Papers and Proceedings of the Royal Society of Tasmania, Volume 114, 1980.

(ms. received 1.11.1978)

AQUAGENE VOLCANISM IN THE TASMANIAN TERTIARY, IN RELATION TO COASTAL SEAS AND RIVER SYSTEMS

by F.L. Sutherland
The Australian Museum, Sydney

(with seven text figures and nine plates)

ABSTRACT

SUTHERLAND, F.L., 1980 (31 v). Aquagene volcanism in the Tasmanian Tertiary, in relation to coastal seas and river systems. Pap. Proc. R. Soc. Tasm., 114: 177-199 (incl. 9 plates). https://doi.org/10.26749/rstpp.114.177 ISSN 0080-4703. Australian Museum, Sydney, New South Wales, Australia

Tertiary aquagene volcanics at over forty localities in Tasmania concentrate in three main regions. The North West Coast - Bass Strait islands examples are mostly related to Miocene high seas. Phreatic tuffs and flow foot breccias erupted from emergent vents (Cape Grim, Trefoil Island, Steep Island, Redpa, Brittons Swamp, Temma, N. Robbins Island and possibly Wynyard). Pillowy lavas represent subaqueous phases of emerging volcanoes (Flat Topped Bluff, S. Robbins Island and Black Pyramid Island). The aquagene volcanics supplement data on levels and depositional depths of Miocene seas and suggest relative levels now up to 110m (early Miocene), 130-140m (early-mid Miocene) and possibly 75m (late-mid Miocene?) above present sea level.

The Mersey-Forth phreatic tuffs and flow foot breccias erupted into dammed sections of leads, successively higher upstream and roughly corresponding to order of eruption from at least six centres (Forth, Paloona, Sheffield, Gads Hill, Borrodaile Plains, Middlesex Plains).

Flow foot breccias formed in Derwent watercourses blocked by earlier flows (Bronte, Great Lake, Waddamana, Wayatinah, Lower Dee, Ouse, Lower Clyde, Meadowbank and Bridgewater). Multiple damming and overtopping is represented at Waddamana and Ouse. Phreatic tuffs erupted from emerging centres (Great Lake, Glenora, Claremont and possibly Plenty).

Zeolitization of aquagene sequences is patchy and most intense near centres of extended activity. Upper Mersey-Forth and Derwent sequences suggest minimum erosion rates of 17-21 and 21-27 m/m.y. respectively over the last 20-25 m.y.

Tasmania provides the best range of Cainozoic aquagene volcanic rocks in Australia, examples elsewhere being sporadic.

INTRODUCTION

Subaerial eruptive rocks dominate Tasmanian Tertiary volcanic successions, but examples of phreatic tuffs and flow foot breccias from aquagene volcanism have been described (Banks 1962a; Sutherland and Corbett 1967; Sutherland 1969; Sutherland and Hale 1970; Sutherland 1973a; 1973b; 1976a; 1976b; 1977a). More complete coastal sequences, with pillow lavas, and inland basaltic leads, with multiple aquagene volcanics, have now been mapped (figure 1) and are described in this paper.

Field work for the present survey was carried out over several trips from February 1971 (Steep Island, Hunter Island), March 1972 (Flat Topped Bluff), April 1972 (Wynyard and Robbins Island), February-March 1974 (Derwent drainage) and

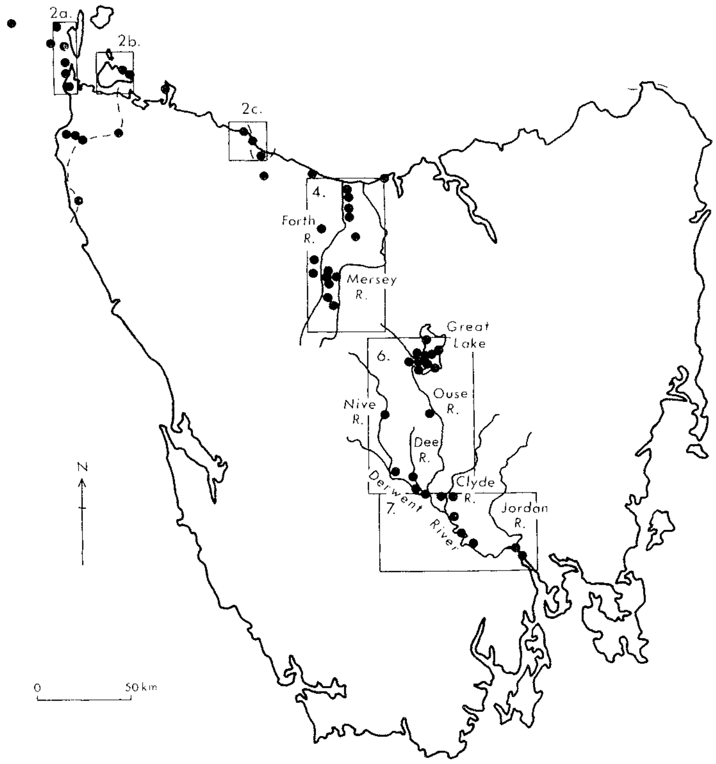


FIG. 1.- Distribution of aquagene volcanics (black dots), Tasmania, with known limits of Miocene marine transgression (dashes).

February-March 1978 (Mersey-Forth drainage). Some aspects of the work on coastal aquagene volcanism were presented at the 45th ANZAAS Congress, Perth, Western Australia.

EMERGENT COASTAL SUCCESSIONS

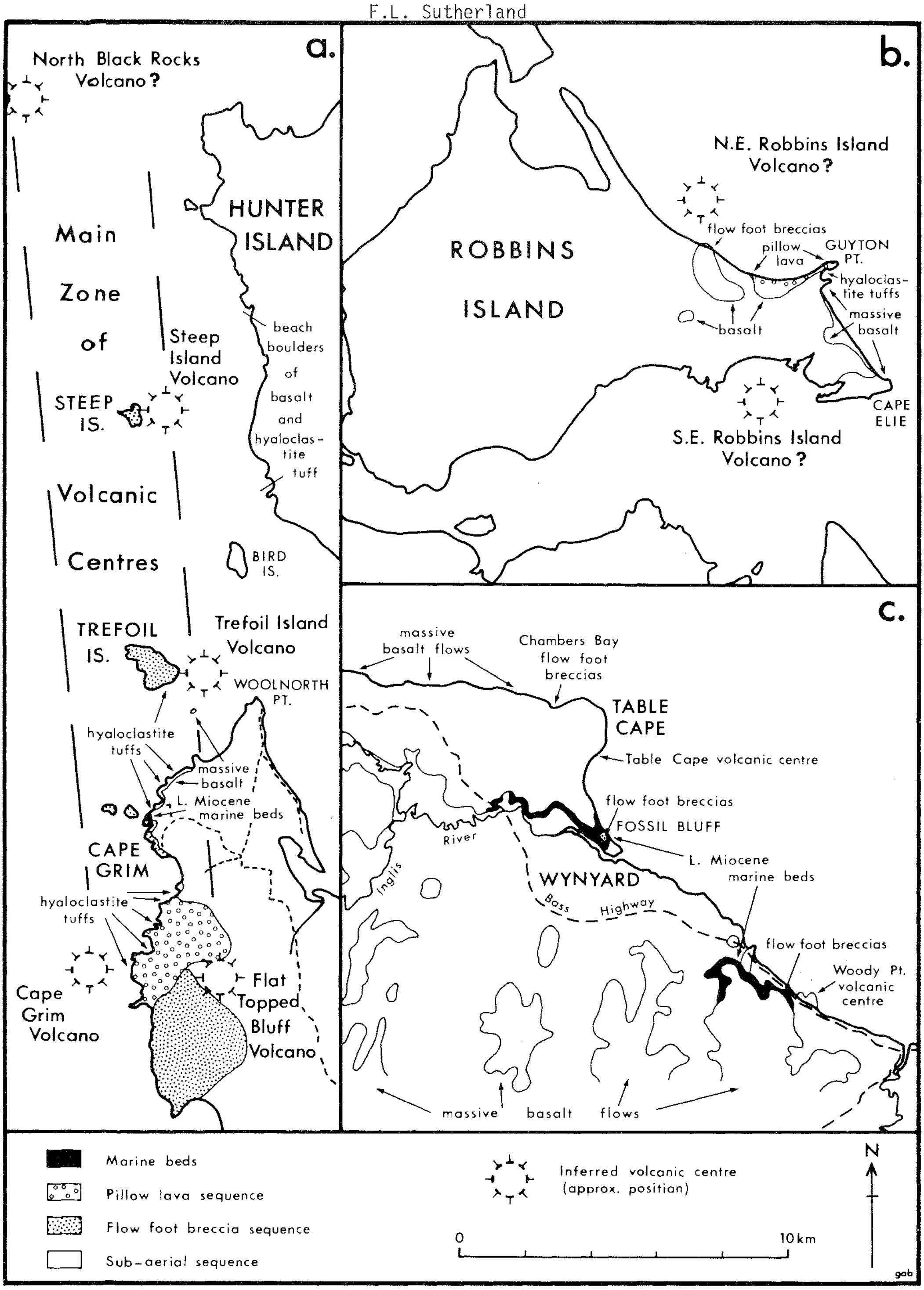
Emergent aquagene volcanic rocks at sixteen sites in coastal north-western Tasmania (figure 2) include sequences with pillowy lavas at Flat Topped Bluff and Robbins Island.

Flat Topped Bluff (Welcome 1:100 000 Sheet 7816)

More complete mapping (figure 3) necessitates reinterpretation of earlier work (Studland Bay Basalts; Sutherland and Corbett 1967). Northern pillowy and columnar lavas are overlain southwards by flow foot breccias, with capping subaerial lavas. The pillowy lavas overlie bedded tuffs and massive basalt with no exposed lower contact (Plate 1).

