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UPPER MANTLE XENOLITHS AND MEGACRYSTS AND THE ORIGIN OF THE BRIGOODA BASALT AND BRECCIA, NEAR PROSTON, QUEENSLAND.

by **A.D. Robertson, F.L. Sutherland, and J.D. Hollis**

ABSTRACT. Two phases of volcanic activity have been recorded in the Garnet Gully area, east of Brigooda. The older volcanic activity occurred during the early Miocene when moderately to strongly undersaturated alkali-basalt, the Brigooda Basalt, was extruded from a single vent. During the late Pleistocene, gaseous outbursts produced several breccia deposits, the largest of which occupies the central part of a maar-like structure at Garnet Gully.

Xenoliths of pyroxenite, garnet pyroxenite, hornblendite, and pegmatitic garnetite accompanied by megacrysts of amphibole and anorthoclase are common. Zircon and sapphire occur as rare inclusions in the breccia.

Experimental temperature-pressure determinations when applied to the Garnet Gully xenolith-megacryst assemblage indicate upper-mantle origins shallower than 60 - 70 km. The presence of CO_2 in inclusions in pyroxene and amphibole suggests that mantle CO_2 may have formed a large percentage of the volatiles in the gaseous outbursts.

INTRODUCTION

Gem quality garnets have been known from the Brigooda district for more than 20 years. The garnet deposits (151° 28′E, 26° 15′S) lie approximately 17 km southwest of Proston and 210 km northwest of Brisbane. The area is held under Mining Lease 136 Nanango. The lease yields gem-quality red garnet, colourless anorthoclase, occasional orthopyroxene and less frequent sapphire and zircon. Associated with the garnet is a suite of xenoliths and megacrysts similar to that recorded by Hollis *et al.* (1983) at Ballogie (southwest of Proston) and characteristic of high pressure assemblages found elsewhere in eastern Australia (Wass & Irvine 1976).

Exon *et al.* (1968) mapped basalt in the vicinity of Brigooda but made no mention of garnet. The presence of the high pressure origin xenoliths and megacrysts accompanying the garnet, east of Brigooda, led Robertson (1974) to believe that the area could contain volcanic rocks of kimberlitic affinity. As a result, a joint study of the occurrence by A.D. Robertson of the Geological Survey of Queensland and F.L. Sutherland and J. D. Hollis of the Australian Museum, Sydney is now in progress.

This paper represents a part of a more detailed study of the basalt, xenoliths, megacrysts and xenocrysts in the Brigooda - Ballogie area.

GEOLOGY OF THE BRIGOODA GARNET DEPOSIT

The geology of the area surrounding the garnet deposit is given in text-fig. 1. Text-fig. 2 shows the distribution of the various volcanic rock types that make up the Brigooda Basalt (new name). The basement rock in the Brigooda

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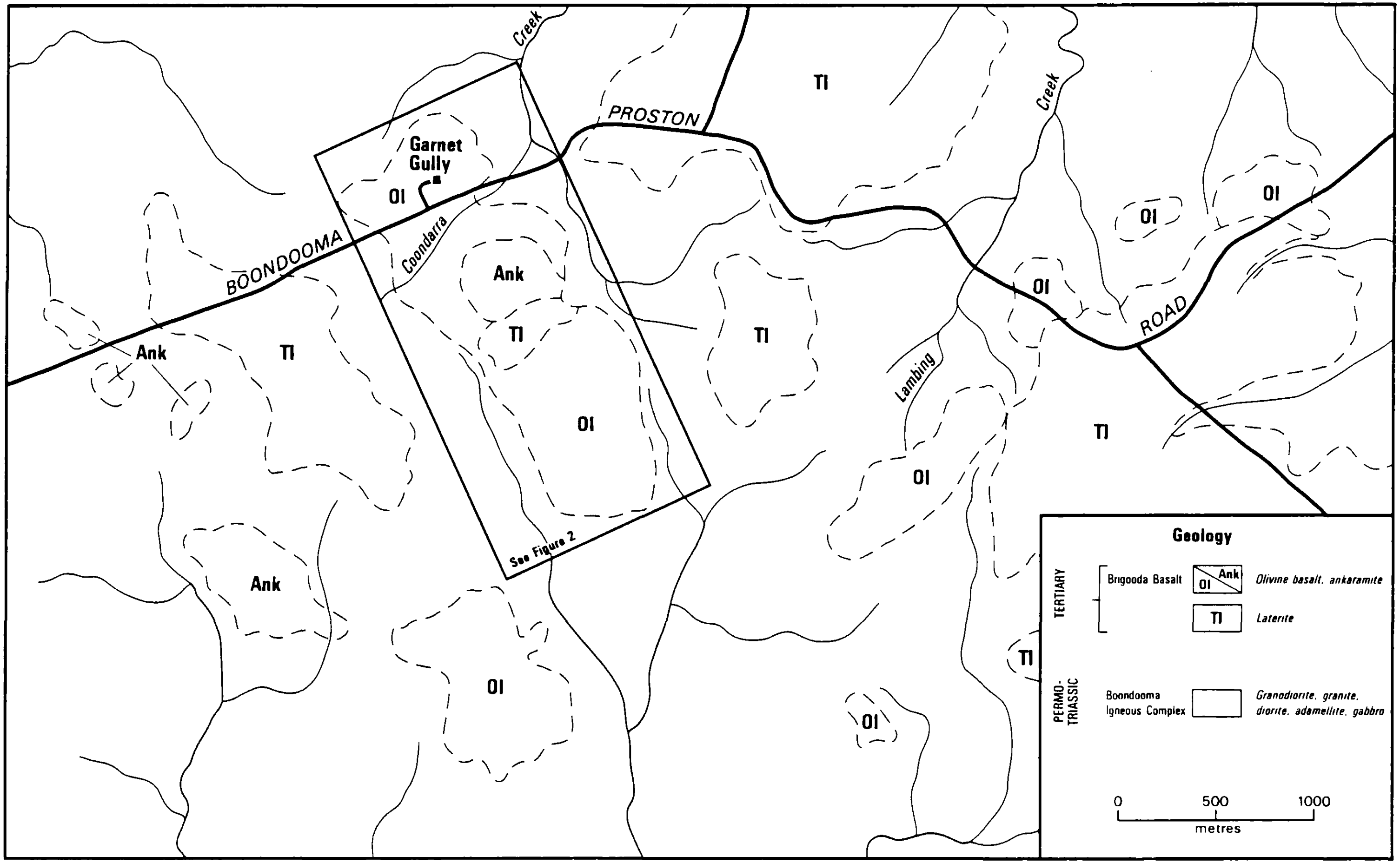

