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Evaluation of Potential Sapphire Source Rocks within the Catchments of Kings Plains Creek and Swan Brook, near Inverell, New South Wales

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ABSTRACT. Basaltic and volcaniclastic rocks in the East Central Volcanic Province, New South Wales, are potential sources of the alluvial sapphires being mined in the New England Gem Fields. The associated drainage catchment areas generally contain sapphire, but only four major catchments contain rich deposits: Frazers, Kings Plains, Reddestone and Marowan. These catchments are thus the most likely targets for sapphire source rocks. The Mount Buckley basalt flows and intrusives divide Kings Plains Creek and Swan Brook catchment areas for alluvial sapphire. Whole-rock analyses show mostly alkaline to strongly alkaline types becoming more undersaturated with time. The top flows are predominantly basanite and nepheline hawaiites whilst the lowest are predominantly alkali olivine basalts and hawaiites. Ultramafic xenoliths in several flows suggest rapid movement from upper mantle levels. Marked variation in major and trace elements between groups of flows suggests that flows were intercalated from different levels. Variation diagrams do not distinguish the 32 to 39 Ma sapphire-associated eastern Central Province basalts from the 19 to 23 Ma sapphire-barren western Central Province alkali-basalts. The Central Province compositional fields also overlap the volcanic provinces in north-eastern Australia, known to contain sapphire (Atherton, McBride and Chudleigh), as well as those believed to be barren. These Australian compositional fields also overlap the corundum-bearing and corundum-less fields for the south-east Asian volcanic provinces. Major and minor element chemistry of basaltic rocks is not a useful exploration tool for discriminating sapphire-bearing from sapphire-barren volcanic provinces, nor for recognising potentially high-grade areas within a sapphire-bearing province. This suggests that basaltic magmas are not the sapphire parent rocks, but only one of their potential carriers.

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Corundum-bearing gem fields have long been associated with areas of basaltic volcanism (Dunstan, 1902). Such gem fields include New England (sapphire) and Anakie (the world's best green and golden yellow sapphire) in Australia (MacNevin, 1972; Broughton, 1979; Coenraads, 1990), and others in south-east Asia, China, Colombia and Africa (see Coenraads, 1992 for detailed list). Sapphires may be found in matrix in basic dykes of alkaline affinity at Yogo Gulch near Utica, Montana, USA (Brownlow & Komorowski, 1988), and at Loch Roag on the Isle of Lewis, Scotland (Jackson, 1984).

Basalts associated with corundum-bearing gemfields are generally nepheline normative and highly alkaline types, showing low SiO_2 and high MgO & TiO_2 (Vichit *et al.*, 1978; Barr & MacDonald, 1981). Coenraads *et al.* (1990) have shown, by means of dating zircon inclusions in New England sapphires, that corundum formation there is probably the same age as the associated basalts. Zircon formation dates in other provinces (Sutherland & Kinny, 1990) suggest that corundum formation may also be considerably older.

Although sapphires are found, in varying quantity and quality, in streams and rivers draining many Cenozoic-Mesozoic "lava field" provinces in eastern Australia, (Spencer, 1983), there has only been economic recovery from two provinces, the Central Province in northern New South Wales (the New England field) and the Hoy Province in central Queensland (the Anakie field).

In recent years, the New England field has contributed over 50% of Australia's sapphire production which, although not well documented, probably exceeds 5 million carats annually (T.J. & P.V. Nunan Pty Ltd, unpublished data, 1989).

Volcanism in the Central Province

The Central Province, in north-eastern New South Wales (Fig.1), is one of a number of Mesozoic-Cenozoic intraplate volcanic provinces which form a discontinuous belt stretching over a distance of 4400 kilometres and up to 300 kilometres wide, within or adjacent to the eastern Australian highlands (Johnson, 1989).

The Central Volcanic Province, comprising Tertiary basaltic volcanics, intrusives and minor sediments, locally overlies and intrudes Devonian to Triassic volcanics, metasediments and plutonics of the Woolomin-Texas Block of the New England Fold Belt (Leitch, 1974). The basaltic rocks yield potassium-argon ages of 19 to 39 Ma (see Coenraads *et al.*, 1990, Table 1; Appendix II, sample B14).

The lavas predominantly include alkali olivine basalts, basanites, hawaiites and nepheline hawaiites (Wilkinson, 1962; Wilkinson, 1966; Binns, 1969; Binns *et al.*, 1970; Duggan, 1972; Wilkinson, 1973; Wilkinson & Duggan, 1973; Street, 1974; McKay, 1975; McQueen, 1975; Barron, 1987; W.J. Stroud, J.K. Karaolis & R.R. Coenraads, unpublished data), and give a database of 114 analyses. Tholeiites occur near Inverell (Duggan, 1972; Wilkinson & Duggan, 1973). and various volcaniclastic rocks have been reported (Lishmund & Oakes, 1983; Sutherland, 1985; Temby, 1986; Barron, 1987). The latter occur extensively in the Inverell-Glen Innes region, usually situated at or near the base of the volcanic pile (Brown & Pecover, 1986a,b; Brown, 1987; Pecover, 1987; Pecover & Coenraads, 1989), and some contain sapphire (Pecover & Coenraads, 1989).

Based on age, structural and drainage data, the Central Province shows at least two distinct periods of volcanic activity – one at 32 to 39 Ma and the other at 19 to 23 Ma (Coenraads, 1990), and based on zircon age data (Sutherland *et al.*, 1991) there may be at least five periods of volcanism. The older episodes forming the eastern portion of the Central Province are sapphire-bearing whereas the youngest, partly tholeiitic, western episode is essentially barren.

Coenraads (1990) summarises the geological and geomorphic evolution of the Central Volcanic Province as follows.

i) Pre-volcanic doming, and/or uplift along the Great Divide altered the pre-volcanic topographic surface producing high ground and radial drainage centred on the East Central Province. This was accompanied by faulting and the opening of deeply penetrating north-north-west trending fractures sub-parallel to the pre-existing fabric of the New England Fold Belt.

ii) Injection of breccias and explosive eruption of pyroclastic material took place prior to 38 Ma, forming a blanket of volcanic debris, (some sapphire-bearing), on the pre-basaltic topography.

iii) Explosive volcanic eruption continued, as well as basalt extrusion, with a general decrease in the amount of explosive activity with time. Early basaltic lavas flowed down valley systems and may be found directly on basement rocks in places.

iv) Major effusive basaltic eruptions took place along the fractures at about 39 to 32 Ma, producing a "lava field" with an overall south-south-east/north-north-west elongation and a shield centred on Maybole.

v) Erosion and reworking, particularly of the less resistant volcaniclastic rocks, took place over some 10 million years forming alluvial concentrations of sapphire and zircon, and also diamonds (from local sources).

vi) The next phase of volcanism, also controlled by south-south-east/north-north-west trending planes of weakness, was further west. Basaltic eruptions grading from tholeiitic to alkaline formed the West Central Province and some volcanics south and west of Armidale between 23 to 19 Ma. The basalts covered the Tertiary alluvium, forming deep leads. East of the East Central Province these Tertiary alluvials have been removed due to the westward migration of the Great Escarpment and the lack of a protective basalt cap. Pockets remain however to the north-west, west and south.

vii) The growth of the West Central Province deflected the west and north-westerly flowing drainage system radiating from the Maybole high and developed a radial drainage pattern centered on the Delungra-Mount Russell areas.

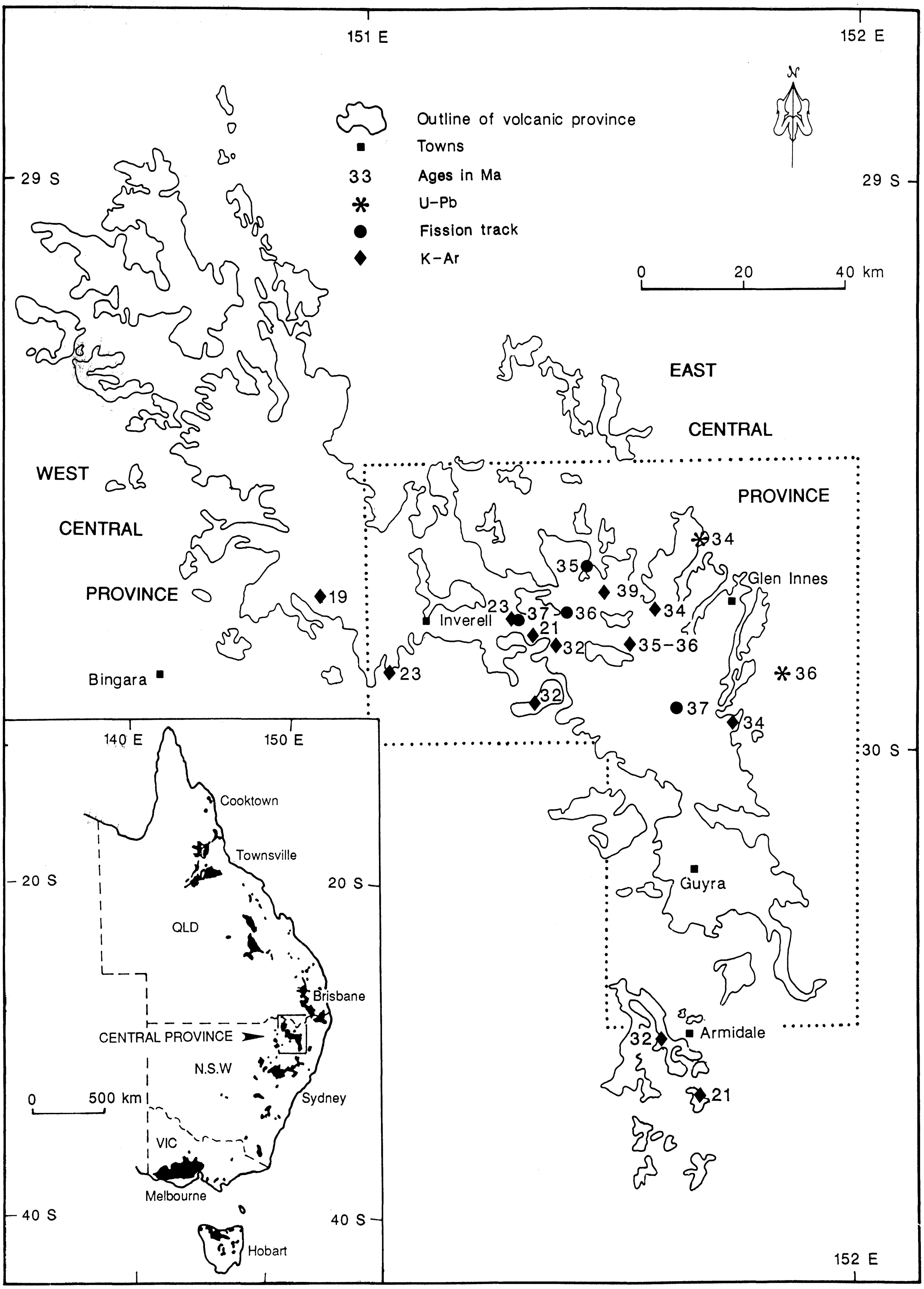

Fig.1. Location of the Central Volcanic Province in north-eastern New South Wales. The province comprises an older sapphire-bearing East Central Province and a sapphire-barren West Central Province. The inset shows Mesozoic-Cenozoic volcanic provinces which form a discontinuous band within or adjacent to the Eastern Australian Highlands. The portion of the Central Province outlined is enlarged in Figure 2.

viii) Since the Tertiary there has been only minor westward migration of the Great Divide (Coenraads & Ollier, 1992). However headward erosion of the radial streams of the Central Province volcanic high has created some classic captures. Retreat, possibly of the order of five kilometres, along some of the streams has cut into and/or topographically inverted basalt filled palaeodrainage.

