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EXCURSION GUIDE

MONARO VOLCANIC PROVINCE

M.C. Brown, K.G. McQueen, I.C. Roach and Graham Taylor

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EXCURSION GUIDE TO THE MONARO VOLCANIC PROVINCE

M.C. Brown, K.G. McQueen, I.Ç. Roach and Graham Taylor

School of Resource and Environmental Science

University of Canberra

PO Box 1

Belconnen ACT 2616

GEOLOGY OF THE MONARO VOLCANIC PROVINCE

Summary

Mafic volcanism in the Monaro Volcanic Province began during the Late Palaeocene and continued into the Early Oligocene. In the far north of the Province minor volcanic activity also occured in the Early Miocene.

Volcanic rocks of the Province are mainly lava flows of hypersthene-normative alkali basalt with some basanite and minor nephelinite lava flows, the latter being more abundant in the upper parts of the volcanic pile. Numerous eruption points have been located and these are widely distributed. They include plugs, dykes and two lava lake fills and consist of nephelinites, basanites, and nepheline-normative alkali basalts. There is no major central volcanic complex and the Province is best described as a lava field.

The volcanic rocks were erupted over a dissected landscape with some older fault scarps and an erosional relief of at least 500m. Maximum relief was in the south-east. Streams flowing into the lava field from the south and west were blocked by lava flows to form substantial lakes. Sequences of lake sediments up to 150 m thick were in turn covered by lavas, forming hyaloclastites and pillow lavas in places.

The volcanic pile built up to a thickness of at least 240 m and possibly 400 m or more in some areas. Many inter-basaltic bauxitic weathering profiles developed during periods of up to 5 million years between successive flows of lava under a cool wet climatic regime.

Since eruption of the lavas there has been some faulting and monoclinal warping. An unknown amount of volcanic rock has been eroded but we do not believe that the lavas formerly covered an area much larger than they do today. This erosion produced the present landscape of flat-topped hills and terraced hillslopes on the lavas and prominent rounded hills on the larger plugs.

The highest part of the Province, which now forms part of the present Great Divide, coincides with a major concentration of young volcanic plugs. A late build-up of volcanic rocks in this part of the Province, fed from the plugs, probably controlled the formation of the Divide in this area.

Magmas were derived from localised, small amounts of partial melting of a heterogeneous garnet-lherzolite mantle at depths greater than 90 km. There has been relatively little fractionation and the rocks of the Province are almost entirely mafic with SiO_2 contents <48% and mg ratios >55. Many are primitive rocks with mantle xenoliths or xenocrysts.

Introduction

The Monaro Volcanic Province consists of early Tertiary mafic lavas, associated intrusions and minor pyroclastics, covering an area of approximately 4,200 km^2 in the south-eastern part of the eastern Australian highlands (Fig.1). The Province occurs on a tableland (the "Monaro") with mean elevation around 900 m, midway between the Snowy Mountains (2000+ m) and the east coast.

The Province is one of many areas of Tertiary and Quaternary intraplate mafic volcanism which occur along the eastern highlands (Johnson, 1989). It is among the oldest of these provinces. Whole-rock and mineral K-Ar dating of basalts and plug rocks (13 samples) from throughout the Province has indicated ages ranging from 55 to 34 Ma (Wellman and McDougall, 1974b, corrected to revised decay constants; Taylor et al., 1990). Pollen floras in sediments from several sites at and near the base of the volcanic sequence all indicate a Late Palaeocene age of around 58-60 Ma. (Taylor et al, 1990). North of the Province, 35 km NNW of Cooma mafic volcanic rocks have been dated at 15.2 to 18.2 Ma (Owen and Wyborn, 1979). K.R. Sharp (pers. comm.) is mapping the northen part of the Province to determine how far south this younger volcanic suite might extend.

Wellman and McDougall (1984a) recognised two types of volcanic province in the eastern Australian highlands - central volcanoes, with well developed intrusive complexes near the centre, and lava fields with no major volcanic centre. They classified the Monaro Volcanic Province as a lava field. This interpretation is strongly supported by recent mapping which has revealed the presence of at least 65 minor volcanic centres, scattered throughout the Province (mapping by authors, students at the University of Canberra and Winston Pratt, NSW Geological Survey). The geochemistry of the mafic volcanic rocks is also similar to that of the other lava fields.

Ollier and Taylor (1988) proposed, on the basis of a drainage analysis, that the present area of the Province is the western remnant of a "Monaro Volcano" centred on Brown Mountain and that the eastern half has been eroded away. However, there is no field or geophysical evidence for a major volcanic centre at or near Brown Mountain, or elsewhere.

For the purposes of this guide most of the volcanic rocks in the Province are classified into nephelinites, basanites, and alkali basalts using a total alkali/silica plot (Fig 3), following Kesson (1973) after Saggerson and Williams (1964) and Strong (1972). We have also recognised some "nephelinites" which are significantly fractionated and contain andesine plagioclase. We refer to these as nepheline hawaiites (cf. Johnson, 1989). Many of the "alkali basalts" of Kesson's classification are mildly hypersthene-normative. Most of these have below 10% normative hypersthene and could be classified as transitional basalts. A few exceed 10% normative hypersthene and strictly fall into the category of olivine tholeiites (Johnson, 1989). We have retained Kesson's original terminology for these rocks and generally refer to them as "hypersthene-normative alkali basalts".

Bedrock Geology.

The Tertiary volcanic rocks of the Province overlie Ordovician to Devonian rocks and a small Jurassic syenite pluton. The Ordovician rocks are a flysch sequence, tightly folded about dominantly north-south trending axes. They are regionally metamorphosed up to sillimanite grade in two low-pressure metamorphic complexes. These complexes, at Cooma and Cambalong, are centred on migmatites and anatectic S-type granite, and more mafic I-type granites respectively (e.g. Joplin, 1942; McQueen et al, 1986).

The Ordovician rocks are overlain by an Early Silurian quartz-rich proximal flysch and these rocks are in turn overlain unconformably by Middle to Late Silurian shallow marine limestones, mudstones and sandstones with some interbedded felsic volcaniclastic rocks. The Silurian rocks show open to tight folding, mostly about north-south trending axes. They are intruded by Late Silurian to Early Devonian granodiorite and adamellite plutons. These are generally elongated

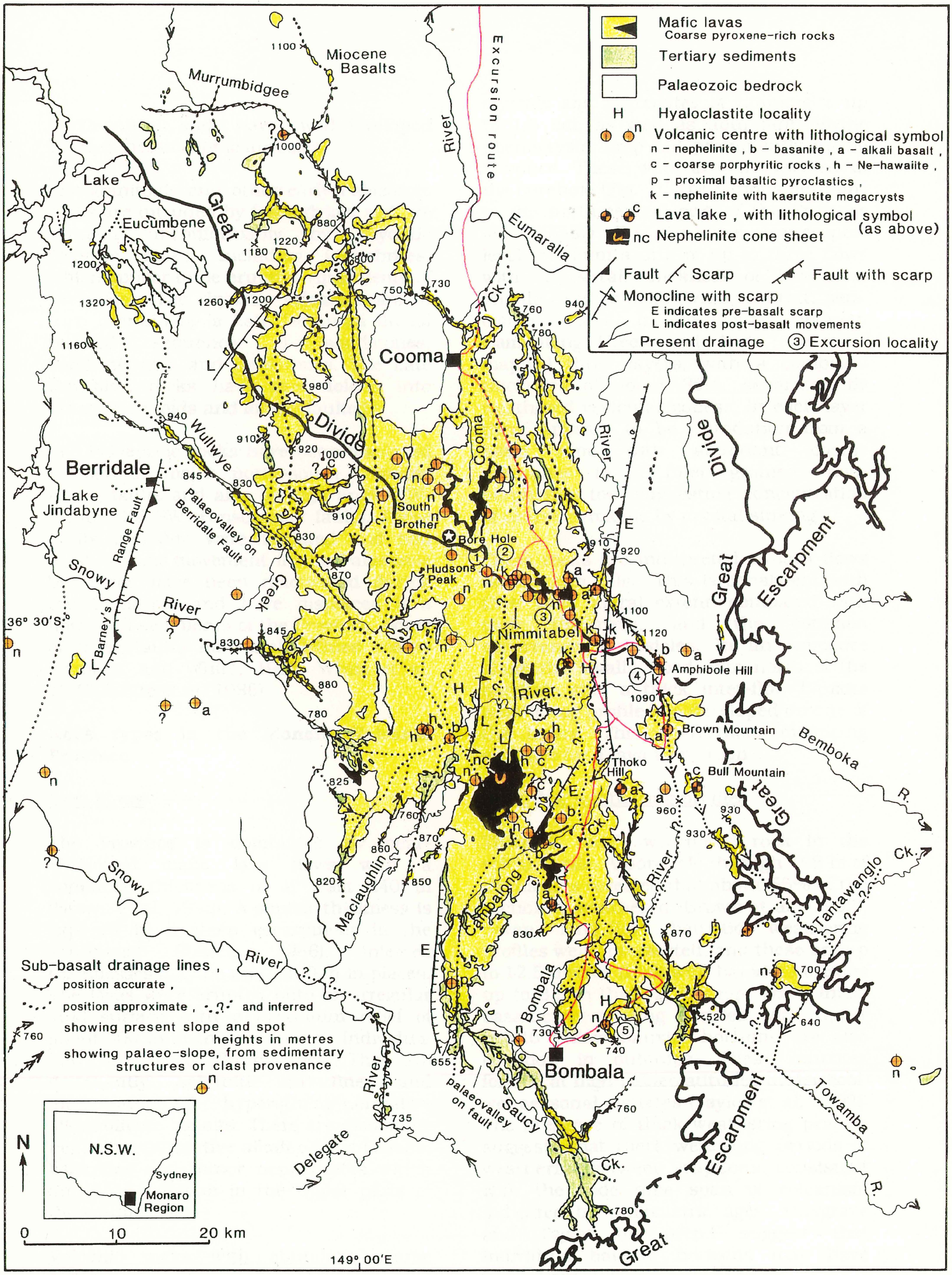

Fig 1. Geological map of the Monaro Volcanic Province. Mapping by the authors, University of Canberra students, W. A. Pratt, D. Ilsley, White et al (1977, 1986). Owen and Wyborn (1979), Veitch (1986), and Edgecombe (1992)

north-south and have well-developed contact metamorphic aureoles.

