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Record 1972/74

THE GEOLOGY AND PETROLOGY OF THE HELEN SPRINGS, NUTWOOD DOWNS, AND PEAKER PIKER VOLCANICS

by

R.J. Bultitude

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SUMMARY

Lavas of probable Lower Cambrian age are poorly exposed in several places in the eastern part of the Northern Territory. The Helen Springs, Nutwood Downs, and Peaker Piker Volcanics consist of a succession of basaltic and rare andesitic lava flows with minor sandstone intercalations.

Labradorite, clinopyroxene, opaque oxide, and devitrified glass or a quartzo-feldspathic residuum account for a high proportion of the total volume of volcanic rocks. Accessory minerals are apatite, quartz, hornblende, and mica. The occurrence of minor amounts of interstitial primary quartz in the lavas is characteristic. Chemical analyses of nine rocks show they are basalts. A tenth analysis is of a tholeiitic andesite.

The majority of the flows show a central, compact or nearly non-vesicular, medium-grained interior grading into a fine-grained vesicular zone in the upper, and also the basal, portions. Basalt from the more massive portions of the flows contains phenocrysts of plagioclase, but feldspar phenocrysts are nowhere abundant.

Vesicles are commonly filled with various secondary minerals, the most common being chlorite, quartz, and chalcedony. The basalts have undergone a certain amount of alteration - the alteration being most extensive and intensive in the upper and basal portions of the flows. Feeder dykes for the flows have not been found.

The lavas of the three formations are very similar, both in hand specimen and thin section. However, there are commonly slight differences from flow to flow, such as the presence or absence of pigeonite. There are also differences marked by the character of the opaque oxide - which is present either as interstitial granules or as microphenocrysts. Clinopyroxene may occur as small interstitial grains or as anhedral phenocrysts ophitically and subophitically enclosing feldspar laths.

The close match in the chemical compositions of lavas from the three formations is also striking. It is concluded, therefore, that the lavas of the Helen Springs, Nutwood Downs, and Peaker Piker Volcanics originated under similar physical conditions, and that they were derived from parent magmas of similar chemical composition.

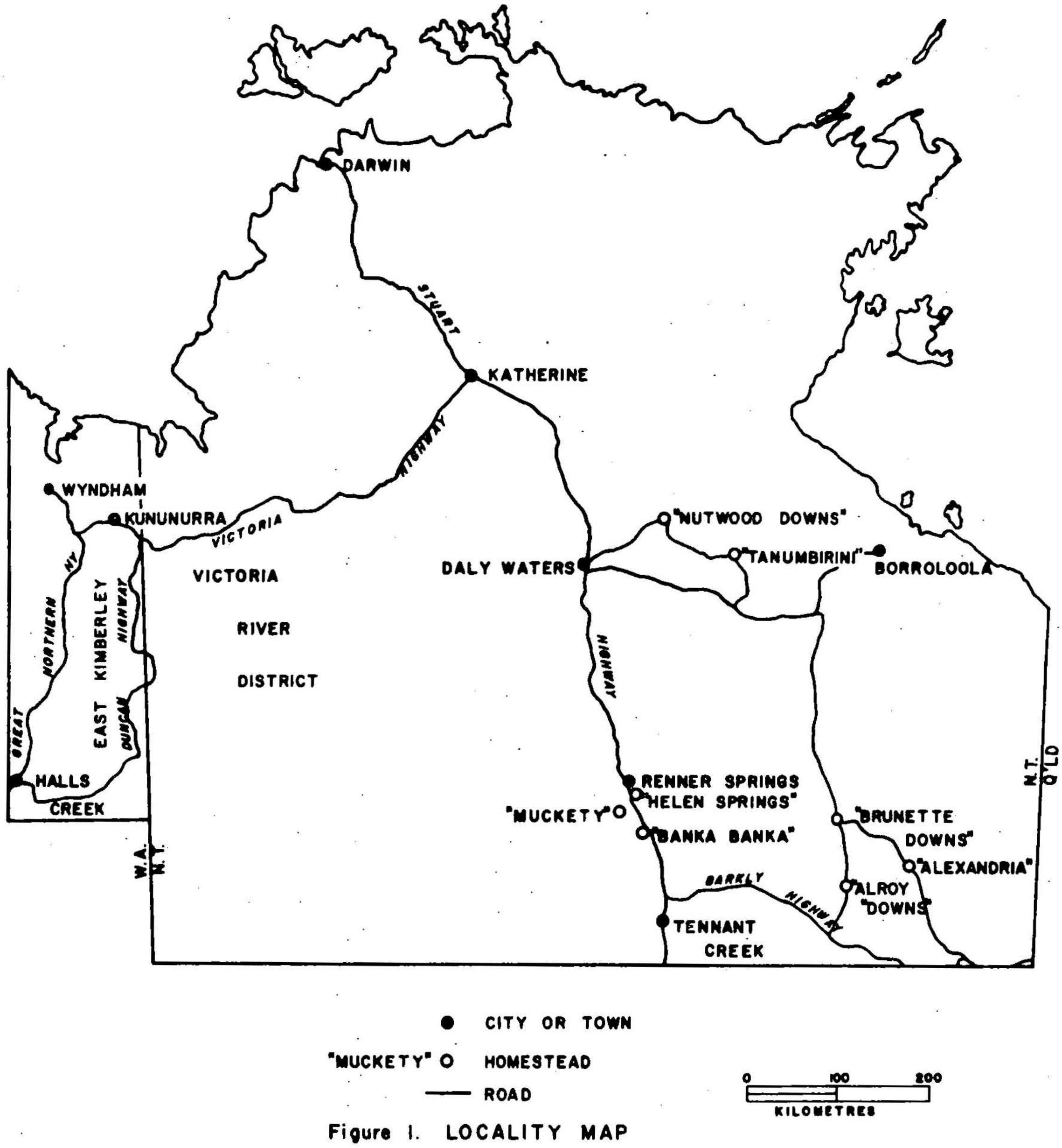

Figure 1. LOCALITY MAP

NT/A356

To accompany Record 1972/74

INTRODUCTION

This is the second of a series of records that describe the geology and petrology of volcanic rocks of probable Lower Cambrian age from northern Australia. The Antrim Plateau Volcanics cover extensive areas in the East Kimberley region of Western Australia and the adjoining Victoria River and Daly River Basin areas in the Northern Territory. Other isolated outcrops of volcanics have been mapped near Helen Springs homestead, near Nutwood Downs homestead, and east of Brunette Downs homestead in the Northern Territory, and north of Camooweal in western Queensland. They have been named the Helen Springs, Nutwood Downs, Peaker Piker and Colless Volcanics respectively. Dunn and Brown (1969) correlated them with the Antrim Plateau Volcanics. All these rocks, possibly except the Peaker Piker Volcanics, have been regarded as belonging to the same episode of volcanic activity. They have been assigned a Lower Cambrian age although they had not been dated isotopically and diagnostic fossils have not been found in the interbedded sedimentary rocks. Smith and Roberts (1963) considered that the Peaker Piker Volcanics are interbedded with the lower Middle Cambrian Burton Beds. However, this is doubtful.

The Helen Springs, Nutwood Downs, and Peaker Piker Volcanics were examined between 1 and 16 August 1971. The Colless Volcanics are to be examined during the 1972 field season. Specimens were collected for detailed petrological examination and chemical analysis. The aim of the project is to compare and contrast these volcanics with the much more voluminous Antrim Plateau Volcanics in the Ord-Victoria region of northern Australia. The Antrim Plateau Volcanics will be described in a separate Record.

Thin sections of 54 rocks collected during the survey have been examined. The approximate positions of homesteads and towns mentioned in this Record are shown on Figure 1. Reference should be made to the geological maps of the Helen Springs, Tennant Creek, Hodgson Downs, and Mount Drummond Sheet areas for more detailed information on the surface distribution of the basic volcanics.

Preamble

Flood basalts, of probable Lower Cambrian age, together with minor pyroclastics and interbedded sediments, crop out over extensive areas in northern Australia. Along the southwestern margin of the Bonaparte Gulf Basin (Fig. 1a), the Antrim Plateau Volcanics crop out intermittently between Cambrian sediments and disappear beneath Recent coastal deposits a few kilometres northeast of Mount Connection. The scattered outcrops of the volcanics between Wyndham and Ragged Range lie at the base of Palaeozoic outliers. Isolated outcrops of the volcanics at Martins Gap, at Kununurra and south-southwestward, north of Cockatoo Spring, and south-southwest and north-northwest of Spirit Hill, are the only Cambrian rocks recorded on the southern and southeastern margins of the Bonaparte Gulf Basin (Kaulback and Veevers, 1969). The thickness of the volcanics has not been measured, but it is estimated that it does not exceed 150 m and along the southeastern margin it is probably less than 30 m (Kaulback and Veevers, 1969).

The Antrim Plateau Volcanics crop out more extensively south of the Bonaparte Gulf Basin, around the margins of the Hardman, Rosewood, and Argyle Basins in the East Kimberley region of Western Australia and the adjoining Victoria River District of the Northern Territory. The formation also crops out along the western margin of the Wiso Basin in a broad north to northeast-trending belt from near Hooker Creek in the south to the valley of the Flora River in the north; from there it occurs in discontinuous outcrops to the northern part of the Daly River Basin near the headwaters of the Reynolds and Adelaide Rivers. Randal (1963) regarded identical rocks cropping out on the eastern side of the Daly River Basin near Katherine township and along the Roper Valley as being continuous, beneath the younger sediments, with the main mass of the volcanics. This correlation was followed by Dunn (1963, 1963a), and Randal and Brown (1967) cite supporting evidence for it from water-bore and scout-hole drilling west and southwest of Larrimah. Dunn regarded the basic volcanics exposed in the extreme southwest and northwest of the Urapunga and Hodgson Downs 1:250 000 Sheet areas respectively as lateral equivalents of the Antrim Plateau Volcanics. Outcrops of Nutwood Downs Volcanics are confined mainly to the central portions of the Hodgson Downs Sheet area. The formation is almost certainly a southern extension of the narrow belt of Antrim Plateau Volcanics exposed along the eastern margin of the Daly River Basin.

The Helen Springs, Peaker Piker and Colless Volcanics occur as small isolated outcrops around the margins of the Georgina Basin (Fig. 1a). The Georgina Basin is a large Palaeozoic sedimentary basin extending from northwestern Queensland into the Northern Territory. The geology of the basin has been described by Smith (1967). Precambrian outcrops define the southwestern, western, northern, and eastern margins of the basin, but the northwestern margin is obscured by Mesozoic sediments which conceal a probable connection with the Daly River Basin. Mesozoic sediments of the Great Artesian Basin conceal the southeastern margin but geophysical surveys and limited drilling have indicated the extent of Palaeozoic sediments in that area. A small part of the western boundary of the Georgina Basin has not been determined (Smith, 1967). This is in the Barrow Creek area where Cambrian sediments of the Georgina Basin may be continuous in the subsurface with those of the Wiso Basin.

The Wiso Basin, which contains mainly Lower Palaeozoic rocks, occupies the region between the Stuart Highway and the eastern and southern watersheds of the Victoria River, and lies between latitudes 15°S and 21°S in the Northern Territory. The name was derived from the Wiso Tableland, a term used by Hossfeld (1954) to describe the elevated desert country between Newcastle Waters, Wave Hill, The Granites, and Barrow Creek. Hossfeld believed the Tableland was underlain by Cambrian sediments continuous with those in the Buldiva Basin to the north - the whole sequence occurring in the Buldiva-Wiso Basin. Hossfeld's term "Buldiva Basin" refers to the Daly River Basin of Noakes (1949). The geology of the Wiso Basin has been described by Milligan et al. (1966) and Randal and Brown (1967).

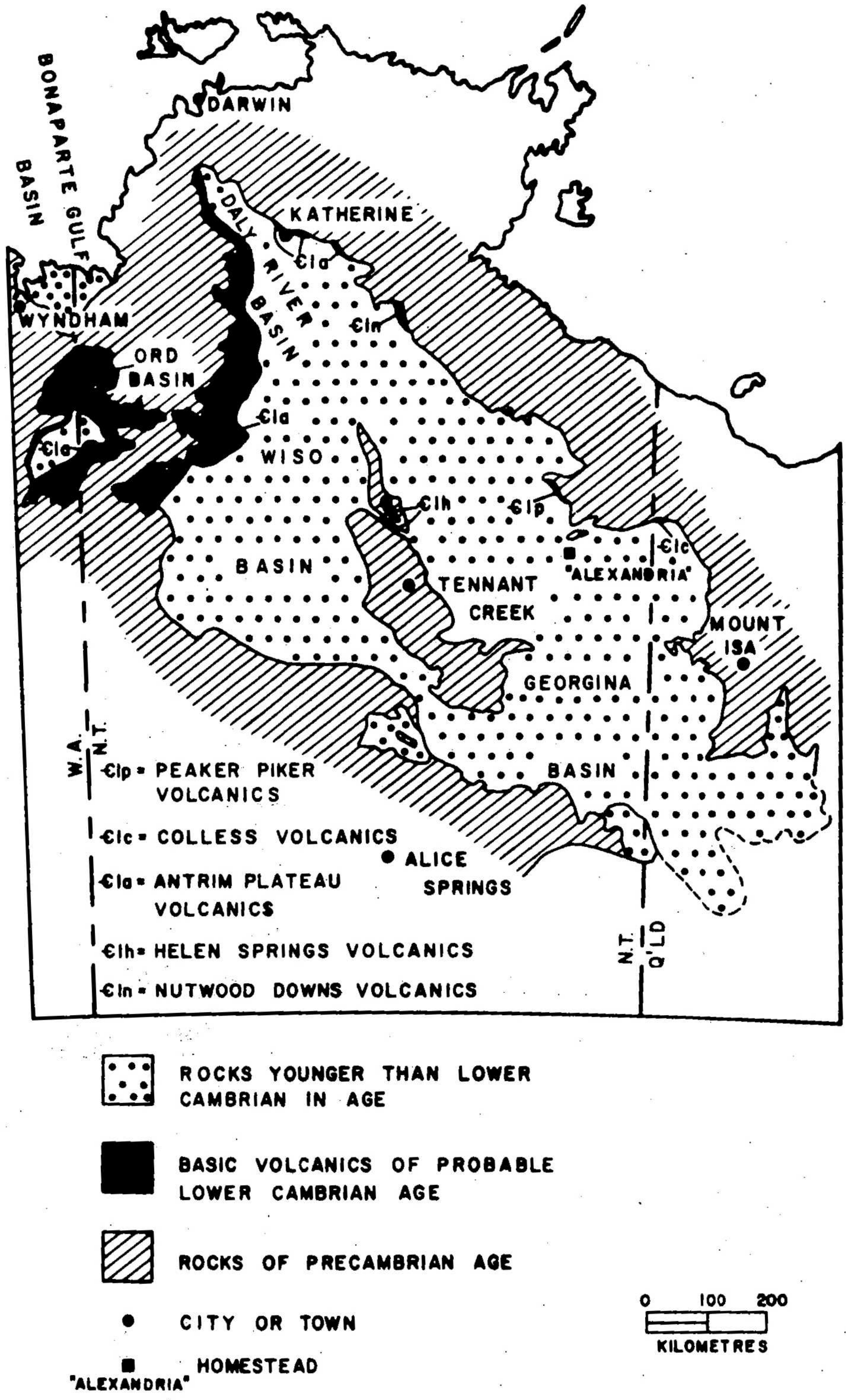

Figure 1a. DISTRIBUTION OF LOWER CAMBRIAN BASIC VOLCANICS, NORTHERN AUSTRALIA

AUS 2/204

To accompany Record 1972/74

The Daly River Basin is developed in Lower Palaeozoic sandstones, siltstones, and carbonate rocks. Lower Cambrian volcanics and Precambrian sandstones, siltstones, and granite crop out around the margins of the Basin; residuals of Lower Cretaceous rocks occur throughout the Basin. The Water Resources Branch, Northern Territory Administration, has supervised the drilling of a number of stratigraphic holes in the Daly River Basin, the results of which will be discussed in a later Record describing the Antrim Plateau Volcanics.

The distribution of the volcanics is shown in Figure 1a. Because of the scale of the diagram the Hardman, Rosewood, and Argyle Basins are collectively referred to as the Ord Basin; the outcrops of Antrim Plateau Volcanics around the margin of the Bonaparte Gulf Basin are not shown for the same reason.

