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THE TERTIARY VOLCANIC ROCKS OF FAR NORTH-WESTERN TASMANIA

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(With four text figures, four plates, and two tables.)

ABSTRACT

The Tertiary volcanic rocks of far north-west Tasmania comprise tuffs, pillow-basalts and breccias, entrail basalts, and massive basalts, and eruptions appear to have occurred at several intervals from Lower to Upper Tertiary times. Sea level fluctuations have been important in determining the form assumed by the flows. The lavas were predominantly saturated black glass olivine basalts with one extrusion of undersaturated olivine alkali basalt. The oldest of the volcanics is a widespread formation of sub-aqueously deposited tuffs. These were followed, after a period of erosion, by massive basalts, including a basal zone of entrail lava, which were probably erupted during an Upper Palaeocene-Upper Eocene marine regression. Extensive submarine eruptions followed, resulting in the formation of large cones composed predominantly of pillow breccias. These were probably formed during a marine transgression in the Upper Eocene-Upper Oligocene. A period of erosion, probably subaerial, dissected these cones, and limestones were later deposited on their eroded flanks during a major marine transgression in the Miocene. A final volcanic phase, probably during an Upper Miocene-Pliocene marine regression, saw widespread eruptions of massive basalts, some of which filled valleys eroded in the older volcanics and sediments. The magmatic history of the eruptions in this area appears to be significantly different from that of the Cainozoic volcanics of Victoria.

INTRODUCTION

The dating of the Tertiary volcanic rocks of Tasmania has long been a problem. Banks (1962b) has recognised that basalt eruptions occurred both before and after the deposition of the Middle Tertiary limestones of North-West Tasmania, but the lack of dated Tertiary sediments beneath the older basalts or above the younger basalts has so far precluded more accurate age determinations. Such sediments have not been found by the authors in this area, but both submarine and subaerial Tertiary volcanic rocks occur and it is possible to establish the succession within these rocks and to relate them to the Miocene limestones. The recent stratigraphic work of Bowler (1963), Taylor (1965), and particularly that of Bock and Glenie (1965), has demonstrated and dated several major Tertiary sea level fluctuations in the Bass Strait area. These appear to correlate with the changes from subaerial to submarine volcanism recorded here, but confirmation of the absolute ages of the rocks must await either direct palaeontological or radiometric dating.

Previous Work

Previous descriptions of the geology of parts of the area have been given by Johnston (1888), Ward (1911), Nye and Blake (1938), Edwards (1941a, b, 1950), Nye (1941), Thomas (1945), Gill and Banks (1956), Banks (1957, 1962a, b), Hughes (1957), Gulline (1959), Longman and Matthews (1962), and Quilty (1965, and in press), but this paper represents the first comprehensive study of the Tertiary volcanic rocks.

Location and Access

The area considered comprises a strip, approximately 5 miles wide, of the western coast of far north-western Tasmania, extending south from Woolnorth Point to Greens Creek, about 10 miles south of Temma, and including Trefoil Island. The Trefoil Island-Woolnorth area (Fig. 1, Fig. 2) was mapped during October, 1965, access to the island being gained by light plane from Smithton. On Woolnorth Estate, a vehicular track allows access between Cape Grim and Woolnorth Homestead, from which a private road connects with the Montagu road. The Marrawah-Redpa area (Fig. 3) was visited later in the same month, and also by one of us (K.D.C.) during November, 1966. Marrawah is easily accessible via the Bass Highway. The Temma area (Fig. 4) was visited by one of us (F.L.S.) during September and November, 1964. Access to this area is by vehicular track, usually passable only with four-wheel drive vehicles, with a ferry crossing at the Arthur River.

Physiography

Edwards (1941a) describes the major physiographic features of the Woolnorth and Marrawah areas and recognizes two major divisions, viz., an extensive, low-level coastal plain merging inland

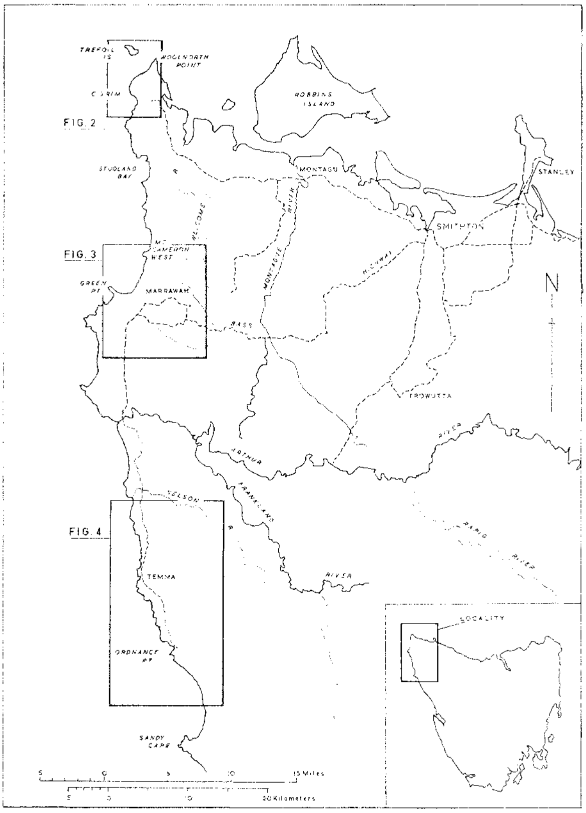

FIG. 1.—Locality map.

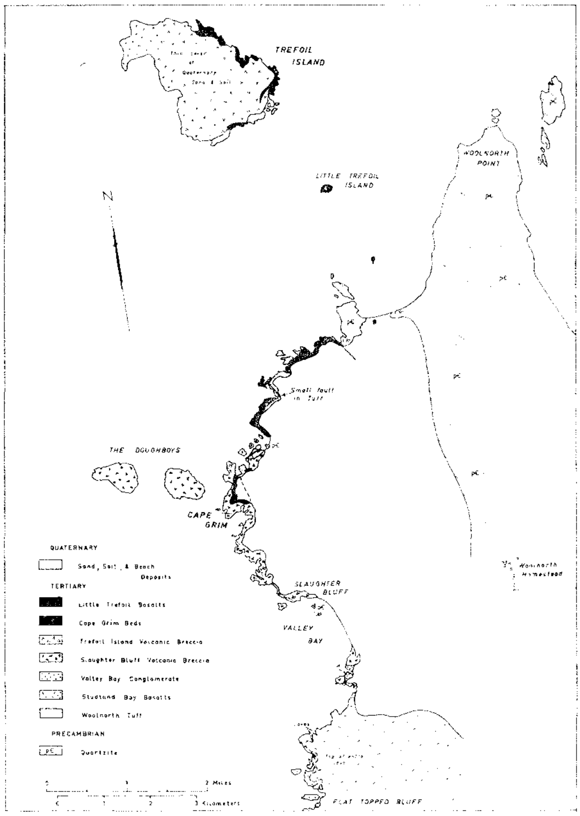

FIG. 2.—Geology of the Trefoil Island-Cape Grim area.

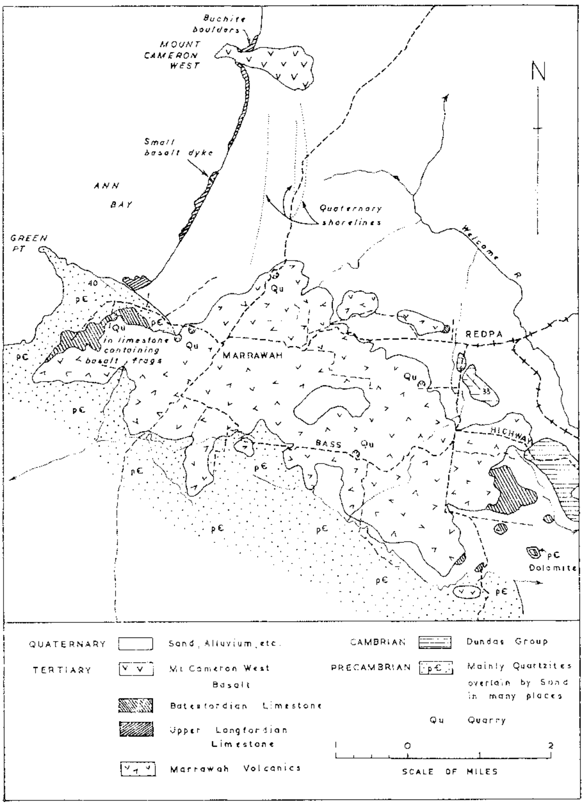

FIG. 3.—Geology of the Marrawah-Redpa area (modified from Gulline, 1959).

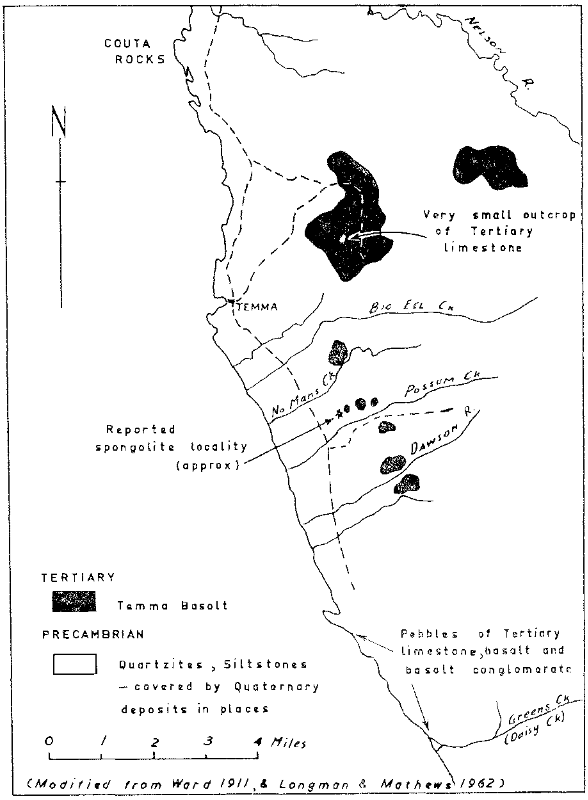

FIG. 4.—Distribution of Tertiary rocks in the Temma area.

into a series of large swamps and covered by Quaternary sand dunes in many coastal areas, and a line of coastal hills (" resumed islands "), including a strip from Woolnorth Point to Studland Bay and the high areas on basaltic rocks around Marrawah. Descriptions of the Quaternary sand ridges in the Marrawah area are also given by Gill and Banks (1956). In the Woolnorth area, outcrops of Tertiary rocks are generally restricted to a narrow coastal strip exposed by wave action, the inland areas being covered by Quaternary soils, sands, gravels and beach deposits.

The physiographic features south of the Marrawah area are dealt with by Ward (1911) and Longman and Matthews (1962). Prominent dunes fringe large stretches of the coast and in places ridges extend inland for about 2 miles. The dunes are associated with a low-lying, and in parts swampy, coastal plain cut in Precambrian mudstones with higher areas of quartzites. The coastal plain is cut in an older erosional surface (The Henty Surface ?) which rises gently inland from about 200 feet above sea-level, and includes the isolated remnants of Tertiary basalt.

STRATIGRAPHY

Basement rocks in the area consist predominantly of Precambrian quartzites. Precambrian dolomite and Cambrian Dundas Group rocks occur south and east of Redpa (Nye, 1941; Gulline, 1959) but these have not been examined. The Tertiary rocks comprise tuffs, pillow breccias, basalts and limestones, and these are described in some detail. Quaternary deposits occur as a superficial cover over many areas. Rock specimens are housed in the collection of the Tasmanian Museum, Hobart, with duplicates of most specimens in the Queen Victoria Museum, Launceston. Specimens of minerals collected from the basalts are housed in the Queen Victoria Museum.

Precambrian Rocks

" Younger " Precambrian rocks form the basement beneath most of the area under consideration. Longman and Matthews (1962) have described these rocks in the Temma-Arthur River area, and Gulline (1959) mentions that Precambrian quartzites occur in the Marrawah and Woolnorth areas, although on general appearance he considered these rocks might be older than the Carbine Group rocks further east (Carey and Scott, 1952).

Bedded and massive quartzites outcrop fairly continuously from Woolnorth Point south to Woolnorth Homestead (Fig. 2), and small isolated outcrops occur at sea level in Valley Bay and just north of Cape Grim. The rocks are folded into broad gentle folds with axes trending north to north-north-east, and dips are low to moderate. The quartzites are pale grey to white, commonly saccharoidal in texture, and cross-bedding and ripple marks are fairly common. Similar quartzites, with some interbedded coarse conglomerates, outcrop on Green Point, near Marrawah (Fig. 3). Here the rocks trend north-west and dip south-west at 30°-60°. Cross-bedding is again abundant, and a large proportion of the bedding surfaces show ripple marks. The ripples vary greatly in form and orientation. Large, four-sided mudcracks (?) also occur.

The age of these quartzites is unknown, but the presence of well-preserved sedimentary structures, the lack of strong deformation, and the presence of dolomite just to the east, suggests correlation with the " Younger " Precambrian Bryant Hill Quartzite (Longman and Matthews, 1962; Gulline, 1959; Carey and Scott, 1952) of the Smithton and Temma areas.

Tertiary Rocks

The probable Tertiary succession is given in Table 1. This table incorporates the major marine transgressions and regressions postulated by Bock and Glenie (1965) from stratigraphic evidence in South-Western Victoria. It is considered that these fluctuations probably also affected north-western Tasmania, and the stratigraphic evidence available seems to support this.

Woolnorth Tuff

The Woolnorth Tuff is that formation of generally flatly bedded vitric tuffs, at least 30 feet thick, outcropping intermittently in shoreline cliffs and platforms between Cape Grim and Woolnorth Point (Fig. 2). It is the oldest formation, apart from the Precambrian, exposed in this area. Similar rocks south of Valley Bay and on Trefoil Island are correlated with this formation. The base of the tuff is nowhere exposed, but would appear to be an unconformity on folded Precambrian quartzites in the type area. The top of the formation is an erosional disconformity, overlain by the Studland Bay Basalts south of Valley Bay, by the Slaughter Bluff Volcanic Breccia in the Cape Grim area, by the Little Trefoil Basalts north of Cape Grim, and by the Trefoil Island Volcanic Breccia and the Little Trefoil Basalts on Trefoil Island. The tuff is considered to be of lower Tertiary age.

The old erosion surface developed on the tuff, as exposed beneath the overlying rocks in a number of places, is in the form of steep cliffs, up to 30 feet or so high, fronted by flat platforms or benches. Some of these platforms are at almost the same level as the present shore platforms. Thus, beneath the Studland Bay Basalt, south of Valley Bay, the old platforms are exposed in places through windows in the basalt on the present shore platforms, while the basalt abuts against and covers old cliffs exposed through vertical erosion windows and in sea caves cut in the present shoreline cliffs (Plate I, Fig. 3). A similar topography exists beneath the Slaughter Bluff Volcanic Breccia and the Little Trefoil Basalts north of Cape Grim. In one place the basalt fills a small undercut cave at the foot of an old cliff, and there are small patches of basalt higher up on the face of the cliff.

The form of the erosion surface is somewhat similar to the present shoreline topography of platforms and cliffs, and the possibility that it represents a former shoreline, at about present sea level, has been considered. However, it is probable that similar features would be developed under most erosional conditions because of the combination of flat bedding, steep joints and faults, and joints parallel to bedding.