The granitoids and other early Palaeozoic rocks are intruded by felsic dykes and are overlain unconformably by rhyolitic volcanic rocks, including ignimbrites, which appear to be eruptive equivalents of the dykes. The rhyolitic volcanics are in turn overlain by a Late Devonian fluvial red-bed sequence of sandstones, conglomerates and mudstones. The Late Devonian rocks have been folded into broad open folds and locally faulted.

The Palaeozoic rocks have been displaced by several major north-south trending thrust faults and also by high angle NW-SE and NE-SW transcurrent faults. These faults probably were initiated and had most of their movement in the Palaeozoic but some have been reactivated during the Cainozoic and have displaced lava flows and sediments of the Province. Some of these faults have well-defined scarps (Lambert and White, 1965; White et al, 1977; White et al, 1986).

Rock types in the Monaro Volcanic Province

Lava Flows

The Province is dominated by near-horizontal mafic lava flows with a combined thickness of at least 240 m (Brown et al, 1992). A similar thickness is exposed in a steep escarpment in the south-east (Veitch, 1986). Inferred thicknesses may be up to 400 m in places. The lavas were erupted onto an irregular land surface with a maximum relief of about 500 m in the south-east. Individual flows are up to 30 m thick. They are dominantly aphanitic to fine- and medium-grained hypersthene-normative alkali olivine basalts. There are also some nepheline-normative alkali olivine basalts, basanites and minor nephelinites which are more common in the upper parts of the volcanic pile.

Volcanic rocks with abundant coarse pyroxenes

Laterally-extensive layers of porphyritic mafic rocks with abundant (up to 30%) crystals and aggregates of titanaugite up to 1.5 cm, as well as abundant olivine phenocrysts, crop out prominently in the Province. These were also intersected in the borehole (Fig. 1). The various outcrops in the north-central part of the Province are probably all at the same stratigraphic level and form a unit of up to three flows with an overall thickness of 15m near Middle Brother peak (Winston Pratt, pers. comm., 1993). In the south, between Cambalong Creek and Ando, we have mapped three layers, with a combined thickness of about 35m, separated by weathered vesicular zones. In each layer there appears to be gradation from a basal zone with abundant coarse pyroxenes to a finer grained, non-porphyritic top, suggesting concentration of coarse pyroxene by crystal sinking.

These rocks are interpreted as lava flows rather than sills. This is consistent with their wide lateral extent, compared with their thickness, and the common occurrence of vesicles. In an exposure along the Myalla Road 3km north of the borehole site, a thick inter-flow bauxite weathering profile has developed on one of the layers. This is further convincing evidence for a lava flow origin.

Inter-flow weathering profiles

There is much weathered rock in the volcanic pile. A borehole through 198 m of the basalts revealed that about 55% of the section is weathered (Brown et al , 1992). Seven inter-flow bauxitic weathering profiles were intersected, and these are up to 12.5 metres thick with bauxite horizons up to 3.5 m thick at the top. Thick inter-basaltic weathering profiles with upper red to yellow bauxite horizons are also common in outcrops. These bauxites formed at high palaeolatitudes under cool, wet seasonal climates (Taylor et al, 1992). The presence of thick weathering profiles suggests that there were long periods of weathering between eruptions, consistent with the wide time span of volcanism indicated by radiometric ages. Musgrave and Taylor (in prep.) suggest that individual bauxite horizons may have formed over 0.5 to 5 million years.

Early Tertiary Sediments

Alluvial, colluvial and lacustrine deposits occur in the Province, either directly beneath the basalts or interbedded with lava flows near the base of the sequence. Thin units of alluvial sand and gravel are widely distributed. Cobble and boulder gravels with clasts up to 3 m occur along the axes of palaeochannels cut into the sub-basalt bedrock. Near the southern and western margins of the Province there are a number of lake deposits up to 150 m thick. They include laminated brown to white clays and silts, dark organic-rich muds, lignites and coals with some interbedded fluvial and lake shoreline sands and gravels.

Some sands and gravels have been cemented to silcrete - a resistant, nearly pure silica rock consisting of quartz clasts in a hard cement of quartz and fine anatase. The clasts are commonly rounded and show solution embayments.

Interactions between lava flows and lake sediments

Hyaloclastites have been found in several exposures and also in the borehole section at the contact between lacustrine sediment and overlying basalts. They consist of chaotic mixtures of vesicular basalt fragments and lacustrine clays, containing near-spherical basalt pillows. In some areas where basalt was extruded over lake deposits, diapirs of clay (1-10 m in diameter) were squeezed up into the overlying basalt while it was still fluid.

Volcanic plugs, lava lakes and other intrusions

At least 65 eruption points have now been located in the Province, including numerous volcanic plugs, a cone sheet, and two probable lava lakes. Exposures of coarse proximal pyroclastics near the base of the sequence suggest that maars may also be present. Known volcanic centres are widely distributed but there is a significant concentration close to the present Great Divide near Nimmitabel.

Volcanic plugs with diameters of 10-400 m have a wide distribution. Many have intruded lavas at the preserved top of the volcanic sequence. Only four radiometric dates are available (57, 47.7, 41 and 34 Ma) and these are within the range of ages for the lavas, but younger than the oldest lava flows. The oldest date is from a coarse pyroxene-rich rock at Mount Cooper which may be an outlier of a flow rather than a plug. The plugs are usually less weathered than the lavas and typically form hills in areas where they are surrounded by lavas. Their topographic expression is more subdued where they have intruded bedrock. Plugs have been identified according to various criteria including their topographic expression, contrast in lithology with surrounding rocks, steep dipping contacts or flow structures, radial or concentric jointing and abundance of xenoliths. Not all of these features are present in every plug. Some possible plugs marked with question marks on Figure 1 are mapped largely on topographic expression.

Most of the plugs consist of aphanitic and fine-grained nephelinites and basanites, commonly with abundant mantle and crustal xenoliths, as well as megacrysts of pleonaste, kaersutite, biotite and rare titanomagnetite. Kaersutite and biotite megacrysts occur only in the most alkali-rich plugs, which are mostly within 10km of Nimmitabel. One occurs near Dalgety at the western margin of the Province. Four cylindrical plugs and some dykes of more fractionated nephelinine-normative hawaiite, lacking mantle xenoliths, occur further south near Jettiba Hill and Avonlake.

A cone-sheet of aphanitic nephelinite with very abundant mantle xenoliths has intruded coarse pyroxene-rich lavas near Rosemount in the south-central part of the Province. The nephelinite outcrop occurs on two-thirds of a 1 km diameter circle and its topographic expression suggests that it dips inwards at about 25°.

In the basalt outliers of the south-eastern part of the Province there are two near-circular and tabular bodies of gabbro/dolerite known as Bull Mountain and Thoko Hill. These are interpreted as differentially-eroded remnants of lava lakes filling former craters, possibly maars. In size and topographic expression they are similar to the Circular Head and Table Cape volcanic centres of north-west Tasmania (Sutherland, F.L. in Johnson, 1989). The Bull Mountain body is 850 m in diameter, approximately 60 m thick, and composed of a medium- to coarse-grained undersaturated gabbro with abundant large titanangite phenocrysts which increase in abundance toward the base (Stockton, 1988). Its contact with underlying basalt is obscured by debris from its steep margins. The Thoko Hill body is 1800 m in diameter, approximately 65 m thick and composed of a fairly uniform medium- to fine-grained undersaturated alkali dolerite with near-vertical columnar jointing. It stands prominently above surrounding areas of basalt and granite. Weathered mafic lapilli tuffs, underlying the dolerite, are exposed in a gully on the western margin. The tuff deposits are interpreted as the remnants of an original crater rim of pyroclastics.

Two small exposures of well-bedded basaltic lapilli tuffs occur about 2 km east of "Red Cliff" homestead, near the base of the volcanic sequence at its southern margin. These rocks must be close to an eruptive centre, possibly a maar, which may underly alluvium on the floor of a 700 m diameter depression immediately to the west.

Volcanism and landform evolution

Numerous authors have discussed the landforms and drainage of the Monaro, (e.g. Clarke, 1860; Sussmilch 1909; Taylor, 1910; Craft, 1933; Taylor et al , 1985; Ollier and Taylor, 1988). Most have postulated major changes in drainage patterns and divides, with some suggesting that volcanism may have been responsible for some of these diversions (Clarke, 1860; Ollier and Taylor, 1988). Craft (1933) and Taylor et al. (1985) have argued for long-term landscape stability.

Figure 1 shows the present drainage lines and our interpretation of the sub-basalt drainage pattern. We have interpreted numerous major and minor palaeo-valleys around the margin of the Province, based on occurrences of long narrow outcrops, or lines of outcrops, of basalt and/or Tertiary sediments that have higher country on either side. Within areas of thick basalt cover the palaeo-drainage is based on extrapolation and other evidence such as compaction-related dips of basalt flows and magnetic anomalies.

The sub-basalt drainage was mainly to the south-east into the Towamba River valley. In a small area in the north-east the palaeo-drainage was northerly as suggested by Taylor et al (1985); and south west of the Province it was to the north-west.

Build-up of the volcanic pile progressively blocked the south-east drainage producing substantial lakes along former tributaries in the south and west. The upper Murrumbidgee River, a major tributary of the system, was eventually diverted into the north-flowing drainage, and the upper Snowy River, another major tributary, was diverted progressively southward until it crossed the divide into the north-west flowing system. Eruption of the Monaro Volcanic Province can thus explain the peculiar pattern of the present day Murrumbidgee and Snowy Rivers.