Aim

This contribution aims to:

1. Differentiate the Central Province into catchment areas along drainage divides or interfluves.
2. Classify the catchments, based on the watershed analysis and drainages from which sapphires have been recovered, as economic (worthy of further exploration), or non-economic. This allows definition of exploration targets, for both alluvial deposits and their potential source rocks.
3. Evaluate potential sapphire source rocks within one of the defined economic areas. Major element and trace element data, together with field data, will be used to test for differences between sapphire-bearing and sapphire-barren parts of the Central Province.
4. Compare lava compositions of the Central Province with those of other sapphire and non-sapphire bearing volcanic provinces in north-eastern Australia and south-east Asia.

Method

1. Watershed analysis of the Central Province. The watershed analysis was carried out at the 1:100,000 scale covering the Inverell, Glen Innes and Guyra sheets. Lines following the highest topographic points or water divides were drawn on the 1:100,000 topographic sheets dividing them into catchment areas shown in Figure 2. Each catchment is named after the principal creek or river flowing in it. Material cannot be moved across a water divide by the normal process of erosion; it can only move within its watershed downslope from its original location. Conversely, the source rocks for a sapphire deposit located within a particular catchment must be, or have been, located upslope within that catchment area.

In some areas source rocks may no longer exist in a catchment area. At a Public Fossicking Area, formerly a mining area, (grid reference GR:630188, Glen Innes 1:25,000 sheet), sapphires and zircons occur in alluvium trapped in cracks and crevasses in Permian granodiorite whilst former basaltic and/or volcaniclastic rocks have been completely eroded.

The watershed analysis was used to define distinct catchment areas which could then be superimposed on maps showing economic sapphire deposits (Fig.2).

2. Definition of specific catchment areas for sapphire exploration. Although sapphire is ubiquitous in almost all East Central Province drainages, only some contain mineable to very rich deposits (MacNevin, 1977; T.J. Nunan & J. McPhee personal communication, 1988). Using this knowledge, drainages with significant sapphires were tabulated by Coenraads & Lawrence (1989) and the extent of the catchments of these economic deposits is presented in Figure 2.

Four catchment areas within the Central Province are classed as economic, and worthy of greater exploration for alluvial deposits and for their potential source rocks, i.e. the Frazers, Kings Plains, Reddestone and Marowan catchments.

The geology and setting of the alluvial sapphire deposits, in particular the important Kings Plains Creek and Reddestone Creek deposits currently held by T.J. & P.V. Nunan (Great Northern Mining), are discussed by Coenraads (1990) and Pecover (1992).

3. Source rock evaluation. Within the four defined catchment areas, outcrops of basalt and volcaniclastic rocks have been mapped and compiled at the 1:25,000 and 1:100,000 scales by Stroud (1989), Willis (1989) and Brownlow (1989).

The basalts appear to have flowed down and filled palaeovalleys, the axes of which have been mapped by Coenraads (1990).

The volcaniclastic rocks are typically red-brown in colour with numerous angular fragments of basement rocks or basalt and are highly altered to clay. They often appear between basalt flows and the underlying basement and probably result from initial explosive volcanism from feeder dykes, such as at Braemar (Pecover & Coenraads, 1989). The volcaniclastic rocks appear to have been quite fluid precursors to the basalt flows as dewatering structures may be observed in directly overlying flows.

Whole-rock chemistry of the volcaniclastic rocks, as potential sapphire source indicators in the economic catchments, is not considered useful because all observed volcaniclastic rocks are weathered to clays. Additional complications include; unknown percentage contamination by country rocks during explosive implacement; unknown original lava type; and unknown amount of reworking. These rocks are discussed by Pecover & Coenraads (1989), chemical analyses and an attempt to unravel their origin is presented by Barron (1987), and their residual heavy minerals are described by Coenraads (1990).

The area chosen for detailed investigation (Figs 2, 3) includes the water-divide between Kings Plains Creek, to the north, and Swan Brook, to the south, as both systems are mined for alluvial sapphires. Mount Buckley, the highest point along the divide, is a logical place for a representative cross section of Central Province volcanic rocks, being likely to contain possible sapphire source rocks and exposing the thickest vertical section.

The countryside is smooth and rolling with the grassed hills being used primarily for grazing. Outcrop is restricted to isolated areas and the determination of continuity between exposures is difficult. The absence of tall vegetation cover, however, permits observation of subtle breaks in slope both on air photo and on the ground. Each change in gradient was assumed to represent a contact between flow units and upon inspection, the break in slope was represented as a small cliff or ungrassed outcrop from which a sample could be taken. The grassed top of the underlying flow was then followed down hill to the next break in slope where another sample could be taken. Thicknesses and dips of individual flows could not be determined, although the appearance (grainsize, vesicles, xenoliths, phenocrysts etc.) of the hand specimen was often distinctive between sample sites (see Appendix II).

Compared with the ideal of using a vertical drill hole, the above technique is poor and considering the influences of pre-volcanic topography, it is possible that a flow may be resampled at a lower level. These possibilities must be borne in mind when interpreting the data.

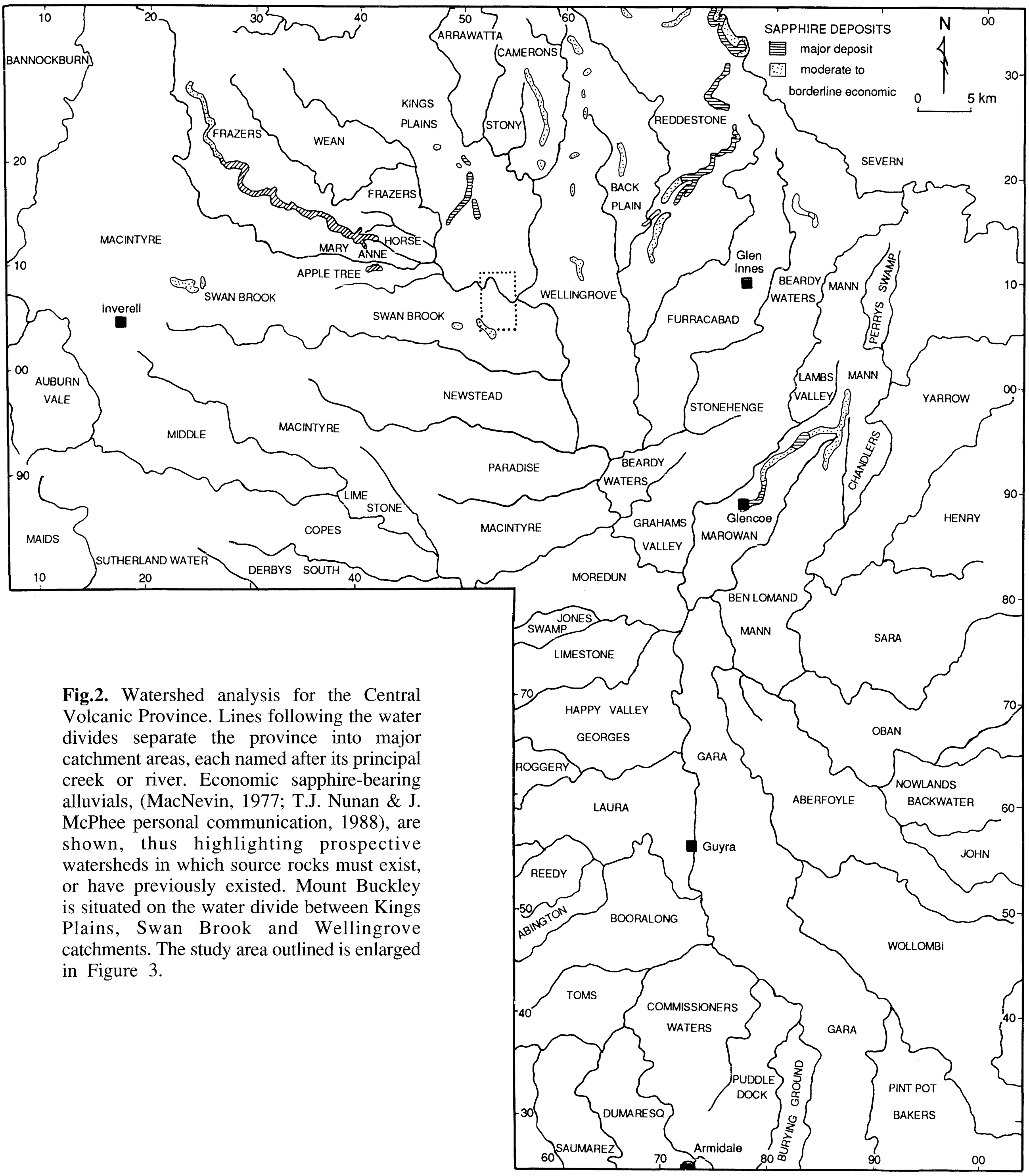

Fig.2. Watershed analysis for the Central Volcanic Province. Lines following the water divides separate the province into major catchment areas, each named after its principal creek or river. Economic sapphire-bearing alluvials, (MacNevin, 1977; T.J. Nunan & J. McPhee personal communication, 1988), are shown, thus highlighting prospective watersheds in which source rocks must exist, or have previously existed. Mount Buckley is situated on the water divide between Kings Plains, Swan Brook and Wellingrove catchments. The study area outlined is enlarged in Figure 3.