Company geological activity has been concentrated mainly in the Georgina Basin - initially in the search of petroleum - and is summarized by Smith (1967). To 31 December 1966, 19 wells had been drilled in the Georgina Basin. Since 1966 renewed company activity, stimulated by the discovery of phosphorite in cores and cuttings from stratigraphic (oil) wells in western Queensland (Russell, 1967) has resulted in extensive drilling in the Alexandria region of the Northern Territory and in the adjoining area of western Queensland.

Because of the blanket of Middle Cambrian and younger sediments, it is not possible to assert that the various isolated outcrops of basic volcanics exposed around the margins of the basins are definitely lateral equivalents and that a more or less continuous sheet of basic volcanics extended in Lower Cambrian time from the East Kimberley District across the northern part of the Northern Territory into northwestern Queensland. However, the available subsurface data from water-bores and stratigraphic and scout holes support such a contention. Much of the region is unoccupied desert and semi-desert. The majority of the drill holes have not penetrated the Middle Cambrian formations. Much of the information has come from drillers logs as recorded in station records and in the files of the Water Resources Branch of the Northern Territory Administration. In many cases, cuttings from the bores are not available and one has to rely solely on drillers identifications of the lithologies of the drill cuttings. Many of the bore logs are incomplete and for some bores no information whatever can be found. Also there are some records referring to bores which can no longer be identified on the ground. Inevitably the list of drill holes will be incomplete.

THE HELEN SPRINGS VOLCANICS

Introduction

The Helen Springs Volcanics crop out in the Helen Springs and Tennant Creek 1:250 000 Sheet areas. The Helen Springs Sheet area is astride the northwestern margin of the Barkly Tableland in the Northern Territory; it lies between longitudes 133°30'E and 135°E and between latitudes 18°S and 19°S. The southern boundary of the Sheet area is about 80 km north of Tennant Creek. The Tennant Creek Sheet area adjoins the Helen Springs Sheet area to the south.

Previous investigations

Noakes and Traves (1954) named the basic volcanic rocks which crop out around Helen Springs homestead and further south near Tennant Creek the Helen Springs Volcanics, and correlated them with the Antrim Plateau Volcanics. They regarded the area (latitude 18°26'S; longitude 133°52.8'E) around Helen Springs homestead as the type area for the formation. There are no type sections.

Tapp (1966) investigated an amethyst deposit in the Helen Springs area. The prospect covered the northern extension of a low ridge which rises 12 m above the level of the Stuart Highway at the Helen Springs turnoff. The amethyst, together with quartz, smoky quartz, chalcedony and chlorite, occurred filling amygdales and large geodes in the Helen Springs Volcanics. Tapp described the volcanics in this area as consisting of "vuggy vesicular basalt and andesite flows" and overlying the "Hayward Creek Beds" (now included in the Helen Springs Volcanics). Tapp noted that "although the individual crystals are small (¾" long), their colouring is ideal for gem-quality stone". Reserves of 18 kg of good-quality amethyst were measured during the investigation.

A small opal find near Helen Springs station was briefly examined by Hays (Crohn, 1960). Workings consisted only of shallow pits and trenches, and the only opal visible at the time of the examination occurred as irregular veinlets in a silified breccia, possibly a fault breccia. None of this opal was of gem quality. The site of the workings (south of the homestead) was pointed out to the writer by the manager of Helen Springs station. The deposits apparently occurred in heavily altered, glassy, vesicular and amygdaloidal basalt from the basal part of the lowermost flow in the Helen Springs Volcanics.

Randal et al. (1966) made a detailed examination of the volcanics during regional mapping in the Helen Springs Sheet area in 1965. They delineated several areas of volcanics other than the main area of outcrop around Helen Springs homestead. Sedimentary rocks conformably underlying the basic volcanics were included in the formation. Randal et al. also mapped heavily altered basic dyke rocks in the Whittington Range as Helen Springs Volcanics and suggested that they represent feeders for some of the flows. However, recent mapping by Mendum and Tonkin (in prep.) has shown that the basic rocks in the Whittington Range form part of the Tomkinson Creek Group of probable Carpentarian age.

Ivanac (1954), Crohn and Oldershaw (1965), and Mendum and Tonkin (in prep.) have briefly described several small exposures of Helen Springs Volcanics in the Tennant Creek area. These exposures have not been examined by the writer.

Distribution

The Helen Springs Volcanics crop out in the Helen Springs Sheet area on the western flanks of the Ashburton Range and in valleys within it around Helen Springs homestead, around Muckety homestead, near Banka Banka homestead, near Renner Springs roadhouse, about 13 km southwest of Ladabah

Bore and near Loveday Creek (Randal et al., 1966). Randal et al. (1966) considered that a small outcrop of tuffaceous sediments about 21 km southwest of Banka Banka homestead belongs to the Helen Springs Volcanics although its age and stratigraphic relationships could not be definitely established. The volcanics, as mapped by Randal et al., are exposed over a total area of about 220 km^2, the largest single area of outcrop being around Helen Springs homestead (104 km^2).

During recent mapping in the Whittington Range in the northern part of the Tennant Creek Sheet area, Mendum and Tonkin (in prep.) delineated a sequence of basic and acid volcanics interbedded with sandstones, siltstones, and shales. They named the volcanics the Whittington Range Volcanics, and included the formation in the Tomkinson Creek Group of probable Lower Carpentarian age. They suggested that at least some of the basic volcanics mapped by Randal et al. (1966) as Helen Springs Volcanics - particularly those exposed in the Whittington Range area - are basalts of Lower Carpentarian age that can be directly correlated with the Whittington Range Volcanics. Randal et al. (1966) commented that in places the Helen Springs Volcanics can be seen "filling valleys eroded into siltstone units of the Tomkinson Creek Beds" and stated that it is often difficult to demonstrate conclusively that the volcanics are not in sequence with the Precambrian rocks.

Although a general similarity may exist between the Helen Springs and Whittington Range Volcanics, the Helen Springs Volcanics differ from the Whittington Range Volcanics, as described by Mendum and Tonkin, in several aspects. Epidote is very rare in the specimens of Helen Springs Volcanics collected from around Helen Springs, Muckety, and Banka Banka homesteads. Acid variants are absent and the volcanics are mainly massive with vesicular zones restricted to the basal and upper portions of flows. They closely resemble samples from the Antrim Plateau Volcanics in both hand specimen and thin section. The Whittington Range Volcanics, on the other hand, contain abundant epidote which mainly occurs filling small irregular amygdales distributed throughout the flows.

Topographic expression

The Helen Springs Volcanics crop out in broad topographic depressions in the Ashburton Range. They underlie extensive areas of black soil plain with few trees and form low mesas capped by thick laterite or laterized sediments. The basal sedimentary rocks form well developed strike-ridges in many places (Fig. 2).

Stratigraphic relationships

The formation rests with a strong unconformity on the Tomkinson Creek Group and is overlain, probably disconformably, by the fossiliferous Lower Middle Cambrian Gum Ridge Formation (Randal et al., 1966). According to Randal et al. the volcanics south of Renner Springs roadhouse overlie siltstones about 600 m lower in the Tomkinson Creek Group than those immediately underlying the volcanics in the areas around Helen Springs and Muckety homesteads.

Age Dating

One specimen from the Helen Springs Volcanics was isotopically dated by the K-Ar whole-rock method at the Australian Mineral Development Laboratories, Adelaide. An age of 511 $\pm$ 12 m.y. was obtained, which is younger than the age inferred for the formation from stratigraphic evidence. Similar ages were obtained on specimens from the Antrim Plateau Volcanics and the Nutwood Downs Volcanics and it seems likely that all samples have lost radiogenic argon since their formation. The problem will be discussed in greater detail in a later Record when more results should be available. A summary of the results obtained so far is given in Appendix I.

Thickness

The maximum thickness of the formation is unknown. At Muckety homestead a bore penetrated 37 m of basalt without intersecting the underlying rocks (Randal et al., 1966). A water-bore sited 6.5 km northwest of the homestead is recorded as having penetrated 47 m of basalt before passing into shale. In dissected country near Helen Springs homestead a minimum thickness of 18 m was measured by Randal et al. (1966). Bore No. 19, Helen Springs station, and Helen Springs Government bore were drilled into basalt but no logs or cuttings are available. Crohn and Oldershaw (1965) recorded a maximum thickness of 15 m for the Helen Springs Volcanics in the Tennant Creek area.

Sampling the formation

The volcanics are rarely exposed in situ and specimens suitable for detailed petrological examination and chemical analysis are rare. The formation has undergone extensive weathering and most of the areas mapped as Helen Springs Volcanics comprise black soil plains supporting stands of Mitchell and Flinders grasses. Small isolated outcrops, mainly of heavily altered basalt, are exposed in several gullies and creek beds and also below laterite cappings. Relatively unweathered dark grey basalt occurs as sparse surface rubble in the black soil areas. Many of the specimens were collected from these areas and therefore it is likely that few flows have been sampled. Thin-section examination of the specimens supports this suggestion. A representative suite of specimens can only be obtained by drilling through the formation.

Geology

The Helen Springs Volcanics consist of tholeiitic basalt (sensu lato) and basal sandstone and sandstone breccia. In most exposures the volcanics are massive, medium- to coarse-grained, extensively ferruginized basalts. The volcanics from near the base of the formation are fine-grained and amygdaloidal or vesicular. Massive specimens are typically dark red-brown to reddish purple with numerous small patches of pale green chlorite (?). Spheroidal weathering occurs in slightly vesicular to massive basalt. South of Helen Springs homestead the basal sandstone is overlain by fine-grained, heavily altered, slightly to moderately vesicular basalt. In places the basal portions of the lava flow are replaced by a soft, pale yellow opaline(?) mineral that probably formed from the intensive alteration of glassy basalt.

Many of the joints, vesicles, and small geodes in the basalts contain well formed crystals of quartz and smoky quartz. Weathering and erosion of the volcanics has concentrated quartz crystals at the surface in several places, such as near the Helen Springs - Muckety boundary fence beside the Stuart Highway (Randal et al., 1966) and the slopes below a small capping of Gum Ridge Formation sediments about 4 km east of Helen Springs homestead. Randal et al. (1966) also mentioned the presence of quartz crystals in the pebble fraction of Mesozoic and Recent sediments in the area.

The volcanics are capped by laterite in several places. The basalt is kaolinized in the pallid zone of the laterite profile, but the original igneous textures usually remain. Thick sections of kaolinized basalt are exposed in the slopes below Mesozoic sediments south of Muckety homestead (Randal et al., 1966). Original igneous textures are recognizable in some parts of the transitional mottled zone of laterite profiles but are generally completely obliterated in the ferruginous zone. Dykes have not been found in the formation.

In the Tennant Creek Sheet area the Helen Springs Volcanics consist of heavily altered fine- to coarse-grained basalts with thin lenses of tuff and agglomerate in the upper part of the section (Ivanac, 1954). The exposed basalts in the area show evidence of explosive volcanic activity by the inclusion of tuffs and agglomerates. Ivanac also mentioned the occurrence of volcanic bombs in the formation in the Blue Moon area.

Table 1. Modal analyses of rocks from the Helen Springs Volcanics

Sample Number	Volume %						
	Plagioclase	Clinopyroxene	Opaque Oxide	Mesostasis	Hornblende	Mica	Secondary Minerals
70772141	45	37	4	13	-	-	1
70772142	38	32	2	24	tr	-	4
70772147	34	18	6	31	-	-	11
70772151	33	19	14	23	tr	-	11
70772152	46	36	5	9	-	-	4

tr = trace (less than 1)

Minimum number of points counted per section : 3 100

Table 2. Locality index for samples of Table 1

Sample	Latitude	Longitude	Locality Description
70772141	18°28'S	133°56'E	Slope of small laterite-capped hill about 3 km E of Helen Springs homestead
70772142	18°26'S	133°57'E	3 km E of Helen Springs homestead
70772147	18°29'S	133°57'E	Floater in black soil plain about 4 km SE of Helen Springs homestead
70772151	18°29'S	133°58'E	Small outcrop at plain level about 6 km SE of Helen Springs homestead
70772152	18°27'S	133°56'E	Small gully about 2.5 km SE of Helen Springs homestead

Table 3. Chemical analyses of five rocks from the Helen Springs Volcanics

	70772141	70772142	70772144	70772147	70772149
	Wt %	Wt %	Wt %	Wt %	Wt %
SiO_2	52.5	52.1	52.2	54.0	52.8
Al_2O_3	14.8	14.7	14.4	13.1	14.4
Fe_2O_3	6.25	2.25	2.35	8.85	6.30
FeO	4.75	7.85	8.15	5.30	4.40
MgO	5.70	7.00	6.40	3.35	5.35
CaO	9.50	10.3	10.0	6.75	9.40
Na_2O	2.55	2.10	2.05	2.60	2.35
K_2O	0.88	0.81	0.87	1.85	0.99
H_2O+	0.37	0.68	0.96	0.65	1.24
H_2O-	1.13	0.90	0.88	1.13	0.99
CO_2	0.08	0.08	0.05	0.04	<0.05
TiO_2	1.00	1.09	1.17	1.90	1.23
P_2O_5	0.11	0.11	0.12	0.16	0.12
MnO	0.15	0.17	0.18	0.14	0.20
TOTAL	99.77	100.14	99.78	99.82	99.82
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Sr	150	140	160	200	160
Rb	20	50	50	120	50
Ba	150	200	200	450	250

Analysts: A.H. Jorgenson (specimens 70772142, 70772144, 70772149), L.W. Castanelli and G.R. Holden (specimens 70772141, 70772147), Australian Mineral Development Laboratories, Adelaide.

Table 4. Locality index for samples of Table 3

Sample	Latitude	Longitude	Locality Description
70772141	18°26'S	133°57'E	Small hill 3 km E of Helen Springs homestead
70772142	18°26'S	133°57'E	3 km E of Helen Springs homestead
70772144	18°27'S	133°54'E	East of junction of track to Helen Springs homestead and Stuart Highway
70772147	18°27'S	133°58'E	Floater in black soil plain 4 km SE of Helen Springs homestead
70772149	18°26'S	133°57'E	Small hill about 3 km E of Helen Springs homestead

Petrography

Massive basalts (sensu lato) from the Helen Springs Volcanics are mainly medium- to coarse-grained and red-brown, reddish to purplish, and dark to light grey. Small phenocrysts of plagioclase, barely discernable to the naked eye, are sparsely distributed throughout the rocks. Secondary ferruginization, as indicated by the presence of irregular red-brown patches and lenticular streaks rich in hematite (?), has affected most specimens. Silicification is also common, particularly in the fine-grained and vesicular rocks (Randal et al., 1966).

Twenty one rocks have been examined in thin section. Modal analyses of five of the least altered, medium- to coarse-grained rocks are given in Table 1 and their localities listed in Table 2. The lavas are dominantly basalts. However, the presence of small amounts of quartz in some specimens (e.g., 70772141, 70772142) indicatesa composition close to andesite. Chemical analyses of five specimens are listed in Table 3. The localities of these samples are noted in Table 4.

Highly crystalline specimens display intergranular or subophitic textures and medium- to coarse grainsize with plagioclase more abundant than ferro-magnesian minerals. Specimens (e.g., specimen 70772156) from near the base of the formation consist of plagioclase laths in a matrix of devitrified glass. The coarser-grained specimens contain minor amounts of interstitial quartz and alkali feldspar (?). Quartz is often present in amygdales.

Chemical analyses of five samples show silica values of between 52 and 54 percent indicating basaltic to andesitic compositions. The chemical characteristics of these rocks will be discussed in a separate Record dealing with the petrochemistry of the Antrim Plateau Volcanics and its correlatives.

Alteration of the original minerals is evident even in the freshest specimens. Some clinopyroxene is partly altered to pale green fibrous amphibole (uralite) and plagioclase is mostly sericitized and chloritized. Randal et al. (1966) described several heavily altered specimens. They observed that, in heavily lateritized rocks with relict igneous textures, the feldspars have been altered to clay minerals and the ferro-magnesian minerals to secondary iron oxides, whereas in silicified specimens the rocks are fairly uniformly replaced by silica. The replacing silica is opaline, cryptocrystalline chalcedony, or fine-grained quartz. In general the plagioclase has been replaced by clearer silica than original glass or ferro-magnesian minerals and consequently the original igneous textures can still be recognized.

