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PRECAMBRIAN GEOLOGY OF THE WESTMORELAND REGION, NORTHERN AUSTRALIA. PART II: CLIFFDALE VOLCANICS

by

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SUMMARY

This Record reports part of the results of 1:100 000 scale geological mapping in the Westmoreland/Calvert Hills area of northwest Queensland and the Northern Territory.

The Cliffdale Volcanics are a sequence of rhyolitic to andesitic ignimbrites, flow-banded rhyolitic lavas, and acid tuffs which form part of the Murphy Tectonic Ridge. The Murphy Tectonic Ridge is the basement to the Carpentarian and Adelaidean succession in the region.

The greatest known thickness of the Cliffdale Volcanics, more than 4000 m, occurs near the junction of the Hedleys Creek (Queensland) and Seigal (Northern Territory) 1:100 000 Sheet areas, but the volcanics may have been much thicker originally as their base is not exposed, and they are overlain unconformably by the Westmoreland Conglomerate, the basal formation of the Carpentarian Tawallah Group. The volcanics are generally flat-lying or shallow-dipping, and form gently undulating terrain. They define the base of the Carpentarian System, and have been dated at 1770 m.y.

Five major units have been recognized, two of which have several sub-units. Only the youngest major unit (Billicumidji Rhyolite Member) has been formally named. The three oldest - Ꝑcc$_{1}$, Ꝑcc$_{2}$, and Ꝑcc$_{3}$ - consist of ignimbrites, and are exposed in a small tectonic basin surrounded by younger granites. Ꝑcc$_{4}$ is a sequence of ignimbrites and minor lavas, and Billicumidji Rhyolite Member (Ꝑcc$_{5}$) consists of lavas and subordinate ignimbrites. Ꝑcc$_{4}$ and Ꝑcc$_{5}$ are much more extensive than the older units, and are flat-lying or shallowly dipping except near faults or some granite contacts.

The ignimbrites commonly show well-defined eutaxitic structures, and are generally red-brown or blue-black, depending on the concentration and state of oxidation of opaque minerals in the groundmass that in many cases is devitrified glass. Phenocrysts of quartz, potash feldspar, and partly sericitized plagioclase are present in different amounts. Because of the lack of suitable exposures, no cooling units have been recognized in the ignimbrites.

The Cliffdale Volcanics have not been regionally metamorphosed, but show effects of thermal metamorphism, such as the development of chlorite, epidote, albite, biotite, and actinolite near granite intrusions.

(b)

Volcanic xenoliths occur in granite at steep intrusive contacts, but not at flat-lying intrusive contacts. Near flat-lying contacts, swarms of north and east-trending quartz-feldspar porphyry, feldspar porphyry, and some dolerite dykes have intruded the volcanics; some of these dykes also cut the granite. The volcanics are also intruded by a thick sill of andesite.

Uranium at the Pandanus Creek Uranium Mine is the only mineralization of present economic importance in the Cliffdale Volcanics. Small quartz veins near some bodies of granite contain minor copper and tin.

Almost all of the volcanics were extruded subaerially, and hence are unlikely to have given rise to volcanogenic stratiform mineral deposits.

INTRODUCTION

The Cliffdale Volcanics of the Westmoreland region are a Precambrian sequence of ignimbrites, lavas, and minor crystal tuffs of acid and intermediate composition. They define the base of the Carpentarian System in Australia (Dunn, Plumb, & Roberts, 1966), and have been dated at 1770 $\pm$ 20 m.y. (Webb, AMDEL Reports AN 2850/75, AN 1814/73). The volcanics are named after Cliffdale Creek, which cuts through part of the outcrop in Queensland, and contain uranium mineralization. They are intruded by granite (which has thermally metamorphosed them in places), and their base is not exposed. They are overlain unconformably by Carpentarian sedimentary and volcanic rocks. The volcanics have not been regionally metamorphosed, and primary textures are well preserved.

Regional Setting

The Precambrian rocks of the Westmoreland region (Hedleys Creek and Seigal 1:100 000 Sheet areas) have been assigned to four main tectonic units (Fig. 1). These are the Murphy Tectonic Ridge, the McArthur Basin, the Lawn Hill Platform, and the South Nicholson Basin. The Murphy Tectonic Ridge is an east-northeast-trending basement inlier consisting of the Cliffdale Volcanics (this Record) and Lower Proterozoic metamorphics and early Carpentarian granite (Gardner, in prep.). It formed a topographic barrier during the Carpentarian, separating and providing sediment to the McArthur Basin to the northwest, and the Lawn Hill Platform to the southeast, both of which contain a thick, relatively undeformed sequence of sedimentary and volcanic rocks (Sweet & Slater, 1975); those of the Lawn Hill Platform, which have been correlated with rocks of the Mount Isa Orogenic Domain to the south (Plumb & Derrick 1975), are overlain unconformably by younger Proterozoic sandstone and siltstone of the South Nicholson Basin.

Distribution and Thickness

The Cliffdale Volcanics form a belt of nearly continuous outcrop between 7 and 18 km wide and 48 km long extending from 26 km east of the Queensland/Northern Territory border west-southwest to the China Wall, 22 km into the Northern Territory (Fig. 1). The volcanics are well exposed over about 350 km^2 in the western part of the Hedleys Creek 1:100 000 Sheet area in Queensland, and about 325 km^2 on the adjoining Seigal 1:100 000 Sheet area in the Northern Territory. Two inliers are exposed within the overlying Westmoreland Conglomerate in the Seigal Sheet area, and a small inlier also occurs to the north of the Hedleys Creek Sheet area.

A minimum thickness of 4000 m is exposed in the Hedleys Creek Sheet area, and 900 m in the Seigal Sheet area. The stratigraphic base of the Cliffdale Volcanics is not exposed, and a regional angular unconformity separates them from overlying Westmoreland Conglomerate and Wire Creek Sandstone.

Subdivision

Five major units of the Cliffdale Volcanics have been mapped in the Hedleys Creek Sheet area (Ecc_1, Ecc_2, Ecc_3, Ecc_4, Ecc_5) and two in the Seigal Sheet area (Ecc_4, Ecc_5). The formal name 'Billicumidji Rhyolite Member' has been proposed for Ecc_5. Some of these units have been further subdivided in places. Descriptions of these units are summarized in Table 1, their distribution is shown in Fig. 2, and their interelationship is shown diagrammatically in Fig. 3. The sequence in the Hedleys Creek Sheet area is reasonably certain, but the more widely separated outcrops in the Seigal Sheet area make the determination of a stratigraphic sequence there less certain.

Ecc_1, Ecc_2, and Ecc_3 are exposed in a shallow structural basin partly bounded by younger granite in the central part of the basement area in the Hedleys Creek Sheet area. Immediately to the west of this basin, parts of Ecc_4 and Ecc_5 crop out, dipping west-northwest at about 30^o; these two units, Ecc_4 and Ecc_5, cross the Sheet boundary, and form most of the Cliffdale Volcanics outcrop in the Seigal Sheet area.

Previous Work

Carter (et al., 1961) defined the Cliffdale Volcanics in Queensland as a succession of lavas and associated pyroclastic material. Although several flows were recognized, they thought the bulk of the volcanics was composed of one or two thick flows. Their nominated type section, about 5 km north-northwest of Billicumidji Waterhole (not shown on map; grid reference HC 929489), includes only part of Ecc_4 and Ecc_5.

The Cliffdale Volcanics in the Northern Territory were described briefly by Roberts et al. (1963) as consisting of rhyolite, rhyodacite, and dacite, porphyritic in quartz and feldspar, and local thin tuff interbeds and rare agglomerate.

Present Investigation

The BMR Westmoreland field party mapped the Proterozoic rocks in the Hedleys Creek and Westmoreland 1:100 000 Sheet areas in the Westmoreland 1:250 000 Sheet area (Carter,

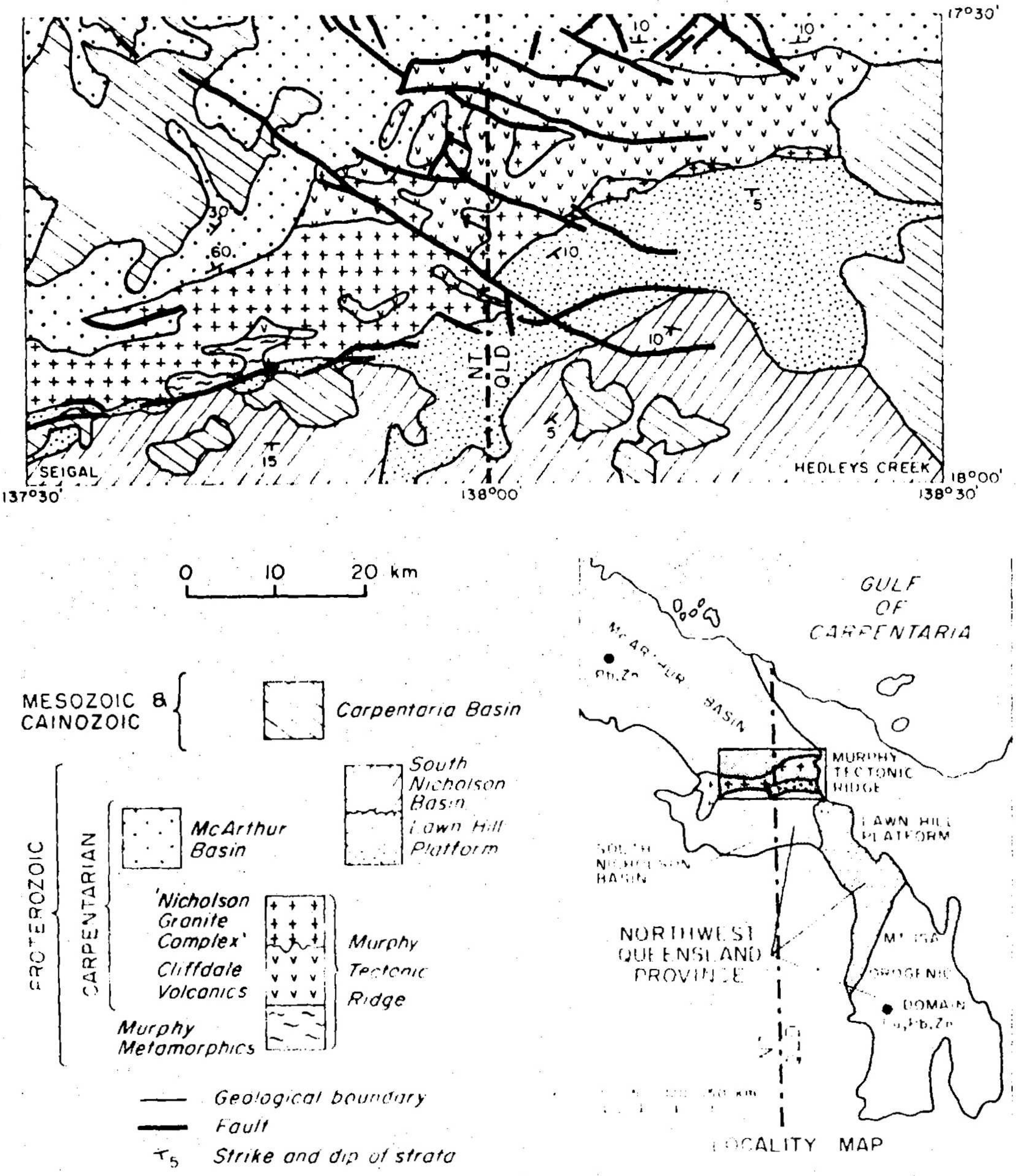

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Fig. 1 Geological sketch map of the Hedleys Creek and Seigal 1:100 000 Sheet areas

Table 1: Subdivisions of the Cliffdale Volcanics

Seigal 1:100 000 Sheet			HEDLEYS CREEK 1:100 000 Sheet		
Unit	Thickness (m)	Rock Type	Unit	Thickness (m)	Rock Type
Pcc_g	100+	Pink, medium-grained granofels	Pcc_g	100+	Pink, medium-grained granofels
Pcc_r	100+	Massive and flow-banded red rhyolitic lava			
Pcc_5	200+	Red rhyolitic lava, minor tuff	Pcc_5	2000+	Red rhyolitic lava, numerous tuff intercalations
Pcc_{5c}	100+	Dark, fine-grained ignimbrite	Pcc_4 (Undivided)	2000+	Andesitic and dacitic blue-black and dacitic red-brown ignimbrite; rhyolitic lava and tuff
			Pcc_{4r}	100	Red rhyolitic lava and vent breccia
			Pcc_{4t}	50+	Purple and green tuff and ignimbrite
Pcc_{4d}	100+	Andesitic to dacite blue-black ignimbrite; minor tuff	Pcc_{4d}	100+	Andesitic blue-black ignimbrite; minor tuff
			Pcc_{4c}	100+	Massive, pink rhyolitic lava
			Pcc_{4b}	100+	Pink and green, fine-grained dacitic ignimbrite
Pcc_{4a}	100+	Red-brown dacitic to rhyolitic ignimbrite	Pcc_3	200	Blue-black dacitic and red-brown rhyolitic ignimbrite
			Pcc_2	200	Pink and grey rhyolitic ignimbrite
			Pcc_1	150+	Red-brown dacitic ignimbrite, lava and tuff

1959), in 1972, and in the Seigal 1:100 000 Sheet area, in the Calvert Hills 1:250 000 Sheet area (Firman, 1959; Roberts et al., 1963), the following year, using 1:25 000-scale colour air photographs taken in 1972. Ground traverses were made by four-wheel-drive vehicles, and areas not accessible to vehicle were examined by helicopter. Geological data were plotted on overlays, and later transferred onto photo-scale planimetric sheets prepared by the Division of National Mapping (Seigal) and the Royal Army Survey Corps (Hedleys Creek). The compilations were reduced photographically to 1:100 000 scale, and redrawn for the preliminary maps accompanying this Record.

Nomenclature and Chemistry

Volcanic rocks containing less than 63 percent SiO_2 are termed andesite, those between 63 and 70 percent are termed dacite, and those containing over 70 percent are termed rhyolite.

Major and trace element analyses of 49 representative samples are shown in Tables 2 and 3. Of these analyses, 10 are of dyke rocks, and 4 are of xenolith rocks collected from inclusions of Cliffdale Volcanics up to a metre across within marginal granite of the Nicholson Granite Complex. Geochemistry of the Cliffdale Volcanics and the Nicholson Granite Complex will be discussed in a separate report.

The chemical analyses were carried out by the Australian Mineral Development Laboratories AMDEL (Report AN 2882/75) using the H3 and B1 schemes. Major elements and Ba, Ce, Mo, Nb, Pb, Rb, Sn, Sr, Th, U, W, Y, and Zr were determined by X-ray fluorescence, and Bi, Co, Cu, Li, Ni and Zn by atomic absorption spectrophotometry.

Unless otherwise stated, textural terms are as defined by Joplin (1968).

Age Determinations

The Cliffdale Volcanics have been isotopically dated by the Rb/Sr method at 1770 ± 20 m.y. (initial Sr^{87}/Sr^{86} = 0.7078 ± 0.0017) by A.W. Webb (AMDEL Report 1814/73). Similar ages have been derived from some phases of the 'Nicholson Granite Complex'* (Plumb & Sweet, 1974) A.W. Webb (AMDEL Report 2850/75., which appears to intrude the Cliffdale Volcanics. Initial Sr^{87}/Sr^{86} ratios for the granite vary from 0.7069 ± 0.0040 for some phases, to 0.7178 ± 0.0038 for other phases. This suggests that some of the granites and volcanics are comagmatic, but that they may not all be so. The age relations of the 'various phases of the 'Nicholson Granite Complex' are discussed by Gardner (in prep.).