Cape Grim area

The best exposures of the Woolnorth Tuff occur

TABLE 1

Proposed Tertiary Succession. Marine phases based on Bock and Glenie, 1965 (*T = Transgression, R = Regression*); *Faunal Units are those of Carter,* 1958.

Marine Phase	Age	Stage (Victorian)	Faunal Unit	Stratigraphic Unit
R	PLIOCENE	KALIMNAN		? { Temma Basalt (?) Little Trefoil Basalts (?) Mt. Cameron West Basalt (?)
— — ? — —		MITCHELLIAN CHELTENHAMIAN		
		BAIRNSDALIAN	11	
T		BALCOMBIAN	10	
		BATESFORDIAN	9	} Marine Limestones
	MIOCENE		8	
T		LONGFORDIAN	7	
			6	
		JANJUKIAN	5	
═R═			4	? } Marrawah Volcanics (?) Trefoil Island Volcanics Breccia (?) Slaughter Bluff Volcanic Breccia (?) Valley Bay Conglomerate (?)
	OLIGOCENE		3	
T	— — — — —	ALDINGAN	2	
			1	
	EOCENE			Studland Bay Basalts (?)
R	— — — — —			Woolnorth Tuff (?)
	PALAEOCENE			
T				

in shoreline cliffs about three-quarters of a mile north of Cape Grim. Here the tuffs are flatly bedded, with an easterly dip of about 4°, except where they are folded adjacent to a small fault (Plate I, Fig. 1). The folding occurs only on the eastern side of the fault and dies out away from it, suggesting that the structures are related, and the nature of the folds suggest deformation while the sediments were more or less unconsolidated. The tuffs show honeycomb weathering, and are fine-grained and well sorted except for rare small quartzite pebbles. The general colour is dull yellowish-brown, while thin bands of slightly finer grained and lighter coloured tuff, 3 to 6 inches apart, produce a prominent banding (Plate I, Fig. 2).

A distinctive feature of the tuffs in this area is the very well developed climbing-ripple lamination (Plate I, Fig. 2). This structure is formed by the downcurrent migration of small ripples under conditions of continuous addition of sediment. The rate and direction of ripple migration in this area indicates a gentle current from approximately south-east. Hills (1965, p. 13) illustrates similar ripple bedding from Pleistocene tuffs in Victoria.

Several small, vertical faults, trending 150° T, affect the tuffs. Displacements are of the order of a few feet or less, although the displacement on the fault associated with the folding is not known. Two sets of vertical joints are also prominent, one parallel to the faults and one at 040° T, and jointing parallel to bedding also occurs.

Near Cape Grim itself the tuffs are exposed on shore platforms, in places covered by a thin veneer of Slaughter Bluff Volcanic Breccia (Plate III, Fig. 5, 6). The tuffs here show slight variations in dip, probably resulting from deposition in small troughs in the basement.

Thin sections of the tuff (T.S. 112, 160*) from

* Numbers refer to the thin section catalogue in the Tasmanian Museum, Hobart.

the type locality show the rock to consist predominantly of glass shards (Plate IV, Fig 1) up to 0.6 mm long but mostly in the range of 0.05-0.2 mm (very fine sand). These constitute about 60-70% of the rock. Each shard has a thin fringe, 0.007-0.01 mm thick, of a birefringent mineral, probably lussatite (a mixture of fibrous chalcedony and opal). The interstices are filled with chalcedony. Rare fragments of olivine and very rare quartz fragments are also present, and these also have lussatite (?) fringes. Many of the shards are pale amber coloured and show very slight birefringence, and these may be palagonite. The fringe of birefringent lussatite (?) gives them a bright outline under crossed nichols (Plate IV, Fig. 1). Vesicles within the glass fragments are also lined with this mineral. That the lussatite (?) was introduced after deposition is evidenced by its presence on the quartz and olivine grains and the thinning or absence of the fringes where grains are in contact.

Valley Bay area

South of Valley Bay there are rare outcrops of tuffs exposed through erosion windows in the Studland Bay Basalts on shore platforms and cliffs. The best exposure is a cliff face between two prominent shoreline caves (Plate I, Fig. 3). Here the tuffs are overlain by "entrail" basalt near the top of the cliff, and the columnar basalt on the shore platform also rests on tuff. The upper contact is very irregular, and a layer of weathered material beneath the "entrail" lava may represent an old soil horizon. The bedding in the tuffs varies from horizontal to almost vertical, and in places is strongly contorted. Cross-bedding is again present, and a number of irregular, sub-vertical clastic dykes, up to 8 inches or so wide and containing angular blocks of tuff, cut through the beds.

A thin section of the tuff from here (113) shows it to consist predominantly of glass shards, up to 0.5 mm long, completely altered to brown palagonite, and cemented by chalcedony.

Trefoil Island

The oldest rocks on Trefoil Island are a series of flatly bedded tuffs exposed on shore platforms and cliffs along the south-eastern coast. The tuffs weather to green and are olive-grey when fresh. They are generally coarser grained than the tuffs in the Woolnorth area, and contain some bands resembling fine agglomerate. Bedding is fairly prominent as an alternation of finer and coarser layers up to 15 inches or so thick. Rare fragments of Precambrian quartzite up to 8 inches long occur in the tuffs, and the coarser layers contain fragments of weathered volcanic material up to several inches across.

The section here is at least 20 feet thick, and the base is not exposed. The tuff is overlain by the Little Trefoil Basalts and by the Trefoil Island Volcanic Breccia. The contact with the latter is not exposed, but appears to be an erosional disconformity since the breccia occurs down to sea level only a short distance from where the tuffs extend to at least 20 feet above sea level. The tuffs are cut by two sets of steep joints, the major one at 145°-165° T, and another at 090°-100° T.

A thin section of the tuff (114) shows it to be more altered than in the Woolnorth area and to be strongly zeolitized. Most of the original glass has been altered to cryptocrystalline quartz, brownish palagonite or clay, although the vesicular nature is still prominent. Many of the fragments and vesicles are fringed with lussatite (?). The large voids and vesicles, particularly in the coarser layers, are mostly lined with a fibrous zeolite, possibly phillipsite, and apophyllite may also be present filling some of the interstices. There are rare fragments of quartz up to 0.25 mm across.

Origin of the tuff

The prominent horizontal bedding, and the presence of cross-bedding and climbing-ripple lamination in the Woolnorth area, indicate that the tuffs were deposited subaqueously. The ripple lamination indicates rapid deposition in an area swept by a gentle current from the south-east. Whether deposition occurred in lakes, lagoons or a shallow sea is not known, but the widespread occurrence of horizontal bedding, the uniformity of the current direction, and the fact that the area was close to the coastline through much of the Tertiary, possibly suggest a submarine environment. The coarser nature of the tuff on Trefoil Island suggests that this area was closer to the source, although there may have been several sources.

Age

The Woolnorth Tuff is older than the Upper Longfordian Cape Grim Beds. It is also older than the Slaughter Bluff Volcanic Breccia, which is considered to be of Upper Eocene-Upper Oligocene age. The erosion surface developed on the tuff was most probably formed subaerially after consolidation, indicating at least a partial marine regression prior to the extrusion of the overlying rocks. This regression possibly corresponds to the Middle Paleocene-Middle Eocene regression recorded from Victoria (Table 1). Thus the tuff is probably not younger than Middle Eocene. The oldest rocks overlying the tuff are the Studland Bay Basalts, which are subaerial and probably extruded during this same regression after dissection of the tuff.

The lower limit for the age of the tuff is not known. The tuff overlies Precambrian quartzite, but is considered to be Lower Tertiary, or possibly Cretaceous, because of the horizontal bedding, the lack of strong induration, the volcanic origin, and the presence of simple jointing similar to that in Lower and Middle Tertiary rocks at Wynyard, the Tamar Valley and other areas.

Studland Bay Basalts

The Studland Bay Basalts are those massive and "entrail" basalts, at least 250 feet thick, exposed along the shoreline between Studland Bay and Valley Bay, and forming Flat Topped Bluff (Fig. 2). The basalts overlie the Woolnorth Tuff and are considered to be older, at least in part, than the Slaughter Bluff Volcanic Breccia. Only their northern extent has been mapped in detail.

The lowermost 50 feet or so of this basalt exhibits a very characteristic form not previously recorded from the Tertiary basalts of Tasmania. The zone can be traced south from Valley Bay for at least a mile, and is overlain by "normal" massive basalt. Several flows may be represented within the zone

TABLE 2

Analyses of basalts from Slaughter Bluff Volcanic Breccia (S.B.V.B.) at Cape Grim and Little Trefoil Basalt (L.T.B.) ½ mile N. of Cape Grim, and chabazite from the Marrawah Volcanics (Chab., M.V.) in quarry 2 miles S.W. of Redpa. Determinations by X-Ray Spectrography (D. I. Groves, Analyst). Na_2O (Chab.) by flame photometry (G. Sanders).

	S.B.V.B.	L.T.B.	(Chab.) M.V.
SiO_2	53.01	49.77	50.29
Al_2O_3	14.46	13.10	21.46
Fe_2O_3/FeO	12.78	13.61	0.36
MgO	6.04	8.82	0.74
CaO	6.87	6.00	4.32
Na_2O	2.70	2.39	4.99
K_2O	1.40	1.36	1.12
MnO	0.19	0.10	0.00
TiO_2	2.25	2.09	0.00
P_2O_5	0.28	0.29	0.02
Ig. Loss	0.76	0.49	15.47
TOTAL	100.74	98.02	98.77

but contacts between flows are not obvious. The basalt consists of a series of overlapping, twisted, more or less tubular bodies, 1 to 4 feet in diameter and up to 8-10 feet long, which commonly show "necking" at their ends. The structures resemble pillows but are elongated and do not show the flattening typical of pillows. The bodies are usually circular but may be oval in cross-section, and generally show a preferential alignment of their long axes (Plate I, Fig. 3, Fig. 5). They show tachylitic margins and radial jointing, and usually have a central vesicle which is commonly mineral-filled. External surfaces are generally rough and cracked, but some show ropy flow structure. Individuals may be moulded against one another to some degree but generally the tubes are not much deformed. This type of basalt grades both laterally and vertically into sections or lenses of massive basalt showing well developed columnar jointing (Plate I, Fig. 4). The proportion of massive basalt within the zone appears to increase to the south.

While the resemblance to pillow lava might suggest a subaqueous origin for this lava, the intimate association with massive basalt and the lack of brecciation indicate that the flows must have been dominantly subaerial. A number of authors have described structures similar to pillows in subaerial pahoehoe-type flows (Cotton, 1944, p. 290). Wentworth and McDonald (1953, p. 35) use the term "entrail pahoehoe", while Rittman (1962, p. 66) describes a similar type of pahoehoe lava, formed under conditions of low pressure and slow rate of flow, and calls it entrail lava. While the term lacks aesthetic appeal, the mode of formation and the structures produced appear to be analogous to those in the Studland Bay Basalts, and the term conveys an excellent impression of the form of the lava.

This lowermost zone of entrail lava overlies the erosion surface previously described in the Woolnorth Tuff, and extends below sea level to the west. An old cliff covered by the basalt has been exhumed just south of Valley Bay (Plate I, Fig. 3). Here the basalt shows vertical cooling columns at the cliff base, nearly horizontal columns against the steep face, and entrail structure over the top.

The entrail basalt is strongly scoriaceous and amygdaloidal in many places, with cavity fillings of calcite, aragonite and chalcedony. Small xenoliths of baked sediment derived from the underlying Woolnorth Tuff are present in places. The zone is overlain by massive basalt with well developed cooling columns, the contact being fairly well defined with no intervening sediments or apparent weathering. This columnar basalt forms a prominent, nearly horizontal horizon, 15 to 20 feet thick, in the cliffs for some distance to the south (Fig. 2). Above this the basalt exposures are poor to the top of Flat Topped Bluff. A lateritized surface may be present on this basalt plateau, as indicated by the extensive areas scattered with pieces of pisolitic ferricrete.

Petrology

A sample collected from the entrail basalt unfortunately was lost, so that a petrological description is not possible at this stage. However, xenolithic (?) blocks of very similar-looking basalt occur in the Slaughter Bluff Volcanic Breccia, and their petrology is described in that section.

Thin sections (115, 116) of massive basalt from the prominent columnar horizon and from near the top of the sequence showed porphyritic olivine basalts with a sub-ophitic groundmass of pyroxene and plagioclase, and a hyaloophitic to intersertal mesostasis. Phenocrystic to granular olivine forms 8-12% of the rocks as corroded subhedral to anhedral crystals up to 2 mm across. The olivine is colourless, fresh in some sections, but largely altered to antigorite in others, and is optically negative with 2V's of about 85°, indicating a composition of about Fo 80-85. The plagioclase (about 40%) is labradorite (about Ab_{45-50}), and forms laths rarely exceeding 1 mm in length. It is sub-ophitically intergrown with anhedral to subhedral augite (25-30%) up to about 0.8 mm. in length. The augite shows pleochroism from pale yellowish to pale violet and is probably titaniferous.

The mesostasis (20-30%) is an opaque black glass with network cracks, grading into areas of brownish-grey glass containing numerous skeletal microlites of pyroxene and feldspar. Iron ore (5%) has largely crystallized as slender rods up to 0.8 mm long and small anhedral grains, mostly restricted to the mesostasis. Small irregular amygdales filled with carbonate are present in some sections. The basalts appear to be saturated "black glass" types (Spry, 1962), with cooling textures related to the Pontville Type (McDougall, 1959).

Origin

The presence of massive basalt within the zone of entrail lava, and the lack of brecciation, indicate subaerial rather than subaqueous conditions for this zone. The very irregular surface over which this early lava flowed may have contributed to the development of the entrail structure, as suggested by Hoffman (1933). However, the possibility of contact with shallow water in places cannot be excluded. The distribution of the basalt types about the pre-existing cliff (Plate I, Fig. 3) also suggests that the entrail lava was not subaqueous since, if so, it would be expected to occur at the base of the cliff rather than over the top. This distribution also shows that the lava flow lapped against the cliff and built up until the cliff was overtopped, suggesting a source somewhere to the west. This is also indicated by the general orientation of the entrail structures.

There are two possibilities for the origin of the massive basalts which overlie the entrail zone. The clean, level contact between the two suggests the flows were related eruptions, the massive form being the result of flow over the smooth surface formed by the top of the entrail flow. Alternatively, the massive flows may be much younger in age and possibly erupted from a different source.

Age

The Studland Bay Basalts are younger than the erosion surface cut in the Woolnorth Tuff. Boulders of basalt identical to the entrail lava are a dominant constituent of the Valley Bay Conglomerate just to the north (Fig. 2), which is overlain by typical Slaughter Bluff Volcanic Breccia, indicating that both these rocks are younger than the entrail zone at least. The presence of xenolithic (?) blocks of similar basalt in the Slaughter Bluff Volcanic Breccia also indicates this. The extrusion of the entrail lava was most probably subaerial and this, together with the fact that it extends below present sea level, suggests possible correlation with the Middle Palaeocene-Middle Eocene marine regression of Bock and Glenie (1965).

As previously mentioned, the overlying massive flows could represent much younger extrusions, possibly of similar age to the Little Trefoil Basalts (Pliocene ?).

Valley Bay Conglomerate

The Valley Bay Conglomerate is that formation of basaltic boulder conglomerate and sandstone outcropping on the shoreline near the southern end of Valley Bay. The conglomerate appears to lie within the Slaughter Bluff Volcanic Breccia, and is probably transgressive across the contact between the breccia and the Studland Bay Basalts. It is 15-20 feet thick.