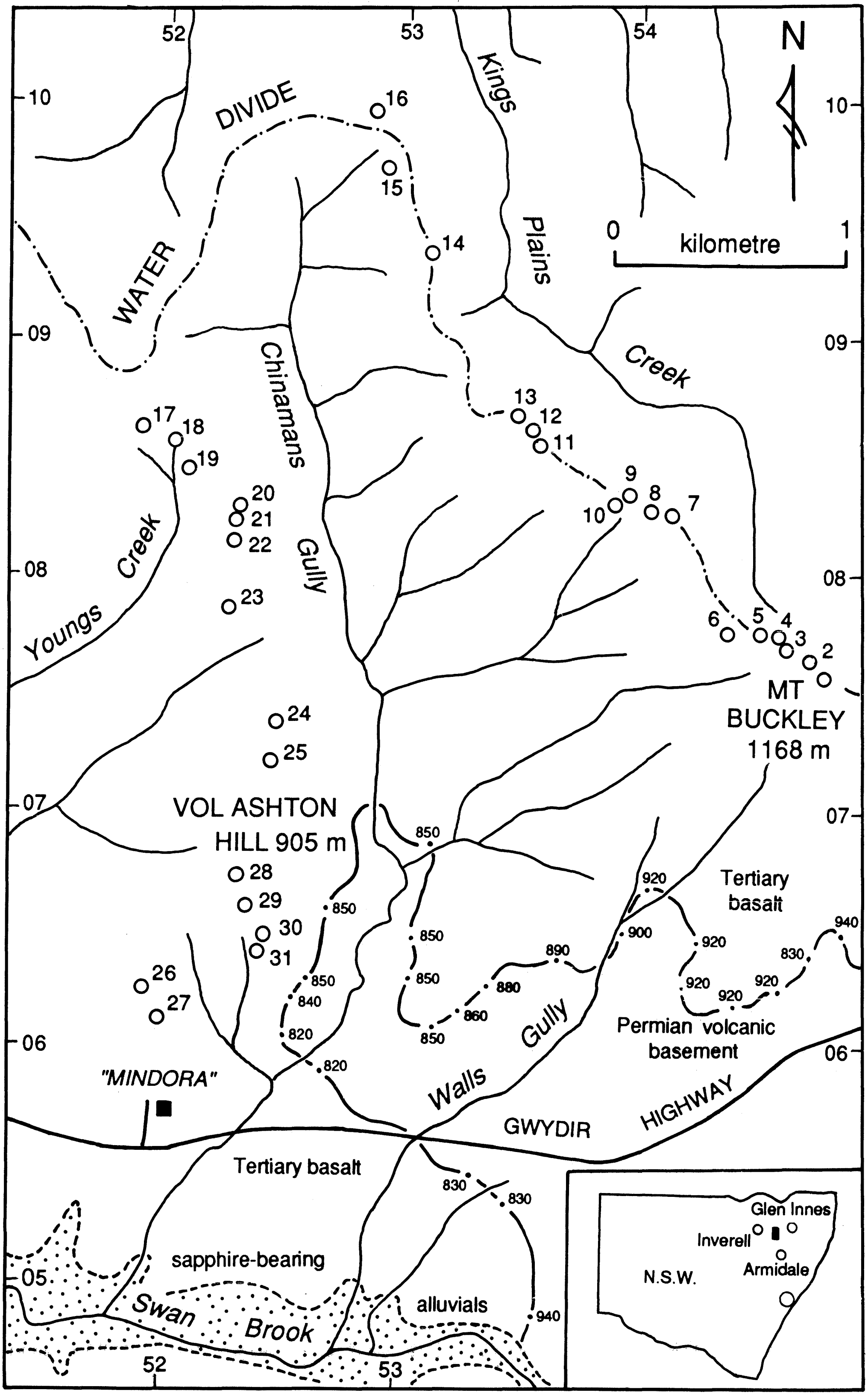

Fig.3. Location of basalt sample localities at Mount Buckley. Elevation and grid references on the Elsmore and Sapphire 1:25,000 topographic sheets are listed in Table 1 (Appendix I). The water divide between the Swan Brook and Kings Plains catchments, and the position and elevation in metres of the contact between Tertiary basalt and the underlying Permian volcanic basement are also shown.

The Mount Buckley Basalts

The 31 samples collected (Fig.3) represent some 300 metres of section. From sample B1 at the top of Mount Buckley (Matheson Trig Station elevation 1168 m GR:547077 Inverell 1:100,000), the traverse followed the ridge down to the north-west, around the head of Chinamans Gully, GR:525100 then south along a spur to Vol Ashton Hill, GR:523069, and finally down a spur to the lowermost flow, B27, resting on basement behind "Mindora" shearing sheds (840 - 860 m elevation, GR:519059). A further four samples B28 to B31 were collected from another spur off Vol Ashtons Hill, GR:524064, with the lowermost flow, B31, also resting on basement.

Flow B14 was chosen as the most suitable for K/Ar dating as it showed neither glassy groundmass nor significant alteration. It yielded an age of 39.0 ± 0.3 Ma. (F.L. Sutherland, personal communication, 1992). Younger ages of 21 Ma (Smith, 1988) and 23 Ma (Coenraads *et al.*, 1990) were measured on basalts 15 to 20 km to the west of "Mindora", however these are topographically lower and it is unlikely that there are any younger flows in the Mount Buckley sequence.

No volcaniclastic rocks were encountered in the Mount Buckley area.

Analytical methods. The basalt samples were sawn to remove all weathering surfaces, cracks and fractures. Each sample was sawn into slices, from which a representative thin section was made for examination (see Appendix II). The slices were broken and crushed in a tungsten carbide N.V. Tema mill. Sources of contamination, such as xenoliths, megacrysts and vugs were removed prior to crushing.

Major and trace element abundances were obtained by X-ray fluorescence spectrometry. Fused borate buttons were used for the major elements and pressed pellets were used to determine 15 trace elements. All samples were prepared in duplicate. Measurements were made on a Siemens SRS1 sequential X-ray spectrometer with a Siemens Kristallaflex 800 X-ray generator.

FeO analyses were made by hydrofluoric acid digestion and titration with cerric sulphate. The volatiles H_2O^-, H_2O^+ and CO_2 were determined by the fusion and collection method using a Leco induction furnace.

Treatment of the analytical data. For meaningful comparisons between rock chemistries (Table 1 [Appendix I]), the raw analytical data were treated as follows.

i) The maximum Fe_2O_3/FeO ratio was set at 0.2. Original ratios above this value were recalculated to 0.2. Although post eruptive alteration may have caused some oxidation of FeO to Fe_2O_3, this value is somewhat arbitrary due to the uncertainty of the pre-eruptive Fe_2O_3/FeO ratio (Wass, 1980).

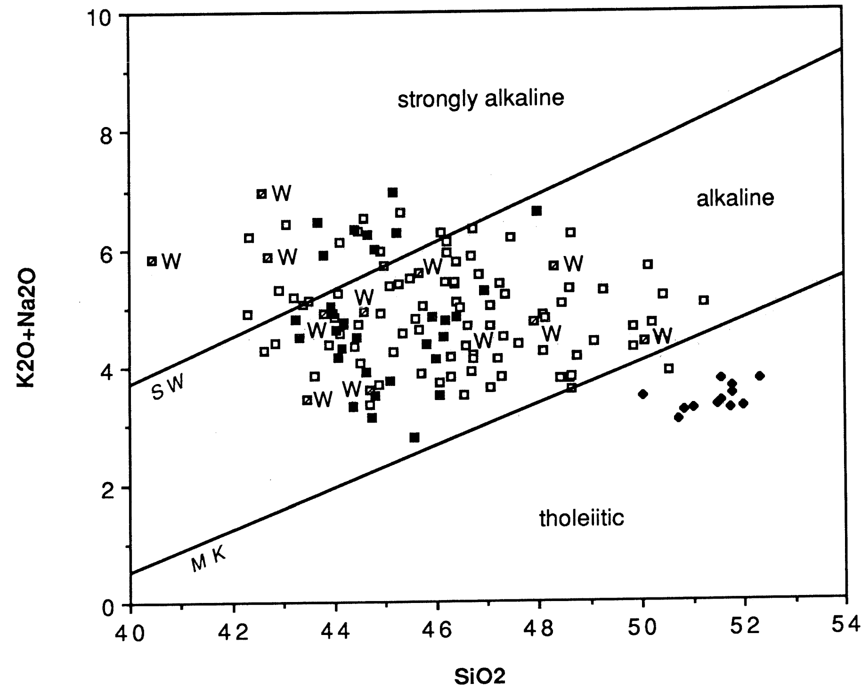

Fig.4. Total alkalis versus silica plot – Central Province, NSW. The lines of MacDonald & Katsura (1964) (MK) and Saggerson & Williams (1964) (SW) divide the plot into sub-alkaline (tholeiitic), alkaline and strongly alkaline fields. All existing analyses of basalts of the Central Volcanic Province are shown as open squares (Wilkinson, 1962; Wilkinson, 1966; Binns, 1969; Binns *et al.*, 1970; Duggan, 1972; Wilkinson, 1973; Wilkinson & Duggan, 1973; Street, 1974; McKay, 1975; McQueen, 1975; Barron, 1987; W.J. Stroud, J.K. Karaolis & R.R. Coenraads, unpubl. data), and the Mount Buckley analyses (this paper) as filled squares. The tholeiites from the Inverell area (Duggan, 1972) are plotted as filled diamonds. Analyses marked with 'w' are alkaline lavas from the sapphire-barren West Central Province.

ii) Volatiles H_2O, CO_2 and S are included in the weight percent oxide totals (Table 1 [Appendix I]). Totals have not been rescaled to 100%.

iii) Samples showing post eruptive alteration must be interpreted with caution. Such evidence was seen in the thin section modal mineralogy, or determined from the chemical analyses as high H_2O+ (greater than 4%) or high CO_2 (greater than 0.5%) from secondary minerals such as zeolite or calcite, and/or a high Fe_2O_3/FeO ratio (greater than 0.75) from oxidation of ferrous iron. Mount Buckley analyses excluded from interpretation are B15 (approximately 20% modal zeolite, 5.02% H_2O); B21 (1.84% CO_2), B22 (alteration of phenocrystal olivine and along fractures, carbonate veining, 2.82% CO_2, $Fe_2O_3/FeO=0.79$); B24 (alteration of phenocrystal olivine, alteration along fractures, $Fe_2O_3/FeO=1.04$); B27 (alteration of phenocrystal olivine, approximately 20% modal zeolite); and B28 (alteration of phenocrystal olivine, presence of zeolite-filled vesicles). They appear to be alkaline, as defined by Wilkinson (1974), based on their modal mineralogy (see Appendix II).