On the volcanic pile a new drainage developed. The WNW-SSE trending concentration of young volcanic centres near Nimmitabel had locally built up the volcanic pile to its highest elevation so that it formed an important drainage divide. The present Great Divide in this area, separating inland and coastal drainage (Fig 1), is inherited from this original volcanic landform. Lateral streams developed beside the tongues of basalt which filled the former valleys around the margins of the Province and some streams cut down into valley-filling flows to re-excavate former valleys.

An unknown volume of volcanic rock has been eroded since eruptions ceased and no primary volcanic landforms remain. The erosional landscape is characterised by flat-topped hills and terraced slopes. Unweathered parts of the thicker flows form flat areas with steep slopes at their edges. Weathered basalt or sediment interbeds form the intervening concave slopes. The largely unweathered volcanic necks usually stand out strongly as rounded hills. Many small ephemeral lakes occur on the volcanic rocks, particularly on areas of low relief.

According to Pillans (1987) these formed by a combination of solution weathering and deflation of clay aggregates from the lake floors during dry periods.

Structural controls on volcanism

There is a structural control on the location of volcanic plugs. Dominant N-S, NE-SW, NW-SE, and E-W lineaments can be recognised on enhanced Landsat MSS images at 1:100,000 scale and most volcanic plugs occur close to these lineaments, commonly at their intersections (Roach, 1991). Some of the plugs are located on mapped fractures. Five plugs occur in E-W, NE-SW and NW-SE shear zones in bedrock granitoids. Wangellic Hill, one of the larger plugs, occurs on a north-south fault which has a 30 m vertical displacement in the Tertiary volcanics. There are also some alignments of 3 or more volcanic plugs evident on Fig 1 which suggest control by bedrock fractures.

Major element geochemistry and mineralogy of the volcanic rocks

Geochemical and mineralogical characteristics of the Monaro Volcanic Province have been described by Kesson (1973), Brown et al (1988) and Roach (1991). Kesson's pioneering study was based largely on samples of the flow rocks. The more recent geochemical and petrographic studies have been extended to volcanic plugs and other intrusions. This has somewhat broadened the known range of geochemical variation in rocks of the Province. In particular we have discovered several kaersutite-bearing nephelinite plugs with higher alkali contents than recorded by Kesson (1973), as well as some fractionated nepheline-normative hawaiite plugs.

The main geochemical and mineralogical characteristics of the Province are summarised below.

(a) All the volcanic rocks have a low SiO_2 content with an overall range from 40.20% to 48.54%.

(b) SiO_2 content is not normally distributed (Fig 2). There are three modes at about 42.7%, 44.25%, and 46.5% SiO_2 (separated at SiO_2 contents of 43.5% and 45.2%). The break at 45.2% SiO_2 is particularly clear.

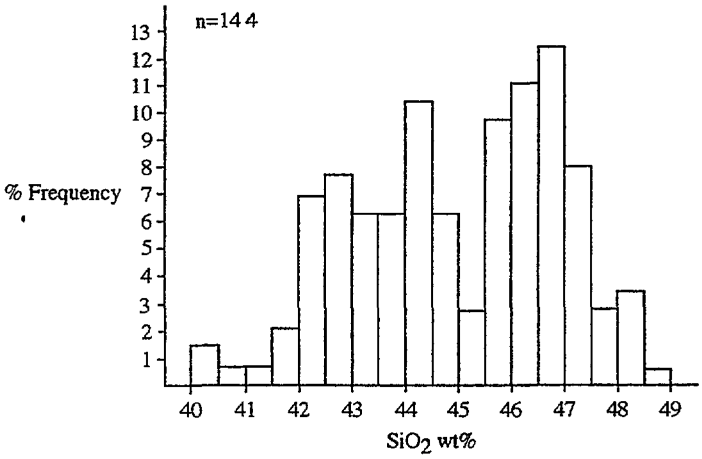

Fig 2. Histogram of % frequency of SiO_2 content of rocks of the Monaro Volcanic Province

(c) Total Na_2O + K_2O varies from 2.5% to 9.06% (Fig 3). Na_2O is more abundant than K_2O. The highest K_2O content is 3.08%.

(d) Most analyses show high Mg:Fe ratios (Fig 4) and also relatively high Ni and Cr.

(e) Rocks with <45% SiO_2 are olivine- and nepheline-normative, while those with >45% SiO_2 are mostly olivine- and hypersthene-normative.

(f) All of the analysed volcanic plugs and other intrusions are nepheline-normative. Some of the flows are also nepheline-normative but none are as undersaturated as the most alkali-rich plugs and most are mildly hypersthene-normative (Fig. 5).

(g) All of the rocks contain olivine and reddish titanaugite with accessory apatite and opaque oxides, and nearly all contain plagioclase. Ferro-magnesian minerals are abundant so that total normative mafic mineral content is mostly >45%. 100An/(An+Ab) is >50, except in a few fractionated nepheline-hawaiite plugs.

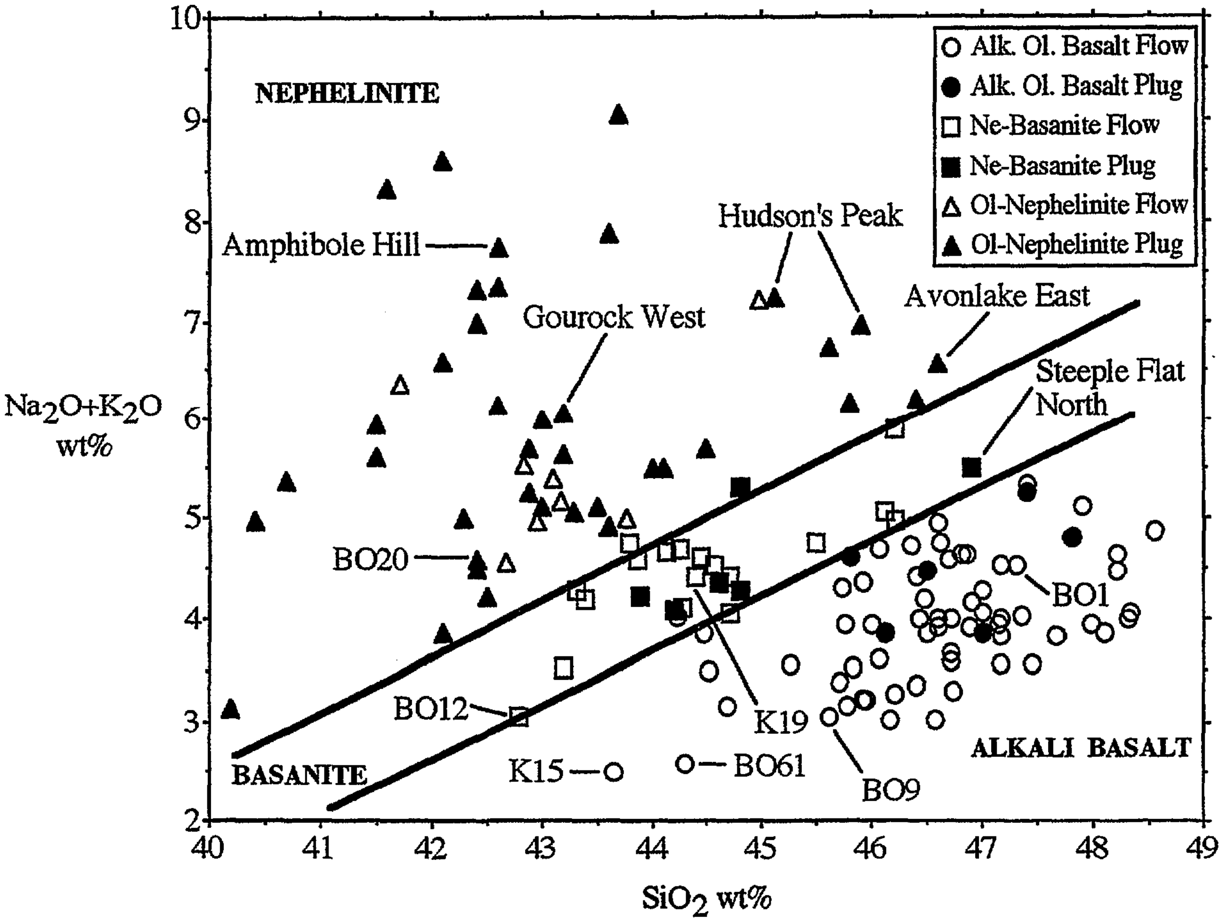

Fig 3. Plot of $Na_2O + K_20$ % vs SiO_2 % for 135 rocks of the Monaro Volcanic Province; showing also rock classification used in this guide, after Kesson (1973)