Bedding within the formation dips 8° northeast (Plate 2, Fig. 2). The contact with the underlying breccia is poorly defined, the base consisting of a boulder bed which resembles the breccia except for the presence of lenses of sand. This is overlain by several feet of friable sandstone which lenses out up-dip and contains a number of prominent calcite veins parallel to bedding. Following this is a series of interbedded boulder and pebble paraconglomerates and conglomeratic sandstones (Plate II, Fig. 2). Bedding planes are poorly defined and there are considerable lateral variations in lithology. The top of the formation is overlain by a thin flow of pillowy lava (Plate II, Fig. 1) followed by typical Slaughter Bluff Volcanic Breccia.

The conglomerates contain sub-angular to well rounded boulders up to 6 feet across, most being less than 1 foot, in an abundant sandy matrix of weathered volcanic material. The boulders and pebbles are predominantly of basalt, but some consist of volcanic breccia similar to the underlying breccia. The basalt boulders are predominantly of the vesicular amygdaloidal type typical of the entrail zone of the Studland Bay Basalts, which occurs just to the south.

A thin section (117) of a basalt boulder showed a petrology closely similar to that of a xenolithic (?) block of amygdaloidal basalt, also probably derived from the Studland Bay Basalts, in the Slaughter Bluff Volcanic Breccia (q.v.). Some of the boulders are more weathered than others and are reddish in colour, indicating a certain amount of weathering before deposition.

The rocks are affected by two sets of joints, the main one at 150°T, and a second set at 025°T. The joints break through pebbles and boulders in places.

A thin section (118) of a sample from one of the sandy layers shows the rock to consist of altered brownish fragments, fragments of "black glass" basalt, isolated feldspar laths, quartz fragments and small patches of fibrous zeolite, bonded mainly by authigenic fibrous chalcedony-opal (lussatite ?). There is very little clay except in the cores of some of the weathered fragments. The brownish fragments are commonly vesicular and are composed of a mixture of cryptocrystalline quartz, palagonite, chalcedony, opal and clay, and probably represent altered glassy material. The basalt fragments are sub-angular to rounded and up to 2 mm long, and vary from slightly altered to strongly decomposed.

Origin

The presence in the conglomerate of very large boulders of local rock types indicates very little transport for these. The lack of cross-bedding or cut-and-fill structures, the very poor sorting, and the local derivation suggest the formation is not of fluvial origin, while the poor sorting and the angularity of many of the boulders are not suggestive of a beach deposit. The combination of large basalt boulders and abundant basaltic sand could be formed near the base of marine cliffs, with large fragments of basalt, already partly rounded by chemical weathering, being shed and covered with sand derived from the adjacent weathered basalt terrain.

Age

The Valley Bay Conglomerate is "interbedded" with the Slaughter Bluff Volcanic Breccia near the base of the latter. It probably represents the deposits associated with a shoreline during the early stages of the marine transgression during which the breccia was formed. This transgression possibly correlates with the Upper Eocene-Upper Oligocene transgression indicated by the work of Bock and Glenie (1965).

Slaughter Bluff Volcanic Breccia

The Slaughter Bluff Volcanic Breccia is that succession of bedded basaltic pillow breccias and associated small lava flows outcropping in shoreline cliffs and platforms in the Valley Bay-Slaughter Bluff-Cape Grim area. The breccia disconformably overlies the Woolnorth Tuff, is "interbedded" with the Valley Bay Conglomerate near its southern limit, and is disconformably overlain by the Upper Longfordian Cape Grim Beds. Its maximum thickness cannot be estimated from available outcrops, but must be considerably in excess of 300 feet and is possibly several thousand feet.

General Description

The breccia is a crudely bedded, darkish, very rough textured rock consisting dominantly of angular basaltic fragments in a finer grained matrix, but also contains numerous isolated pillow-like bodies and some small flows of pillowy lava. It outcrops as bold coastal cliffs up to several hundred feet high, and also constitutes the two small islands off Cape Grim known as the Doughboys. An old erosion surface cut in the Woolnorth Tuff is preserved under the breccia north of Cape Grim (Plate III, Figs. 5, 6). Elsewhere the breccia extends below sea level, although small fragments of tuff are present within the breccia at the base of Cape Grim. At its southernmost exposure it is "interbedded" with the Valley Bay Conglomerate (q.v.), and at Cape Grim it is overlain disconformably by the Cape Grim Beds (Plate II, Fig. 4).

Large-scale bedding is prominent in nearly all cliff outcrops of the breccia (Plate II, Figs 3, 4) but is generally not distinguishable across the shore platforms. The beds dip generally north-easterly and dips range from 15° to 45°, 30° being the most common. As the bedding in the underlying Woolnorth Tuff remains essentially horizontal, the dips in the breccia probably represent the original depositional slopes. Bedding thicknesses range from 4 to 30 feet, most units being 10 to 20 feet thick. Large-scale "cross-bedding" is visible on the south-eastern side of Cape Grim (Plate II, Fig. 4).

The proportions of fragments and pillows vary considerably within and between beds. On the southern point of Cape Grim the lowermost unit, about 40 feet thick, is rich in pillows (Plate II, Fig. 3) and contains several small flows of pillowy lava (Plate III, Fig. 1). The upper 10 feet of this unit consists largely of basalt fragments with some isolated pillows. The next bed, about 15 feet thick, also consists mostly of angular fragments but with rare pillows and large pillow fragments. Higher still a bed was noted in which the matrix was the dominant constituent (Plate III, Fig. 2). The general colour of the breccia is dark grey, but the upper parts of some layers are distinctly lighter coloured, being almost orange-yellow (Plate II, Fig. 3). This suggests some surface alteration before deposition of the overlying unit.

In places the breccia shows continuous narrow zones of highly altered material, a foot or so wide, which appear to follow joints and are more or less parallel to bedding.

The constituents of the breccia are of four types, viz., fragments, isolated pillow-like bodies, small lava flows, and the matrix.

Fragments

These are up to several feet long, but mostly less than 1 foot, angular and randomly arranged in the matrix. Many show a chilled margin, sometimes with flow structure, on one side only (Plate II, Fig. 6), indicating that they are fragments of broken-up pillow-like bodies. Other evidence also indicates that the breccia was formed mainly by the breaking up of lava flows similar to the small flows still preserved. Most of the fragments consist of moderately vesiculated, dark coloured basalt, with a well developed tachylitic cooling margin. Some show thick double or multiple cooling crusts (Plate II, Fig. 6), giving them a banded appearance.

Associated with the normal basaltic fragments are rare fragments of very vesicular amygdaloidal basalt, up to 8 feet long, with carbonate cavity fillings (Plate III, Fig. 2). These blocks contrast markedly with the surrounding fragments and are more common in some layers than others. They do not show the well developed cooling crusts typical of the other fragments, and no recognizable pillows of this type of basalt were seen, suggesting they may have a slightly different origin.

Isolated pillow-like bodies

These are oval to circular in cross-section and mostly show radial jointing. A large central vesicle is usually present, in some cases filled with minerals. The pillows are up to 6 feet or so long, most being 2 to 5 feet in length and 1 to 3 feet in diameter. Partially broken examples also occur (Plate II, Fig. 5). Some of the bodies are roughly cylindrical and resemble portions of the entrail lava previously described from the Studland Bay Basalts. The outer surfaces are rough and cracked, and some show ropy flow structure. The majority of the bodies are isolated, and in some cases the break-off area can be seen (Plate II, Fig. 5). There are also examples of several bodies interconnected by narrow waists.

Minerals collected from the central vesicles include calcite, aragonite, chalcedony, zeolite (phillipsite ?), apophyllite, and hydrated calcium silicates.

Small lava flows

The greatest concentration of these appears to be in the lowermost layers exposed around the foreshore of Cape Grim, and a good example occurs overlying the Valley Bay Conglomerate (Plate II, Fig. 1). The flows are up to 40 feet wide and 10 feet thick. They have a very characteristic appearance, consisting of a series of interconnected and in places anastomosing tubules, tongues, pillows and entrail-like structures which wrap around and lie in contact with one another but which are, for the most part, separated by their individual cooling crusts (Plate 3, Fig. 1). Some of the flows are quite similar to parts of the entrail lava previously described in the Studland Bay Basalts.

Matrix

The matrix of the breccia consists of small, angular, tachylitic fragments, less than one inch across, with abundant calcite and aragonite distributed as blebs, veins and radiating masses. It strongly resembles the palagonitic matrix of the Trefoil Island Volcanic Breccia (Plate I, Fig. 6; Plate IV, Fig. 2) and likewise weathers readily.

Petrology

Thin sections of the normal basalt forming blocks and pillows showed little petrological variation. Sections 119, 120, 121 and 122 contain olivine and pyroxene phenocrysts and microphenocrysts, plagioclase laths and pyroxene grains, set in a groundmass of black glass with a hyaloophitic texture. The olivine and pyroxene phenocrysts tend to be glomeroporphyritic and in some cases the pyroxenes group around a nucleus of olivine crystals. The olivine forms 8-12% of the rock as crystals ranging up to 3 mm across, some with euhedral outlines and some showing corrosion. It is chrysolite with 2V's close to 90° and negative optical sign, rarely encloses small pyroxene grains, and is commonly partly or completely altered to serpentine, mainly antigorite. The pyroxene phenocrysts form less than 5% of the rock and range up to 1.8 mm across. The pyroxene is a pale grey augite, and the larger phenocrysts generally consist of several "welded" plates about 0.4 to 1.0 mm across. Some of the smaller phenocrystic pyroxene and olivine is subophitically intergrown with plagioclase laths.

The plagioclase is a labradorite of composition about Ab_{40}-Ab_{36}. It shows zoning, combined albite, Carlsbad and pericline twinning, and ranges from microlites to phenocrystic laths up to 1.5 mm in length with a tendency to flow alignment. A few of the crystals show corroded cores. In some sections small feldspars are crowded into rare segregations or veinlets 0.5 mm wide. Pyroxene granules (15-20%), usually less than 0.3 mm across, are scattered in the groundmass, tending to form clustered groups and rarely small segregations. The mesostasis of the rock is an opaque black glass forming 30-40% of the rock. It is altered to a greenish serpentinitic clay (?) in places, and contains small amygdales filled with clay and chalcedony. One section (120) showed a corroded quartz xenolith, 1 mm long, outgrown with prisms of clino-pyroxene up to 0.1 mm long. The basalts are saturated black glass types related to the Bridgewater type (Edwards, 1950; McDougall, 1959) but differing in the presence of pyroxene phenocrysts.

Thin sections (123, 124) of basalt samples from the breccia underlying the Valley Bay Conglomerate, although similar to those just described from the breccia above the conglomerate, show some differences. The olivine is generally less altered, no pyroxene phenocrysts were observed, and a little carbonate is present in the groundmass. Corroded quartzite xenoliths with reaction rims of prismatic clino-pyroxene are present. One partially fused feldspar (?) xenolith was observed (section 124) showing development of sillimanite or mullite (?) as felted fibrous masses wrapped around the unfused remnants in a colourless glass. Small isolated needles of the sillimanite (?) were also present within the feldspar remnants.

A thin section (125) of a sample of the amygdaloidal basalt forming xenolithic (?) blocks in the breccia at Cape Grim showed a somewhat weathered basalt containing phenocrysts of olivine, up to 2 mm across, completely altered to serpentine and carbonate. There are no pyroxene phenocrysts. The feldspar is plagioclase, about Ab_{40}, and forms numerous laths and anhedral plates ranging up to 0.8 mm long. The pyroxene occurs as pale coloured augite grains rarely greater than 0.2 mm across, and tends to be intergranular but is also subophitically intergrown with, and poikilitically enclosed by, the feldspar. The rock is a saturated black glass basalt with a texture resembling the Jordan type of McDougall (1959).

A chemical analysis of a basalt sample from Cape Grim (section 120) is given in Table 2. It resembles previously reported analyses of Tasmanian Tertiary black glass basalts (Edwards, 1950; Spry, 1962) but is slightly higher in silica and slightly lower in lime and magnesia.

Origin

The dips measured in the breccia range from 15° to 45° and vary from northerly to easterly. Similar dips appear to be present on the Doughboys. The dips show little sign of closure along the 2 miles of coastal outcrop, suggesting that the breccia originated from eruptions along a north-west trending fissure offshore from the present coast. The large-scale "cross-bedding" at Cape Grim may have originated by transfer of the point of origin of the material to a different position along the fissure.

The breccia, with its pillow-like bodies and pillow fragments in a glassy fragmental matrix, strongly resembles the hyaloclastite pillow breccias formed by subaqueous volcanic activity (Rittman, 1962; Honnorez, 1963; Silvestri, 1963; Sturiale, 1963; Solomon, 1964; and others). The prominent bedding and the uniform dips, the complete lack of any massive basalts within the breccias, the very thick chilled margins on many of the pillows and fragments, and the lack of pyroclastic bombs, also point to a subaqueous origin, while the thickness and wide areal extent of the breccias indicate the eruptions were submarine rather than beneath a freshwater lake.

The alternative theory of origin, that of subarial eruptions, is diffcult to justify. Although various authors have considered it possible for pillow-type basalts to form under subaerial conditions (Lewis, 1914; Hoffman, 1933; Stark, 1938), it is generally conceded that pillow breccias must be subaqueous because of the rapid chilling involved (Rittman, 1962; &c.). Hoffman (1933, p. 194) attributes "cross-bedded" pillow breccias in the Columbia River basalts to the breaking up of subaerial pillow lavas, due to flow over an uneven surface, and deposition of the breccia over the end of the flow, producing layers resembling delta foresets. While this mechanism may be possible, the phenomenon has not been observed in nature, and it is extremely doubtful if it could account for the thicknesses observed in the Slaughter Bluff Volcanic Breccia.

The origin postulated by the authors is of a series of submarine eruptions along a northwest fissure with its northern end located not far west of the Doughboys. The earliest lava flows must have been quickly chilled and immobilized, possibly blocking the vent with an initial hyaloclastite breccia (Silvestri, 1963). Further flows would be extruded through this crust to form pillow lava and breccia on contact with seawater, and a linear cone would be built up with steepening slopes. The stable slope angle would eventually become the angle of repose of the breccia material in seawater. The increase in slope would substantially contribute to the brecciation of the lava because of the gravitational effect. Thus each of the beds or layers of breccia possibly represents a broken-up lava flow deposited on part of the slope of the cone.

In thick flows it seems possible that patches of the pillow lava within the flow or near its base could be carried down the slope within the breccia mass and come to rest before being brecciated. This would explain the isolated flow remnants observed within the breccia in several places. Alteration and "weathering" by seawater between eruptions probably accounts for the lighter colour of the upper surfaces of many of the beds, while the altered zones along joints roughly parallel to bedding may represent slip surfaces of small submarine landslides.

The blocks of scoriaceous amygdaloidal basalt within the breccia do not show the thick chilled margins or the pillow forms of the normal basalt, and are probably xenolithic. The only similar basalt observed is the entrail lava of the Studland Bay Basalts, and the blocks possibly represent fragments of this basalt torn off from the vent and deposited with the breccia.