Basal tuffs and basalt. Tuffs up to 10 m thick partly intercalate with and

FIG. 2.- Distribution of aquagene volcanics, volcanic centres and marine beds, north-western Tasmania (a) Woolnorth and off-shore islands, (b) Robbins Island, (c) Wynyard district. Figure opposite.


a.
North Black Rocks Volcano?
Main Zone of Volcanic Centres
HUNTER ISLAND
Steep Island Volcano
STEEP IS.
beach boulders of basalt and hyaloclastite tuff
BIRD IS.
TREFOIL IS.
Trefoil Island Volcano
WOOLNORTH PT.
hyaloclastite tuffs
massive basalt
L. Miocene marine beds
CAPE GRIM
hyaloclastite tuffs
Cape Grim Volcano
Flat Topped Bluff Volcano
b.
ROBBINS ISLAND
N.E. Robbins Island Volcano?
flow foot breccias
pillow lava
GUYTON PT.
hyaloclastite tuffs
massive basalt
basalt
CAPE ELIE
S.E. Robbins Island Volcano?
c.
massive basalt flows
Chambers Bay flow foot breccias
TABLE CAPE
Table Cape volcanic centre
flow foot breccias
FOSSIL BLUFF
L. Miocene marine beds
Inglis River
WYNYARD
Bass Highway
flow foot breccias
Woody Pt. volcanic centre
massive basalt flows
Marine beds
Pillow lava sequence
Flow foot breccia sequence
Sub-aerial sequence
Inferred volcanic centre (approx. position)
0
10km
N
gab

disconformably underlie the pillowy lava. Closely bedded vitric tuffs, with some cross-bedding, predominate and show localized fault drags, contorted bedding, load casting, clastic dykes and autobrecciation. Coarser alternation of lapilli tuffs, between 0.05 and 0.3 m thick (Grid ref. 7816-043906) are cemented with secondary minerals and contain sporadic fragments of scoriaceous basalt.

The basal basalt is blocky columnar to platy with radiating joints. Abundant quartzite and vein quartz inclusions up to 0.45 m across (Grid ref. 7816-038901) suggest underlying Precambrian basement (Plate 2). The flow is folded with the tuffs (Plate 1) into anticlinal domal structures with limbs dipping up to 40° (Grid refs 7816-046914, 051922).

Pillowy and columnar flows. These lavas, up to 100m thick, are exposed in shore-line cliffs. Entrail-like pillow lavas grade into pillowy sheets and interspersed lenses of massive columnar basalt. Pillows up to 10m long range from 0.3 to 1.2m across, with amygdales of zeolites, carbonates, clay and silica, and interstices may contain hyaloclastite tuff.

Pillowy flow sheets up to 20m wide and 1.5m thick mould underlying pillow lava. More massive flow sheets up to 5m thick pass into 'mega pillows' (Plate 3) and elongate lenses of massive columnar basalt reach 10m in thickness. Pillowy structures suggest flow from a north-north-easterly direction.

Flow foot breccias. These form steep cliffs, but were examined where they overlie pillowy lavas. South of Hippo Point larger pillow fragments lie in a coarse fragmentary to finer tachylytic matrix, cemented by carbonate and zeolite and including rare fragments of vitric tuff. Crude bedding dips mostly 20-40° south-westerly but swings south-easterly at Bluff Point. Here beds rich in flow foot fragments succeed more fragmented finer grained beds containing blocks of amygdaloidal basalt derived from underlying pillowy flows.

Capping flows. Massive subhorizontal basalts, at least 6 to 20m thick, are poorly exposed under soils and wind blown sands, but show a strongly scoriaceous base above 80m elevation.

Eruptive history. The tuffs above the basal flow represent phreatic eruption into shallow water. They resemble tuffs showing easterly regional dips under north-easterly dipping flow foot breccias and interbedded basalt conglomerates around Cape Grim and Slaughter Bluff (Sutherland and Corbett 1967). They are coarsest at Flat Topped Bluff, suggesting an offshore vent for the Cape Grim volcano north-west of Flat Topped Bluff (figure 2a).

Deformation of these basal units preceded or accompanied eruption of pillowy lavas from a subaqueous vent north-east of Flat Topped Bluff. Minor tuffs within pillowy sequences suggest phreatic emergence before subaerial flows from a southerly breach built a delta of flow foot breccias into surrounding waters and then capped a 'tuya' volcano.

The Flat Topped Bluff volcano appears to partly post-date the Cape Grim volcano and petrographically is mildly alkaline or transitional olivine basalt compared to more tholeiitic olivine basalt from Cape Grim.

These aquagene volcanic rocks suggest eruption into waters relatively at least 80m and possibly up to 110m above present sea-level. They contain no micro-fossils to characterize marine or non-marine deposition (P.G. Quilty, pers. comm.), but are overlain by latest Oligocene - early Miocene marine beds of the Cape Grim transgression (Quilty 1972; Sutherland 1973a).

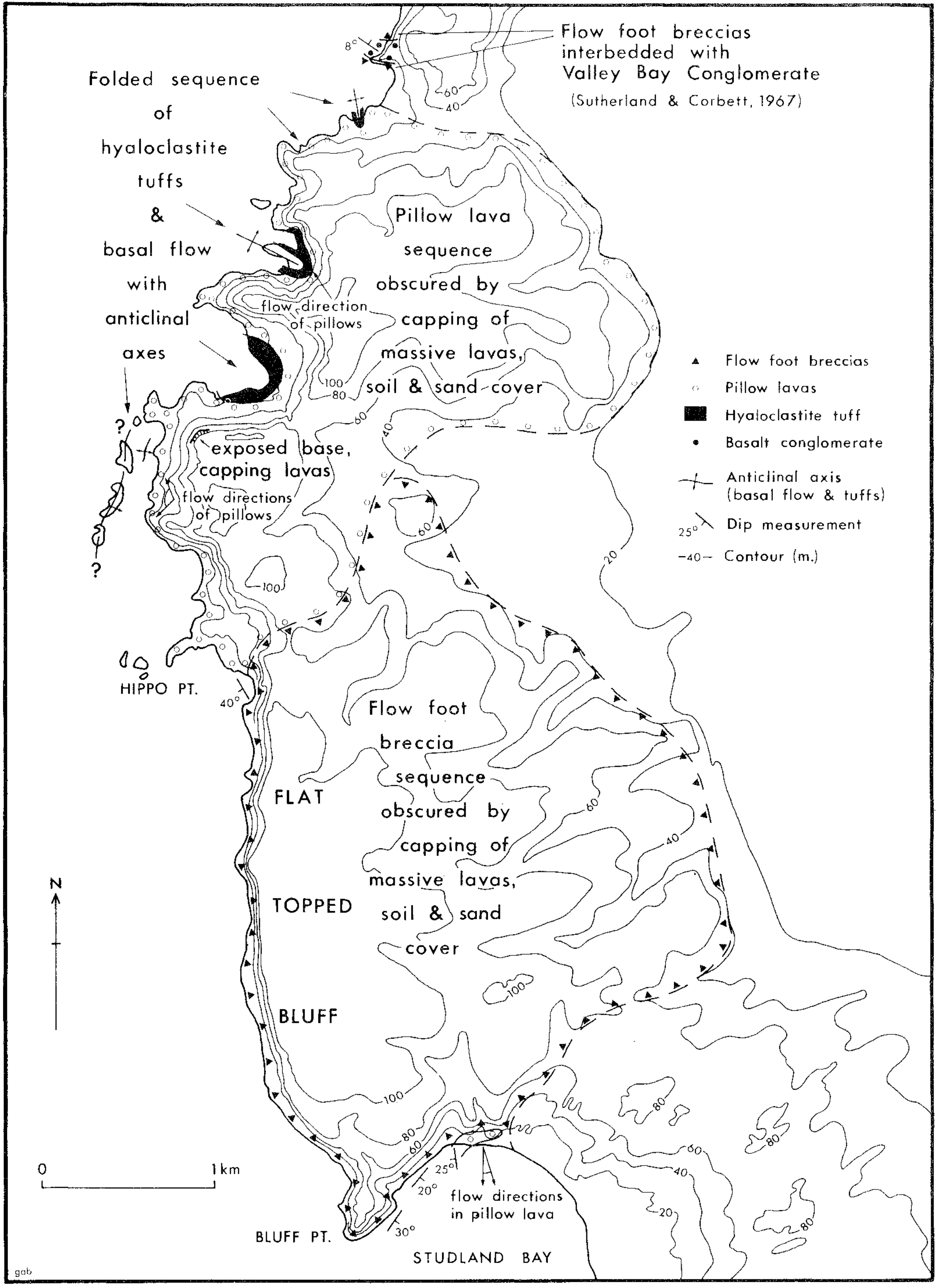


FIG. 3.- Detailed distribution of volcanic units, Flat Topped Bluff.

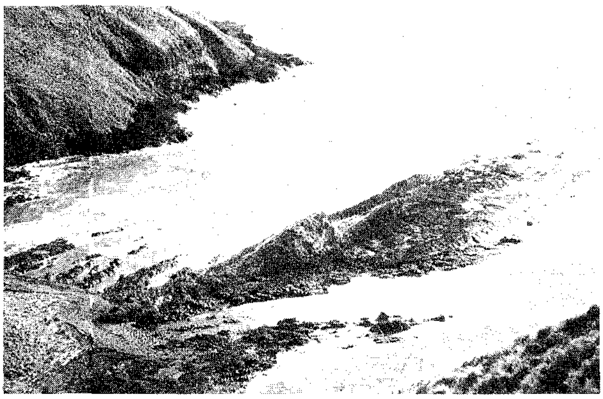


PLATE 1.- Anticlinal dome formed by basal basalt extending into sea (right) and flanked by dipping beds of tuffs exposed in coves (lower left), with overlying pillowy lavas forming promontories (upper left and lower right). North end Flat Topped Bluff, 1 km south-west of Valley Bay, looking west-south-westerly.

Robbins Island (Circular Head 1:100 000 Sheet 7916)

Aquagene lavas are associated with fine-grained, laminated vitric tuffs (figure 2b). South of Guyton Point (Plate 4) tuffs below pillowy lavas show small scale current and normally graded bedding, gentle warping and soft sediment deformation. At Little Bluff, Ransonnet Bay, tuffs are thinly interbedded with zeolitized flow foot breccias and dip 10° south-south-easterly (Plate 5).