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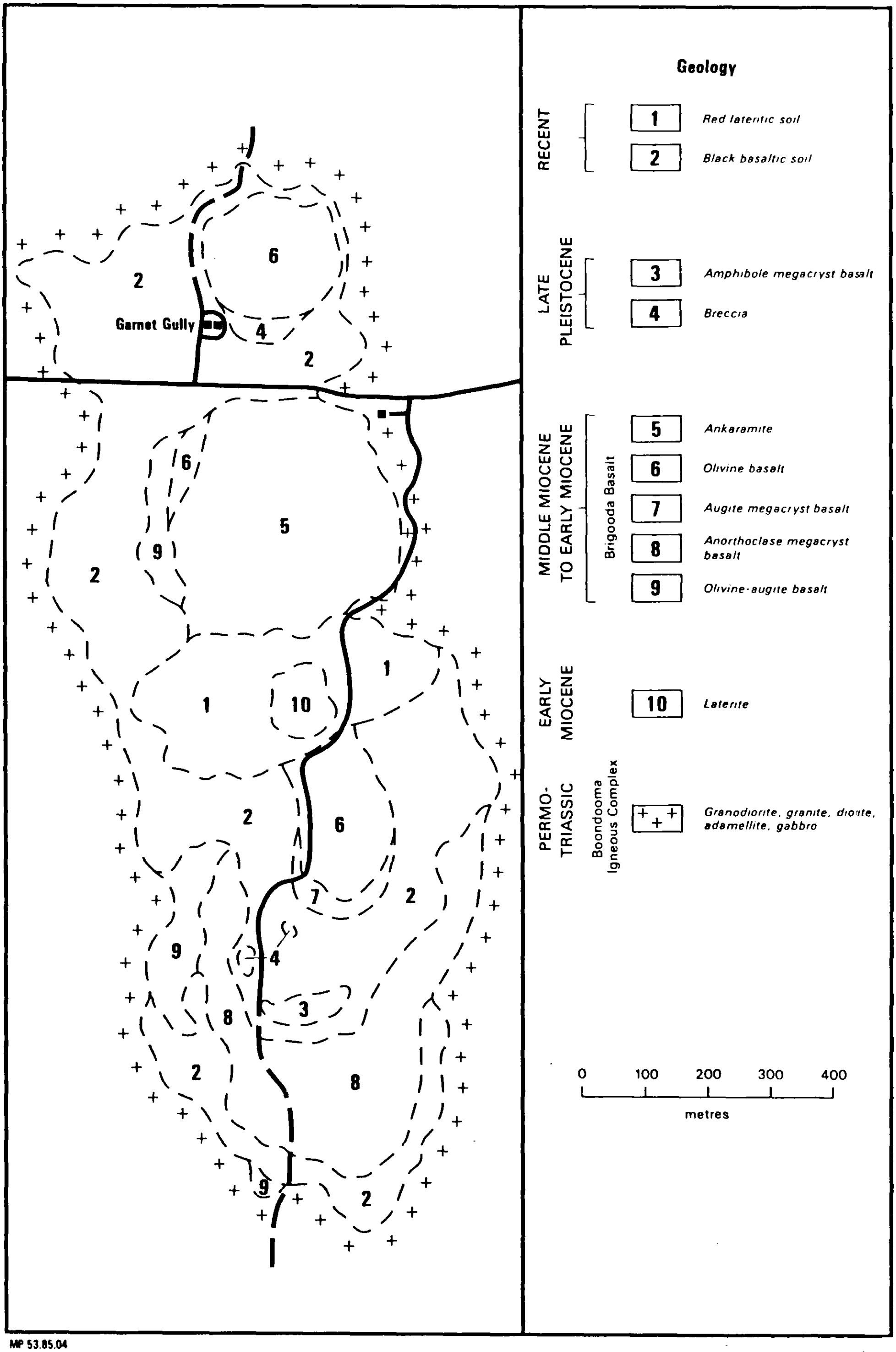
Text-fig. 1: General geology of the Garnet Gully area - Brigooda.



