to alkali olivine basalt and olivine tholeiite (see Fig. 2). Unlike contemporary volcanics in other parts of Australia, the Newer Volcanics include very few salic differentiates: eroded trachyte plugs occur in the Macedon and Trentham districts and a trachyphonolite at Mt Wilson.

Although composition varies widely, certain rock types are more abundant than others. The most extensive group of lavas is of alkali olivine basalt to basalt transitional to olivine tholeiite. Nepheline basalt is less abundant.

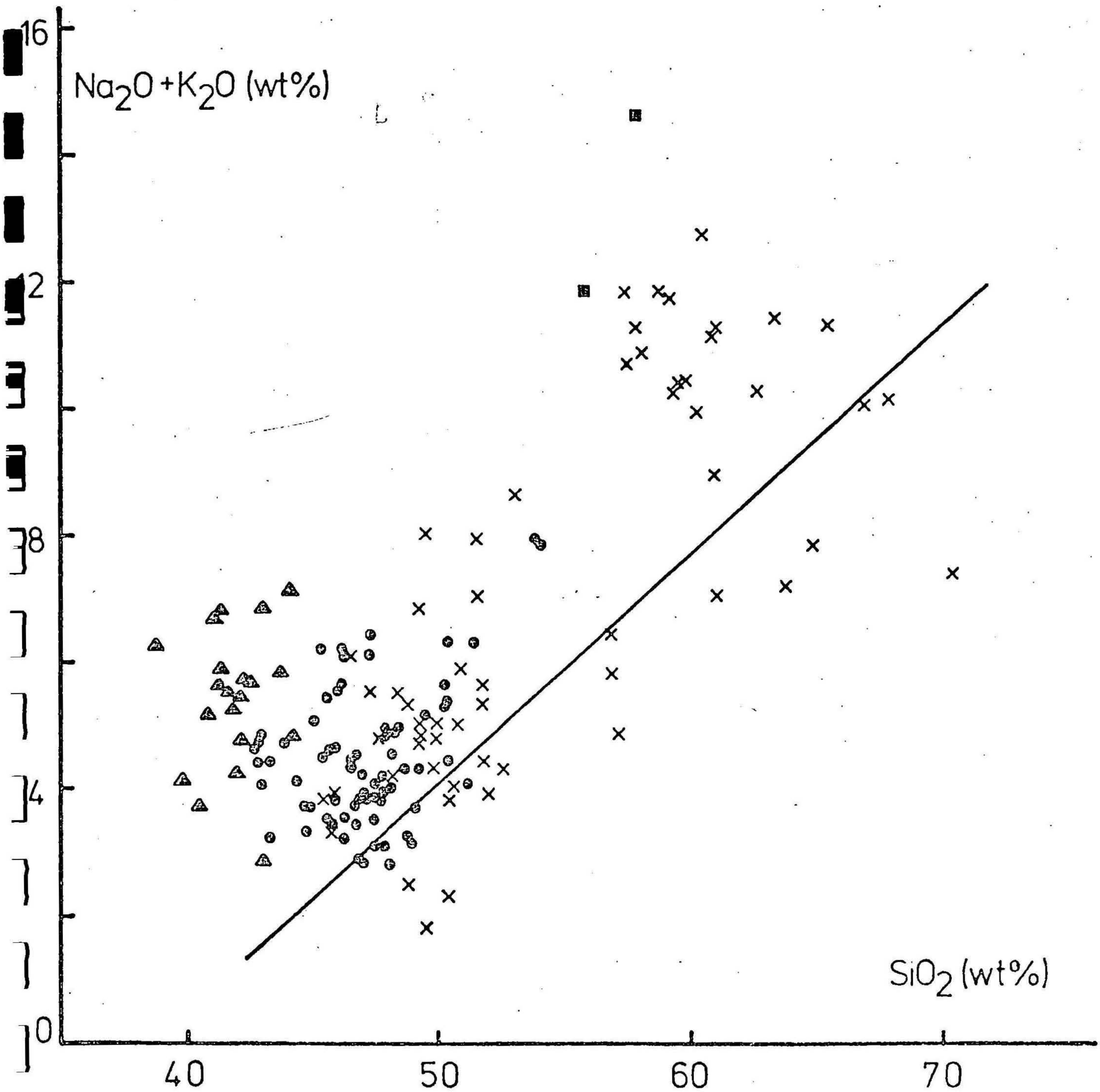

Fig. 2 - Total alkalis (Na_2O+K_2O) - silica diagram for rocks of the "Newer Volcanics" (X) and the "Older Volcanics" (nephelinites ▲ alkali basalts ⊙ and phonolites ▣)