Pillowy lavas. These resemble 'megapillows' (Plate 6) and reach 40m in thickness between Big Bluff and Guyton Point. They include minor hyaloclastite breccia and flow directions dip shallowly north north west-to east-north-east.

Massive lava. Platy jointed basalt extends south of Guyton Point from a gentle domal structure to Cape Elie where fragments of coarse sub-aerial (?) tuff appear amongst basaltic beach boulders.

Eruptive history. The pillowy and massive lavas are petrographically similar alkali olivine basalt containing small lherzolitic xenoliths. They contrast with flow foot breccias at Ransonnet Bay, which are highly altered, but more saturated olivine basalts.

The evidence suggests separate centres of eruption north-east and south-west of Robbins Island (figure 2), partly erupting into waters relatively 20-40m above present sea-level. Pillowy lavas, structurally and petrographically similar to Robbins Island examples outcrop further east on Circular Head Peninsula (P.W. Baillie, Tasmanian Mines Department, and author's observations), but flowed from the east and are unlikely extensions for Robbins Island.

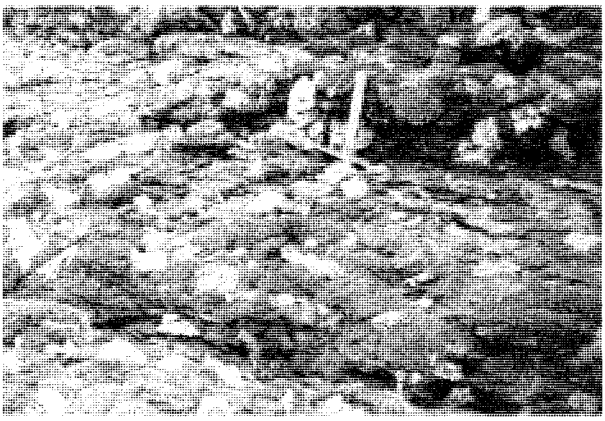


PLATE 2.- Basal basalt flow containing abundant inclusions of Precambrian quartzites, shore exposure, north west side Flat Topped Bluff, 0.75 km north of Hippo Point.

Coastal Marine Aquagene Volcanism

Earliest Miocene marine beds (figure 2a, b) overlie flow foot breccias at Cape Grim and underlie those at Fossil Bluff and Woody Point, Wynyard (Sutherland and Corbett 1967; Quilty 1972). Eruption is indicated into Early Miocene seas standing at least

75-80m above present sea-level and possibly up to 110m if Flat Topped Bluff volcano grew in coeval seas. These levels agree with estimates (71-106m) using maximum depositional depths of Miocene marine sedimentation (Quilty 1972).

Early to mid-Miocene marine beds (early Longfordian to Batesfordian) occur with aquagene volcanics at Marrawah-Redpa and Brittons Swamp, but relative ages were uncertain (Sutherland & Corbett 1967; Quilty 1972). An older age was based on basalt fragments in the limestones, but Quilty placed the basalts above the sediments and explained the fragments by distant transport. Subsequent examination confirms Quilty's placement and shows that the bulk of basalts are flow foot breccias erupted into Batesfordian seas over 106-130m above present level; this agrees with sedimentational depths (125-140m; Quilty 1972). The basalt fragments in Batesfordian limestone, however, petrographically match the overlying basalts and have a glassy altered mesostasis unlikely to survive prolonged transport. They may derive from initial eruptions, prior to deltaic extension of Batesfordian flow foot breccias. Higher temperature zeolitization, which developed tacharanite, near a basalt intrusion at Linnanes Road quarry, Bass Highway (Sutherland 1976b) and in phreatic tuffs north of Seymour Hill suggest eruptive sources for flow foot breccias.

Mid-Miocene marine sediments at Temma (Balcombian?; Banks 1962b) lie near weathered flow foot breccias and massive capping basalt, suggesting eruption into a sea 75m above present level.

Aquagene Volcanic Islands

Aquagene volcanic rocks off north-western Tasmania resemble coastal occurrences and their wide distribution in Bass Strait favours marine associations (figures 1 and 2).

West-dipping flow foot breccias and coarser phreatic tuffs at Trefoil Island (Sutherland and Corbett 1967) suggest eruption from a vent to the east into seas 80m above present level.

PLATE 3.- Megapillow extending from pillowy lava, shore line north-west side Flat Topped Bluff, 0.75km north of Hippo Point, looking eastwards.

Steep Island, circumnavigated by plane and boat, showed flow foot breccias dipping westerly on the north-west side. Massive basalt, flow foot breccias and vitric tuff form beach debris on the western shore of Hunter Island facing Steep Island. This suggests an offshore aquagene vent (figure 2). The flow foot breccias were photographed and sampled on Steep Island by Miss Sandra Bowdler, Australian National University and like most Hunter Island debris are petrographically olivine tholeiites. Exceptional shore boulders of coarse alkali basalt from Hunter Island resemble Mt Cameron West basalt, 30km to the south, but transport from that area is unlikely and they probably come from nearby submerged outcrops.

Aerial inspection identified flow foot breccias forming prominent rocks west of Steep Island (North and South Black Rock) and contrary dips suggest more than one centre. These fall on north north westerly alignments with coastal centres (Flat Topped Bluff, Cape Grim, Trefoil Island, Steep Island and North Black Rock), probably reflecting control by basement faulting (figure 2).

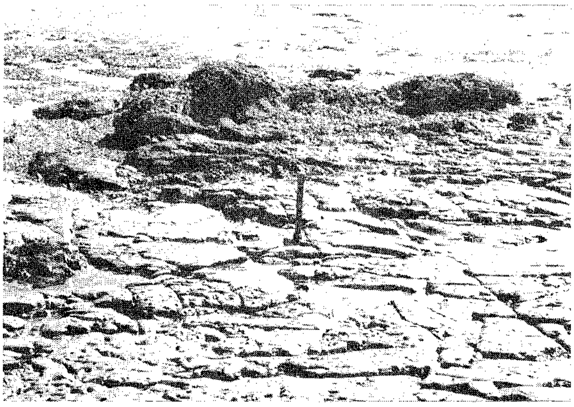


PLATE 4.- Jointed bedded tuffs (foreground) underlying pillowy lava, Guyton Point, Robbins Island.

Photographs of Black Pyramid Island, taken during a rare landing (Green and Macdonald 1963), reveal apparent aquagene structures. The lower 30m resembles the pillowy and columnar flows of Flat Topped Bluff volcano and is overlain by about 3m of near-horizontal beds resembling outcrops of vitric tuffs from Cape Grim and Trefoil Island volcanoes. A 40m thick capping of flow foot breccias dips northerly and suggests eruption from the south into seas over 73m above present level. If identified correctly, this sequence represents classic emergence of a subaqueous vent.

Volcanism and Miocene Seas

Coincidence of aquagene volcanics and marine deposits in north-western Tasmania supplements evidence of high Miocene sea-levels in Bass Strait. It supports sedimentation depths determined from fossils (Quilty 1972), giving seas up to 110m (Early Miocene) and 130-140m (Mid-Miocene) above present level.

Absence of marine aquagene volcanics elsewhere in Tasmania may reflect several factors. The other coastlines are more dominated by resistant dolerites, granite and older Precambrian blocks that may have barred marine incursion. Some potential inlets for marine encroachment were already blocked by thick basalt fills prior to Miocene marine transgression and some early Miocene marine inlets may have become blocked by basalts erupted during erosional hiatus in sedimentation, forestalling later marine incursion. Subaerial lavas fill valleys in Early Miocene marine beds to below sea-level at Cape Grim-Woolnorth, Mt Cameron West and Table Cape. Sedimentation breaks in the Australian marine record occur in mid-Early Miocene and post-Middle Miocene times (Quilty 1977), so that dating of basalt fills are needed to assign them to a particular hiatus.

PLATE 5.- Flow foot breccias interbedded with finely-bedded tuffs, dipping south, foreshore 4km west of Guyton Point, Little Bluff, Ransonnet Bay, Robbins Island.

Absolute levels of Miocene seas based on present heights of marine beds and aquagene volcanics are uncertain due to possible later tectonic movements. Quilty (1972) considered that differences in heights of deposits from north-western to north-eastern Tasmania reflected eastward downtilting, but other factors may apply as faunal units range over 80m in thickness and may be transgressed by aquagene volcanism and erosional breaks. Benching between 60-75m above sea-level on King Island and Flinders Island, Tasmania (Jennings 1959; Kershaw and Sutherland 1972) probably mark old sea-levels. These match the youngest (?) Miocene marine level at Temma (75m) and if related do not support significant post-mid Miocene eastward downtilting. Indeed, there is evidence of some relative uplift of Tasmania since the Last Interglacial with maximum rates in the north-eastern sector (Colhoun 1978).

INLAND BASALTIC LEADS

Aquagenic volcanics have been recognized in the ancestral Mersey-Forth (Sutherland 1976b) and Derwent River systems (Banks 1955; Anandalwar 1960; Sutherland and Hale 1970; Sutherland 1973b, 1976a, 1977a) and pillowy contacts were described from lava infilling wet sediments in the ancestral Tamar River (Sutherland 1971).

Mersey-Forth Leads (figure 4)

Basaltic breccias, agglomerates and tuffs up to 150m thick in Oligocene-Miocene leads under Borrodaile Plains and Gads Hill (Spry 1958), near Moina (Paterson 1967) and at Paloona (Burns 1964) were thought to indicate nearby centres, but are aquagene volcanics not necessarily formed close to a vent.

Basalt remnants and silicified sub-basaltic sediments suggest at least 300m of incised relief in upper leads (Jennings 1963; Rawlings 1967) and more subdued relief around 200m in lower leads (Burns 1964). The eruptive history, location of centres, drainage dislocations and burial depths are revised from examination of sections in several leads. Initial lead positions (figure 4) are approximate and would change during volcanism.