Age

The Slaughter Bluff Volcanic Breccia is overlain disconformably by the Upper Longfordian Cape Grim Beds. Evidence will be presented (see Cape Grim Beds) that this disconformity probably represents a period of subaerial erosion between the time of formation of the breccia and the marine transgression during which the Cape Grim Beds were deposited. This period possibly correlates with the marine regression recorded by Bock and Glenie (1965) in the Upper Oligocene of south-western Victoria (Table 1). Thus the breccia was probably formed during an earlier marine transgression, possibly the Upper Eocene-Upper Oligocene one of Bock and Glenie. The fact that the breccia rests on an erosion surface cut in the Woolnorth Tuff, which is considered to be Lower Tertiary, supports this. Volcanic activity is recorded in both the lower and upper parts of the Oligocene in the Bass Strait succession (Esso Exploration Australia, Inc., 1966). This includes an Upper Oligocene "tuffite" cone which may be approximately contemporaneous with the Slaughter Bluff Volcanic Breccia cone in age.

Trefoil Island Volcanic Breccia

The Trefoil Island Volcanic Breccia is that basaltic pillow breccia, at least 200 feet thick, which constitutes most of Trefoil Island and is best exposed in cliffs and short platforms around the island. It disconformably overlies the Woolnorth Tuff and is overlain by the Little Trefoil Basalts. Over much of the island the breccia is covered with Quaternary sands and soils.

The contact with the Woolnorth Tuff is not exposed but would appear to be an erosional disconformity. Around much of the eastern half of the island the breccia is overlain by the massive Little Trefoil Basalt. The contact between the two is very irregular, indicating considerable erosion prior to the eruptions of the younger basalt.

The breccia is generally similar to the Slaughter Bluff Volcanic Breccia but has less prominent bedding, fewer isolated pillows and pillowy flows, and lacks the xenolithic (?) blocks of amygdaloidal basalt. Bedding is generally difficult to distinguish, but on the south side of the island rough layering dips about 25°-30° west. These are probably original dips, since the bedding in the underlying Woolnorth Tuff is horizontal. Rare thin lava flows occur within the breccia in places, some showing pillow structure. For the most part the breccia consists of about 40% basaltic blocks in a fragmentary matrix. The blocks range from a few inches to a few feet across and show tachylitic margins. Isolated pillow-like bodies also occur. These have oval to round cross-sections, some being flattened on one side, and show radial jointing and commonly a large central vesicle filled with calcite and aragonite (Plate I, Fig. 6). The matrix of the breccia consists of angular, randomly assorted, tachylitic fragments, ranging up to an inch in size, set in an abundant lime carbonate cement with seams of gypsum (Plate IV, Fig. 2).

Petrology

A thin section (126) of a block showed a porphyritic basalt, with a hyaloophitic groundmass, containing olivine phenocrysts and feldspar laths set in a black glass forming almost half the rock. The olivine (10-15%) is chrysolite, with 2V's close to 90°, and occurs as grains and phenocrysts ranging up to 2.5 mm across, many with euhedral to subhedral outlines. The phenocrysts tend to be glomeroporphyritic, partly or mostly altered to antigorite and generally corroded, with some enclosed patches of glassy groundmass. The feldspar (about 40%) is labradorite, of composition about Ab_{35}, and forms laths, rhombs and microlites up to 0.9 mm long. The black glass of the groundmass is altered in places to greenish-brown nontronite (?), and contains rare vesicles filled with chalcedony. The rock is a saturated black glass olivine basalt with a cooling texture related to the Ouse and Bridgewater types (Edwards, 1950, McDougall, 1959).

A section (127) of the breccia matrix shows that many of the fragments have concave margins (Plate IV, Fig. 2). The tachylite consists of pale yellow glass, probably palagonite, containing crystals of olivine and laths, rhombs and microlites of feldspar. Some of the crystals are truncated at the margins of the fragments. The olivine varies from minute grains up to phenocrysts over 2 mm across that tend to be glomeroporphyritic. The proportion of olivine differs between fragments, being almost absent from many of the smaller fragments and making up about 15% of the largest fragments. Some of the olivines are euhedral, others are strongly corroded, and some contain inclusions of dark glass in contrast with the pale glass of the groundmass. The olivine is chrysolite, with 2V's close to 90° and negative optical sign, and is generally unaltered. The feldspar is labradorite, and forms about 30% of the tachylite fragments, in laths rarely exceeding 0.5 mm in length.

Many of the tachylite fragments contain infilled vesicles up to 3 mm across. Most of these are fringed with layers of greenish opal and lussatite (?) and filled with opal, chalcedony, aragonite, calcite, analcime and nontronite (?), either separately or in combination. The tachylite glass shows darker, brownish areas, particularly around vesicles and on the outer margins of fragments.

A cement of granular calcite, enclosing nests of gypsum plates ringed with clusters of radiating aragonite, separates the tachylite fragments by widths of up to 2 mm. The tachylite of the matrix appears to represent a palagonitised and more quickly chilled phase of the hyaloophitic basalt forming the blocks and pillows in the breccia.

Origin and age

The distinct similarity to the hyaloclastite pillow breccias described in the literature, and to the Slaughter Bluff Volcanic Breccia, suggests a similar origin, from submarine eruptions, for the Trefoil Island Volcanic Breccia. The westerly dip suggests the source was somewhere east of the island.

The age of the breccia is difficult to establish. It is younger than the Woolnorth Tuff (Middle Palaeocene-Middle Eocene ?) and older than the Little Trefoil Basalts (Pliocene ?), and possibly corresponds approximately in age with the Slaughter Bluff Volcanic Breccia (Upper Eocene-Upper Oligocene?). Volcanic activity forming "tuffite" cones is recorded in the Bass Strait succession in the Upper Oligocene and Lower Miocene (Esso Exploration Australia, Inc., 1966) and is possibly related to that forming the Trefoil Island Volcanic Breccia.

Marrawah Volcanics

The Marrawah Volcanics are those basaltic breccias, pillow breccias, and associated lava flows outcropping in the Marrawah-Redpa area. Their distribution is shown in Fig. 3. The volcanics overlie "Younger" Precambrian rocks and are disconformably overlain by Miocene limestones. The thickness of the volcanics is unknown, but is at least several hundred feet.

A 15-foot section of the volcanics is exposed in a quarry about one mile north of Marrawah along the old sand road to Montagu (Fig. 3). Here the rock consists of basalt fragments in a weathered matrix, with no obvious layering or grading. The fragments vary in size but are generally less than 2 feet across, and form about 65% of the rock. They show tachylitic margins up to several inches thick, passing inwards to a coarser grained, generally more decomposed centre. Most of the fragments are angular. In marked contrast with the majority of the fragments are rare blocks of scoriaceous and amygdaloidal basalt. The largest of these is 7 feet long and 5 feet high, showing chilled margins and a large crack, also with chilled edges, extending from the base towards the centre.

A large quarry on the Marrawah Beach road exposes a section of the volcanics 200 feet wide and 80 feet high. The rock here shows crude layering dipping 10°-15° south-west (Plate III, Fig. 3). The rock is dominantly pillow breccia, consisting of 10-20% of blocks and pillow-like bodies, up to 2 feet across, in a finer grained fragmentary matrix. Some of the layers contain up to 75% blocks and pillows. Parts of the breccia are rich in elongate pillows up to at least 8 feet in length, with subcircular to flattened, lens-shaped cross-sections. These show chilled tachylitic margins and many have a central vesicle filled with lime carbonate minerals. Some of the blocks show chilled margins on one side only, indicating that they were derived from broken-up pillows. The matrix of the breccia consists of angular tachylitic palagonitised (?) fragments, up to 1-2 inches across, mixed with abundant calcium carbonate, and is somewhat weathered.

The freshest exposure is in a quarry on the north side of the Bass Highway about 2 miles south-west of Redpa (Fig. 3). The breccia here is similar to that just described but contains some fragments of scoriaceous amygdaloidal basalt. Thin massive basalts are interbedded with the breccias, and both dip 25°-30° west (Plate III, Fig. 4). The massive basalts are up to 4 feet thick, have ropy flow structure on some of the margins, and are closely and irregularly jointed. Patches of pillow lava up to 50 feet wide are also present, and appear to occupy channels in the breccia. This may have been caused by displacement of the unconsolidated breccia material by the more dense pillow lava flowing down the slope.

A feature of the breccia in the above quarry is the presence of abundant white minerals as cavity linings and fillings and as an inter-fragmental cement. These contrast markedly with the dark tachylitic basalt fragments, some of which contain large vesicles up to a foot across in which large, well-formed crystals have grown. Minerals identified by X-ray powder patterns and other means include apophyllite, chabazite, natrolite, tacharanite and its breakdown products tobermorite and gyrolite, calcite, opal, and nontronite. The chabazite has a different habit to that normally found in the Tasmanian Tertiary basalts, occurring as crystals of hexagonal aspect similar to that figured by Dana (1957, Fig. 979) for gmelinite. A chemical analysis (Table 2) shows that it is a soda-rich chabazite, containing over four times the amount of soda in the normal Tasmanian chabazites (authors' unpublished analyses). It is interesting to note that soda-rich hexagonal chabazite crystals (herschelite) are also described from palagonitic basalt in Catania, Sicily (Deer, Howie, and Zussman, 1963, p. 395).

Pillow breccias are also exposed in a quarry near Redpa (Fig. 3). The rock here is strongly weathered and was not examined in detail. Other examples of massive basalts within the Marrawah Volcanics were observed in road cuts about one mile east of Marrawah along the Marrawah-Redpa road, and in a small quarry in a paddock about one-quarter of a mile south-west of the large quarry on the Marrawah Beach road. Close and irregular jointing appears to be characteristic of these massive basalts.

Petrology

Most of the basalts sampled from the Marrawah Volcanics, both from the breccias and the massive flows (thin sections 129, 130) are olivine basalts with a dark, glassy, hyaloophitic-textured groundmass, related to the Ouse and Bridgewater Types of Edwards (1950) and McDougall (1959). Chrysolitic olivine (10-15%) forms corroded, glomerophorphyritic, euhedral to anhedral crystals up to 2 mm across, with some alteration to antigorite. The plagioclase (30-40%) has a composition of about Ab_{45}, and ranges from microlites up to phenocrystic laths 1.5 mm long. Augite occurs as granular to prismatic microlites in the mesostasis, and as small grains, rarely exceeding 0.3 mm in length, in places forming small segregations. The mesostasis (30-50%) varies from a hylaoophitic to almost intersertal black glass base, and includes numerous microlites of iron ore which, in places, show parallel orientation. Greenish chalcedony usually occurs scattered through the rock filling small vesicles.

These rocks generally resemble the basalts in the similar Trefoil Island and Slaughter Bluff Volcanic Breccias, but appear to lack the phenocrystic pyroxene found in the latter. Some variations in rock types are present in the Marrawah Volcanics which were not observed in the other breccias, and these are described below.

A thin section (132) of the massive basalt from the quarry 2 miles south-west of Redpa is notable for the flow alignment of the feldspars. These wrap around glomeroporphyritic phenocrysts of chrysolitic olivine (8%) up to 2 mm. across. The feldspar (45%) is plagioclase, about Ab_{65}, and the laths range up to 1 mm. Small olivine grains are subophitically intergrown with the feldspar laths, and purplish, pleochroic, titaniferous augite (20%) forms intergranular grains, slender prisms and microlites up to about 0.5 mm long. The mesostasis is an intersertal greyish glass containing granules and rods of iron ore and anhedral plates of feldspar subophitically intergrown with, or poikilitically enclosing, the pyroxene and iron ore. Greenish chalcedony fills small vesicles. The rock is related in texture to the Jordon Type of McDougall (1959).

A section (128) of a basalt sample from the breccia quarry on the sand road to Montagu shows an olivine basalt with phenocrysts of olivine and feldspar set in an extremely fine-grained crystalline groundmass which supersedes the usual glassy mesostasis. Chrysolitic olivine (15%) is glomeroporphyritic and forms euhedral and anhedral grains up to 1.2 mm across, some showing corrosion and most being partly altered to antigorite. The feldspar phenocrysts (30%) form laths up to 1.2 mm long and have a composition of about Ab_{65}. The groundmass consists of numerous minute needles and grains of colourless augite, feldspar and iron ore, rarely exceeding 0.2 mm and mostly less than 0.1 mm. Some of the feldspar phenocrysts, particularly the smaller and presumably later ones, have their edges intergrown with the groundmass constituents. Small clearer areas, poikilitically including groundmass grains, are filled with pale yellow-green chalcedony (?).

The massive basalt from the quarry one-quarter of a mile south-west of the quarry on the Marrawah Beach Road, in thin section (131) proved to be an olivine limburgite. There are numerous small, glomeroporphyritic phenocrysts of olivine (about 15%) averaging about 0.2 mm across, but ranging up to 0.5 mm. Outlines are euhedral to anhedral, some showing corrosion, and the olivine is mostly unaltered. Pyroxene (30%), probably augite, occurs as pale greenish prisms and microlites mostly less than 0.1 mm long and in places clustered into small segregations. These constituents, with small grains of iron ore (5%), are set in a reddish-brown glassy base that forms from one-third to almost one-half of the rock. Small rounded amygdales up to 0.4 mm across are scattered through the groundmass and are filled with yellowish chalcedony, in some cases with a carbonate core.

Origin

The presence of pillows and pillow fragments within the breccias, and the similarity to the Trefoil Island and Slaughter Bluff Volcanic Breccias, strongly suggest a submarine origin for the Marrawah Volcanics. The few dips observable are westerly, suggesting a source somewhere east of Marrawah, possibly located on a major north-westerly fault line mapped to the south by Longman and Matthews (1962). The extension of this fault would pass somewhere between Marrawah and Redpa.

Age

The Marrawah Volcanics are overlain disconformably by Batesfordian limestone, as is discussed under Miocene Marine Sediments, indicating a period of strong erosion, probably subaerial, prior to the marine transgression during which the limestone was deposited. The relationship is analogous to that between the Slaughter Bluff Volcanic Breccia and the Cape Grim Beds. The lower limit to the age of the volcanics is not known but it is suggested that they probably correspond approximately in age with the Slaughter Bluff Volcanic Breccia (Upper Eocene-Upper Oligocene ?) because of the similar environment of formation and the similar relationship to the limestone.

Miocene Marine Sediments

Miocene marine sediments occur in a number of places around North-West Tasmania (Banks, 1962a) and provide the only presently available means of directly dating the associated volcanic rocks. Upper Longfordian sediments occur up to about 150 feet above sea level at Cape Grim and near sea level around Mt. Cameron West and at Green Point near Marrawah. Batesfordian sediments occur between about 130 feet and 300 feet above sea level in the Marrawah-Redpa area and near Temma (?). The contact between the Longfordian and Batesfordian sediments is not exposed, but it seems likely that continuous deposition is represented. Brief descriptions of these rocks will be given only to show their relationship to the volcanic rocks.

Cape Grim Beds

The Cape Grim Beds are those breccias, conglomerates and fossiliferous calcarenites outcropping in cliffs on the northern and eastern sides of Cape Grim (Fig. 2). The beds disconformably overlie the Slaughter Bluff Volcanic Breccia and are overlain by a small outcrop of massive basalt correlated with the Little Trefoil Basalts. The succession is approximately 150 feet thick and is considered by Quilty (1965, and in press) to be Upper Longfordian in age (Faunal Units 7, 8 of Carter, 1958) on the basis of the foraminifera

The sediments occupy a north-trending channel cut in the Slaughter Bluff Volcanic Breccia, probably near the eastern perimeter of the original volcanic cone. The channel is approximately 300 feet wide and 150 feet deep, and its base slopes northwards from about 100 feet above sea level on the east side of Cape Grim (Plate II, Fig. 4) to below sea level just north of Cape Grim. That this slope is not the result of later tilting is indicated by the fact that the bedding in the Woolnorth Tuff, which underlies the breccia is horizontal or dips very slightly east.

