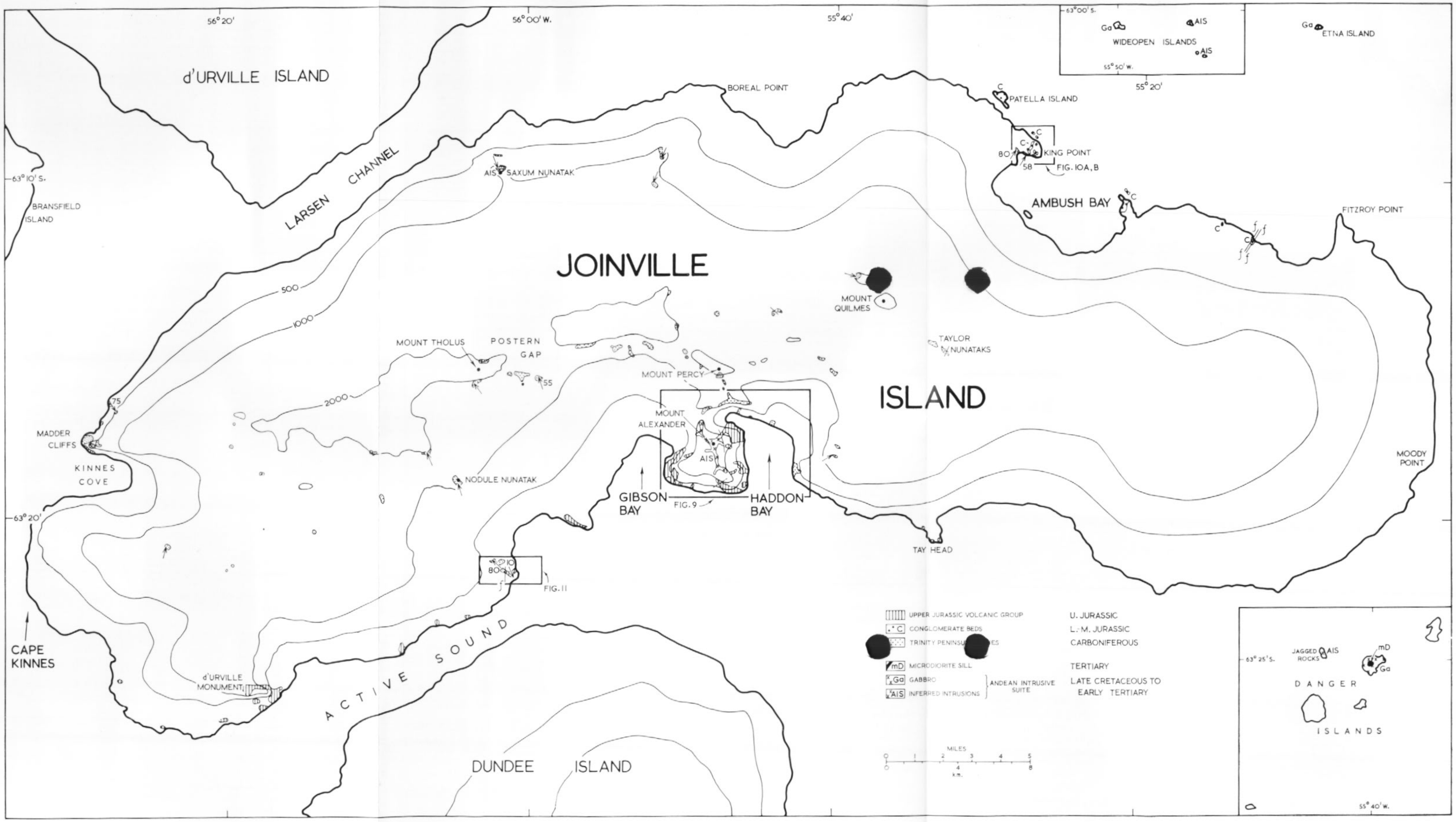

Fig. 2. Geological sketch map of the Joinville Island area. The contours are in feet.

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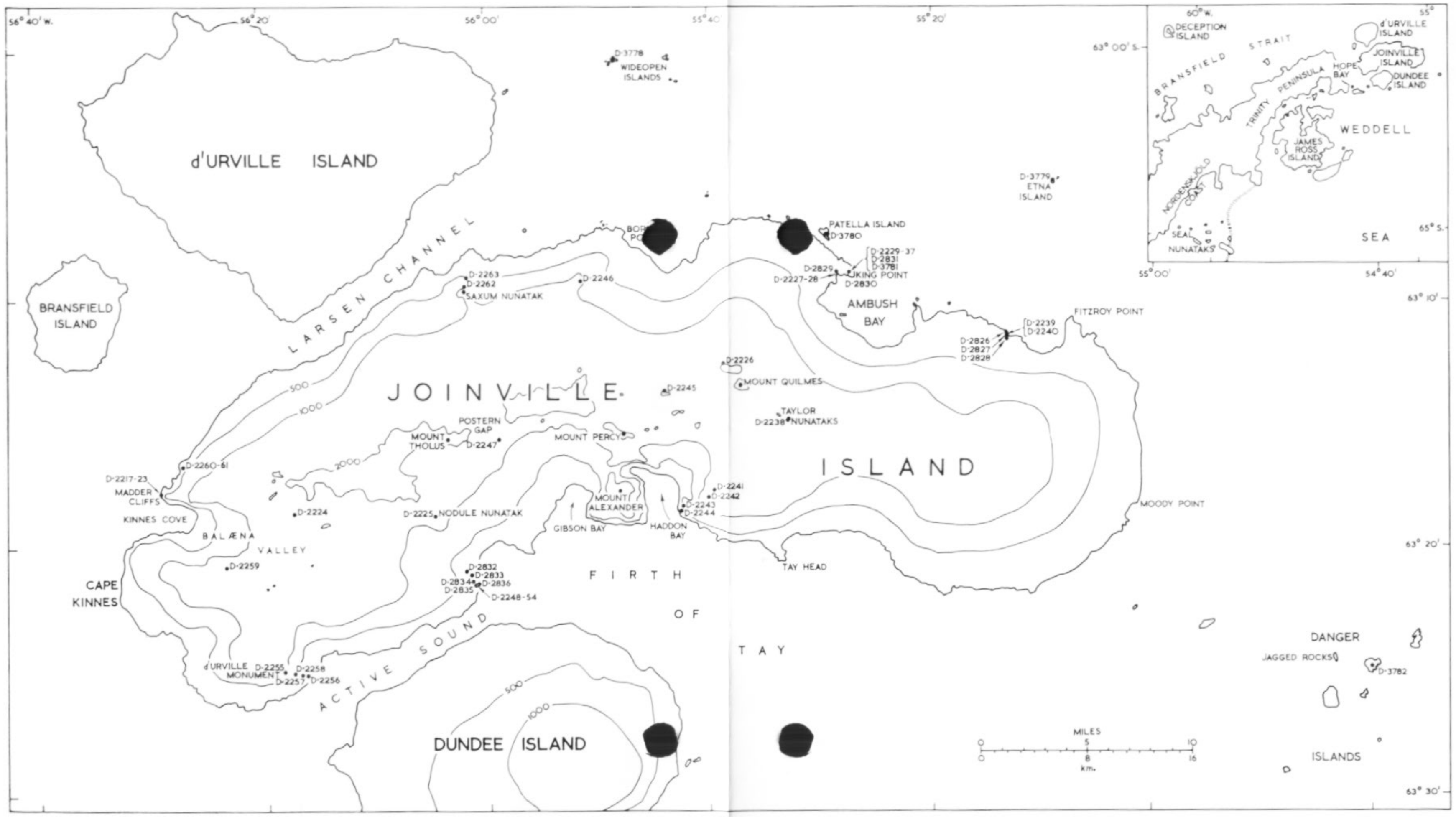


Fig. 1. Sketch map of the Joinville Island area showing the physiography, place-names and station numbers. The contours are at 500, 1,000 and 2,000 ft. (152, 305 and 610 m.). The inset shows the position of Joinville Island in relation to north-east Graham Land.