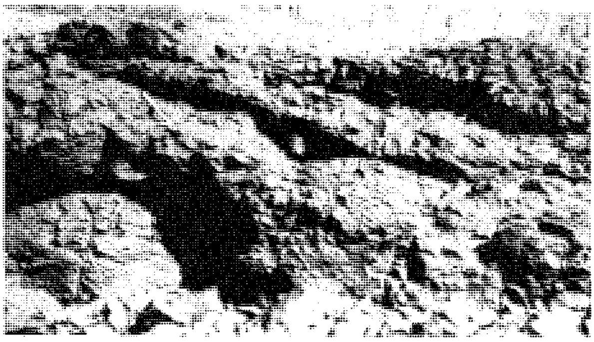


PLATE 6.- Pillowy lava (side view) dipping seawards to the north-east, foreshore west of Guyton Point, Ransonnet Bay, Robbins Island.

Lorinna-Liena Leads (Mersey 1:100 000 Sheet 8144). Massive flows fill the gutters of these leads - poorly exposed near Lorinna between 430-540m above sea-level, but well exposed in a thick flow in Ration Tree Creek between 390-490m (east Liena Lead). At least three flows occur on Lemonthyme Road between 440-550m (south Lorinna Lead). The highest overlies fine-grained inter-basaltic sediments (520-540m) along an irregular intrusive pillowy contact dipping north-west and underlies soft unsorted sediments which contain blocks of basalt and dip up to 25° north, but become rarer in basalt fragments and subhorizontal towards the top. The beds contain altered horizons and may represent old partly weathered fluvial or landslip deposits.

Gads Hill volcano. The lower flows and sediments are followed by fine-grained vitric tuffs, exposed in a 3m cliff above 540m elevation, 2km south east of Lorinna (Grid ref. 8114-DP295992) and in the Ration Tree Creek section, where 0.1m of tuff at 495m elevation underlies tachylytic agglomerate in Shaws Creek. The agglomerate dips over 35° south-west and contains fragments of basalt, Ordovician limestone, rare dolerite, chert and vein calcite up to 15cm across in zeolitized tachylytic matrix. It grades up into massive fine basaltic agglomerates and coarse tachylytic tuffs to over 550m elevation. These horizons resemble phreatic deposits and probably erupted from a partly submerged vent east of Gads Hill, as they do not appear in Lemonthyme Road south of Gads Hill.

Flow foot breccias form prominent cliffs (Plate 7) south of Ration Tree Creek,

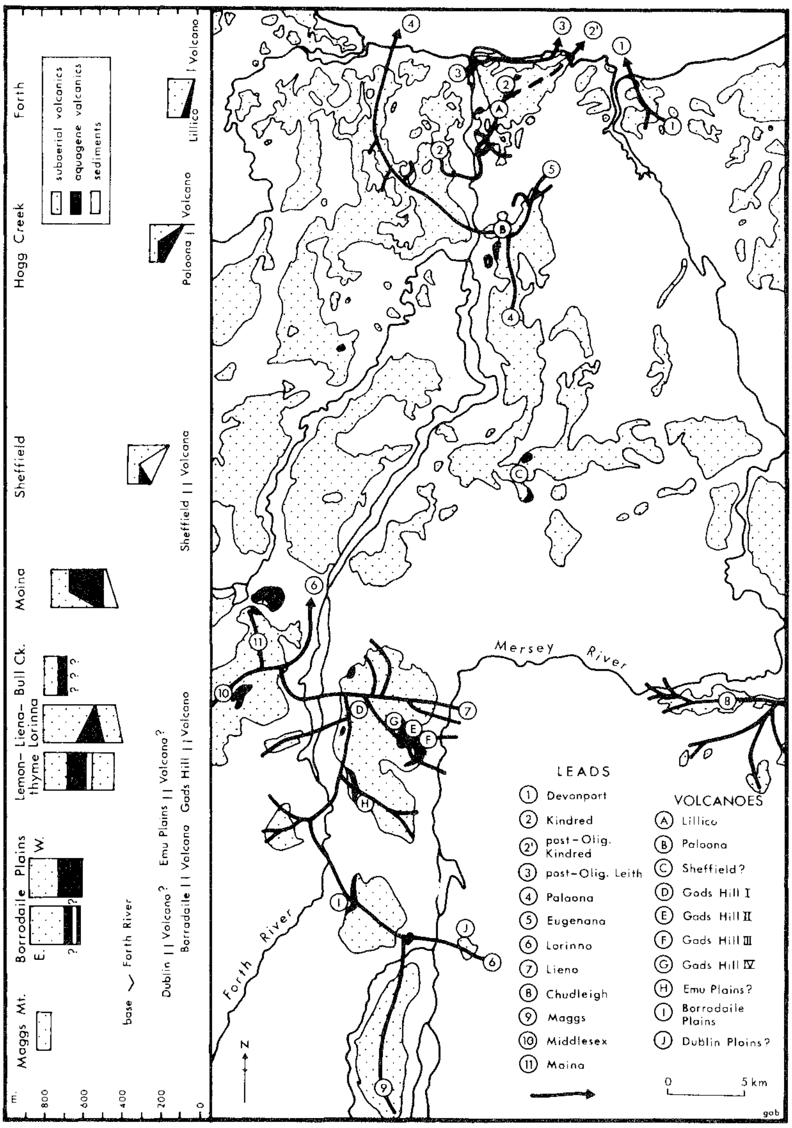


FIG. 4.- Distribution of aquagene volcanics (black areas) and volcanic centres (lettered circles) in relation to deep leads (numbered circles) of the ancestral Mersey-Forth drainage (after Jennings 1963 and Burns 1964). Volcanic sections with aquagene volcanics, showing relative elevations and thicknesses, are shown opposite their projected geographic position on the map.

where they dip 20-25° westerly, but are disfigured by landslips on the north side. They are capped by massive scoriaceous to columnar flows from 620m to over 800m elevation on Emu Plains. Massive basalt with a vertical to bulbous lateral contact cuts the breccias on Olivers Road (Grid ref. 8114-DP324988) and may form a feeder dyke for a capping flow.

The Ration Tree Creek section is strongly zeolitized (Sutherland 1965, 1976b) and secondary minerals will be detailed elsewhere. The species and habits would require burial depths around 700-1500m to form, but as zeolitization is irregular in the Upper Mersey-Forth sequences and overtopping into the Mole Creek Valley is not substantial (Jennings 1963), it more likely reflects elevated temperatures during late-stage extrusion from the Gads Hill volcano.

A four stage growth is suggested for this volcano (figure 5).

a) subaerial lavas blocked the Lorinna-Liena Leads north of Gads Hill, damming the Liena Lead.
b) phreatic eruption of tuffs and breccias further ponded the drainage into a substantial lake.
c) eruption of subaerial lavas into the lake built a delta of flow foot breccias westwards.
d) overtopping of the lake by subaerial lavas fed from dykes and late stage zeolitization around the centre.

The distribution of the volcanics suggests fissure-like growth (figure 5), possibly with some east-south-easterly migration of activity, and location on a north-westerly trending basement fault extending from Moina (Jennings 1963).

Emu-Borrodaile Plains volcanoes

Flow foot breccias in Lemonthyme Road near Addison Creek are stratigraphically higher (580-675m elevation) and unrelated in dip to Ration Tree Creek breccias. The lowest breccias (580-600m elevation) overlie and partly intrude fine-grained mudstone and minor hyaloclastite tuff. Pillowy intrusive tongues (Plate 8) dip north-north-westerly up to 25°, a similar attitude to underlying boulder beds and flow. This suggests a source under Emu Plains which changed to aquagene volcanism, probably from damming of the southern Lorinna Lead by growth of the Gads Hill volcano.

The highest Lemonthyme Road breccias (600-675m elevation) dip up to 40° north-north-easterly to north-easterly. This suggests eruption into the ponded Lorinna Lead from a further upstream source, probably near Borrodaile Creek, where 120m of zeolitized tachylytic tuffs and overlying flow foot breccias are exposed in landslips. Growth of this Borrodaile volcano would dam higher drainage and build the aquagene volcanics to elevations of 720m.

Unzeolitized flow foot breccias, 15m thick, dip south westerly below Borrodaile Plains around 620m elevation in the Mersey-Arm junction road (Grid ref. 8114 DP-331853), above 10m of massive basalt and sub-basaltic sediments. The lowest basalts in the section, they appear unconnected to the Borrodaile centre, but may relate to flows between 600-760m elevation east at Dublin Plains (Ford 1960). Eruption from Dublin Plains into the Lorinna-Maggs Lead junction could explain the limited damming and breccia flow direction.

Unzeolitized flow foot breccias at 660m elevation, dipping north from the Lorinna junction, 1 km south of Machinery Creek on Olivers Road, may represent flows that descended from upstream leads and backed into earlier dammed sections of Liena Lead.

Maggs Lead (Mersey 1:100 000 Sheet 8114)