Line separates alkaline from tholeiitic basalts (after Macdonald and Natsura, 1964)

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Chemical analyses of the Newer Volcanic lavas have been published by Stanley (1909), Grayson & Mahony (1910), Skeats & Summers (1912), Skeats & James (1937), Edwards (1938), Edwards & Crawford (1940), Yates (1954), Bahat (1971), and Green (1973).

The first major petrological study was carried out by Edwards (1938); but he concentrated on the rocks from central Victoria, with only scant data on the youthful volcanoes of the Western District. On petrographic criteria he was able to subdivide the volcanics into various rock types, but chemically distinct rock types have been grouped together because of petrographic similarities. He subdivided the labradorite basalts of Victoria into four groups: the Footscray, Malmsbury, Gisborne, and Trentham types; but his criterion, the presence or absence of iddingsite, is not thought to be adequate. Many of these lavas are transitional between alkaline and sub-alkaline; and care is needed in classifying them. The total-alkali-silica diagram of MacDonald & Katsura (1964), although satisfactory for distinguishing alkaline from tholeiitic lavas, is inadequate for transitional lavas such as predominate in Victoria.

Two main groups of labradorite basalt can be distinguished chemically (although gradations exist between them): olivine tholeiite (Footscray and Trentham type 'labradorite-basalt' of Edwards), and alkali olivine basalt (transitional basalt) (Table I, Anals. 1 and 2). Although both groups contain normative hypersthene, the olivine tholeiite contains more magnesium and less sodium, and therefore normative olivine and hypersthene in excess of diopside, whereas the transitional or alkali olivine basalt shows less normative hypersthene than diopside (see Wilkinson, 1968).

Petrographically the olivine tholeiite consists of olivine, clinopyroxene, plagioclase, opaque oxides, and glass. Olivine is generally absent from the groundmass; nor has orthopyroxene been recorded so far, no doubt partly because many of the rocks are hypocrystalline. Olivine tholeiite forms extensive lava plains around the Footscray and Werribee districts and to the northwest of Melbourne.

Chemically the Victorian olivine tholeiite (and transitional basalt) are characterized by a higher potash content (K_2O = 1.3 wt %) and lower lime (CaO = 8.5 wt %) than tholeiites from other parts of the world. They are most similar to the Columbia River basalt (Waters, 1961) and an olivine tholeiite from the Tweed Shield volcano in northern New South Wales (Wilkinson, 1968, table 1, no. 2), although the latter contains less K_2O than the Victorian lavas. The high potash content, a feature pointing to continental rather than oceanic tholeiites, could result in the presence of modal alkali feldspar in the groundmass, although none has been reported as yet.

The transitional or alkali olivine basalt consists of olivine, clinopyroxene, plagioclase, opaque oxides, and glass; olivine is a common constituent of the groundmass. Throughout much of the province it forms extensive lava plains together with the olivine tholeiite. More evolved members of the series occur farther west of Melbourne in the Camperdown district; for example, hawaiite lava (10% normative hypersthene) forms extensive 'Stony Rise' lava plains below the Mt Porndon and Mt Rouse scoria cones (Table I, Anals. 3 and 4).

The trachyte of the Macedon area may represent the salic differentiates of the transitional basalt (Table I, Anals. 5 and 6). The mineralogy of the trachytic plugs varies - some contain anorthoclase, some do not; and femic minerals differ. These features indicate slight differences in genesis.

A third group of lavas is the nepheline basanite in the west of the province, especially in the Camperdown region of the Western District. Many of the scoria cones are composed of nepheline basanite, and many are underlain by lava plains of transitional (hypersthene-normative) alkali olivine basalt and hawaiite.