THE GEOLOGY OF JOINVILLE ISLAND

By D. H. ELLIOT

ABSTRACT. Joinville Island is a geological continuation of north-east Graham Land, and folded geosynclinal sediments belonging to the Trinity Peninsula Series predominate over other rock types. These sediments are mainly sandstones and shales, and they have suffered orogenic folding about approximately east-north-east axes during the early Mesozoic. These rocks are either unconformably overlain or faulted against gently dipping coarse conglomeratic sediments, of (?) Lower to Middle Jurassic age, which were derived mainly from the Trinity Peninsula Series and which probably underlie most of the eastern end of the island. Sub-horizontal intermediate to acid volcanic rocks of Upper Jurassic age occur along the north shore of Active Sound and at one locality they are faulted against the Trinity Peninsula Series. Gabbros of the Andean Intrusive Suite form a number of offshore islands; they are of interest because of their feldspathic character and the mineral layering and flow structure visible in the field. Intrusions of a similar age are inferred to have thermally metamorphosed some of the Trinity Peninsula Series siltstones near Haddon Bay and Mount Quilmes, and to be intruded into (?) volcanic rocks on the Mount Alexander peninsula. There are a few dykes, some of which, together with a small outcrop of basic rocks, have affinities to the Miocene James Ross Island Volcanic Group.

THIS paper brings together the unpublished field observations and preliminary reports on the geology of Joinville Island (lat. 63°15′S., long. 55°45′W.) and offshore islands by Croft (1947, Pt. 13), Standring (1956), Bibby (1960) and Nelson (Aitkenhead and Nelson, 1962). Stations D.2217-2263 were visited by Standring, D.2825-2836 by Bibby and D.3778-3782 by Nelson (Fig. 1).

As pointed out by Bibby (1960, p. 3), Joinville Island is dominated by the same climatic conditions that prevail on the west coast of Graham Land. There is a very extensive snow cover and rime ice obscures many outcrops; this results in the isolation of exposures, few relationships between rock groups, and it unfortunately renders difficult the interpretation of air photographs. The geology of north-east Graham Land was first described by the Swedish South Polar Expedition, 1901-03 (Nordenskjöld, 1905; Andersson, 1906), and the results of investigations since 1945 by the Falkland Islands Dependencies and British Antarctic Surveys have been summarized by Adie (1958), who has also given an up-to-date outline of the stratigraphy (1964). Recently, detailed reports on specific areas of north-east Graham Land have been published by Aitkenhead (1965), Elliot (1965, 1966), Bibby (1966) and Nelson (1966).

GENERAL STRATIGRAPHY

The stratigraphy and the inferred ages of the rocks of Joinville Island are set out in Table I. Folded geosynclinal sediments of the Trinity Peninsula Series form the greater part of Joinville Island (Fig. 2), including the mountainous area which trends eastwards from Madder Cliffs (Fig. 3a) to Taylor Nunataks, and it is only along the southern coast and the physiographically distinct eastern end of the island that rocks of other groups crop out. The folding of these geosynclinal sediments demonstrates that they are older than the other sediments and the volcanic rocks. Shallow-water conglomerates and sandstones occur at King Point and west of Fitzroy Point; they have been tentatively assigned a Lower to Middle Jurassic age and it is likely that they underlie most of the eastern end of the island. Intermediate to acid volcanic rocks of probable Upper Jurassic age form d'Urville Monument and the coastal outcrops in that area and to the east as far as Gibson Bay. Those islands to the east and north of Joinville Island which have been visited are composed of gabbros assigned to the Andean Intrusive Suite; thermal metamorphism of the Trinity Peninsula Series siltstones east of Haddon Bay and near Mount Quilmes was probably caused by intrusions of a similar age. It is suggested that the Mount Alexander peninsula is formed of volcanic rocks and members of the Andean Intrusive Suite. There are a few outcrops of rocks probably related to the James Ross Island Volcanic Group. A few dykes of indeterminate age occur at King Point and a Tertiary microdiorite sill caps the gabbro at one of the Danger Islands.

Br. Antarct. Surv. Bull., No. 12, 1967, p. 23-40.

TABLE I. GENERAL STRATIGRAPHICAL SUCCESSION OF JOINVILLE ISLAND

Age	*Succession*
Tertiary	Minor intrusions and a group of basic rocks
	Andean Intrusive Suite
Cretaceous	
Upper Jurassic	Volcanic group
(?) Lower to Middle Jurassic	Conglomerate beds
(?) Carboniferous	Trinity Peninsula Series

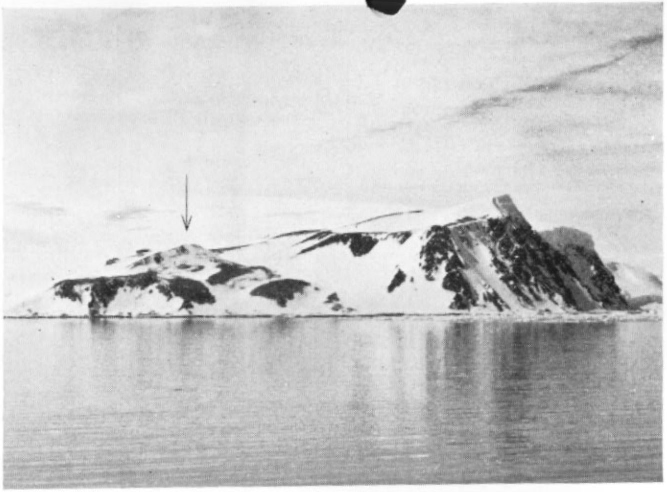
TRINITY PENINSULA SERIES

A folded sequence of clastic sediments forms the outcrops in the central range of the island and a few coastal exposures to the north and west. The succession has not been determined in detail, though Croft (1947, Pt. 13, p. 6) recorded greywackes and some siltstones at Madder Cliffs (Fig. 3b) but shales, although present, were not seen *in situ*. The greywackes were seen to enclose clay pebbles, mainly about 1 in. (2·5 cm.) in diameter, and at one place on the north-west facing part of the outcrop there is a sedimentary breccia interbedded with banded siltstone. Croft also noted that the greywackes are very similar to those of Scar Hills, Hope Bay. Standring (1956, p. 25) has stated that where much rock is exposed greywackes and sandstones predominate markedly over shales and siltstones, and that shales are more common along the central ridge of the island. Bibby (1960, p. 5) has given more detail for two localities: at Madder Cliffs there are interbedded greywackes and mudstones, the latter varying between 1 and 6 ft. (0·3 and 1·8 m.) in thickness, whereas the lithology at King Point is more varied and greywackes grade up into shales that are again succeeded by greywackes. The lower group of greywackes includes sandstones and in places conglomerates and intraformational breccias with which mudstone bands are interbedded. Both at Madder Cliffs and King Point quartz veining is prominent. The term "greywacke" is used here because it has been used by Croft, Standring and Bibby in their preliminary reports; the only specimens of the coarse sediments are immature feldspathic sandstones (p. 28)

The rocks examined microscopically are sandstones and siltstones, the latter including a number of thermally metamorphosed rocks which are described on p. 29. The coarse sediments are immature feldspathic sandstones which differ little from those of north-west Trinity Peninsula (Elliot, 1965, p. 4), and modal analyses of two of them are given in Table II (D.2225.2, 2238.1).

The sandstones are composed of quartz, feldspar and lithic fragments set in a fine-grained matrix of quartz and micaceous minerals (Fig. 4a). The quartz exhibits varying degrees of undulose extinction which must be primary because shearing of the rocks is only very slight. Much of plagioclase (Ab$_{88}$An$_{12}$ to Ab$_{97}$An$_{3}$) is altered but there is no clear-cut division of types as in the sediments from north-west Trinity Peninsula. Orthoclase is the dominant alkali-feldspar but a little microcline is also present. The lithic fragments are mainly of acid intrusive and extrusive rocks, of which fine-grained quartzo-feldspathic types are conspicuous

Fig. 3. a. Madder Cliffs at the western end of Joinville Island viewed from the west. Fig. 3b is a closer photograph of the north-western side of the rock outcrops (arrowed). (Photograph by H. E. Chapman.)
b. Greywackes of the Trinity Peninsula Series at Madder Cliffs viewed from the north-west. (Photograph by H. E. Chapman.)
c. d'Urville Monument at the south-west of Joinville Island viewed from the south. The outcrops are composed of rocks of the Upper Jurassic Volcanic Group. (Photograph by H. E. Chapman.)
d. Horizontal layering in (?) gabbros at Jagged Rocks, Danger Islands. (Photograph by P. H. H. Nelson.)



a

b

c

d

TABLE II. MODAL ANALYSES OF FIVE SANDSTONES FROM JOINVILLE ISLAND

Minerals and rock fragments			D.2225.2	D.2238.1	D.2236.1	D.2237.1	D.2239.3
Quartz	Folk's types	1	98	94	424	421	376
		2	56	41			
		3	43	82			
		4	0	0			
		5	8	13			
		6	0	3			
	Strain lamellae*		2	1	29	29	1
Plagioclase			201	271	158	167	314
Alkali-feldspar	Orthoclase		10	60	46	89	83
	Microcline		0	0	3	0	0
Igneous rock fragments	Granitic		31	38	18	25	25
	Granite-gneiss		2	8	0	0	0
	Acid volcanic		109	9	13	11	7
	Andesitic		7	0	0	0	1
Metamorphic rock fragments	Quartz-mica-schist		21	4	2	5	13
	Metasiltstone		0	0	7	0	0
Sedimentary rock fragments	Silt		10	1	35	1	0
	Shale		6	2	27	0	0
Detrital micas	Biotite		11	1	4	3	25
	Muscovite		2	2	4	7	5
Heavy minerals	Iron ore		2	13	16	15	11
	Leucoxene		5	3	2	0	0
	Zircon		2	2	1	0	0
	Apatite		0	0	0	0	1
Matrix			374	352	211	227	138

* Quartz grains with strain lamellae belong to type 3. 1,000 points were counted on each thin section.