Nomenclature. The basalts are named on their chemical composition and normative components following Green & Ringwood (1967) and Coombs & Wilkinson (1969). The criteria used by Johnson (1989: 13) to separate sub-alkaline (tholeiitic) from alkaline rocks requires that sub-alkaline rocks have normative quartz, or more than 10% normative hypersthene. This scheme however classifies as sub-alkaline a number of earlier Central Province analyses (in which the percentage SiO_2 was calculated by difference and, as a result, is probably too high). These are however clearly alkaline based on their mineralogy (McKay, 1975; McQueen, 1975) according to Wilkinson's (1974) criteria (containing mauve-pink titaniferous augite as the only pyroxene, olivine as a groundmass phase, and various amounts of modal felspathoid). Analyses are shown on an alkalis ($Na_2O + K_2O$) versus silica plot (Fig.4) with the dividing lines of MacDonald & Katsura (1964) and Saggerson & Williams (1964) provided as a reference. This diagram possesses limitations for those rocks which plot close to the alkalic-tholeiitic dividing line, (Wilkinson 1974).

The alkaline rocks (Fig.5) have been classified using the scheme proposed by Coombs & Wilkinson (1969) based on their normative plagioclase versus differentiation index (D.I. = normative quartz + orthoclase + albite + nepheline + leucite). Rocks with D.I. under 75 and greater than 5% normative nepheline include basanite or are prefixed with "nepheline" as shown in Figure 6.

Chemical Features of the Mount Buckley Lavas

All the Mount Buckley Series rocks are basic, as SiO_2 lies between 45 and 50% (Carmichael *et al.*, 1974: 29). Plots of normative hypersthene or nepheline against

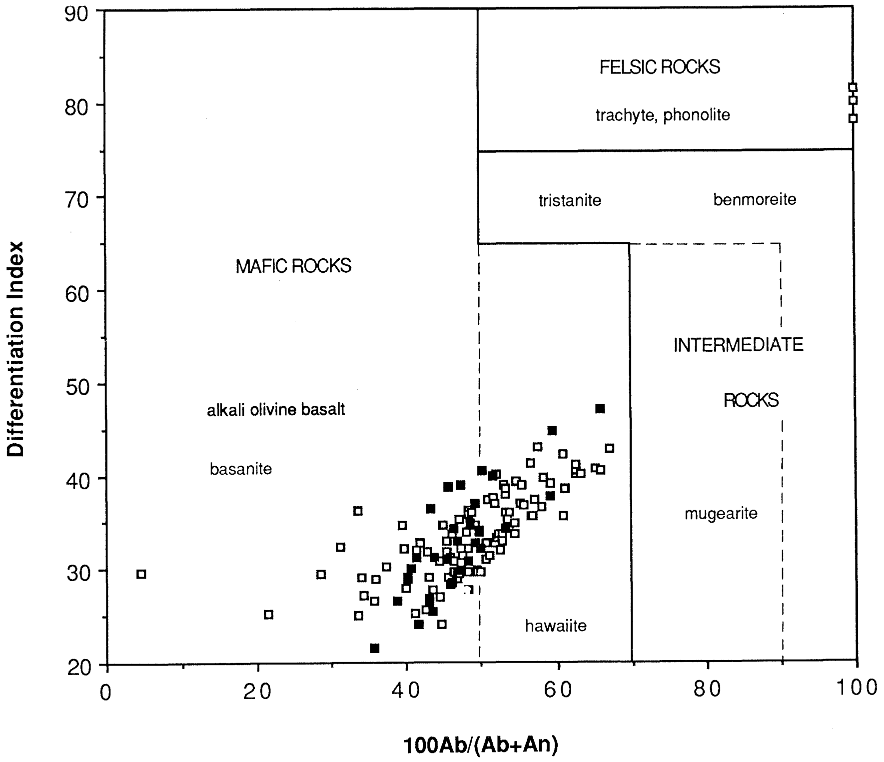

Fig.5. C.I.P.W. normative plagioclase versus differentiation index (D.I. = normative quartz+ orthoclase + albite + nepheline + leucite) – Central Province, NSW. All existing analyses of basalts of the Central Volcanic Province are shown as open squares (see Fig.4 for sources of database), and the Mount Buckley analyses (this paper) as filled squares. The analyses in the felsic field are phonolites from the Swan Peak Plug (W.J. Stroud, J.K. Karaolis & R.R. Coenraads, unpublished data).

normative plagioclase composition (Fig.7) shows most are alkali olivine basalts and basanites. The uppermost flows are predominantly basanite and nepheline hawaiites whilst the lowermost are predominantly alkali olivine basalts and hawaiites.

A positive correlation can be seen on the normative plagioclase versus differentiation index plot (Fig.5). However there is no systematic variation between

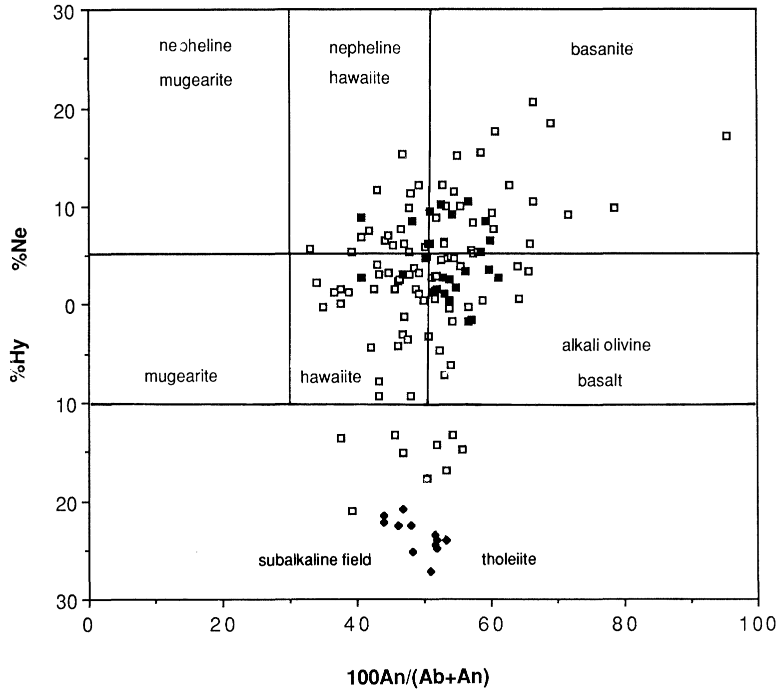

Fig.6. C.I.P.W. nepheline or hypersthene versus normative plagioclase – Central Province, NSW. Lines of Coombs & Wilkinson (1969) subdivide the field of alkaline rocks. Rocks with greater than 5% normative nepheline include basanites, or are prefixed with "nepheline". All analyses for the Central Province are shown, with the Mount Buckley basalts shown as filled squares, and the tholeiites from the Inverell area as filled diamonds. Note some of the earlier Central Province analyses of basalts described as alkaline, based on their modal analyses, plot in the subalkaline field as %SiO2 has been calculated by difference and is probably erroneously high (McQueen, 1975).

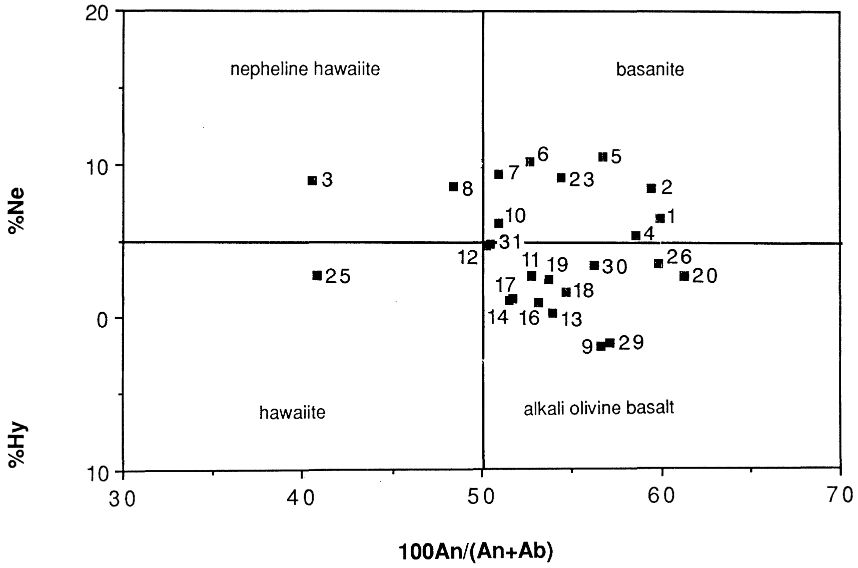

Fig.7. C.I.P.W. nepheline or hypersthene versus normative plagioclase for the Mount Buckley analyses. The uppermost flows (B1 to B10) are largely nepheline hawaiites and basanites and the lower flows (B11 to B31) are largely alkali olivine basalts and hawaiites. Flows B9 and B23 are the only exceptions to this observation.

stratigraphic position and position on this plot.

In terms of alkalis ratio, K_2O:Na_2O, the Mount Buckley flows (Fig.8) tend to cluster about the line K_2O:Na_2O = 1:2 between the sodic Hawaiian alkalic suite (McDonald & Katsura, 1964) and the potassic Tristan de Cunha alkalic series (Baker *et al.*, 1964).

Chemistry versus stratigraphic position at Mount Buckley. Normative hypersthene or nepheline (Fig.9), major oxides (Fig.10), and trace elements (Fig.11) were plotted versus flow number to discern any trends.