The base of the sediments is difficult to define, consisting of coarse talus-type material grading downwards into typical volcanic breccia and upwards into conglomerate containing sub-angular to rounded basalt boulders. On the western side of the channel these basal beds conform roughly to the steep dip slope of the underlying volcanic breccia, but show downward thickening towards the base of the channel. The bedding in the overlying limestones is sub-parallel to the sides of the channel as viewed in transverse section (Plate II, Fig. 4), but the dips become flatter upwards as seen in longitudinal section, north of Cape Grim. This also suggests that the beds were deposited in a sloping channel.

The mode of origin of this channel, whether by submarine or subaerial erosion, is of some importance in determining the age of the Slaughter Bluff Volcanic Breccia. The fact that the channel is sloping suggests that submarine or tidal currents were not responsible. Also, the presence of conglomerate at the base of the Cape Grim Beds indicates either current or wave action, suggesting that the volcanic cone was either partly or completely emergent at some time prior to the marine transgression during which the limestones were deposited.

Thus there is some evidence for a marine regression between the time of formation of the Slaughter Bluff Volcanic Breccia and the major marine transgression in which the Upper Longfordian Cape Grim Beds were deposited. Such a regression can possibly be correlated with the Upper Oligocene-Lower Miocene regression indicated elsewhere in Bass Strait (Bock and Glenie, 1965, Esso Exploration Australia Inc., 1966).

Mt. Cameron West-Marrawah-Redpa area

Flatly bedded limestones are exposed in the intertidal zone along much of the shoreline of Ann Bay and also just north of Mt. Cameron West (Fig. 3). At Mt. Cameron West the beds are at least 30 feet thick and are overlain disconformably by the Mt. Cameron West Basalt (Gill and Banks, 1956). Quilty (in press) assigns these beds an Upper Longfordian age (Faunal Units 7, 8 of Carter, 1958) on the basis of the foraminifera, and correlates them with the Cape Grim Beds. The beds extend below sea level and were apparently deposited on a deeply dissected surface, since Precambrian basement rocks occur up to about 150 feet above sea level just inland from Ann Bay.

Scattered outcrops of limestone occur up to at least 300 feet above sea level around the low hills east of Green Point and also in the Redpa area (Fig. 3; Nye, 1941; Gill and Banks, 1956; Gulline, 1959). The beds are at least 150 feet thick, and Quilty (in press) assigns them a Batesfordian age (Faunal Unit 9 of Carter, 1958). It is noticeable that the outcrops fringe the mound of Marrawah Volcanics, and in the Green Point area the hills behind the limestone outcrops are capped with the volcanics. South of Redpa the limestones rest on steeply dipping Precambrian dolomite, and the base is about 130 feet above sea level (Nye, 1941). However, in the other areas the base of the limestones is not exposed, and their relationship to the Marrawah Volcanics is difficult to determine.

There are continuous outcrops of volcanics down the Marrawah Beach road from about 300 feet above sea level to below the level of the adjacent Precambrian basement, indicating that the limestones do not form a laterally continuous unit. Thus *either* the limestones are older and were deeply eroded prior to the eruption of the volcanics, *or* they are younger and were deposited in separated valleys cut through the volcanics. The limestone in a small quarry in this area contains many angular to sub-rounded fragments of weathered basalt, up to 8 inches or so long, some of which show tachylitic margins and large vesicles. Thin sections (133, 134, 135) of some of the fragments showed them to have textures identical to those shown by the Marrawah Volcanics.

Thus there is strong evidence that the Marrawah Volcanics are older than the Miocene limestones and were subject to considerable erosion prior to the deposition of the limestones. The distribution of the limestone outcrops suggests the sediments were deposited in deep valleys cut in the flanks of the mound of volcanics, as seems to be the case at Cape Grim.

Temma area

A small outcrop of Tertiary limestone occurs near Temma (Ward, 1911; Longman and Matthews, 1962). The limestone is about 250 feet above sea level and is less than 20 feet thick. It rests unconformably on "Younger" Precambrian rocks and is overlain by the Temma Basalt (Fig. 4). Banks (1957, 1962a) suggests the fossils from this limestone possibly indicate a Balcombian age, but no detailed examination of the fauna has been made, and the limestone may be equivalent to the Batesfordian limestone at Marrawah.

The majority of aboriginal stone implements found in the Temma area are composed of spongolite. This spongolite is of marine origin and probably of Tertiary age (P. G. Quilty, pers. comm.). Boulders of similar rock, probably derived from the Miocene limestone, have been observed between Possum Creek and No Mans Creek just west of the basalt outcrops (Prof. W. Jackson, University of Tasmania, pers. comm.). An outcrop of similar rock was observed near sea level a little north of Mt. Cameron West (Mr. E. Abblitt, pers. comm.) and was probably the source of the aboriginal spongolite implements found in that area.

Pebbles of Tertiary limestone occur along the beach between Ordnance Point and Greens Creek, south of Temma (Ward, 1911), suggesting that limestone outcrops occur below sea level in this area.

Mt. Cameron West Basalt

The Mt. Cameron West Basalt is that massive basalt, at least 500 feet thick, composing Mt. Cameron West and disconformably overlying Upper Longfordian limestone near sea level. The basalt has been described by Edwards (1940a, b), Thomas (1945), and Gill and Banks (1956). It extends below sea level to the west and appears to represent a single flow. The basalt shows well developed columnar jointing and has pipe amygdales near its contact with the limestone in some places. It shows flow structure where its base steps down over a small ledge cut in the limestone beneath its southern flank, indicating flow down the valley from the east.

Petrology

The petrology of this basalt is markedly different from that of the other basalts examined, and it was classified as an analcite-olivine dolerite by Edwards (1940b).

Chilled basalt from within 5 feet of the contact, in thin sections (136, 137) showed olivine phenocrysts set in a fine grained groundmass of feldspar, pyroxene and iron ore. The olivine crystals range up to 2 mm across, are mostly strongly corroded, and have a composition of about Fo_{80-65} as suggested by the negative optical signs and 2V's of 80°-85°. The crystals are usually altered along margins and cracks with dense dustings of fine secondary magnetite, and in places show more extensive alteration to chlorite. Many of the olivines contain small inclusions of anhedral pyroxene and squarish grains of iron ore similar to those in the matrix, indicating that crystallization of these constituents commenced during olivine growth. Feldspar forms 50-60% of the rock as numerous laths and intersertal plates. Pyroxene occurs as small intergranular grains and prisms less than 0.1 mm long, with rare larger grains. It is a faintly coloured augite, weakly pleochroic from pale green to pink, and in places forms small segregations. Iron ore is disseminated through the groundmass as irregular to squarish grains averaging less than 0.05 mm. A little colourless glass is present, and contains slender needles and prisms of apatite. It is slightly analcitized in places, and includes patches of indeterminate greenish chloritized (?) and carbonatized matrix. A few amygdales are present, with fillings of carbonate, analcite, and other zeolites.

About 100 feet above the base, in thin section 138, the basalt is a much coarser rock. Olivine is abundant, forming 15-20% of the rock as grains and phenocrysts up to 3 mm across, with a tendency to be glomeroporphyritic. It shows 2 V's close to 90° and is altered to serpentine along crystal edges and cracks. Pyroxene has crystallised as large plates, up to 3 mm in size, ophitically intergrown with the feldspar and olivine and poikilitically enclosing smaller crystals of these minerals. The pyroxene is a titan-augite, showing conspicuous pleochroism and zoning, generally with paler coloured cores. The pleochroic scheme is X = straw yellow, Y, Z = violet. The feldspar forms laths and anhedral plates up to about 1.5 mm long. The laths have a composition of about Ab_{35} and show Carlsbad, albite and pericline twinning. Iron ore is present as irregular to skeletal crystals up to 1 mm long, in places intergrown with and moulding feldspars. Apatite is present as coarse prisms up to 1 mm long and as slender needles in the mesostasis. Analcite, greenish chloritized (?) and carbonatized material, and a little radiating zeolite, form the mesostasis.

Basalt samples from various heights above 150 feet to the top of Mt. Cameron West in thin sections (139, 140, 141, 157) are generally similar to that just described but differ in the nature of the pyroxene. In the higher samples this mineral occurs as much smaller prismatic crystals, rarely greater than 0.5 mm long, and is intergranular rather than forming large, ophitically intergrown plates. The body colour is paler, being mainly yellowish-brown, with any marked pleochroism being confined to the crystal edges. The prisms may form rare but conspicuous radiated segregations. Small biotite flakes are generally present, mostly formed around the iron ore, and the olivines show partial alteration to serpentine (?). Thus the Mt. Cameron West basalt represents an undersaturated alkali basalt magma, related to the teschenites and basanites.

A small xenolith within the basalt was observed in thin section 138 (Plate 4, Fig. 3). The xenolith is a strongly corroded fragment 3 mm x 2 mm, mantled along most of its margin by a zone up to 0.9 mm wide composed of a very fine grained mosaic of plagioclase (?) with some granular iron ore. In one place this mosaic shows a tendency to a sheaf-like alignment normal to a concave surface of the fragment, with a row of thin plates of iron ore followed by a dusting of fine magnetite near the contact. The fragment has a dense rim of small grains of iron ore and greenish cubic and octahedral spinels up to 0.05 mm in size. The fragment consists of anhedral plagioclase (probably labradorite) as laths and plates, 0.3 to 0.5 mm long, poikilitically enclosing numerous prisms of colourless orthopyroxene (?) up to 0.1 mm long, prisms of sillimanite or mullite (?), and small greenish spinels. There are also patches of cloudy glassy material containing crystallites. Part of the xenolith shows strong development of the sillimanite (?) as elongate prisms up to 0.4 mm long growing inward from the margin amidst a finer felted mass of the mineral. The xenolith appears to represent a thermally metamarphosed basaltic (?) inclusion, and the outer zone possibly represents a fusion rim of feldspathic glass, now devitrified.

Origin and age

The Mt. Cameron West Basalt is probably a single flow which filled a deep valley cut in the underlying sediments and extended below present sea level. The only indication of flow direction suggests flow from the east. The valley was presumably cut during a period of lowered sea level and represents a considerable period of erosion, while the massive nature of the basalt and the lack of pillow structure, brecciation, &c., indicate that the flow was erupted subaerially. The most likely times at which such conditions were present, considering the fact that marine transgression affected the area during Longfordian and Batesfordian times, and from the evidence of sea level fluctuations in other Bass Strait areas (Jennings, 1957; Gill, 1962; Bowler, 1963; Bock and Glenie, 1965), were during the Upper Miocene-Pliocene and during the Pleistocene. Considerable erosion of the confining valley walls is indicated by the present prominent exposure of the basalt ridge, suggesting that a Pliocene age is more probable.

Basalt dyke

An isolated basalt dyke, 1 foot wide and 10 feet long, was observed in the Upper Longfordian sediments at about low tide level on the beach of Ann Bay, about 2 miles north of the Marrawah camping ground (Fig. 3). A thin section (142) from this dyke texturally resembles a slightly coarser variety of the chilled contact at Mt. Cameron West, and the pyroxene is a strongly pleochroic titan-augite. The phenocrystic olivine has been completely altered to carbonate, but contains small inclusions of pyroxene and iron ore, as in the Mt. Cameron West Basalt. Numerous small oval vesicles are present, generally lined with botryoidally layered carbonate and limonite (?) and filled with calcite and/or analcite and other zeolites.

Buchites

Just north of Mt. Cameron West several boulders of conglomeratic rock were found amongst the basalt pebbles on the shore. The rock consists of white quartzite fragments, up to several inches across, set in a speckled bluish-grey matrix. Some of the quartzite fragments have indefinite borders while others have sharp borders with a thin dense marginal zone. Thin sections (143, 144) showed an unusual rock consisting of strongly corroded and fused quartzite fragments set in a glassy groundmass containing numerous elongate crystals of sanidine and pyroxene (Plate IV, Fig. 4). Most of the quartzite fragments show strongly corroded quartz grains in an almost colourless to brownish glass that may form up to 70% of the fragment. The quartz grains are fringed with needles of tridymite (?) which have grown both inwards and outwards from the margins, and the intervening glass is laced with numerous long, thin crystals of tridymite and/or sillimanite or mullite up to 0.5 mm long but mostly much less. The borders of the fused quartzite fragments are generally darker and grade into the glassy matrix.

This matrix is composed of two types of glass. One is pale coloured to almost colourless, with some cloudy patches due to granulation with minute globules of iron ore (?). The other is brownish and forms globular to elongated patches, up to 2 mm across, within the first type. The edges of these patches are irregular and generally dark with concentrations of granular iron ore, and the glass shows a tendency to devitrify and become anisotropic. The lighter coloured glass is the more abundant, although in parts the two are present in approximately equal proportions.

Numerous elongate crystals of sanidine and pyroxene have grown in the glassy groundmass. The sanidine (25-30% of the groundmass) occurs as skeletal crystals, with euhedral to subhedral outlines, forming laths, with squarish to rectangular cross-sections, up to 2 mm but mostly less than 1 mm in length. In a few places radiating and sheaf-like groups of the crystals have formed, possibly representing growth around a nucleus. The sanidine shows Carlsbad twinning and tends to be associated with the brownish glass, which fills the hollow interiors of the crystals. Rare squarish tablets of feldspar, up to 0.5 mm across, with strongly vermiculated cores and thin sanidine outgrowths, are also present. The pyroxene (10-15% of the groundmass) occurs as colourless, euhedral to subhedral prisms up to about 1 mm long. It is mostly orthopyroxene, probably enstatite, but some clinopyroxene, probably diopside, also occurs. The pyroxene is mostly associated with the lighter coloured glass. There is a colourless fringe around many of the crystals due to the absence of iron ore globules, the iron presumably having been incorporated into the pyroxene.

Other minerals are developed to a lesser extent in the groundmass. One area, 5 mm x 2 mm, lacks the usual crystals and shows considerable development of sillimanite or mullite (?), associated with squarish prisms and hexagonal plates of cordierite less than 0.1 mm long, thin rods of iron ore, and small globules of yellowish green opal. Cordierite also occurs within small blotches of brownish glass around the margins of the more impure quartzite fragments. Rare patches composed almost entirely of small, stumpy plagioclase laths, probably labradorite, also occur, as well as isolated corroded quartz crystals and small quartzite fragments.

The mineralogy of this rock suggests it is a buchite formed by strong thermal metamorphism of a conglomerate containing numerous quartzite or sandstone pebbles and some argillite fragments. Some of the quartz grains show undulose extinction typical of the Precambrian quartzites, suggesting the quartzite fragments were derived from local Precambrian quartzites like those at Green Point. Buchites have been previously described in Tasmania from the Apsley area, where Triassic sandstones have been baked adjacent to a Tertiary basalt neck (Spry and Solomon, 1964). The fused textures developed in the sandstone at Apsley in many respects resemble those in the quartzite fragments just described, although many of the latter lack the development of cordierite, possibly due to the absence of a clay cement.