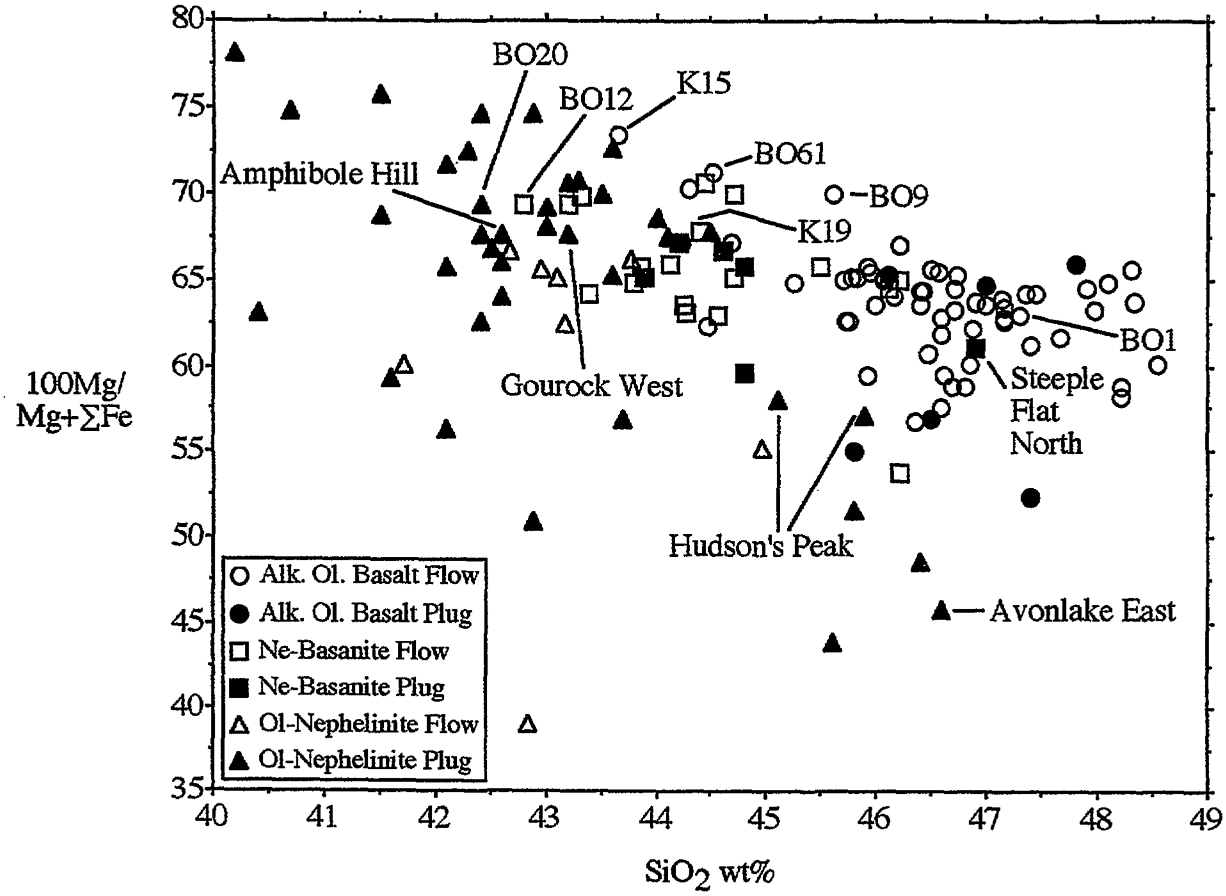

Fig 4. Plot of mg ratio vs SiO_2 % for 135 rocks of the Monaro Volcanic Province

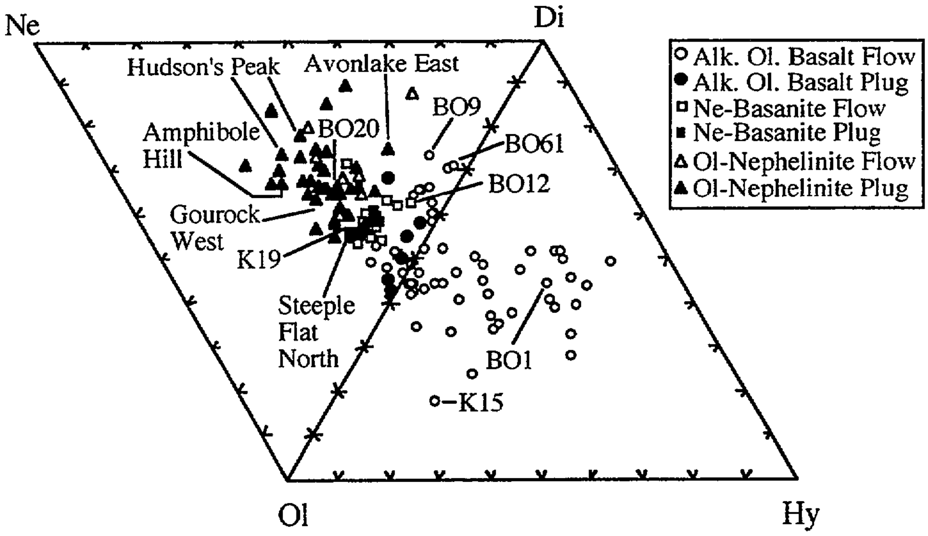

Fig 5. Triangular plots of normative nepheline, olivine, diopside, and hypersthene based on 135 analyses of rocks of the Monaro Volcanic Province. Raw data for FeO% and Fe_2O_3% were used in norm calculations

Nepheline occurs in some of the more undersaturated rocks usually as interstitial anhedral grains in holocrystalline rocks but also as euhedral crystals enclosed in glass in some of the nephelinite plugs. Interstitial analcite and other zeolites also occur in some of the undersaturated rocks and interstitial sanidine is common. The most alkali-rich nephelinites contain very little or no plagioclase.

(h) Megacrysts of pleonaste occur in many of the finer grained volcanic plugs. Corroded megacrysts of kaersutite and minor biotite occur in several of the most alkali-rich volcanic plugs. These rocks also contain minor groundmass biotite. Titanomagnetite megacrysts occur in one of the plugs at "Gourock ".

(i) Xenoliths of mantle spinel lherzolites and crustal rocks, as well as mantle xenocrysts, are common in both the lavas and intrusive rocks. Xenoliths are particularly abundant and large in some of the aphanitic nephelinite intrusives. Small quartz xenocrysts, with narrow pyroxene reaction rims, occur in many of the rocks.

Relationships between intrusions and lava flows

The compositions of rocks from the lava flows and intrusions show some overlap but there are some significant differences in their chemistry. These differences are well illustrated on alkali vs silica and normative plots (Figs 3 and 5). All the known plug rocks are nepheline-normative, which interestingly suggests that we have not yet located or sampled the feeders for the hypersthene-normative alkali basalt flows which make up the bulk of the Province. Extrusive rocks equivalent to the most alkali-rich nephelinites are also not represented in the samples. Feeders for the hypersthene-normative alkali basalt lavas must either be largely covered, or relatively inconspicuous. The latter is likely, as other feeder intrusions have been recognised because of a strong contrast between their composition and that of the surrounding basalt lavas. Lavas (and/or pyroclastics) corresponding in composition to the most alkaline plugs were probably deposited at the top of the volcanic pile and may have been largely stripped off by subsequent erosion.

Major element and mineralogical evidence for the nature of volcanism

The mafic composition of the rocks and the presence in many of xenoliths and xenocrysts of mantle materials indicate that the magmas are mantle-derived. Harker plots of major elements against SiO_2 (e.g. Figs 3, 4) show a wide scatter, showing that the rocks could not have been derived from a single primary magma. Kesson (1973) concluded that the Province was built up from eruptions of primary magmas of alkali basalt, basanite and nephelinite composition, together with differentiates of these magmas. The extra geochemical data collected since then support this conclusion.

Fractionation has in general not gone beyond a stage where mantle xenoliths and xenocrysts are absent or where the Mg/Fe ratio has fallen significantly. Most rocks have a range of $100Mg/(Mg+\Sigma Fe)$ (mg ratio) between a "primitive" 75 and a more fractionated 55. Only 9 rocks have an mg ratio less that 55 (Fig. 4). Probably the most fractionated rock is a nepheline-hawaiite from the Avonlake East plug (Figs 3-6 and Tables 1, 2). This rock is a felsic differentiate of a primary basanite or nephelinite magma, with an mg ratio of 46 and 69.5% normative light minerals including 15.8% normative orthoclase. Rocks at Hudson's Peak and the upper levels of the Bull Mountain lava lake show a felsic fractionation trend which is less pronounced than for the nepheline-hawaiites.

The coarse porphyritic flow rocks with abundant pyroxenes have higher Ca and Mg contents than the other rocks, consistent with a partly cumulate origin for the titanaugite and olivine phenocrysts. They also have a low SiO_2 content, are nepheline-normative and have high mg ratios (see analyses BO61 and BO9, Table 1 and Figs 3-6). We suggest that these coarse-grained rocks are products of rapid eruption of relatively large volumes of magma in which large crystals of pyroxene and olivine had already formed, and that the eruptions essentially emptied their magma chambers. These silica-poor magmas formed laterally-extensive flows and must have been very mobile, despite the presence of some suspended crystals. The coarse pyroxene and olivine crystals were able to settle out and concentrate near the base of the flows before they solidified.

The volcanic rocks can be grouped into at least two and probably three classes on the basis of silica content alone (Fig. 2). The alkali/silica plot (Fig. 3) indicates that further subdivision may be valid. Two clusters are readily apparent and these include most of the basanites and the alkali basalt lavas with >45% of SiO_2, which comprise the bulk of the Province. The rocks which have relatively high SiO_2 and alkalis, and show felsic fractionation trends form another cluster.

Rocks with less than 43.5% SiO_2 show a particularly wide scatter of alkali contents. Primitive rocks (e.g. BO12 and Amphibole Hill) are at, or near, the extremes of this range and most of the others have high mg ratios (Fig. 3). We suggest that the primary magmas for these low-silica rocks are the products of very localised partial melting of small proportions of a heterogeneous mantle. The small proportion of partial melting has produced a wide range of magma compositions from perhaps relatively small percentage variations in mantle composition.

The marked low in the SiO_2 frequency plot at about 45% SiO_2 implies that the mildly hypersthene-normative basalts, the major rock type with >45% SiO_2, should be considered as a distinct suite of rocks in the Province, formed by mantle processes significantly different in style from those which formed the basanite and nephelinite magmas. Francis and Ludden (1989) noted a comparable but more pronounced low in the distribution of SiO_2 contents, at about 44% SiO_2, in mafic volcanic rocks from Fort Selkirk in the Yukon. Their explanation may be applicable to the Monaro Volcanic Province. They concluded that nepheline-normative rocks with less than 44% SiO_2 were formed by partial melting of amphibole-garnet-clinopyroxene veins in lherzolite mantle. Rocks with >44% SiO_2, which included a hypersthene-normative suite, resulted from the partial melting of an olivine-clinopyroxene-orthopyroxene assemblage of the host lherzolite

The wide variety of primary magmas, the restricted fractionation of primary magmas, and the evidence for localised production of at least some of the magmas is consistent with the interpretation that the Province is a lava field. Tertiary central volcanoes in eastern Australia typically show a wide range of felsic differentiates of mafic magmas, presumably developed in large magma chambers below the main volcanic centres (e.g. Johnson, 1989).