Plagioclase occurs mainly as small euhedral groundmass laths (average grainsize 0.2 mm x 0.03 mm) in the highly crystalline rocks and also as microphenocrysts (average grainsize 2 mm x 0.5 mm). Phenocrystic plagioclase, although never present in more than minor amounts (less than an estimated 10% by volume), is present in most sections. The microphenocrysts usually appear as isolated tabular grains; rarely as glomeroporphyritic groups (e.g., specimen 70772139). Some grains appear to have been partly resorbed. Smaller microlites possessing somewhat ragged outlines occur in the fine-grained glass-rich rocks from near the base of the formation. Most plagioclase grains are sericitized. In some specimens plagioclase is replaced by chlorite, generally associated with sericite. The phenocrysts are particularly susceptible to replacement. Many of the altered grains have a clouded appearance. Rare cruciform intergrowths caused by the interpenetration of two individual laths occur in section 70772139.

Plagioclase compositions as measured on groundmass grains using the method of Michel-Lévy range from An_{52} to An_{60}. Determinations were carried out only on unaltered feldspars from the least-altered specimens. Randal et al. (1966) determined that many of the plagioclase grains in heavily altered rocks were partly albitized as well as extensively sericitized.

Clinopyroxene is not as abundant as plagioclase in the highly crystalline rocks. There is a marked decrease in the proportion of clinopyroxene granules to feldspar laths in the fine-grained rocks; in several hypocrystalline types, the presence of clinopyroxene (or former clinopyroxene) cannot be confirmed. In rocks with a low glass content clinopyroxene forms small blocky subhedral grains (0.3 mm x 0.1 mm) and relatively large anhedral plates (1.0 mm x 0.5 mm) partly, but rarely completely, enclosing feldspar laths. Simple twinning of clinopyroxene is common in the larger grains, multiple twinning is rare. Many of the larger grains are zoned.

<u>Augite</u> is the most abundant pyroxene. <u>Pigeonite</u> occurs in the majority of specimens (e.g., 70772136, 70772142, 70772143, 70772144, 70772145, 70772149, 70772150, 70772152, 70772153). The pigeonite is distinguished from augite by its small 2V (0–15°), pseudo-uniaxial figures being obtained on many of the grains. There is no indication of inversion of the pigeonite to orthopyroxene. Randal et al. (1966) did not detect the presence of pigeonite in the Helen Springs Volcanics.

Fresh unaltered clinopyroxene is colourless, and altered grains are pale green. Pyroxene is locally uralitized. The replacing amphibole is fibrous, and is slightly pleochroic from pale green to pale yellowish green. Replacement occurred preferentially along cleavage planes, the cores being more susceptible to alteration than the edges. Rarely, grains have been partly replaced by massive hornblende, distinctly pleochroic from blue-green to yellow-green.

Many of the altered clinopyroxene grains occur as brown amorphous grains containing secondary opaque oxide along fractures, cleavage planes, and around grain margins. Red-brown iron staining is common. The presence of original clinopyroxene is difficult to ascertain in many of the heavily altered basalts - particularly in the fine-grained rocks containing abundant devitrified glass. Some of the irregular patches of secondary hematite (?) may be completely replaced clinopyroxene.

Chlorite is a rare minor replacement of clinopyroxene in the sections examined by the writer. However, Randal et al. (1966) asserted that clinopyroxene was partly replaced by chlorite in several sections.

Very rarely the clinopyroxene grains contain small rounded inclusions (0.1 mm) believed to be altered <u>olivine</u> (e.g. in specimens 70772141 and 70772145), completely replaced by fine fibrous aggregates of pale yellow-green chlorite (?) with thin stringers of associated secondary opaques.

Accessory <u>opaque minerals</u> (less than 6 percent by volume) are present in most of the highly crystalline massive basic volcanics. However, Specimen 70772151 includes a comparative abundance of anhedral opaques (14 percent by volume) in interstices between feldspar laths. The opaque grains occur in two grain sizes: one about 0.3 mm (relatively large subhedral grains) and the other about 0.05 mm (small anhedral intergranular grains). Many of the larger grains possess a poikilitic habit, enclosing or partly enclosing small plagioclase laths. Several have embayed outlines and appear to have been partly resorbed (e.g, in specimen 70772136).

Many of the opaque grains have a narrow irregular margin of orange-red to dark red-brown secondary hematite (?). Adjacent plagioclase and clinopyroxene grains are commonly stained with the red-brown oxidation products. In specimen 70772138 secondary hematite (?) is associated with interstitial quartz. The dark red-brown colour of many of the basic volcanics and the presence of irregular red-brown streaks and patches in otherwise dark grey basalt indicates that the primary opaque oxide has been altered, at least partly, to hematite (?).

Secondary hematite (?) is also a by-product of uralitization of clinopyroxene. Most of the secondary iron ore is translucent under strong transmitted light.

Devitrified glass, primary quartz, and fine quartz-alkali feldspar(?) intergrowths have been grouped together under the heading mesostasis for determination of the modal mineral content. The bulk of the mesostasis in the medium-grained highly crystalline rocks (e.g. specimens 70772141, 70772142) consists of quartz and subordinate alkali feldspar (?); devitrified glass is rare. However, devitrified glass forms the bulk of the mesostasis in the more quickly chilled rocks (e.g., specimens 70772147, 70772151 and 70772152).

Devitrified glass ranges in amount from less than 5 percent to more than 50 percent by volume. The character of the glass varies from much dark red-brown, abundantly or nearly opaque, material in the fine-grained amygdaloidal rocks (e.g. specimens 70772156 and 70772155) from near the base of the formation to minor red-brown, pale red-brown, pale pink, or practically colourless, crypto-crystalline slightly birefringent material in the coarse-grained highly crystalline rocks. The devitrified glass forms interstitial patches up to 1.0 mm in diameter (but generally less than 0.5 mm) in the massive basalts and commonly contains tiny feldspar microlites, granules and rods of opaque oxide (extensively oxidized to hematite?), and needles of apatite.

In most of the coarser-grained rocks (e.g., specimens 70772141, 70772142) the bulk of the interstitial late-stage residuum has crystallized to fine-grained, often graphic-like, intergrowths of quartz and alkali feldspar. These intergrowths are generally so fine that the presence of alkali feldspar cannot be definitely established by optical means. However the tiny patches of low-relief mineral in contiguity with the quartz grains are considered to be alkali feldspar. However, holocrystalline rocks are rare, as a careful search will result in the discovery of at least traces of interstitial devitrified glass in most sections. The coarsest-grained rocks contain 5-20 percent devitrified glass.

Most of the specimens contain primary quartz. In several of the coarsely crystalline rocks quartz accounts for an estimated 10-20 percent by volume of the total composition. It is a late stage crystallization product and usually forms small anhedral interstitial grains. The grains generally show sharp extinction and may contain inclusions of acicular apatite.

Large anhedral grains of secondary quartz occur in amygdales. Smaller grains, together with granules of secondary hematite (?), form small patches in massive basalt. The quartz grains infilling the amygdales and patches are characterized by undulose extinction and numerous, very fine, opaque and semi-opaque inclusions ('dust').

A few of the quartz-rich highly crystalline rocks (e.g., specimens 70772136, 70772147, 70772154) contain accessory amounts of primary hornblende and mica. The primary hornblende forms small subhedral tabular grains (0.1 mm x 0.05 mm) in interstices. The grains are slightly pleochroic from yellowish green to greenish pink. Only two or three grains were observed in any one section.

In most thin sections examined, clinopyroxene is replaced by uralite. Replacement occurred preferentially along cleavage planes. Rarely clinopyroxene has been partly replaced by massive amphibole (e.g., in specimens 70772141, 70772146), which is pleochroic from yellowish green to greenish yellow.

A few small flakes of primary mica occur in specimen 70772136. Pleochroism is strong - from pinkish red to colourless. Long slender needles of apatite were detected in most sections. The apatite is mainly confined to the interstitial devitrified glass and quartzo-feldspathic residuum and is assumed to have crystallized very late.

Chlorite (2-15 percent by volume) occurs in every specimen examined and is the principal secondary mineral found in the rocks. Specimens 70772141, 70772142 and 70772152 are comparatively fresh rocks and contain only traces of chlorite (less than 5 percent by volume). The chlorite varies in its mode of occurrence from that of an alteration product after olivine(?) or clinopyroxene to that of an amygdale filling. Most rocks also contain interstitial patches of chlorite, much of which has probably replaced glass. The chlorite occurs as pale yellow or pale yellow-green aggregates of very fine-grained plates. Pleochroism in varying shades of pale green is very slight.

Relatively large patches of chlorite in specimen 70772150 are zoned, small, pale yellow fibrous grains forming an outer margin and aggregates of very fine, much more deeply coloured (yellow-green) fibrous grains concentrated in the centres.

Minor amounts of secondary calcite and hematite (?) occur in some rocks (e.g., 70772149, 70772150, 70772151, 70772159) - mainly occupying interstices, replacing groundmass constituents and filling vesicles in amygdaloidal specimens.

Small irregular amygdales are common in the volcanic rocks (70772155, 70772156) from near the base of the formation. The amygdales range up to 2 mm in diameter. Blue-green chlorite, quartz, and calcite have been observed as vesicle fillings. Amygdales in specimen 70772156 appear to be filled entirely with calcite while those in specimen 70772155 are filled with blue-green chlorite and quartz. The chlorite occurs as short fibrous aggregates lining the walls of the amygdales and the quartz grains are confined to the central portions.

Sediments underlying the volcanic rocks

Sandstone with minor siltstone underlies basic volcanics in the outcrop areas near Helen Springs homestead, Renner Springs roadhouse, and Loveday Creek. These basal sediments have already been discussed in some detail by Randal et al. (1966). Contacts with the overlying basic volcanics are apparently conformable and hence the rocks have been mapped as part of the Helen Springs Volcanics. Figure 2 depicts the basal sandstone overlain by heavily altered basalt. The basalt is resting on a bedding plane of the sandstone. The predominant rock type is a buff, laminated to thinly bedded, massive to flaggy, semi-friable sandstone (Fig. 3) with large-scale cross-bedding in sets up to 7 m thick. The grainsize varies from fine to medium sand but sorting is good within individual laminae.

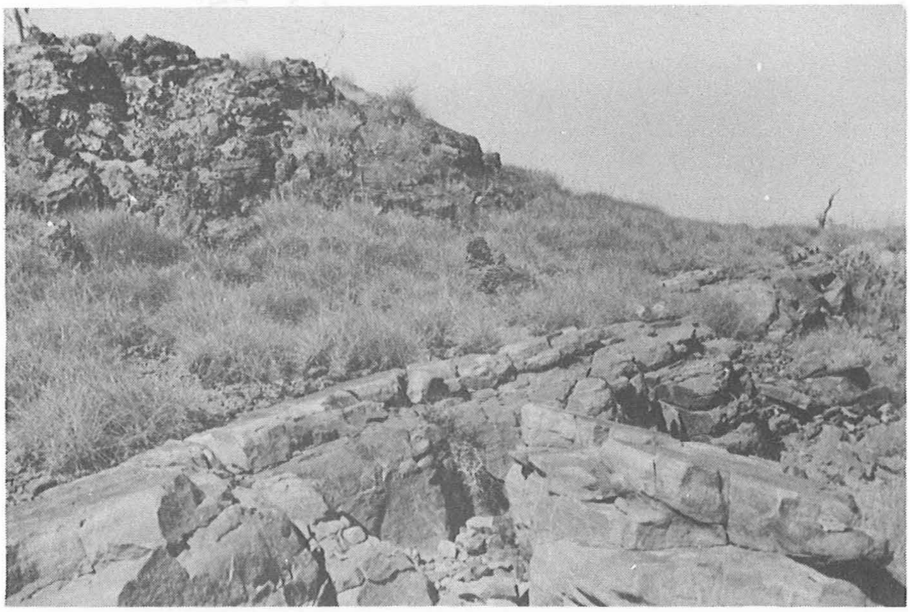

Fig.2. Basalt overlying basal sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead (Neg. No. M/1241).

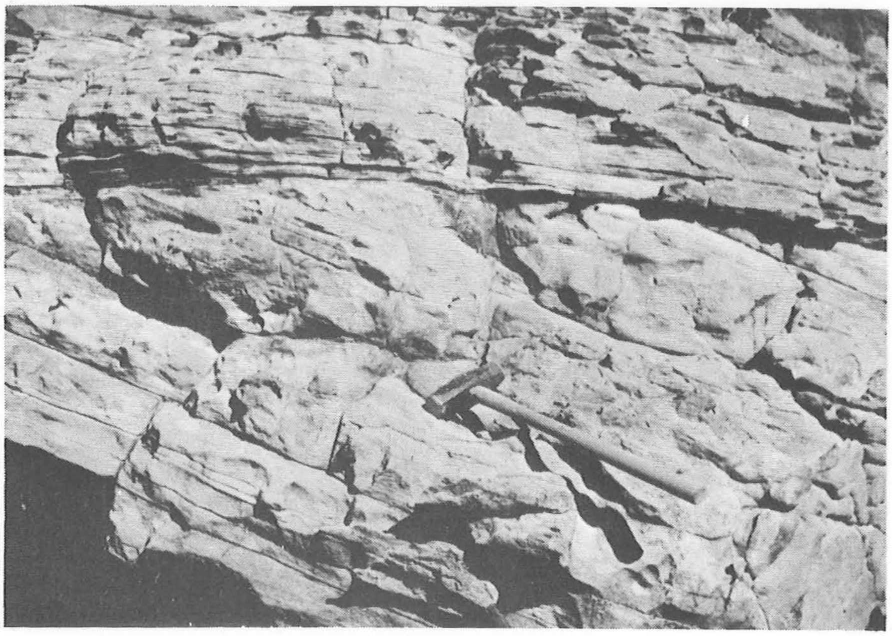

Fig.3. Cross-bedded sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead (Neg. No. GA/5832).

Fig.4. Aboriginal rock engravings in basal sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead. Scale is indicated by sledge hammer, upper left corner (Neg. No. GA/5833).

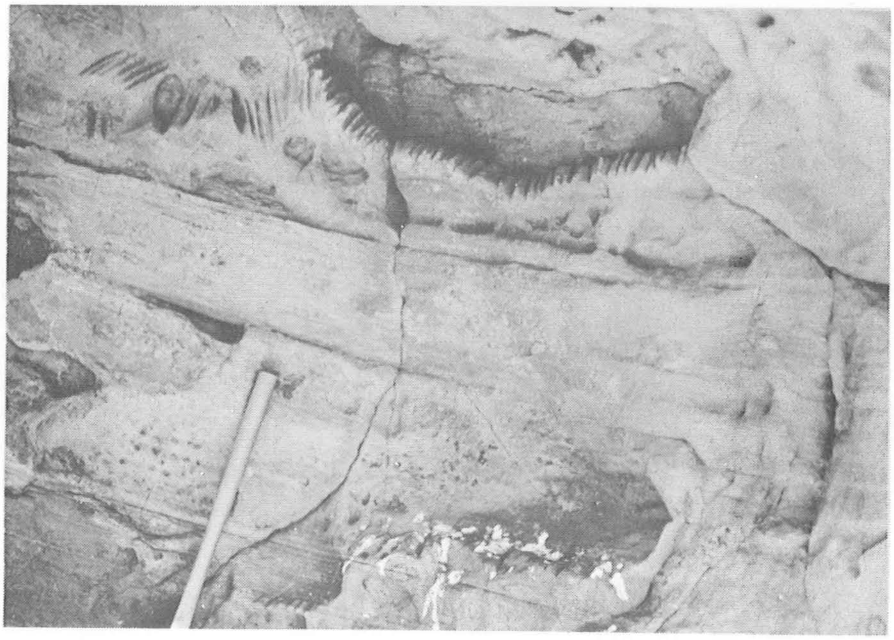

Fig.5. Abraded grooves in basal sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead (Neg. No. GA/5844).

Many of the sandstone boulders possess smooth flat surfaces (original bedding planes). Designs and motifs (Fig. 4) by aboriginal artists were found engraved on the smooth flat surface of a large sandstone boulder in one place. Abraded grooves (Fig. 5) in the sandstone were found in a nearby overhang.