Increasing silica undersaturation with time appears in Figure 9. The upper flows, B1 to B10 are basanites and

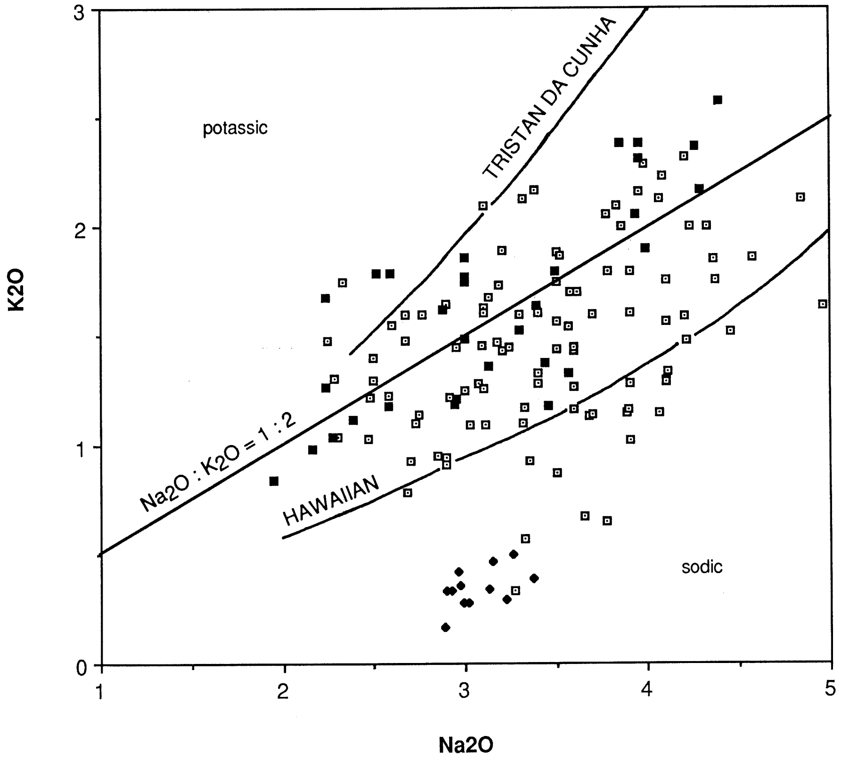

Fig.8. Na_20 versus K_2O plot – Central Province, NSW. Basalts of the Central Volcanic Province are plotted, with the Mount Buckley analyses shown as filled squares. The field for the Central Province is centred about the line Na_20:K_2O = 2:1 and lies between the sodic Hawaiian alkalic suite (McDonald & Katsura, 1964) and the potassic Tristan de Cuhna series (Baker *et al.*, 1964). The group of analyses low in K_2O (filled diamonds) are the tholeiites in the vicinity of Inverell mapped by Duggan (1972).

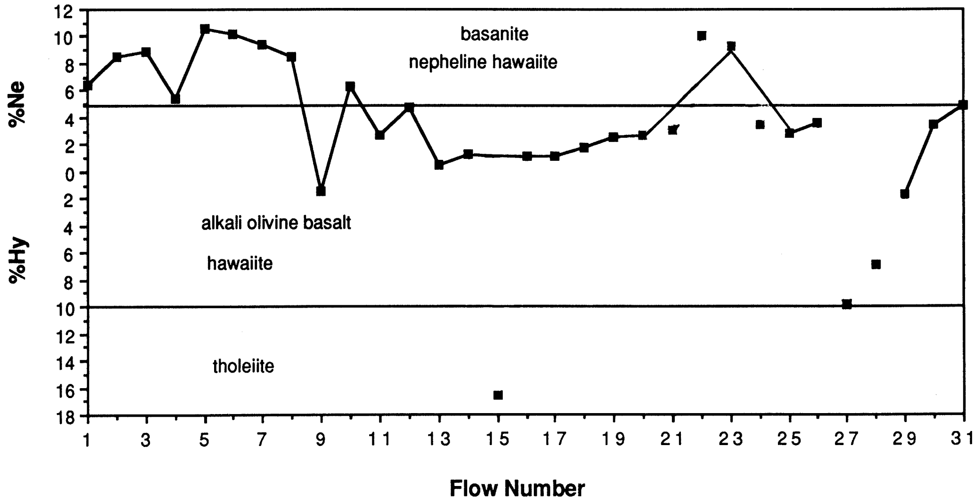

Fig.9. C.I.P.W. nepheline or hypersthene versus flow number – Mount Buckley. The numbers are from 1, the youngest flow at the top of Mount Buckley to the lowermost flows. The plot shows that the uppermost flows are, in general, more undersaturated than the lowermost flows. B15, B21, B22, B24, B27 and B28 are not considered suitable for comparison of normative mineralogy and are not linked to adjacent flows by the solid line.

nepheline hawaiites (greater than 5% normative nepheline) with one coarse alkali olivine basalt (B9). B3 is chemically quite distinct having the highest Zn (119 ppm), Zr (377 ppm), K_2O (2.71%), Na_2O (4.63%), P_2O_5 (1.01%) and Ga (25 ppm), high Sr (1237 ppm), low Ca (7.02%), Ni (92 ppm), MgO (6.27%) and V (103 ppm) and the lowest Cr (94 ppm) and Cu (27 ppm). B9 also differs from its neighbours with distinct CaO, Zr, Nb and Cu values, but their field relations are conformable. The lower flows B11 to B26 are mildly undersaturated alkali olivine basalts or hawaiites with one basanite (B23). The additional lower flows, B29 to B31 are also alkali olivine basalts.

Figures 10 and 11 show systematic correlations between the different major and trace elements, such as Al_2O_3, MgO, CaO, Na_2O, P_2O_5, V, Cr and Ni. Some adjacent units within the Mount Buckley sequence behave as groups, the members of each group being chemically and petrographically consistent. Flows B16, B17, B18 and B19 are coarse grained alkali olivine basalts; flows B10, B11, B12 and B13, are a fine grained basanite and alkali olivine basalts; and flows B5, B6, B7 and B8 are basanites and a nepheline hawaiite. Some elements in these groups change in a regular way from unit to unit

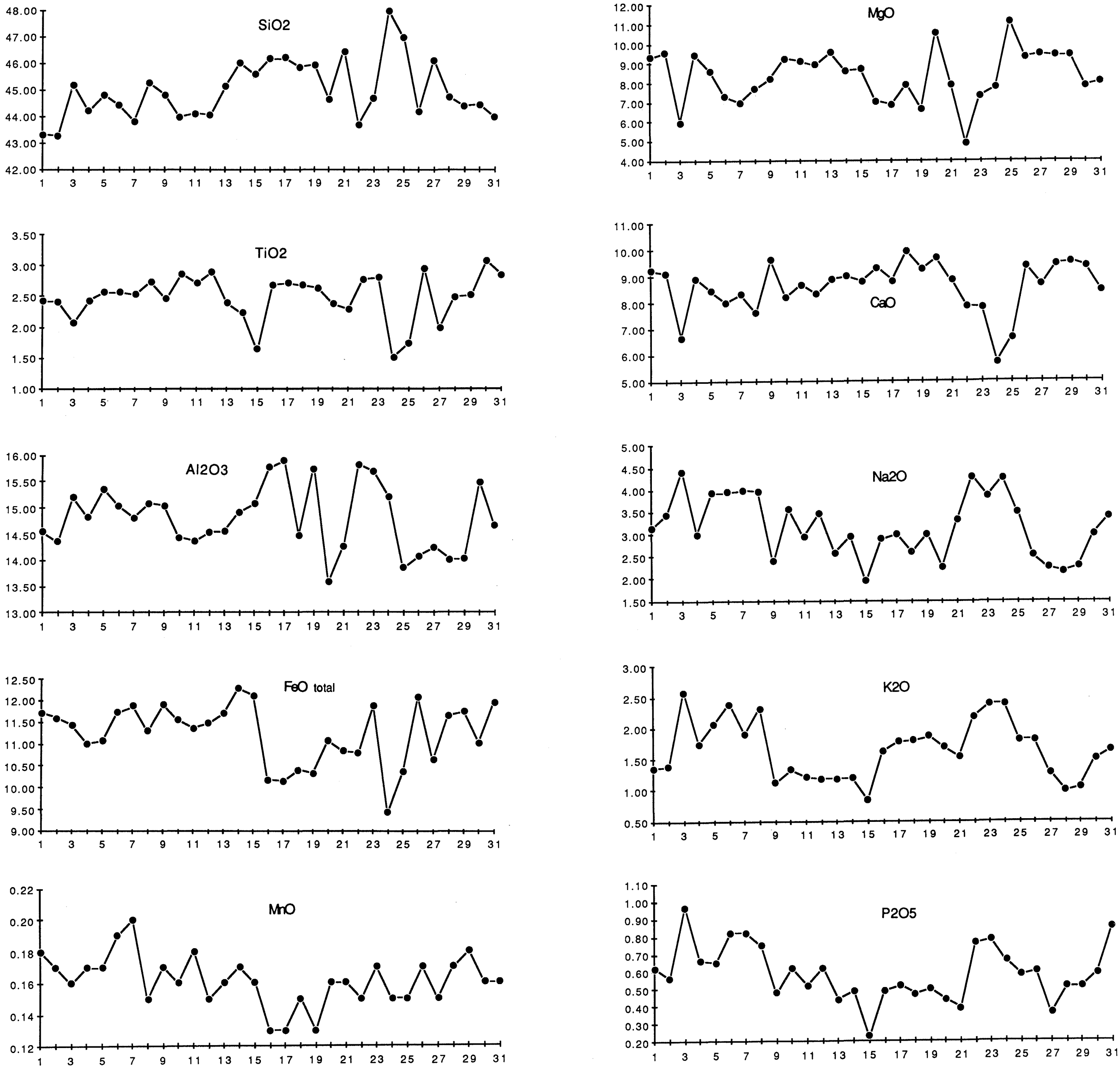

Fig.10. Major elements versus flow number. The plots allow comparisons to be made between successive flows. Number 1 is the youngest, uppermost flow on Mount Buckley. Major elements are plotted as oxide weight percents.