Xenolith and trace element evidence for the mantle source of the volcanic rocks

Mantle xenoliths preserved in the finer grained plug rocks are similar to those of the Newer Volcanic Province of Victoria (Johnson, 1989). They are mostly Cr-diopside bearing Cr-spinel lherzolites but also include minor dunites, wehrlites and harzburgites (Roach, 1991; Edgecombe, 1992). Rare amphibole-bearing spinel lherzolite xenoliths, showing textural equilibrium between amphibole and the other minerals, have been found in the Amphibole Hill plug. Other rare xenolith types include phlogopite-bearing Cr-spinel lherzolite xenoliths (Edgecombe, 1992) and clinopyroxenite-veined Cr-spinel lherzolite xenoliths (Roach 1992), both observed in the Amphibole Hill plug. Lower crustal xenoliths consist solely of two-pyroxene, plagioclase granulites with equant, granular textures. Upper crustal xenoliths include quartzite, feldspathic sandstone and vein quartz. The very abundant mantle and crustal xenoliths in some of the plug rocks attest to high ascent rates of their magmas, probably in the order of hours to days (Ozawa, 1983; Bezant, 1985).

Edgecombe (1992) analysed a small number of mantle xenoliths from five plugs (Amphibole Hill, Inverlochie, Rosemount cone sheet, Telegraph Hill, Wangellic Hill) and calculated the source pressure and temperature using the Wells (1977) thermometer and the Sachtleben and Seck (1981) thermobarometer. She concluded that mantle xenoliths in the Province were derived from a depth of about 45 or 50 kilometres (13-16 kb pressure), just below the crust/mantle boundary in eastern Australia.

Trace element enrichment patterns suggest a deeper source for the magmas than the more direct evidence from the xenoliths. Three of the most primitive rocks of the Province exhibit an overall range of 20x to 100x primitive mantle enrichment in incompatible elements (LILE and LREE) and a 2x to 8x primitive mantle enrichment in HREE (Fig. 7).

These trace element signatures, particularly the low enrichment in Ti and Y, suggest that the magmas were derived from an enriched, garnet-bearing lherzolite source (Sun and McDonough, 1985), as proposed by Kesson (1973). The lack of garnet lherzolite xenoliths may be explained by a rheological change in the behaviour of mantle rocks near the spinel/garnet lherzolite boundary above which rocks are brittle and below which they deform plastically (S.Y. O'Reilly, pers. comm.).

Variation in the amounts of Rb, Ba, Sr, and P in the trace element signature from the Province indicate the influence of amphibole, phlogopite and perhaps apatite on the magmas. These phases were probably present as veins in the upper mantle and lower crust, and magmas would have been modified as they ascended through this region. The overall enrichment of each rock is indicative of the degree of partial melting and the amount of dilution of incompatible elements in individual magmas.

McDonough et al. (1985) discussed the sources of eastern Australian magmas and concluded that they originated in the Low Velocity Zone. This has been defined seismically by Finlayson (1982) as between 90 and 190km below eastern Australia. O'Reilly (pers. comm., 1992) concluded that mantle xenolith and geochemical studies of the Southern Highlands Province (north of the Monaro) indicated magma derivation from around 90km depth.

Roach (1991) compared plots of Ni, Cr, V and Sc against the MgO contents for all the Monaro rocks with the partial melting curves of Hart and Allegre (1980), and the olivine and clinopyroxene fractionation curves described in Johnson (1989, pp.

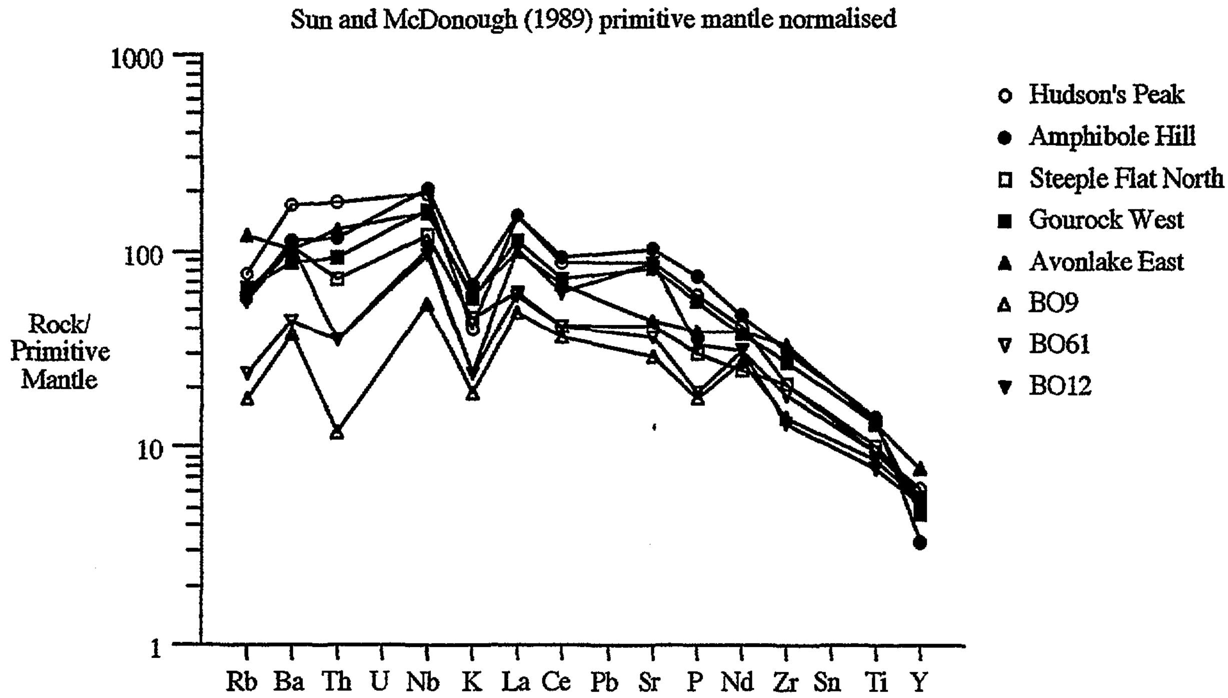

Fig 6. Spider diagram of trace element enrichment factors for selected rocks of the Province, including rocks seen on the excursion

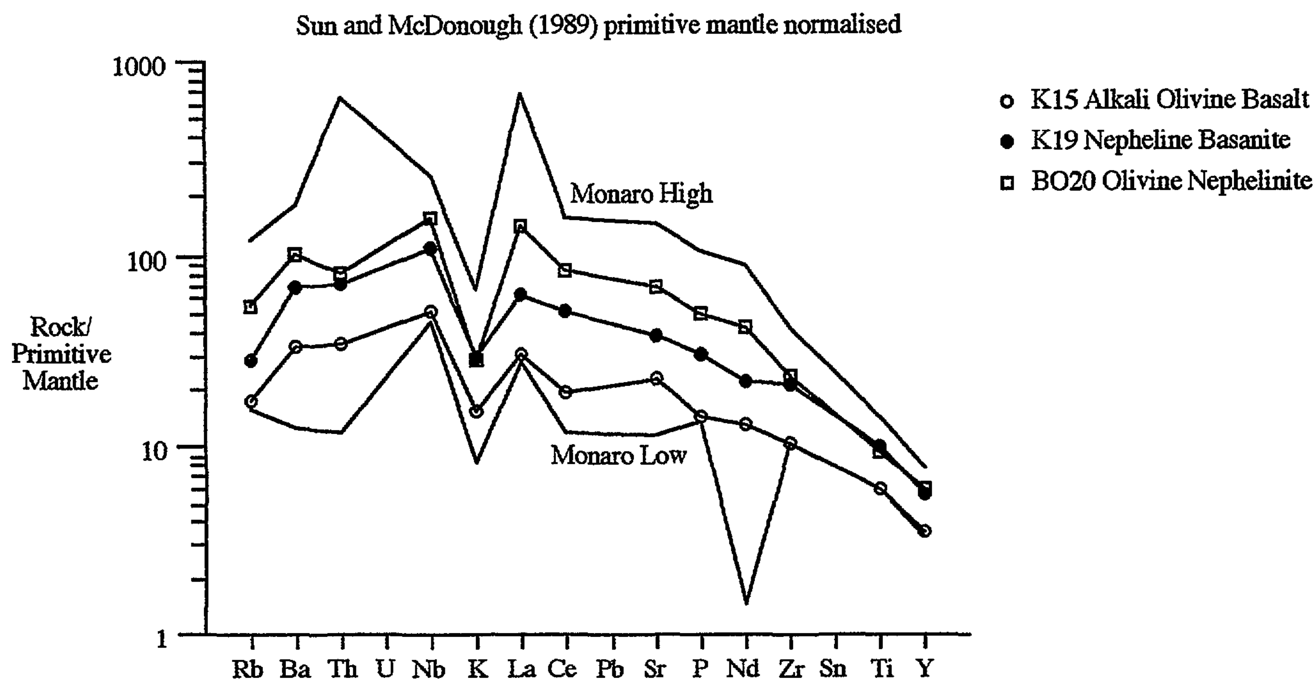

Fig 7. Spider diagram of trace element enrichment factors for samples of nephelinite, basanite, and alkali basalt selected for their primitive geochemical characteristics. Also showing range of enrichment factors for the Province

228-230). These indicated that the primary magmas fractionated equal amounts of olivine and clinopyroxene during ascent. The total amount of olivine and clinopyroxene fractionated was not large as indicated by the relatively unfractionated nature of the Province as a whole. Roach (1991) also concluded that nephelinite melts in the Province were derived after about 5% partial melting of an enriched lherzolitic source, consistent with the predictions of Frey et al (1977) that a 4-6% melt will yield an olivine nephelinite, 5-7% a nepheline basanite and 11-15% an alkali olivine basalt.