This area was not studied by Edwards (1938), although he refers to it as containing the type limburgitic basalt (nepheline basanite), rare examples of which also occur in central Victoria (Gisborne, Baynton, Springfield, and the plains north of Melbourne). The earliest petrological studies of the Camperdown area were by Grayson & Mahoney (1910) and Mahony (1931); Skeats & James (1937) presented several chemical analyses. Many of the nepheline basanites and more evolved lavas contain high-pressure cognate and xenolithic inclusions, which have recently been studied (Irving, 1974; Ellis, 1974).

The nepheline basinite (Table 1, Anal. 7) is distinguished from the alkali olivine basalt by its lower silica and higher alkali content. It is fine-grained hypocrystalline, composed of euhedral phenocrysts of olivine, labradorite, titanuagute, and granular magnetite in a glassy matrix. Interstitial nepheline is present in a few holocrystalline samples. The more evolved nepheline hawaiite from Lake Keilumbete and nepheline mugearite from Mt Anakie were evolved under high pressure (20-30 kb) and relatively hydrous conditions by fractionation of, predominantly, kaersutite from a parental basanitic magma (Ellis, 1974). Green (1973) has studied the behaviour under high pressure of the nepheline basanite from Mt Leura. The trachyphonolite from Mt Wilson (Mahoney, 1931) may represent an end member of this lineage. It is a moderately fine-grained rock composed of sanidine, anorthoclase, aegirine-augite, sodalite, magnetite, and apatite (Mahoney, 1931).

Lavas containing less silica are not common within the Newer Volcanics. They include 'limburgite' (Table I, Anal. 8) and 'woodendite' (Table I, Anal. 9), described by Edwards (1938). They have been found at Woodend, Western Hill, Kings' Quarry, Melbourne Hill, Springfield, Chintin, the eastern side of the Heathcote ridge, Snowdon Hill, in the Djerriwarrah Creek, Gisborne, Hepburn, and Mt Ridley.

Analcime-bearing limburgite (analcime basanite) has been tentatively identified from Snowdon Hill, Springfield, Gisborne, and Western Hill. Little work has been done on these rocks.

The potash-rich rock described as 'woodenite' (Skeats & Summers, 1912) from Racecourse Hill, Woodend, is a dense hypocrystalline rock composed of phenocrysts of olivine, clinopyroxene, and plagioclase with xenocrysts of enstatite in a glassy groundmass. Patchy alkali feldspar (which also infills rare vesicles) and pleochroic green pyroxene have crystallized in parts of the groundmass. It is similar (Table I, Anal. 9) to the analcime basalt quoted by Wilkinson (1962, Table 1).

Small flows of potash-rich trachybasalt (up to 3.2 wt % K_2O) are found in the Ballarat and Daylesford area; the anorthoclase trachybasalt from Turpines Falls also falls within this group. Petrographically the rock consists of numerous anorthoclase crystals (up to 1 cm), corroded olivine, and a little brown pyroxene in a groundmass of oligoclase to andesine and granular clinopyroxene. Anorthoclase forms corroded aggregates, many of which enclose olivine.

Examples near Trentham consist of phenocrysts of labradorite set in a subtrachytic groundmass of plagioclase laths (Ab_{65}), alkali feldspar, iron ore, clinopyroxene, and green glass. Smaller amounts of more evolved potash-rich hawaiite are found at Daylesford, Woodend, Trentham, Bullarto, Sailors Falls, and Turpins Falls (near Kyneton).

CONCLUSION

The Newer Volcanics consist of lava flows, scoria cones, and tuff deposits, occurring mostly to the west of Melbourne as extensive plains and valley flows. Their distribution appears to have been only controlled in part by local tectonic activity, and possibly as a result of this migration, centres of volcanic activity did not apparently migrate with time.

The lavas range in composition from nepheline basanite through alkali olivine basalt (transitional basalt) to olivine tholeiite, with differentiated types including trachyte, alkali trachyte, and trachyphonolite. They also include analcime-bearing and potash-rich varieties.