Flows capping Maggs Mt above 760-880m elevation may be upstream continuations

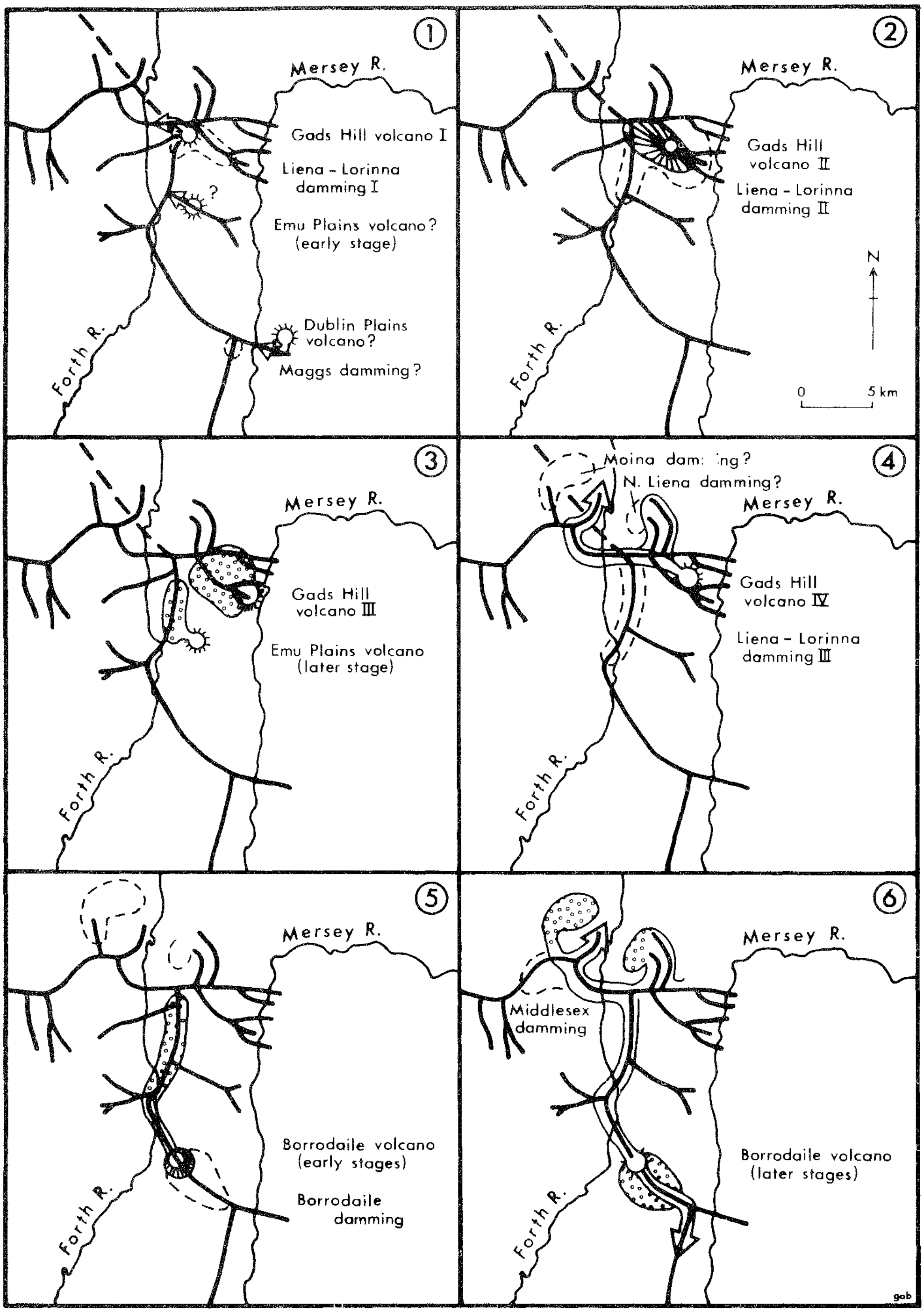

①
Mersey R.
Gads Hill volcano I
Liena - Lorinna damming I
?
Emu Plains volcano? (early stage)
Dublin Plains volcano?
Maggs damming?
Forth R.
②
Mersey R.
Gads Hill volcano II
Liena - Lorinna damming II
N
0
5 km
Forth R.
③
Mersey R.
Gads Hill volcano III
Emu Plains volcano (later stage)
Forth R.
④
Moina damming?
N. Liena damming?
Mersey R.
Gads Hill volcano IV
Liena - Lorinna damming III
Forth R.
⑤
Mersey R.
Borrodaile volcano (early stages)
Borrodaile damming
Forth R.
⑥
Mersey R.
Middlesex damming
Borrodaile volcano (later stages)
Forth R.
gab

FIGURE 5

from Borrodaile Plains (Spry 1958). Zeolitization in the basal Maggs succession, away from known centres, belongs to the top of the chabazite zone, usually developed under 200-700m of burial. This suggests less than 80-580m stripped from Borrodaile-Maggs successions.

The Forth River lies at 340-360m elevation relative to the present basalt top at 880m and estimated Miocene top between 960-1420m. This gives average lowering of 21-27m/m.y.(min.) to 43-54m/m.y.(max.) over the last 20-25 m.y. This exceeds average lowering for Tasmania (10-15m/m.y.) since burial of Jurassic dolerites (Sutherland 1977b), but is expected after late Mesozoic/early Tertiary epeirogeny.

Middlesex-Moina Leads (Forth & Mersey 1:100 000 Sheets 8115 & 8114)

These leads joined the Lorinna Lead (Jennings 1963). The Moina Lead contains basalt breccias associated with Early Miocene sediments above 490m elevation (Paterson 1967). The breccias reach 660m elevation on Cradle Mountain Road and are unzeolitized with south-westerly to south-easterly dips. Massive basalts occur down from Moina to 540m elevation 0.75 km along Lake Gairdner Dam Road where they are updragged (?) against easterly-dipping sands overlying Ordovician sandstones.

The breccias suggest a dammed Moina lead, either blocked locally or by flows in the Middlesex or Lorinna Leads, before overtopping with lavas to over 760m elevation. Absence of phreatic tuffs and zeolitization favours distant sources for the breccias.

Flow foot breccias, over 40m thick, underlie massive lavas at 720m in the Middlesex Lead at Bull Creek. Mildly zeolitized, they dip easterly from an upstream source and are the highest breccias found in the Mersey-Forth Leads. They may owe their elevation to damming of the Lorinna Lead by the Borrodaile flows.

Paloona-Kindred Leads (Forth 1:100 000 Sheet 8115)

The ancestral Forth probably flowed into Bass Basin via Paloona and Kindred Leads (Burns 1964). The oldest flows under Miocene (?) sediments petrographically match late Eocene-early Oligocene alkali basalts and olivine nephelinite in the adjacent Devonport Lead (Sutherland 1973a).

Forth volcano. 'Pyroclastics' are common in the Don-Forth interfluve (Burns 1964). Tachylytic lapilli tuffs are interbedded with flows south of Lillicos Beach (Grid ref. 8115-DQ400423) and flow foot breccias extend from 50-75m elevation below Forthside Hill in Fulton Creek down to 15m elevation 0.5 km east of Forth Post Office. The tuffs rest on alkali basalt but petrographically resemble the flow foot breccias and olivine tholeiite flows that extend north east to 40m high cliffs at Don Heads.

The Fulton Creek breccias, zeolitized with tacharanite, suggests a nearby centre between Lillico and Forth, which dammed upstream drainage. The capping flows diverted the Paloona Lead westwards and developed the post-Oligocene Leith Lead across the old Kindred Lead. The new Kindred Lead shifted eastwards and post-Oligocene flow fillings can be traced from Forthside Hill to Don Heads.

Paloona-Sheffield volcanoes. Gorge-blocking agglomerate in Hogg Creek (Burns 1964) is flow foot breccia formed after initial damming by flows downstream of Paloona. Vitric

---

FIG. 5.- Tentative reconstruction of volcanic history, Upper Mersey-Forth Leads (strong lines) from initial eruption of flows into the Liena-Lorinna Leads up to filling of the Maggs Lead and damming of the Middlesex Lead (1-6), with volcanic vents (hachured circles), valley filling flows (symbolic arrowed directions, not showing flow into all tributaries), approximate limits of upstream damming (dashed areas), phreatic cones (shaded deposits), flow foot breccias (open dotted areas) and major fault (strong dashed line).

tuffs above Tertiary sands in the Eugenana Lead (Burns 1964) may represent phreatic emergence of the Paloona volcano. The breccias at 80-200m elevation east of Hogg Creek dip north-north-easterly to west-south-westerly and converge on a focus about 1.5 km south of Paloona. They are moderately zeolitized, but further upstream west of Hogg Creek, between 180-200m elevation in Paloona Power Station road cuts, breccias under capping flows (Plate 9) are unzeolitized.

The Paloona centre erupted olivine tholeiites, but other flows in the Lead include alkali basalts. The higher flows extensively dammed the Lead to form Lake Sheffield and its sediments reach 300m elevation south of Sheffield.

Flow foot breccias overlie Lake Sheffield sediments in poor exposures on Claude Road and in abandoned railway cuts 2-3 km south-west of Sheffield. They are olivine tholeiites and fresh specimens from railway excavations donated to the Queen Victoria Museum, Launceston, in 1914 are strongly zeolitized with development of tacharanite. This suggests eruption into southern Lake Sheffield from a nearby centre.

PLATE 7.- Cliffs of flow foot breccias, dipping westwards under capping lavas, south side Ration Tree Creek above Olivers Road, Upper Mersey Valley. Underlying tuffs form the poorly exposed foreground.

Mersey-Forth Aquagene Volcanism

Aquagene volcanics in Mersey-Forth Leads relate to six and possibly eight or more centres (figure 5). Flow foot breccias suggest waters up to 120m deep, backing upstream up to 15 km from blockages. Breccias lie successively higher upstream (figure 5), corresponding roughly to order of eruption, with pre-Miocene breccias in the lower Kindred and Paloona Leads and Miocene breccias in the higher Lorinna, Liena, Moina and Middlesex Leads.

Most aquagene centres erupted olivine tholeiites. In the Upper Mersey-Forth lower flows include alkali and transitional basalts, but with vigorous growth of Gads Hill and Borrodaile volcanoes initiating aquagene activity, tholeiitic basalts appear and dominate the capping lavas (petrologic examinations; Spry 1958 and this study).

Zeolitization in the Mersey-Forth basalts is patchy, becoming more intense with higher temperature associations around large centres with several eruptive phases (Gads Hill volcano). Away from eruptive centres, low grade zeolitization may develop by burial in thicker sequences (Maggs Mt).

PLATE 8.- Pillowy lava bulbs and tongues intruding sediments and dipping north-easterly, Lemonthyme Road, south of Addison Creek, Upper Forth Valley.

Other Aquagene Volcanism

Other leads in north-western Tasmania contain aquagene volcanics, but many sequences are deeply weathered and poorly exposed. Flow foot breccias were observed in the Expressway near Penguin and east of Upper Castra. Extensive pyroclastics, up to 200m thick, near West Ridgley, Cam River (Gee 1977) are partly tachylytic and may represent phreatic eruptions from the centre in a river section dammed by a basal flow.

DERWENT LEADS (Figures 6 & 7)

Basalts, with aquagene horizons, overlie Palaeocene-Oligocene sediments of the ancestral Derwent (Harris 1968) and are isotopically dated late Oligocene-early Miocene (21-30 m.y.; Sutherland *et al.* 1973 ; Sutherland 1976a). This survey describes aquagene volcanics at eighteen localities and the episodic damming is discussed in descending order downstream.