D.2225.2	Sandstone from the Trinity Peninsula Series; Nodule Nunatak.
D.2238.1	Sandstone from the Trinity Peninsula Series; Taylor Nunataks.
D.2236.1	Sandstone from the conglomerate beds; King Point
D.2237.1	Sandstone from the conglomerate beds; King Point.
D.2239.3	Sandstone from the conglomerate beds; west of Fitzroy Point.

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e. A labradorite crystal with three composition zones: the most basic ($Ab_{44}An_{56}$) is pale grey, the intermediate ($Ab_{65}An_{35}$) is black and the acid (white; $Ab_{78}An_{22}$) forms the outer rim and also thin lamellae and the rectangular patches in the intermediate zone; gabbro at the Wideopen Islands (D.3778.1; X-nicols; ×40).

f. Glass shards in a vitric tuff; south-east of Kinnes Cove (D.2259.1; ordinary light; ×40).

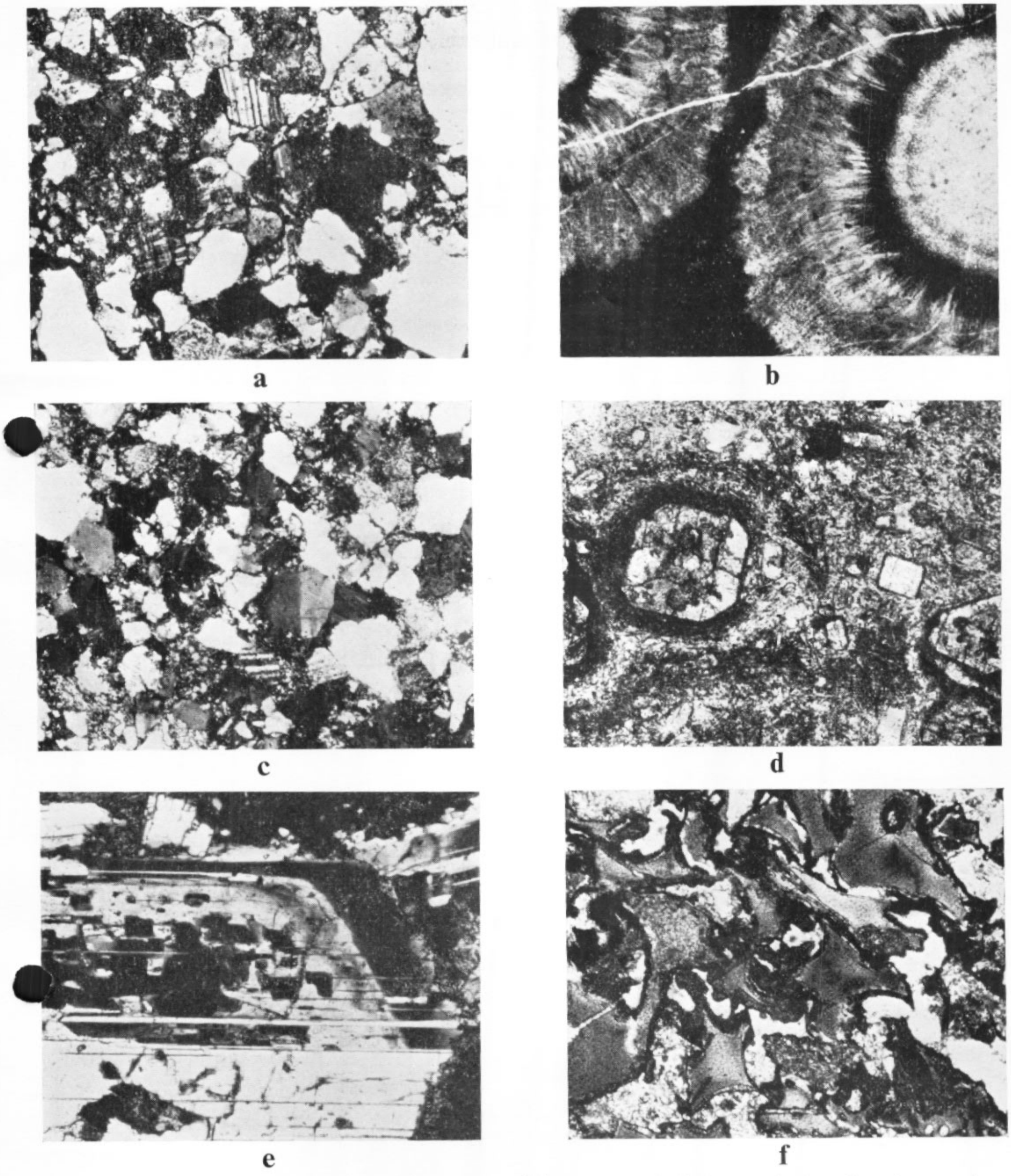

Fig. 4. a. A Trinity Peninsula Series sandstone comprising quartz, plagioclase and microcline clasts set in a fine-grained matrix; Taylor Nunataks (D.2238.1; X-nicols; ×40).

b. Quartz-haematite rock composed of quartz aggregates (white) with a chalcedony rim (black to grey) and interstitial haematite (black); a narrow quartz vein traverses the rock; east of Haddon Bay (D.2243.4; ordinary light; ×40).

c. A sandstone in which strain lamellae are visible in some quartz grains; conglomerate beds at King Point (D.2237.1; X-nicols; ×40).

d. Pseudomorphs after pyroxene set in a trachytic-textured matrix of plagioclase microlites in an intermediate lava; south-east of Nodule Nunatak (D.2835.5; ordinary light; ×40).

in one of the specimens (D.2225.2). There are a number of quartz-mica-schist and granite-gneiss fragments, and also some siltstones and shales which were probably penecontemporaneous. Biotite is conspicuous as a detrital mineral in one of the sediments (D.2225.2). The matrix is a fine-grained aggregate of quartz, micaceous minerals including sericite and chlorite, and irresolvable material. There has been a certain amount of corrosion of the clasts by the matrix.

The size distribution has been obtained from the thin-section data using McBride's (1962, p. 66) method. The results have been plotted as cumulative percentage curves (Fig. 5) and the sorting has been derived by the graphic standard deviation (Folk, 1959, p. 44). With about 35 per cent matrix (Table II, D.2225.2, 2238.1) and a moderately sorted sand-sized fraction (Fig. 5), these rocks can be considered as bimodal and exhibiting textural inversion. On Folk's (1959, p. 111) classification, which ignores the fine-grained matrix, these immature feldspathic sandstones are plagioclase-arenites of the arkose clan (Fig. 6). These sediments are directly comparable with those of north-west Trinity Peninsula (Elliot, 1965, figs. 5 and 6).

Brecciation is a common feature in a number of the siltstones; some of this was probably caused by penecontemporaneous plastic flow (D.2247.1), whereas in other cases it appears to be a dynamic effect and to have been accompanied by the introduction of quartz and pyrite (D.2227.2), and intense prehnitization (D.2224.1).

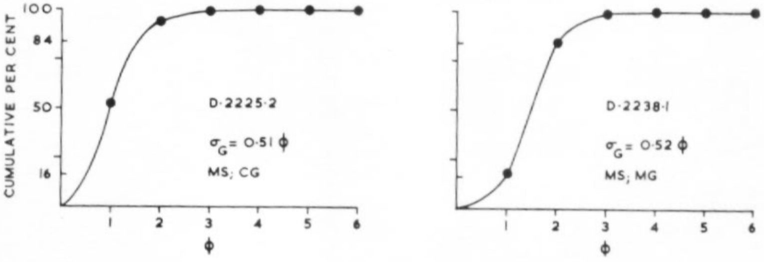

Fig. 5. Cumulative curves from the size-analysis data of the sand-sized fractions of two Trinity Peninsula Series sandstones from Joinville Island. $\sigma_G = (\phi 84 - \phi 16)/2$; MS moderately sorted; CG coarse-grained; MG medium-grained.

