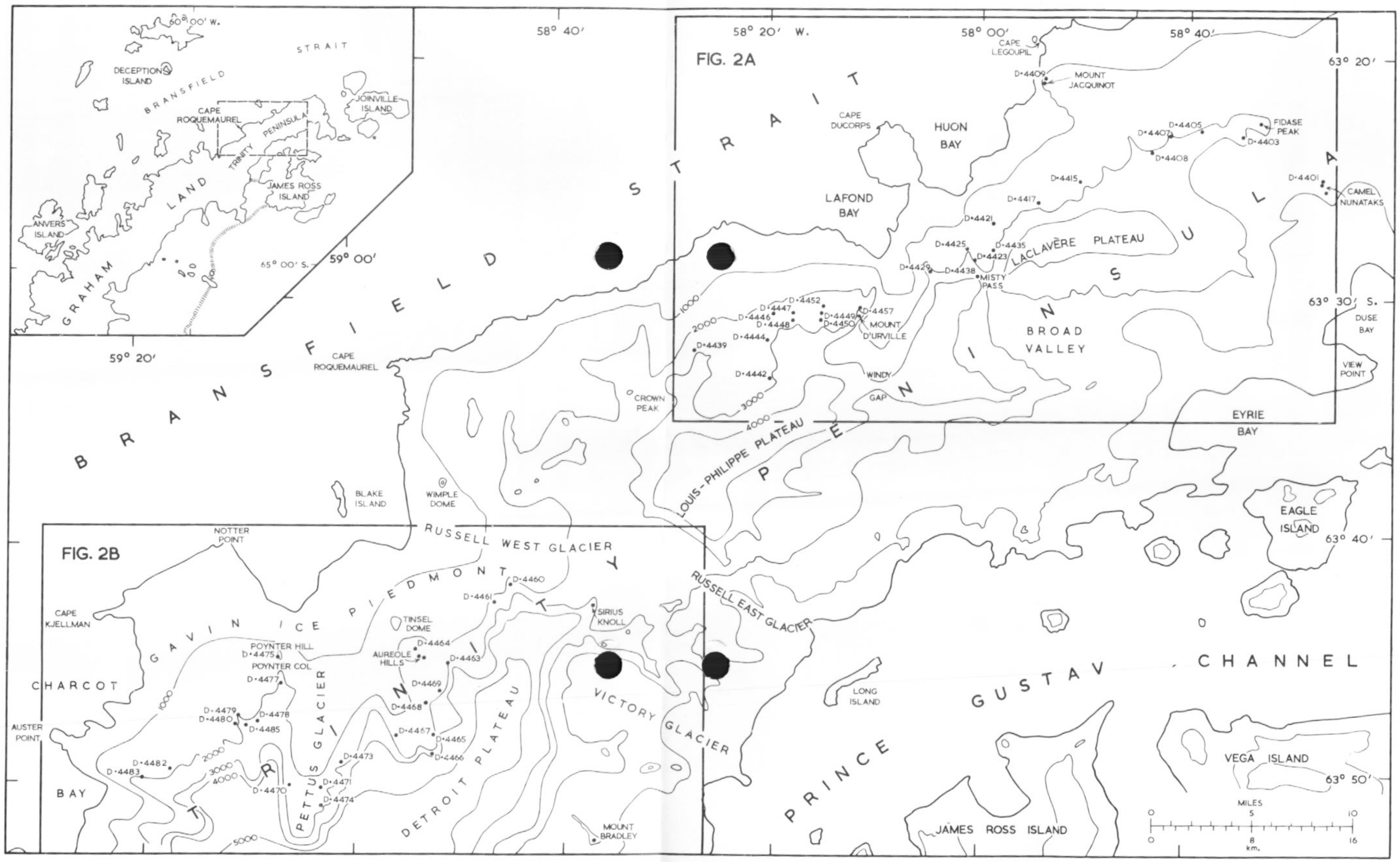


Fig. 1. Sketch map of north-west Trinity Peninsula showing the physiography, place-names and station numbers. The inset shows the position of the area in north-east Graham Land.