Thin sections of the sandstone show that the clasts (average grainsize 0.4 mm) from the coarser-grained laminae are well sorted and highly rounded and are composed predominantly of quartz grains with very minor feldspar, quartzite, chert, siltstone, and accessory tourmaline. Grains are fairly closely packed and possess moderate to high sphericities. In some specimens (e.g., 70772137) irregular overgrowths of secondary quartz envelop many of the quartz grains. Grains are commonly coated with a thin film of red-brown limonite (?). Grains (average grainsize 0.2 mm) from the finer-grained laminae are markedly more angular than the larger clasts from the coarser-grained laminae. A poorly defined bimodal distribution of grains is displayed in specimen 70772143, which consists mainly of rounded quartz grains (0.4 mm in diameter) with scarce clasts of quartzite, chert, and siltstone. Small subrounded quartz grains (0.2 mm in diameter) occur in interstices between the larger clasts.

Randall et al. (1966) concluded that lithification of the sediments was due to the development of secondary overgrowths on quartz grains accompanied by some interpenetration and contact solution and squashing of clayey siltstone clasts. The rocks contain virtually no clay or siltstone matrix or pebbles. Fossils have not been found.

Randal et al. (1966) observed that the volcanics are underlain by sedimentary breccia with a sandy matrix at some places, the sedimentary sequence consisting either entirely of breccia or breccia interbedded with cross-bedded sandstone. The pebbles in the breccia consist of quartzite and siltstone derived from the Tomkinson Creek Group. The sandy matrix is similar in appearance to, and contains the same types of grains as, the cross-bedded sandstone. Randal et al. also described the occurrence of about 2 m of laminated siltstone, interbedded with the more usual buff sandstone, southwest of Wiggenty Well near Muckety homestead.

The maximum thickness (about 10 m) of the basal sandstone measured by the writer is at a locality about 6 km southeast of Helen Springs homestead. Randal et al. (1966) noted that the thickness of the basal sediments varied considerably - from about 2 cm to a maximum observed thickness of about 12 m. The thicker sections are composed mainly or completely of red-brown to buff cross-bedded sandstone, whereas many of the sections less than 3 m thick consist largely or entirely of sandy breccia.

The sandstones underlying the volcanics are strongly indurated for 2-10 cm below the contact surface (e.g., specimen 70772137). Shallow ridges and furrows (Fig. 6) on the contact surface have apparently been caused by the viscous drag of lava over the surface of partly consolidated sediments.

Randal et al. (1966) found inclusions of partly melted sedimentary rocks in the volcanics. They also described the occurrence of abundant sillimanite (?) or mullite(?) needles in indurated sandstone from near the sandstone-basalt contact north of Loveday Creek.

Fig.6. Small-scale ridges and shallow grooves (to right of hammer) on the contact surface of the basal sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead (Neg. No. GA/5840)

Palaeogeographic significance

Pillow lavas and palagonite breccias, as might be expected from extrusion of lava into a water body, have not been found in the Helen Springs Volcanics. It is therefore assumed that the lavas were extruded subaerially. Randal et al. (1966) observed that in places where the base of the basalt is well exposed there are no signs of an erosional unconformity with the basal sedimentary rocks; the basalt everywhere rests on a bedding plane. The lack of an unconformity implies a terrestrial environment for the sediments if the basalt was extruded subaerially. The rapid variations in thickness of the basal sandstone, the very large scale of the cross-bedding, the lack of pebbles and clay matrix, and the absence of fossils, suggest that it is an aeolian dune sandstone. The basal sandy breccias can be interpreted as deposits of intermittent streams containing locally derived pebbles from surrounding hills of Tomkinson Creek Group rocks.

Structure

The Helen Springs Volcanics have not undergone any obvious tectonic deformation and for the most part are probably in their original structural attitude, filling valleys eroded into siltstone units of the Tomkinson Creek Group. However, in areas around Helen Springs homestead, Muckety homestead,

Fig.7. Strike-ridge formed by basal sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead (Neg. No. GA/5847).

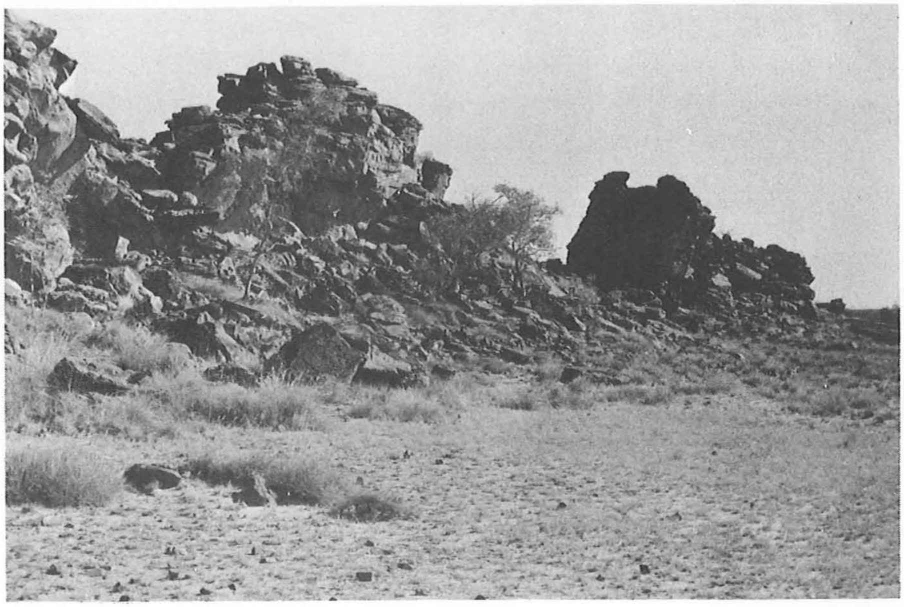

Fig. 8. Basal sandstone, Helen Springs Volcanics, 6.5 km southeast of Helen Springs homestead (Neg. No. M/1241).

and Loveday Creek, the underlying siltstones have been heaved upwards at several separate localities. Domes have been produced in the volcanics and basal sediments. The domes vary from near-circular to elliptical in plan, with dimensions from about 0.5 km to 2.5 km across. In detail the contact has abrupt changes of strike so that the outline of the domes has many small promontories and embayments. The basal lava flow dips outward from the domes at angles varying from 5° to 30°. The basal sandstone often forms a prominent strike-ridge (Figs. 6 and 7). Randal et al. (1966) give a more detailed description of the domal structures.

Water-bore data

Most of the water-bores in the Helen Springs Sheet area are sited in grassy 'downs' country where, according to Randal et al. (1966), they are obtaining supplies from the mainly carbonate sequence of the Middle Cambrian Anthony Lagoon Beds. On the flanks of, and within, the Ashburton Range, the bores may be obtaining water from the Gum Ridge Formation. Bores near Helen Springs homestead may be obtaining water from within the Helen Springs Volcanics or at its contact with the underlying Tomkinson Creek Group. Most bores are less than 91 m deep (Randal et al., 1966) but few logs have recorded the depth of the aquifers.

Only one bore from the list supplied by the Mines Branch, Northern Territory Administration, of water bores drilled in the Helen Springs 1:250 000 Sheet area is recorded as having penetrated Helen Springs Volcanics. Water Bore R.N.6647, sited 6.5 km northwest of Muckety homestead, is recorded as having penetrated 46.2 m of basalt before passing into shale. Lithological logs are missing from the majority of the bore data sheets. However, Randal (1969) presented a list of water-bores, interpreted by him as having penetrated the Helen Springs Volcanics. These are noted in Appendix 4.

Discussion

Noakes and Traves (1954) regarded the Helen Springs Volcanics as Lower Cambrian in age and equated them to the Antrim Plateau Volcanics in the Ord-Victoria region. Subsequent mapping (Randal et al., 1966) proved the presence of volcanics on the western flanks of the Ashburton Range where they apparently underlie the Middle Cambrian Gum Ridge Formation on the eastern side of the Wiso Basin. The volcanics have also been reported in the Hidden Valley Bore in the Daly Waters Sheet area, and are suspected in Burge Bore near the southern part of Lake Woods (Randal and Brown, 1967). It is possible that the two volcanic units are semi-continuous beneath the younger Cambrian rocks of the Wiso Basin. Similarly, the Helen Springs Volcanics and the Nutwood Downs Volcanics may be connected by dis(?)-continuous occurrences beneath the younger deposits of the Georgina and Daly River Basins in the Beetaloo and Tanumbirini Sheet areas.

THE NUTWOOD DOWNS VOLCANICS

Introduction

The Nutwood Downs Volcanics crop out in the central and western portions of the Hodgson Downs 1:250 000 Sheet area in the valley of the Hodgson River. The Hodgson Downs Sheet area is in the northeastern part of the Northern Territory and forms part of the drainage basins of the Roper, Towns, and Limmen Bight, Rivers; it is bounded by longitudes 133°30'E and 135°E and latitudes 15°S and 16°S. Bore data from Nutwood Downs station suggest the formation extends into the northern part of the Tanumbirini Sheet area. Basic volcanics have been intersected in water-bores drilled in the northern central part of the adjoining Tanumbirini 1:250 000 Sheet area to the south. These have been correlated with the Nutwood Downs Volcanics (Paine, 1963).

Previous investigations

Woolnough (1912) was the first geologist to record a visit to the Hodgson Downs Sheet area. During a reconnaissance of the Northern Territory he travelled south along the Hodgson River from Roper Bar to Nutwood Downs homestead and then southeast to Tanumbirini homestead. He noted the occurrence of basalt west of the Hodgson River and commented on the good quality of the grazing country in the region underlain by the basalt. Jones (1955) and Mackay (1957) of the Bureau of Mineral Resources briefly described the formation in reports on the water resources of Nutwood Downs homestead. Mackay tentatively correlated the basic volcanics around Nutwood Downs homestead with the Antrim Plateau Volcanics and referred to them by that name. However, Dunn (1963) formally designated the formation the Nutwood Downs Volcanics, in the report on the systematic geological mapping of the Hodgson Downs Sheet area. Some of the specimens of Nutwood Downs Volcanics collected during this survey were submitted to the Australian Mineral Development Laboratories, Adelaide for detailed thin section descriptions. A copy of the report is given in Appendix 5.

Topography

The drainage basin of the upper Hodgson River referred to by Dunn (1963) as the Nutwood Downs Basin is formed on Cambrian sediments and basic volcanics and is enclosed by scarps of Cretaceous rocks (Mullaman Beds) on three sides. The lava flows are essentially flat-lying or gently dipping (in a westerly direction) and give rise to 'rolling downs' type country.

Stratigraphic relationships

The Nutwood Downs Volcanics conformably overlie the Bukalara Sandstone which in turn overlies rocks of the Upper Proterozoic Roper Group with a marked unconformity (Dunn, 1963). Limestone overlies the volcanics in the bank of a creek about 9.5 km southwest of Nutwood Downs homestead. Limestone has also been recorded in bore cuttings from the area (Mackay, 1957). By correlation with a similar sequence in the adjoining Katherine Sheet area to the northwest (Randal, 1963), the limestone has been included in the Tindall Limestone of lower Middle Cambrian age (Dunn, 1963). The limestone is apparently conformable with the underlying formation (Mackay, 1957; Dunn, 1963).

Age

Fossils have not been found in the Bukalara Sandstone or in the sandstones in the Nutwood Downs Volcanics. However, the two formations have been assigned a Lower Cambrian age (Dunn, 1963) because the rocks show no obvious erosional break with the overlying lower Middle Cambrian limestone and they overlie the Proterozoic sediments with strong unconformity.

A single specimen submitted to the Australian Mineral Development Laboratories for K-Ar whole rock age determination yielded an age of 500 $\pm$ 12 m.y. (see Appendix I). This age is younger than that inferred for the formation from stratigraphic evidence. The Antrim Plateau, and Helen Springs Volcanics display similar discrepancies between the ages inferred from field evidence and the ages calculated from K-Ar isotope measurements.

The technical details supplied by A.M.D.L. are listed in Appendix I. The problem will be discussed in greater detail in a later Report.

Thickness

The maximum thickness of the formation is not known. Dunn (1963) recorded a thickness of about 122 m. Water-bore data indicate a thickness of about 61 m for the formation.

Geology

Mackay (1957) stated that the volcanic rocks consist of massive basalt, amygdaloidal basalt, andesite, agglomerate, and tuff. Dunn (1963) reported that "the volcanics are tholeiitic basalt, agglomerate and tuff; in places the basalt contains numerous quartz, jasper and chalcedony - filled amygdales. The presence of sandstone dykes in the basal lava flow suggests that it was extruded before the underlying Bukalara Sandstone was lithified. In places the lavas are overlain by a flaggy feldspathic sandstone which is included in the Nutwood Downs Volcanics."

The volcanics are poorly exposed. The formation consists of a succession of flat-lying or gently dipping (in a westerly direction) lava flows with subordinate interbedded sandstone. Agglomerate and tuff beds were not found, nor were sandstone units immediately overlying the lavas. The lavas and associated sediments have been little disturbed since their formation. The upper portions of flows consist of heavily altered, highly vesicular or amygdaloidal basalt. Amygdales are filled with quartz, chlorite, and chalcedony. The vesicular or amygdaloidal zones form small steep-sided terraces in hillsides. The flow tops are dark red-brown, light brown, and grey in colour and are generally very soft and crumbly. They are sheeted or schistose in many exposures, the foliation paralleling flow margins. Spheroidal weathering occurs in slightly vesicular basalt near the tops of flows. The massive portions of the flows are represented by rubble-strewn slopes and flat-lying areas.

The vesicular zones grade downward into massive, medium-to coarse-grained, comparatively fresh, dark grey basalt. The vesicular portions of flows are invariably more extensively altered than the massive portions. Flow junctions were not observed due to poor exposures. The thicknesses of individual lava flows are unknown. The comparatively coarse grainsize of specimens from the massive portions of flows suggests the flows are relatively thick, probably of the order of 30 m or more. Minimum thicknesses of about 15 m (bases not exposed) were measured on lava flows about 10 km northwest of Nutwood Downs homestead, and 17 km northwest of the homestead along the banks of Snake Creek.

Petrography

Twenty three rocks from the Nutwood Downs Volcanics have been examined in thin section. The lavas are mostly basalts (sensu lato) whose dominant constituents are plagioclase and clinopyroxene. Microtextures range from intersertial through intergranular to subophitic. Modal analyses of 3 samples from the formation are listed in Table 5, and localities are shown in Table 6.

Chemical analyses of 3 specimens from the Nutwood Downs Volcanics are listed in Table 7. Accepting the upper SiO_2 percentage limit of basic rocks to be 53, these rocks are basalts. The analytical results will be discussed in a later Record together with the chemical characteristics of the Antrim Plateau, Helen Springs, Peaker Piker, and Colless, Volcanics.

Plagioclase is the most abundant primary mineral and in massive basalt accounts for 40-50 percent by volume of each rock. The feldspar content decreases markedly in the 'glass'-rich amygdaloidal rocks from the upper portions of flows. In the highly crystalline rocks the feldspar grains form small euhedral moderately zoned tabular laths with an average grainsize of 0.1 - 0.2 mm x 0.05 mm. Smaller microlites occur in the fine-grained basalts from the upper portions of flows. In addition, the rocks usually contain scarce, euhedral to subhedral plagioclase phenocrysts of relatively coarse grainsize (1.5 mm x 0.5 mm). The phenocrysts appear as isolated lath-like grains in the majority of specimens; rarely as small glomeroporphyritic aggregates (e.g., specimens 70772167, 70772.69).

In most of the rocks the plagioclase grains (particularly the phenocrysts) are extensively replaced by fine-grained aggregates of pale yellow-green chlorite (?) and sericite(?). Altered grains are characterized by a clouded appearance. Phenocrysts in section 70772173 have been partly replaced by quartz as well as by chlorite (?) and sericite (?). In specimen 70772166 the bulk of the plagioclase is unaltered.

Plagioclase composition determined in section 70772166 on unaltered groundmass grains using the method of Michel-Lévy, is about An_{50}.

Clinopyroxene has a mode of occurrence similar to that described for clinopyroxene in the Helen Springs Volcanics. Some of the pyroxene in specimen 70772170 is pigeonitic ($2V=0^o$). Pigeonite has not been identified in any of the other sections examined. Clinopyroxene was not detected in specimen 70772162 - a glass-rich amygdaloidal basalt. Many of the small granules of opaque oxide are believed to be secondary replacements of clinopyroxene.