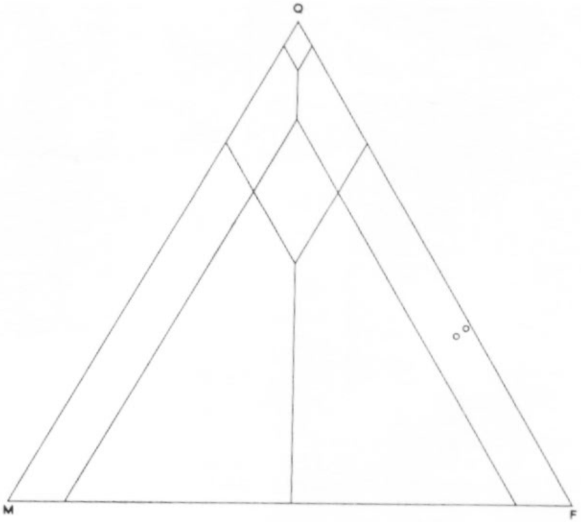

Fig. 6. Mineralogical classification (Folk, 1959, p. 111) of the two Trinity Peninsula Series sandstones from Joinville Island. Q quartz (less type 6)+chert; M metamorphic rock fragments+quartz of type 6; F plagioclase+alkali-feldspar+igneous rock fragments. Both sandstones belong to the arkose clan and are plagioclase-arenites.

The coarse siltstones are finer-grained varieties of the sandstones but without the lithic fragments. Angular to sub-rounded quartz, subordinate plagioclase and rare alkali-feldspar grains are set in an argillaceous matrix in which iron ore, sphene and zircon are the heavy minerals and which also includes coarser detrital muscovite and biotite flakes. The finer-grained rocks have an increased amount of argillaceous material and they pass into shales.

Thermal metamorphism

Siltstones, which have been thermally metamorphosed by unexposed intrusions, crop out near Mount Quilmes and east of Haddon Bay. These rocks are black hornfelses which lack definite sedimentary structures except in two instances (D.2242.1, 2) where a strong parting might be parallel to the original bedding. East of Haddon Bay they were medium- to coarse-grained siltstones which now comprise angular to sub-rounded quartz grains, micaceous minerals, recrystallized iron ore and a little oligoclase. Muscovite and biotite flakes are present, and they may be either unorientated or have a good parallelism which has probably been controlled by original sedimentary lamination. Cordierite spots are present in one rock (D.2241.1). The specimen from Mount Quilmes (D.2226.1) is brecciated and the composition of the fragments is not uniform. Some fragments are quartzo-feldspathic but most are formed of a medium-grained siltstone which has a few quartz crystals and iron ore grains set in unorientated biotite flakes. All these rocks belong to the albite-epidote-hornfels facies of contact metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 203-05).

The coastal outcrops east of Haddon Bay include some silicified and haematitized rocks. The least altered type (D.2243.1), which was probably derived from a siliceous siltstone, is a very fine-grained hornfels composed of quartz, chlorite, sericite and leucoxene. There are also a few quartz veins and these include biotite flakes which also occur in the main mass of the rock. The haematite forms some thin bands but most of it is finely dispersed.

The more altered rocks are dark red in colour, structureless and cut by veins of quartz and epidote; on fresh surfaces, one of them (D.2243.4) consists of aggregates (1–5 mm. across) of clear quartz surrounded by white fibrous radiating rims (up to 1·0 mm. wide), together with interstitial haematite. In thin section (Fig. 4b) this spherulitic rock is composed of numerous round aggregates of either quartz or quartz and chalcedony. The haematite is concentrated between the aggregates and it becomes dispersed on passing into the chalcedony rim; it is also disseminated in those quartz aggregates lacking chalcedony. Calcite occurs in a number of aggregates and in some of them it forms a ragged core to the quartz. There are a few epidote veinlets. Veinlets (0·01–0·05 mm. wide) of quartz traverse the rock and give it a brecciated appearance. In thin section the other rock (D.2243.3) has areas and lenses of haematite in a quartz groundmass. The rock was brecciated following the haematitization and this was accompanied by the introduction of some epidote and quartz which forms a network of veinlets.

One other rock in this area (D.2244.2) has been affected by this silicification. It is a fine-grained (0·01–0·05 mm.) mosaic of quartz with a little acid feldspar and some intergranular sericitic shreds. A little iron ore is present and there are stringers and areas of fine-grained epidote. The rock has been silicified and recrystallized but it is not known whether it was a siliceous siltstone or an acid volcanic tuff or lava, and because of this it is included with the other metasomatized rocks described above.

The haematitization is later than the thermal metamorphism, because at the grade of metamorphism which gives biotite the haematite would have been reduced to magnetite. It is inferred that the silicification and haematitization are either Andean or post-Andean in age. The quartz and epidote veins are later than the metasomatism.

Conglomerate Beds

West of Fitzroy Point, around Ambush Bay and at Patella Island shallow-water conglomeratic sediments crop out. Near Fitzroy Point they are sub-angular conglomerates of variable sorting and induration (Bibby, 1960, p. 5). The boulders, of which a few attain 8–10 ft. (2·4–3·0 m.) in length, are mainly cobble to pebble grade and they include greywackes, sandstones, mudstones and indurated shales; Standring noted that generally the boulders are sub-angular whereas the pebbles are rounded. A coarse sandstone forms the matrix which is current-bedded where it predominates. Coarse sandstones and siltstones are interbedded with the conglomerates.

At King Point, Bibby reported that the coarse constituents of the conglomerates are mainly pebble grade, better sorted and extremely well rounded. Standring observed a few boulders up to 2 ft. (0·6 m.) across and a few quartz and jasper pebbles in addition to those seen at the other locality. He also noted that, where the induration is slight, erosion has led to the formation of pillars with protective boulder caps. Coarse sandstones and pebbly sandstones with included siltstone fragments are also interbedded with the conglomerates. Patella Island (Aitkenhead and Nelson, 1962, p. 6) is composed of massive faintly bedded conglomerates (Fig. 7a) in which the cobbles are angular. The air photographs show that the promontory at the east side of Ambush Bay and the offshore islands north-west of King Point are geologically similar to Patella Island. One of the outcrops at Tay Head has been eroded to give boulder-capped pillars but the appearance on the air photographs is more like that of an outcrop of the (?) volcanic rocks on the Mount Alexander peninsula (p. 36), and it is therefore tentatively included with them.

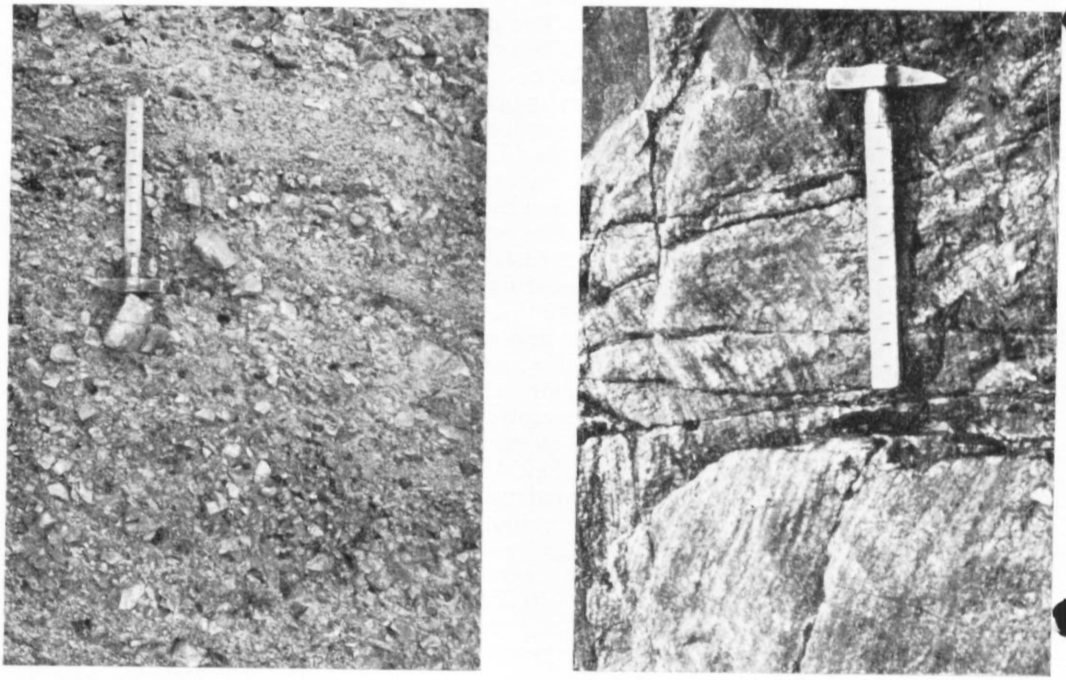

Fig. 7. a. Faintly bedded conglomerates of (?) early Mesozoic age; Patella Island (D.3780). (Photograph by P. H. H. Nelson.)
b. Banding a few inches in thickness in a gabbro; Etna Island (D.3779). (Photograph by P. H. H. Nelson.)