Text-fig. 2: Detailed geology of the Garnet Gully area.

area consists of a porphyritic phase of what McTaggart (1963) and Exon *et al.* (1968) referred to as the Boyne River Granite. More recently Murphy *et al.* (1976) have included the Boyne River Granite in the Boondooma Igneous Complex. Potassium feldspar crystals to 8 cm in length are common, set in a medium- to coarse-grained granodioritic groundmass. Outcrop is usually poor and covered by colluvial wash and younger lateritised sediments. The well developed joint pattern striking northeast and northwest is highlighted by the dendritic drainage pattern. Granitic material of the Boondooma Igneous Complex intrudes metasediments, schists and gneisses of Palaeozoic age to the east of Brigooda (Murphy *et al.* 1976).

Covering much of the granite in the Brigooda area are deeply weathered and ferruginised sediments of Cainozoic age. They range from poorly consolidated polymictic conglomerate to poorly sorted sandstone. Sands derived from the granite have been consolidated in situ or after minimal tranport. Much of this material has been deeply weathered (during the Oligocene) and now consists mainly of quartz grains set in a clay matrix. In some areas, these sands are overlain by lateritised sediments.

In general, there is a poorly differentiated profile developed in the weathered sequence. The upper surface has been ferricreted, at depth the ferruginous sediments give way to mottled and bleached material.

Uplift and erosion during the late Oligocene to early Miocene resulted in the disruption of the deeply weathered sedimentary profile. Remnant caps are all that are left of this once extensive sedimentary cover.

During the Miocene, basaltic lavas (Brigooda Basalt) extruded from at least one vent to the east of Brigooda flowed into valleys between the caps of deeply weathered sediments. An ankaramite lava flowed westward while the majority of the basalt flowed eastward from a vent located north of the Boondooma - Proston road at Garnet Gully (Text-figs 1 & 2).

Several periods of uplits and erosion (Murphy *et al.* 1976) have occurred since the late Miocene resulting in the erosion and removal of parts of the lava flows.

The Brigooda Basalt

Brigooda Basalt is the name given to a sequence of basaltic and ankaramite flows emanating from a low conical hill adjacent to the Boondooma - Proston road at Garnet Gully. At least five flows can be identified as originating from the vent (see text-fig. 2)

Glassy olivine-augite basalt was the first of the lavas to be extruded and was followed by anorthoclase megacryst basalt, anorthoclase-augite megacryst basalt and finally an undersaturated olivine basalt. Most of the lava flowed southward from the vent before turning eastward along a pre-existing drainage system.

The relationship of the ankaramite to the other flows is questionable. Text-fig. 1 shows remnants of an ankaramite flow that appears to have originated from the vent at Garnet Gully, flowed initially southward, then westward, and finally northwestward. Field relationships indicate that the ankaramite may overlie the glassy olivine-augite basalt but no further relationship can be deduced from field evidence.

In the southern part of the main outcrop area at Garnet Gully (Text-fig.2), floaters of fine-grained to glassy lava containing numerous fragments of amphibole (amphibole megacryst basalt) occur in black soil in cultivation. No outcrop of this rock type has been recorded.

Breccia consisting mainly of pulverised granite and intruded by basaltic lava occurs adjacent to the southern side of the vent at Garnet Gully (Text-fig. 2). Similar breccia outcrops have been recorded in the vicinity of the amphibole megacryst basalt float. This breccia has been emplaced after the extrusion of the Brigooda Basalt.

Petrology

The olivine-augite basalt is a fine grained to glassy lava containing microphenocrysts of olivine and augite in a groundmass of clinopyroxene, granular opaques, yellowish to brown glass and minor nepheline. Plagioclase feldspar appears as small thin laths that are difficult to distinguish under the microscope. X-ray diffraction analysis indicates that feldspar exceeds nepheline in the groundmass. Much of the olivine has been altered to a blood red iddingsite and granular opaques. Spinel, clinopyroxene and plagioclase feldspar occur as xenocrysts. Black reaction rims around spinel are common and the clinopyroxene xenocrysts with their strongly developed reaction rims are characteristic of this lava type.