* Name not yet approved

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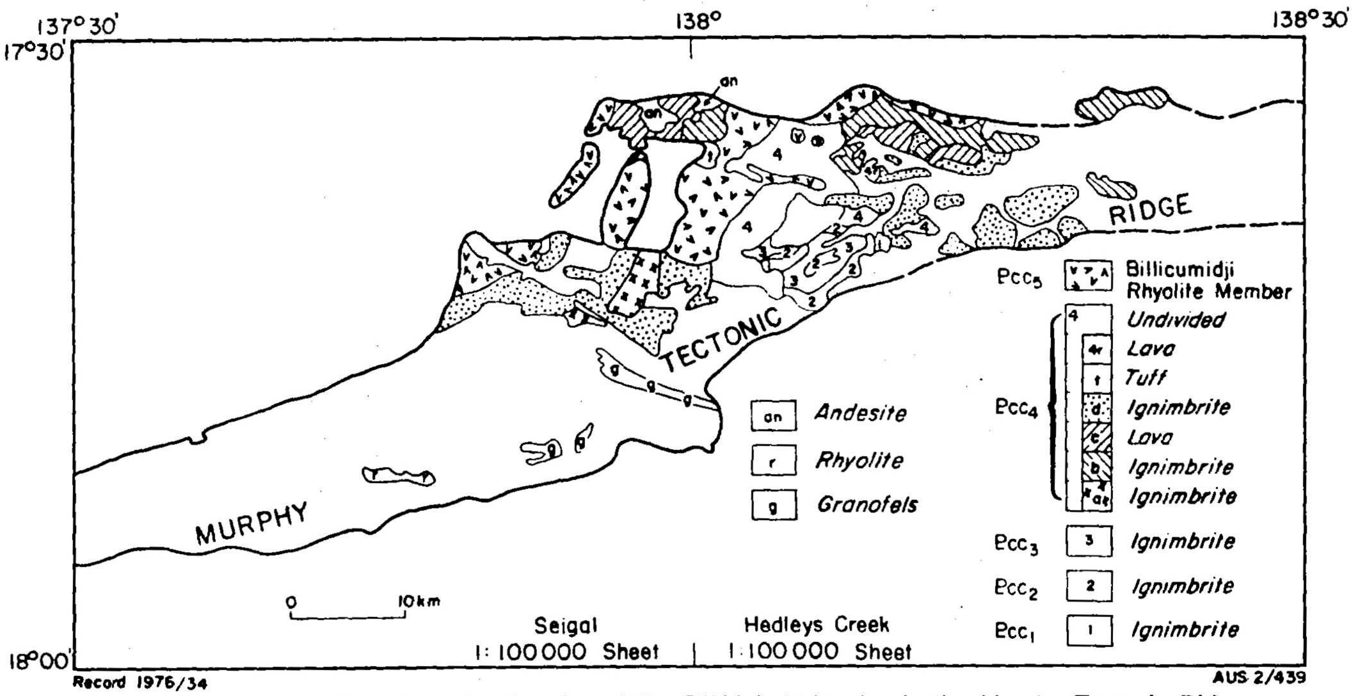

Fig. 2 Distribution of units and sub-units of the Cliffdale Volcanics in the Murphy Tectonic Ridge

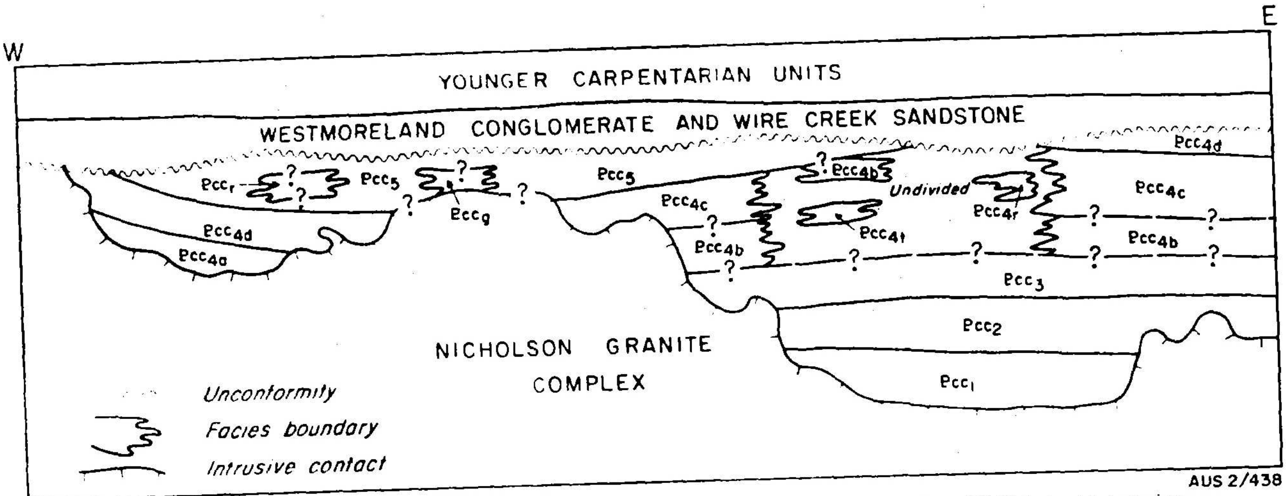

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Fig 3 Diagrammatic relationship of units and sub-units within the Cliffdale Volcanics

Regional Correlations

Acid volcanics of similar age to the Cliffdale Volcanics are known in other parts of northern Australia. These include the Edith River Volcanics of the Pine Creek Geosyncline, various volcanics underlying the McArthur Basin in the Arnhem Land area, and volcanics of the Tewinga Group in the Mt Isa area (Plumb & Derrick 1975).

DESCRIPTION OF ROCK UNITS

UNIT Ƀcc$_1$

Ƀcc$_1$ consists of dacitic ignimbrite, porphyritic dacitic lava, and minor tuff. Ƀcc$_1$ forms irregular outcrops at the northeastern and southwestern margins of a tectonic basin formed by granite intrusions between about 6 km southeast and 6 km southwest of Billicumidji Waterhole (grid reference HC 929487), Hedleys Creek Sheet area. The unit forms undulating hills and strike ridges; the rocks are poorly exposed, and mainly form a rubbly scree. The unit is defined as the part of the Cliffdale Volcanics that underlies Unit Ƀcc$_2$, a prominent marker band.

The unit is at least 150 m thick; its base is not exposed. The most easterly outcrop, at grid reference HC 980450, about 6 km southeast of Billicumidji Waterhole, is nominated as the reference area.

Lithology

The ignimbrite is red-brown and thinly banded, and consists of scattered microphenocrysts of white alkali fledspar in the cryptocrystalline groundmass. Eutaxitic structures are well displayed on weathered surfaces, where many flattened altered pumice fragments are seen to contain epidote.

The dacitic lava is red-brown to purple, and contains phenocrysts of quartz and red alkali feldspar and white to yellow plagioclase in a cryptocrystalline groundmass. Some purple-grey, more readily weathered rocks are associated with the dacite, and may be ignimbritic intercalations, as they are similar in appearance to weathered ignimbrites in Ƀcc$_3$. In thin sections of the dacite, embayed phenocrysts of quartz, 3 to 5 mm across, make up 5 to 15 percent of the rock, and euhedral feldspars of similar size amount to 10 to 15 percent. Alkali feldspar phenocrysts are more abundant than those of plagioclase; they are cloudy, and generally show simple twinning. The plagioclase is highly sericitized, and its original composition is difficult to determine. Scattered flakes and aggregates of biotite, which are less than 0.5 mm across make up to 5 percent of the dacite, and are pseudomorphed by chlorite and opaque grains. The groundmass of the dacite consists of glass devitrified to cryptocrystalline, hypidomorphic-granular quartz and feldspar. The amount of opaque minerals in the groundmass and their degree of oxidation determine the colour of the rock which is red, brown, or, less commonly, black. Laminar flow banding is not apparent in hand specimens, but in thin sections a fluidal fabric, denoting flowage, can be seen around many phenocrysts thus distinguishing the dacite as a lava and not an ignimbrite.

The tuff is grey, medium to fine-grained, and massive.

UNIT Ᵽcc$_2$

Ᵽcc$_2$ consists of two pale pink to grey, rhyolitic ignimbrites, both of which are a characteristic light buff colour on colour aerial photographs, and together form a prominent marker. The upper ignimbrite is microporphyritic. The lower ignimbrite contains abundant fragments of volcanic rocks and pumice set in a crytocrystalline groundmass which shows well developed eutaxitic structures. The unit conformably overlies Ᵽcc$_1$, and is overlain conformably by Ᵽcc$_3$ (Fig. 4): In the southwestern part of the basin Ᵽcc$_2$ and Ᵽcc$_3$ lens out and Ᵽcc$_1$ is overlain by Ᵽcc$_4$; elsewhere its base is locally intruded by granite.

Ᵽcc$_2$ is confined to the tectonic basin in the Hedleys Creek Sheet area, and crops out as cuestas up to 50 m high, fringing granite outcrops. The eastern part of the basin contains the upper ignimbrite, which dips 5° to 10° northwest. In the northern part of the basin both ignimbrites dip south at about 20° beneath Ᵽcc$_3$, and the lower ignimbrite is overlapped by Ᵽcc$_4$. On the western side of the basin, Ᵽcc$_2$ dips west at 5°-10°, probably owing to local tilting during granite emplacement. It is faulted against granite (Ᵽgn$_5$) on the southwestern and southern sides of the basin. An inlier of Ᵽcc$_2$ appears to occupy the core of an anticline near the centre of the basin.

Ᵽcc$_2$ is not completely exposed at any one locality; hence its maximum thickness, probably over 200 m, is uncertain. The reference area is located at grid reference HC 970450, about 6 km southeast of Billicumidji Waterhole.

Fig. 4. Jointed, flat-lying rhyolitic ignimbrite of Unit Pcc_2 (pale) overlain by blocky dacitic ignimbrite of Unit Pcc_3 (dark). Hedleys Creek Sheet area, 6 km southeast of Billicumidji Waterhole. Neg M/1424-31

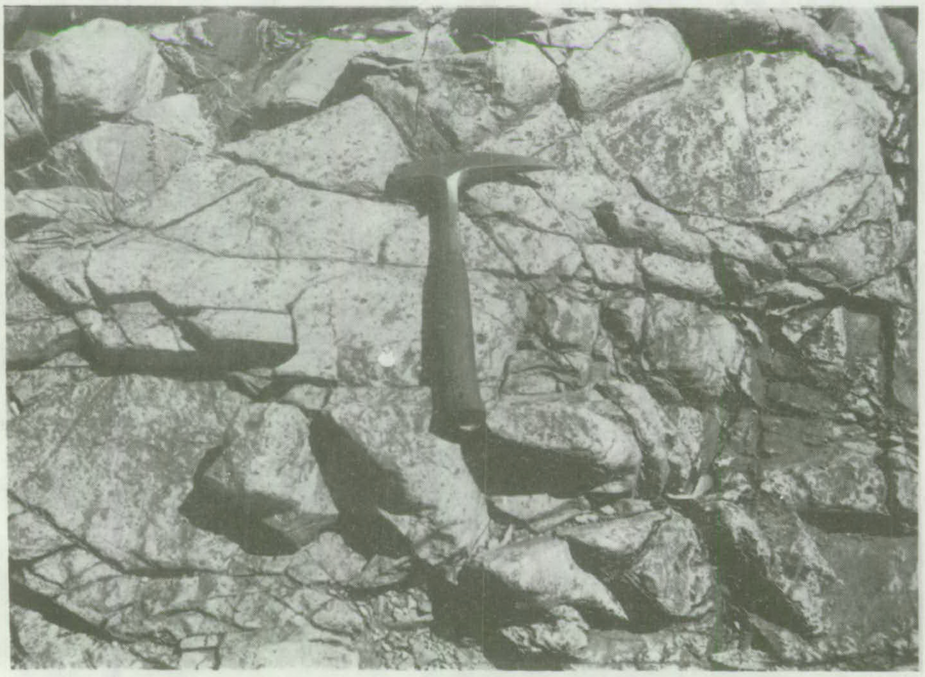

Fig. 5. Closely spaced vertical joints in pavement developed on rhyolitic ignimbrite of Unit Pcc_2, 6 km southeast of Billicumidji Waterhole. Neg M/1424-28

The unit forms jointed pavements (Fig. 5) and flaggy scree. Closely spaced vertical joints are well developed, as also are horizontal joints which produce topographic benches. Cleavage and shearing are prominent locally, but jointing is the dominant overall structural feature.

Lithology

The lower ignimbrite has a prominent eutaxitic structure, and is red to pink, although it weathers to a characteristic pale grey-green. It contains abundant fragments of various volcanic rocks, pumice, and shards, together with scattered microphenocrysts of partly sericitized plagioclase, cloudy alkali feldspar, and rare quartz, and also bent flakes of chloritized biotite. The volcanic rock fragments make up 20 to 30 percent of the rock, and range in size from ash to lapilli; most are red and microporphyritic, and some are of ignimbrite, and were probably derived from Ecc$_1$. Flattened pumice fragments form thin lenses, up to 5 mm long, with frayed ends; they have been recrystallized to an aggregate of quartz, feldspar, and chlorite. The groundmass of the ignimbrite is pink and cryptocrystalline to microcrystalline, and was probably originally glassy. A high degree of welding is indicated by flattened shards and pumice fragments which give the rock a fluidal foliation. The groundmass consists of quartz, feldspar, minor sericite, clay, chlorite and abundant fine opaque dust: spherical, polycrystalline aggregates present are the result of devitrification.

The upper ignimbrite is grey to pink, and contains microphenocrysts of embayed beta-quartz (5 to 15 percent of the rock), red to pink, partly cloudy tabular alkali feldspar (5 to 15 percent), and partly bleached biotite flakes (about 1 percent) which are commonly bent. The groundmass is devitrified to a microcrystalline aggregate of quartz and feldspar and abundant small granules of magnetite. It contains some thin lenses of quartz up to 0.5 mm long, which may be silicified shards. Some elongate polycrystalline aggregates of quartz and feldspar, up to 1 mm long, are flattened pumice fragments. Cuspate and lumate shards in some thin sections indicate a lack of welding.

UNIT Ecc$_3$

Ecc$_3$ comprises two blocky ignimbrites: a lower one which is red-brown and rhyolitic (71 percent SiO_2), and an upper one which is blue-black and dacitic (67 percent SiO_2). The upper ignimbrite is locally absent.

The unit is confined to the Hedleys Creek Sheet area. It occupies the central region of the tectonic basin, and also crops out to the west, where it is intruded by granite (Bgn_5) and overlain by Bcc_4; in this western area it dips 20^o to 30^o to the west-northwest. In addition, a small outcrop of weathered ignimbrite similar to that of Bcc_3 is present 12 km southeast of Billicumidji Waterhole. This ignimbrite appears to underlie part of Bcc_4 and probably belongs to Bcc_3.

Bcc_3 conformably overlies Bcc_2 in the east, and is the youngest unit within the tectonic basin. West of the basin its relationship with Bcc_4 is obscured by poor exposures, and by faults, dykes, and granite. However, here the unit is thought to interfinger with the lower part of Bcc_4.

The two ignimbrites are each about 100 m thick. The reference area is 6 km southeast of Billicumidji Waterhole, adjacent to the reference areas for Bcc_1 and Bcc_2.

The ignimbrites form bare, undulating hills with depressions along major joints and faults. Near granite outcrops, many joints are occupied by porphyritic acid dykes. The joints are in two sets at right angles and are generally vertical. Unlike in Bcc_2, there appears to be no closely spaced flat-lying jointing. Both lower and upper ignimbrites form rubbly and blocky scree on massive and well jointed pavements. The upper ignimbrite also forms exfoliated rounded boulders (Fig. 6).