The sanidine-pyroxene glassy groundmass of the rock presumably represents the metamorphosed matrix of the conglomerate, but its original composition is difficult to determine precisely. The presence of patches of one glass within another suggests either development of two immiscible liquids on fusion (Spry and Solomon, 1964, p. 528), or areas undergoing devitrification within a glass. The boulders have either washed up from around a basalt neck near the shores of Mt. Cameron West, or were derived from inclusions weathered out of the basalt flow.

Little Trefoil Basalts

The Little Trefoil Basalts include those massive basalts, at least 50 feet thick, exposed between Woolnorth Point and Cape Grim, around the eastern shore of Trefoil Island, and on Little Trefoil Island. The basalts disconformably overlie the Woolnorth Tuff, Slaughter Bluff Volcanic Breccia, Trefoil Island Volcanic Breccia, and the Cape Grim Beds.

The southernmost exposure is at Cape Grim, where a small outcrop of massive basalt, showing spheroidal weathering, overlies the Cape Grim Beds about 150-200 feet above sea level. Just north of Cape Grim massive basalt outcrops on the foreshore as vertical to sub-vertical dyke-like bodies (Plate III, Figs. 5, 6). These trend easterly to north-easterly and cut the Woolnorth Tuff and Slaughter Bluff Volcanic Breccia. They are up to 10 feet wide and 30 feet high, and form curved, bifurcating bodies in plan. They strongly resemble dykes but could possibly be interpreted as fillings of erosional channels in the sub-basalt surface. Ropy flow structure was observed on the inner surface of the large dyke shown in Plate III, Fig. 6.

A flow of massive basalt outcrops almost continuously along the shore from just north of the dyke-like bodies to the south-west part of Woolnorth Point (Fig. 2). The thickness exposed is mostly less than 15 feet. The basalt extends below present sea level, although the Woolnorth Tuff is exposed through erosion windows in the floor of the flow in places, and sub-basalt cliffs in the tuff are also exposed. Much of the basalt shows well developed cooling columns, the majority being vertical and 1-2 feet across, with some up to 5 feet across. Where the edge of the basalt cuts across a small fault in the Woolnorth Tuff, three-quarters of a mile north of Cape Grim, there is no displacement of the basalt. The main basalt outcrop ends abruptly to the north with a straight north-westerly trending contact with the Precambrian. This contact corresponds to a fault downthrowing the Woolnorth Tuff against the Precambrian, which apparently formed a small scarp against which the basalt lapped. Basalt shingles form beach ridges on the eastern side of Woolnorth Point (Edwards, 1941a). The basalt is a saturated black glass type (Edwards, 1950) and the shingles were most probably derived from the Little Trefoil Basalts.

Massive basalt, with well developed cooling columns, is conspicuous along the eastern shore of Trefoil Island, where it overlies old platforms cut in the Woolnorth Tuff and the Trefoil Island Volcanic Breccia, and abuts against old cliffs in the breccia with a very irregular contact. The basalt is at least 50 feet thick and extends below sea level.

Petrology

Thin sections of samples from all the occurrences of massive basalt described above show saturated black glass olivine-basalt types of Spry (1962), with some variations in texture.

A sample from the outcrop above the Cape Grim Beds in thin section (145) is a somewhat weathered basalt but otherwise closely resembles the basalts of the Slaughter Bluff Volcanic Breccia. Like them it contains a little phenocrystic pyroxene that may form ring-like clusters around olivine phenocrysts. However, the glassy groundmass is crystallized to a greater extent, and the rock texturally approaches the Jordan Type of McDougall (1959).

Basalt from the dykes and the flow north of Cape Grim (thin sections 146, 147, 148, 149) is similar, but the groundmass is almost completely crystallized. Olivine forms about 8-12% of the rock in typical grains and corroded phenocrysts, up to 2.2 mm across, altered along cracks and margins to dark brownish nontronite (?). Plagioclase (40-45%) occurs as laths and anhedral plates mostly less than 1 mm long, and is labradorite with composition Ab_{40-35}. The groundmass pyroxene is a colourless to faintly pinkish very weakly pleochroic augite occurring in grains and prisms rarely longer than 0.5 mm. The pyroxene tends to be intergranular to subophitic toward the feldspar laths, and in cases is poikilitically enclosed by the intersertal feldspar. Iron ore (5-10%) has crystallized with a tendency to form elongated laths up to 1 mm long. Small irregular to rounded amygdales in the groundmass are filled with carbonate, nontronite (?) or opal.

The basalt from the dykes differs from that of the flow in having 3-5% phenocrystic pyroxene similar to that in the outcrop above the Cape Grim Beds. The phenocrysts which are up to 2.5 mm across, consist of a number of pyroxene plates welded together, and are pale fawn augite, generally riddled with inclusions of olivine, iron ore, glass, and other materials. In places the pyroxenes are intergrown with olivine crystals. The basalts resemble the Jordan Type of McDougall (1959).

Thin sections (150, 151) of the massive basalts from the eastern part of Trefoil Island are less crystallized types than those above. They have a hyloophitic textured black glass groundmass, and are related to the Ouse and Bridgewater Types (Edwards, 1950; McDougall, 1959). No phenocrystic pyroxene was observed, and in thin section this basalt closely resembles the Slaughter Bluff Volcanic Breccia horizon below the Valley Bay Conglomerate. Section 152 differs slightly in that pyroxene has crystallized from the glassy mesostasis as sheaves of thin, elongate prisms intergrown with the feldspar.

A chemical analysis of a basalt sample (section 147) is given in Table 2, and is again typical of the saturated black glass basalts of Tasmania (Spry, 1962), being slightly poorer in silica and richer in magnesia than the sample from the Slaughter Bluff Volcanic Breccia (q.v.)

Origin

Petrologically, all the basalt types represented in the Little Trefoil Basalts can be derived from variations in cooling conditions in a single flow, but it is also possible that each occurrence represents a different eruption. The massive nature, well developed cooling columns, and the lack of pillow structure or brecciation indicate that the eruptions were subaerial. If a single flow is represented, then the difference in level between the basalt above the Cape Grim Beds and that along the shore to the north can be explained by eruptions from the vent of the old fissure volcano off the Doughboys. The lava in this case flowed down the north-east flank, over the shelf formed by the Cape Grim Beds, and on through the low area between Woolnorth Point and Trefoil Island. Alternatively, much of the lava may have been derived from the "dykes" just north of Cape Grim.

The Trefoil Island basalts appear more glassy than the others, and while this may have been due to more rapid cooling on the western margin of the same flow, it could mean that these basalts belong to a separate flow, possibly derived from the old volcanic centre east of Trefoil Island.

Age

The Little Trefoil Basalts are younger than the Upper Longfordian Cape Grim Beds, where they overlie. The eruptions were subaerial, and the basalts flowed down valleys cut below present sea level. Periods of low sea level occurred in the Upper Miocene-Pliocene and in the Pleistocene (Bowler, 1964; Bock and Glenie, 1965, Jennings, 1959). The degree of dissection of the basalt suggests the older age is the more likely.

Temma Basalt

Massive basalt, up to 100 feet thick, outcrops in the Temma area, and its distribution is shown in Fig. 4. Most of the outcrops probably represent remnants of a single flow. The basalt unconformably overlies " Younger " Precambrian rocks, and at one place overlies and bakes Miocene limestone (Ward, 1911; Hughes, 1957; Longman and Matthews, 1962; Banks, 1962a). The base of the basalt descends westwards from over 300 feet to about 220 feet above sea level. The location of the eruptive centre is not known.

A thin section (153) of a sample from the outcrop on the Balfour track just south of Possum Creek showed a porphyritic olivine black glass labradorite basalt, with a partly crystallized hyaloophitic glassy groundmass containing elongate prisms of augite. The section mineralogically and texturally closely resembles section 152 from the Little Trefoil Basalts, and shows affinity with the Bridgewater and Jordan Types (Edwards, 1950; McDougall, 1959).

The Temma Basalt is younger than the underlying Middle (?) Miocene limestone and appears to represent subaerial eruption following considerable and in places complete erosion of the limestone. This erosion probably took place during the Upper Miocene-Pliocene regression in western Bass Strait (Bock and Glenie, 1965; Bowler, 1964), and the degree of dissection of the basalt suggests a Pliocene rather than a Quaternary age. Thus the Temma Basalt is probably similar in age to the Little Trefoil and Mt. Cameron West Basalts.

Ordnance Point area

Basalt shingles occur along the beach between Ordnance Point and Greens (Daisy) Creek, apparently derived from offshore outcrops (Ward, 1911). A thin section (154) of a pebble showed it to be a black glass type similar to that described from the Temma Basalt but with a more abundant glassy mesostasis, and is related to the Bridgewater Type (Edwards, 1950; McDougall, 1959).

Fragments of basalt conglomerate were also collected from this area. The conglomerates are generally fine grained but one specimen consisted of fragments of vesicular and dense basalt, up to several inches across, in a very abundant calcite matrix. The more common conglomerate consists of fragments of tachylitic basalt, mostly less than 1 inch across, in a matrix of smaller fragments and abundant calcite. A thin section (155) showed the rock to consist of a random mixture of angular to rounded black glass basalt fragments, mostly of the Ouse Type but also of the more crystallized Bridgewater and Jordan Types (Edwards, 1950; McDougall, 1959). In many of the fragments the black glass has been completely altered to yellow palagonite, but in others it is completely fresh. The fragments are set in a matrix of recrystallized calcite forming about 30-40% of the rock. In some respects the rock resembles the palagonitised tachylitic matrix found in the Trefoil Island and Slaughter Bluff Volcanic Breccias and in the Marrawah Volcanics, but differs in that the fragments show some rounding and are not all palagonitised.

Two possible origins are suggested for this conglomerate. Firstly, it may represent redeposited detritus derived from an off-shore basalt breccia similar to the pillow breccias at Trefoil Island, Cape Grim and Marrawah. The fragments of unpalagonitised basalt would be derived from the basalt blocks or pillows, and the palagonitised fragments from the brecciated matrix. Alternatively, the detritus may have been derived from a " littoral cone " formed where the Temma Basalt flowed into the sea and was chilled, fragmented and palagonitised. Such cones are described from Hawaii by Moore and Ault (1965). More crystallized patches of lava protected from contact with sea water would form the unpalagonitised and less chilled basalt.

PROPOSED ERUPTIVE HISTORY

Volcanism commenced in far north-western Tasmania probably in the Lower Tertiary, with explosive activity in the vicinity of Trefoil Island and possibly elsewhere. Vitric olivine-basalt tuffs from the eruptions accumulated to depths of over 30 feet in shallow marine (?) waters over an area of at least several square miles, forming the Woolnorth Tuff.

An erosion surface, with cliffs and platforms, was cut in this tuff following regression of the sea, possibly during Upper Palaeocene-Upper Eocene times. Further volcanism took place, this time with extrusions of saturated phenocrystic olivine basalt from a vent west of Flat Topped Bluff. The early flow or flows consisted mainly of entrail lava, this form possibly being the result of slow, restricted flow over the irregular erosion surface of the tuff, although contact with shallow water may have occurred in places. Whether the massive basalts which form the upper part of the Studland Bay Basalts were also erupted during this period is not certain, and they may represent much later effusions.

Marine transgression began, possibly in or shortly before Oligocene time, after these eruptions. Detritus derived from erosion of the basalt accumulated below sea level at the base of cliffs in the Valley Bay area, forming the Valley Bay Conglomerate. The pillow breccia underlying this conglomerate probably represents eruptions from the centre off Flat Topped Bluff into this encroaching sea.

General marine submergence had taken place when this fissure became strongly active again, probably in the Oligocene. A succession of saturated phenocrystic olivine basalt lavas were poured out as submarine flows, accompanied by brecciation and pillow development, to form the large cone of Slaughter Bluff Volcanic Breccia. Xenoliths of the older Studland Bay Basalts were apparently incorporated into the flows, as well as fragments of the underlying Woolnorth Tuff and Precambrian quartzites. Pyroxene had begun to crystallize in the magma chamber by this stage, and was carried up as phenocrysts with the olivine. Submarine centres or fissures east of Trefoil Island and east of Marrawah also probably became active about this time, forming the Trefoil Island Volcanic Breccia and the Marrawah Volcanics. Pyroxene phenocrysts are apparently absent from these two rocks, suggesting that pyroxene had not begun to crystallize in their magmas at the time of extrusion. The Marrawah Volcanics occur further inland and at a relatively higher level than the other volcanic cones suggesting that the Marrawah volcano may have been closer to the original shoreline. This could account for the presence of massive flows within the volcanics.

The submarine eruptions appear to have been followed by complete or partial marine regression, possibly in the Upper Oligocene, exposing the volcanic cones to erosion. This was followed by widespread marine transgression in the Lower Miocene, represented in this area by the Upper Longfordian and Batesfordian limestones deposited around the partly eroded volcanic cones in the Slaughter Bluff and Marrawah areas.

Regression of this high sea appears to have commenced before the end of the Miocene, followed by erosion and deep dissection of the newly deposited sediments, the old volcanic cones and the Woolnorth Tuff. Deep valleys were carved to below present sea level, probably by Lower Pliocene time. Renewed volcanism, probably in the Pliocene, filled these valleys with lava. A flow or flows of saturated phenocrystic olivine basalt, probably extruded from the Slaughter Bluff fissure and possibly also from the centre east of Trefoil Island, filled a broad valley between Trefoil Island and Woolnorth Point, forming the Little Trefoil Basalts. Crystallization of some of the groundmass constituents had progressed in the magma, below this centre, by this time, and pyroxene phenocrysts, riddled with inclusions of these constituents, were carried up with the olivine phenocrysts. A saturated phenocrystic olivine basalt flow was also extruded in the Temma area, forming the Temma Basalt, and this possibly flowed down into the sea to form a littoral cone off Ordnance Point.

A lava entirely different to those of all the other Tertiary eruptions in the area was extruded in the vicinity of Mt. Cameron West at about this time. Here a flow of undersaturated phenocrystic olivine alkali basalt filled a valley to a depth of at least 500 feet, forming the Mt. Cameron West Basalt. Rocks around, or incorporated into, the volcanic vent, were metamorphosed and fused to form buchites.

Volcanic activity in the area probably ceased prior to the beginning of the Quaternary, since which time the volcanic rocks and associated sediments have been subject to further erosion and dissection, and in places covered with dunes and other Quaternary deposits.

DISCUSSION

The far north-west of Tasmania is a Cainozoic volcanic province characterized by extrusions dominantly of saturated phenocrystic olivine black glass basalts, with localized extrusion of undersaturated phenocrystic olivine alkali basalt. The initial extrusion, which produced the Woolnorth Tuff, was explosive, but all subsequent activity appears to have been effusive. Although the lava type remained essentially uniform, two very different forms of basalt were produced, viz., massive, columnar basalt and basaltic pillow breccia. This is considered to have depended upon whether the eruptive centre was above or below sea level at the time of eruption. The pillow breccia basalts generally show a lesser degree of crystallization than the massive basalts, as would be expected in an aqueous environment. Some of the centres appear to have produced both forms at different times, indicating a fluctuating sea level. An attempt has been made to correlate these changes from subaerial to submarine volcanism with sea level fluctuations indicated by stratigraphic work in the Bass Strait area, and the results are promising. It would be of interest to check these results by other methods, such as palaeomagnetic or radioactive dating.