Table 5. Modal analyses of rocks from the Nutwood Downs Volcanics

Sample Number	Volume Percent						
	Plagio-clase	Clino-pyroxene	Opaque Oxide	Mesost-asis	Horn-blende	Mica	Secondary Minerals
70772166	47	32	4	12	tr(<1)	-	5
70772170	45	25	3	11	tr(<1)	-	16
70772171	50	21	4	17	-	-	8

tr = trace

Minimum number of points counted per section : 2,500

Table 6. Locality index for samples of Table 5

Sample	Latitude	Longitude	Locality Description
70772166	15°36'S	134°06'E	Flicks Waterhole
70772170	15°33'S	134°05'E	By side of track to Hodgson Downs homestead
70772171	15°39'S	134°05'E	Small hilltop about 0.5 km N of Flicks Waterhole

Table 7. Chemical analyses of three rocks from the Nutwood Downs Volcanics

	70772166	70772169	70772170	70772170*
	Wt %	Wt %	Wt %	Wt %
SiO_2	52.9	52.7	52.3	52.6
Al_2O_3	14.4	14.6	14.6	14.7
Fe_2O_3	3.50	2.30	1.90	3.05
FeO	7.55	9.00	8.90	8.10
MgO	5.70	5.35	5.90	5.75
CaO	9.15	7.15	8.50	8.05
Na_2O	2.20	2.95	2.95	2.95
K_2O	1.12	3.15	1.29	1.38
H_2O+	0.92	1.06	1.58	1.31
H_2O-	0.81	0.24	0.57	0.55
CO_2	0.08	0.05	$<$ 0.05	0.16
TiO_2	1.25	1.24	1.22	1.14
P_2O_5	0.13	0.12	0.12	0.12
MnO	0.18	0.20	0.18	0.15
TOTAL	99.89	100.11	100.06	100.01
	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Sr	160	120	160	150
Rb	60	70	60	60
Ba	250	300	200	150

Analysts: A.H. Jorgenson (specimens 70772166, 70772169, 70772170), L.W. Castanelli and G.R. Holden (specimen 70772170*), Australian Mineral Development Laboratories, Adelaide.

* Sample for analysis from same specimen as 70772170

Table 8. Locality index for samples of Table 7

Sample	Latitude	Longitude	Locality Description
70772166	15°36'S	134°06'E	Flicks Waterhole
70772169	15°33'S	134°05'E	Beside track to Nutwood Downs homestead
70772170	15°33'S	134°05'E	By side of track to Hodgson Downs homestead.

Many clinopyroxene grains are partly uralitized. Replacement of clinopyroxene occurred preferentially along cleavage planes. Tiny blebs and stringers of secondary opaque oxide are commonly associated with the fibrous amphibole. Clinopyroxene is also replaced by pale yellow-green chlorite in several specimens (e.g., 70772163, 70772167, 70772170). Chlorite replaces both clinopyroxene and uralite in specimen 70772167. The replaced parts of the clinopyroxene grains are typically amorphous, dirty green or brown; the dull colour is probably due to the effects of weathering. Commonly, altered pyroxene is patchily covered by red-brown secondary hematite (?).

Several clinopyroxene grains in specimens 70772161, 70772166 and 70772173 are rimmed, and partly replaced, by massive, late-stage, primary hornblende.

The highly crystalline medium-grained basalts contain minor amounts (5 percent by volume) of opaque oxide. The opaque oxide forms small (0.1 mm x 0.05 mm), subhedral to anhedral, interstitial granules and relatively large (0.4 mm x 0.3 mm), subhedral, poikilitic grains, enclosing or partly enclosing small plagioclase laths. Two generations of opaque oxide are recognizable in some specimens. In specimen 70772172 the opaque oxide forms microphenocrysts. The opaque minerals are commonly rimmed with red-brown, translucent, secondary hematite (?). Surrounding plagioclase and clinopyroxene grains are stained by secondary iron oxide.

Red-brown <u>devitrified glass</u> occurs in every section and ranges from very scarce (rare in specimens 70772166 and 70772170) in the massive medium-grained basalts to abundant (40 percent by volume in specimen 70772179) in amygdaloidal specimens from the upper portions of flows. The devitrified glass contains feldspar microlites, needles of apatite, and numerous tiny granules and rods of opaque oxide and forms small interstitial patches (up to 0.5 mm in diameter) in the massive basalts.

The bulk of the interstitial late-stage residuum in specimens 70772161, 70772166 and 70772170 crystallized to fine-grained graphic-like intergrowths of quartz and alkali feldspar. Narrow overgrowths of alkali feldspar mantle several groundmass plagioclase grains. The alkali feldspar has a colourless homogeneous appearance with low relief and refractive indices less than those of quartz.

Several samples (e.g., 70772166, 70772171, 70772172, 70772173) contain primary quartz. The quartz is a late-stage crystallization product and occurs as anhedral interstitial grains.

Accessory amounts (less than 1 percent by volume) of primary hornblende occur in many of the massive highly crystalline basalts. The hornblende forms small (0.2 mm x 0.1 mm) euhedral to subhedral tabular grains, generally associated with interstitial quartz and quartz-alkali feldspar intergrowths. Hornblende also mantles and partly replaces clinopyroxene grains. The hornblende is distinctly pleochroic from brownish green to pale yellowish green.

Traces of primary mica were found in two specimens (70772169, 70772172). The mica occurs as small (0.1 mm x 0.05 mm) flakes generally associated with primary hornblende and is pleochroic from dark red-brown to pale brown.

Apatite, as long slender needles, was detected in every section.

Chlorite, generally in minor amounts (5-20 percent), occurs in every specimen examined. Its mode of occurrence varies from that of an alteration product after plagioclase and clinopyroxene to small irregular patches and fibrous masses in amygdales. Interstitial patches of chlorite believed to be replacement of glass occur in every specimen. Some of the larger patches of chlorite are rimmed by a narrow layer of secondary hematite (?). The chlorite is pale yellow or pale yellow-green and occurs as aggregates of very fine-grained fibres. Pleochroism in varying shades of pale green is very slight and interference colours are low first-order greys.

Minor amounts of secondary calcite and hematite (?) occur in many of the basalts, occupying interstices, replacing groundmass constituents, and filling amygdales in vesicular parts of flows.

Pumpellyite (?) has been tentatively identified in specimens 70772169 and 70772179. It is confined to interstitial areas in specimen 70772169 and is commonly associated with quartz and chlorite. The small fibrous grains are distinctly pleochroic from blue-green to colourless. Birefringence colours are as high as upper first order, but tend to be masked by anomalous interference colours. The pumpellyite (?) is never present in more than trace amounts; it is believed to be a replacement of glass. Small clusters of fine acicular fibres of the mineral are associated with chlorite in amygdales in specimen 70772179.

Small irregular amygdales up to 3 mm in diameter are common in the lavas and are concentrated mainly in the upper portions of flows. The amygdales are filled with a variety of minerals, the most common being chlorite, hematite (?), and quartz. The infilling minerals are zonally arranged in many cases. Many amygdales in specimen 70772162 are lined with an outer layer of quartz, the central portions being filled with secondary hematite (?). Most of the amygdales in specimen 70772179 are lined with a thin outer layer of fine-grained chlorite together with rare pumpellyite(?), the central portions being filled with a mosaic of quartz grains.

Interbedded sediments

Intercalations of fine- to medium-grained, flaggy to blocky, buff to red-brown sandstone occur in the Nutwood Downs Volcanics. The interbeds are characteristically very thin, the maximum observed thickness being about 3 m. In most exposures the sandstone is less than 1.5 m thick. The sandstone occurs mainly as rubble of angular blocks on the surface; rarely the beds form small steep-sided terraces in hillsides (e.g. in the hills bordering Snake Creek).

The sandstone has been extensively silicified and contains large (up to about 10 cm in diameter) subrounded to rounded clasts of heavily altered, highly vesicular basalt (Fig. 9). The basalt fragments occur throughout the sediments but are concentrated in the basal portions of the beds. The contacts between the sandstone units and the overlying lava flows are generally obscured. In a few exposures, sandstone was observed overlying heavily altered highly vesicular basalt (Fig. 10). Cross-bedding in the sandstone layers is uncommon. Metamorphic effects caused by the inundation of the sediments under later lava flows are very slight.

Examination of thin sections confirms that the sandstone consists mainly of quartz with minor feldspar (plagioclase and microcline), opaque oxide, lithic fragments (basalt, siltstone, chert, quartzite), and accessory muscovite and tourmaline. The thin sections were not chemically tested for the presence of orthoclase. The grains (average grainsize 0.15 mm) are subangular to rounded, most being subrounded. Many are coated with a thin film of brown iron oxide (limonite?). Basalt fragments are markedly larger and more angular than the other clasts; presumably because they were derived from erosion of surrounding basalt and had been transported for shorter distances. Most of the specimens are characterized by closed frameworks and are well sorted. Minor quartz, chalcedony, and a fine-grained clay(?) fraction form the matrix. Some of the quartz grains have narrow syntaxial rims of secondary quartz.

Several specimens (e.g., 70772158, 70772175, 70772177) display a bimodal distribution of grains. Relatively large (average grainsize 0.4 mm) quartz grains together with rare microcline, chert, and quartzite clasts are distributed throughout a 'groundmass' of smaller (average grainsize 0.15 mm) subangular to rounded grains. The grains making up the larger-size fraction are highly rounded, possess high sphericities and are less abundant than the smaller grains.

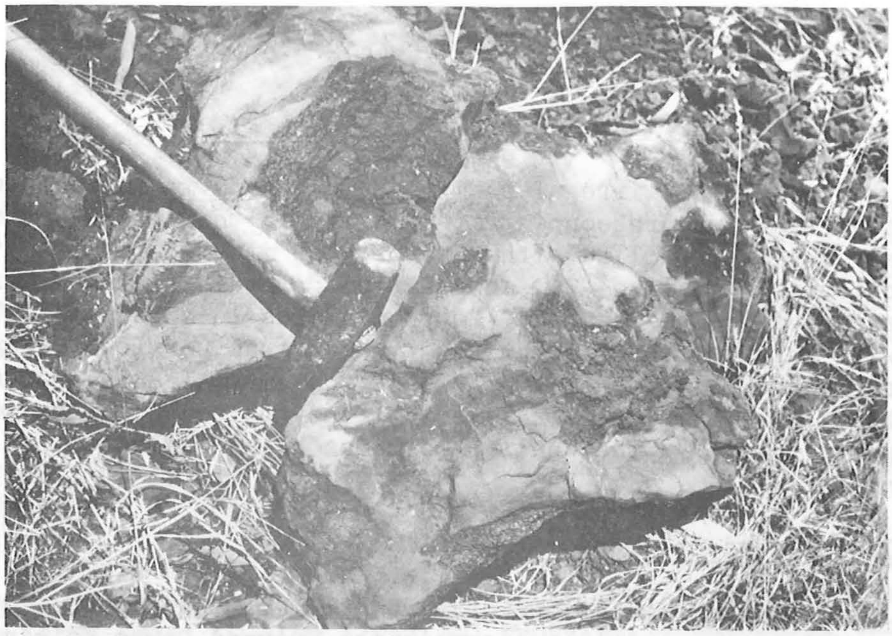

Fig.9. Sandstone containing large, angular clasts of vesicular basalt, Nutwood Downs Volcanics. Exposed in creek bank 3 km southwest of Arkdip Lagoon, Hodgson River (Neg. No. GA/5848).

Fig.10. Thin sandstone bed overlying vesicular flow top, Nutwood Downs Volcanics. Exposed in creek bank 3 km southwest of Arkdip Lagoon, Hodgson River. Position of contact marked by hammer-head (Neg. No. GA/5838).

Some of the specimens (e.g., 70772159, 70772164, 70772178) possess open frameworks, fine to medium grainsizes and are poorly sorted. A fine-grained, largely indeterminate silty(?) fraction forms the matrix between clasts in specimens 70772164 and 70772178. Chalcedony is the cementing medium in specimen 70772159. Heavily ferruginized basalt fragments occur in specimen 70772178.

Water-bore data

All logs of registered water-bores in the Hodgson Downs Sheet area and those in the northern half of the Tanumbirini Sheet area were checked by staff at the Mines Branch, Northern Territory Administration, for the occurrence of Lower Cambrian basic volcanics. Unfortunately, drillers' logs are the only ones available for all these bores at present. Geological logs have been prepared for two bores (registered numbers 7189 and 7689) by staff at the Mines Branch and are presented in Appendix 4. The positions of, and other available data relating to, water-bores that are assumed from drillers'logs to have intersected the Nutwood Downs Volcanics are also listed. Geological logs of bores drilled in 1971 should be available in the near future.

Discussion

The Nutwood Downs Volcanics and Antrim Plateau Volcanics are petrographically similar and occupy a similar stratigraphic position. They are believed to belong to the same widespread Lower Cambrian volcanic sequence which covered large parts of the Northern Territory. West of the Hodgson River the Nutwood Downs Volcanics disappear beneath the cover of Lower Cretaceous rocks. Isolated outcrops occur in the eastern tributaries of the Strangways River. These are about 110 km east of BMR Scouthole L2, near Western Creek homestead, where amygdaloidal basalt was encountered below fossiliferous Middle Cambrian limestone at about 50 m (Randal and Brown, 1967). The scout hole is itself about 100 km east of the nearest outcrop of the main western mass of the Antrim Plateau Volcanics in this region, but between the scout hole and the outcrops, bores on the Dry River Stock Route and the Willeroo-Top Springs road intersected basalt at depth. In addition, the most northerly outcrops of the Nutwood Downs Volcanics in the Strangways River watershed are only 21 km from outcrops of the Antrim Plateau Volcanics in the valley of the Roper River.

THE PEAKER PIKER VOLCANICS

Introduction

The Peaker Piker Volcanics crop out in the Mount Drummond 1:250 000 Sheet area, which is bounded by latitudes 18°S and 19°S and longitudes 136°30'E and 138°00'E. The southern boundary of the area is 95-115 km north of the Barkly Highway and the eastern margin is the Queensland border. The Peaker Piker Volcanics crop out in the western and southwestern portions of the Sheet area and north of Mitchiebo Waterhole. Surface exposures cover a total area of approximately 140 sq km.

In 1968 six holes were drilled by the Bureau of Mineral Resources in the northern portion of the Georgina Basin to supplement surface mapping. The stratigraphic hole BMR Alroy No. 2 entered weathered, red-brown amygdaloidal basalt (sensu lato) at about 460 feet* (140 m) and bottomed in fresher more massive basalt at 571 feet (174 m). The hole was sited on the top of Mount Lamb (latitude 19°30'50"S; longitude 136°17'30"E) in the Alroy 1:250 000 Sheet area. Bastian and Thieme (1970) equated this basalt with the Peaker Piker Volcanics which crops out about 95 km to the north and northeast in the Mount Drummond Sheet area. They also correlated the formation with the Colless Volcanics which crop out west of Lawn Hill homestead, Queensland and with the Helen Springs Volcanics around Tennant Creek.

Previous investigations

Until the Mount Drummond Sheet area was mapped by geologists from the Bureau of Mineral Resources in 1959, little was known of its geology. The Peaker Piker Volcanics were named and briefly described by Smith and Roberts (1963) in their report on the geology of the Sheet area. They did not designate a type section although in an unpublished file note Smith (1961) indicated the area (latitude 18°45'00"S; longitude 136°15'20"E) south of Peaker Piker Creek and about 9.5 km east of Bullock Waterhole as the type area for the volcanics.

General features

The volcanics form small mesas and low rounded hills. In several places weathering of the volcanics has produced small areas of black soil contiguous with outcrops of the unit.

The formation unconformably overlies both the Mullera Formation and the Mittiebah Sandstone of the Upper Proterozoic South Nicholson Group (Smith and Roberts, 1963) and is in turn overlain, apparently conformably, by the Burton Beds (Fig. 11) of lower Middle Cambrian age. The distribution of the volcanics is shown in Figure 12. The lavas appear to be essentially flat-lying or sub-horizontal.