The composition of the boulders shows that the conglomerates have been derived mainly from the Trinity Peninsula Series (Bibby, 1960, p. 5) but there is no other positive indication of their age. According to Standring (1956, p. 25), they are reminiscent of the Jurassic conglomerates but they differ from those of Hope Bay and Church Point in having little or no bedding. Bibby (1960, p. 5), although remarking on their similarity to the thick conglomerate beds of Upper Cretaceous age on Sobral Peninsula, favoured a Lower to Middle Jurassic age. The plant remains recovered by Standring from King Point are too poorly preserved for positive identification. The absence of volcanic fragments, which are conspicuous in the Sobral Peninsula conglomerates (Elliot, 1966, p. 15), favours the age suggested by Bibby, although the degree of induration is similar to that of the Upper Cretaceous sediments.

A few of the finer sediments have been examined microscopically and modal analyses are given in Table II (D.2236.1, 2237.1, 2239.3). However, too much significance should not be attached to these modes because the sandstones are interbedded with conglomerates. These rocks are feldspathic sandstones but they differ from those of the Trinity Peninsula Series in their comparative freshness, lower percentage of matrix and greater quartz : feldspar ratio. Angular to sub-rounded quartz, plagioclase and alkali-feldspar grains, and lithic fragments are set in a fine-silt to clay-sized matrix of quartz and micaceous minerals. The quartz grains include a number with strain lamellae (Fig. 4c) which suggests a source rock other than the Trinity Peninsula Series, because such grains are rare in those sediments and the metamorphic grade and immaturity of the sediments would not induce strain lamellae (Aitkenhead, 1965, p. 40; Elliot, 1965, p. 12). The plagioclase is mainly albite ($Ab_{90}An_{10}$–$Ab_{97}An_3$) but there is also a little acid andesine ($Ab_{64}An_{36}$–$Ab_{66}An_{34}$). Much of the plagioclase and alkali-feldspar is heavily sericitized. The grain-size is up to 0·6 mm. but the lithic fragments, particularly the siltstones in specimen D.2236.1, are much coarser (up to 1·5 mm.). The pebbly sandstone (D.2233.1) from King Point differs only in its slightly greater grain-size and the presence of pebbles, many of which are siltstones similar to those of the Trinity Peninsula Series (p. 29).

UPPER JURASSIC VOLCANIC GROUP

Intermediate to acid volcanic rocks assigned an Upper Jurassic age crop out near d'Urville Monument and in the coastal exposures eastwards to Gibson Bay. The coastal outcrop 3 miles (4·8 km.) south-east of Nodule Nunatak was closely examined by Bibby (1960, p. 5), who recorded rhyolites and andesites which are horizontal or dip slightly to the south-east. Petrographic examination of these rocks shows that they are intermediate to acid lavas, including some devitrified types, and a few acid tuffs. d'Urville Monument (Fig. 3c) was also briefly visited by both Standring and Bibby (1960, p. 8). An examination of the air photographs of this area does not reveal anything significant, and it is suggested that the predominant rocks are acid lavas similar to those examined microscopically and rock types similar to those occurring at the outcrop south-east of Nodule Nunatak. By inference, the small coastal exposures between these two localities and to the west of d'Urville Monument are also formed by such volcanic rocks, though the similarity of the Trinity Peninsula Series renders distinction on the air photographs difficult; south-east of Nodule Nunatak, where the Trinity Peninsula Series is known to occur close to the volcanic rocks, there is no distinctive change in the outcrop appearance. Volcanic rocks are also inferred to be present on the Mount Alexander peninsula (p. 36).

South-east of Nodule Nunatak

Those rocks which are not devitrified are intermediate to acid lavas, and in the hand specimen they have feldspar and ferromagnesian phenocrysts in aphanitic matrices. They are all severely altered and in many cases it is not possible to distinguish alkali-feldspar from plagioclase in thin section. The feldspar phenocrysts are up to 2·0 mm. in length; some are identifiable as plagioclase and a composition of $Ab_{69}An_{31}$ has been recorded (D.2834.1), whereas others are almost certainly alkali-feldspar. Pseudomorphs (up to 3·0 mm. in length) with pyroxene morphology are numerous; they are now composed of chlorite (D.2834.1), or quartz and chlorite (D.2835.2), or chlorite and sericite (D.2835.5; Fig. 4d). The matrix has a trachytic texture of feldspar microlites (0·05 mm. long) with some chlorite and finely disseminated iron ore; it is silicified in places. There are also vesicles filled by secondary minerals such as chlorite, sericite, calcite and quartz. One specimen (D.2836.3) is a more acid rock in that alkali-feldspar predominates among the phenocrysts.

The devitrified rocks are very similar in the hand specimen to those described above but the phenocrysts are up to 4·0 mm. in length and they are set in a devitrified quartzo-feldspathic matrix. The plagioclase is very heavily altered but a composition of $Ab_{52}An_{48}$ has been recorded in specimen D.2835.3. Alkali-feldspar may be present but it is concealed by the intense alteration. Pseudomorphs after pyroxene are common; the minerals forming them include chlorite, calcite and quartz. One rock (D.2252.1) has a green alkali amphibole which is partly replaced by chlorite. The presence elsewhere (D.2835.4) of a similar mineral with pyroxene morphology suggests that the amphibole is also forming pseudomorphs. In some places the devitrified matrix comprises feldspar microlites with a little interstitial quartz, iron ore, chlorite and sericite (D.2251.1). In other instances, the matrix had started to crystallize before vitrification because there are orientated feldspar microlites in an otherwise devitrified groundmass (D.2252.1); quartz is present in varying amounts and there is some leucoxene, chlorite, sericite and prismatic apatite. Secondary alteration has developed some areas of coarser quartz and of quartz/alkali-feldspar intergrowths (D.2251.1, 2835.3).

The one flow-banded lava (D.2836.1) is similar to the rocks described above except for the presence of a flow texture in the matrix. There has also been some autobrecciation because the matrix appears to be formed of devitrified fragments in a devitrified base.

The acid tuffs have lithic fragments (1–10 mm. in length) in an aphanitic base. The matrix contains angular quartz and feldspar crystals set in a fine-grained quartzo-feldspathic base which is partly silicified (D.2835.1). The silicified rock has xenoliths of sandstones and siltstones many of which are similar to those of the Trinity Peninsula Series and, in being sheared, they are similar to those from north-west Trinity Peninsula and they represent a level where the dynamic component of regional metamorphism was more intense; there are also andesite and acid lava fragments. The other tuffs (D.2249.1, 2836.2) have xenoliths of intermediate to acid volcanic rocks only.

d'Urville Monument

The specimens from d'Urville Monument are devitrified acid lavas which have quartz, feldspar and ferromagnesian phenocrysts (up to 3·5 mm.) in an aphanitic siliceous matrix. The quartz phenocrysts are angular and corroded, and many have been fractured. The plagioclase phenocrysts are heavily altered but in one specimen (D.2855.2) they have a composition of $Ab_{62}An_{38}$. There are a few biotite phenocrysts and most of them have been altered to chlorite and leucoxene. The matrix is a devitrified quartzo-feldspathic aggregate which encloses leucoxene, a few feldspar microlites (D.2256.2), a little dispersed sericite and chlorite, and rare grains of allanite, zircon and apatite.

ANDEAN INTRUSIVE SUITE

One of the Wideopen Islands and Etna Island to the north of Joinville Island, and one of the Danger Islands to the east, were visited by Nelson (Aitkenhead and Nelson, 1962, p. 6), who recorded plutonic rocks which probably belong to the Andean Intrusive Suite. The Trinity Peninsula Series near Mount Quilmes and east of Haddon Bay has suffered thermal metamorphism which is attributed to underlying intrusions of a similar age. Intrusive rocks are also inferred to crop out on the Mount Alexander peninsula (p. 36).