The anorthoclase megacryst-bearing basalt ranges from a fine grained to glassy black rock with phenocrysts of clinopyroxene and altered olivine in a groundmass of clinopyroxene, plagioclase feldspar and interstitial glass. Nepheline can replace the glass and the rock type approaches a basanite in composition. Fragments of altered mica, clinopyroxene, and oxide-rimmed spinel are present. Anorthoclase occurs as corroded megacrysts, some of which exhibit secondary feldspar overgrowths not in optical continuity with the host mineral.

The augite megacryst basalt contains microphenocrysts of olivine and rare clinopyroxene in a groundmass of clinopyroxene, granular opaques and plagioclase laths with interstitial nepheline and yellow volcanic glass. Olivine is almost completely altered to iddingsite. Throughout the groundmass, numerous rounded to elongate bodies occur, composed of feldspar and/or yellow glass and more rarely of zeolite. The most characteristic feature of this rock type is the large rimmed megacrysts of augite (up to 10 cm in length). These megacrysts are occasionally accompanied by anorthoclase. Xenocrysts of orthopyroxene, clinopyroxene and rare garnet are enclosed in the lava. The augite megacryst basalt has been recorded from the southern part of the main outcrop area at Garnet Gully (Text-fig. 2) and is overlain by olivine basalt. To the southwest of the first occurrence, this rock type has been found as rubble outcrop. Occasional corroded xenocrysts of plagioclase have been recorded in the lava from this latter locality.

Olivine basalt appears to be the final phase of the eruption from the vent at Garnet Gully. The rock is a fine-grained black basalt containing microphenocrysts of olivine in a groundmass of feldspar laths, granular opaques and clinopyroxene. Occasional individual feldspar laths approach the size of the olivine phenocrysts. When present, xenocrysts of clinopyroxene are almost completely replaced by granular opaques. Aggregates of olivine crystals showing granulation and strong undulose extinction occur in the basalt. These olivine aggregates are interpreted as remnants of sheared lherzolite. X-ray diffraction analysis of the fine groundmass material indicates the presence of nepheline.

Medium to coarse grained ankaramite consists of olivine, titanaugite, plagioclase laths and opaques with patches of interstitial glass. The olivine and titanaugite have a strong tendency to be glomeroporphyritic and occasional crystals of augite are subophitic to plagioclase. Large clinopyroxene exhibits strong zoning from augite to titanaugite. Normal zoning is not uncommon in the feldspar.

The amphibole megacryst basalt occurs as float in black soil. It is a fine-grained to glassy rock containing numerous fragments of amphibole, feldspar, olivine, two pyroxenes, brown spinel and apatite, in a glassy groundmass that contains microlites of feldspar, euhedral augite and olivine and granular opaques. Fine fragments of brown hornblende, spinel, potassium feldspar and mica also appear in the groundmass. Garnet is a common xenocryst in this basalt.

The breccia adjacent to the south side of the vent at Garnet Gully and the known exposures of breccia in the vicinity of the amphibole megacryst basalt float are similar in composition. Approximately 70% of the breccia is composed of pulverised granite (fragments varying in size from 1 to 15 cm), the remainder being a glassy olivine basalt (approximately 10 %) and a large variety of mafic - ultramafic inclusions (approximately 20%). Fragments (up to 5 cm in length) of Cr-diopside-spinel lherzolite are most abundant. Xenoliths of pyroxenite, garnet pyroxenite, garnetite, syenite, olivine gabbro, olivine basalt and amphibole megacryst basalt are common. Xenocrysts of amphibole, orthopyroxene, clinopyroxene, anorthoclase, garnet, magnetite, ilmenite, mica and spinel are common. Zircon (rare) has been recovered only from the weathered residue. It is assumed that occasional sapphires found in the alluvium with the garnet are derived from the breccia.

A fine grained volcanic rock (occurring as float adjacent to the amphibole megacryst basalt) contains microphenocrysts of titanaugite and rare olivine in a groundmass of titanaugite, granular opaques, nepheline and rare feldspar. Xenocrysts of clinopyroxene and spinel exhibiting reaction zones are common and occasionally small clinopyroxenite xenoliths have been noted. A similar rock type but containing more plagioclase was found as loose boulders at the vent site. This latter rock, mineralogically, could be classed as a basanite.

Significance of the Breccia

Two main areas of brecciation have been mapped in the Garnet Gully area. In both instances, the soil surrounding the breccia produces an abundance of xenoliths, megacrysts, and xenocrysts. The breccia located on the southern side of the vent at Garnet Gully appears to be of limited extent obliterating at that point a narrow zone of sheared granite encircling the vent position.