CAINOZOIC VOLCANIC PROVINCE by A.K. FERGUSON *

INTRODUCTION

Basaltic rocks, both intrusive and extrusive, considered as 'Older Volcanics' have been described from the Glenelg River, north of Casterton (Hogg, 1899; Skeats, 1923), to areas east of Omeo (Skeats, 1923 and 1926; Edwards, 1939). The largest areas of outcrop of Older Volcanics are, however, east of Geelong (see Fig. 1), on the Bellarine Peninsula (Coulson, 1933; Ladd 1971), Mornington Peninsula, (including Flinders and Phillip Island) (Keble, 1950) at Korkuperrimul Creek in the Ballan Graben (Jacobson & Scott, 1937; Mazzoni, 1972); in Gippsland (Edwards, 1934; Baragwanath, 1925; Mahoney, 1931; Baker, 1945); on the Dargo (Skeats, 1923, 1926) and Bogong (Beavis, 1962) High Plains; and east of Omeo, between the Buchan and Snowy Rivers (Skeats, 1923-1926; Edwards, 1939; Crohn, 1950). Smaller outcrops are also known from near Casterton and Coleraine (Hogg, 1899; Skeats, 1923), near Euroa (Edwards, 1934), Aireys Inlet, Curlewis, and Maude (near Portarlington), and in the Moorabool River (Coulson, 1933, 1938) in and around the Melbourne area (Chapman & Theile, 1911; Jutson, 1913; McCance, 1932; Edwards, 1939) and the Silvan-Wandin-Emerald area (Williams, 1963; Edwards, 1939).

The Older Volcanic rocks are usually preserved in downthrown fault blocks (e.g. Ballan Graben and Gippsland) or as isolated outcrops upon uplifted and dissected blocks (e.g. Dargo and Bogong High Plains) and consequently their outcrop is limited. Most lavas form relatively thin flows (less than 50 m). Coulson (1938) estimates that the tuff exposed on the beach at Curlewis (Bellarine) may be up to 100 m thick, and Keble (1950) estimates (from bore-hole data) that the thickness of the basaltic sequence (including basalt, tuff, ash,

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clay, and coal) may be greater than 600 m. According to Keble (1950), the basaltic sequence at Flinders reached such a thickness because lava flowed south, from a fissure vent somewhere north of French Island, into a sinking basin south of Flinders.

The Older Volcanics are composed of lava flows consisting of 'orinanites, titanaugite-basalts, titanaugite-dolerites and basalts, olivine-basalts, monchiquites, rare nephelinites and occasional camptonites with a few dykes of phonolite and tinguaite' (Edwards, 1939). The dykes are often associated wih the lavas, but in many areas, such as Ballarat, Bendigo (Stillwell, 1913), Daylesford, Castlemaine, Maldin, Gippsland (Edwards, 1934; Baker, 1945), and Omeo (Skeats, 1912), have been recorded separately.

PETROGRAPHY

The basaltic rocks of the Older Volcanics range from nepheline and analcime-bearing types, usually rich in mafic constituents (mainly olivine and pyroxene), to olivine and augite basalt and rarely to differentiated types containing abundant alkali aluminosilicates. Nearly all are altered to some degree; veins of serpentine run throughout some rocks, with the groundmass, interstitial glass, and olivine serpentinized; in others secondary zeolites including analcime, natrolite, phillipsite, gmelilite, stilbite, sphaerostilbite, and chabazite, with calcite, aragonite, halloysite, and magnetite, have been deposited in vugs and joints, as at Flinders (Mitchell, 1931; Rew, 1969).

The nomenclature of the Older Volcanic basaltic rocks from Victoria, like that of the Newer Volcanics, is inaccurate, and in the following discussion an attempt is made to apply the nomenclature of a recent classification scheme for basalts (Macdonald & Katsura, 1964, modified by Coombs & Wilkinson, 1969). Wherever appropriate the old terminology is given brackets.

a) <u>Olivine-analcime basalt</u> (Table I, Anal. 10) (crinanite and crinanite basalt) occurs as flows and dykes in the Gippsland area and in bores from the Dargo High Plains. It is coarsely ophitic and contains phenocrysts of olivine, titanaugite, and labradorite, with subordinate ilmenite and other opaque minerals and interstitial analcime. Edwards (1939) notes that where the pyroxene is in contact with the analcime it is often greenish, and may be aegirine-augite. A little biotite has also been noted.