The rocks examined by Nelson are all gabbros and they are of interest because of their feldspathic composition and their banding. At the Wideopen Islands locality (D.3778), the visible flow structure gives rise to a prominent banding which dips at 70° to the south; at Etna Island (D.3779) the flow structure is again very pronounced and the banding, which is a few inches in thickness, dips at 80° to the west (Fig. 7b). Massive gabbro was also recorded from one of the Danger Islands (D.3782) and here it exhibits strong jointing at 040° and 130°, with a visible flow structure parallel to the 040° direction. Pronounced horizontal bedding of the minerals was observed at one place on the west coast of the island. Observation from that island and from the ship revealed that Jagged Rocks also displays pronounced horizontal light grey-green and dark bands (Fig. 3d); this may be due to layering in a gabbroic intrusion though it might alternatively be bedding of sediments or volcanic rocks.

Modal analyses of these gabbros are given in Table III; the specimen from Etna Island (D.3779.2) will be described in detail. It is a medium-grained pale grey rock, which in thin section has plagioclase laths (up to 1·5 mm.) in ophitic intergrowth with pyroxene (up to 5·0 mm.) and biotite. The plagioclase is a basic labradorite ($Ab_{32}An_{68}$–$Ab_{39}An_{61}$) with slight marginal zoning; some of it has a patchy zoning and replacement which is better displayed in

Table III. Modal analyses of three gabbros from the Joinville Island area

	Specimen number		
	D.3778.1	D.3779.2	D.3782.1
Quartz	—	*	—
Plagioclase	76·1	84·7	86·5
Olivine	—	0·1	—
Hypersthene	—	0·2	—
Augite	13·2	6·2	1·1
Hornblende	—	3·2	—
Actinolite	—	—	3·3
Biotite	*	3·3	—
Chlorite	—	0·2	7·4
Iron ore	2·2	1·5	1·6
Apatite	0·1	0·3	0·1
Talc	—	0·2	—
Serpentine	—	0·1	—
(?) Iddingsite	8·4	*	—
Plagioclase composition	$Ab_{58}An_{42}$	$Ab_{68}An_{32}$	$Ab_{68}An_{32}$

* Present but not recorded.

D.3778.1	Gabbro; Wideopen Islands.
D.3779.2	Gabbro; Etna Island.
D.3782.1	Gabbro; Danger Islands.

another of the gabbros (D.3778.1). Many of the sparsely distributed augite crystals are replaced by pale green hornblende. Olivine ($Fo_{65}Fa_{35}$) is rare and it has been altered to iddingsite, antigorite, talc and iron ore. Most of it is rimmed by either augite or hypersthene. Primary red-brown biotite forms a few ophitic crystals and it also rims much of the iron ore which is a titaniferous magnetite. Apatite prisms and interstitial quartz crystals are the accessory minerals.

The other gabbros are coarser-grained and non-ophitic. One (D.3782.1) is intensely altered and the plagioclase crystals (up to 10 mm. in length) have been replaced extensively by prehnite and a zeolite. The other (D.3778.1) contains numerous (?) iddingsite pseudomorphs after olivine, and some of the plagioclase crystals (Fig. 4e) exhibit the patchy zoning and replacement by more acid plagioclase which has been recorded from the gabbros of the Nordenskjöld Coast (Elliot, 1966, p. 19) and studied in detail on better examples from the Anagram Islands (Fraser, 1964) and Stonington Island (Fraser, 1965). Fig. 4e shows the core of a crystal of composition $Ab_{44}An_{56}$ replaced by andesine ($Ab_{65}An_{35}$) which also forms part of the normal zoning. The outer zone of this crystal has an oligoclase ($Ab_{78}An_{22}$) composition, and similar plagioclase also forms small areas in the core of the crystal. Little rectangular areas of iron ore are present in this crystal but they are more prominent elsewhere.

The highly feldspathic character of these gabbros and the indication that at least one of them (D.3779.2) is a feldspar cumulate with interprecipitate augite and biotite, together with the pronounced flow structure and mineral banding visible in the field, all suggest that these gabbros are parts of layered basic intrusions.

MINOR INTRUSIONS AND ASSOCIATED EXTRUSIVE ROCKS

King Point

The dykes at King Point are heavily altered porphyritic microdiorites composed of plagioclase phenocrysts in a matrix of plagioclase, iron ore and secondary minerals. The plagioclase phenocrysts (up to 2·5 mm. long) are replaced by sericite and calcite, and their composition cannot be determined. Two of the dyke rocks (D.2830.1, 2) have a few chlorite pseudomorphs after a ferromagnesian mineral. The groundmass has either a trachytic texture (D.2830.2) or is non-trachytic and is composed of a felted mass of plagioclase laths (0·1–0·5 mm.; $Ab_{62}An_{38}$) and interstitial chlorite, iron ore and quartz.

East of Haddon Bay

One of the dykes (D.2243.2) is a dolerite composed of heavily altered plagioclase laths (up to 0·7 mm.) and brownish pink titaniferous augite which in places has a subophitic relation to the feldspar. The numerous iron ore grains have been completely replaced by leucoxene and the extensive alteration has also caused the development of chlorite, actinolite and quartz. A few narrow epidote-quartz veins traverse the rock. The other dyke rock (D.2244.1) is coarser-grained (up to 1·5 mm. in length) and more extensively altered. Epidote-quartz veins are again present but they are much coarser-grained and the rock appears to be slightly brecciated.

The silicified and haematitized rocks (p. 29) crop out at these localities and they also carry epidote-quartz veins. As the dolerites have only the epidote-quartz veins, they are inferred to be later than the silicification and haematitization which is either Andean or post-Andean. The alkaline character of the dykes allies them to the Miocene James Ross Island Volcanic Group (Nelson, 1966), and the epidote-quartz veining is therefore a more recent event.

South-east of Kinnes Cove

This locality (D.2259) has been reported by Standring (1956) on his geological map and by Bibby (1960, fig. 1) to be formed of rocks of the Trinity Peninsula Series, so the specimens must be a set of associated basic rocks. The rocks include an ophitic dolerite, a porphyritic olivine-basalt, a vitric tuff and a lithic lapillistone composed of basaltic fragments in a vitric tuff matrix. It is possible that the dolerite and olivine-basalt are lithic fragments in a pyroclastic rock and that all the specimens come from a volcanic vent or the remnants of a pyroclastic deposit. The composition of these rocks suggests affinities to the James Ross Island Volcanic Group (Nelson, 1966).

The fine-grained vesicular dolerite (D.2259.3) has in thin section an ophitic texture composed of slightly pinkish augite grains (up to 1·5 mm.) and intensely altered plagioclase crystals (up to 1·5 mm.) and laths (up to 0·5 mm.). The iron ore is completely replaced by leucoxene and there is some intergranular secondary chlorite and calcite. The vesicles are filled by fibrous and scaly growths of chlorites.

The one lava (D.2259.4) has vesicles and phenocrysts in a fine-grained matrix, the vesicles clearly diminishing away from one of the surfaces of the hand specimen which is inferred to be the top of a flow. Microscopically, there are pseudomorphs (up to 1·0 mm.) of chlorite after olivine and heavily saussuritized plagioclase phenocrysts in a brownish glassy base which encloses thin feldspar microlites and some fibrous amphibole (? actinolite). The vesicles are composed of either penninite or (?) prochlorite; the cross-cutting veinlets include these minerals and calcite, quartz and pyrite.

The vitric tuff (D.2259.1; Fig. 4f) consists of partially devitrified brown glass shards with some pyroxene grains, interstitial secondary quartz and veins of secondary minerals which include a zeolite, pyrite, quartz and calcite. The devitrification of the shards results in fibrous chlorite and actinolite as well as unidentifiable material.

The lithic lapillistone (D.2259.2) has angular fragments (up to 2·0 cm. long) set in a fine greenish matrix. The lithic fragments include an ophitic dolerite and numerous basaltic rocks which are similar to those already described (D.2259.3, 4). The matrix of the tuff is composed of small basalt fragments, glass shards as in the vitric tuff, vesicles filled mainly by chlorite, and areas of secondary minerals.

Danger Islands

On one of the Danger Islands (D.3782) the gabbro is capped by a porphyritic microdiorite, which was probably intruded as a sill. It is a very coarse porphyritic rock (D.3782.2) with plagioclase phenocrysts up to 10 mm. long in a matrix of feldspar and ferromagnesian minerals. The phenocrysts have a composition of $Ab_{66}An_{34}$ and they are extensively altered to sericite, saussurite and a zeolite similar to that in the underlying gabbro (D.3782.1). The groundmass plagioclase is similar in composition and alteration, and it is intergrown with augite, iron ore and a brown secondary mineral, (?) iddingsite, which also marginally replaces some of the pyroxene and fills interstices.