Towards the southern end of the main mass of volcanics (at Garnet Gully) a second and much larger occurrence of breccia has been observed. Much of it is overlain by black soil and basaltic wash and the breccia appears to occur as basement to a large circular depression. Outside the main structure, the glassy olivine-augite basalt, a number of small circular to elliptical occurrences of breccia have been found. On the basis of the relationship of this breccia to the earlier formed olivine-augite basalt and the similarity in the mineralogical and textural relationship between the small breccia occurrences and the breccia in the large circular depression, the latter breccia postdates extrusion of at least part of the Brigooda Basalt. This hypothesis is also supported by the presence of rock types in the breccia similar to those found in the flows associated with the Brigooda Basalt. Potassium-argon dating of anorthoclase from the breccia (see later) indicates that the breccia formed through volcanic activity at a much later date.

The southern breccia is considered to represent part of a maar-like structure caused by volcanic gas outbursts accompanied by a relatively low volume of liquid magma. The presence of inclusions containing CO_2 in the pyroxene and hornblende and possibly garnet indicates that mantle CO_2 may have been the major source of volatiles producing the maar-like structure rather than ground water and surface drainage as suggested by Lorenz (1973). The breccia adjacent to the southern side of the vent is considered to be an offshoot venting of gas from the main structure to the south.

Xenoliths, Megacrysts and Xenocrysts

Cr-diopside-spinel lherzolites are found in all the flows of the Brigooda Basalt except the ankaramite flows and are well represented in the xenolith assemblage in the breccia. Lherzolite nodules are rarely found as float. In the vicinity of the breccia, clinopyroxenite, hornblende-bearing clinopyroxenite, garnet-hornblende clinopyroxenite, garnet-spinel clinopyroxenite, garnet-clinopyroxene hornblendite, spinel-clinopyroxene hornblendite and garnetite are relatively common xenoliths. Mafic and felsic granulite, hypersthene gabbro, syenite, websterite and spinel-bearing pyroxenite are not common.

Megacrysts of black kaersutite, white to clear anorthoclase, green to black clinopyroxene and brown to black orthopyroxene are relatively abundant. The kaersutite is most abundant in the amphibole megacryst basalt and as loose fragments in black soil covering the southern breccia occurence. Hollis *et al.* (1983) give the percentage of amphibole in the amphibole megacryst basalt as 48.7%. Analysis shows that the TiO_2 content is typical of kaersutite and like those from Ballogie is relatively rich in alkalis and define a limited homogeneous field. This field falls across typical kaersutite compositions for megacrysts found elsewhere in eastern Australia (Sutherland & Hollis 1982) for Mg-Fe-Ti (see also Hollis *et al.* 1983).

The Brigooda feldspar is sodic anorthoclase that has been found in pieces up to 10 cm length in black soil covering the southern breccia occurrence. It also occurs as a megacryst in an early flow of the Brigooda Basalt.

The pyroxenes (also occurring as megacrysts) occasionally exceed 10 cm in diameter but the most common size recovered from heavy mineral concentrate is 0.5 to 1 cm. Most are dull blue-grey to shiny black augite and bronzite that, over a powerful light, separate into semi-translucent green Cr-bearing endiopsidic augite and amber brown bronzite.

The garnet, much of it gem quality, occurs both as megacrysts and xenocrysts. It ranges in size from sand grains to pieces that have been known to exceed 20 cm in length. The majority of the garnet recovered from the black soil can be cut into one carat stones while pieces to 1 cm diameter are not uncommon. At Brigooda, the source of the garnet appears to be the breccia and the amphibole megacryst basalt. The garnets are pyrope almandines with a refractive index that ranges from 1.747 to 1.751 (refractive index measured in the D-line of Na). They have a relatively high Ti and low Ca and Cr content, similar to the Ballogie garnets (Hollis *et al.* 1983) and exhibit limited compositional range. Much of the large garnet masses are composed of interlocking anhedra showing vague banding and are the result of disaggregation of garnetites at depth. Some of the garnet pieces contain chalcopyrite blebs and fine hair-like rutile rods as inclusions.

The garnet, pyroxene and amphibole of the pyroxenites and the large crystals show similar composition suggesting they are related. The garnet compositions fall within the typical range of mantle garnet pyroxenites from the spinel lherzolite zone. Pressure-temperature estimates for the suites based on co-existing garnet-pyroxene compositions and on a kaersutite geobarometer fall between 10 - 15 kb and 1000 - 250^{o}C (Hollis *et al.* 1983; Sutherland, Hollis & Robertson, unpublished data).

Minerals that appear as xenocrysts rather than megacrysts are titanphlogopite, spinel ilmenite, titano-magnetite and magnetite. Whether zircon and/or sapphire can be classed as megacrysts or as xenocrysts is not known. These minerals are only known from concentrates derived from weathered material.

Age Dating

Suitable material for potassium-argon age dating is difficult to recover from the various flows because of the quantity of glass encountered in the groundmass. Samples of anorthoclase from the breccia and amphibole from the amphibole megacryst basalt were used to date the Brigooda Basalt and age of formation of the breccia.