Further investigation of some of the basaltic islands in Bass Strait should provide additional information on the Cainozoic volcanism in relation to sea level fluctuations. Of interest in this regard is Black Pyramid, approximately 25 miles north-west of Cape Grim. One of the authors (F.L.S.) has examined colour photographs of the island taken on one of the rare landings (Green and MacDonald, 1963). These show massive basalts with well developed cooling columns forming the lower part of the island, overlain at about 100 feet above sea level by a prominent horizon of near-horizontal strata, followed by over 100 feet of apparently non-columnar, and possibly brecciated basalt (?). A thin section (156) of a basalt sample collected by R. H. Green from the lower columnar horizon showed it to be a porphyritic saturated olivine basalt similar to sections 147, 148, and 149 of the Little Trefoil Basalts.

The pillow basalts described show similarities in form to the Cambrian pillow lavas of Tasmania (Scott, 1951, 1952; Solomon, 1964), but are markedly different petrologically, the Cambrian lavas being invariably spilitic in nature. There are few previous records of Tertiary pillow basalts in Tasmania. Banks (1962b) briefly records the pillow form of the basalt at Cape Grim (Slaughter Bluff Volcanic Breccia). Banks (1955) and Anandalwar (1957) describe a horizon of pillow lava up to 50 feet thick from Macquarie Plains, in the Derwent Valley, and attribute it to possible extrusion into a small lake. Voisey (1949) describes a 215 foot section of " block lavas " and tachylitic breccias in the Liawenee Canal and around the shores of Great Lake in the Central Plateau. He remarked on the similarity of the block lava to pillow basalts but did not directly equate them with subaqueous extrusion. The present authors have re-examined these exposures and were struck with their similarity to the pillow breccias in the far north-west. The basalt type is likewise similar (Edwards, 1950), while palaeomagnetic dating of basalts in this area indicate an Upper Cainozoic age (Green and Irving, 1958). The authors consider this rock represents extrusion of basalt into a former, and presumably freshwater, lake, possibly formed by damming of the drainage by the initial eruptions. Judging from the distribution of the rock, as mapped by Voisey (1949), the lake was at least half the size of the present Great Lake.

Comparison can also be made of the abundant zeolites and associated amygdale minerals found in the " block " basalt at Great Lake (Sutherland, 1965) with those in the pillow breccias of the far north-west. The two mineral suites are somewhat similar, but differ mainly in the presence of soda-rich zeolites (natrolite and sodic chabazite) in the latter. Whether this difference can be attributed to extrusion into a freshwater environment at Great Lake as compared to a marine environment in the far north-west is not yet certain.

It is of interest to compare the Tasmanian Cainozoic pillow lavas and breccias with similar rocks in the Cainozoic volcanics of Victoria (Condon, 1951; Bowler, 1963). The " boulder tuff " reported by Stach and McIvor (1937) from Lady Percy Julia Island also appears, from their description, to be a pillow breccia. From these comparisons it is apparent that in both Tasmania and Victoria pillow basalts were formed by subaqueous extrusions, into either marine or freshwater environments, at various times in the Cainozoic, and that saturated to near saturated olivine basalts were mostly involved.

The present study provides further information on the relationship between basalt magma type and the Cainozoic volcanic history of Tasmania. The preliminary survey of Edwards (1950) indicated that petrologically the Tasmanian basalts did not fall into an older series (characterized by undersaturated titan-augite basalts and of Lower Tertiary age) and a younger series (characterized by saturated black glass basalts and of Upper Pliocene to Quaternary age) as in Victoria. Edwards, however, based his conclusions partly on the fact that in the Launceston area undersaturated titan-augite basalts, similar to those of the older series of Victoria, disconformably overlie sediments he considered to be Miocene. Subsequent dating, however, has shown these sediments to be as old as Palaeocene-Eocene (Gill and Banks, 1956; Gill, 1962), and recent field investigation suggests the basalts may not be younger than early Miocene (Sutherland, 1966). Nevertheless, the results of the present study confirm Edward's initial conclusion, since the saturated black glass basalts of the far north-west are considered to range in age from Pliocene to pre-Miocene and to be possibly as old as Palaeocene-Eocene. The undersaturated titan-augite Mt. Cameron West Basalt, on the other hand, is probably as young as Upper Miocene-Pliocene. Thus the Cainozoic magmatic history of Tasmania, in the far north-west at least, appears to be significantly different to that of Victoria.

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REFERENCES

ANANDALWAR, M. A., 1957.—Geology and Structure of the Middle Derwent Valley. *M.Sc. Thesis, unpub.*, Geol. Dept. Tas. Uni.

BANKS, M. R., 1955.—Tertiary Fossil Forest at Macquarie Plains. *Tasm. Nat.*, **11**, 3, pp. 1-11.

BANKS, M. R., 1957.—The Stratigraphy of Tasmanian Limestones. *Miner. Resour. Tasm.*, **10**, pp. 39-85.

——————, 1962a.—Cainozoic Marine Succession—in the Geology of Tasmania. *J. Geol. Soc. Aust.*, **9**, 2, pp. 233-236.

——————, 1962b.—Cainozoic Volcanism—*Ibid.*, pp. 239-241

BOCK, P. E. and GLENIE, R. C., 1965.—Late Cretaceous and Tertiary Depositional Cycles in South-Western Victoria. *Proc. Roy. Soc. Vic.*, **79**, 1, p. 153-163.

BOWLER, J. M., 1963.—Tertiary Stratigraphy and Sedimentation in the Geelong-Maude area, Victoria. *Proc. Roy. Soc. Vict.*, **76**, 1, pp. 69-137.

CAREY, S. W. and SCOTT, B., 1952.—Revised Interpretation of the Geology of the Smithton District. *Pap. Roy. Soc. Tasm.*, **86**, pp. 63-70.

CARTER, A. N., 1958.—Pelagic Foraminifera in the Tertiary of Victoria. *Geol. Mag.*, **95**, pp. 297-304.

CONDON, M. A., 1951.—The Geology of the Lower Werribee River, Victoria. *Pap. Roy. Soc. Vict.*, **63**, pp. 1-24.

COTTON, C. A., 1944.—*Volcanoes as Landscape Forms.* Whitcombe and Tombs, Ltd., Christchurch.

DANA, E. S., 1947.—*A Textbook of Mineralogy.* Ed. W. E. Ford. John Wiley and Sons., Inc., New York.

DEER, W. A., HOWIE, R. A., and ZUSSMAN, J., 1963.—Rock Forming Minerals, Vol. 4, Framework Silicates. W. Clowes and Sons Ltd., *London.*

EDWARDS, A. B., 1941a.—The North-West Coast of Tasmania. *Proc. Roy. Soc. Vict.*, **53**, 2, pp. 233-267.

——————, 1941b.—The Crinanite Laccolith of Circular Head, Tasmania. *Proc. Roy. Soc. Vict.*, **53**, 2, pp. 403-415.

——————, 1950.—The Petrology of the Cainozoic Basaltic Rocks of Tasmania. *Proc. Roy. Soc. Vict.*, **62**, 1, pp. 97-120.

ESSO EXPLORATION AUSTRALIA, INC., 1966.—Esso Bass—1. Well Completion Report.

GILL, E. D., 1962.—Cainozoic—in Geology of Tasmania. *J. Geol. Soc. Aust.*, **9**, 2, pp. 233-253.

—————— and BANKS, M. R., 1956.—Cainozoic History of the Mowbray Swamp and Other Areas in North-Western Tasmania. *Rec. Q. Vict. Mus.*, **6**, pp. 1-41.

GREEN, R. and IRVING, E., 1958.—The Palaeomagnetism of the Cainozoic Basalts from Australia. *Proc. Roy. Soc. Vict.*, **70**, 1, pp. 1-18.

GREEN, R. H. and MACDONALD, D., 1963.—The Black Pyramid Gannetry. *The Emu*, **63**, 3, pp. 177-184.

GULLINE, A. B., 1959.—The Underground Water Resources of the Smithton District. *Undergr. Wat. Supply Pap., Tasm.*, **5**.

HILLS, E. S., 1965.—*Elements of Structural Geology.* Methuen and Co. Ltd., London.

HOFFMAN, M. G., 1933.—Structural Features in the Columbia River Lavas of Central Washington. *Jour. Geol.*, **41**, pp. 184-195.

HONNOREZ, J., 1963.—Sur l'Origine des Hyaloclastites. *Bull. Volcan.*, **25**, 1, pp. 253-258.

HUGHES, T. D., 1957.—Limestones in Tasmania; *Miner. Resour. Tasm.*, **10**.

JENNINGS, J. N., 1959.—The Submarine Topography of Bass Strait. *Proc. Roy. Soc. Vict.*, **71**, 1, pp. 49-72.

JOHNSTON, R. M., 1888.—*Systematic Account of the Geology of Tasmania.* Govt. Print., Hobart.

LEWIS, J. B., 1914.—The Origin of Pillow Lavas. *Bull. Geol. Soc. Amer.*, **25**, pp. 591-654.

LONGMAN, M. J. and MATTHEWS, W. L., 1962.—Geology of the Bluff Point and Trowutta Quadrangles. *Tas. Dept. Min. Tech. Rep.*, **6**, pp. 48-54.

MCDOUGALL, I., 1959.—The Brighton Basalts, Tasmania. *Pap. Roy. Soc. Tasm.*, **93**, pp. 17-28.

MOORE, J. G. and AULT, W. U., 1965.—Historic Littoral Cones in Hawaii. *Pacif. Sci.*, **19**, 1, pp. 3-11.

NYE, P. B., 1941.—The Lower Tertiary (Miocene) Marine Sedimentary Rocks of the Far North-Western Districts of Tasmania. *Pap. Roy. Soc. Tasm.*, **(1940)**, pp. 11-17.

NYE, P. B., and BLAKE, F., 1938.—The Geology and Mineral Deposits of Tasmania. *Bull. Geol. Surv. Tasm.*, **41**.

QUILTY, P. G., 1965.—Correlation of Tasmanian Tertiary Marine Deposits—in Symposium on Geology of Bass Strait. *38th Congress (Hobart), A.N.Z.A.A.S., Section C*, ABSTRACTS.

————, 1966.—The Age of Tasmanian Marine Tertiary Rocks. *Aus. J. Sci., in press.*

RITTMAN, A., 1962.—*Volcanoes and Their Activity.* Engl. Transl. E. A. Vincent. John Wiley and Sons, Inc., New York.

SCOTT, B., 1951.—The Petrology of the Volcanic Rocks of South-East King Island, Tasmania. *Proc. Roy. Soc. Tasm.* **(1950)**, pp. 113-136.

————, 1952.—Occurrence of Pillow Lavas near Penguin. *Proc. Roy. Soc. Tasm.*, **88**, pp. 271-272.

SILVESTRI, S. C., 1963.—Proposal for a Genetic Classification of Hyaloclastites. *Bull. Volcan.*, **25**, 1, pp. 315-321.

SOLOMON, M., 1964.—Spilites, Keratophyres and the Rosebery-Mt. Lyell Ores. *Ph.D. Thesis, unpub.*, Geol. Dept. Tas. Uni.

SPRY, A. H., 1962.—Igneous—in the Geology of Tasmania. *J. Geol. Soc. Aust.*, **9**, 2, pp. 255-284.

———— and SOLOMON, M., 1964.—Columnar Buchites at Apsley, Tasmania. *Quart. J. Geol. Soc. Lond.*, **120**, pp. 519-545.

STACH, L. W. and McIVOR, E., 1937.—Lady Julia Percy Island—General Geology: Petrology. McCoy Society *Proc. Roy. Soc. Vict.*, **49**, 2, pp. 336-348.

STARK, J. T., 1938.—Vesicular Dike and Subaerial Pillow Lavas in Borabora, Society Islands. *Jour. Geol.*, **46**, pp. 225-238.

STURIALE, C., 1963.—Pillows and Hyaloclastites on the Island of Ustica (Sicily). *Bull Volcan.*, **25**, 1, pp. 259-262.

SUTHERLAND, F. L., 1965.—Some New Occurrences of Zeolites and Associated Minerals in the Tertiary Basalts of Tasmania. *Aus. J. Sci.*, **28**, 1, p. 26.

————, 1966.—The Tertiary Volcanics of the Tamar Valley, Northern Tasmania—A Preliminary Report. *Aus. J. Sci.*, **29**, 4, pp. 114-115.

TAYLOR, D. J. 1965.—The Mid-Tertiary Foraminiferal Sequence. Esso Bass—1 Well, Tasmania. *Geol. Surv. Vict., Unpub. Rep.*

THOMAS, D. E., 1945.—In Report of the Director of Mines, Tasmania, for year ended 31st Dec., 1943.

VOISEY, A. H., 1949.—The Geology of the Country around the Great Lake, Tasmania. *Pap. Roy. Soc. Tasm.* **(1948)**, pp. 95-104.

WARD, L. K., 1911.—The Mt. Balfour Mining Field. *Bull. Geol. Surv. Tasm.*, **10**.

WENTWORTH, C. K. and MACDONALD, G. A., 1953.—Structures and Forms of Basaltic Rocks in Hawaii. *U.S. Geol. Surv. Bull.*, **994**.

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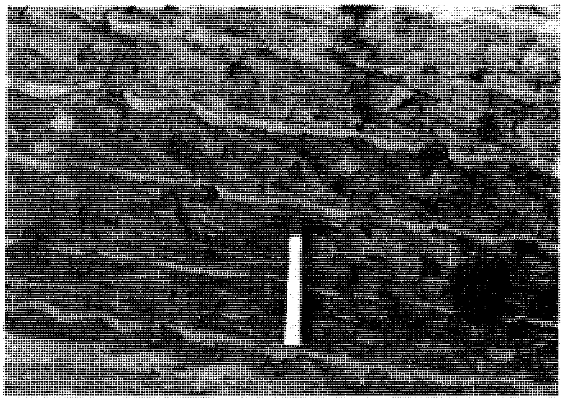

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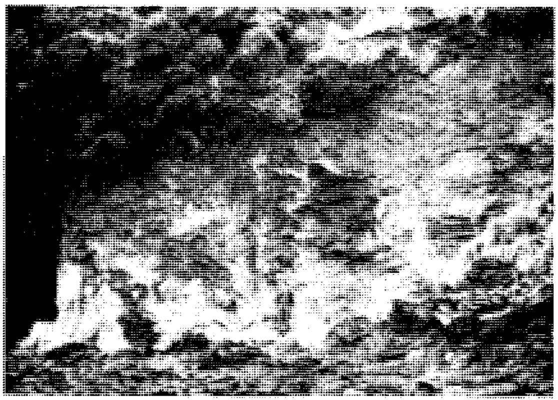

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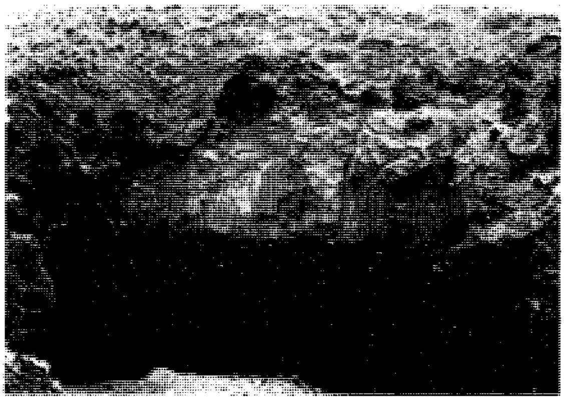

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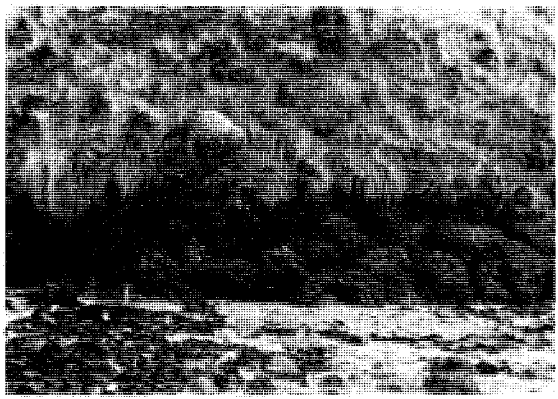

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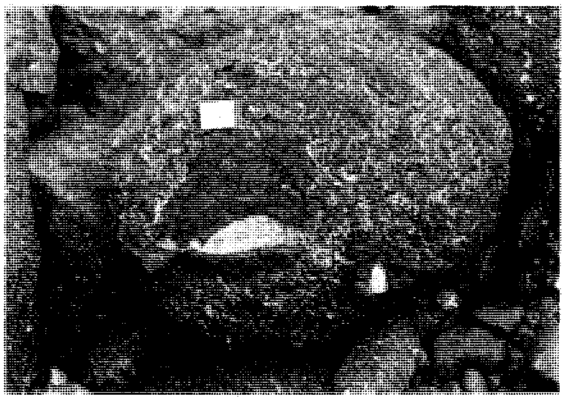

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PLATE I.