Lithology

Both ignimbrites contain phenocrysts of quartz and alkali feldspar in a microcrystalline, highly siliceous groundmass. Pumice and volcanic rock fragments are abundant, and well-formed eutaxitic structures are ubiquitous.

The lower ignimbrite is red-brown, and contains numerous volcanic rock and pumice fragments. Quartz phenocrysts form 10 percent of the rock; they are embayed and generally 2 to 3 mm across; some are fractured and cemented by calcite. Tabular phenocrysts of feldspar make up about 20 percent of the ignimbrite, and are 2 to 4 mm long; subhedral, pink alkali feldspar and white plagioclase are present in about equal amounts. Those of alkali feldspar are simply twinned and slightly cloudy. Those of plagioclase show alteration to sericite; this obscures most twinning - hence compositions generally cannot be determined otically, although some original zoning can be distinguished. Small chlorite

Fig. 6. Rounded boulders of dacitic ignimbrite of Unit Pcc_{3}, 6 km southeast of Billicumidji Waterhole, Hedleys Creek Sheet area. Neg M/1424-34

Fig. 7. Isolated low hill of dacitic ignimbrite of Sub-unit Pcc_{4d} 10 km east of Billicumidji Waterhole. Neg M/1375-27

flakes, some bent, are accompanied by fine opaques and granular sphene and epidote; together these form about 2 percent of the rock; they are probably pseudomorphs after biotite. The volcanic rock fragments form up to 10 percent of the ignimbrite, and are mainly in the lapilli size range. Both porphyritic and aphyric volcanic rocks are represented. Most of the fragments are equant and angular, and have not been deformed. Flattened pumice fragments, present as elongate lenses with frayed ends, form up to 10 percent of the rock; they range up to 5 cm in length, although most are less than 20 mm long, and consist of devitrified glass. Devitrified glass shards amount to up to 10 percent of the ignimbrite, and are only moderately welded.

The groundmass of the lower ignimbrite is pale red and is mostly microcrystalline devitrified glass. It shows a fluidal fabric due to compression and welding of glass shards and pumice fragments. Accessory minerals present include fine acicular apatite, granular fluorite, stumpy zircon, calcite, and a green-brown metamict mineral which is possibly allanite.

Except for its blue-black colour, the upper ignimbrite closely resembles the lower red-brown ignimbrite. However, it contains fewer phenocrysts, fewer rock and pumice fragments, and fewer shards.

Because of their differences, the two ignimbrites are considered to be the products of two separate eruptions.

UNIT Ecc_4

Ecc_4 comprises the rocks underlying prominent rhyolite lavas of Ecc_5 outside the tectonic basin. It consists of numerous ignimbrites, tuffs, and lava flows, many of which have been mapped as separate sub-units (Fig. 2). In the Seigal Sheet area the two main sub-units present are Ecc_{4a} and Ecc_{4d}, both consisting of ignimbrite. In the Hedleys Creek Sheet area sub-units Ecc_{4b} and Ecc_{4d} (ignimbrite), Ecc_{4c} (lavas), and Ecc_{4t} (tuff), and undivided Ecc_4, crop out.

Each sub-unit is at least 100 m thick (the average height of hills formed by the various sub-units), and Ecc_4 as a whole has a maximum thickness of at least 2000 m: it is intruded by granite and its base is not exposed. The reference area and reference section for the unit (here undivided) is about 7 km southwest of Billicumidji Waterhole, from HC 885450 to HC 855466.

Stratigraphic relationships between the sub-units are generally uncertain because of concealed contacts and widely separated outcrops. Ᵽcc$_{4a}$, which is confined to the Seigal Sheet area, consists of red-brown ignimbrite, and is overlain by blue-black ignimbrite tentatively recognized as Ᵽcc$_{4d}$. Thin banded and graded-bedded tuff (Fig. 16), in part conglomeratic, overlies sub-unit Ᵽcc$_{4a}$ in the Seigal Sheet area (grid reference S 140425), and is similar to, but coarser-grained than, tuff exposed 200 m below the top of Ᵽcc$_{4}$ in the Hedleys Creek Sheet area (at HC 843433). This suggests that sub-unit Ᵽcc$_{4d}$ is equivalent to the upper part of Ᵽcc$_{4}$ in the type area. Similar banded tuff has also been recorded 2 km south-southeast of the Norris Copper mine (S 030410), 11 km southwest of the other occurrence in the Seigal Sheet area. Ᵽcc$_{4b}$ is overlapped, apparently conformably, in the Hedleys Creek Sheet area by Unit Ᵽcc$_{5}$, but it is thought to be older than sub-unit Ᵽcc$_{4c}$, which in turn appears to be older than Ᵽcc$_{4d}$. The interpreted relationships of the sub-units, and of the other units of the Cliffdale Volcanics, are shown diagrammatically in Figure 3.

Sub-unit Ᵽcc$_{4a}$

Ᵽcc$_{4a}$ comprises red-brown ignimbrites cropping out in the Seigal Sheet area. The ignimbrites show thin banding, highlighted by preferential weathering (Fig. 13-15). They contain small phenocrysts of white plagioclase, pink alkali feldspar, and quartz, volcanic rock fragments of mostly lapilli size, flattened pumice fragments, and minor small aggregates of biotite-chlorite and opaque minerals. The ignimbrites are cut by veins up to 3 mm wide consisting of quartz and epidote in a pale red, partly streaky microcrystalline groundmass.

Phenocrysts of plagioclase are up to 3 mm across, and form up to 30 percent of the rock; they are highly sericitized, especially in their cores (although some rims are fresh, and show zoning), and are also altered to clay and chlorite. Alkali feldspar phenocrysts amount to up to 15 percent of the rock; they are partly cloudy, and contain dusty opaques and minor chlorite and calcite. Phenocrysts of quartz form up to 5 percent of the rock; they are embayed, and contain inclusions of devitrified groundmass which also forms veinlets and fracture fillings. Mafic minerals are uncommon, but up to 2 percent is present in some specimens; they are represented by bleached and altered biotite flakes (and possibly hornblende) largely replaced by opaque minerals, sphene, and chlorite. Some of the flakes are wrapped around phenocrysts, and some in the groundmass are bent. There are also scattered opaque grains.

Fig. 8. Typical outcrop of flow-banded rhyolitic lava of Sub-unit Pcc_{4c} 12 km east of Billicumidji Waterhole, Neg GA/9230

Fig. 9. Columnar jointing in dacitic ignimbrite of Sub-unit Pcc_{4b}, near Lagoon Creek (HC 830557). Neg GA/9227

The volcanic rock fragments closely resemble the host rock. The pumice fragments contain chlorite flakes and fine magnetite or hematite grains. Their quartzo-feldspathic groundmass is coarser-grained than that of the host rock.

The groundmass of the red-brown ignimbrites is devitrified glass, and consists of quartz, feldspar, and minor sericite, chlorite, sphene, and other secondary minerals. The red-brown colouration is due to minute grains of hematite in the groundmass. The devitrification has resulted in a micrographic fabric, but this has not completely obliterated the eutaxitic structure. Some of the flattened glass shards form pressure tails around phenocrysts; the resulting banding (Figs 13-15) is discontinuous and lenticular, distinguishing it from flow banding found in rhyolite lavas. A common feature in the groundmass is the presence of small irregular fragments of quartz, some of which are flattened, and form lenticular plates.

Sub-unit Ɛcc$_{4b}$

Rocks of Sub-unit Ɛcc$_{4b}$ are red, pink, and less commonly pale grey ignimbrites showing prominent eutaxitic structures. The ignimbrites show spectacular columnar jointing bordering Lagoon Creek at HC 830557 (Fig. 9), where at least five sets of joints are developed. The ignimbrites contain up to 20 percent red volcanic rock fragments between 1 and 20 mm long, as well as phenocrysts of feldspar and rare quartz. Phenocrysts of alkali feldspar are reddish and slightly cloudy, whereas those of plagioclase are white and altered to sericite and clay, especially in their cores. The feldspar phenocrysts are about 2 mm long, and make up between 10 and 20 percent of the rock; the two types of feldspar are present in about equal amounts. Pumice fragments, some containing aggregates of chlorite and opaques, form between 10 and 30 percent of some ignimbrites. The pumice-rich ignimbrites have a well-developed fluidal fabric formed by flattened shards in the groundmass. Aligned amygdaloidal structures 3 to 10 mm long, are present locally.

In most ignimbrites the groundmass is generally pink devitrified glass consisting of quartz, feldspar, and opaques. Some specimens show areas of relict perlitic cracks.

Sub-unit Pcc_{4c}

Sub-unit Pcc_{4c} consists of red to pink rhyolite lava which is massive and flow-banded (Fig. 8). The massive part is microporphyritic, with pink potash feldspar laths up to 2 mm long forming up to 5 percent, and small aggregates of biotite-chlorite, nearly 1 mm across, forming about 1 percent of the rock. Some of the biotite-chlorite aggregates are aligned, and impart a streaky appearance to the rock. The groundmass is pale red and cryptocrystalline. The flow-banded part of the rhyolite is also microporphyritic, but the pink and white feldspar phenocrysts are not obvious on weathered surfaces. Some of the flow banding consists of overlapping lenticular streaks of material which resembles flattened pumice fragments. However, most of the flow banding is marked by thin continuous layers of quartz, feldspar, and devitrified glass. Some of the banding is convolute. Spherulites and vesicles lined with chalcedony are present locally.

Sub-unit Pcc_{4d}

Pcc_{4d} consists of blue-black to grey ignimbrite. It crops out in the Seigal Sheet area and also along both sides of Cliffdale Creek in the Hedleys Creek Sheet area, commonly forming hills covered with blocky rubble (Figs 7, 10). These hills are higher than those consisting of adjacent and apparently older sub-units, and are a distinctive dark green on colour aerial photographs. At one locality in the Seigal Sheet area (S 064430), the sub-unit appears to overlie Pcc_{4a}, and is intruded by granite; nearby it contains pods of greisenized granite. About 1 km to the north, there is a tin prospect (Traceys Table), consisting of three small pits, and also a small copper prospect, in the ignimbrite.

The ignimbrite contains phenocrysts of plagioclase and fragments of acid volcanic rocks and pumice enclosed in a light grey, cryptocrystalline groundmass. Two specimens were also found to contain unaltered and partly chloritized augite phenocrysts: one of these came from an ignimbrite in the Hedleys Creek Sheet area about 100 m below the top of Unit Pcc_4 and the other came from the Seigal Sheet area, suggesting that these two ignimbrites are possibly equivalent. The phenocrysts of plagioclase are about 3 mm long, and amount to up to 20 percent of the rock; they are much sericitized, expecially the cores, and their composition cannot be determined optically. Minor alkali feldspar, quartz, and actinolite phenocrysts are present in the sub-unit in the Seigal Sheet

Fig. 10. Dislodged blocks of finely banded, blue-black dacitic ignimbrite of Sub-unit Ᵽcc$_{4d}$, 15 km southeast of Traceys Table prospect, Seigal Sheet area. Neg GA/9202

Fig. 11. Crag, 20 m high, formed from dyke of rhyolitic breccia (forming a volcanic fissure?) in Sub-unit Ᵽcc$_{4r}$, 4.5 km northeast of Billicumidji Waterhole, Hedleys Creek Sheet area. Neg GA/9159

Fig. 12. Rhyolitic breccia forming dyke shown in Figure 11, a probable volcanic fissure. Sub-unit Ꝑcc$_{4r}$, 4.5 km northeast of Billicumidji Waterhole. Neg GA/9243

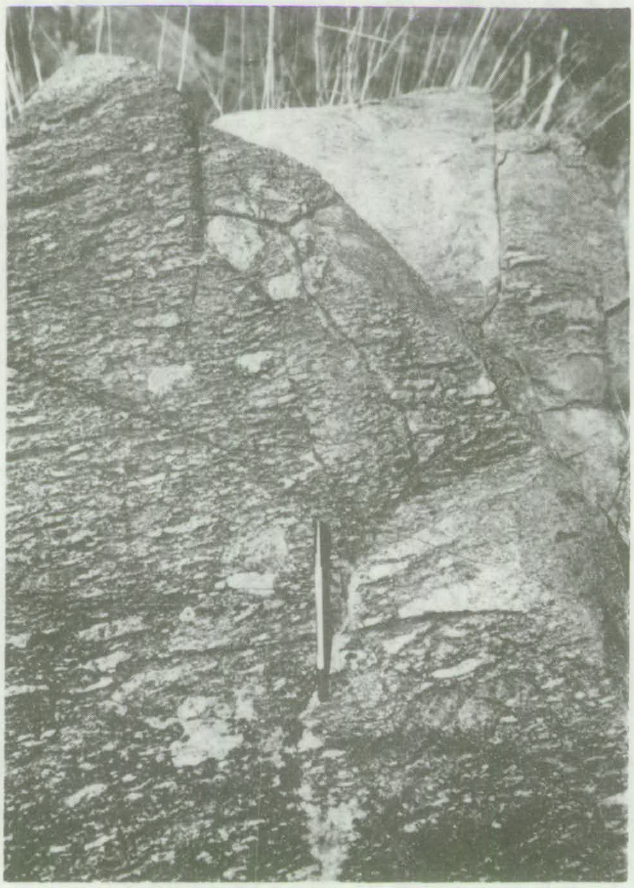

Fig. 13. Flattened pumice fragments in ignimbrite of Unit Ꝑcc$_{4}$ (undivided), 6 km southeast of Billicumidji Waterhole, Neg GA/9195

area. The ignimbrite also contains up to 1 percent of chloritic pseudomorphs after biotite. Elongate fragments of porphyritic volcanic rocks form about 10 percent, and flattened pumice fragments up to 10 percent. Rock and pumice fragments are less abundant in the Seigal Sheet area. Relict perlitic cracks are present in the devitrified glassy groundmass, which now consists of quartz, feldspar, and minor chlorite, epidote, clay, opaques, and, in the Seigal Sheet area, biotite, actinolite, and sphene. Some of the groundmass is fluidal, owing to compression and welding of shards. A granular fabric is locally developed adjacent to intrusive granite contacts, where fresh biotite and actinolite are probably metamorphic rather than magmatic. Three of the blue-black ignimbrites from the Seigal Sheet area have been chemically analysed: they range in composition from andesite to dacite (Table 2).

Sub-unit Ecc_{4r}

Ecc_{4r} consists of massive and flow-banded red rhyolitic lava (Table 2) which is locally vesicular and spherulitic. The flow banding is contorted in places, and the lava was evidently highly viscous when it was emplaced. The sub-unit crops out over 2 sq km, about 4.5 km northeast of Billicumidji Waterhole, where it forms low dome-shaped hills. It has a distinctive light pink pattern on the colour aerial photographs.

Near the western limit of outcrop of the sub-unit, a north-trending dyke of rhyolite breccia forms a prominent isolated crag, 100 m long and over 20 m high (Figs 11 & 12). A vertical foliation in the rhyolite lava next to this dyke indicates vertical movement, and the dyke probably fills the fissure from which the rhyolite was erupted.

Sub-unit Ecc_{4t}

Rocks of Ecc_{4t} finely banded purple, red, and green flaggy tuffs. The banding is due to variations in grainsize, and some bands show graded bedding. Some intercalations within the tuffs have eutaxitic structures, and are probably ignimbritic, some are microporphyritic, and contain sparse pumice fragments, and some are conglomeratic. Hills made up of the flat-lying tuff are up to 100 m high, but basal contacts are not exposed. The Billicumidji Rhyolite Member overlies this sub-unit at several localities.