The amphibole from the megacryst-bearing basalt gave a K/Ar age of 17.8 ± 0.2 Ma (early Miocene) and compares favourably with the K/Ar age of 16.0 ± 0.2 Ma from anorthoclase from the Ballogie eruption (Hollis *et al.* 1983). Anorthoclase concentrate from the breccia gave K/Ar ages of 0.381 ± 0.025 and 0.451 ± 0.040 Ma (late Pleistocene). These results are considered reasonably accurate and were much younger than had been expected. It did substantiate, however, that the formation of the breccia occurred after the eruption of the Brigooda Basalt as indicated in part by breccia developed in glassy olivine-augite basalt.

This late Pleistocene age for the formation of the volcanic breccia and the emplacement of a large proportion of xenoliths and the garnet represents the youngest age to be recorded for volcanic activity in southern and central Queensland. It is younger that the volcanic activity at Coalstoun Lakes (0.6 Ma, Wellman 1978) but not as spectacular as regards magmatic outpouring.

Chemistry of the Brigooda Basalt

Chemical analyses of selected samples of the Brigooda Basalt, breccia and granite from the Boondooma Igneous Complex are given in Table 1. (Grid co-ordinates for the 15 samples of Table 1 are given in Table 2.) Apart from the breccia and the granite, all the volcanic materials analysed have a SiO_2 content of less than 48% as well as having high TiO_2 and K_2O.

The Alkalis:Silica values are plotted in text-fig. 3 relative to tholeiite (Macdonald and Katsura 1964 (M+K); Irvine and Baragar 1971 (I+B)), moderately undersaturated (Strong 1972 (S)) and strongly undersaturated (Saggerson & Williams 1964 (S+W)) dividing lines. Apart from the ankaramite, all samples of the Brigooda Basalt fall either within the moderately undersaturated or in the strongly undersaturated fields that correspond to the basanite and nephelinite fields respectively of Griffin (1977). The ankaramite falls across Strong's dividing line between moderately undersaturated (basanite) and weakly undersaturated (alkali-basalt) volcanic rocks. This latter field corresponds to Griffin's alkali basalt-hawaiite field. The Soda: Potash diagram (text-fig. 4) shows the various rock types attributed to the Brigooda Basalt are sodic in nature.

All the lava types in the Brigooda Basalt can be classed as alkali basalts as defined by Macdonald and Katsura (1964). However, for volcanic rock types containing nepheline, Strong (1972) considers the use of the alkalis to silica ratio to be more a convenient measure of their degree of undersaturation rather than predicting degrees of undersaturation from the percentage nepheline generated in the norm.

The amount of normative nepheline is partly determined by the oxidation state of the iron in the sample and the resultant normative nepheline will depend upon the value accepted for the FeO/Fe_2O_3 ratio prior to calculating the norm. The state of oxidation of iron in the Brigooda Basalt exceeds that (1.5 % Fe_2O_3) suggested by Coombs (1963) for a normal basalt.

On the basis of the Alkali:Silica values, the high TiO_2 and K_2O and its sodic nature, the Brigooda Basalt is a strongly to moderately undersaturated basalt belonging to the continental alkali-basalt series.

Origin of the Brigooda Basalt, Breccia and Xenoliths

The lherzolite xenoliths in the Brigooda Basalt indicate transport in fractionated magma eruptions from the mantle. The pyroxene assemblage is