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ITINERARY

Canberra to Cooma

The highway from Canberra to Cooma follows the Murrumbidgee Corridor, a fault-controlled valley bounded on the west by the Murrumbidgee fault. The Murrumbidgee River, part of Australia's major river system, lies at the foot of the east-facing fault scarp. Forested high country west of the scarp contains mostly Late Silurian - Early Devonian S-type granitoids of the Murrumbidgee Batholith. The Murrumbidgee Corridor is underlain by Middle and Late Silurian felsic volcanic and sedimentary rocks. High country to the east is mostly in Ordovician and Early Silurian sedimentary rocks with some granitoid plutons.

Further south the highway crosses the Bredbo and Eumaralla Rivers, tributaries of the Murrumbidgee. Alluvial flats of the Eumaralla River are underlain by 80 m of Miocene lacustrine sediments.

The town of Cooma (population 8,000) sits on an anatectic granite and surrounding migmatites of the early Palaeozoic Cooma Metamorphic complex. Basalts of the Monaro Volcanic Province are encountered about 5 km before Cooma. Cooma was the base town for construction of the large Snowy Mountains Hydroelectric and Irrigation Scheme built from the 1950's through to the 1970's. Immigrants from many different countries worked on this major engineering project. Near the park along the main street there is a relief map of the scheme, together with a display of flags from all the nations represented amongst the workers.

Cooma to Hudson's Peak

The highway passes through fertile grasslands of the Monaro Volcanic Province, with a terraced topography formed by differential erosion of fresh and weathered lava flows. Several exposures of reddish intra-flow bauxites can be seen. Areas of timbered country are inliers of Silurian and Ordovician sedimentary bedrock which formed hills in the sub-basalt landscape. Most of the prominent rounded hills on the skyline to the west and south are volcanic plugs. The gravel road ("The Peak" Road on Fig 8) to Hudson's Peak passes some small deflation hollows forming shallow lakes on basalt about 2 km from the highway turnoff (on the left). Trees on the basaltic high country around Hudson's Peak are mostly snow gums (Eucalpytus pauciflora).

Locality 1 (Fig. 8): Hudson's Peak

Hudson's Peak (1234 m) is a nephelinite plug, located on the Great Divide, and is the highest point on the main area of the Monaro Volcanic Province. From here it is possible to get an excellent view of much of the northern part of the Province and the surrounding region.

On the skyline to the west is the main range of the Snowy Mountains, with Mount Kosciusko, Australia's highest peak (2228 m), rising a little above the general plateau level almost due west of Hudson's Peak.

The three prominent, rounded hills to the NNW (7-12 km) are North, Middle, and South Brother Peaks. These are all nephelinite volcanic plugs. The bore hole (Bega BMR No. 7) was collared on the plateau 2.5 km south of South Brother. Bondo Hill, 10 km due north, is also a nephelinite plug.

The high forested country to the east (15 km) is underlain by Early Devonian I-type granitoids of the Bega Batholith, and Silurian and Ordovician metasedimentary rocks. This area is bounded by a west facing scarp which is close to the present eastern margin of the Tertiary volcanic rocks.

To the southeast (26 km) the television mast on Brown Mountain (1241 m) is visible. The surrounding forested plateau is the largest of several outliers of Tertiary volcanic rocks between the main area of the Province and the Great Escarpment further to the east. Thoko Hill (1161 m), an eroded remnant of a lava lake, is the partly forested hill to the right of Brown Mountain.

The nearest large hill to the south-west (4 km) is Jinny Brother Peak and the smaller more distant hill to the left (with trig station) is Bald Hill. These are both nephelinite volcanic plugs. The prominent cone-shaped hill on the distant skyline to the SSW is Mt. Delegate. It is capped by Early Silurian quartz-rich flysch. The forested country about 7 km WSW is an inlier of Late Ordovician and Early Silurian sedimentary rocks.

Hudson's Peak itself consists of a medium-grained and somewhat fractionated olivine nephelinite with titanaugite phenocrysts up to 5 mm. It is coarser grained than most of the plug rocks and lacks xenoliths. Outcrops show an unusual close-spaced joint pattern which produces long bladed blocks with variable plunge. For details of its chemistry, see Figs 3-6 and Tables 1 and 2.

Whole-rock K-Ar dating of 4 samples from Hudson's Peak, gave ages between 38$\pm$1 and 41.1$\pm$1.6 Ma and a basalt lava flow on the flank at 1190m gave an age of 46.1$\pm$0.8 Ma (Wellman and McDougall, 1974b).

Locality 2 (Fig. 8):"The Peak" road 300m east of "The Peak" homestead

The low cutting on the north (right) side of the road exposes about 2 m of bauxite with an irregular upper surface overlain by a younger alkali basalt flow.

The bauxite has a fragmental fabric with small pebble-sized clasts. It also contains rounded sand-sized grains of quartz. X-ray diffraction analysis indicates that gibbsite is the main component, with less abundant goethite.

The overlying basalt has weathered to soft grey and brownish materials, probably rich in smectite clay, containing relatively fresh corestones of vesicular basalt.

Locality 2 to "Gourock"

The highway from "The Peak" turnoff to the entrance to "Gourock" crosses more basalt country, with inter-flow bauxites well exposed in cuttings at the turn-off and elsewhere. Another deflation lake is seen on the east (left) side of the road.

Locality 3 (Fig 8): 100 m west of "Gourock" homestead

South of the track, coarse porphyritic mafic rocks are exposed on a low scarp. These contain about 30% titanaugite crystals and aggregates (up to 1.5 cm) as well as olivine phenocrysts and plagioclase laths (up to 2 mm) in a finer groundmass. The titanaugite crystals stand out on the weathered surface and the olivine is reddish due to weathering. The rocks here belong to one of the extensive layers of coarse, pyroxene-rich rocks which we have interpreted as crystal-bearing lava flows. These flows probably represent major eruptions from a subsurface magma chambers where large pyroxene and olivine crystals had already formed. Rocks BO9 and BO61 (Tables 1 and 2, Figs. 3-6) are similar rocks from other localities in the Province.

About 3-4m above the level of the track there are exposures of a medium-grained mafic rock with fewer and smaller pyroxene phenocrysts. We interpret this rock as part of the same flow, relatively depleted in mafic phenocrysts by crystal settling.

The top of the flow is covered by debris from a low hill immediately to the south. This is a nephelinite plug ("Gourock West") containing mantle xenoliths (up to 2.5 cm) and pleonaste megacrysts. The plug is one of three, about 250m apart and on the same alignment. All three plugs consist of nephelinites but each differs from the other in its detailed chemical composition and xenolith and megacryst content. Geochemistry of the "Gourock West" plug is shown on Tables 1 and 2 and Figs 3-6.

"Gourock" to Nimmitabel

The highway passes through terraced topography developed on lava flows. Eucalypt trees become abundant on the basalt country near Nimmitabel which has a higher rainfall than the open grasslands further west.

Lunch will be served at Nimmitabel. This small town is the highest in the Monaro region (1080 m). It is a local centre for the grazing industry and, until recently, had

	Hudson's Peak	Amphibole Hill	Steeple Flat North	Gourock West	Avonlake East	BO9	BO61	BO12	K15	K19	BO20	BO1
SiO_2	45.90	42.60	46.90	43.20	46.60	45.60	44.30	42.80	43.65	44.39	42.30	47.30
TiO_2	2.03	3.05	2.20	2.82	2.86	1.85	2.08	1.70	1.31	2.19	2.07	1.88
Al_2O_3	16.93	13.62	15.82	13.88	15.82	11.50	12.20	12.90	10.02	14.36	12.70	15.50
Fe_2O_3	2.20	2.93	1.70	2.53	3.49	2.60	2.70	3.70	3.87	2.33	4.10	3.70
FeO	6.80	7.60	8.50	8.10	6.80	7.70	7.00	7.00	9.96	8.24	6.70	6.00
MnO	0.17	0.16	0.17	0.17	0.18	0.14	0.13	0.14	0.22	0.20	0.16	0.13
MgO	5.80	10.47	8.11	10.85	3.96	11.60	10.90	11.00	18.19	10.99	12.60	7.30
CaO	9.79	7.92	9.00	9.34	8.18	13.40	13.30	11.80	6.19	9.92	10.40	8.83
Na_2O	4.45	4.66	3.45	3.53	3.89	2.20	1.50	2.00	1.78	3.09	3.70	2.90
K_2O	2.50	3.09	2.05	2.55	2.67	0.86	1.08	1.06	0.71	1.34	1.32	1.63
P_2O_5	1.28	1.59	0.65	1.19	0.84	0.38	0.41	0.72	0.32	0.67	1.10	0.68
H_2O+	1.44	2.06	1.30	1.66	3.90	1.00	1.70	2.90	1.92	0.65	1.40	1.90
H_2O-	0.23	0.20	0.21	0.32	0.80	0.30	1.10	0.50	0.82	0.79	0.20	0.90
CO_2	0.21	0.08	0.07	0.06	0.03	0.20	0.20	0.10	0.21	0.01	0.10	0.20
Rest						0.51	0.51	0.69	0.26	0.33	0.70	0.51
Total	99.73	100.03	100.13	100.20	100.02	99.84	99.11	99.01	99.43	99.50	99.55	99.36
mg ratio	57.03	67.67	60.95	67.68	45.76	69.99	70.29	69.36	73.49	67.84	72.44	62.94
Or	14.76	18.24	12.10	15.05	15.76	5.08	6.37	6.26	4.19	7.91	7.79	9.62
Ab	14.34	4.90	18.34	5.50	24.86	9.86	9.61	11.07	15.05	13.03	7.51	24.52
An	18.82	7.12	21.61	14.49	17.81	18.95	23.35	23.07	17.24	21.34	14.14	24.44
Ne	12.62	18.69	5.87	13.19	4.35	4.74	1.66	3.16	0.00	7.1	12.88	0.00
Mt	3.20	4.26	2.47	3.68	5.07	3.78	3.92	5.38	5.62	3.38	5.96	5.38
Il	3.86	5.80	4.19	5.36	5.44	3.52	3.96	3.23	2.49	4.17	3.94	3.58
Ap	3.03	3.76	1.54	2.82	1.99	0.90	0.97	1.70	0.76	1.59	2.60	1.61
Di	17.30	17.33	15.21	19.22	13.98	35.97	31.8	24.47	9.06	18.82	23.93	11.87
Hy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.03	0.00	0.00	7.71
Ol	9.98	17.54	17.15	18.78	5.99	14.91	13.83	16.38	31.61	20.29	18.32	7.04
Diff. Index	41.72	41.84	36.31	33.75	44.97	19.67	17.65	20.49	19.24	28.04	28.19	34.14