MOUNT ALEXANDER PENINSULA

The area between Gibson Bay and Haddon Bay has not been investigated but a little can be inferred from the air photographs and an annotated panorama taken by Standring (1956), who observed the area when there was considerably less snow cover than at the time of the aerial survey.

Fig. 8 is a sketch from Standring's panorama and it includes some interpretation from the air photographs. The horizontal layering in the rocks is not always clear but it can be inferred for outcrops with greater scree cover. There are three places where there is evidence from the air photographs (Fig. 9) of a geological boundary, and one of them, near the south end of the peninsula, is almost certainly an intrusive contact because the junction is near vertical and it is only thermally metamorphosed contacts which are not preferentially eroded. The rocks of the central ridge have a different weathered appearance compared to the layered rocks, though Standring recorded dipping structures at an outcrop to the north of Mount Alexander and gently dipping structures at the southern peak of the central ridge and at Mount Alexander. The structures at and to the north of Mount Alexander can be seen on the air photographs.

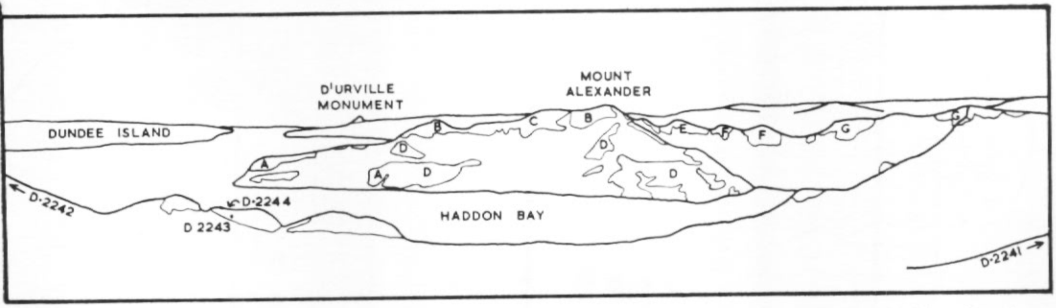

Fig. 8. A sketch from a panorama of the Mount Alexander peninsula; looking west across Haddon Bay from between stations D.2241 and 2242. The annotation corresponds to Standring's field observations.
A. Horizontal layering in reddish rock.
B. Inclined layering in reddish rock.
C. Massive dark rock.
D. Dark grey-weathering rock.
E. Steeply dipping layering in reddish rock.
F. Grey-weathering rock.
G. Trinity Peninsula Series.

The information available from the outcrops east of Haddon Bay (D.2243, 2244) is of limited use. Thermally metamorphosed Trinity Peninsula Series siltstones are present but their relationship to the quartz-haematite rocks is unknown. It is possible that the silicified rock (D.2244.2; p. 29) is volcanic in origin and that acid volcanic rocks form the greater part of the outcrop and have been faulted into place. From the physiography and the distribution of rock types, there is some evidence of faulting across the north end of the central ridge, along Haddon Bay and in the parallel erosion features of the coastal outcrops (D.2243, 2244). To the west of Gibson Bay, volcanic rocks are known from at least two localities and they are also inferred for the other coastal outcrops.

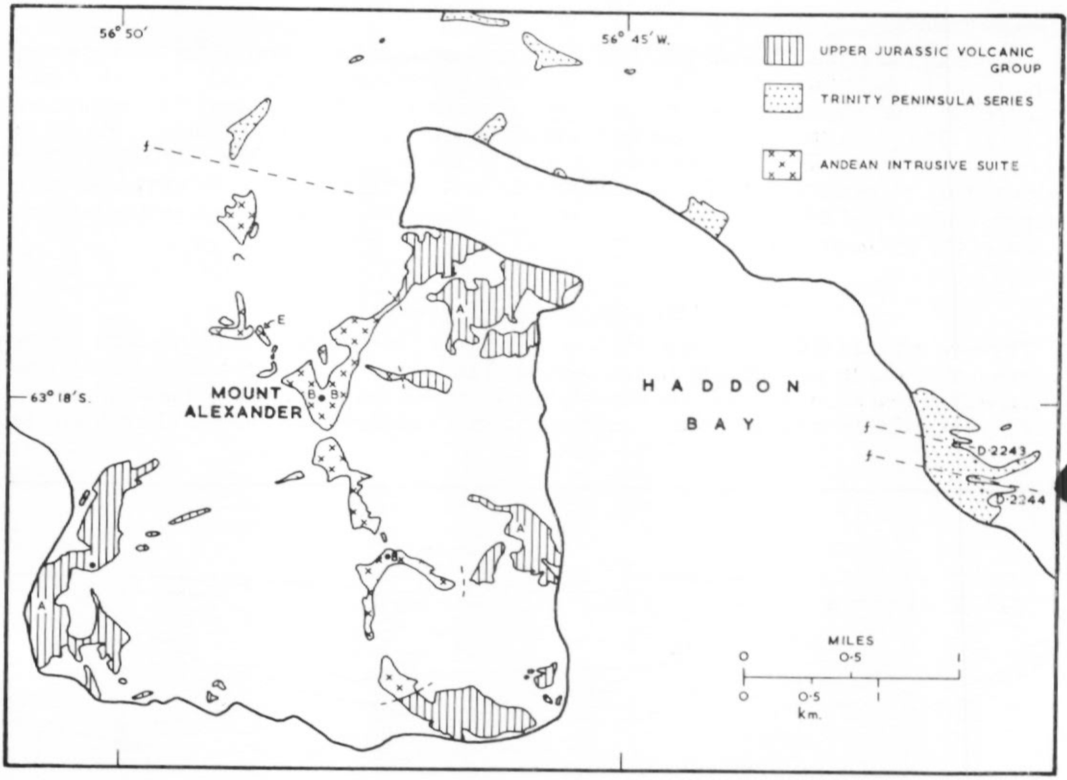

Fig. 9. A geological sketch map of the Mount Alexander peninsula area (see Fig. 8).
A. Horizontal layering.
B. Inclined layering.
E. Steeply dipping layering.

The horizontal layering in the rocks of the Mount Alexander peninsula excludes the Trinity Peninsula Series, and the appearance of the outcrops on the air photographs also excludes the conglomerate beds which crop out on the north coast of Joinville Island. Some of the exposures are not markedly different from those at d'Urville Monument, and it is tentatively suggested that these are bedded volcanic rocks, probably of the Upper Jurassic Volcanic Group. Further, it is suggested that the central ridge, with the marked contact at its southern end, is formed of plutonic rocks of the Andean Intrusive Suite. The thermally metamorphosed rocks east of Haddon Bay indicate that such rocks are present. The steeply dipping structures north of Mount Alexander may be a joint direction and the reddish colour noted by Standring may mean that this rock is an acid pluton. The gently dipping structures at Mount Alexander could be attributed to layering in a basic intrusion.

STRUCTURAL GEOLOGY

Trinity Peninsula Series

Standring (1956, p. 23) reported vertical beds and steep northward dips in the main central ridge of Joinville Island and less steep dips to the south at outcrops elsewhere. At Madder Cliffs there are small asymmetrical folds with steeper southern limbs and the structure was interpreted as a large asymmetrical syncline with associated minor flexures. Bibby (1960, p. 7) agreed with this interpretation and added that on the evidence of the northerly dips (and hence an anticlinal axis) at King Point (Fig. 10) the structure is better termed a synclinorium. Folding of this type has been reported for the Trinity Peninsula Series farther south (Aitkenhead, 1965, p. 54; Elliot, 1965, p. 22).

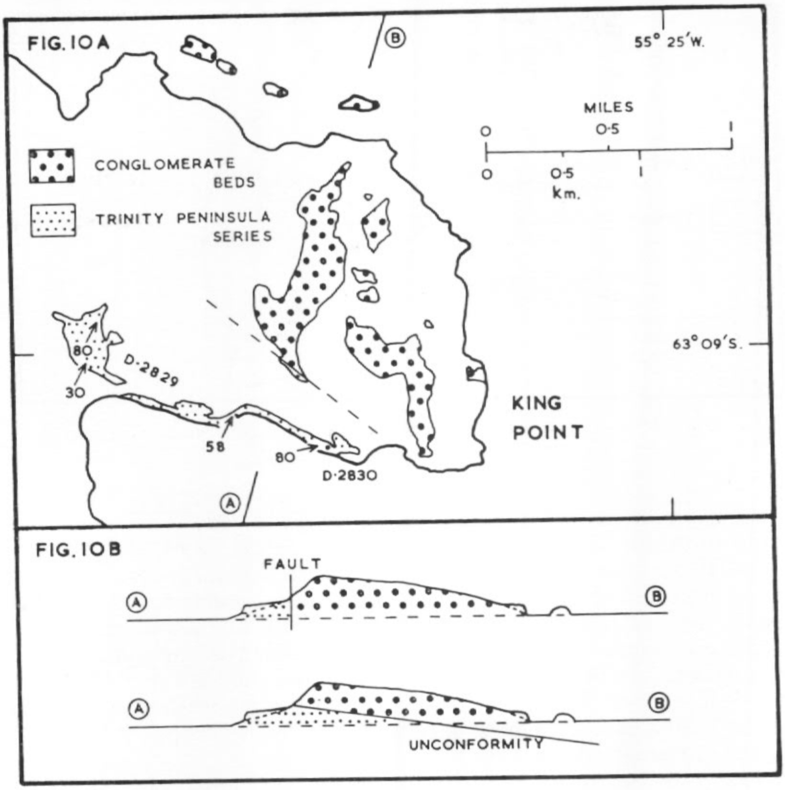

Fig. 10. A. Sketch map of King Point, Joinville Island.
B. Cross-section along the line A—B in Fig. 10A to show the alternative interpretations of the geological boundary.