Undivided Ecc_4

The undivided part of Ecc_4 consists of red-brown ignimbrites, blue-black ignimbrites, rhyolite lavas and minor tuff, and is well exposed in the reference area (Fig. 17), where there are at least 16 individual flows.

The succession exposed is as follows:

Top

- Red ignimbrite overlain by lava of Billicumidji Rhyolite Member
- Blue ignimbrite
- Red-brown ignimbrite
- Black ignimbrite
- Red lava (R 3)
- Blue-black ignimbrite
- Pink lava, brecciated (R 2)
- Blue-black ignimbrite
- Red flow-banded lava (R 1)
- Blue-black ignimbrite, brecciated
- Blue-black ignimbrite
- Red-brown banded ignimbrite
- Blue-black ignimbrite
- Red-brown ignimbrite
- Blue-brown ignimbrite

Base: Intrusive granite (Egn_5)

This succession is over 2000 m thick: this is a minimum thickness, as the base of the unit is intruded by granite.

In the reference area the unit has been tilted by the intruding granite, and dips to the west at 30° and forms steep hills, but elsewhere it is generally flat-lying, and forms undulating terrain where much less of the sequence is exposed.

Eight of the flows in the reference section are blue-black ignimbrites similar to those of Ecc_{4d}. A prominent feature of these ignimbrites is a thin, lenticular, layering caused by variations in composition and flattening of pumice fragments (Figs 13 & 14). Volcanic rock fragments up to 10 cm across form up to 10 percent of some of the middle ignimbrites, but are less abundant in higher and lower flows. One analysed sample, an augite-bearing blue-black ignimbrite, has a silica content of 56 percent, and hence is an andesite (Sample 13761208, Table 2).

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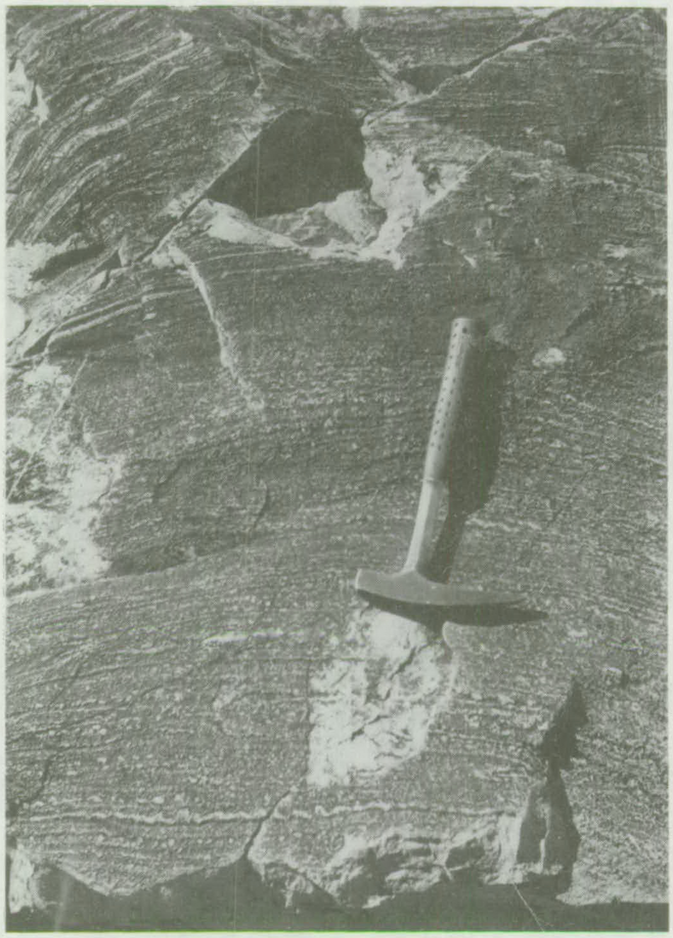

Fig. 14. Thin layering in ignimbrite of Unit Ꝑcc$_4$ (undivided), 6 km southeast of Billicumidji Waterhole, Neg M/1424-20

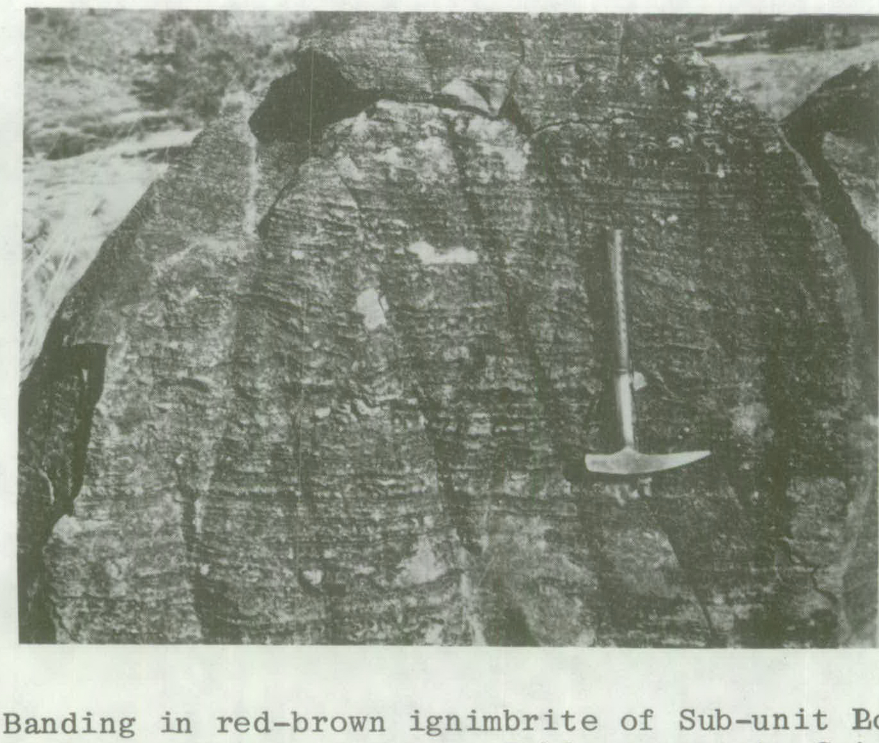

Fig. 15. Banding in red-brown ignimbrite of Sub-unit Ꝑcc$_{4a}$, 15 km southeast of Tracys Table prospect, Seigal Sheet area. Neg GA/9193

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Fig. 16. Graded bedding in tuff of Sub-unit Pcc_{4d} (overlying Sub-unit Pcc_{4a}), 10 km southeast of Tracys Table prospect, Seigal Sheet area.

Neg GA/9169

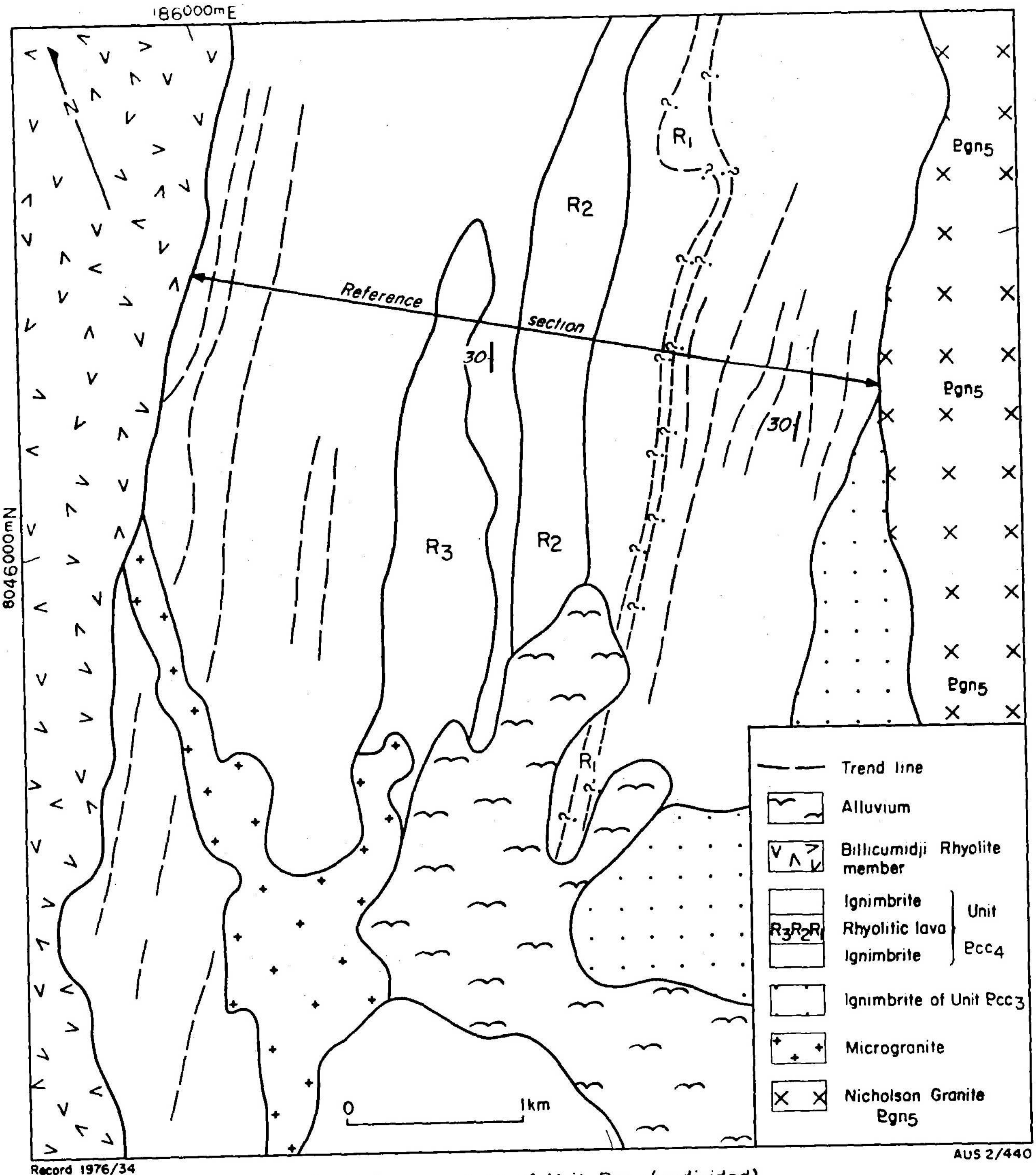

Fig. 17 Reference area of Unit Pcc4 (undivided)

A small tuffaceous lens about 2 m thick is present in blue-black ignimbrite near the top of the section (at HC 843438). It is dark grey, thinly bedded, and medium to fine-grained, and shows graded bedding. It may have been deposited in a small shallow lake.

At least five flows in the reference sections are red to brown ignimbrites, which are irregularly intercalated with other ignimbrites and lavas. They are prominently banded, and are similar petrographically to the red-brown ignimbrites of sub-unit Ecc_{4a}. Traces of pyrite were found in red-brown ignimbrite near a granite contact. One sample of red-brown ignimbrite from the reference section has been chemically analyzed: it is dacite, and has a silica content of 66.1 percent (sample 73761209, Table 2).

A feature particularly noticeably in the red-brown ignimbrites is colour zoning due to bleaching around small fractures and veins, indicating some alteration of the groundmass. The alteration zones are a few millimetres across.

Three tabular rhyolite bodies lie about mid-way in the reference section, and others are present in the general area. They are red to pink, microporphyritic or aphyric, and commonly show flow banding which ranges from planar to convolute. Their contacts commonly appear sheared. The lowest rhyolite is about 1000 m stratigraphically below the Billicumidji Rhyolite Member, is a few metres thick, and appears to extend along strike for at least 2000 m; it shows convolute flow banding and some brecciation at its most northerly exposure (HC 8874770). The middle rhyolite generally lies about 150 m above the lower one. It is lenticular and conformable, wedging cut in the north, and joining with the uppermost rhyolite in the south. It has a maximum thickness greater than 200 m over a strike length of more than 4000 m. In the south it is poorly exposed and is possibly intruded by microgranite. The uppermost rhyolite is separated from the middle rhyolite by a blue-black ignimbrite about 50 m thick. It is similar in shape and size to the middle rhyolite, and its top is about 650 m below the top of the unit. Rhyolite also occurs within a fault wedge immediately south of the reference section; it may be a combination of the middle and upper rhyolites in the reference section.

Several outcrops some distance from the reference section have been mapped as undivided Ecc_4. These include small scattered outcrops of weathered ignimbrite in the alluvial plains near Cliffdale Creek; flat-lying red-brown and blue-black ignimbrite south of the reference section, at locality HC 830410; and similar rocks within a fault block to the north of the reference section.

Phenocrysts of plagioclase make up about 1 percent of the rocks, and are altered to sericite, chlorite, and, less commonly, epidote; their compositions cannot be determined optically. Phenocrysts of alkali feldspar form about 2 percent of the rocks and are only slightly clouded. Chlorite is generally associated with aggregates of fine-grained opaques, and has probably replaced primary biotite.

The groundmass of the rhyolites is devitrified, and consists of a granular assemblage of quartz and partly altered fine grains, are ubiquitous, and delineate some of the flow-banding. Spherulitic and comb fabrics (Spry, 1974) are developed in some feldspathic bands and are outlined by iron-staining of alkali feldspar. Micrographic intergrowths of quartz and alkali feldspar are common in the groundmass of massive rhyolite, forming patches up to 3 mm across. Fine subhedral quartz grains form aggregates in the groundmass: in massive rhyolites these aggregates are irregular, whereas in flow-banded rhyolites they form thin laminae. A feature of these quartz aggregates is their relatively large size (0.1 to 0.5 mm across) compared with other grains in the groundmass; in some bands the quartz increases in size from the margins to the centre, suggesting increasing degrees of crystallization and these bands resemble veinlets of secondary quartz.

A yellow-green flaky mineral, possibly nontronite, occurs with chlorite as aggregates and thin veins in altered rhyolites.

Chemical analyses of three rhyolites show silica contents between 73 and 78 percent (Table 2).