b) <u>Olivine-nephelinite and nephelinite</u> (Table I, Anal. 11 & 12) (nephelinite, monchiquite, limburgite) are known as dykes and flows from the Ballan Graben at Drouin West, on the Bogong High Plains, and at the You Yangs (Baker, 1936). They contain 5-25 vol. % nepheline, and plagioclase is generally less than 5 vol. %. The rest of the rock is largely composed of olivine and augite phenocrysts, with rare kaersutite and accessory magnetite in a fine-grained matrix mainly of augite and magnetite. Typically, the colour index is high (60 to 80% vol.). Most of the rocks previously described as limburgite (occurring as dykes and flows) are fine-grained mafic nephelinite to basanite, usually with nepheline and plagioclase together less than 10-15 vol. %, and the rest of the rock composed of pyroxene, olivine, and glass, with a little hornblende or biotite or both.

c) <u>Alkali olivine basalt to basanitoid</u> (Table I, Anal. 13).

(i) <u>Nepheline normative type</u> (limburgite, monchiquite, basalt, olivine-basalt, titanaugite-basalt) show no modal nepheline but contain up to about 10 wt % normative nepheline (Table I, Anal. 13) and form the second most common petrographic type of the Older Volcanics. It is represented in bores at Gippsland, Flinders, and Cape Schank, on the Dargo and Bogong High Plains, at Maude, in the Ballan Graben, and at Bellarine. Titanaugite and olivine are the main phenocrysts in a matrix of finer-grained augite and plagioclase (labradorite). Glassy varieties are also known. Edwards (1939) distinguishes an 'iddingsite-bearing basalt', which differs only in that part of the olivine has been altered to iddingsite. Iddingsitized basalt is rarer in the Older Volcanics than in the Newer Volcanics (Edwards, 1939), and occurs at Portarlington, Ballan Graben, Flinders, Cape Schank, Evelyn and near Mirboo.

(ii) Hypersthene-normative type (Table I, Anal. 14) (titanaugite-basalt, basalt, olivine basalt, doleritic basalt, and dolerite) is probably the major basaltic type of the Older Volcanics. Also, petrographically and chemically it most closely resembles basalts of the Newer Volcanics. The hypersthene-normative basalt contains phenocrysts of olivine and a little augite in a finer-grained matrix of plagioclase and augite with accessary magnetite. Some varieties contain a little glass (now altered to serpentine), and may also lack significant augite, in which case glass and plagioclase are usually more abundant. Olivine is the only phenocrystal phase. This type of tholeiite is fairly evenly represented in all outcrops of the Older Volcanics.

(iii) Hawaiite (Table I, Anal. 15) (mugearite, andesine basalt). Three occurrances of hawaiite have been described, from Aberfeldy (Baragwanath, 1925), from a dyke and a flow near West Head, Flinders (Wong, 1966), and from a dyke on the Dargo High Plains (Edwards, 1939). An average of four analyses is given in Table I, Analysis 5. The original Fe_2O_3 content (7.02 wt %) has been recalculated to 2.0 wt %. Petrographically the rock consists of phenocrysts of feldspar, augite, and olivine in a matrix of oligoclase to andesine, augite, glass, and accessory magnetite.

d) Differentiated types (Table I, Anal. 16) (phonolite, tinguaite) are rare in the Older Volcanics and are represented only by phonolite dykes near Omeo and Cobungra (Edwards, 1939), phonolite and tinguaite pipes near Harrietville (Skeats, 1921), and a phonolite dyke from Mt Smythe (near Mt Hotham) (Beavis, 1962). Typically they contain xenocrysts of basaltic hornblende reacting to form pyroxene and ores. Apart from one (Beavis, 1962, Anal. 1, p. 375) which appears to be an altered 'phonolite' (Beavis, pers. comm.), these rocks are nepheline-normative (Table I, Anal. 16) and thus probably related to the lineage of the nephelinites.