Smith and Roberts (1963) described a lensoid lava tongue interbedded in a siltstone-shale sequence 6 m below Middle Cambrian fossils. They concluded that the formation is lower Middle Cambrian in age. This is the only record of probable Middle Cambrian volcanicity around the margins of the Georgina Basin, but volcanics elsewhere in the Northern Territory (as well as in Western Australia and Queensland), including the Helen Springs Volcanics on the Basin's northwestern margin, underlie fossiliferous Middle Cambrian sequences and are regarded as Lower Cambrian in age. Dunn and Brown (1969) disagreed with Smith and Roberts' interpretation and suggested that, because of the similarities between the formation and other basic volcanics of probable Lower Cambrian age in Northern Australia, a

* All measurements were originally recorded in inches and feet. Standard sized drilling bits were also used - the sizes being given in inches. Consequently all measurements pertaining to the stratigraphic hole are given in inches and feet as originally recorded. Metric conversions are given in brackets.

Lower Cambrian age would be more likely for the Peaker Piker Volcanics. Lava lenses in the basal portions of the Burton Beds have not been found by the writer.

In stratigraphic hole BMR Alroy No. 2, basalt correlated with the Peaker Piker Volcanics is overlain by about 78 m of predominantly dolomite (unit B of Bastian and Thieme) which is in turn overlain by about 47 m of a predominantly siltstone-limestone succession (unit C of Bastian and Thieme). Unit C is richly fossiliferous in parts, the fossil assemblage indicating a lower Middle Cambrian age (Bastian and Thieme, 1970). Bastian and Thieme correlated unit C with the Burton Beds in the Mount Drummond and Ranken Sheet areas and stated that "unit C generally overlies unit B with a sharp break, apart from a doubtful possibility of intertonguing in Alroy No. 2". The surface rocks have been mapped as the Wonarah Beds (Randal, 1966). A Lower Cambrian rather than a Middle Cambrian age would therefore appear to be the more likely age for the basalt in BMR Alroy No. 2. Because of the probable Lower Cambrian age for similar volcanics elsewhere and in light of the evidence obtained from stratigraphic hole BMR Alroy No. 2, the formation is regarded by the writer as being of probable Lower Cambrian age.

The Peaker Piker Volcanics are particularly susceptible to lateritization and weathering and their petrology is therefore difficult to determine. The formation is very poorly exposed. Outcrops examined by the writer consist of intensely ferruginized, dark red and red-brown, vesicular and massive basalt (sensu lato). The volcanics have been so extensively and intensely altered that the original igneous textures have been obliterated in many specimens. Difficulty was experienced in even recognizing the original volcanic nature of some of the rocks. None of the surface specimens collected were considered worth thin sectioning. According to Smith and Roberts (1963) the volcanics "appear to be mainly vesicular and non-vesicular basalts with rare dolerite flows, though some bands may be intermediate in composition. South of Peaker Piker Creek the volcanics contain unfossiliferous sandstone lenses near the base". They quote a maximum observed thickness of about 37 m for the formation.

The Peaker Piker Volcanics have not been folded, but in some places they have been faulted; the age of the faulting is unknown, since the various Cambrian units affected have no younger Palaeozoic cover.

The volcanics intersected in BMR Alroy No. 2 are relatively fresh when compared with specimens of Peaker Piker Volcanics collected from surface exposures. A summary of the descriptions of the cores and cuttings is given below. More detailed descriptions are presented in Appendix 2. Drilling details are presented in Appendix 3.

Petrography

Basalt (sensu lato) from the upper portion of the volcanic sequence is light grey, medium-grained, extensively altered and moderately amygdaloidal. With increasing depth the basalt becomes somewhat less altered and more massive. However, small amygdales still occur randomly

Fig.11. Peaker Piker Volcanics (foreground) overlain by the Burton Beds (background), 1.5 km south of Peaker Piker Creek. Scale is indicated by figure under overhang (Neg. No. GA/5828).

distributed throughout the otherwise massive basalt. The amygdales are filled mainly with dark green chlorite (?) together with minor quartz, agate, chalcedony, and rare calcite.

A heavily altered zone of red-brown moderately amygdaloidal basalt occurs at around 530 feet (161.5 m) and probably represents the top of a lava flow. The altered amygdaloidal basalt grades downwards into predominantly massive, medium-grained, altered, grey basalt.

Ten specimens of cuttings and core from about 3 m intervals in the section 460 to 570 feet (140.2 - 173.7 m) have been examined in thin section. Each thin section from cuttings was made from a minimum of four chips to preclude the possibility of 'contamination' of cuttings from a higher level.

The volcanic succession has been tentatively separated into two individual lava flows, the boundary being placed at about 530 feet (161.5 m). The cuttings and core are of hypocrystalline amygdaloidal basalt composed predominantly of plagioclase and clinopyroxene set in a groundmass of devitrified glass. The specimens are invariably altered. The upper portions of the two flows and the basal portion of the uppermost flow have been affected most by alteration. Chlorite, sericite, and celadonite (?) are common secondary minerals. Small amygdales occur in all the core and cuttings examined, but are most abundant in the intervals 460-470 feet (140.2 - 143.3 m) and 525-560 feet (160.0 - 170.7 m). These zones correspond to the upper portions of the two flows (and probably also include the basal portion of the uppermost flow) and grade downwards and upwards into central zones comprising more massive basalt.

Amygdales are filled with minerals including chlorite, celadonite (?), quartz, chalcedony, calcite, hematite (?), and prehnite.

One chemical analysis of altered basalt from drill hole BMR Alroy No. 2 is presented in Table 9.

Plagioclase is the most abundant crystalline phase present in the rocks. Its mode of occurrence is similar to that described for plagioclase in the Helen Springs and Nutwood Downs Volcanics. The feldspar is zoned and occurs mainly as small subhedral to euhedral laths (0.2 mm x 0.05 mm). In addition, the rocks contain up to 5 percent (estimated) euhedral to subhedral plagioclase phenocrysts of relatively coarse grainsize (1.5 mm x 0.5 mm). They appear as isolated lath-like grains.

Many of the feldspar laths are extensively replaced by pale green, pale yellow-green and yellow-brown chlorite as fine fibrous grains and by fine flakes of sericite. Phenocrysts tend to be more heavily altered than the groundmass laths. Most minerals, particularly the feldspar from the moderately to highly vesicular or amygdaloidal zones are more extensively altered than those from the more massive portions. Many of the altered grains have a clouded appearance.

Table 9. Chemical analysis of one specimen of Peaker Piker Volcanics

	70773000
	Wt %
SiO_2	50.3
Al_2O_3	14.2
Fe_2O_3	5.25
FeO	3.90
MgO	8.65
CaO	5.65
Na_2O	2.10
K_2O	1.41
H_2O+	2.60
H_2O-	4.10
CO_2	0.30
TiO_2	1.01
P_2O_5	0.11
MnO	0.05
Total	99.63
	p.p.m.
Sr	200
Rb	20
Ba	150

70773000 - Core sample from BMR Alroy No. 2, interval 492' - 492'5" (150 - 150.1 m).

Analysts: L.W. Castanelli and G.R. Holden, Australian Mineral Development Laboratories, Adelaide.

The feldspar in specimen 70773000 is only partly replaced by yellow-brown chlorite and is characterized by a relatively fresh appearance. The feldspar is labradorite, a composition of An_{58} being determined by the combined Carlsbad Albite twin method on an unaltered groundmass lath. A composition of An_{54} was determined by the method of Michel-Lévy.

Clinopyroxene. Augite is not as abundant as plagioclase and appears to have been a relatively minor constituent in the glass-rich specimens from the upper portions of the flows. Pigeonite has not been detected. The clinopyroxene occurs mainly as small euhedral to subhedral interstitial grains (0.1 mm x 0.05 mm); rarely as comparatively large (0.3 mm x 0.2 mm) rectangular plates subophitically and ophitically intergrown with plagioclase laths. Many of the grains are replaced, either partly or completely, by various secondary minerals, the most common being chlorite (as aggregates of fine, pale yellow-green to 'murky'-brown, fibrous grains). A grey-green pleochroic mineral of the montmorillonite (?) group replaces clinopyroxene in several specimens (e.g., 70773002, 70773009). Fibrous amphibole is a replacement in specimen 70773003. The 'murky'-brown colouration of the patches of chlorite and amphibole is probably a weathering effect.

The sections contain minor amounts of opaque oxide (less than an estimated 5 percent by volume) as small (0.05 - 0.01 mm) interstitial, subhedral to anhedral granules.

Devitrified glass accounts for an estimated 15-50 percent by volume of the rocks from the entire interval, but is most abundant in the upper and basal portions of the flows. The colour of the devitrified glass ranges from reddish brown to black, semi-opaque. The more deeply coloured varieties are restricted to the relatively glass-rich upper and basal portions of the flows. The devitrified glass is slightly birefringent and is studded with tiny granules and rods of opaque oxide. It occurs in interstices and filling spaces between feldspar laths. Devitrified glass in specimen 70773003 contains feldspar microlites. Apatite needles occur in devitrified glass in specimen 70773000. In specimen 70773009 devitrified glass is extensively replaced by pale yellow-green to 'murky'-brown chlorite.

Rare interstitial patches of a quartzo-feldspathic (?) residuum occur in specimens 70773000, 70773007 and 70773008. The presence of alkali feldspar could not be definitely established by optical means.

Chlorite is present (5-20 percent) in every section examined. Its mode of occurrence is similar to that in the Helen Springs and Nutwood Downs Volcanics. The chlorite forms pale yellow-green to pale 'murky' brown, fibrous aggregates. Pleochroism is very slight and interference colours are low first-order greys.

Small irregular amygdales occur in every specimen examined but are most abundant in the upper portions of the two flows and in the basal portion [525-530 foot (160.0-161.5 m) interval] of the uppermost flow. The amygdales are filled with various secondary minerals, the most common being chlorite, celadonite (?), and chalcedony. Some amygdales contain quartz, hematite (?), calcite, and prehnite.

The infilling minerals are arranged in concentric layers in the larger amygdales. The walls of the amygdales are lined with a thin layer of very fine-grained, yellowish brown chlorite, the centres filled with relatively coarse fibres (0.5 - 0.1 mm) of pale blue-green chlorite. The chlorite filling amygdales in specimen 70773000 has been identified by X-ray diffraction methods as pennine. In specimen 70773009, some amygdales contain an inner zone of relatively coarse-grained pennine and a central zone of calcite. Celadonite (?) (e.g., in specimens 70773003 and 70773006) or chalcedony (e.g., in specimens 70773000 and 70773010) formsthe outer linings of some amygdales. In specimen 70773006 amygdales are completely filled with celadonite (?) while some of the amygdales in specimen 70773010 are filled entirely with chalcedony. Secondary quartz, chalcedony, hematite (?), and prehnite occur in the centres of some amygdales, (e.g., in specimens 70773000, 70773005, 70773006). In specimen 70773005 prehnite fills the centres of some amygdales, the outer zone being composed of fine-grained yellowish brown chlorite. In other amygdales prehnite forms the outer lining and the centres are filled with relatively coarse fibres of pale blue-green chlorite. Rarely, prehnite is the sole vesicle infilling.

Minor amounts (less than an estimated 10 percent by volume) of an unidentified mineral possibly belonging to the montmorillonite group were observed in specimens (e.g. 70773009) from the upper portions of the two flows. The mineral occurs as small, subhedral, tabular to blocky grains, characterized by well developed basal cleavages and parallel extinction. Birefringence colours range up to middle second-order. Pleochroism is quite marked, from pale grey-green to colourless. The outlines of most of the grains suggest that the mineral is a replacement of clinopyroxene rather than olivine; however, several grains appear to be pseudomorphs after olivine. Portions of some grains in section 70773009 (from the upper portion of the volcanic sequence) are reddish brown, but the colour is not uniform. The coloured patches are markedly pleochroic from red-brown to practically colourless.

In specimen 70773006[from the 480-485 foot (146.3 - 147.8 m) interval, BMR Alroy No. 2] clinopyroxene (?) and/or olivine (?) is pseudomorphed by a brownish red mineral (iddingsite ?), markedly pleochroic to pale yellow. High birefringence colours are partly masked by the colour of the grains. The iddingsite (?) grains have rims of opaque oxide. The outlines of some of the iddingsite(?) grains are characteristic of olivine. The pseudomorphs appear to have undergone alteration in the upper portions of the flows to form the pale grey-green mineral of the montmorillonite (?) group. The 'alteration' was probably due to the greater susceptibility of the uppermost portions of the flows to weathering.

Celadonite (?) is present in most samples and accounts for about 5 percent of the mineral content. Specimen 70773010 is an exception, containing an estimated 20 percent of celadonite (?). The mineral is distinctly pleochroic from bright blue-green to pale yellowish green. Birefringence colours range to upper first-order.

The principal mode of occurrence is as aggregates of fine fibrous grains in amygdales. Celadonite (?) also occurs as a replacement of a mineral of the montmorillonite (?) group (e.g., in specimen 70773010) and in interstices where it has presumably replaced glass. In specimen 70773006 celadonite (?) appears to be replacing chlorite.

Prehnite occurs as a vesicle infilling in specimen 70773002 from practically at the top of the lower flow /535-540 foot (163.1 - 164.6 m) interval/. Prehnite has not been detected in any of the other sections.

Distribution of basic volcanics correlated with the Peaker Piker Volcanics

The IMC Development Corporation carried out an extensive drilling programme in the Alexandria, Wonarah, Lulu, Avon Downs, Bowgan, and Brunette Districts in the Alexandria region on the Barkly Tableland between 1967 and 1969 in search of phosphate deposits. The following data have been supplied by the IMC Corporation and the writer wishes to express his appreciation for the co-operation of the company in supplying this information.

The holes were drilled using rotary drilling techniques. Mayhew 1000 drilling rigs were mainly used. Basic volcanics, interpreted by IMC geologists as Peaker Piker Volcanics, were intersected in 26 drill holes. Sixteen of the holes are situated in the Alroy, and one in the Ranken, 1:250 000 Sheet areas - in the area south and southeast of Wonarah Telegraph Station and about 115 km south of stratigraphic hole BMR Alroy No. 2 and 290 km southwest of known outcrops of Peaker Piker Volcanics. The volcanics are overlain in the subsurface by the Wonarah Beds. Farther north in the Mount Drummond Sheet area they are overlain by the Burton Beds. The Wonarah Beds and the Burton Beds (also the Anthony Lagoon Beds in the Brunette Downs and Wallhallow Sheet areas) are generally regarded as lateral equivalents of each other (Smith, 1967).

Six holes (A30, A31, A36, A40, A59, A62) are sited in the area extending from southwest of Mittiebah homestead (Mount Drummond 1:250 000 Sheet area) to northwest of the homestead and close to exposures of Peaker Piker Volcanics. Drill holes BG 21 and BG 22 are located in the northwestern corner of the Mount Drummond Sheet area - again close to outcrops of Peaker Piker Volcanics. The remaining drill hole, BG 3, which penetrated probable Peaker Piker Volcanics is situated west of Benmara homestead in the Calvert Hills 1:250 000 Sheet area. The positions of these drill holes are listed in Table 10 and are also shown in Figure 12. The depths at which the volcanics were intersected are also given in Table 10, as are the total depths (when known) of the holes. Core samples of the volcanics were not taken. Some of the samples of the cuttings are stored in the BMR store, Canberra, and the remainder in the Northern Territory Mines Department store in Darwin. Specimens of the drill cuttings have not been examined by the writer. Table 11 gives the sites of three drill holes (BG4, BG5, BG6) which bottomed in micaceous, feldspathic, quartz sandstone interpreted by IMC geologists as being either Lower Cambrian Bukalara Sandstone or Precambrian Mittiebah Sandstone; basic volcanics were not intersected in these holes.