Thus the overall structure of the Trinity Peninsula Series is of folding about axes approximately east-north-east to west-south-west to give asymmetrical folds with steeper north-dipping limbs and forming part of a synclinorium. There are a number of local departures from this general outline but they may be caused by either intrusion or faulting of which there is no direct evidence except near Mount Quilmes and east of Haddon Bay. The age of the folding, by comparison with other parts of north-east Graham Land, is early Mesozoic.

Some relationships with other rock groups are shown at King Point and in the coastal outcrop south-east of Nodule Nunatak. At King Point, the Trinity Peninsula Series is in contact with the conglomerate beds and, although Standring (1956, p. 24) suggested they are separated by a fault, Bibby (1960, p. 7) re-examined the outcrop when there was very little snow cover and noted that there are none of the usual signs of faulting such as occur where the conglomerate beds are involved in movement (p. 38). He suggested that an unconformity is an alternative explanation for the boundary, and that a plane of unconformity dipping at slightly less than 30° would satisfy the requirements (Fig. 10) of the field observations. The boundary, if it is a fault, trends south-east (129°). Examination of the air photographs throws no light on this problem.

The outcrops south-east of Nodule Nunatak are composed of the Trinity Peninsula Series and volcanic rocks (Fig. 11). The contact is obscured by scree debris but it can be traced to within a few yards (Bibby, 1960, p. 7) by a change in scree fragments which is so sharp that it gives the impression of being faulted. Glacial action would lead to a greater mixing of the fragments and therefore frost-action, weathering the rocks *in situ*, is preferred by Bibby as an explanation. The inferred boundary trends north (003°).

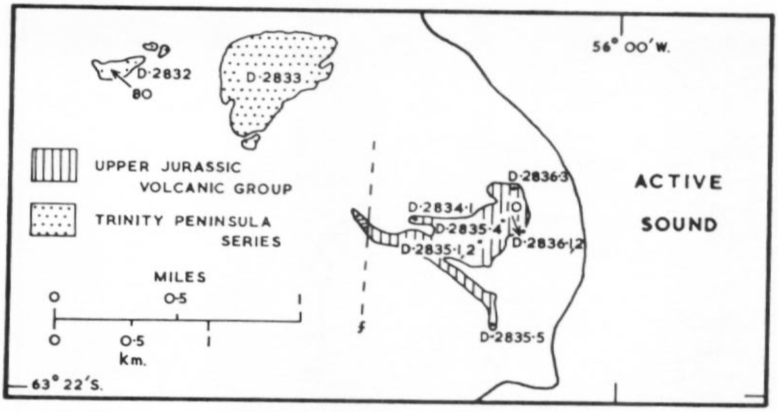

Fig. 11. Sketch map of the outcrops south-east of Nodule Nunatak.

Conglomerate beds

Little structure has been recorded from the conglomerate beds. At Patella Island the rocks have a gentle dip to the south (Aitkenhead and Nelson, 1962, p. 6), at King Point there is a low dip to the north-west and near Fitzroy Point it is to the north-east, though Bibby noted that the presence of current-bedding means no particular significance should be attached to dip measurements. The air photographs show that the beds are sub-horizontal.

Two faults trending south-west (222°) have been recorded at the outcrop west of Fitzroy Point and the conglomerate beds exhibit slickensiding and they are shattered and veined with calcite within 6–7 ft. (1·8–2·1 m.) of the dislocation. Bibby (1960, p. 8) remarked that the orientation of the faults, at approximately right-angles to the proposed fault at King Point, may be significant in the interpretation of the geology there.

Standring (1956, p. 24) suggested that the eastern end of Joinville Island reflects a different type of lithology and structure, and that the conglomerate beds are separated from the Trinity Peninsula Series by a fault at King Point. Bibby's alternative explanation of this contact, an unconformity (p. 37), does not invalidate Standring's hypothesis concerning the lithology and structure, though the marked physiographic change in the truncation of the central ridge to the east of Taylor Nunataks suggests that something more than an unconformity is necessary to account for it. Major faults trending approximately north-west to south-east have been inferred for Russell East and Russell West Glaciers (Aitkenhead, 1965, p. 54) and Misty Pass (Elliot, 1965, p. 23) on Trinity Peninsula. Although the contact at King Point may not be faulted, it is possible that north-west to south-east trending faults separate the eastern end of Joinville Island from the more elevated areas to the west.

Upper Jurassic Volcanic Group

The faulted relationship with the Trinity Peninsula Series south-east of Nodule Nunatak has already been discussed (p. 37) and at that locality the volcanic rocks form beds which are horizontal or dip gently to the south-east. Bibby (1960, p. 7) stated that there is a great thickness of volcanic rocks exposed to the east of this geological boundary and that this favours his interpretation of it being a fault. There is no reported structure for the d'Urville Monument area and unfortunately scree covers the outcrops and nothing can be seen clearly on the air photographs. If Tay Head is formed of volcanic rocks, then probably it also has the same relationship to the Trinity Peninsula Series to the north-west that is present along the north side of Active Sound.

It is also suggested (p. 35) that the Mount Alexander peninsula may be separated from the mainland by a fault which trends approximately east-south-east. This and other faults which have been postulated on Joinville Island may fit into the late Tertiary block-faulting pattern which is present elsewhere in Graham Land.

CONCLUSIONS

Joinville Island and the offshore islands considered in this paper are clearly a geological continuation of Trinity Peninsula. Outcrops are unfortunately sparsely distributed throughout the island; only two geological contacts, at King Point and south-east of Nodule Nunatak, have been observed in the field, though a third has been inferred on the Mount Alexander peninsula from a study of the air photographs.

The Trinity Peninsula Series is a succession of clastic sediments folded about approximately east-north-east axes into a synclinorium with steeper north-dipping limbs to the individual flexures. The coarse sediments are immature feldspathic sandstones and their mineralogy and texture, together with the repetitive lithology, suggest deep-water deposition. These rocks are in contact with conglomerate beds at King Point.

In that area and to the east, shallow-water conglomeratic sediments crop out but, although they were clearly derived at least in part from the Trinity Peninsula Series and are younger than the regional metamorphism of those rocks, their age is only inferred as Lower to Middle Jurassic. A fault or an unconformity has been suggested for the contact at King Point, but neither case gives clear evidence of the type of dislocation separating the eastern end of the island from the area to the west.

The rocks assigned to the Upper Jurassic Volcanic Group are intermediate to acid lavas and tuffs which form horizontal or gently dipping beds along the north shore of Active Sound. They have a fault relationship with the Trinity Peninsula Series at one outcrop south-east of Nodule Nunatak. Volcanic rocks are also inferred for Tay Head and the Mount Alexander peninsula.

Gabbros have been recorded from the offshore islands to the north and east of Joinville Island. The feldspathic character of these rocks and their banded appearance in the field suggest that they may form parts of layered basic intrusions. Plutonic rocks are inferred to underlie the Trinity Peninsula Series near Mount Quilmes and east of Haddon Bay, and to be intruded into volcanic rocks on the Mount Alexander peninsula.

The Trinity Peninsula Series is intruded by microdiorite dykes of uncertain age at King Point, and by alkaline dolerites east of Haddon Bay. The dolerites and the group of associated basic rocks south-east of Kinnes Cove are tentatively assigned to the Miocene James Ross Island Volcanic Group. The coarse porphyritic microdiorite capping the gabbro at one of the Danger Islands also belongs to the Tertiary to Recent phase of vulcanicity.

Faults have been inferred for several localities and it is suggested that they are part of the block-faulting of Tertiary age; this faulting may also account for the physiographically distinct eastern end of the island.

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