Table 1 *Major elements, mg ratios, norms, and Differentation Indices of selected rocks of the Monaro Volcanic Province. Norms are calculated using raw data for FeO% and Fe_2O_3%.*

	Hudson's Peak	Amphibole Hill	Steeple Flat North	Gourock West	Avonlake East	BO9	BO61	BO12	K15	K19	BO20	BO1
Ba	1200	800	730	600	720	260	307	750	236	479	714	609
Rb	48	36	38	41	76	11	15	35	11	18	35	35
Sr	1850	2150	870	1700	930	605	759	1858	476	822	1475	956
Pb	12	8	7	6	9	2	5	3	5	7	2	4
Th	15	10	6	8	11	1	3	3	3	6	7	4
U	3	3	1	2	2	67	<1	1			<1	1
Zr	230	340	230	300	360	155	203	146	117	237	267	218
Nb	140	150	87	115	110	38	69	72	37	77	110	81
Y	28	15	26	21	36	25	26	24	16	26	27	28
La	103	103	42	77	69	33	41	71	21	43	96	68
Ce	154	164	74	126	120	63	73	106	34	93	151	118
Nd	55	64	33	50	52	36	41	42	18	30	58	49
Sc	16	13	19	17	15	51	43	28			21	24
V	208	183	206	193	218	291	273	171	105	169	181	185
Cr	61	256	110	285	46	513	511	303	315	280	403	90
Mn	1318	1240	1318	1318	1395	1385	1205	1426			1431	1326
Co	56	84	57	72	36	47	51	47			49	32
Ni	58	251	137	244	29	199	178	285	490	221	408	105
Cu	68	73	79	68	91	43	55	73	53	50	65	43
Zn	79	105	93	94	110	72	84	89	108	82	87	94
Sn	10	4	10	8	6	4	4	<4			<4	<4
Hf	6	10	6	8	10	3	<3	<3			<3	<3
Ga	11	21	30	17	24	17	16	17	13	14	19	21
As	20	13	7	15	7	4	<4	<4			<4	<4
Cs	2	0	1	0	2	5	<5	<5			<5	<5

Table 2 *Trace element analyses of selected rocks from the Monaro Volcanic Province*

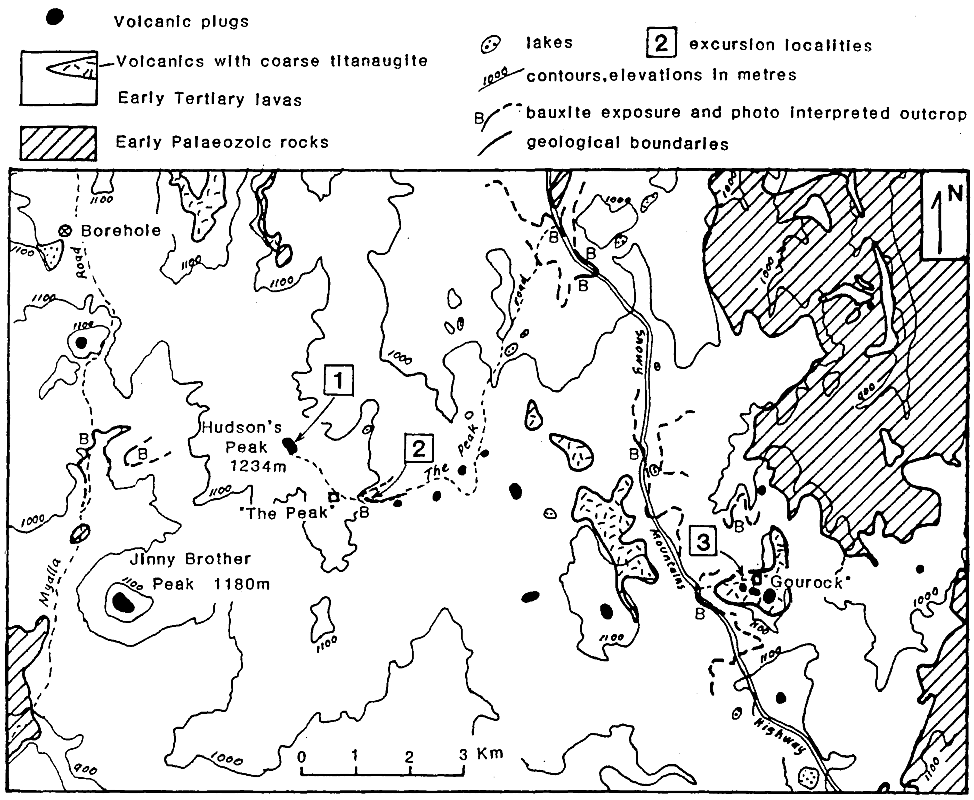

Fig 8. Geological sketch map of the Hudson's Peak and Gourock area between Cooma and Nimmitabel

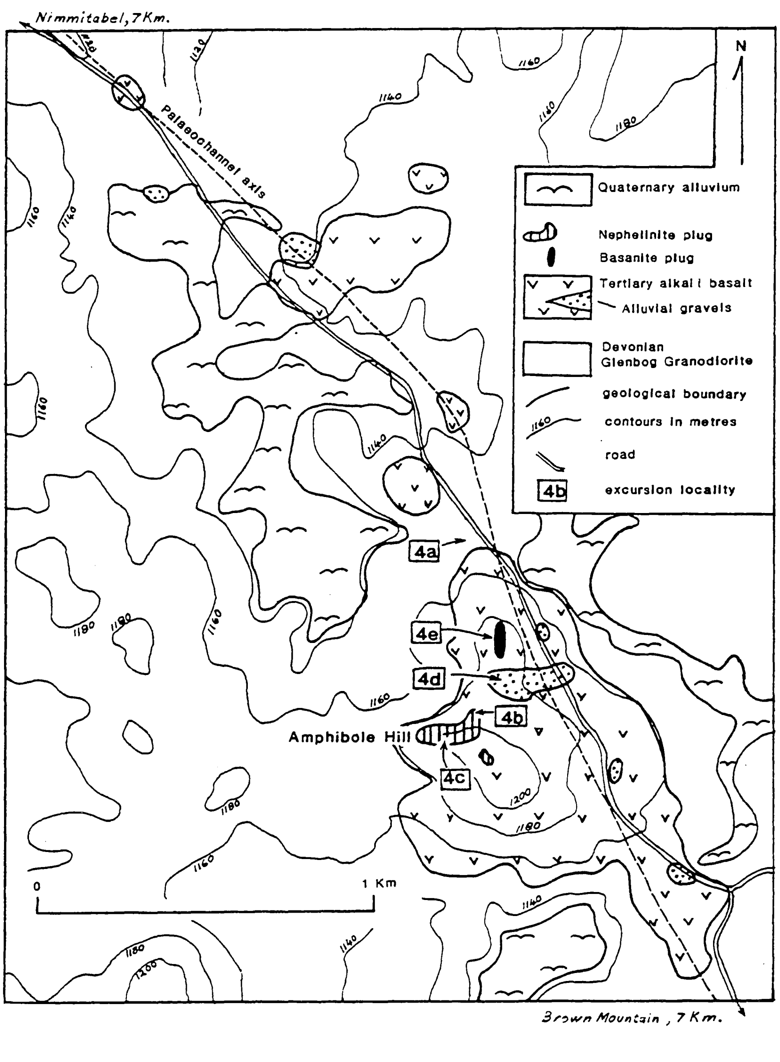

Fig 9. Geological map of the "Amphibole Hill" area, 8km ESE of Nimmitabel, locality 4

a sawmill cutting timber from the forest country to the east. The town has also been used as a movie set ("The Overlanders") depicting a typical, small Australian country town in the early 1940's.

Nimmitabel is built on porphyritic, hypersthene-normative alkali basalt which contains scattered phenocrysts of titanaugite (up to 5mm) and olivine and plagioclase (2-3mm). (See Sample BO1, Tables 1 and 2 and Figs 3-6). The stone tower on the western side of the town is built of this rock. It was originally constructed as a windmill for grinding grain.

Nimmitabel to "Amphibole Hill"

The road east from Nimmitabel climbs a slope on bedrock granitoids and metasediments which was onlapped by the Early Tertiary lava flows. Mount Emerald, on the right about 5 km from the town, is an elevated outlier of lava flows.

Locality 4 (Fig 9): "Amphibole Hill", 9 km ESE of Nimmitabel

NB: This locality is on private property with the kind permission of the landowner Mr Ingram. He has requested that the group stay together, and has asked us to inform participants that they enter at their own risk.