BILLICUMIDJI RHYOLITE MEMBER* (Ꝑcc$_5$) (new name)

The Billicumidji Rhyolite Member of the Cliffdale Volcanics, consists of at least five flow-banded (Figs 18, 19) and massive red rhyolitic lava flows and minor intercalations of tuff and ignimbrite. It is the youngest unit of the Cliffdale Volcanics, and is unconformably overlain by the Westmoreland Conglomerate, which locally contains clasts of red rhyolite similar to that at the top of the member. However, most of its contacts with the Westmoreland Conglomerate are faults. The distribution of the member is shown in Figure 2 as well as on the 1:100 000 geological maps. On the colour air photographs, the rhyolites appear pale pink. The main outcrop is a northtrending belt straddling the junction of the Seigal and Hedleys Creek Sheet areas, and extending north about 13.5 km from a prominent east-trending fault (HC 840425) to a faulted contact with the Westmoreland

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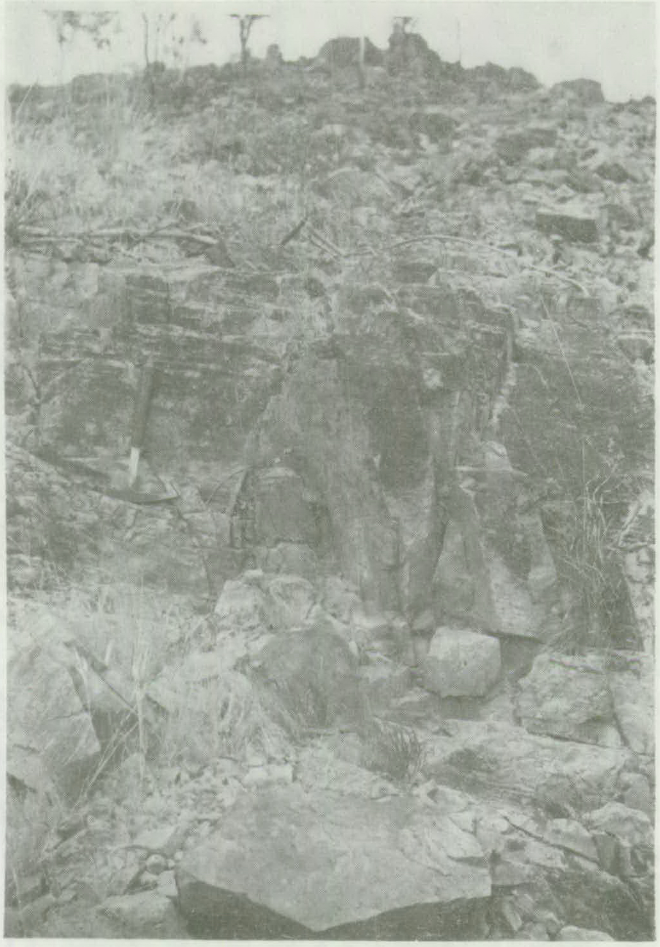

Fig. 18. Gently dipping flow-banding in lava of Billicumidji Rhyolite Member, 10 km northwest of Billicumidji Waterhole. Neg M/1424-36

Fig. 19. Steeply dipping flow-banding in lava of Billicumidji Rhyolite Member, upturned near fault, 15 km southwest of Billicumidji Waterhole. Neg M/1424-2

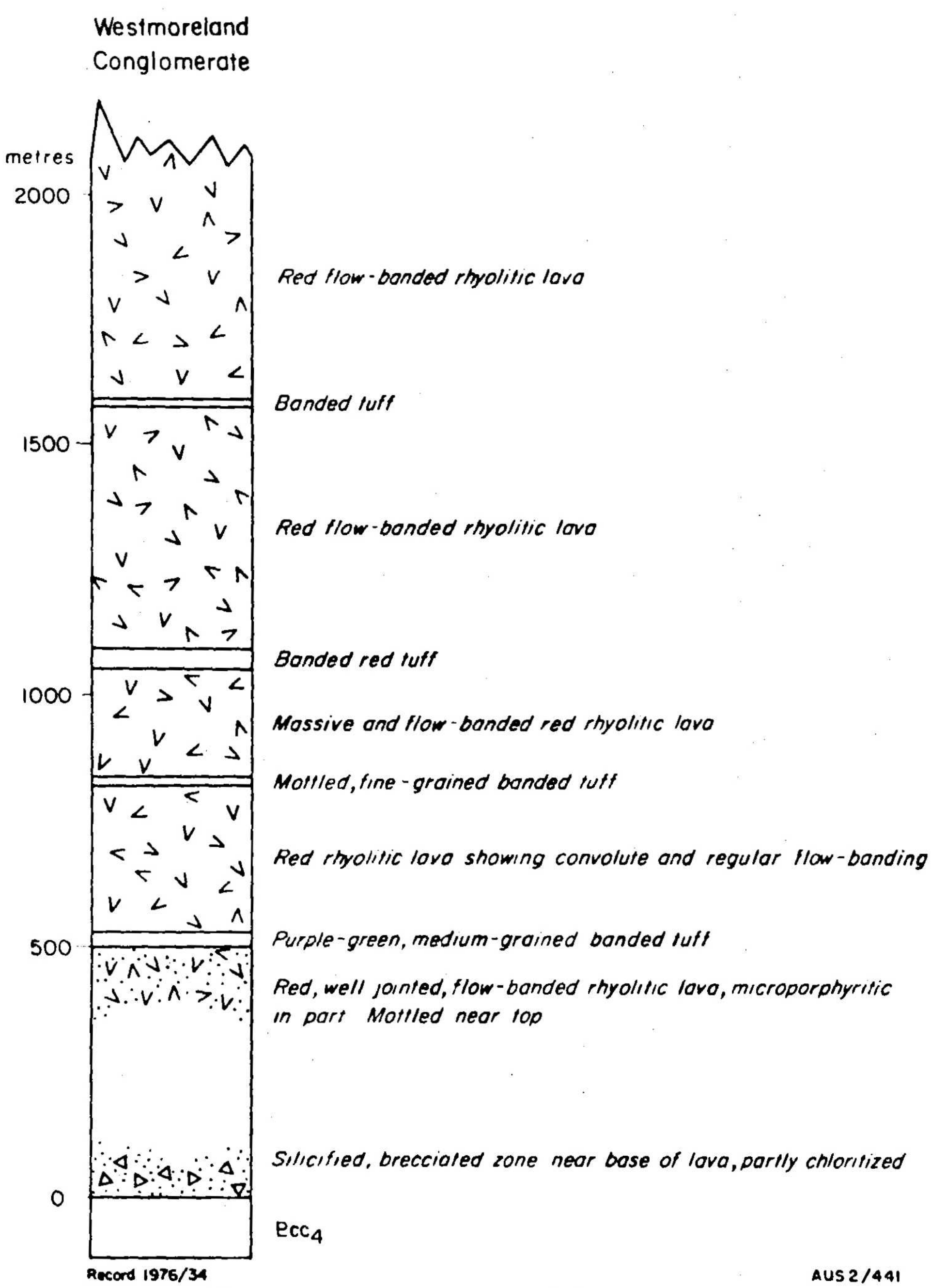

Fig. 20 Sequence exposed in reference section of Billicumidji Rhyolite Member

Conglomerate (HC 864558). Several west-northwest-trending faults cut the eastern margin of the belt. The flows in this belt trend north-northeast, and dip west at about 30°. Two inliers of the Billicumidji Rhyolite Member are present to the west of the belt, at S 120460 and S 080500. A lens of dark grey, fine-grained ignimbrite within the rhyolite north of the Norris copper mine is denoted by the symbol Ecc_{5i}. In the Hedleys Creek Sheet area red rhyolite lava underlying Westmoreland Conglomerate near grid references HC 940565 and HC 015565, and rhyolite lava capping ignimbrite of Ecc_4 at HC 905540 and HC 925535, are also included in the member.

The reference section extends from the basal contact with ignimbrites of Ecc_4, at HC 855466, for about 4.5 km to the west-northwest, to S 175482, in the Seigal Sheet area, where the rhyolite is overlain by Westmoreland Conglomerate. A thickness of at least 2000 m is indicated for the member here, using the average dip of 30° as shown by four uniformly dipping layers of ignimbrite. The highly viscous nature of the rhyolitic lavas is indicated by convolute flow-banding. Details of the stratigraphy in the reference section are given in Figure 20. The section contains four tuffs, 1 to 10 m thick, separating the five rhyolites. At the reference section the tuffs dip too steeply and are too thin to map at 1:100 000 scale; where the sequence is more gently dipping, they have not been mapped separately, and are collectively grouped as sub-unit Ecc_{5t} in areas where the sequence is more gently dipping. It is generally not possible to distinguish between the five rhyolite lavas in or away from the type section. However, the upper part of the lowest rhyolite in the type section is characterized by a mottled appearance, and similar mottling has been observed in the sequence elsewhere at about the same stratigraphic position. Convolute and regular flow banding, including small basins and domes up to 10m across, are present in all of the rhyolites, which are resistant to weathering and erosion, and characteristically form hills and cappings.

The member is cut by numerous faults, many of which are quartz-filled, and is intruded by several dykes of acid porphyry and at least two of dolerite.

Lithology

The rhyolite lavas are red to pale pink. Although mainly flow-banded, some of the rhyolite is massive, and contains vugs which are lined or, more rarely, filled with quartz accompanied by chlorite, epidote, calcite, or clay minerals.

Angular fragments of rhyolite and quartz near the base of some lavas may represent flow-base breccias. Other breccia-like textures in rhyolites appear to have resulted from the infilling of vugs and voids by secondary minerals, especially quartz and chlorite.

Microphenocrysts of pink alkali feldspar and white plagioclase up to 2 mm long form up to three percent of the lava. Some of the phenocrysts are aligned parallel to, and some distort the flow banding.

Intercalations* (Ƀcc_{5t}, Ƀcc_{5i})

The Billicumidji Rhyolite Member contains thin lenses of tuff and ignimbrite, designated Ƀcc_{5t} and Ƀcc_{5i}, respectively. However, a lens mapped immediately north of the Norris copper mine as Ƀcc_{5i} displays a subtrachytic fabric in part, and is possibly an acid to intermediate lava flow. The intercalations are dark green-brown on colour aerial photographs, in contrast to the pale pink colour of the rhyolites.

The tuffs are thin but widespread. They are dark green to brown and medium to fine-grained, and consist mainly of quartz and feldspar. Rock fragments and pumice are uncommon, but shards are abundant in some bands. An unusual specimen (73761201) from the northwestern part of the Hedleys Creek Sheet area (HC 865555) consists largely of deformed 'amygdales' in a devitrified cryptocrystalline groundmass which shows colloform banding and convolute flow-banding, outlined by fine-grained opaque material; the amygdales are filled with calcite, chlorite, and minor epidote. The rock also contains cloudy alkali feldspar and sericitized plagioclase as microphenocrysts up to 0.5 mm long.

<u>RHYOLITE</u> (Ƀcc_r)

An isolated outcrop of red rhyolite near Fish River at S 920245, in the Seigal Sheet area, is mapped as Ƀcc_r. The rhyolite is estimated to be at least 200 m thick, but its stratigraphic position is uncertain. The rhyolite is in contact with granite of the 'Nicholson Granite Complex' and schists of the Murphy Metamorphics. The contact with granite, is poorly exposed, but was thought to be non-intrusive by earlier workers, indicating that the granite here is older than the Cliffdale Volcanics. However, no evidence was found during the present work to support this contention; if anything, the existing evidence (possible chilled margin of the granite, and recrystallization of the volcanics; C.M. Gardner, pers. comm.) supports the opposite view.

GRANOFELS (Ꝑcc$_g$)

Granofels, mapped as a unit of the Cliffdale Volcanics, forms two large roof pendants in poorly exposed phases (Ꝑgn$_1$ and Ꝑgn$_2$) of the 'Nicholson Granite Complex'. The most extensive outcrop is a wedge-shaped block 10 km long and up to 1.5 km wide extending southeast from the Seigal Sheet area to the Hedleys Creek Sheet area. (at S 105340). The other outcrop is about 7 km to the southwest, at S 178263, where a belt of granofels about 6 km long and 0.26 to 0.5 km wide trends northeast.

The northern outcrop consists of a broad ridge up to 10 m high which is cut by numerous northwest-trending vertical porphyry dykes. The southern outcrop area contains isolated rubbly exposures in which few lineaments are visible. In both areas, contacts with adjacent granite are not exposed. The granofels is well jointed, and forms blocky exposures partly covered by rubbly scree.

Lithology

The granofels is mainly pink and fine-grained, and contains equal quantities of anhedral plagioclase and alkali feldspar phenocrysts up to 2 mm long. The phenocrysts constitute up to 10 percent of the rock, and are set in a fine, and in places convolutely banded, granoblastic groundmass. The alkali feldspar phenocrysts are slightly clouded and are commonly oriented parallel to the foliation. Those of plagioclase are extensively altered to sericite and iron oxide. Subhederal flakes of biotite up to 1 cm long form up to 5 percent of the rock; they contain inclusions of granular quartz and feldspar, and are extensively replaced by chlorite and commonly calcite. The flakes of biotite are probably of primary magmatic origin. Unaltered flakes of green and brown biotite about 0.1 mm across which are either randomly oriented or aligned parallel to layering in the groundmass are probably of metamorphic origin.

The groundmass is fine-grained, and consists of a granoblastic mosaic of quartz, alkali feldspar, altered plagioclase, opaques, and red iron oxide (which gives the granofels its red colour). The thin banding in the rocks is due to grainsize variations of these minerals. The bands are about 5 mm thick, and range in grainsize from about 0.2 mm to 0.05 mm. Abundant triple-point junctions between interlocking grains indicate that the rocks have been recrystallized (Spry, 1974).

Quartz forms subhedral grains which make up about 40 percent of the groundmass. Many of these grains contain tiny, clear, circular inclusions possibly of feldspar, which have a refractive index lower than that of quartz. Very fine opaque dust is also commonly concentrated in zones. Subhedral grains of alkali feldspar in the groundmass commonly show simple or cross-hatch twinning, and are unaltered. Fresh Oligoclase forms about 30 percent of the groundmass; it occurs as subhedral grains which are partly altered to sericite and iron oxide. Some euhedral grains of magnetite about 0.01 mm across are concentrated in fine layers in the groundmass; some larger grains, about 0.1 mm across, are fractured and cemented by chlorite. The main accessory minerals are zircon, sphene, and a metamict yellow-brown mineral which may be allanite. Traces of hornblende were observed in one sample. Chemical analyses of two granofelsic rocks show silica contents of 70 and 73 percent (Table 2).

Discussion

The granobalstic fabric and numerous triple-point junctions at grain boundaries indicate that the rocks have been recrystallized. Some of the inclusions in the quartz grains may originally have been microlites. The unaltered alkali feldspar in the groundmass probably formed during recrystallization. The layering is thought to be a primary feature, but the subhedral biotite flakes which are generally parallel to it are fresh and are therefore probably metamorphic in origin. The sericitic alteration of plagioclase, both in phenocrysts and groundmass grains, is similar to that in unmetamorphosed rocks of the Cliffdale Volcanics.

The granofels cannot be directly related to any one of the unmetamorphosed subunits of the Cliffdale Volcanics. The prominent convolute banding and absence of relict pumice or rock fragments suggest that the rocks may originally have been lavas rather than ignimbrites. Although contacts with granite are not exposed, there seems little doubt that the granofels occurs as roof pendants in the Nicholson Granite Complex, and that granite intrusion was responsible for the recrystallization.

MINOR INTRUSIONS IN THE CLIFFDALE VOLCANICS

The Cliffdale Volcanics are cut by many small dykes which appear to be older than the overlying Westmoreland Conglomerate. Most of the dykes are of acid porphyry, and contains phenocrysts of feldspar (either alkali feldspar of plagioclase, or both) and commonly quartz. Mafic phenocrysts are absent or rare. Some of the thicker dykes have chilled margins which are aphyric, and commonly show a vertical flow foliation. A few dykes are basaltic, and show subophitic textures. A small irregular stock of microgranite and a circular (perhaps saucer-like) body of andesite intrude Unit Bcc$_4$. The dykes are easily identified on the colour air photographs.

Many of the acid dykes occur in north and east-trending swarms. Some dykes also cut granite, and some only occur in granite. The dykes in the Cliffdale Volcanics are most abundant where there are high-level phases of granite, such as Bgn$_5$, present nearby. The dykes are probably comagmatic with such granite phases, the dykes representing the final phase of magmatic activity.

Basic dykes cutting the volcanics and the granite generally trend east-northeast, in contrast to the general west-northwest and north-northeast trends of the acid dykes. They may be related to basic dykes and sills reported by several exploration companies to intrude the overlying Westmoreland Conglomerate. That they are younger than the acid dykes is apparent in the northwestern part of the Hedleys Creek area, at HC 840546, where an east-trending acid dyke is cut by a northeast trending basic dyke.

DYKES INTRUDING UNIT Bcc$_1$

Several dykes intrude Unit Bcc$_1$ and extend into younger units, but only two dykes lie wholly within Unit Bcc$_1$. They are microporphyritic, 1-2 m thick, and contain phenocrysts of plagioclase enclosed in a dark, aphanitic groundmass. The absence of quartz and alkali feldspar phenocrysts suggests that these dykes are unlikely to be feeders for any of the extrusive units of the Cliffdale Volcanics.