Nive Lead (Nive & Shannon 1:100 000 Sheets 8113 & 8213). Lavas erupted into the lead 14 km north west of Bronte Park from 900-600m elevation. Four flows of alkali, tholeiitic and transitional olivine basalts broaden west of Bronte, with a base at 560m elevation. They include 3-6m of pillowy lava and breccia under an olivine tholeiite at 650m on the Lyell Highway, east Nive crossing. Some diversion or damming of the Nive is indicated, possibly by downstream eruption from suspected dykes (Prider 1948) as basalts near Tarraleah contain glomeroporphyritic alkali basalt and orthopyroxene-olivine tholeiite, types not recognized at Bronte.

Flow foot breccias, over 10m thick, about 380m in elevation underlie massive olivine tholeiite on Long Spur (Grid ref. 8213-609050). This suggests flow into the Derwent-Nive junction dammed by earlier downstream lavas.

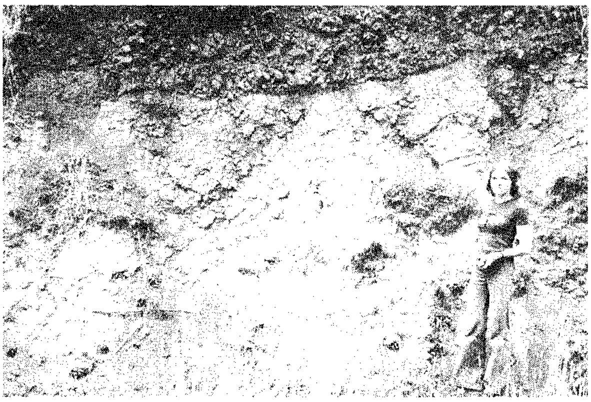


PLATE 9.- Massive lava overlying quench zone of flow foot breccias (weathered), Paloona Power Station Road, west of Hogg Creek.

Dee-Ouse Leads (Meander & Shannon 1:100 000 Sheets 8214 & 8213). Basalts fill the leads around Great Lake (Voisey 1949), Waddamana (Fairbridge 1949) and west of Ouse (Jennings 1955). The Waddamana section from 540-960m elevation includes olivine nephelinite, alkali olivine basalts, transitional olivine basalts, olivine tholeiites and tholeiite, with three horizons of flow foot breccias in Waddamana-Bashan Plains Road between 580-700m (Grid refs 8213-792325 to 801315). This suggests repeated damming until lavas overflowed divides into tributaries of the Ouse and Dee Leads.

Flows probably travelled considerable distances as petrographically related lavas occur around 920m elevation four and twelve km upstream and around 1000m elevation at Skittleball Plains seventeen km upstream of Waddamana. The Skittleball Plains tholeiite (23.6 m.y.) blocked the upper Ouse and may have ponded ancestral Great Lake, which received extensive phreatic tuffs and flow foot breccias from local emergent centres (Sutherland and Hale 1970; Sutherland *et al.* 1973; Sutherland 1973b). Older (65m thick) and younger (48m thick) aquagene successions with separate flow cappings suggest two pondings of Great Lake between 21.8 and 23.6 m.y., with later activity zeolitizing the earlier succession (Sutherland 1976b).

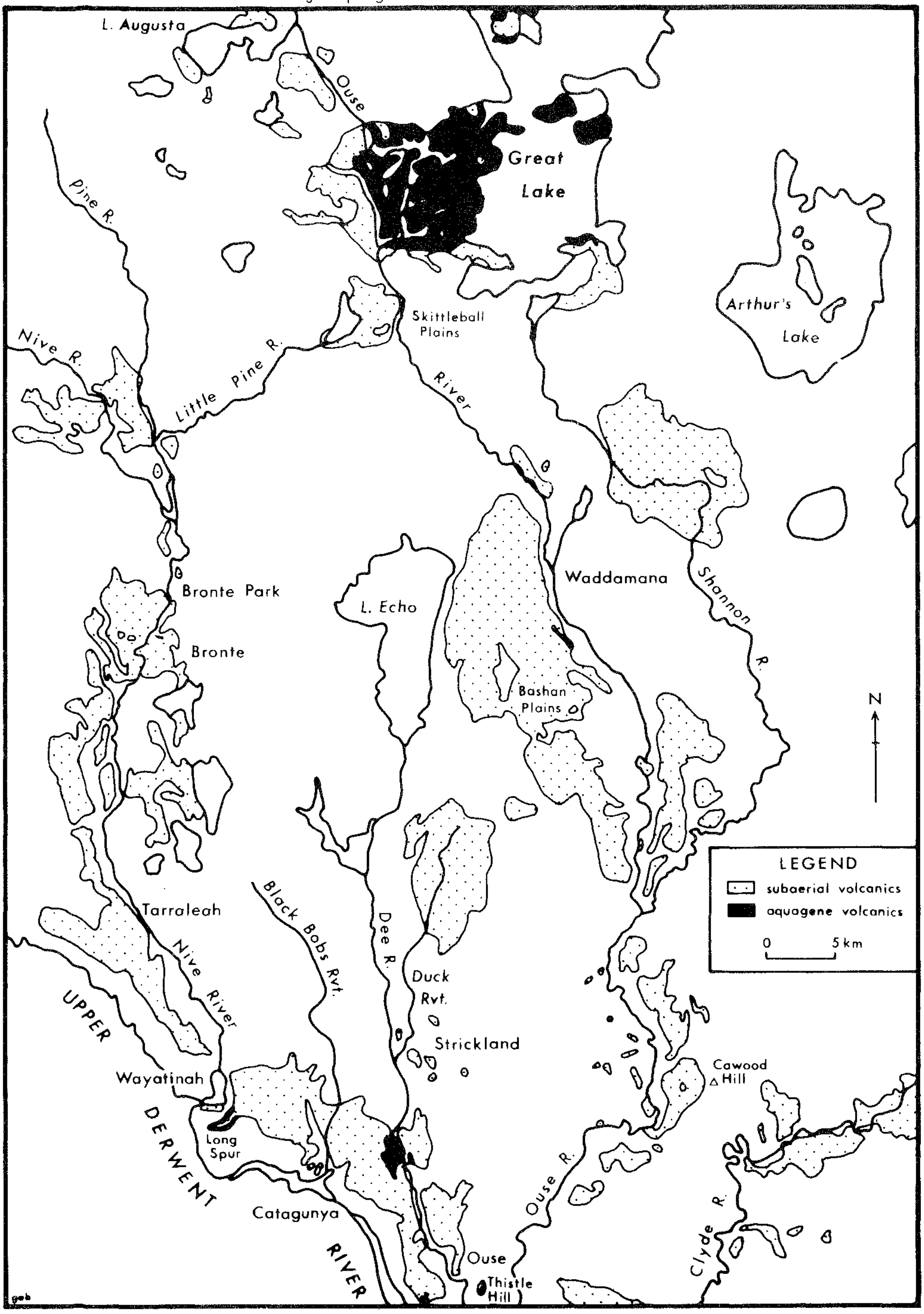


FIG. 6.- Distribution of aquagene volcanics in relation to basaltic fills and drainage, Upper Derwent and tributaries.

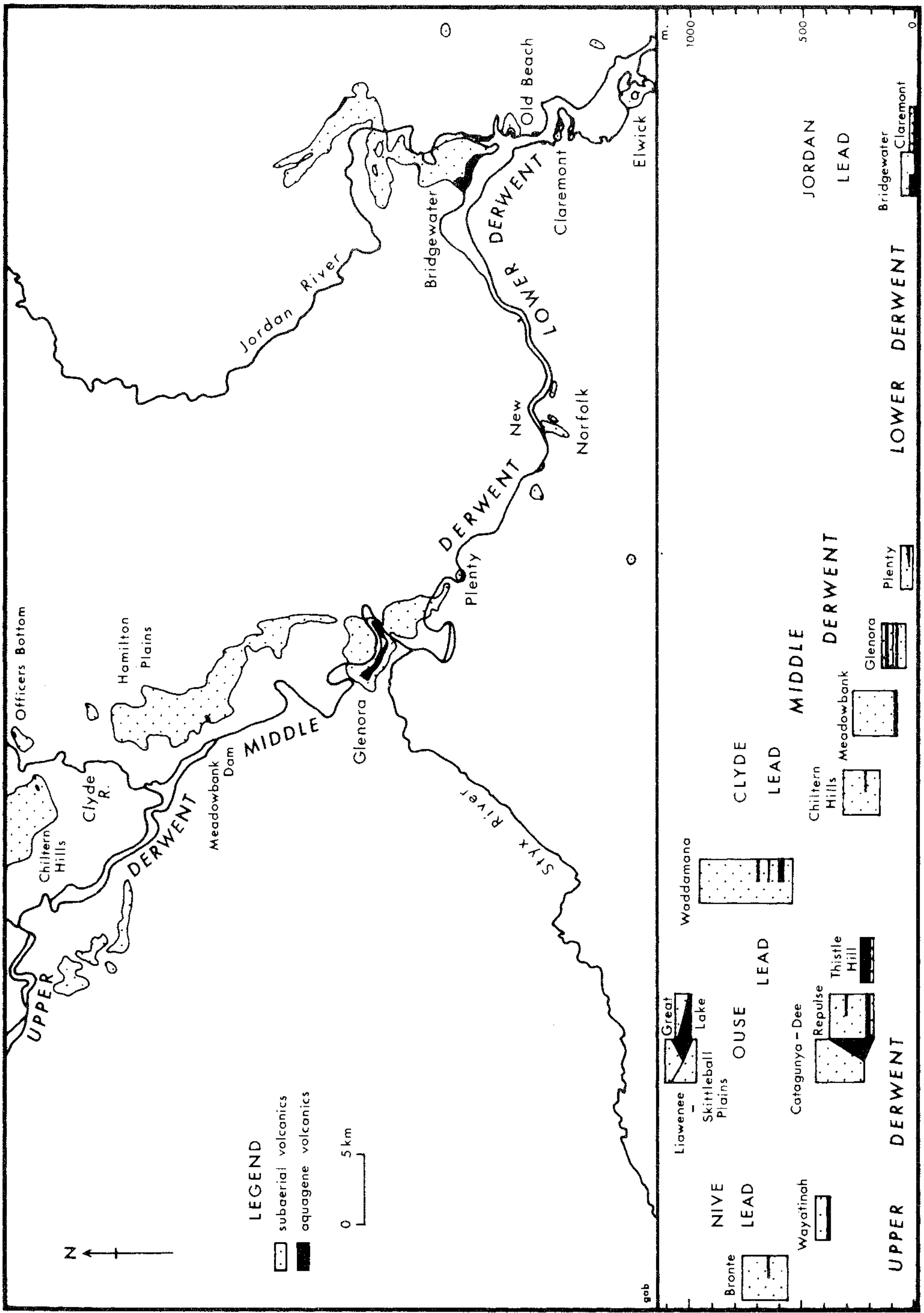


FIG. 7.- Distribution of aquagene volcanics in relation to basaltic fills and drainage, Middle-Lower Derwent and tributaries. Volcanic sections with aquagene volcanics, showing relative elevations and thicknesses, are shown below their projected geographic positions on the maps.