"Amphibole Hill" is a plug of aphanitic nephelinite intruding an outlier of alkali basalt flows with interbeds of quartz granule and pebble gravels. A smaller plug of fractionated basanite intrudes the same outlier. The basalt and sediment outlier is one of several which occur along a straight, probably fracture-controlled, sub-basalt valley which can be mapped for 10 km north-west of "Amphibole Hill". The base of the outliers is lower than bedrock granodiorite hills on either side of the palaeo-valley and their altitude decreases to the NW.

Locality 4a The granitoid tors and outcrops are part of the Glenbog Granodiorite. This is an Early Devonian I-type hornblende-biotite granodiorite, one of many plutons in the Bega Batholith which occupies much of the country east of Nimmitabel. Mafic enclaves which are relics of the igneous protolith of the granodiorite are common. Alkali basalt outcrops immediately to the SE are close to the axis of the palaeo-valley.

Localities 4b and 4c are on the "Amphibole Hill" plug (see Tables 1 and 2 and Figs 3-6 for geochemistry). At 4b near the NE margin, kaersutite megacrysts (up to 3 cm) are very abundant. At the top of the hill mantle xenoliths (up to 10 cm) and kaersutite megacrysts are both abundant. The mantle xenoliths include spinel lherzolites, harzburgite, olivine websterite and orthopyroxenites (Edgecombe, 1992). The rock here has gently-plunging, thin columnar joints and steep-dipping flow banding (common in the aphanitic nephelinites). K-Ar dating of the kaersutite megacrysts gave an age of 47.7$\pm$3 Ma.

Locality 4d Exposures here are of quartz granule and pebble gravels which have been converted to a silcrete. Silcretes are quartz-rich rocks formed by near-surface processes and are common in Australia.

Locality 4e This small steep-sided hill is formed by an elongated plug or dyke of porphyritic basanite with abundant plagioclase phenocrysts (up to 3 mm) and some titanaugite phenocrysts (up to 8 mm). The basanite is somewhat fractionated and lacks xenoliths. It is shown as "Steeple Flat North" on Tables 1 and 2 and Figs 3-6.

"Amphibole Hill" to Locality 5

Our route continues south for 13 km through eucalypt forest on granitic rocks and then basalts of the Brown Mountain outlier. On reaching the Snowy Mountains Highway we turn west and travel for 5 km through forested granite country before returning to the Monaro Highway at the Bombala turnoff. From here we travel south along the Monaro Highway for 25 km to the village of Bibbenluke. Just beyond Bibbenluke we turn left down a gravel road, head east for 8 km to the Cathcart-Bombala road, then SW for 6 km to locality 5.

Most of the southward journey is through grassland and open eucalypt forest on basalt flows. Two kilometres SE of the turnoff from the Snowy Mountains Highway, road cuttings expose cross sections of steep-sided, basalt-filled valleys in bedrock granite. Further south, the lava lake remnant of Thoko Hill is prominent to the east (left hand side). Just past the small settlement of Ando there is a lake on the west (right) side of the road. This is in a small deflation hollow with a low mound of wind-blown sediment on its eastern margin. Just before Bibbenluke there is an inlier of flat-lying Late Devonian sandstone and conglomerate on the west (right) side of the road. Some larger lakes are seen 5 km SE of Bibbenluke.

Locality 5 (Fig 10): Cutting along Cathcart-Bombala road, 7 km SW of Cathcart

The cutting shows products of the interaction between two subaqueous basanite lava flows and lacustrine clays. The south face exposes the most complete section. Fig 10 shows the upper half of this section. About 10m of pillow lavas, at the eastern end, are overlain by a unit (about 22 m thick) which consists mainly of unbedded soft yellowish material containing blocks of white clay up to 0.5 m and pillows of aphanitic and glassy basanite. The soft material is a mixture of fragments of white clay and weathered volcanic glass and is interpreted as a hyaloclastite/hyalotuff produced by explosive interaction of fluid lava, water and wet lake sediment. Interestingly, this material contains significant amounts of potassium feldspar as well as halloysite. The larger blocks of clay have a hardened, baked rim, which retains the imprint of the surrounding hyaloclastite, and some blocks contain well preserved moulds of plant fossils. These features suggest that lumps of lake sediment were chaotically incorporated into the hyaloclastite while it was still hot.

Overlying the hyaloclastite is a bed of laminated clay about 0.5m thick, which dips 5^{0} west. This in turn is overlain by about 13 m of basanite pillow lava which grades upwards and westward into another weathered hyaloclastite unit (about 7m thick) containing abundant isolated basanite pillows. Pillows in the pillow lava are 1-5 m across and show radial and concentric jointing. Tongues of the underlying clay have been squeezed up between pillows at the base of the flow and interstices between pillows are filled with soft yellowish material, probably weathered hyaloclastite. Narrow zones of alteration which extend well up into the basanite may have formed along steam vents.

Sample BO12 (Figs. 3-6 and Tables 1 and 2) is from a small basanite pillow within the lower hyaloclastite. Basanite from near the outside of the pillow consists of small euhedra of olivine (0.1-1mm) and thin euhedral augite prisms (0.1-0.3mm) in about 60% brown glass containing skeletal opaques. The overlying pillow lava has almost identical chemical composition and a sample from a pillow margin has similar petrography. A sample from the centre of a 3m pillow has less glass; the crystals are a little larger, and plagioclase laths are present.

The original lake at this site probably formed when lava flows dammed a southern tributary of the main south-easterly flowing palaeo-drainage.

Return journey

Between Locality 5 and Bombala the road passes through the Coolumbooka Granodiorite, an early Palaeozoic I-type pluton. This is overlain unconformably by gently-dipping Late Devonian fluvial sediments on the eastern outskirts of Bombala. Bombala is a typical Australian country town with three hotels, a licenced club, hospital, primary school and high school. The population is supported chiefly by the grazing and forestry industries. Bombala was one of the sites considered for construction of Australia's national capital. The town is built mostly on a highly deformed Late Ordovician flysch sequence, exposed in road cuttings west of the Bombala River. The return journey to Canberra is northward through Bibbenluke, Nimmitabel and Cooma.

Dinner - we hope we get you there in time.

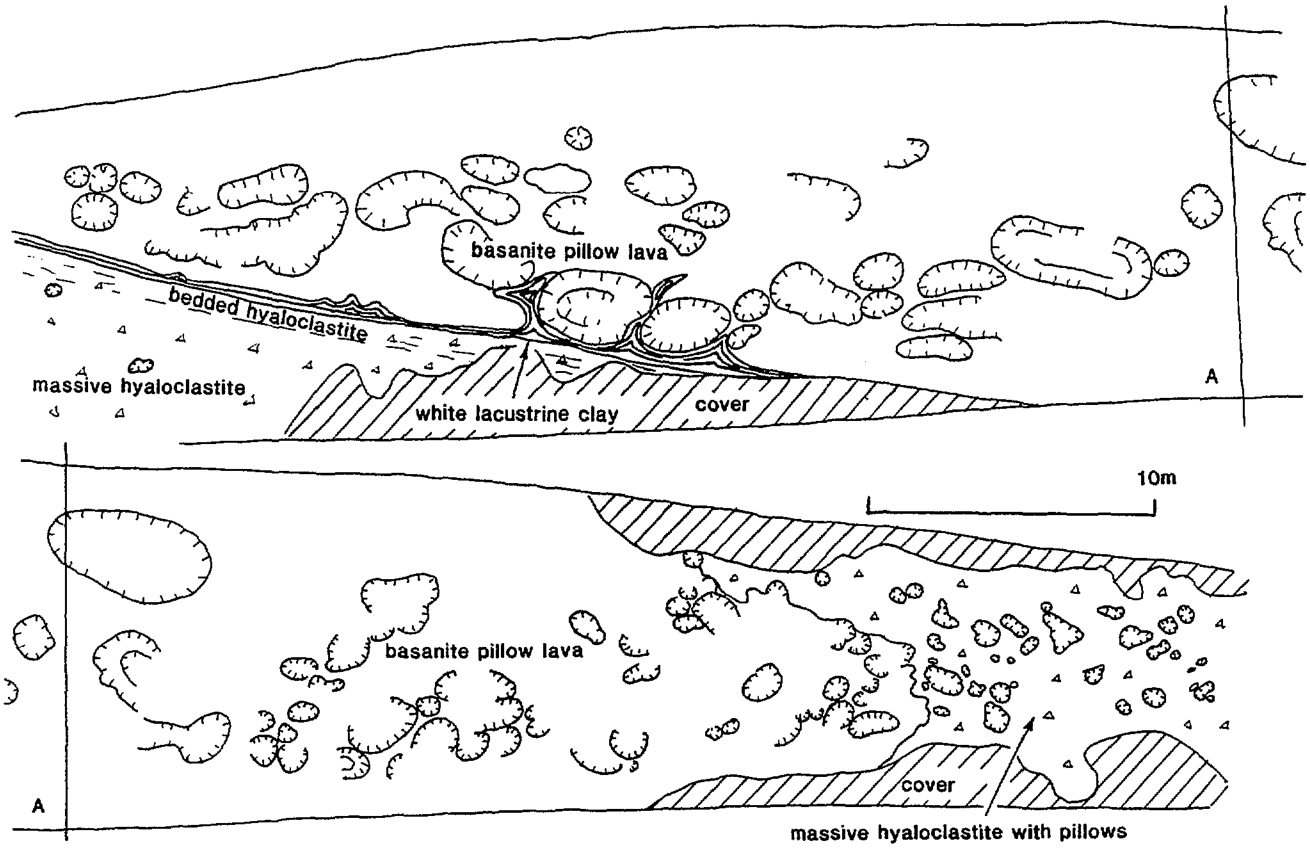

Fig 10. Sketch of the western end of cutting on the south side of the Cathcart-Bombala road 2.2km WSW of Pipeclay Creek, locality 5.