Table 10. IMC drill holes penetrating basic volcanics correlated with the Peaker Piker Volcanics

IMC Drill Hole	Latitude	Longitude	Depth at which Drill Hole Penetrated Volcanics (feet)	Total Depth (feet)
A30	18°51'S	137°00'E		65(19.8m)
A31	18°39'S	136°59'E		185(56.4m)
A36	18°45'S	136°43'E		135(41.1m)
A40	18°29'S	136°38'E		60(18.3m)
A59	18°48'S	137°02'E	132.5 (40.4m)	
A62	18°47'S	136°59'E	125 (38.1m)	
BG 3	17°51'S	136°31'E		45(13.7m)
BG21	18°08'S	136°35'E	77.5 (23.6m)	
BG22	18°15'S	136°32'E	42.5 (13.0m)	
W37	19°57'S	136°26'E	155 (47.2m)	190(57.9m)
W50	19°59'S	136°17'E	120 (36.6m)	
W51	19°58'S	136°21'E	165 (50.3m)	
W53	19°59'S	136°22'E	125 (38.1m)	
W59	19°57'S	136°26'E	150 (45.7m)	
W60A	19°56'S	136°27'E	180 (54.9m)	
W61	19°58'S	136°27'E	152.5 (46.5m)	
W62	19°58'S	136°29'E	170 (51.8m)	
W104	19°59'S	136°15'E	57.5 (17.5m)	
W105	19°59'S	136°16'E	70 (21.3m)	
W107	19°58'S	136°18'E	110 (35.5m)	
W113	19°59'S	136°23'E	95 (29.0m)	
W114	20°00'S	136°24'E	100 (30.5m)	
W115	19°59'S	136°25'E	137.5 (41.9m)	
W116A	19°59'S	136°26'E	137.5 (41.9m)	
W117	19°59'S	136°27'E	147.5 (45.0m)	
W123	19°56'S	136°32'E	185 (56.4m)	

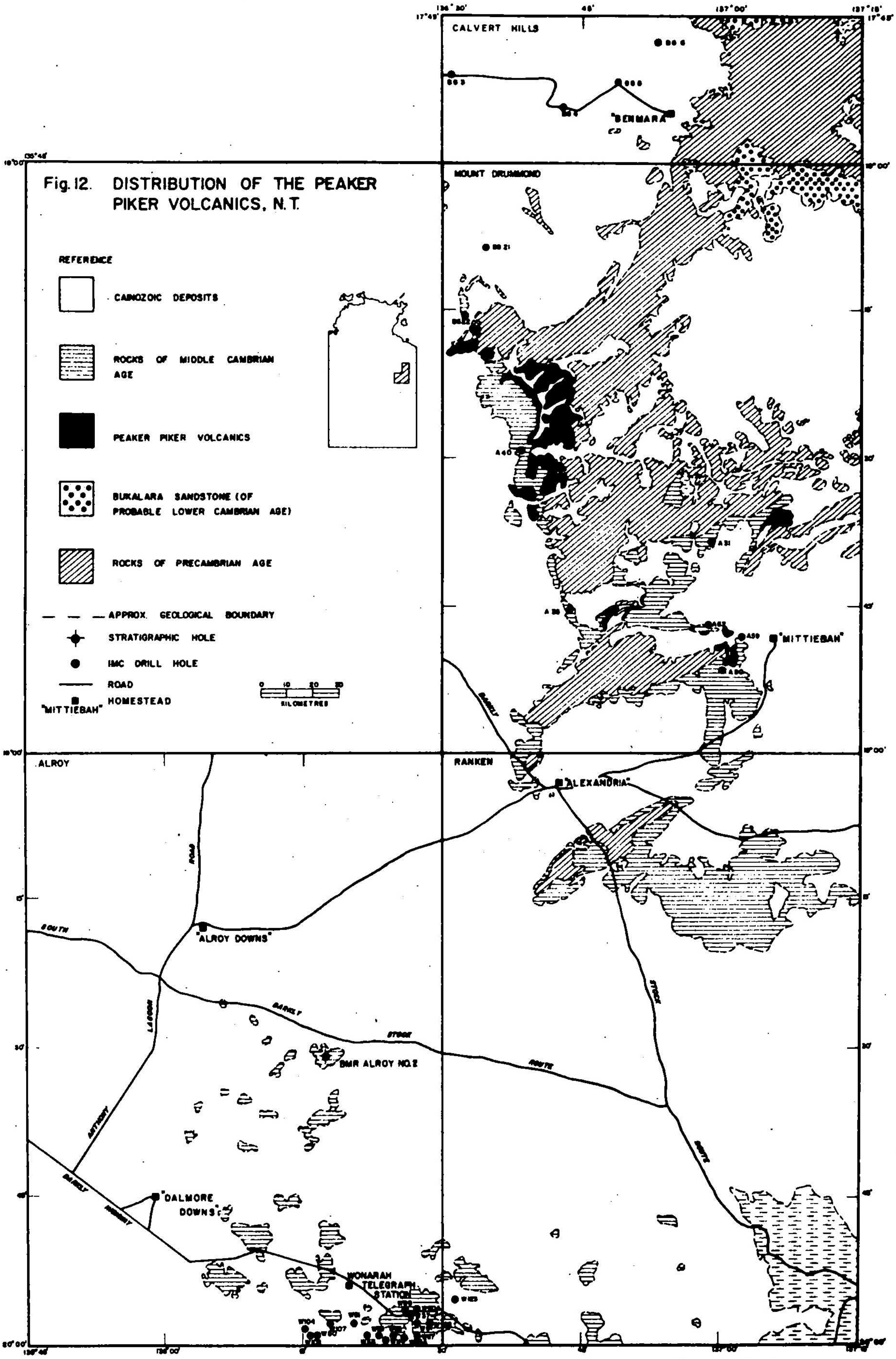

Fig. 12. DISTRIBUTION OF THE PEAKER PIKER VOLCANICS, N.T.

NT/A357

To accompany Record 1975/74

Several other wells and bores drilled in the Georgina Basin have penetrated Precambrian basement rocks without intersecting basic volcanics below the Middle Cambrian sequences. These have been described by Smith (1967, 1967a) and are also listed in Table 11.

Bore No. 1 Alexandria (R.N. 735) penetrated the Cambrian sequence and bottomed in the Mittiebah Sandstone without intersecting the Peaker Piker Volcanics. They are not evident beneath the Cambrian sequence in the eastern part of the Brunette Downs Sheet area : Papuan - Apinaipi Brunette Downs No. 1 was spudded in Cambrian limestone and passed into the Mittiebah Sandstone at 1060 feet (323 m) (Randal, 1966a).

The information supplied by the IMC Corporation is of considerable value as it indicates that basic volcanics of probable Lower Cambrian age are much more widespread in the subsurface in the Barkly Tableland region than originally indicated from surface mapping. It is tempting to hypothesize that much of the area between Camooweal in Queensland and the East Kimberley district of Western Australia was covered by basaltic lava flows in Lower Cambrian time. Water-bore data, therefore, could be of particular value in confirming the presence or otherwise of basic volcanics in the subsurface in areas covered by the younger sediments of the Georgina Basin. However, a large portion of the area is semi-desert and undeveloped; secondly, water-bore data in many cases are scanty and incomplete; and thirdly, many bores have not penetrated the younger Middle Cambrian formations.

Water-bore data

None of the 15 bores drilled in the Mount Drummond Sheet area penetrated basic volcanics and only one bore in the Alroy Sheet area is reported as having intersected volcanic rock. Bore No. 14 (R.N. 414; latitude 19°09'54"S, longitude 135°25'36"E) drilled on Rockhampton Downs station is listed by Randal and Nichols (1963) as having penetrated about 24.4 m of volcanic rock. The driller's approximate geological log is as follows:-

0 - 4.9m	clay
4.9 - 29.3m	volcanic rock
29.3 - 32.3m	sandstone
32.3 - 38.4m	water stone
38.4 - 45.4m	clay

However in a later publication dealing with groundwater resources in the Barkly Tableland, Randal (1967) referred the complete sequence penetrated in bore R.N. 414 to the Wonarah Beds.

There are over 350 water-bores in the Alroy, Avon Downs, Brunette Downs, and Ranken 1:250 000 Sheet areas, but only about half of the available logs have drillers' descriptions of rock types. In the majority the drillers' terms are too vague to be of any stratigraphic value.

Table 11. Holes drilled in the Georgina Basin that penetrated Precambrian basement rocks without intersecting Lower Cambrian volcanics

Well or Bore Name	Latitude	Longitude	Total Depth (feet)
BG 4	17°54'S	136°43'E	140 (42.7m)
BG 5	17°52'S	136°49'E	135 (41.1m)
BG 6	17°48'S	136°53'E	45 (13.7m)
Alexandria No. 1 (R.N. 735)	19°03'S	136°47'E	1760 (536.5m)
Brunette Downs No. 1	18°35'42"S	136°05'06"E	2060 (627.9m)
Canary No. 1	23°15'30"S	140°22'43"E	3218 (980.9m)
Elizabeth Springs No. 1	23°20'44"S	140°34'12"E	1410 (429.8m)
Marduroo No. 1	24°02'20"S	139°54'15"E	3861 (1176.8m)
Ammaroo No. 1	21°37'54"S	135°23'47"E	612 (186.5m)
Ammaroo No. 2	21°39'13"S	135°23'53"E	840 (256.0m)
Lucy Creek No. 1	22°23'50"S	136°38'40"E	3627 (1105.5m)
Netting Fence No. 1	22°56'05"S	138°02'06"E	6666 (2031.8m)
Morstone No. 1	19°34'15"S	138°30'50"E	2504 (763.2m)
BMR 11 (Cattle Creek)	20°00'33"S	137°50'06"E	1501 (457.5m)
Lake Nash No. 1	20°54'18"S	137°53'20"E	1315 (400.8m)
BMR 13 (Sandover)	21°51'25"S	136°09'06"E	3331 (1015.3m)
Epenarra No. 5A (Yellow-hole)	20°17'18"S	135°14'12"E	650 (198.1m)
Epenarra No. 9 (Salt)	20°29'18"S	135°04'12"E	179 (54.6m)

None of the water-bores on the Wallhallow 1:250 000 Sheet area for which geologists' logs are available are recorded as having penetrated basic volcanics. Unfortunately only drillers' logs are available for most holes. Some of these are recorded as having intersected volcanics and are listed in Appendix 4. Also listed are waterholes that possibly penetrated basic volcanics which can be correlated with the Peaker Piker Volcanics. Drillers' descriptions such as "black type of clay", "soft red rock" and "hard black rock" may actually refer to basalt cuttings. However, as the validity and accuracy of the drillers' identifications of the lithologies of drill cuttings are subject to considerable doubt, no conclusions will be drawn from these reports until the actual cuttings (if available) are examined. The following water data together with that summarized in Appendix 4 were obtained from the Mines Branch of the Northern Territory Administration.

The following holes were each logged by a geologist and did not intersect volcanics; holes bottoming in formations of Middle Cambrian or younger age are: Registered Number (total depth in metres) -

4947 (85.3), 4948 (102.1), 4970 (91.4), 4971 (54.9)
5884 (67.1), 5927 (77.1), 6841 (100.6), 6842 (100.6),
6843 (76.2), 7315 (61.0).

The following holes were each logged by the driller and apparently did not intersect volcanics or possible volcanics:

2744 (61.0), 2751 (87.8), 2752 (112.5), 4644 (79.2),
4645 (39.6), 7662 (106.7), 7685 (57.9).

DISCUSSION

The results of the petrographic and chemical investigation of the Helen Springs, Nutwood Downs, and Peaker Piker Volcanics, presented in this Record, have strengthened the contention of earlier workers that the three formations belong to the same episode of volcanic activity, and are correlatives. The lavas are of uniform chemical and mineralogical compositions. Therefore, it is probable that they were produced under similar physical conditions from magmas of similar chemical compositions. Nine of the rocks analysed are tholeiitic basalts, ($SiO_2 < 53\%$), the tenth a tholeiitic andesite. The relatively high silica contents indicate that the lavas are trending towards an andesitic composition. The potash content is variable, but in most specimens it is less than 1 percent. Soda content ranges over a very limited range (2-3 percent). Feeder dykes for the flows have not been found; they are presumed to be covered by lava sheets.

The lavas from the three formations bear a striking resemblance, both in hand specimen and thin section, to lavas from the much more voluminous Antrim Plateau Volcanics in the Ord-Victoria region of northern Australia. Chemical compositions of lavas from the Antrim Plateau Volcanics closely match those of the Helen Springs, Nutwood Downs, and Peaker Piker Volcanics. The petrochemistry of these rocks will be discussed in greater detail in a separate Record.

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APPENDIX I

K-Ar geochronology report and data*

Constants Used: K^{40} = 0.0119 atom %; $\lambda_\beta = 4.72 \times 10^{-10}$/yr; λ_e = 0.584×10^{-10}/yr.

1. Sample No: 70772166

Locality: Flicks Waterhole, Hodgson Downs 1:250 000 Sheet area.

Grid Ref. 174 027 (Latitude 15°36'S; longitude 134°06'E).

Analytical Data:

% K : 0.948
0.950

% Atmospheric Ar^{40} : 4.5
Radiogenic Ar^{40}/K^{40} : 0.03345

Age: 500 ± 12 m.y.

Petrography

This is a relatively coarse-grained basaltic rock whose dominant constituents are plagioclase, clinopyroxene, and opaques. The texture is subophitic and interstitial quartz is common. Although unevenly distributed, secondary chloritic material is quite abundant. The alteration product varies from yellow to green in colour and mainly occurs interstitially, although many pyroxene and some plagioclase grains are partly altered. A trace of amphibole is present in this rock.

2. Sample No. 70772142

Locality: 3 km east of Helen Springs homestead, Helen Springs 1:250 000 Sheet area.

Grid Ref. 158 683 (Latitude 18°26'S; longitude 133°57'E).

Analytical Data:

% K : 0.631
0.631

% Atmospheric Ar^{40} : 8.0
Radiogenic Ar^{40}/K^{40} : 0.03429

Age: 511 ± 12 m.y.

*Supplied by Australian Mineral Development Laboratories, Adelaide. Investigation and Report by A.W. Webb and G.G. Lowder.

Petrography

This is a slightly porphyritic basalt or basaltic andesite with an intergranular to subophitic texture. Plagioclase and clinopyroxene are the dominant constituents and some of the pyroxene is pigeonitic. Poikilitic opaque grains are numerous and interstitial quartz is not uncommon. There are some pseudomorphs which are possibly after olivine, and amphibole occurs as very rare grains. Plagioclase and pyroxene both show minor alteration to chlorite, but most of the chlorite ($\pm$ 5%) in the rock occurs in the interstices between plagioclase laths and this chlorite has probably replaced primary volcanic glass.

APPENDIX 2

Description of drill core and cuttings from the stratigraphic hole BMR Alroy No. 2

A. Description of drill core - hand specimen

Core No. 14. 485 - 495 feet (147.8 - 150.9 m). Recovered 9 feet 8 inches (3.0 m)

Heavily altered, medium-grained grey basalt (sensu lato) - mainly massive; however a few small amygdales occur in parts. The amygdales are filled mainly with dark green chlorite. Small patches of dark green alteration product (chlorite) are common. Minor calcite in thin veinlets.

B. Description of drill cuttings - hand specimen

Interval (feet)	Description of Cuttings
450-455 (137.2-138.7m)	dolomite.
455-460 (138.7-140.2m)	dolomite + very rare basalt fragments.
460-465 140.2-141.7m)	basalt; light grey, heavily altered - numerous amygdales. Minor dolomite.
465-510 (141.7-155.4m)	basalt; grey, medium-grained, mainly massive. Some chips are slightly amygdaloidal. Amygdales filled mainly with dark green chlorite (?) together with minor agate and chalcedony. Rare calcite.
510-515 (155.4-157.0m)	basalt; mixture of dark grey, medium-grained mainly massive basalt and red-brown, heavily altered, slightly to moderately amygdaloidal basalt. Amygdales mainly very fine and filled with dark green chlorite (?).
515-530 (157.0-161.5m)	basalt; massive, dark grey, medium-grained, extensively altered.
530-535 (161.5-163.1m)	basalt; mixture of massive, dark grey medium-grained basalt similar to above and more heavily altered, red-brown, moderately amygdaloidal basalt. Most amygdales are fairly small and filled with dark green chlorite (?) together with minor quartz and chalcedony and rare calcite.

535-555 (163.1-169.2m)	basalt; heavily altered, dark red-brown, slightly to moderately amygdaloidal. Amygdales are characteristically very fine.
555-560 (169.2-170.7m)	basalt; mainly massive, heavily altered, grey basalt. Minor red-brown, heavily altered, slightly to moderately amygdaloidal basalt (contamination?)
560-570 (170.7-173.7m)	basalt; massive, medium-grained, grey — comparatively fresh appearance.

APPENDIX 3

Details of drilling and well History - BMR Alroy No. 2

Details of Drilling

The following details relating to the 1968 BMR drilling programme in the Alexandria - Wonarah area, N.T., have been taken from the Report of the drilling by Bastian and Thieme (1970).