DYKES INTRUDING UNIT Bcc$_2$

A number of porphyry dykes, 0.5 to 2 m thick, intrude Unit Bcc$_2$ near contacts with granite (Bgn$_5$) in the south. Some of these dykes also cut the granite, the probable source for many of them. The dykes intersect one another, and were probably intruded along joints. They are leucocratic, and contain phenocrysts of quartz, red alkali feldspar and white plagioclase 2 to 4 mm across, set in an aphanitic quartz-feldspar groundmass. The phenocrysts of quartz are commonly embayed, those of alkali feldspar are cloudy, and show simple twinning, and those of plagioclase are zoned and variably sericitized, obliterating any twinning. There are also some flakes of fresh muscovite and chloritized biotite. Minor calcite and traces of colourless and purple fluorite occur as alteration products of feldspar and in the groundmass. The groundmass is fine-grained (0.1-0.5 mm), and comprises a hypidiomorphic-granular assemblage of quartz and feldspar, together with some magnetite; in places quartz and feldspar form a micrographic fabric. The groundmass is coarser than that of extrusive rocks of similar compositon.

DYKES INTRUDING UNIT Ecc_3

Acid dykes up to 10 m wide and 3 km long form north and east-trending swarms in Ecc_3 near granite (Egn_5). These dykes are vertical, and form narrow ridges, many of which paradoxically are in valleys. Chilled margins and a vertical foliation are common features. Two types of dykes can be recognized. The most common type contains phenocrysts of quartz and feldspar in a pink to grey aphanitic groundmass which is granular and locally micrographic. The other type has similar groundmass features but is aphyric.

A plug-like intrusion of acid porphyry at HC 905420 is of similar mineralogy to the dykes intruding Ecc_3.

DYKES INTRUDING UNIT Ecc_4

Two main types of dykes, acid and basic, are seen to intrude Ecc_4.

Acid dykes. A number of north and east-trending acid dykes intrude ignimbrites of Ecc_4, especially near granite (Egn_5), which they also intrude. Most of the dykes are less than 3 m thick, although two (at HC 880517) are more than 400 m thick. The dykes crop out over strike lengths of up to 10 km. The dykes are concentrated in four main areas - three in the Hedleys Creek Sheet and one in the Seigal Sheet area. One area is near the type section of Ecc_4 where dykes trend west-northwest from an outcrop of the Egn_5 granite. Some of these dykes also intrude the Billicumidji Rhyolite Member. They trend parallel to major faults in the vicinity. A second area is an outcrop of undivided Unit Ecc_4 north of Cliffdale Creek (around HC 900520), where north and east-trending dykes intersect, with no obvious sequence of intrusion. One dyke in this second area forms large rounded boulders, which contrast with the flaggy to blocky outcrops of other dykes; it contains phenocrysts of alkali feldspar between 5 and 25 mm long, plagioclase averaging 5 mm in length, and rounded quartz about 3 mm across. Another dyke in this

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second area, near an outlier of Billicumidji Rhyolite Member trends north at HC 932535. It has a medium-grained, hypidiomorphic-granular (granitic) texture, and consists almost entirely of quartz and feldspar. The third area in the Hedleys Creek Sheet area is farther to the east, near HC 060540. Here a swarm of pink microporphyritic dykes trends west-northwest for up to 10 km, parallel to two nearby major faults. Most of these dykes are a few metres thick. The area of dyke concentration in the Seigal Sheet area is around and to the east of the Tracys Table Copper prospect, near S 065435. Here intersecting north and east-trending dykes cut blue-black and red-brown ignimbrites. Many of the dykes also cut nearby intrusive granite, Ᵽgn$_5$, and most are 0.5 m to 3 m wide.

The acid dyke rocks are red to pink, and generally contain phenocrysts of feldspar and commonly quartz in a fine-grained groundmass. A few of the dykes are aphyric. Phenocrysts of plagioclase 2 to 4 mm long form up to 15 percent of the rock; they are strongly sericitized. Subhederal phenocrysts of alkali feldspar 2 to 5 mm long make up 5 to 20 percent of the rock, and commonly show mild clouding. Phenocrysts of quartz are subhedral and embayed, and may amount to 10 percent. The only mafic phenocrysts are biotite flakes which are bleached and altered to chlorite or iron oxide. The groundmass consists of a fine-grained hypidiomorphic-granular assemblage of quartz, alkali feldspar, plagioclase, biotite-chlorite, and minor iron oxide. Alteration products comprise sericite, clay, calcite and sphene. Fluorite is also present in some dykes. The alkali feldspar shows a pale red clouding due to finely dispersed iron oxide. Spherulites of alkali feldspar are common around phenocrysts and also as patches in the groundmass. Micrographic intergrowths of alkali feldspar and quartz are present locally.

Basic dykes. Ᵽcc$_4$ is also intruded by two basic dykes and a small pipe in the Hedleys Creek Sheet area, and by at least, four dykes in the Seigal Sheet area. One of the dykes in the Seigal Sheet area (S 152357) intrudes Ᵽgn$_2$ granite near its contact with sub-unit Ᵽcc$_{4d}$. Most of these dykes are less than 3 metres wide, although one in the Hedleys Creek Sheet area, at HC 820542 is 30 m thick. This dyke trends northeast for more than 5 km. Another basic dyke, about 1 km to the northeast, has a similar trend. A third basic intrusion in the Hedleys Creek Sheet area is a pipe-like body which cuts Sub-unit Ᵽcc$_{4b}$ at HC 085546. The three basic dykes intruding Unit Ᵽcc$_4$ in the Seigal Sheet area are north and east of the Norris copper mine (S 026430). One of these dykes, at S 050420, is in the northern part of a thick basic intrusive which continues southwest for more than 40 km, also intruding granite.

Although the basic dykes are unaltered, they weather more easily than the adjacent acid volcanics, and form shallow depressions. Soil developed on them is ferruginous, and gives rise to denser vegetation (mainly spinifex and other grasses) than that on adjacent soils. As a result, the dykes stand out on colour aerial photographs as dark green lineaments. Exposures consist of rounded boulders or flaggy joint blocks.

The basic dykes are fine to medium-grained and mainly aphyric and even-grained (some microphenocrysts of feldspar are present in one dyke). The fabric is hypidiomorphic granular (gabbroic) in the medium-grained dykes and subophitic and intersertal in fine-grained varieties. All the dykes contain colourless or pale brown augite, plagioclase, chlorite-sphene aggregates, and opaques, and most also contain biotite and hornblende and minor quartz-feldspar mesostasis. Augite makes up between 20 and 30 percent of the rock; it is unaltered, except where the outer margins of some grains are partly rimmed by brown hornblende. Calcic plagioclase, probably labradorite, makes up between 20 to 40 percent of the rock and forms euhedral laths showing normal zoning; sericitic alteration varies from intense in some cores to nil at rims, but most grains are only slightly affected. Pale green, subhedral, equant grains of chlorite pseudomorph and irregularly replace yellow-green biotite. They also form scattered, ragged, interstitial patches and veins, and make up 5 to 15 percent of the rock. Some biotite pseudomorphs contain fine opaque grains, granular aggregates of sphene, actinolite needles, epidote, sphene, and minor calcite; the replacement of biotite by chlorite is thought to be a late-stage magmatic reaction. Some unaltered biotite is preserved in most dykes. Opaques form between 0.5 percent and 5 percent of the basic rock; they occur as small cubic grains, some of which are present as inclusions in augite, and biotite or chlorite, and also as skeletal crystals. Very fine dusty opaques are also associated with chlorite. The absence of olivine or olivine pseudomorphs and the presence of interstitial quartz indicate that the basic dykes are probably tholeiitic.

DYKES INTRUDING THE BILLICUMIDJI RHYOLITE MEMBER

The Billicumidji Rhyolite Member is also intruded by both acid and basic dykes. The acid dykes are confined to the area of outcrop of the member that contains its reference section, and to the large inlier about 5 km to the west. Most of these are 1 to 2 m wide, and trend northeast, in contrast to the north and east trends of acid dykes intruding older units. Some dykes can be traced up to 3 km, but many are offset or trunciated by northwest and northeast-trending faults. They have been seen to intrude the various rhyolite lavas at various stratigraphic levels.

The acid dykes contain phenocrysts 2 to 4 mm long of alkali feldspar or plagioclase or both, set in a pink to red aphanitic groundmass. Some dykes also contain sparse phenocrysts of quartz. The groundmass consists of a hypidiomorphic granular assemblage of quartz, feldspar, and minor biotite and chlorite. Sericite and clay minerals are common alteration products. The groundmass of the dykes is coarser-grained (average grainsize about 0.4 mm) than that of adjacent rhyolite lavas and ignimbrites. The similarity in composition of these dykes to the acid dykes cutting older units of the Cliffdale Volcanics suggests a common source for all the acid dykes.

The basic dykes intruding the Billicumidji Rhyolite Member are easily eroded, and are typically exposed as a rubble of spheroidally weathered boulders in valleys. They are characteristically dark green on colour aerial photographs, and form a deep red soil. They are medium-grained, and commonly show a subophitic texture. Their main constituents are plagioclase (altered to sericite and clay) and pyroxene, which is commonly pseudomorphed by amphibole; biotite, chlorite, opaques, and interstitial quartz are minor constituents. Grains of pyrite can be seen in some specimens. The presence of up to 5 percent quartz indicates that the dolerite is probably tholeiitic.

Tholeiitic dykes are associated with some of the uranium deposits in the Westmoreland Conglomerate (Hills & Thakur, 1975), about 10 km to the northeast, and colinear with the trend of the dolerite dykes exposed in the northwest part of the Hedleys Creek Sheet area. Dolerite dykes and sills have also been reported at other places in the Westmoreland Conglomerate.

MICROGRANITE

A Y-shaped north-trending intrusion of microgranite crops out at the southern end of the reference area for Unit Ɇcc$_4$ at HC 850440 (Fig. 17). The microgranite intrudes blue-black ignimbrite near the top of Unit Ɇcc$_4$, and cuts across two associated rhyolite flows, although its contact with these rhyolites is not exposed. The microgranite is discordant in the north where it is in contact with the base of the Billicumidji Rhyolite Member and concordant in the south, where it is faulted out. The microgranite is massive and crops out as low domes. It is closely jointed at 120^{o}, and is sheared near faults. Its appearance on colour aerial photographs closely resembles that of most rhyolites.

The microgranite is pink, and contains phenocrysts, about 2 mm long, of alkali feldspar (5 to 15 percent of the rock), quartz (about 5 percent), and extensively sericitized plagioclase (about 3 percent) in a fine-grained hypidiomorphic-granular assemblage of quartz and feldspar. It more closely resembles the acid porphyry dykes than any of the phases of the Nicholson Granite Complex.

ANDESITE (Ꞓcc$_a$)

A saucer-like body of porphyritic fine-grained and medium-grained andesite forms a roughly circular outcrop, about 3 km across, 4 km west of Lagoon Creek (Fig. 21) in the northeastern corner of the Seigal 1:100 000 Sheet area (S 150550). The andesite body is probably an intrusion, but it appears to be concordant with the underlying pink ignimbrite and rhyolite of Unit Ꞓcc$_4$. Banding in the country rock at the base of the intrusion outlines a basin-shaped depression with inward dips of 5^{o} to 30^{o} around the margins. The upper part of the intrusion has been removed by erosion. Flow banding, in the surrounding Unit 4 around the southern and western margins is generally less steeply dipping than elsewhere, and the rocks have not been affected by contact metamorphism. The andesite forms massive to blocky exposures, and its outcrop is dark green on colour aerial photographs.

The outer part of the intrusion is formed of fine-grained andesite consisting of small phenocrysts of augite, chlorite pseudomorphs, and plagioclase up to 3 mm long set in a grey, microcrystalline groundmass which locally shown flow banding. In some rocks the phenocrysts show a preferred orientation. The augite phenocrysts occur separately or with chlorite, and make up 5 to 10 percent of the rock. They are colourless in thin section and unzoned. A thin rim of hornblende(?) was noted in one section (74760016); otherwise the augite is unaltered. Euhedral, tabular chlorite (penninite) pseudomorphs make up 5 to 10 percent of the rock, and are accompanied by minor magnetite and epidote. Some of the pseudomorphs show 6 and 8-sided cross sections, and some interpenetration twins are present. Plagioclase phenocrysts make up 5 to 15 percent of the rock, and are extensively altered to sericite and minor epidote and chlorite. The groundmass consists of a granular to intergranular microcrystalline assemblage of euhedral plagioclase, equant augite, patches and veinlets of chlorite, pale brown alkali feldspar which has altered to clay minerals, and opaque granules. A subtrachytic fabric is developed in places. Interstitial quartz is commonly present. Secondary minerals present are epidote, sericite, actinolite, and clay. At least part of the groundmass is probably devitrified glass.

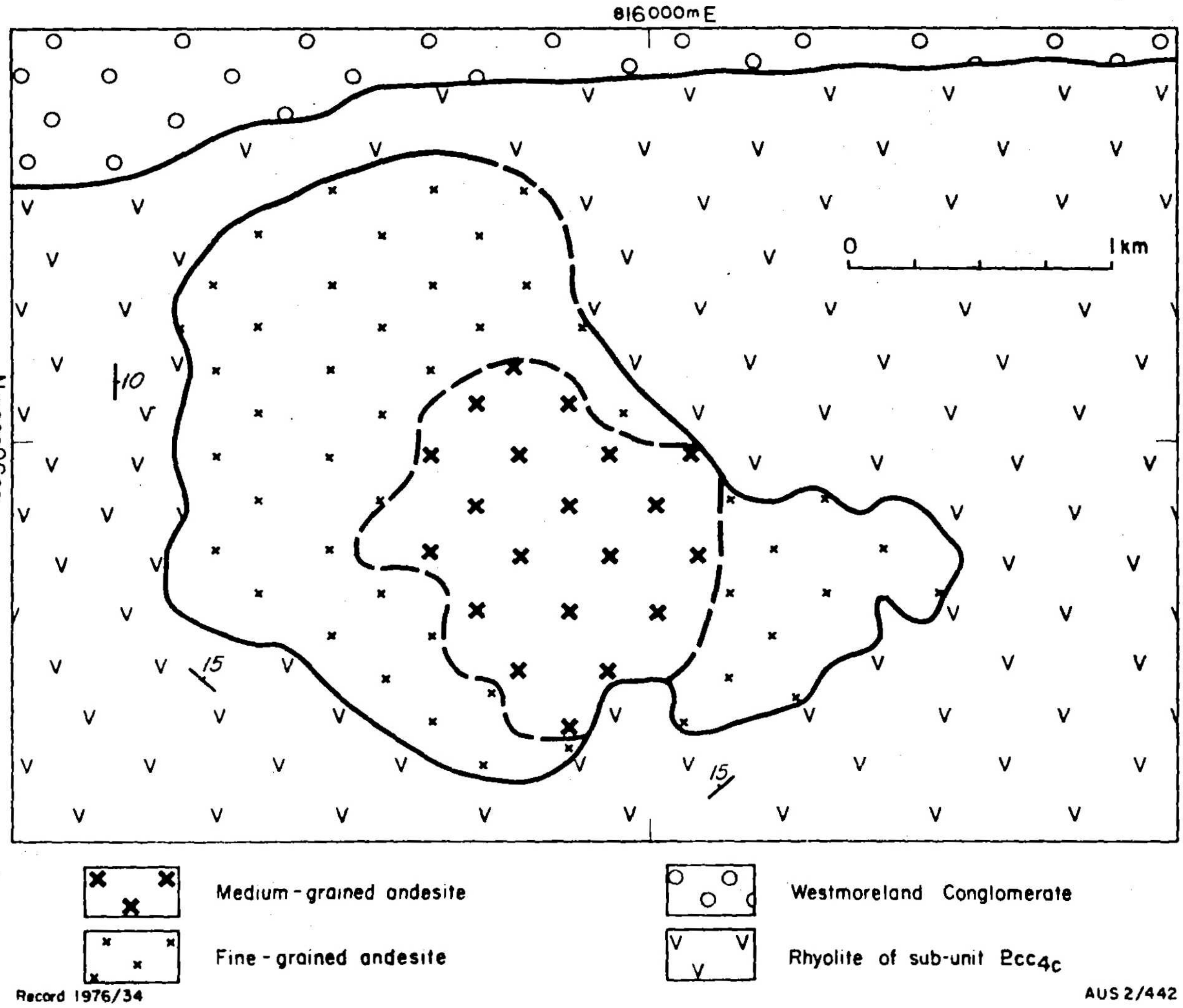

Fig. 21 Map of probably intrusive andesite body (Ecc$_a$)

The inner part of the intrusion consists of medium-grained andesite which is similar mineralogically to the fine-grained andesite, although it has a higher phenocryst content. The plagioclase phenocrysts are extensively replaced by granular epidote and sericite, and some of the augite phenocrysts are zoned.