Repeated eruption down the lower Ouse and Dee Leads is represented by multiple flow remnants of up to twelve horizons in the Selma-Hartfield, Ousedale and Duck Creek - Strickland areas. Flow foot breccias appear in the Upper Derwent separated by lavas entering the lead below the Ouse and Dee junctions.

Upper Derwent Lead (Meander & Shannon 1:100 000 Sheets 8214 & 8213). The lowest flow foot breccias are olivine tholeiite capping massive alkali basalt around 200m elevation on Thistle Hill, 1.5 km south-west of Ouse. Two further horizons lie above Repulse Dam, 5.5 km west-south-west of Ouse. Tholeiitic breccias overlie massive olivine tholeiite above 200m elevation in a landslip and pass into massive tholeiite above 212m, and poorly exposed olivine tholeiite breccias appear around 312m elevation.

Extensive flow foot breccias in the Dee River banks along the highway 9 km north west of Ouse overlie massive basalt and sub-basaltic sediments above 200-320m elevation. The breccias dip easterly about 20° north-west of Dee crossing and are at least 45m thick, but possibly extend to 380m elevation for a maximum thickness of 180m. Massive capping flows, and draped interbasaltic sediments 3 km north-west of Dee crossing, outcrop up to 440m on Big Snake Hill. Breccias are not obvious west along Catagunya Road and massive flows fill the lead down to 220m elevation in Black Bobs Rivulet. The Dee-Catagunya basalts are all olivine tholeiites. Most probably entered down the Dee Lead, but dips in the breccias suggest some discharge into the Derwent from the Nive lead upstream.

Field and petrographic relationships tentatively suggest the following events —

a) Eruptions down Ouse or upstream leads repeatedly dammed the Derwent around Ouse and formed flow foot breccias at levels between 200-312 m elevation.
b) Eruptions down Dee Lead dammed the Derwent into a substantial lake between the Dee and Nive junctions.
c) Eruption down Nive Lead into the lake formed flow foot breccias to 380m elevation before overtopping.
d) Further eruptions down Dee Lead capped the Upper Derwent successions.

Clyde Lead (Shannon & Tyenna 1:100 000 Sheets 8213 & 8212). Basalts in Clyde Lead reach basal elevations of 370m east of Bothwell and include basanites, alkali basalts and olivine tholeiites. Sources are not obvious, but may include plugs at Shiners Hill, 12 km east-north-east of Bothwell, a vent-like breccia east of Sherwins Neck (Stephenson 1973) and overspilling from the Ouse Lead near Cawood Hill.

Minor flow foot breccias up to 3m thick are found in the flows in the lower Clyde east of Officers Bottom and around Chiltern Hills. They suggest limited local damming of the Clyde-Derwent junction by lavas descending these leads.

Middle Derwent Lead. Below Clyde junction, olivine tholeiites dominate Hamilton Plains - Meadowbank Dam sections. Basal flow foot breccias up to 10m thick on Meadowbank Dam road above 80m elevation, 0.5 km from the Dam, indicate downstream damming, possibly by lavas backing into the lead along Allendale Rivulet from a centre east of Glenora (Anandalwar 1960).

The Glenora centre incorporates at least seven flows of olivine tholeiite, with basal tuffs and breccias and pillow lava up to 15m thick, interbedded with fluvial and lacustrine sediments and fossil forests. The volcanic rocks overlie sediments of Lake Glenora and current bedded tachylytic tuffs and a pillowy horizon indicate episodic phreatic activity and quenching of lava.

Coarse tachylytic tuffs are interbedded with massive olivine tholeiites between 20-40m elevation above the Lyell Highway opposite Plenty. The overlying flows are interbedded with thin tuffaceous (?) sediment and on the north side overlie Tertiary conglomerates, sands and clays in a lead cut in Triassic sandstones. The conglomerate contains cobbles of scoriaceous olivine tholeiite, but precise relationships to the tuffs and lower basalt are unexposed. The tachylytic tuffs resemble phreatic deposits, possibly erupted from a local centre into a dammed course of the Derwent.

Lower Derwent Lead (Derwent 1:100 000 Sheet 8312). Massive basanite enters the Lead at New Norfolk, overlying basaltic conglomerates and sands and olivine tholeiite (Sutherland 1976a). It reaches 40 m elevation and may be responsible for the level of damming and phreatic eruption at Plenty.

Flow foot breccias near the Jordan-Derwent junction at Bridgewater are disconformably overlain by massive olivine tholeiite of the Brighton Basalt (Sutherland 1977a). The breccias dip west-south-westerly (n.b. not easterly as inadvertently recorded in Sutherland) and probably erupted locally into the Derwent estuary standing 25-30m above present level.

Water-laid tachylytic tuffs, associated with flow foot breccias and olivine tholeiite flows between Old Beach and Claremont, suggest eruption into a higher Derwent course from a centre north-east of Claremont (n.b. as located in fig. 6, Sutherland 1976a, and not north-west as inadvertently recorded in that text).

Aquagene volcanics in the Lower Derwent indicate stands up to 30-40m above the present estuary, either due to downstream damming by lavas at Bridgewater, Claremont, Elwick and East Risdon or due to high Miocene sea-levels around Tasmania.

Derwent Aquagene Volcanism

Aquagene volcanics in Derwent sections (figure 7) mostly follow massive flows which dammed watercourses. Phreatic deposits erupted from emerging centres at Great Lake, Glenora, Claremont and possibly Plenty, but most flow foot breccias discharged into dammed confluences. Zeolitization was only pronounced adjacent to extended activity at Great Lake.

The flow foot breccias indicate lake levels up to 250m above the present Derwent drainage and maximum water depths up to 180m. Capping subaerial lavas reach thicknesses and heights up to 420m above present river levels, giving minimum erosion rates of 17-21m/m.y. for the last 20-25 m.y.

TASMANIAN SYNTHESIS

Tasmanian aquagene volcanism coincided with extensive Oligocene - Miocene outpourings and is concentrated in regions of Miocene marine transgression (north-western coast and off-shore islands) and major basaltic leads (Mersey-Forth and Derwent drainages). Further substantial finds are unlikely as most basaltic areas have been studied.

Coastal aquagene volcanism provides additional information on relative Miocene sea-levels. The inland aquagene volcanism provides information on repeated blocking and damming of the leads. The most continuous aquagene sections appear in coastal exposures, possibly due to eruption into widespread marine waters and good exposure in sea cliffs, but equivalent outcrop distances (up to 6 km) and thicknesses (over 80m) occur within inland leads.

Most aquagene volcanics are olivine tholeiites, with some examples of alkali or transitional olivine basalts and tholeiite. This probably reflects the most voluminous compositions erupted during wide spreading melting in the peak of volcanism and aquagene activity.

AUSTRALIAN COMPARISONS

The Tasmanian occurrences provide the best range of Cainozoic aquagene volcanism in Australia, compared with sporadic examples reported elsewhere in eastern Australia.

South East Australia

Vitric tuffs and tuffites drilled in Bass Strait are probably extensively developed in Miocene cones identified in marine seismic sections (Brown 1976). They represent submarine equivalents of north-western Tasmania coastal and island aquagene volcanoes.

In the Victorian Older Basalts, pillowy lava interbedded with early Miocene marine beds (Bowler 1963) is typical flow foot breccia formed by flow over the Miocene shore. Similar breccias in the Newer Volcanics on Lady Julia Percy Island (Stach and McIvor 1937) probably represent emergent eruption into Pleistocene seas. Maars, a feature of the Newer Volcanics in Western Victoria - South Australia, represent phreatic eruptions (Ollier and Joyce 1964) but such features are not preserved in the older Tasmanian province.

Aquagene volcanics are not well documented in New South Wales, but include flow foot breccias under a basalt plateau near Tuena, 0.5 km south of Abercrombie River, 1 km west of Noarla Homestead (P. Morrissey and author's observations).

North-eastern Australia

In the younger Queensland volcanics, maar-like tuff rings around Atherton (deKeyser *et al.* 1968) may result from activity in a high rainfall district (Stephenson *et al.* 1979).

Agglomerates and tuffs on Stevens Island, South Barnard Group (deKeyser and Lucas 1968) show features resembling phreatic and base surge deposits (R. Gunthorpe and author's observations). Similar palagonitic tuffs and agglomerates, with cross beds and scours, and some pillow lavas in volcanic islands in Torres Strait are related to phreatic and subaqueous activity as cones emerged from Pleistocene seas (Willmott *et al.* 1973).

Pillowed younger basalts have been noted in the Herbert and Wild River leads, west of Ingham-Innisfail region and minor flow foot breccia underlies Oligocene basalt on Recliffe Plateau. northern Bowen Basin (Stephenson *et al.* 1979).

South-West Pacific - Southern Ocean

Vitric tuffs and flow foot breccias below sheet lava in Norfolk and Phillip Island basalts, South West Pacific, are attributed to emergent eruption into Pliocene seas forming phreatic and quench features (Jones and McDougall 1973). They closely match structures in coastal island volcanoes of north-western Tasmania.