FIG. 1.—Woolnorth Tuff. Note prominent horizontal bedding, folding adjacent to small fault, development of cliffs and platforms. Outcrop in type area, ¾ mile north of Cape Grim, looking north.

FIG. 2.—Woolnorth Tuff. Note climbing ripple lamination, thin, lighter coloured bands. Locality as for Fig. 1, looking north.

FIG. 3.—Exhumed cliff of Woolnorth Tuff exposed under Studland Bay Basalts, just south of Valley Bay, looking east. Note entrail lava above cliff, columnar basalt at cliff base, horizontal and contorted bedding and clastic dykes in tuff.

FIG. 4.—Studland Bay Basalts. Lens of columnar basalt within entrail basalt forms roof of sea cave. Locality approx. 50 feet south of Fig. 3.

FIG. 5.—Typical entrail lava of Studland Bay Basalts, near sea level just south of Valley Bay. Hammer rests on small outcrop of Woolnorth Tuff.

FIG. 6.—Trefoil Island Volcanic Breccia. Boulder showing small pillows with tachylitic margins and large, mineral-filled central vesicles, in typical calcareous tachylitic matrix.

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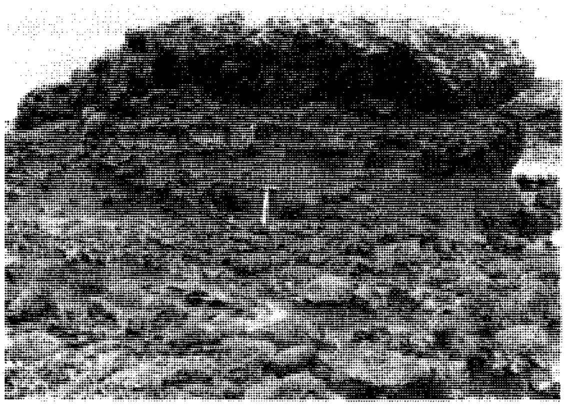

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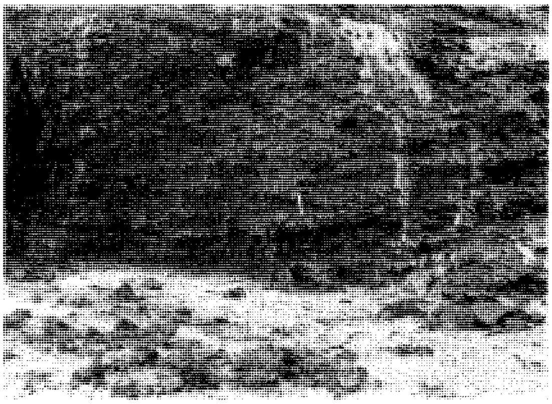

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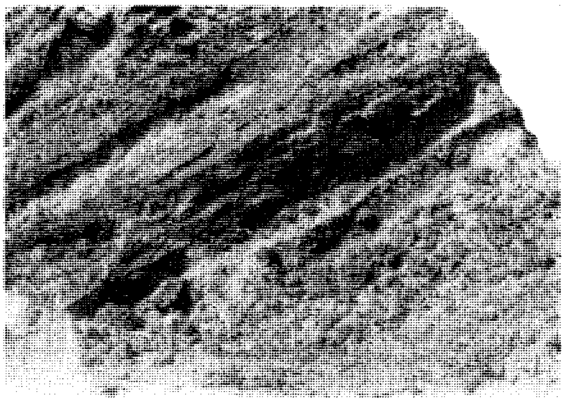

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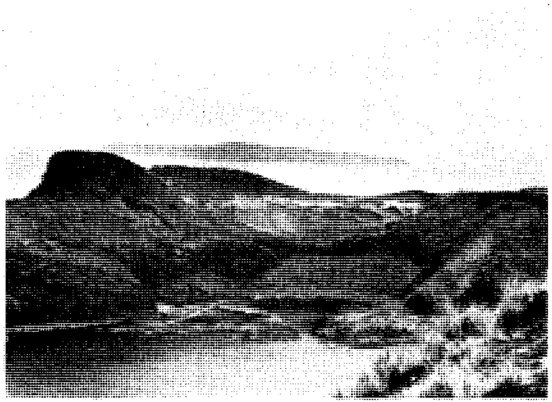

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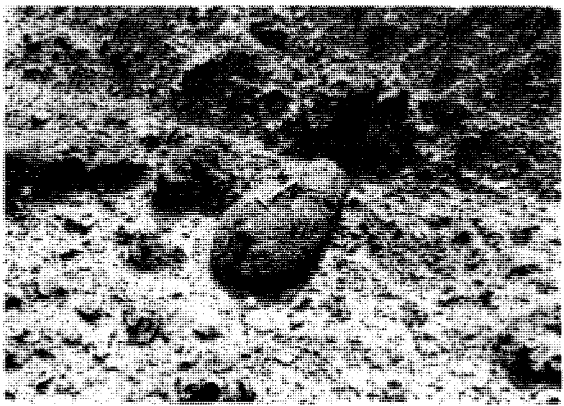

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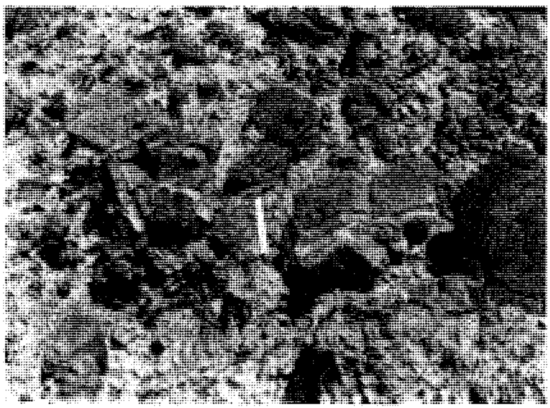

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PLATE II.

FIG. 1.—Valley Bay Conglomerate. Upper contact with small flow of pillowy lava in Slaughter Bluff Volcanic Brecia. Note large boulders of amygdaloidal basalt in abundant sandy matrix.

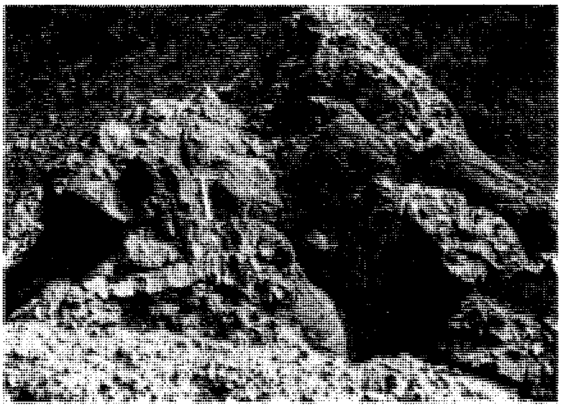
FIG. 2.—Valley Bay Conglomerate. Note large boulders, lateral variations in lithology. Looking east.

FIG. 3.—Slaughter Bluff Volcanic Breccia. Note crude inclined bedding, variations in proportions of pillows, fragments and matrix in different layers, lighter coloured zones at tops of beds. West side of Cape Grim.

FIG. 4.—Cape Grim Beds in channel in Slaughter Bluff Volcanic Breccia, east side of Cape Grim, looking north with Trefoil Island in the background. Note coarse "cross-bedding" in breccia.

FIG. 5.—Isolated pillow, with broken-off rear end, in Slaughter Bluff Volcanic Breccia, south of Cape Grim.

FIG. 6.—Typical view of Slaughter Bluff Volcanic Breccia. Note broken pillows and fragments with double and multiple cooling crusts. West side of Cape Grim.



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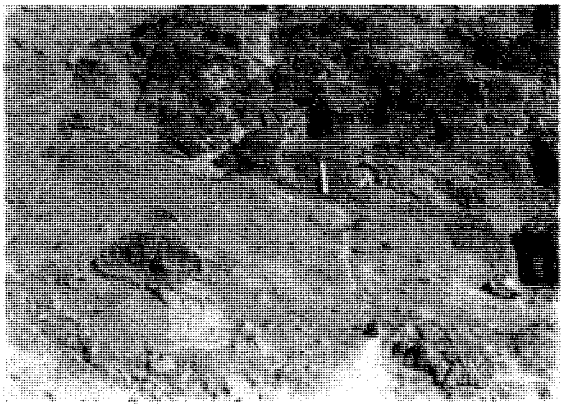

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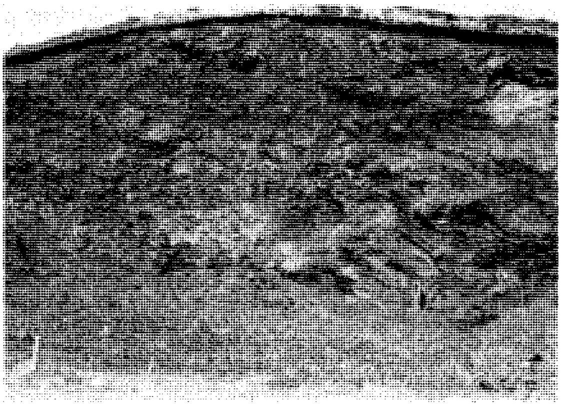

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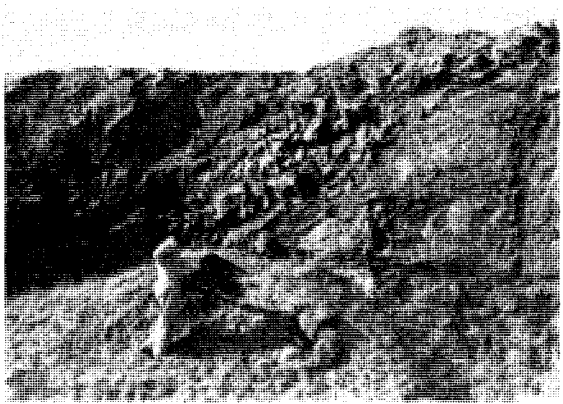

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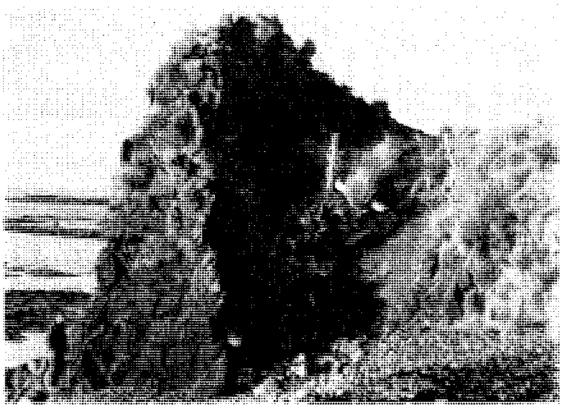

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PLATE III.

FIG. 1.—Pillowy lava in Slaughter Bluff Volcanic Breccia. Note moulded form of pillows. South side of Cape Grim.

FIG. 2.—Layer rich in matrix, Slaughter Bluff Volcanic Breccia. Note block of amygdaloidal basalt in left foreground. West side of Cape Grim.

FIG. 3.—Marrawah Volcanics, quarry on Marrawah Beach road. Note variations in proportions of pillows, blocks and matrix.

FIG. 4.—Flow of massive basalt within pillow breccias, Marrawah Volcanics. Quarry near Bass Highway, 2 miles south-west of Redpa. Looking North.

FIG. 5.—Dyke-like body of Little Trefoil Basalt in Woolnorth Tuff. Note veneer of breccia on tuff to right. Shore platform just north of Cape Grim.

FIG. 6.—Dyke-like bodies of Little Trefoil Basalt. Note breccia overlying Woolnorth Tuff between the dykes. Shoreline cliff, just north of Cape Grim.

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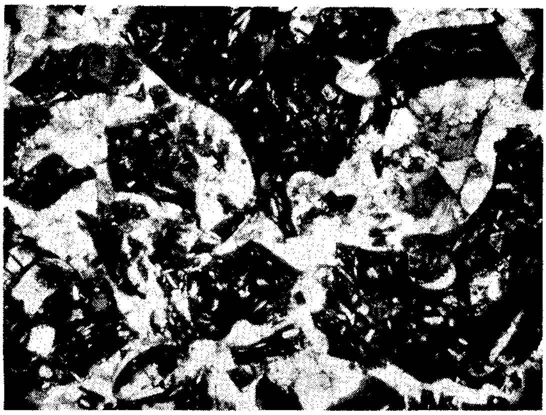

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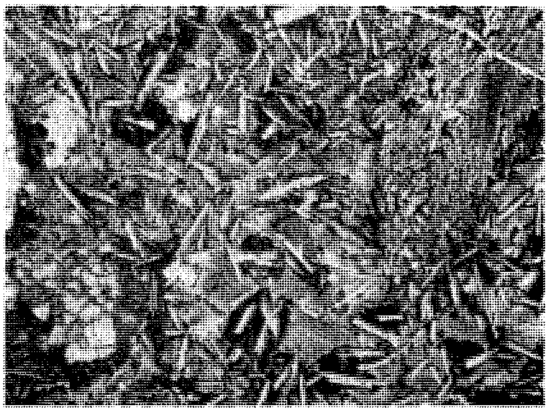

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PLATE IV.

FIG. 1.—Photomicrograph of Woolnorth Tuff. Note partial alteration of glass shards (dark); fringes of lussatite (?) on shards and olivine fragment (light); interstices filled with chalcedony. Crossed nichols.

FIG. 2.—Photomicrograph of matrix of Trefoil Island Volcanic Breccia. Fragments of vesicular palagonite (dark) cemented by calcite (white) with nests of gypsum (grey). Crossed nichols.

FIG. 3.—Photomicrograph of small xenolith in teschenitic Mt. Cameron West Basalt. Note reaction rim of plagioclase (?) and iron ore; dense border of iron ore and spinels; enstatite (?) and sillimanite (?) poikilitically enclosed by plagioclase. Ordinary light.

FIG. 4.—Photomicrograph of buchite from Mt. Cameron West. Note partially fused quartzite fragment (lower left); areas of darker and lighter coloured glass; sheaves and laths of sanidine; prisms of pyroxene. Ordinary light.