STRUCTURE

Structures in the Murphy Tectonic Ridge have been caused mainly by granite emplacement and tensional faulting. The marked contrast between the tightly folded Murphy Metamorphics and the younger and unmetamorphosed Cliffdale Volcanics indicates that there was at least one period of tectonism, regional metamorphism, uplift, and erosion before the eruption of the acid volcanics.

Cover rocks which unconformably overlie the basement of metamorphics, granite, and the Cliffdale Volcanics are displaced by block faults, most of which extend into the basement. The prominent Calvert Fault is one such fault; it runs diagonally southeast across the Murphy Tectonic Ridge for a distance of more than 160 km, and is filled with quartz for much of its length. Many of the contacts between basement and cover rocks are faulted.

The Cliffdale Volcanics were erupted as a series of extensive flat-lying pyroclastic and lava flows onto a probably irregular land surface. They are still predominantly flat-lying, although they dip more steeply adjacent to some faults and intrusive granite contacts.

Intrusion of granite Pgn_5 southwest and southeast of Billicumidji Waterhole produced the basin-like structure where the oldest known volcanic units (Ꝑcc_1, Ꝑcc_2, Ꝑcc_3) are preserved. The basin is about 5 km in diameter, and the volcanics around its margin dip inwards at up to 20^{o}.

Many northwest and west-northwest-trending faults cut both basement and cover rocks. Most of these form linear depressions, a few of which are quartz-filled. Some faults have caused apparent horizontal displacements of up to 10 km; however, this may be due to small vertical movements in the gently dipping sequences of volcanics. Not all faults in the basement postdate the granite intrusions; for instance, in the west, near Crystal Hill tin mine, five northeast-trending faults cutting older granite are truncated by high-level granite. The greatest intensity of faulting in the basement is near Billicumidji Waterhole.

The Cliffdale Volcanics are cut by sets of vertical or steeply dipping joints trending north and along many of which acid porphyry dykes have been intruded. Horizontal jointing is also well developed.

Rocks of the Cliffdale Volcanics commonly have a primary foliation resulting from the flattening of pumice fragments and welding of glass shards soon after the flows were extruded. Contorted flow banding in rhyolite lavas formed at the time of extrusion.

Minor folding is apparent at the southeastern margin of the tectonic basin, where several open folds plunge gently to the northwest. These folds are probably related to the intrusion of adjacent granite Pgn_2.

Two possible eruptive centres for some of the acid volcanics have been found. One of these is the fissure from infilled with rhyolitic breccia, from which a small rhyolitic flow (Pcc_{4r}) was probably extruded, near Billicumidji Waterhole, at HC 962513 (Fig. 11). Similar rhyolitic breccia forms a circular area of Billicumidji Rhyolite Member about 11 km to the west (HC 855506).

The high-level granites of the 'Nicholson Granite Complex', particularly phases Pgn_5, Pgn_6, and Pgn_8, were probably comagmatic with the Cliffdale Volcanics, and their locations may indicate the position(s) of magma chamber(s) which were the immediate sources for the volcanics. The swarms of acid porphyry dykes intruding the volcanics are closely related spatially to the granites, and are considered to be a final magmatic phase. They are not the main feeders to the volcanics.

MINERALIZATION

A brief description of known mineral occurrences within the Cliffdale Volcanics is given below.

PANDANUS CREEK URANIUM MINE (S 990428)

At this mine primary pitchblende(?) and the secondary uranium minerals gummite, uranophane, and sklodowskite were reported by Roberts et al. (1963) and Morgan (1965) to occur in en-echelon shear zones up to 2 m wide. The host rocks consist of bleached, intensely altered acid volcanics and are

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unconformably overlain nearby by sandstone of the Westmoreland Conglomerate. The shear zones strike north-northeast (075°), and dip 70° to the northwest. Away from the shear zones, the volcanics are less altered and show eutaxitic structure. A small circular pod of medium-grained biotite granite is poorly exposed in a creek bed about 600 m southwest of the mine. This granite probably intrudes the volcanics, and the uranium mineralization may be genetically associated with it.

Ore was mined by open cut, and was stockpiled prior to hand sorting and grading. Minor underground development was carried out from several shafts and drives. Grades of up to 160 lb/ton U_3O_8 have been reported. Selective mining and sorting to 1962 yielded 312 tonnes of ore averaging 8.37 percent U_3O_8. An extensive diamond drilling program was carried out in the area in the late 1960s by the Broken Hill Pty Co. Ltd (M. El Hussen, pers. comm, 1975), but the results are not known.

PROSPECTS

Traceys Table (S 065440): Cu, Sn

Copper mineralization at Traceys Table consists of a ferruginous gossan containing malachite and quartz in bleached blue-black ignimbrite (Ecc_{4d}). Ore from a pit about 2 m deep has been stockpiled. The mineralization may be related to an east-trending feldspar porphyry dyke extending from a granite body (Pgn_5) about 6 km to the east.

Drusy quartz reefs cutting the blue-black ignimbrite near the copper prospect contain traces of finely disseminated cassiterite. Three small costeans have been put into the reefs.

Copper prospects at S 107375 and S 109372

These prospects comprise several pits in sheared granite and volcanics adjacent to the Calvert Fault. The mineralization consists of malachite and other secondary copper minerals in quartz-filled fractures and joints. An earthy gossan containing quartz is present in places.

Copper prospect at S 106381

At a small pit minor amounts of malachite coat joints and fractures in red-brown ignimbrite (Ecc_{4a}). An east-trending porphyry dyke crops out nearby.

Copper and lead at HC 861466

At this locality traces of disseminated chalcopyrite, in part oxidized to malachite, together with galena were found at the northern end of a northwest-trending quartz reef. The reef is about 0.5 m wide and 1 km long, and cuts ignimbrite of Unit Ecc_4. Some of the quartz is amethystine.

Copper prospect at HC 021440

Traces of malachite fill joints in blue-black ignimbrite of Ecc_{4d} at this locality.

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TABLE 2. MAJOR-ELEMENT CHEMICAL ANALYSES AND C.I.P.W. NORMS.
Analyses carried out by AMDEL (Report 2882/75) are marked thus*.
Rock types and localities are given in Table 4.

Rock Unit	Ɛcc$_1$	Ɛcc$_1$	Ɛcc$_2$	Ɛcc$_2$	Ɛcc$_3$	Ɛcc$_3$
Registered No.	74760038	74760039	74760040	74760041	74760042	74760043
SiO_2	69.00	66.35	78.66	73.44	67.50	71.09
TiO_2	0.49	0.45	0.07	0.10	0.41	0.22
Al_2O_3	14.11	15.09	11.94	13.56	15.67	14.49
Fe_2O_3	1.66	1.17	1.38	1.46	1.20	0.83
FeO	2.15	2.55	0.15	0.30	2.35	1.45
MnO	0.12	0.06	0.01	0.02	0.05	0.03
MgO	0.46	1.23	0.46	0.67	0.95	0.67
CaO	1.77	2.57	0.03	0.69	2.84	1.87
Na_2O	2.50	2.58	0.18	2.30	2.88	2.35
K_2O	6.01	4.62	5.50	5.37	4.47	5.11
P_2O_5	0.11	0.12	n.d.	n.d.	0.11	n.d.
H_2O+	0.89	1.92	1.40	1.11	1.11	1.20
H_2O-	0.01	0.04	0.02	0.01	0.01	0.02
Total	99.28	98.74	99.80	99.03	99.55	99.33

Quartz	26.84	26.11	56.74	37.84	25.62	32.73
Corundum	0.55	1.51	5.73	2.77	1.22	1.73
Orthoclase	36.09	28.20	33.03	32.40	26.83	30.77
Albite	21.49	22.54	1.55	19.87	24.75	20.26
Anorthite	8.19	12.36	0.15	3.50	13.58	9.45
Diopside	-	-	-	-	-	-
Hypersthene	3.19	6.35	1.16	1.70	5.19	3.40
Magnetite	2.45	1.75	0.32	0.76	1.77	1.23
Hematite	-	-	1.18	0.97	-	-
Ilmenite	0.95	0.88	0.14	0.19	0.79	0.43
Apatite	0.27	0.29	-	-	0.26	-

n.d. - not detected - detection limit 0.04%

Table 2 cont.

Rock Unit	Ecc_{4a}	Ecc_{4a}	Ecc_{4a}	Ecc_{4a}	Ecc_{4b}	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}
Registered No.	73761236	73761252	74760826	74760913	74760037	73761218	73761224*	73761225*
SiO_2	74.57	69.71	69.13	74.61	69.21	58.06	61.26	66.02
TiO_2	0.09	0.26	0.25	0.14	0.45	0.85	0.64	0.43
Al_2O_3	13.13	15.32	15.46	12.33	13.72	15.89	16.63	15.24
Fe_2O_3	0.41	1.46	2.15	1.13	1.67	4.07	1.75	1.73
FeO	0.75	1.10	0.76	0.89	2.55	3.85	3.35	2.25
MnO	0.02	0.03	0.04	0.04	0.06	0.09	0.08	0.06
MgO	0.20	0.71	0.36	0.32	0.39	3.10	2.03	1.29
CaO	1.17	0.59	1.40	0.65	1.84	5.25	4.16	3.58
Na_2O	4.68	3.47	3.24	2.62	3.50	2.83	3.60	3.20
K_2O	3.11	5.31	6.07	5.55	4.67	3.52	3.58	3.93
P_2O_5	n.d.	0.06	0.05	n.d.	0.09	0.21	0.15	0.14
H_2O+	0.46	0.99	0.66	0.74	1.06	1.74	1.45	0.96
H_2O-	0.05	0.15	0.06	0.06	0.10	0.14	0.07	0.06
Total	98.65	99.17	99.62	99.10	99.31	99.60	98.75	98.89
Quartz	32.89	27.41			26.12	12.99	14.00	22.98
Corundum	-	3.00			-	-	-	-
Orthoclase	18.72	32.01			28.11	21.28	21.75	23.72
Albite	40.34	29.94			30.16	24.49	31.31	27.65
Anorthite	5.75	2.59			8.09	20.74	19.18	15.96
Diopside	0.14	-			0.52	3.61	0.85	1.02
Hypersthene	1.38	2.25			3.44	8.70	8.69	4.93
Magnetite	0.61	2.16			2.47	6.04	2.61	2.56
Hematite	-	-			-	-	-	-
Ilmenite	0.17	0.50			0.87	1.65	1.25	0.83
Apatite	-	0.15			0.22	0.51	0.37	0.34

n.d. not detected. detection limit 0.04%

Table 2 cont.

Rock Unit	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}	Ecc_{4d}
Registered No.	73761246	73761248	72762017	73761208	73761209	74760802	74760817	74760915
SiO_2	69.01	72.31	66.17	56.16	66.11	59.59	64.94	63.58
TiO_2	0.28	0.16	0.31	0.85	0.43	0.58	0.51	0.79
Al_2O_3	15.89	14.86	17.01	15.47	15.16	13.00	16.54	15.62
Fe_2O_3	2.63	0.86	0.83	3.89	1.07	1.35	1.92	2.54
FeO	0.20	0.90	2.15	2.95	2.80	4.26	2.45	2.97
MnO	0.02	0.02	0.06	0.12	0.06	0.08	0.06	0.08
MgO	0.34	0.49	0.76	4.87	1.81	5.60	1.18	1.69
CaO	2.41	1.04	3.02	5.10	1.68	5.06	2.97	2.81
Na_2O	3.78	3.83	3.97	2.41	2.80	2.06	3.10	3.30
K_2O	4.63	4.39	3.91	3.47	5.05	4.52	4.74	3.83
P_2O_5	n.d.	n.d.	0.07	0.20	0.10	0.32	0.12	0.22
H_2O+	0.48	0.76	1.42	2.70	1.84	2.44	0.79	1.61
H_2O-	0.04	0.06	0.02	0.12	0.08	0.18	0.05	0.05
Total	99.70	99.68	99.71	98.29	98.99	99.05	99.37	99.10

Quartz	23.85	30.31	19.77	11.95	23.52	11.52	19.99	20.80
Corundum	0.28	1.94	0.94	-	2.34	-	1.20	1.46
Orthoclase	27.58	26.24	23.51	21.47	30.74	26.72	28.02	22.64
Albite	32.23	32.77	34.17	21.35	24.40	17.43	26.23	27.92
Anorthite	12.05	5.22	14.78	22.15	7.91	12.88	13.95	12.50
Diopside	-	-	-	2.34	-	8.17	-	-
Hyporsthene	0.85	1.96	4.84	12.67	8.41	15.91	5.12	6.41
Magnetite	-	1.26	1.22	5.91	1.60	1.96	2.78	3.68
Hematite	2.65	-	-	-	-	-	-	-
Ilmenite	0.47	0.31	0.60	1.69	0.84	1.10	0.97	1.50
Apatite	-	-	0.17	0.50	0.24	0.75	0.28	0.52
		-	-	-	-	-	-	-

n.d. - not detected - detection limit 0.04%

Table 2 cont.

Rock Unit	Ecc_{4d}	Ecc_{4r}	Ecc_5	Ecc_5	Ecc_5	Ecc_5	Ecc_5	Ecc_5
Registered No.	74760828	72762037	73761214	72762028	72762029	74760836	74760845	74760869
SiO_2	65.53	76.08	73.12	78.09	74.39	74.66	73.67	73.35
TiO_2	0.61	0.18	0.13	0.13	0.20	0.18	0.14	0.13
Al_2O_3	15.85	12.10	12.45	10.67	13.10	12.73	13.31	13.41
Fe_2O_3	2.34	1.21	1.80	0.35	1.75	1.62	0.79	1.29
FeO	2.52	0.25	0.80	0.20	0.45	0.52	1.48	1.07
MnO	0.07	0.01	0.06	0.06	0.02	0.02	0.06	0.04
MgO	1.18	0.39	0.33	0.24	0.18	0.37	0.26	0.18
CaO	2.95	0.05	0.07	0.21	0.74	0.19	0.58	0.73
Na_2O	3.19	0.28	0.24	0.75	2.81	1.32	3.00	3.44
K_2O	4.39	8.03	9.63	7.50	5.73	6.75	6.09	5.89
P_2O_5	0.15	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
H_2O+	0.93	1.20	0.55	0.77	0.51	1.11	0.43	0.43
H_2O-	0.05	0.10	0.11	0.13	0.01	0.15	0.03	0.03
Total	99.76	99.88	99.28	99.11	99.88	99.66	100.05	100.02

Quartz	21.69	43.66	34.72	45.04	34.50	40.27	30.48	28.70
Corundum	0.85	2.90	1.53	0.96	0.94	2.98	0.80	0.12
Orthoclase	25.95	48.13	57.69	45.12	34.07	39.90	35.99	34.81
Albite	26.99	2.40	2.06	6.46	23.92	11.17	25.38	29.11
Anorthite	13.66	0.25	0.35	1.06	3.69	0.75	2.68	3.43
Diopside	-	-	-	-	-	-	-	-
Hypersthene	4.76	0.98	0.83	0.61	0.45	0.92	2.59	1.21
Magnetite	3.39	0.32	2.43	0.47	0.94	1.22	1.15	1.87
Hematite	-	1.01	0.15	0.03	1.11	-	-	-
Ilmenite	1.16	0.35	0.25	0.25	0.38	0.34	0.27	0.25
Apatite	0.35	-	-	-	-	0.07	0.07	0.07

n.d. - not detected - detection limit 0.04%

Table 2 cont.