Cainozoic aquagene volcanism occurred on spreading sea-floors bounding the Tasmanian and Australian coasts (Veevers and McElhinny 1976). Pillows with intercalated oceanic ooze were drilled in Late Eocene basalt basement about 150 km west of Tasmania (DSDP Site 282; Kennett *et al.* 1975). Aquagene oceanic Miocene basalts exposed on Macquarie Island (Varne and Rubenach 1972) contrast with Tasmanian continental aquagene basalts in being metamorphosed to green schist facies and associated with amphibolite facies intrusives.

ACKNOWLEDGEMENTS

Considerable help was received from officers of the Hydro-Electricity Commission, Tasmania, in arranging hire of vehicles for much of the field work. Mr. G.E. Hale and staff, Geology Section, H.E.C., provided copies of many geological maps and drilling records. Mr. R.H. Green, Queen Victoria Museum, Launceston, provided accommodation and assistance in the Mersey-Forth area and information on Black Pyramid Island. Mr. P. McGuire and family provided accommodation and assistance with travel on Hunter Island, where the author was accompanied by Mr. D.J. Jennings, Tasmanian Department of Mines. Miss S. Bowdler, Department of Prehistory, Australian National University, supplied material from Steep Island. Mr. M.E. Murrell accompanied the field trip to Robbins Island. Mr. B. Ritchie, Van Diemen's Land Co., gave permission for field work on the property at Flat Topped Bluff. Ms J. Hingley, the Australian Museum, assisted with field work in north-western Tasmania.

The project was initially sponsored by the Tasmanian Museum and Art Gallery, under the Director, Mr. D. Gregg, prior to its continuation on the author's employment at the Australian Museum. Dr. P.G. Quilty, School of Earth Sciences, Macquarie University, kindly examined material for fossils from Flat Topped Bluff. Dr. M.R. Banks, Geology Department, University of Tasmania commented on the script.

REFERENCES

Anandalwar, M.A., 1960: Geology and structure of the Middle Derwent Valley. *Pap. Proc. R. Soc. Tasm.*, 94: 13-24.

Banks, M.R., 1955: Tertiary fossil forest at Macquarie Plains. *Tasmanian Naturalist*, II(3): 1-11.

__________, 1962a: Volcanism *in* Cainozoic. In Spry, A. and Banks, M.R. (Eds): GEOLOGY OF TASMANIA. *J. geol. Soc. Aust.*, 9: 233-253.

__________, 1962b: Marine Succession. In Cainozoic, *ibid.*

Bowler, J.M., 1963: Tertiary stratigraphy and sedimentation in the Geelong-Maude area, Victoria. *Proc. R. Soc. Vict.*, 76: 69-137.

Brown, B.R., 1976: Bass Basin - Some aspects of the petroleum geology. In Leslie, R.B., Evans, H.J. and Knight, C.L. (Eds): ECONOMIC GEOLOGY OF AUSTRALIA AND PAPUA NEW GUINEA - 3. PETROLEUM. Aust. Inst. Min. Metall., Parkville, Victoria, 67-82.

Burns, K.L., 1964: One mile Geological map series K/55-6-29, Devonport. *Explan. Rep. geol. Surv. Tasm.*

Colhoun, E.A., 1978: Recent Quaternary and geomorphological studies in Tasmania. *Austr. Quat. Newsletter*, 9: 5-13.

Fairbridge, R.W., 1949: The geology of the country around Waddamana, Central Tasmania. *Pap. Proc. R. Soc. Tasm.* (1948): 111-151.

Ford, R.J., 1960: The geology of the Fisher River area. *Pap. Proc. R. Soc. Tasm.*, 94: 25-32.

Gee, R.D., 1977: Geological Atlas 1 mile series. Zone 7 Sheet 28 (8015N). Burnie. *Explan. Rep. geol. Surv. Tasm.*

Green, R.H. and Macdonald, D., 1963: The Black Pyramid gannetry. *The Emu*, 63(3): 177-184.

Harris, W.K., 1968: Tasmanian Tertiary and Quaternary microfloras. Summary Report. *Palaeont. Rep. geol. Surv. S.Aust.* 5/68.

Jennings, I.B., 1955: Geology of portion of the Middle Derwent area. *Pap. Proc. R. Soc. Tasm.*, 89: 169-190.

__________, 1963: One mile Geological map series K55-6-45, Middlesex. *Explan. Rep. geol. Surv. Tasm.*

Jennings, J.N., 1959: The coastal geomorphology of King Island, Bass Strait, in relation to changes in the relative level of land and sea. *Rec. Q. Vict. Mus.*, N.S. 11, 39 pp.

Jones, J.G. and McDougall, I., 1973: Geological history of Norfolk and Philip Islands, South West Pacific Ocean. *J. geol. Soc. Aust.*, 20: 239-257.

Kennett, J.P., Houtz, R.E., *et al.*, 1975: Initial Reports of the Deep Sea Drilling Project. XXIX, Washington (U.S. Government Printing Office). 9. Site 282: 317-363.

Kershaw, R.C. and Sutherland, F.L., 1972: Quaternary geomorphology of Flinders Island. *Rec. Q. Vict. Mus.*, 43.

Keyser, F. de, and Lucas, K.G., 1968: Geology of the Hodgkinson and Laura Basins, north Queensland. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.*, 84.

Ollier, C.D. and Joyce, E.B., 1964: Volcanic physiography of the western plains of Victoria. *Proc. R. Soc. Vict.*, 77: 357-376.

Paterson, S.J., 1967: Tertiary deep lead deposits in the Moina area. *Pap. Proc. R. Soc. Tasm.*, 101: 251-260.

Prider, R.T., 1948: Geology of the country around Tarraleah, Tasmania. *Pap. Proc. R. Soc. Tasm.* (1947): 127-150.

Quilty, P.G., 1972: The biostratigraphy of the Tasmanian Marine Tertiary. *Pap. Proc. R. Soc. Tasm.*, 106: 25-44.

____________, 1977: Cenozoic sedimentation cycles in Western Australia. *Geology*, 5: 336-340.

Rawlings, G.E., 1967: Sub-basaltic sediments and metasediments of the Mersey-Forth area. *Pap. Proc. R. Soc. Tasm.*, 101: 267-270.

Spry, A.H., 1958: Precambrian rocks of Tasmania, part III. Mersey-Forth area. *Pap. Proc. R. Soc. Tasm.*, 92: 117-137.

Stach, L.W. and McIvor, E., 1937: Lady Julia Percy Island - general geology: petrology. McCoy Society. *Proc. R. Soc. Vict.*, 49(2): 336-348.

Stephenson, P.C., 1973: Geological examination of No. 5 dam site on the Clyde River. *Tech. Rep. Dep. Mines Tasm.*, 16: 195-198.

Stephenson, P.J., Griffin, T.J. and Sutherland, F.L., 1979 in prep: Cainozoic volcanism in Northeastern Australia. In Henderson, R.A. and Stephenson, P.J. (Eds.) GEOLOGY & GEOPHYSICS OF NORTH EASTERN AUSTRALIA. *Geol. Soc. Aust. Qd Div.*, James Cook Univ. Press, Townsville.

Sutherland, F.L., 1965: Some new occurrences of zeolites and associated minerals in the Tertiary basalts of Tasmania. *Aust. J. Sci.*, 28: 26.

_______________, 1969: A review of the Tasmanian Cainozoic volcanic province. *Spec. Publs geol. Soc. Aust.*, 2: 133-144.

_______________, 1971: The geology and petrology of the Tertiary volcanic rocks of the Tamar Trough, northern Tasmania. *Rec. Q. Vict. Mus.*, 36.

_______________, 1973a: The geological development of the southern shores and islands of Bass Strait. *Proc. R. Soc. Vict.*, 85(2): 133-144.

_______________, 1973b: Igneous rocks, Central Plateau. In Banks, M.R. (Ed.): THE LAKE COUNTRY OF TASMANIA. *R. Soc. Tasm.*, Hobart: 43-54.

_______________, 1976a: Cainozoic volcanic rocks. In Leaman, D.E., Geological Atlas 1:50 000 series. Sheet 82 (8312S). Hobart. *Explan. Rep. geol. Surv. Tasm.* 35-56 and Appendix 5, 111.

_______________, 1976b: Tacharanite from Tasmania. *Min. Mag.*, 40: 887-890.

_______________, 1977a: Cainozoic volcanic rocks. In Leaman, D.E., Geological Atlas 1:50 000 series. Sheet 75 (8312N). Brighton. *Explan. Rept. geol. surv. Tasm.* 25-37.

_______________, 1977b: Zeolite minerals in the Jurassic dolerites of Tasmania: their use as possible indicators of burial depth. *J. geol. Soc. Aust.*, 24: 171-178.

_______________ and Corbett, K.D., 1967: The Tertiary volcanic rocks of far north-western Tasmania. *Pap. Proc. R. Soc. Tasm.*, 101: 71-90.

_______________ and Hale, G.E.A., 1970: Cainozoic volcanism in and around Great Lake, Central Tasmania. *Pap. Proc. R. Soc. Tasm.*, 104: 17-32.

_______________, Green, D.C. and Wyatt, B.W., 1973: Age of the Great Lake basalts, Tasmania, in relation to Australian Cainozoic volcanism. *J. geol. Soc. Aust.*, 20: 85-93.

Varne, R. and Rubenach, M.J., 1972: Geology of Macquarie Island and its relationship to oceanic crust. In Hayes, D.E. (Ed.): ANTARCTIC OCEANOLOGY II: THE AUSTRALIAN-NEW ZEALAND SECTOR, ANTARCTIC RES. SERIES, 19: 251-266. *Amer. Geophys. Union*, Washington, D.C.

Veevers, J.J. and McElhinny, M.W., 1976: The separation of Australia from other continents. *Earth-Sci. Rev.*, 12: 139-159.

Voisey, A.H., 1949: The geology of the country around Great Lake, Tasmania. *Pap. Proc. R. Soc. Tasm.* (1948): 95-104.

Willmott, W.F., Whitaker, W.G., Palfreyman, W.D., and Trail, D.S., 1973: Igneous and metamorphic rocks of Cape York Peninsula and Torres Strait. *Bull. Bur. Miner. Resour. Geol. Geophys. Aust.*, 135.