The drilling was carried out by Thompson Drilling Pty Ltd, Acacia Ridge, Queensland, under sub-contract to Drilling Services, Darwin. Equipment consisted of a Mayhew 1000 rig mounted on an International SB170 4 x 6, a compressor (120 psi), and a 600 gallon (2 727 l) water tank mounted on a similar unit. Down-the-hole hammers were used as long as possible in each hole as these gave large cuttings and rapid penetration. Diamond bits were used for coring.

Cuttings were taken at 5 ft (1.5 m) intervals and either represented the bottom foot (0.3 m) of the interval when cuttings were abundant [as in the zone 0 to 200 ft (0-61 m)] or the whole interval when cuttings became less abundant [below 200 ft (61 m)]. Cores were taken at a lithology change.

Well history

WELL NAME	:	BMR Alroy No. 2
LOCATION	:	Latitude 19°30'50"S Longitude 136°17'30"E Top of Mt Lamb
ELEVATION	:	880 ft (268.2 m)
TOTAL DEPTH	:	571 ft (174.0 m)
DATE COMMENCED	:	26/10/68
DATE COMPLETED	:	3/11/68
STATUS	:	Abandoned - target (basement) reached.

Drilling details

Depth (feet)	Diameter of Hole (inches)	Bits Used	Circulating Medium
0 - 200 (0-61m)	$6\frac{3}{4}$ (17.1 cm)	$6\frac{3}{4}$ in (17.1cm) down-the-hole hammer	Air
200 - 353 (61-107.6m)	6 (15.2 cm)	6 in (15.2cm) down-the-hole hammer	Air
353-571 (107.6-175m)	$4\frac{3}{4}$ (12.1 cm)	$4\frac{3}{4}$ in (12.1cm) down-the-hole hammer	Air

Basalt (sensu lato) was intersected in BMR Alroy No. 1 at about 460 ft (140.2 m) and the hole was still in basalt when abandoned at 571 ft (174.0 m). The interval 485-495 ft (147.8 - 150.9 m) was cored, the recovery rate being 97% [9 feet 8 inches (3.0 m) of core recovered].

APPENDIX 4

Groundwater - Bore Records

A. Hodgson Downs Sheet area

Registered Number	Total Depth (m)	Supply (litres/min)	Lithology	Grid Reference	Date Drilled
644	24.1	0	0 - 4.6 - Soil 4.6 - 18.6 - Gravel 18.6 - 24.1 - Basalt	161003	1952
677	12.5	0	0 - 11.9 - Loam and clay 11.9 - 12.5 - Basalt	192996	1955
881	15.8	0	Probably basalt	175002	1955
1468	38.7	0	Sandstone overlying volcanics	191983	1955
1487	26.5	0	" " "	165005	?
2878	158.5	76	0 - 15.8 - Sandstone 15.8 - 120.4 - Basalt 120.4 - 158.5 - Sandstone	159013	1959
4883	?	0	Nutwood Downs Volcanics	183002	?
5027	153.0	14	0 - 6.1 - Basalt 6.1 - 12.2 - Sandstone 12.2 - 18.3 - Shale and basalt 18.3 - 42.7 - Pink shale 42.7 - 153.0 - Grey shale	175079	1965
7189	76.2	90	0 - 54.9 - Basalt 54.9 - 76.2 - Sandstone	187991	1970
7689	67.1	?	0 - 3.0 - Rubble 3.0 - 61.0 - Basalt 61.0 - 67.1 - Sandstone	175014	1970

B. Tanumbirini Sheet area

Registered Number	Total Depth (m)	Supply (litres/min)	Lithology	Grid Reference	Date Drilled
880	34.4	0	0 - 3.4 - Basalt 3.4 - 17.1 - Sandy clay 17.1 - 21.3 - Soft limestone 21.3 - 28.0 - Sandy clay 28.0 - 33.8 - Hard limestone 33.8 - 34.4 - Basalt	196977	?

C. Helen Springs Sheet area

6647***	53.3	68	0 - 6.1 - Topsoil & travertine 6.1 - 47.2 - Basalt 47.2 - 53.3 - Shale		1969

*** situated 6.5 km northwest of Muckety homestead.

C. Helen Springs Sheet area (after Randal, 1969)

Registered Number	Station No. or Name	Position	Total Depth (m)	Aquifer	Supply (litres/min)
108	Helen Springs No. 7	16 km north of Helen Springs homestead	70.1	Helen Springs Volcanics or Tomkinson Creek Group	30
419	North-South S/R* (Helen Springs)	1.6 km east of Helen Springs homestead	19.2	Helen Springs Volcanics	114
420	North-South S/R (Muckety)	2.4 km east of Muckety homestead	18.3	Helen Springs Volcanics	Good
421	North-South S/R (Banka Banka)	3.2 km southeast of Banka Banka homestead	23.2	Helen Springs Volcanics	Poor
927**	North-South S/R (Banka Banka)	3.2 km southeast of Banka Banka homestead	23.2	Helen Springs Volcanics	16
1194	Banka Banka No. 9	1.6 km north of Banka Banka homestead	36.6	Helen Springs Volcanics?	38
1286	Helen Springs Homestead Well	Helen Springs homestead	5.8	Helen Springs Volcanics	-
1287	Helen Springs Garden Well	Helen Springs homestead	9.4	Helen Springs Volcanics	-
4601	Helen Springs No. 18	0.8 km southeast of Maryville	-	Helen Springs Volcanics or Tomkinson Creek Group	-
4602	Helen Springs No. 19	4.8 km northeast of Helen Springs homestead	50.3	Helen Springs Volcanics	45
4667	Muckety Homestead	Muckety homestead	106.7	Helen Springs Volcanics	16

* S/R = Stock Route

** Replacement bore for R.N. 421.

D. Wallhallow Sheet area

Registered Number	Station No. or Name	Total Depth (m)	Summary of Drillers' Logs		Position	Supply (litres/ min)	Year Drilled
524	Barkly Stock Route No. 2	65.2	0 - 30.5	Volcanic rock	17°59'S; 135°00'E	57	?
			30.5 - 48.8	Pipe clay			
			48.8 - 61.0	Sandstone, sand and clay			
			61.0 - 65.2	Limestone			
525	Barkly Stock Route No. 1 - 10th Bore	73.8	0 - 6.1	Soil and yellow rock	17°59'S; 135°17'E	57	?
			6.1 - 23.2	Yellow clay and yellow rock			
			23.2 - 41.8	Red volcanic rock			
			41.8 - 44.8	Limestone			
			44.8 - 50.9	Red volcanic rock			
			50.9 - 56.1	Limestone			
			56.1 - 62.2	Red volcanic rock			
			62.2 - 73.8	Limestone			
597	Homestead Bore - Anthony Lagoon Station	61.6	0 - 23.8	Limestone	17°58'S; 135°33'E	57	1919
			23.8 - 49.4	Volcanic rock			
			49.4 - 61.6	Limestone			
599	Anthony Lagoon No. 4	121.3	0 - 18.9	Limestone	17°56'S; 135°30'E	57	1934
			18.9 - 45.7	Red and yellow clay, some limestone			
			45.7 - 63.4	Limestone			
			63.4 - 93.6	Yellow and red clay, some limestone			
			93.6 - 100.3	Red rock			
			100.3 - 110.9	Limestone			
			110.9 - 114.9	Grey shale			
			114.9 - 121.3	Red volcanic rock			

Registered Number	Station No. or Name	Total Depth (m)	Summary of Drillers' Logs		Position	Supply (litres/ min)	Ye Dri
600	Yellow Bore No. 5 - Anthony Lagoon	94.8	0 - 33.2	Clay, minor limestone	17°54'S; 135°28'E	68	19
			33.2 - 42.1	Limestone			
			42.1 - 57.9	Clay and limestone			
			57.9 - 82.3	Chocolate shale			
			82.3 - 94.8	Limestone and grey shale			
601	Green Bore No. 6 - Anthony Lagoon	84.1	0 - 23.2	Clay	17°53'S; 135°38'E	64	19
			23.2 - 30.5	Limestone			
			30.5 - 48.8	Red and yellow clay			
			48.8 - 52.4	Limestone sandstone and shale			
			52.4 - 63.1	Red rock			
			63.1 - 75.9	Limestone			
			75.9 - 84.1	Limestone, grey shale and sandstone			
606	Anthony Lagoon No. 8	94.2	0 - 7.6	Clay	17°54'S; 135°10'E	91	19
			7.6 - 13.7	Red rock			
			13.7 - 94.2	Clay, shale, limestone			
952	No. 1 Bore - Wallhallow	110.6	0 - 13.1	Clay	17°32'S; 135°46'E	114	19
			13.1 - 59.1	Volcanic sandstone			
			59.1 - 110.6	Limestone and flint			
2158	Anthony Lagoon No. 15	59.1	0 - 7.6	Conglomerate	17°58'S; 135°04'E	68	19
			7.6 - 21.3	Limestone			
			21.3 - 36.6	Clay, minor sand			
			36.6 - 42.7	Red conglomerate			
			42.7 - 59.1	Limestone, minor red conglomerate			

Registered Number	Station No. or Name	Total Depth (m)	Summary of Drillers' Logs		Position	Supply (litres/ min)	Year Drilled
2746	Creswell Downs No. 15	99.1	0 - 28.3	Clay, minor sandstone	453 751	49	1961
			28.3 - 40.8	Sandstone and basalt			
			40.8 - 99.1	Very hard sandstone			
3148	Anthony Lagoon No. 25	76.2	0 - 45.7	Clay	284 753	68	?
			45.7 - 63.1	Soft brown rock			
			63.1 - 68.6	Limestone			
			68.6 - 76.2	Soft red rock			
5406	Shandon Downs No. 31	96.3	0 - 88.7	Yellow, red, white and black clay	17°34'S; 135°12'E	45	1966
			88.7 - 96.3	Sandstone, minor grey clay			
7102		161.5	0 - 21.3	Clay, siltstone, laterite	17°48'S; 136°22'E	53	1970
			21.3 - 39.6	Sandstone, shale, chert, limestone			
			39.6 - 70.1	Limestone, quartz, clay			
			70.1 - 77.7	Quartz and sandstone			
			77.7 - 108.2	Basalt			
			108.2 - 161.5	Sandstone, quartz, siltstone			
7627	Anthony Lagoon - New No. 6	82.3	0 - 22.9	Clay	17°52'S; 136°27'E	53	1971
			22.9 - 31.7	Limestone			
			31.7 - 48.8	Clay			
			48.8 - 77.7	Limestone			
			77.7 - 82.3	Mudstone, limestone			
7683	Kiana No. 2	61.0	0 - 39.6	Limestone	17°13'S; 135°44'E	34	1971
			39.6 - 61.0	Hard black rock			

Registered Number	Station No. or Name	Total Depth (m)	Summary of Drillers' Logs		Position	Supply (litres/ min)	Year Drilled
7684	Kiana No. 5	53.3	0 - 25.9	Slippery back	17°13'S; 136°05'E	45	1971
			25.9 - 41.1	Sandy clay			
			41.1 - 53.3	Hard sandstone			

The following holes have each an incomplete log because circulation was lost during drilling, and there was no sample return for some intervals.

Registered Number	Station No. or Name	Total Depth (m)	Summary of Drillers' Logs		Position	Supply (litres/ min)	Year Drilled
2750		119.5	0 - 91.4	Clay and limestone	17°40'S; 136°10'E	?	?
			91.4 - 119.5	No sample			
4588		64.0	0 - 59.4	Clay and dolomite	17°56'S; 136°54'E	?	?
			59.4 - 64.0	No sample			
6531****		114.3	0 - 91.4	Limestone, silty limestone and cherty limestone	17°51'S; 135°58'E	?	?
			91.4 0 114.3	No sample			
6700****		132.6	0 - 118.9	Clay, sandstone, siltstone and limestone	17°35'S; 135°46'E	?	?
			118.9 - 132.6	No sample			
7100		103.6	0 - 93.0	Sandy clay, silty clay and limestone	17°32'S; 135°36'E	?	?
			93.0 - 103.6	No sample			
7101			0 - 54.9	Sandy clay, silty clay and limestone	17°48'S; 136°21'E	?	?
			54.9 - 91.4	No sample			

Registered Number	Station No. or Name	Total Depth (m)	Summary of Drillers' Logs		Position	Supply (litres/ min)	Year Drilled
7103****		82.3	0 - 61.0	Clay, limestone and silty limestone	17°08'S; 136°44'E	?	?
			61.0 - 82.3	No sample			
7314****		91.4	0 - 22.9	Clay, silty sandstone and silty limestone	17°15'S; 136°55'E	?	?
			22.9 - 91.4	No sample			
7316****		97.5	0 - 38.1	Sandy siltstone and limestone	17°15'S; 136°11'E	?	?
			38.1 - 97.5	No sample			
7512		91.4	0 - 54.9	Clay and limestone	17°15'S; 136°53'E	?	?
			54.9 - 91.4				

**** Hole logged by a geologist

APPENDIX 5

Thin-section descriptions - Nutwood Downs Volcanics

AP. 6006. T.S. 7430 R. 14423. The sandstone is medium-grained, heavily silicified. It consists of well-rounded quartz grains ranging in size from 0.08 mm to 0.50 mm, and averaging 0.15 mm, set in a matrix of cryptocrystalline and microcrystalline silica. Each grain has a thin coating or discolouration of ferruginous matter. Irregular fragments of iron-rich trachytic lava occur in the sandstone. Their connection with the main mass of lava in which the sandstone occurs is unknown; they may be true detrital fragments. It is of note that they do not show chilled margins, as does the main lava. The overall impression given by the sandstone is that it was already silicified when incorporated into the lava. There are patches of fibrous brown quartz (perhaps inverted from tridymite or cristobalite) in the sandstone; these are almost certainly directly connected with the volcanism, and are probably due to recrystallisation of the original quartz to tridymite or cristobalite and subsequent inversion back to quartz. The sandstone/lava contact is chilled, and the lava (an iron-rich trachyte) is here very fine-grained and almost isotropic At the contact there is a zone of hybrid rock, with fragments of sandstone and trachyte intermingled.

A.P. 6013. T.S. 7437 R. 14424. A rather weathered, vesicular trachyte, consisting of laths of oligoclase in a pale brown, partly devitrified groundmass, with abundant leucoxene and limonite representing altered opaques. Very minor amounts of interstitial quartz occur. The upper surface of the trachyte was evidently cavernous, due to exposed vesicles, and these cavities are now filled with silicified medium-grained sandstone. The sandstone closely resembles that occurring as blocks in lava (A.P. 6006); it consists of rounded grains of quartz of average size 0.15 mm (with a few larger, well-rounded grains), set in a matrix of microcrystalline silica and quartz. The silicification must have occurred after the detrital grains were deposited on and in the trachyte. At a later stage, massive limonite-goethite was introduced, partly replacing the siliceous matrix of the sandstone and filling vesicles in the trachyte.

A.P. 6032 T.S. 7456 R. 14425. It appears that the main body of the rock is the top surface of a trachyte lava with a vesicular weathered surface. The sandstone has been deposited on this irregular surface, and the number of lava fragments (of flaky shape) incorporated in the sandstone decreases upwards, i.e. away from the lava surface. Finally, at the top of the specimen there is a thin layer of fairly pure, limonitic sandstone. The trachyte consists of laths of sodic plagioclase with interstitial haematite - limonite. The sandstone consists of rounded grains of quartz (with a skin of limonite) in the fine-to medium-grained range. Cementing material is quartz with fibrous structure. Vesicles in the lava are filled with silica and limonite.

A.P. 6033 T.S. 7457 R. 14426. This is a vein-filling consisting of various forms of silica. The spherulitic red mineral is jasper, i.e. cryptocrystalline silica with radiating structure. Crystallized quartz comprises the remainder of the specimen. This is not necessarily an amygdale filling; very similar material is found as veins cutting Archaean granite-gneisses in South Australia. However, in view of the proximity of this specimen to A.P. 6006, it is likely that it is a vein or amygdale filling in or near the lava.

A.P. 6034 T.S. 7458 R. 14427. This is a jasper with radiating structure; small pockets of clear quartz often contain bladed hematite. Small white spots in hand specimen consist of the same radiating fibrous quartz but without the hematitic colouring matter.

Thin sections described by H.W. Fander, Australian Mineral Development Laboratories, Adelaide.