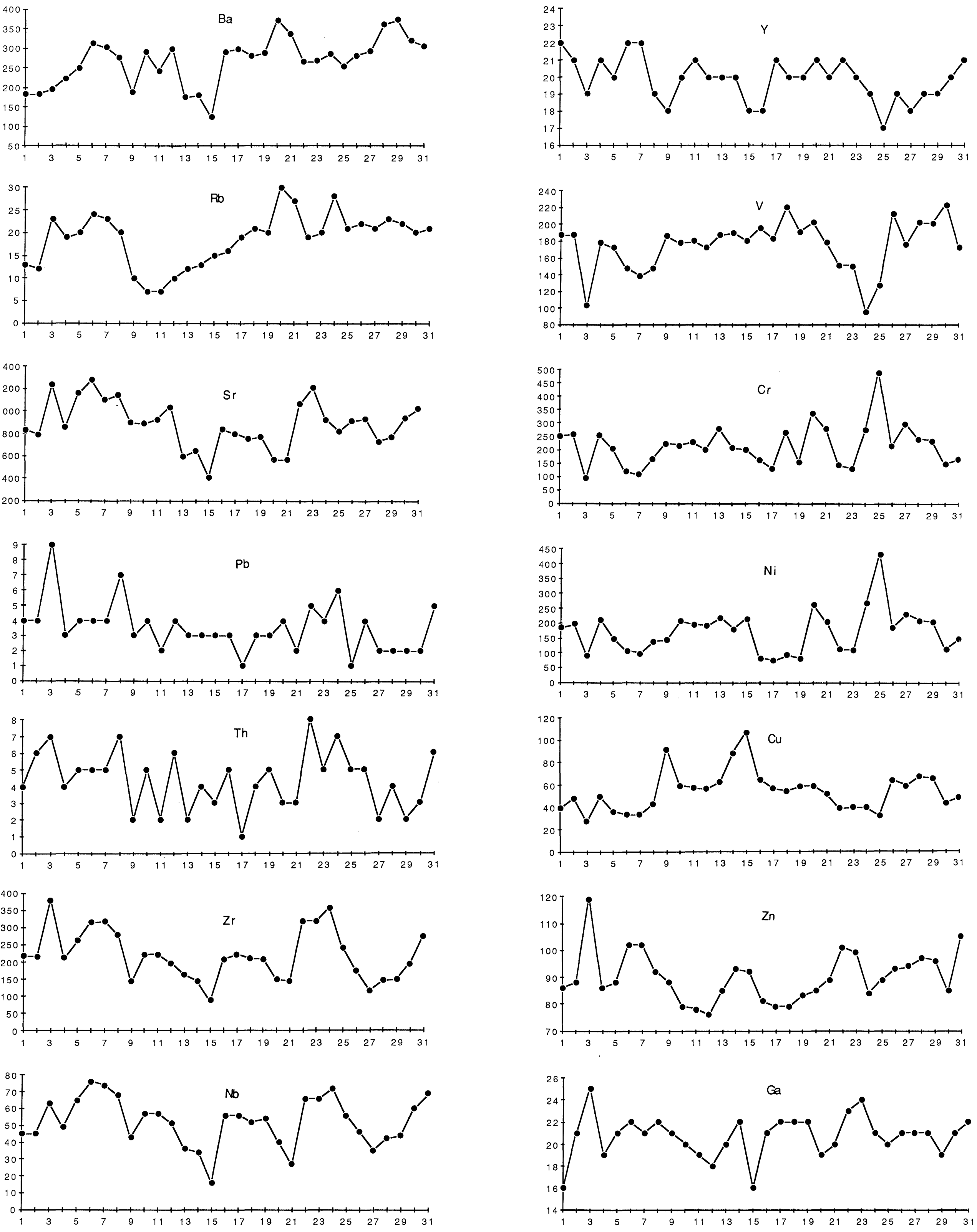

Fig.11. Trace elements versus flow number. The plots allow comparisons to be made between successive flows. Number 1 is the youngest, uppermost flow on Mount Buckley. Trace elements are plotted as parts per million.

indicating a possible fractionation pattern.

Overall, the Mount Buckley sequence (Figs 10, 11), ignoring chemically distinct B3, shows SiO_2 increasing reasonably smoothly from 45% in B1 to 48% in B19. V decreases from B1 to a minimum in B7 then increases again from B8 to B18. CaO follows a similar trend with a minimum at B8. MgO also shows a minimum in B7.

Xenolith-bearing and primary lavas at Mount Buckley. Ultramafic xenoliths occur in B1, B2, B4, B6, B7, B10, B12, B24 and B25. The pyroxenite and lherzolite bearing flows, described by Wilkinson (1973), are in a small tributary of Youngs' Creek (GR:520075 Inverell 1:100,000, Fig.3; L. Stewart, personal communication). The tributary incises Vol Aston Hill, comprised of flows B24 and B25. Wilkinson (1973) interpreted the pyroxenites and peridotites to be samples of essentially unmodified, layered upper mantle. Such xenoliths are characteristic of more alkaline and undersaturated melts which move directly and rapidly from upper mantle levels to the surface. These xenolith-bearing melts are either primary or are produced by high pressure crystal fractionation (Irving & Green, 1976; Wass, 1980). Primary alkaline magmas show Mg-values ($100Mg/\{Mg+Fe^{2+}\}$) of 66 to 75, which represent liquids that could be in equilibrium with upper mantle residual olivine compositions (Fo89 - Fo99) and high Ni values (greater than 300 ppm) B25 (Mg-value = 69, Ni = 429 ppm) satisfies these criteria and shows the highest MgO, Cr and Ni in the sequence. The rest of the xenolith-bearing flows have Mg values below 65 and Ni less than 300 ppm, suggesting high pressure fractionation in the mantle (Green *et al.*, 1974) or direct derivation from more iron rich peridotite (Wilkinson & Binns, 1977). Such conditions of rapid transport to the surface also help the preservation of sapphires in carrier magmas (Coenraads *et al.*, 1990)

The coarse grained flows (B9, B11, B14, B15, B16, B17, B18, and B19) lack xenoliths, a feature noted by Wass (1980) for flows in the Southern Highlands. This may indicate either a longer transit time to the surface or temporary residence in a magma chamber for such flows. This would reduce their role as sapphire carriers.

Comparison between the Sapphire-bearing East and Sapphire-barren West Central Province

The Central Province analyses were separated into those from the sapphire-bearing East and sapphire-barren West Central Province. Analyses near the dividing boundary (the MacIntyre River) were included with the East as these incorporate the majority and are likely to include both sapphire-bearing and sapphire-barren flows. This grouping was to test whether the sapphire-barren flows form a separate subset or a distinct smaller

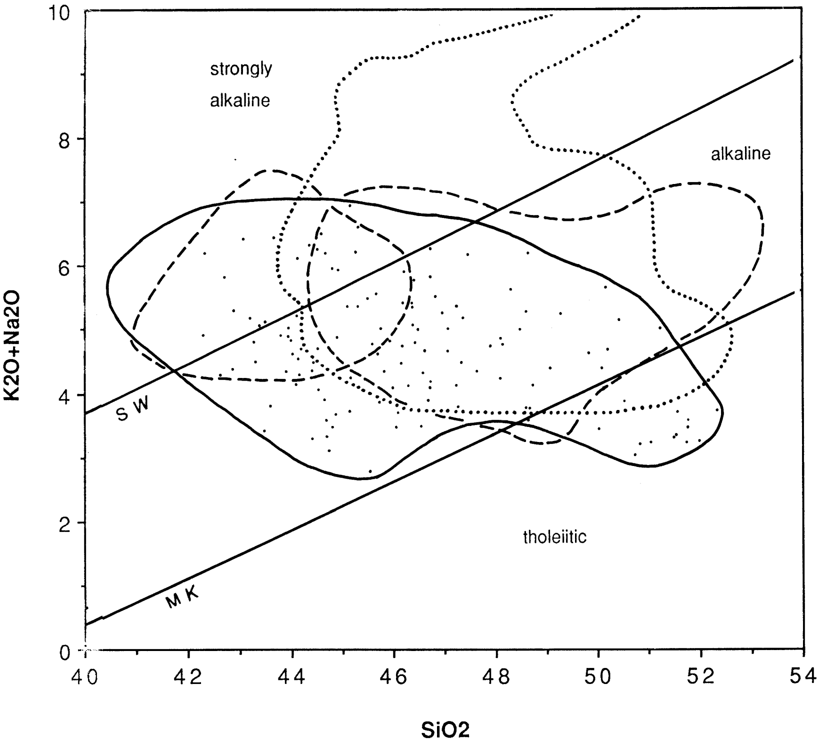

Fig.12. Total alkalis versus silica plot – Central Province, NSW. Dot points indicate the compositional database for the Central Province basalts. The compositional field of the Central Volcanic Province, outlined by a solid line, and that of the north-eastern Australian corundum-bearing provinces (Atherton, Chudleigh and McBride; Stephenson *et al.*, 1980), outlined by a dotted line, are superimposed on the overlapping fields for the corundum-bearing (dashed line, left hand field) and corundum-less (dashed line, right hand field) south-east Asian volcanic provinces (Vichit *et al.*, 1978).

compositional field, as was observed by Vichit *et al.*. (1978) for the south-east Asian volcanic provinces. However, apart from more tholeiitic compositions, the remaining sapphire-barren West Central Province analyses range over the entire compositional field, (see samples flagged with 'w' in Fig.4). The tholeiites found by Duggan (1972) are distinct from any basalts in the East Central Province. Such tholeiites may be an indicator against finding sapphire as they show evidence of some low pressure fractional crystallisation (Wilkinson & Duggan, 1973), suggesting residence at shallower levels.

Comparison between the Central Province and other Volcanic Provinces in North-eastern Australia and South-east Asia

Stephenson *et al.* (1980) compare the compositional fields for the north Queensland volcanic provinces on a number of variation diagrams (alkalis versus silica, K_2O versus Na_2O, AFM, and normative plagioclase versus differentiation index plots). The compositional fields largely overlap one another, and those known to have associated sapphire (Atherton, Chudleigh and McBride) are not significantly different from the rest of the north Queensland provinces. Not surprisingly, the Central Province compositional field also overlaps these plots (Fig.12). The implications are that, either all the north Queensland provinces and the West Central Province are potentially sapphire-bearing, or more likely, that this type of data and its scatter are insufficient to predict likely sapphire-bearing and sapphire-barren provinces.

Conclusions

1. The East Central Province was broken up into catchments and those containing the most alluvial sapphire were selected as the most likely places to characterise sapphire source rocks.
2. The Mount Buckley basalts increase in undersaturation with time, from predominantly alkali olivine basalts and hawaiites to predominantly basanites and nepheline hawaiites. They probably represent intercalated flows from several different mantle and crustal sources, particularly as many of the major and trace element values for flows, such as B3 and B9, vary markedly from their neighbouring flows. Flow B25 is a possible primary representative. A large number of the flows carry high pressure inclusions, implying their rapid movement from upper mantle depths.
3. There is little distinction between the compositions from the sapphire-bearing East Central Province and the sapphire-barren West Central province on the variation diagrams, apart from the tholeiites west of Inverell.
4. The compositional fields for the north-eastern Australian volcanic provinces and the Central Province overlap with no apparent compositional variation between those fields known to contain corundum and the remainder.
5. The compositional field for the Central Province overlaps both the corundum-bearing and corundum-less fields for the south-east Asian volcanic provinces.
6. Chemical variations in basaltic fields do not appear sensitive indicators to predict economic sapphire deposits.

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APPENDIX I

Table 1. Mount Buckley basalt analyses and C.I.P.W norms.