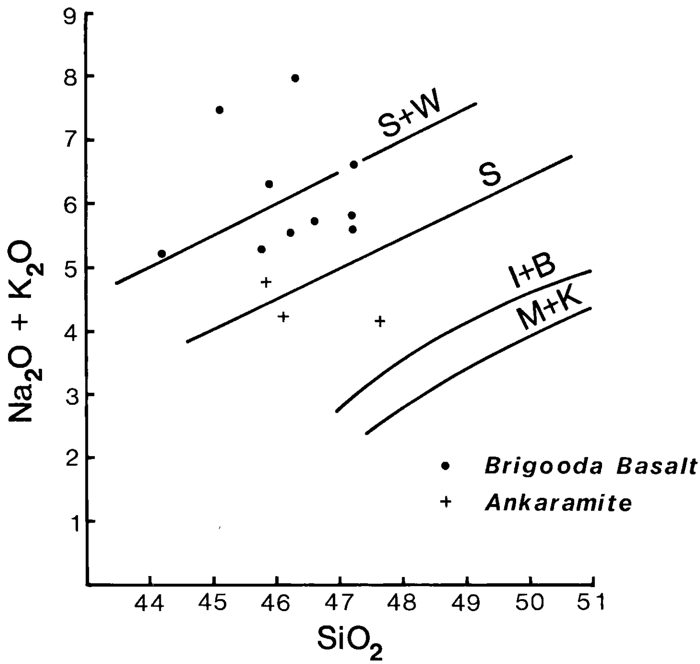


Figure 3 : Alkalis : Silica Diagram See text for code

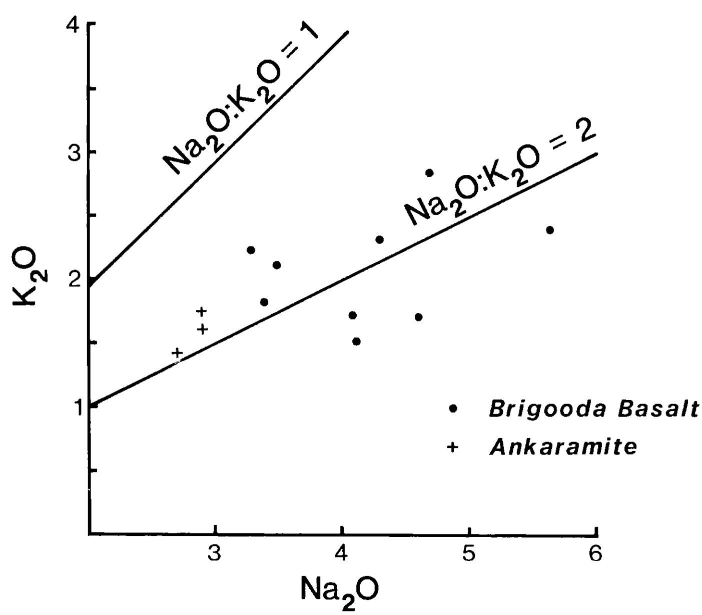


Figure 4 : Soda : Potash diagram

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	47.20	46.20	45.10	45.90	45.80	47.20	44.20	46.60	47.20	45.80	46.10	47.6	56.20	70.50	46.30
TiO_2	2.10	2.00	2.00	2.20	2.00	1.80	2.80	1.80	1.80	2.00	2.00	2.10	1.20	0.57	1.80
Al_2O_3	13.90	13.60	14.00	13.80	12.30	13.70	12.70	14.0	13.80	13.70	13.70	14.30	12.90	14.50	13.70
Fe_2O_3	8.00	7.80	9.50	7.20	4.30	3.10	4.90	4.80	2.40	3.00	2.60	8.90	5.80	1.50	5.10
FcO	3.50	4.50	4.10	5.40	6.60	8.50	7.70	6.90	8.80	8.60	8.80	2.90	1.90	0.70	7.30
MnO	0.17	-	0.23	0.21	0.18	0.18	0.17	0.21	0.15	0.15	0.18	0.14	0.11	0.12	0.21
MgO	5.40	7.90	5.20	6.60	9.10	9.10	12.20	9.20	8.80	9.60	9.50	6.00	5.40	0.80	8.30
CaO	9.20	8.80	7.50	8.60	10.70	8.60	7.60	8.40	8.70	10.00	10.10	10.30	4.90	2.20	7.80
Na_2O	4.30	3.50	4.70	4.60	3.30	4.10	3.40	3.80	4.10	2.90	2.90	2.70	2.60	3.20	5.60
K_2O	2.30	2.10	2.80	1.70	2.00	1.70	1.80	1.90	1.50	1.70	1.60	1.40	2.90	4.10	2.40
H_2O+	2.46	2.33	3.25	2.40	2.45	1.06	1.31	1.75	1.65	1.66	1.52	2.93	5.34	1.34	0.11
P_2O_5	1.30	1.10	1.40	1.20	0.95	0.63	0.70	0.79	0.57	0.77	0.68	0.69	0.60	0.15	1.20
CO_2	<0.10	0.20	<0.10	<0.10	0.10	<0.10	<0.10	0.20	0.20	0.22	<0.10	0.20	0.10	<0.10	0.10
Total	99.83	100.03	99.78	99.81	99.78	99.67	99.48	100.35	99.67	100.10	99.68	100.16	99.95	99.68	99.92
				CIPW NORMS											
Qtz	-	-	-	-	-	-	-	-	-	-	-	-	10.77	29.75	-
C	-	-	-	-	-	-	-	-	-	-	-	-	-	1.16	-
Or	13.59	12.41	16.55	10.05	11.82	10.05	10.64	11.23	8.87	10.05	9.46	8.27	17.14	24.23	14.19
Ab	22.00	20.90	17.53	21.80	13.06	19.69	14.30	19.80	22.17	16.45	16.45	22.84	22.00	29.07	14.36
An	11.84	15.20	8.84	11.99	12.85	13.96	14.08	15.54	14.83	19.35	19.64	22.77	14.97	9.93	5.16
Ne	7.79	4.72	12.04	9.28	8.05	8.13	7.84	6.69	6.78	4.38	4.38	-	-	-	17.89
Di	20.84	16.32	15.97	18.75	27.05	19.98	15.34	16.01	18.97	19.43	21.10	18.52	3.90	-	20.47
Hy	-	-	-	-	-	-	-	-	-	-	-	8.33	19.58	4.10	-
Ol	10.83	17.69	14.44	14.89	15.23	18.79	25.51	20.34	18.23	19.60	18.71	6.83	-	-	17.84
Mt	2.87	3.09	3.40	3.19	2.81	3.03	3.25	3.01	2.94	3.03	9.99	2.93	1.91	0.55	3.19
Il	3.99	3.80	3.80	4.18	3.80	3.42	5.23	3.42	3.42	3.80	3.80	3.99	2.28	1.08	3.42
Ap	2.07	2.60	3.30	2.83	2.24	1.49	1.65	1.86	1.34	1.82	1.60	1.63	1.42	0.35	2.83
CC	-	0.45	-	-	0.23	-		0.45	0.45	0.45	-	-	0.23	-	0.23