Rock Unit	Bcc_5	Bcc_g	Bcc_g	Bcc_a	Bcc_a	Dyke	Dyke	Dyke
Registered No.	74760893	73761276	73761278	74760018	74760019	72762032	72762034	72762040
SiO_2	79.05	69.99	73.17	60.85	55.48	76.63	75.88	74.30
TiO_2	0.16	0.35	0.22	0.78	0.83	0.08	0.03	0.16
Al_2O_3	10.28	13.87	13.47	15.68	15.85	12.40	12.85	12.01
Fe_2O_3	1.16	2.15	1.54	1.74	1.77	0.36	0.38	0.47
FeO	1.01	1.80	1.00	4.65	5.45	0.75	0.20	1.10
MnO	0.04	0.02	0.02	0.10	0.12	0.04	0.01	0.03
MgO	0.42	0.46	0.18	2.05	6.07	0.30	0.20	0.46
CaO	0.25	0.69	0.33	5.09	5.05	0.28	0.46	0.52
Na_2O	1.30	2.25	2.15	2.62	2.46	2.30	2.79	1.14
K_2O	4.21	6.98	7.33	3.51	3.53	5.78	5.32	7.59
P_2O_5	n.d.	n.d.	n.d.	0.20	0.14	n.d.	n.d.	n.d.
H_2O+	1.36	0.74	0.40	1.74	2.77	1.03	0.90	0.95
H_2O-	0.10	0.10	0.08	0.22	0.17	0.03	0.08	0.03
Total	99.35	99.40	99.89	99.23	99.68	99.98	99.10	98.76

Quartz	53.95	28.00	31.73	17.25	5.23	40.07	38.74	37.01
Corundum	3.18	1.38	1.41	-	-	1.87	1.70	1.00
Orthoclase	24.88	41.84	43.56	21.32	21.56	34.52	32.03	45.86
Albite	11.00	19.31	18.29	22.78	21.50	19.66	24.05	9.86
Anorthitic	1.11	3.47	1.65	21.24	22.62	1.40	2.33	2.64
Diopside	-	-	-	2.80	1.96	-	-	-
Hypersthene	1.75	2.16	0.69	10.02	22.31	1.79	0.53	2.63
Magnetite	1.68	3.16	2.25	2.59	2.65	0.53	0.56	0.70
Hematite	-	-	-	-	-	-	-	-
Ilmenite	0.30	0.67	0.42	1.52	1.63	0.15	0.06	0.31
Apatite	0.05	-	-	0.49	0.34	-	-	-

n.d. - not detected - detection limit 0.04%

Table 2 cont.

Rock Unit	Xenoliths			
Registered No.	74760035	74760036	73761270	73761271
SiO_2	71.90	72.28	66.91	67.13
TiO_2	0.25	0.24	0.45	0.43
Al_2O_3	14.80	14.88	15.69	15.46
Fe_2O_3	0.31	0.44	1.96	0.51
FeO	1.65	1.55	1.75	3.20
MnO	0.04	0.05	0.06	0.05
MgO	0.48	0.57	0.74	0.99
CaO	1.71	1.15	4.67	3.55
Na_2O	3.57	2.43	3.02	2.69
K_2O	4.12	5.07	2.87	4.20
P_2O_5	n.d.	n.d.	0.12	0.11
H_2O+	0.75	0.84	0.79	1.24
H_2O-	0.09	0.12	0.11	0.06
Total	99.66	99.63	99.13	99.64

Quartz	30.25	34.92	28.01	24.87
Corundum	1.38	3.35	-	0.31
Orthoclase	24.63	30.36	17.26	25.24
Albite	30.55	20.83	26.00	23.14
Anothite	8.58	5.78	21.16	17.18
Wollastonite	-	-	-	-
Diopside	-	-	1.32	-
Hypersthene	3.67	3.65	2.22	7.43
Magnetite	0.45	0.65	2.89	0.75
Hematite	-	-	-	-
Ilmenite	0.48	0.46	0.87	0.83
Apatite	-	-	0.29	0.27

n.d. - not detected - detection limit 0.04%

Table 2 cont.

Rock Unit	Dyke	Dyke	Dyke	Dyke	Dyke	Dyke	Dyke
Registered No.	72762042	73761238	73761243	74760815	74760820	73761204	74760032
SiO_2	73.82	73.21	73.52	63.63	63.35	52.52	51.30
TiO_2	0.18	0.22	0.17	0.62	0.52	1.78	1.46
Al_2O_3	12.76	13.33	13.57	14.38	14.66	13.82	14.74
Fe_2O_3	0.25	0.74	0.55	0.82	0.97	2.64	4.22
FeO	1.40	1.15	1.40	3.90	3.92	9.55	8.45
MnO	0.03	0.02	0.03	0.06	0.07	0.22	0.17
MgO	0.47	0.38	0.34	2.75	3.42	3.71	3.55
CaO	0.60	0.77	0.30	3.85	3.91	6.90	6.83
Na_2O	2.31	3.05	2.45	2.38	2.68	2.16	2.22
K_2O	6.17	5.93	6.36	4.80	4.91	2.97	3.07
P_2O_5	n.d.	n.d.	n.d.	0.24	0.24	0.24	0.45
H_2O+	0.88	0.68	0.89	1.59	1.30	2.42	2.43
H_2O-	0.02	0.06	0.09	0.07	0.01	0.12	0.17
Total	98.89	99.53	99.68	99.09	100.05	99.03	99.06
Quartz	34.53	30.41	33.37	17.88	14.53	6.25	5.79
Corundum	1.22	0.50	2.14	-	-	-	-
Orthoclose	37.20	35.46	38.07	28.37	29.02	18.18	18.80
Albite	19.94	26.11	21.00	20.14	22.68	18.93	19.47
Anorthite	3.04	3.87	1.51	14.38	13.47	19.94	21.97
Diopside	-	-	-	2.59	3.56	11.63	8.39
Hypersthene	3.36	2.15	2.77	11.15	12.45	17.03	15.29
Magnetite	0.37	1.09	0.81	1.19	1.41	3.97	6.34
Hematite	-	-	-	-	-	-	-
Ilmenite	0.35	0.42	0.33	1.18	0.99	3.50	2.87
Apatite	-	-	-	0.57	0.57	0.57	1.11

n.d. - not detected - detection limit 0.04%

TABLE 3. TRACE-ELEMENT ANALYSES (p.p.m.)
Analyses carried out by AMDEL (Report 2882/75)
are marked thus*. Rock types and localities are given in Table 4

Rock Unit	Ecc$_1$	Ecc$_1$	Ecc$_2$	Ecc$_2$	Ecc$_3$	Ecc$_3$
Registered No.	74760038	74760039	74760040	74760041	74760042	74760043
Ba	1150	1300	420	1100	1150	1150
Ce	140	130	70	110	130	140
Mo	n.d.	n.d.	n.d.	4	n.d.	n.d.
Nb	10	10	20	10	10	10
Pb	38	32	24	20	34	26
Rb	240	195	350	210	175	200
Sn	6	6	24	n.d.	n.d.	n.d.
Sr	110	270	34	115	300	210
Th	24	20	28	16	18	20
U	8	4	8	n.d.	6	4
W	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Y	45	25	40	25	20	25
Zr	330	270	115	125	230	220
Bi	n.d.	n.d.	n.d.	n.d.	n.d.	4
Co	n.d.	8	n.d.	n.d.	10	5
Cu	12	10	5	2	5	2
Li	27	33	28	20	33	20
Ni	n.d.	5	n.d.	5	5	5
Zn	95	55	15	15	50	40

n.d. - not detected
detection limit

Mo	4 ppm
Sn	4 ppm
U	4 ppm
W	10 ppm
Bi	4 ppm
Co	5 ppm
Ni	5 ppm

Table 3 cont.

Rock Unit	Ɛcc$_{4a}$	Ɛcc$_{4a}$	Ɛcc$_{4b}$	Ɛcc$_{4d}$	Ɛcc$_{4d}$	Ɛcc$_{4d}$	Ɛcc$_{4d}$
Registered No.	74760826	74760913	74760037	74760802	74760817	74760828	74760915
Ba	1050	170	1400	1400	1150	1750	1350
Ce	70	100	140	100	100	130	130
Mo	10	10	6	10	10	10	10
Nb	10	25	10	15	10	10	15
Pb	30	14	22	28	28	28	22
Rb	230	310	210	220	185	170	130
Sn	4	4	6	4	4	4	4
Sr	270	50	220	340	340	340	260
Th	22	44	20	24	12	22	14
U	4	44	6	8	4	6	14
W	10	10	n.d.	10	10	10	10
Y	25	65	30	20	25	30	35
Zr	290	170	320	220	380	290	300
Bi	8	8	n.d.	8	8	8	10
Co	5	5	n.d.	28	14	12	16
Cu	3	3	8	41	14	20	13
Li	7	3	33	21	15	10	14
Ni	n.d.	n.d.	n.d.	120	n.d.	n.d.	n.d.
Zn	n.a.	n.a.	65	n.a.	n.a.	n.a.	n.a.

n.a. not analysed
n.d. not detected
detection limit
W 10 ppm
Bi 4 ppm
Ni 5 ppm

Table 3 cont.

Rock Unit	Ecc$_a$	Ecc$_a$	Dyke	Xenoliths	Xenoliths
Registered No.	74760018	74760019	74760032	74760035	74760036
Ba	1050	1200	1200	1600	1550
Ce	110	80	140	160	140
Mo	n.d.	n.d.	4	10	6
Nb	10	n.d.	10	15	10
Pb	22	20	20	40	32
Rb	130	120	110	330	330
Sn	n.d.	n.d.	n.d.	6	n.d.
Sr	310	370	380	220	190
Th	12	10	12	18	20
U	4	4	4	6	6
W	n.d.	n.d.	280	180	10
Y	30	15	20	35	20
Zr	220	180	150	200	220
Bi	n.d.	n.d.	n.d.	4	n.d.
Co	20	25	40	n.d.	n.d.
Cu	20	32	35	n.d.	n.d.
Li	32	52	56	70	75
Ni	5	50	5	n.d.	n.d.
Zn	65	55	110	25	20

n.d. not detected

detection limit

Mo	4 ppm
Nb	10 ppm
Sn	4 ppm
W	10 ppm
Bi	4 ppm
Co	5 ppm
Cu	2 ppm
Ni	5 ppm

TABLE 4. LOCALITIES AND DESCRIPTIONS OF CHEMICALLY ANALYSED ROCKS

Rock Unit	Registered No.	Rock Type	Grid Reference
Ᵽcc$_{1}$	74760038	Red ignimbrite	HC 976446
Ᵽcc$_{1}$	74760039	Porphyritic purple lava	HC 904435
Ᵽcc$_{2}$	74760040	Porphyritic pink ignimbrite	HC 965438
Ᵽcc$_{2}$	74760041	Pumice-rich pink ignimbrite	HC 935413
Ᵽcc$_{3}$	74760042	Blue-black ignimbrite	HC 885440
Ᵽcc$_{3}$	74760043	Red-brown ignimbrite	HC 925444
Ᵽcc$_{4}$	7371236	Red-brown ignimbrite	HC 824422
Ᵽcc$_{4a}$	73761252	Red-brown ignimbrite	S 143403
Ᵽcc$_{4a}$	74760826	Red-brown ignimbrite	S 043383
Ᵽcc$_{4a}$	74760913	Red-brown ignimbrite	HC 923523
Ᵽcc$_{4b}$	72762037	Red rhyolite	HC 831557
Ᵽcc$_{4d}$	73761218	Blue-black ignimbrite	S 070442
Ᵽcc$_{4d}$	73761224	Blue-black ignimbrite, augite-bearing	S 073427
Ᵽcc$_{4d}$	73761225	Blue-black ignimbrite, augite-bearing	S 073427
Ᵽcc$_{4d}$	73761246	Blue-black ignimbrite	S 158424
Ᵽcc$_{4d}$	73761248	Blue-black ignimbrite	HC 824422
Ᵽcc$_{4d}$	72762017	Blue-black ignimbrite	HC 030518
Ᵽcc$_{4d}$	73761208	Blue-black ignimbrite, augite-bearing	HC 857465 (from type section)
Ᵽcc$_{4d}$	73761209	Red-brown ignimbrite	HC 857465 (from type section)
Ᵽcc$_{4d}$	74760802	Blue-black ignimbrite	S 147340
Ᵽcc$_{4d}$	74760817	Blue-black ignimbrite	S 990383
Ᵽcc$_{4d}$	74760828	Blue-black ignimbrite	S 038416
Ᵽcc$_{4d}$	74760915	Blue-black ignimbrite	S 034418
Ᵽcc$_{4r}$	72762037	Red rhyolite	HC 861455
Ᵽcc$_{5}$	73761214	Red lava	HC 830474
Ᵽcc$_{5}$	72762028	Red lava	HC 852504
Ᵽcc$_{5}$	72762029	Red lava	HC 927535
Ᵽcc$_{5}$	74760836	Red lava	HC 818428
Ᵽcc$_{5}$	74760845	Red lava	S 919243
Ᵽcc$_{5}$	74760869	Red lava	S 904245
Ᵽcc$_{5}$	74760893	Red lava	HC 867555
Ᵽcc$_{g}$	73761276	Pink granofels	S 100322
Ᵽcc$_{g}$	73761278	Pink granofels	S 080275
Ᵽcc$_{a}$	74760018	Fine-grained andesite	S 146551
Ᵽcc$_{a}$	74760019	Medium-grained andesite	S 153556
Dyke	72762032	Quartz-feldspar porphyry	HC 912387
Dyke	72762034	Quartz-feldspar porphyry	HC 364437
Dyke	72762040	Quartz-feldspar porphyry	HC 877366
Dyke	72762042	Quartz-feldspar porphyry	HC 841412
Dyke	73761238	Quartz-feldspar porphyry	S 145434
Dyke	73761243	Quartz-feldspar porphyry	S 154432
Dyke	74760815	Feldspar porphyry	S 023422
Dyke	74760820	Feldspar porphyry	S 981350
Dyke	73761204	Dolerite	HC 864557
Dyke	74760032	Dolerite	S 153367
Xenolith	74760035	(in granite, Ᵽgn$_{5}$) - Ᵽcc 1?	HC 890417
Xenolith	74760036	(in granite, Ᵽgn$_{5}$) - Ᵽcc 1?	HC 890417
Xenolith	73761270	(in granite, Ᵽgn$_{5}$) Blue-black ignimbrite Ᵽcc$_{4d}$	S 150348
Xenolith	73761271	(in granite Ᵽgn$_{5}$) Blue-black ignimbrite, Ᵽcc$_{4d}$	S 152357