Sample Number	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15
Location	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley
1:25000 Map Sheet	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire
Grid Reference	54800756	54730765	54630769	54600774	54520775	54380775	54130825	54040827	53950834	53890829	53560854	53530860	53470867	53090936	52890972
Elevation (metres)	1168	1160	1142	1135	1129	1115	1100	1078	1065	1056	1050	1045	1043	1035	1015
Oxide wt%															
SiO2	43.31	43.26	45.18	44.20	44.81	44.41	43.80	45.25	44.81	43.96	44.10	44.04	45.12	46.00	45.57
TiO2	2.42	2.41	2.08	2.43	2.57	2.57	2.53	2.73	2.46	2.86	2.71	2.89	2.39	2.23	1.64
Al2O3	14.55	14.36	15.20	14.82	15.35	15.03	14.81	15.08	15.03	14.43	14.36	14.54	14.56	14.92	15.07
Fe2O3	4.12	3.71	5.05	3.18	3.09	4.30	3.81	3.90	3.29	4.10	4.20	4.78	3.92	2.14	2.18
FeO	8.00	8.25	6.88	8.15	8.29	7.86	8.45	7.79	8.95	7.86	7.58	7.17	8.17	10.35	10.15
MnO	0.18	0.17	0.16	0.17	0.17	0.19	0.20	0.15	0.17	0.16	0.18	0.15	0.16	0.17	0.16
MgO	9.32	9.56	5.94	9.44	8.60	7.29	6.97	7.67	8.20	9.22	9.10	8.91	9.55	8.62	8.70
CaO	9.22	9.12	6.65	8.92	8.43	8.00	8.30	7.62	9.60	8.19	8.67	8.30	8.87	8.98	8.79
Na2O	3.13	3.44	4.39	3.00	3.93	3.95	3.99	3.95	2.39	3.57	2.95	3.46	2.58	2.94	1.95
K2O	1.36	1.38	2.57	1.75	2.06	2.38	1.90	2.31	1.12	1.33	1.21	1.18	1.18	1.19	0.84
P2O5	0.62	0.56	0.96	0.66	0.65	0.82	0.82	0.75	0.48	0.62	0.52	0.62	0.44	0.49	0.23
S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.03
H2O+	2.77	2.58	3.35	2.42	1.86	2.10	3.48	1.48	2.51	2.17	2.99	2.37	2.14	0.93	4.29
H2O-	0.77	0.74	0.91	0.59	0.47	0.57	0.52	0.46	0.53	0.56	0.67	0.67	0.55	0.40	0.73
CO2	0.17	0.22	0.10	0.19	0.11	0.12	0.13	0.08	0.10	0.08	0.07	0.06	0.03	0.06	0.09
Original Total	99.94	99.76	99.42	99.92	100.39	99.59	99.71	99.22	99.65	99.11	99.31	99.15	99.67	99.43	100.42
Total Fe as FeO	11.71	11.59	11.42	11.01	11.07	11.73	11.88	11.30	11.91	11.55	11.36	11.47	11.70	12.28	12.11
original Fe2O3/FeO	0.52	0.45	0.73	0.39	0.37	0.55	0.45	0.50	0.37	0.52	0.55	0.67	0.48	0.21	0.21
required Fe2O3/FeO	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
New Fe2O3	1.98	1.96	1.94	1.87	1.88	1.99	2.01	1.92	2.02	1.96	1.93	1.94	1.98	2.08	2.05
New FeO	9.92	9.82	9.68	9.33	9.38	9.94	10.07	9.58	10.09	9.79	9.63	9.72	9.91	10.40	10.26
New Total	99.73	99.59	99.11	99.79	100.27	99.36	99.53	99.02	99.52	98.90	99.08	98.87	99.48	99.42	100.41
Orthoclase	8.06	8.15	15.17	10.32	12.16	14.08	11.24	13.63	6.63	7.88	7.17	6.95	6.99	7.02	4.97
Albite	14.49	13.46	20.72	15.44	13.84	14.60	16.30	17.65	20.22	18.68	19.94	20.52	21.03	22.44	16.53
Nepheline	6.50	8.48	8.91	5.38	10.53	10.18	9.44	8.55	0.00	6.25	2.74	4.73	0.44	1.33	0.00
Anorthite	21.63	19.67	14.18	21.82	18.15	16.25	16.90	16.57	26.96	19.40	22.34	20.67	24.63	23.99	29.84
Diopside	15.44	16.61	9.77	13.68	15.17	14.15	14.84	12.89	13.78	13.53	13.64	12.99	13.21	13.88	9.52
Hyperthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.51	0.00	0.00	0.00	0.00	0.00	16.64
Olivine	20.80	20.69	16.89	20.85	18.73	17.50	16.91	17.91	18.44	20.55	20.30	20.06	21.97	20.90	11.02
Magnetite	2.87	2.84	2.81	2.71	2.73	2.89	2.91	2.78	2.93	2.84	2.80	2.81	2.87	3.02	2.97
Ilmenite	4.60	4.57	3.95	4.62	4.89	4.88	4.80	5.19	4.67	5.43	5.14	5.48	4.55	4.24	3.12
Apatite	1.46	1.33	2.28	1.57	1.54	1.94	1.93	1.77	1.13	1.46	1.24	1.47	1.05	1.15	0.55
Calcite	0.39	0.50	0.23	0.43	0.25	0.27	0.30	0.18	0.23	0.18	0.16	0.14	0.07	0.14	0.20
Water	3.54	3.32	4.26	3.01	2.33	2.67	4.00	1.94	3.04	2.73	3.66	3.04	2.69	1.33	5.02
Total	99.78	99.62	99.17	99.83	100.32	99.41	99.57	99.06	99.54	98.93	99.13	98.86	99.50	99.44	100.38
100An/An+Ab	59.9	59.4	40.6	58.6	56.7	52.7	50.9	48.4	57.1	50.9	52.8	50.2	53.9	51.7	64.4
Differentiation Index	29.05	30.09	44.8	31.14	36.53	38.86	36.98	39.83	26.85	32.81	29.85	32.2	28.46	30.79	21.5
Rock Name	basanite	basanite	ne-hawaiite	basanite	basanite	basanite	basanite	ne-hawaiite	AOB	basanite	AOB	AOB	AOB	AOB	AOB
Trace Elements (ppm)															
Ba	183	184	196	223	250	312	302	276	189	290	243	298	176	181	126
Rb	13	12	23	19	20	24	23	20	10	7	7	10	12	13	15
Sr	832	786	1236	856	1160	1279	1100	1145	896	885	924	1035	592	645	403
Pb	4	4	9	3	4	4	4	7	3	4	2	4	3	3	3
Th	4	6	7	4	5	5	5	7	2	5	2	6	2	4	3
U	1	0	2	2	1	2	2	0	2	2	1	1	1	2	1
Zr	217	215	377	212	261	314	318	279	143	221	222	196	162	143	87
Nb	45	45	63	49	65	76	74	68	43	57	57	51	36	34	16
Y	22	21	19	21	20	22	22	19	18	20	21	20	20	20	18
V	187	187	103	178	172	148	138	148	186	178	180	172	187	190	180
Cr	251	257	94	253	203	117	106	166	223	216	228	202	277	207	202
Ni	185	197	91	210	148	106	97	138	144	206	195	191	217	180	215
Cu	39	48	27	49	36	33	33	43	91	59	57	56	62	88	106
Zn	86	88	119	86	88	102	102	92	88	79	78	76	85	93	92
Ga	16	21	25	19	21	22	21	22	21	20	19	18	20	22	16
K/Rb	868	955	928	765	855	823	686	959	930	1577	1435	980	816	760	465

Table 1 (cont'd).