1 & 2, olivine-augite basalt; 3, anorthoclase megacryst basalt; 4 & 5, Augite megacryst basalt; 6, 8, 9, olivine basalt; 7, hornblende megacryst basalt; 10, 11 & 12, ankaramite; 13, breccia; 14, granite; 15, nepheline-bearing olivine basalt.

Table 1: Selected chemical analysis of Brigooda Basalt, breccia and granite.

similar in composition to that found in the Ballogie breccia pipe (Hollis *et al.* 1983) and other pyroxenes commonly found in mantle-derived xenoliths in eastern Australia. They are more Mg-rich than those typical of crustal granulites.

The recent work of Oba *et al.* (1982) indicates that the Ti content of kaersutite reflects the approximate pressure of crystallisation. The kaersutite

Table 2

Grid References of analysed samples given in Table 1.

Sample Number	Rock Type	Grid Reference*
1	Olivine-augite basalt	443960
2	Olivine-augite basalt	449952
3	Anorthoclase megacryst basalt	450950
4	Augite megacryst basalt	448953
5	Augite megacryst basalt	449951
6	Olivine basalt	450954
7	Hornblende megacryst basalt	452951
8	Olivine basalt	433966
9	Olivine basalt	472957
10	Ankaramite	446961
11	Ankaramite	433947
12	Ankaramite	433949
13	Breccia	450952
14	Granite	448961
15	Nephéline-bearing olivine basalt	443966

*All Grid References refer to the Boondooma 1:100 000 Sheet (9145) series R 631, edition 1.

recovered from the Brigooda Basalt in association with co-existing garnet-pyroxene compositions gave pressures ranging between 10 and 15 kb and temperatures between 1000 and 1250 °C (Sutherland, Hollis & Robertson, unpublished data).

The application of experimental temperature-pressure data to results obtained from Brigooda xenoliths and megacrysts indicate that the basalt and many of the xenoliths and megacrysts were derived in the mantle at depths shallower than 60-70 km (Sutherland, Hollis & Robertson, unpublished data). The anorthoclase, euhedral zircon and croundum, however, are more likely to be of crustal derivation (Stephenson 1976 ; Hollis 1982 ; Hollis & Sutherland 1983), although anorthoclase can crystallise experimentally at pressures up to 15 kb in the presence of CO_2 (Arculus *et al.* 1977).

The abundant fluid inclusions containing CO_2 in pyroxenes and amphiboles indicate the role CO_2 has played in the crystallisation of these minerals. It also suggests that mantle CO_2 may have been the major source of volatiles producing the breccia in the Garnet Gully area.

A build up of volatiles accompanied by a limited amount of strongly undersaturated magma, developed in the same region of the mantle after the emplacement of the Brigooda Basalt. Following along the same line of ascent as the Brigooda magma, the ascending volatile enriched magma burst through to the surface at a point of weakness possibly created by the initial emplacement of the Brigooda Basalt. Xenoliths of the older basalt stripped from the conduit and xenoliths and megacrysts drawn from the mantle form part of the breccia. The amphibole megacryst basalt is considered to be a part of the Brigooda Basalt sequence brought to the surface by the gaseous outbursts together with mantle derived pegmatoid garnetite that is the source of the gem quality garnet.

CONCLUSIONS

The Brigooda Basalt is a moderately to strongly undersaturated alkali basalt derived from the mantle and extruded at the surface in the early Miocene. Gaseous outbursts in the late Pleistocene, caused by a build up of volatiles and a minor amount of strongly undersaturated magma in the same area of the mantle as the parent magma of the Brigooda Basalt, produced the breccia in the Garnet Gully area. Xenoliths, megacrysts and xenocrysts were emplaced in the breccia during the gaseous outbursts. The presence of CO_2 in the inclusions in pyroxene and amphibole suggests that mantle CO_2 may have played a significant part in the gas-blasts.

Experimental temperature-pressure determinations when applied to the Brigooda xenoliths and megacrysts indicate upper-mantle origins shallower than 60 - 70 km. The abundance of amphibole in the breccia also suggests a volatile-rich and hydrous mantle beneath the Brigooda region.

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