PETROCHEMISTRY

Edwards (1939) concluded that the parent magma of the Older Volcanics approximates to the 'olivine-basalt magma type', comparable with the Newer Volcanics, although the latter show distinct tholeiitic tendencies.

Mazzoni (1972), however, recognizes two main types of basalts from the Older Volcanics of the Ballan Graben: a group of olivine nephelinite and nephelinite, very undersaturated in silica and a near-saturated group of basanitoid, alkali-olivine basalt, and olivine tholeiite (see Fig. 2). The chemical trends in each series can be accounted for by removal of various amounts of olivine and pyroxene.

Considered as a whole the Older Volcanics range from strongly undersaturated nephelinite to near-saturated hypersthene-normative olivine tholeiite. The two phonolite analyses available are strongly undersaturated and are considered as possible differentiates of the more primitive olivine nephelinite. The hawaiite analyses represent slightly evolved alkali-olivine basalt.

INCLUSIONS

Like the Newer Volcanics, the Older Volcanics contain a variety of mafic to ultramafic inclusions; they also contain a single eclogite inclusion.

At Cape Paterson, Baker (1945) described the occurrence of dunite nodules and an eclogite nodule in a volcanic neck consisting of agglomerate, tuff, and dense basalt blocks. The eclogite contained almandine-pyrope, omphacite, and a little spinel.

In the Ballan Graben volcanics, Mazzoni (1972) has described a range of mafic to ultramafic nodules as well as megacrysts. The most abundant 'xenolith' is a typical four-phase lherzolite of olivine-enstatite-Cr-diopside-spinel occuring as nodules 2 to 12 cm across in both lavas and dykes. Mafic pyroxenite and gabbroic xenoliths, including kaersutite-bearing types, are also found in the Ballan Graben. These consist of kaersutite, aluminous sahlite, bytownite, rare olivine, and accessory spinel. Similar inclusions are also known in lavas from the High Plains, Flinders, Gippsland, and Mt Useful.

Megacrysts described by Mazzoni (1972) include anorthoclase feldspar, aluminous augite, kaersutite (up to 3 x 4 x 8 cm), and titaniferous biotite. Anorthoclase, amphibole, and biotite megacrysts are known from lavas and dykes near Flinders, and pyroxene megacrysts have been found in lavas from High Plains.

Two unusual inclusions described by Mazzoni (1972) deserve special mention, as they have not been described elsewhere from the Newer or Older Volcanics. The first is a group of pyroxenite to gabbroic inclusions characterized by aluminous salite (called sodic pyroxene by Mazzoni, 1972) which have exsolved lamellae of ilmenite along planes of the form (110) in the pyroxene. Associated phases are plagioclase (bytownite), apatite, and magnetite. The second unusual type is an alkali pegmatoidal clot containing alkali feldspar, sodic pyroxene to aegirine, and fine-grained zeolites. No nepheline was observed.

COMPARISON BETWEEN THE NEWER AND OLDER VOLCANICS

Although the Newer and Older Volcanics are in some respects similar (e.g. both predominantly alkali olivine basalts to olivine tholeiites), there are some marked differences:

1. The Older Volcanics contain a strongly nepheline-normative series as well as a near-saturated series, whereas the Newer Volcanics under-saturated series is only mildly nepheline-normative.

2. Iddingsitization of olivine in lavas of the Older Volcanics is of only local significance and much less than in the Newer Volcanics.

3. Augite-rich basalts are more common in the Older Volcanics.

4. The Older Volcanics are commonly altered and some contain abundant zeolites.

5. Dykes are rare in the Newer Volcanics.

6. Evolved rocks such as trachyte and alkali trachyte are commoner in the Newer Volcanics.

Despite these differences, as Edwards (1939) notes, 'it cannot of course, be claimed that the petrological examination of any specimen is sufficient to assign it to one or other suite'.

Edwards (1939) noted that differentiated Newer Volcanics are rich in both soda and potash, whereas comparable rocks among the Older Volcanics are richer in soda than potash. Although this holds true between phonolites of the Older Volcanics and trachyte of the Newer Volcanics, it is not always true between two basalts from the near-saturated series of both ages.

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