Sample Number	B16	B17	B18	B19	B20	B21	B22	B23	B24	B25	B26	B27	B28	B29	B30	B31
Location	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley	Mt Buckley
1:25000 Map Sheet	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Sapphire	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore	Elsmore
Grid reference	52850996	51890862	52020856	52090845	52300830	52290823	52270816	52260786	52470737	52450711	51920625	51980612	52330673	52350660	52440649	52400642
Elevation (metres)	1005	1015	990	960	955	948	940	940	911	892	884	855	903	892	875	865
Oxide wt%																
SiO_2	46.16	46.20	45.85	45.94	44.63	46.43	43.67	44.65	47.98	46.95	44.15	46.08	44.73	44.39	44.44	43.95
TiO_2	2.68	2.71	2.67	2.62	2.37	2.29	2.77	2.80	1.51	1.74	2.95	1.99	2.49	2.51	3.07	2.84
Al_2O_3	15.76	15.90	14.47	15.73	13.58	14.26	15.82	15.68	15.21	13.86	14.08	14.24	14.01	14.03	15.48	14.65
Fe_2O_3	2.97	3.45	3.64	3.28	3.05	3.29	4.98	3.83	5.07	3.44	3.62	3.68	3.60	3.31	3.84	3.95
FeO	7.51	7.04	7.13	7.38	8.33	7.88	6.32	8.44	4.89	7.27	8.84	7.35	8.43	8.77	7.58	8.40
MnO	0.13	0.13	0.15	0.13	0.16	0.16	0.15	0.17	0.15	0.15	0.17	0.15	0.17	0.18	0.16	0.16
MgO	7.03	6.83	7.88	6.60	10.53	7.87	4.86	7.31	7.72	11.07	9.29	9.44	9.36	9.38	7.82	8.03
CaO	9.28	8.79	9.89	9.23	9.65	8.81	7.82	7.75	5.69	6.59	9.34	8.64	9.42	9.50	9.32	8.42
Na_2O	2.88	3.00	2.59	3.00	2.24	3.30	4.28	3.85	4.26	3.49	2.52	2.24	2.16	2.27	3.00	3.39
K_2O	1.62	1.77	1.79	1.86	1.68	1.53	2.17	2.38	2.37	1.80	1.79	1.27	0.98	1.04	1.49	1.64
P_2O_5	0.49	0.52	0.47	0.50	0.44	0.39	0.76	0.78	0.66	0.58	0.60	0.36	0.51	0.51	0.59	0.85
S	0.02	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
H_2O+	2.40	2.76	2.35	2.59	2.49	1.08	2.43	1.66	2.65	2.07	1.71	3.35	3.24	2.87	2.35	2.25
H_2O-	0.59	0.61	0.49	0.50	0.38	0.41	1.00	0.45	0.45	0.34	0.47	0.57	0.72	0.53	0.74	1.02
CO_2	0.01	0.06	0.09	0.08	0.03	1.84	2.82	0.05	0.29	0.02	0.08	0.04	0.09	0.03	0.21	0.29
Original Total	99.53	99.78	99.46	99.45	99.57	99.54	99.86	99.81	98.90	99.37	99.62	99.40	99.92	99.33	100.09	99.84
Total Fe as FeO	10.18	10.14	10.41	10.33	11.07	10.84	10.80	11.89	9.45	10.37	12.10	10.66	11.67	11.75	11.04	11.95
original Fe_2O_3/FeO	0.40	0.49	0.51	0.44	0.37	0.42	0.79	0.45	1.04	0.47	0.41	0.50	0.43	0.38	0.51	0.47
required Fe_2O_3/FeO	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
New Fe_2O_3	1.73	1.72	1.76	1.75	1.88	1.84	1.83	2.01	1.60	1.76	2.05	1.81	1.98	1.99	1.87	2.03
New FeO	8.63	8.60	8.82	8.76	9.39	9.19	9.15	10.07	8.01	8.78	10.25	9.04	9.89	9.96	9.35	10.13
New Total	99.41	99.61	99.27	99.30	99.45	99.39	99.54	99.63	98.55	99.20	99.46	99.21	99.76	99.20	99.89	99.65
Orthoclase	9.57	10.47	10.57	11.00	9.94	9.04	12.82	14.06	13.98	10.66	10.56	7.50	5.80	6.14	8.80	9.66
Albite	22.33	23.24	18.66	20.68	13.90	22.21	17.68	15.50	29.62	24.39	14.70	18.94	18.28	19.20	18.98	19.65
Nepheline	1.10	1.16	1.77	2.54	2.74	3.09	10.04	9.23	3.46	2.76	3.57	0.00	0.00	0.00	3.46	4.89
Anorthite	25.27	24.67	22.55	23.95	22.04	19.57	17.54	18.48	15.40	16.84	21.84	25.04	25.63	25.02	24.37	19.94
Diopside	14.22	12.33	18.55	14.76	18.39	17.57	13.43	11.90	5.42	9.59	16.25	12.26	13.97	15.08	13.57	11.77
Hyperthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.85	6.88	1.76	0.00	0.00
Olivine	15.14	15.38	15.42	14.41	21.28	16.67	12.10	18.18	20.19	25.30	20.19	14.36	16.25	19.68	17.24	19.50
Magnetite	2.51	2.49	2.55	2.54	2.73	2.67	2.65	2.91	2.32	2.55	2.97	2.62	2.87	2.89	2.71	2.94
Ilmenite	5.09	5.15	5.07	4.98	4.49	4.35	5.26	5.31	2.86	3.30	5.60	3.78	4.73	4.77	5.83	5.40
Apatite	1.16	1.24	1.11	1.17	1.05	0.92	1.80	1.85	1.56	1.38	1.43	0.86	1.21	1.21	1.39	2.01
Calcite	0.02	0.14	0.20	0.18	0.07	0.00	0.00	0.11	0.66	0.05	0.18	0.11	0.20	0.07	0.48	0.66
Water	2.99	3.37	2.84	3.09	2.87	1.49	3.43	2.11	3.10	2.41	2.18	3.92	3.96	3.40	3.09	3.27
Total	99.40	99.64	99.29	99.30	99.50	97.58	96.75	99.64	98.57	99.23	99.47	99.24	99.78	99.22	99.92	99.69
100An/An+Ab	53.1	51.5	54.7	53.7	61.3	46.8	49.8	54.4	34.2	40.8	59.8	56.9	58.4	56.6	56.2	50.4
Differentiation Index	33	34.87	31	34.22	26.58	34.34	40.54	38.79	47.06	37.81	28.83	26.44	24.08	25.34	31.24	34.2
Rock Name	AOB	AOB	AOB	AOB	AOB	hawaiite	hawaiite	basanite	hawaiite	hawaiite	AOB	AOB	AOB	AOB	AOB	AOB
Trace Elements (ppm)																
Ba	291	298	280	288	372	337	266	268	286	255	282	293	361	373	319	305
Rb	16	19	21	20	30	27	19	20	28	21	22	21	23	22	20	21
Sr	838	800	753	773	564	565	1066	1211	924	817	914	931	730	772	937	1022
Pb	3	1	3	3	4	2	5	4	6	1	4	2	2	2	2	5
Th	5	1	4	5	3	3	8	5	7	5	5	2	4	2	3	6
U	2	1	1	1	2	3	3	3	3	2	2	2	0	2	1	2
Zr	208	221	209	208	148	143	318	317	357	241	173	117	146	149	194	272
Nb	56	56	52	54	40	27	66	66	72	56	46	35	42	44	60	69
Y	18	21	20	20	21	20	21	20	19	17	19	18	19	19	20	21
V	195	183	220	191	202	178	151	150	95	127	212	176	202	201	223	172
Cr	162	129	263	153	337	280	143	130	276	489	216	297	240	234	147	163
Ni	81	73	92	80	261	203	111	110	268	429	186	230	208	204	113	146
Cu	64	56	54	58	58	51	38	39	39	32	63	58	66	65	43	48
Zn	81	79	79	83	85	89	101	99	84	89	93	94	97	96	85	105
Ga	21	22	22	22	19	20	23	24	21	20	21	21	21	19	21	22
K/Rb	841	773	708	772	465	470	948	988	703	712	675	502	354	392	618	648

APPENDIX II

Brief Petrographic Descriptions of Mount Buckley Basalts
(Australian Museum specimen nos DR13549 to DR13579)

B1, B2 basanite

Very fine grained holocrystalline rock, porphyritic, showing evidence of flow banding. Subhedral to anhedral equant olivine gives the rock a porphyritic texture within a groundmass of euhedral plagioclase laths, stubby euhedral augite prisms, opaque minerals and interstitial nepheline. Some minor alteration is evident in B2.

B3 nepheline hawaiite

A very fine grained rock with euhedral altered olivine and ragged anhedral nepheline crystals in a groundmass of euhedral plagioclase laths, opaque minerals and glass. A small patch of anhedral zeolite was noted.

B4, B5 basanite

Medium to fine euhedral to subhedral olivine plenocrysts in groundmass of euhedral to subhedral elongate plagioclase laths, equant euhedral to subhedral opaques and augite. Minor alteration of the olivine. Some interstitial glass is evident in B5.

B6 basanite

A very fine grained hypohaline rock with a porphyritic texture similar to B3. Subhedral to euhedral olivine, ragged low relief inclusions consisting of equigranular anhedral grains in a groundmass of smaller plagioclase laths and brown glass.

B7 basanite

Euhedral olivine phenocrysts or megacrysts in a fine groundmass of short euhedral plagioclase laths and brown glass.

B8 nepheline hawaiite

Similar to B6.

B9 alkali olivine basalt

A medium-grained holocrystalline rock. Glomoporphyritic texture with medium-sized, zoned, single euhedral crystals or clots of subhedral crystals of pink augite and medium euhedral plagioclase laths. Groundmass comprises of equant subhedral to euhedral finer plagioclase. olivine, pyroxene and opaques with minor brown glass.

B10 basanite

Spectacular phenocrysts or megacrysts of equigranular euhedral olivine in a fine groundmass of short euhedral plagioclase laths. Similar appearance to B7 except groundmass is mostly granular with only minimal glass.

B11 alkali olivine basalt

Euhedral equant and elongate olivine (with some minor alteration along cracks and around the rims), euhedral elongate plagioclase and some pink augite aggregates in a fine holocrystaline groundmass of plagioclase laths and euhedral augite and opaques.

B12 alkali olivine basalt

Subhedral equant olivine in a fine holocrystaline groundmass of euhedral subparallel plagioclase laths which give the rock a fluidal texture, euhedral equant augite and opaques.

B13 alkali olivine basalt

Medium to fine subhedral equant to elongate olivine phenocrysts in a holocrystaline groundmass of finer subhedral to anhedral olivine, plagioclastic laths, very fine equant euhedral augite prisms and opaques.

B14 alkali olivine basalt

Medium sized subhedral to euhedral equant to elongate plenocrysts of olivine and zoned pink augites with plagioclase displaying subophitic texture in a fine to medium grained groundmass of elongate euhedral plagioclase equant subhedral olivine, augite and opaques. Rock is essentially equigranular holocrystalline with less than 2% interstitial alteration products. K/Ar dating of this sample yielded an age of 39.0 ± 0.3 Ma. (average of duplicate analyses 39.1 ± 0.3 Ma and 38.8 ± 0.3 Ma, F.L. Sutherland, personal communication, 1992)

B15 alkali olivine basalt

A fine to medium grained rock comprising subhedral to euhedral olivine, pink augites displaying a subophitic relationship with the included plagioclase, and equant euhedral opaque minerals. The rock is essentially holocrystalline with interstitial areas filled with a equant anhedral low relief, low birefringence zeolite. Sample is unsuitable for chemical comparison.

B16, B17, B18, B19 alkali olivine basalt

Medium to coarse grained glomoporphyritic aggregates of subhedral pink augite and medium to coarse grained elongate subhedral to euhedral plagioglase which are crudely aligned imparting a trachytic texture to the rock. Some altered clots of euhedral crystals probably were olivine phenocrysts or megacrysts. The groundmass consists of fine euhedral augite and isotopic brown glass with some euhedral, equant and acicular opaque minerals. Zoning of augite from light centres to pink rims indicates titanium enrichment. B17 contains some ragged edged euhedral feldspars with a curved, less distinct zoning. B18 and B19 include more aggregates of ophitic pink augite.

B20 alkali olivine basalt

Fine to medium grainsize, euhedral single augite (zoned with a darker pink rim) and olivine crystals in a finer granular groundmass comprising euhedral augite, subhedral opaques and feldspar laths with some minor anhedral granular aggregates of alkali feldspars.

B21 hawaiite

Equant to elongate subhedral olivine megacrysts in a holocrystaline fine to medium grainsize groundmass of plagioclase, pink augite and opaques.

B22 hawaiite

Quite altered with carbonate occurring in veins. Original olivine phenocrysts have been extensively altered to orange iddingsite?. The fine grained groundmass consists of subhedral plagioclase laths, opaques and glass. The alteration and presence of carbonate indicates sample is unsuitable for chemical comparison.

B23 basanite

Subhedral equant to elongate olivine phenocrysts, otherwise like B22 with less alteration.

B24, B25 hawaiite

Euhedral, equant olivine phenocrysts in a granular groundmass of fine to medium grained olivine. The olivine is considerably altered red-brown around edges of grains and along fractures. The groundmass consists of euhedral plagioclase laths, small euhedral brownish augite and opaques. Alteration of the olivine and along fractures make this sample unsuitable for chemical comparison. B25 shows much less alteration of the groundmass olivine.

B26 alkali olivine basalt

Abundant medium to fine euhedral olivine phenocrysts in a fluidal textured fine granular groundmass of elongate euhedral plagioclase laths, equant augite and opaques.

B27 alkali olivine basalt

Olivine phenocrysts in a fine to medium grained granular groundmass of elongate euhedral plagioclase, equant augite, and opaques. Extensive alteration of the phenocrystal olivine and presence of approx 20% modal zeolite make this sample unsuitable for chemical comparison.

B28, B30 alkali olivine basalt

Abundant euhedral elongate to equant olivine phenocrysts in a fine grained groundmass of plagioclase, augite and dark brown isotopic glass. Extensive alteration of the phenocrystal olivine and zeolite filled vesicles make this sample unsuitable for chemical comparison. B30 has fewer phenocrysts.

B31 alkali olivine basalt

Euhedral elongate to equant olivine phenocrysts as in B28 in a glassy groundmass of with minor fine plagioclase laths.