GEOLOGY OF NORTH-WEST TRINITY PENINSULA, GRAHAM LAND

By D. H. ELLIOT

ABSTRACT. The dominantly granitic provenance of the geosynclinal Trinity Peninsula Series is deduced from the mineralogy of the sandstones and pebbly shales, and the depositional environment and mode of deposition of the coarser sediments are deduced from the repetitive lithology, sedimentary structures and microscopic textures. The pre-Jurassic folding of the Trinity Peninsula Series into an anticlinorium was accompanied by low-grade regional metamorphism which increases towards the south-west. An additional stratigraphic unit is proposed for a succession of banded hornfelses which are (?) pre-Upper Jurassic but younger than the regional metamorphism of the Trinity Peninsula Series. The Upper Jurassic Volcanic Group forms only a few isolated outcrops. The intermediate to acid intrusions of the Andean Intrusive Suite show the effects of the assimilation of sediments and of strong shearing stress.

THIS paper describes the results of geological investigations in north-west Trinity Peninsula between Fidase Peak (lat. 63°23′S., long. 59°30′W.) and Charcot Bay (lat. 63°48′S., long. 59°35′W.), except the area between Crown Peak and Cape Roquemaurel (Fig. 1). A considerable amount of work has already been done in adjacent areas, first by the Swedish South Polar Expedition, 1901–03 (Nordenskjöld, 1905; Andersson, 1906) and since 1945 by the Falkland Islands Dependencies Survey working from Hope Bay (Adie, 1958).

The oldest rocks, which include the clastic sediments underlying the Mount Flora Beds at Hope Bay, are a regionally metamorphosed geosynclinal assemblage called the Trinity Peninsula Series (Adie, 1957). This series crops out extensively in Trinity Peninsula and elsewhere in Graham Land, and it is believed to be late Palaeozoic in age. Middle Jurassic sediments and Upper Jurassic volcanic rocks post-date the regional metamorphism of the Trinity Peninsula Series. These rocks, particularly the volcanic group, crop out extensively farther south in Graham Land. Recent work by American geologists at Cape Legoupil has indicated the possible existence of a period of geosynclinal sedimentation of Cretaceous age. The Andean Intrusive Suite (Adie, 1955) forms numerous intrusive complexes in Trinity Peninsula and farther south.

GENERAL STRATIGRAPHY

The stratigraphy of north-west Trinity Peninsula is given in Table I. The most important addition to previous accounts of the stratigraphy of north-east Graham Land is the sequence of metamorphosed sediments, called the banded hornfelses, which are believed to be younger

TABLE I. GENERAL STRATIGRAPHICAL SUCCESSION OF NORTH-WEST TRINITY PENINSULA

Age	*Succession*	*Thickness* (ft.)	(m.)
Tertiary	Andean Intrusive Suite		
Cretaceous	Sediments of Cape Legoupil	13,000	3,960
Upper Jurassic	Volcanic group		
?	Banded hornfelses	500	153
(?) Carboniferous	Trinity Peninsula Series	12,000	3,660

than the late Palaeozoic Trinity Peninsula Series but older than the Upper Jurassic Volcanic Group (p. 16). There is no reason to believe that any of the sediments from north-west Trinity Peninsula, apart from the banded hornfelses and the Cretaceous sediments at Cape Legoupil, belong to any succession but the Trinity Peninsula Series, although the absence of fossils in the Trinity Peninsula Series and the lithological similarity of the Cretaceous sediments from Cape Legoupil (Halpern, 1964) render differentiation between the two sequences difficult.

The parts of north-west Trinity Peninsula which have been mapped fall into two distinct areas: the north-east area between Fidase Peak and Mount d'Urville (Fig. 2A) and the south-west area between Sirius Knoll and Charcot Bay (Fig. 2B).

North-west Trinity Peninsula is composed mainly of clastic sediments belonging to the Trinity Peninsula Series. In the north-eastern area they occur to the exclusion of all other rock types except for a few dykes. The clastic sediments comprise a geosynclinal assemblage of sandstones, siltstones and shales. In the south-western area the Trinity Peninsula Series is more deformed and the argillaceous sediments have been converted into phyllites. In addition to the sandstones there are a few pebbly shales and greenschists. The Trinity Peninsula Series is overlain by a succession of gently dipping banded hornfelses which have been intruded by quartz-plagioclase-porphyry dykes of probable Upper Jurassic age. The few other dykes, which cut the Trinity Peninsula Series and the isolated outcrops of pyroclastic rocks, are probably of this age. Intermediate to acid rocks of the Andean Intrusive Suite have invaded both the Trinity Peninsula Series and the banded hornfelses. Thermal metamorphic effects have been observed at only one outcrop of Trinity Peninsula Series greenschists and in the banded hornfelses. A probable Tertiary dyke cuts the Trinity Peninsula Series at Mount Jacquinot.

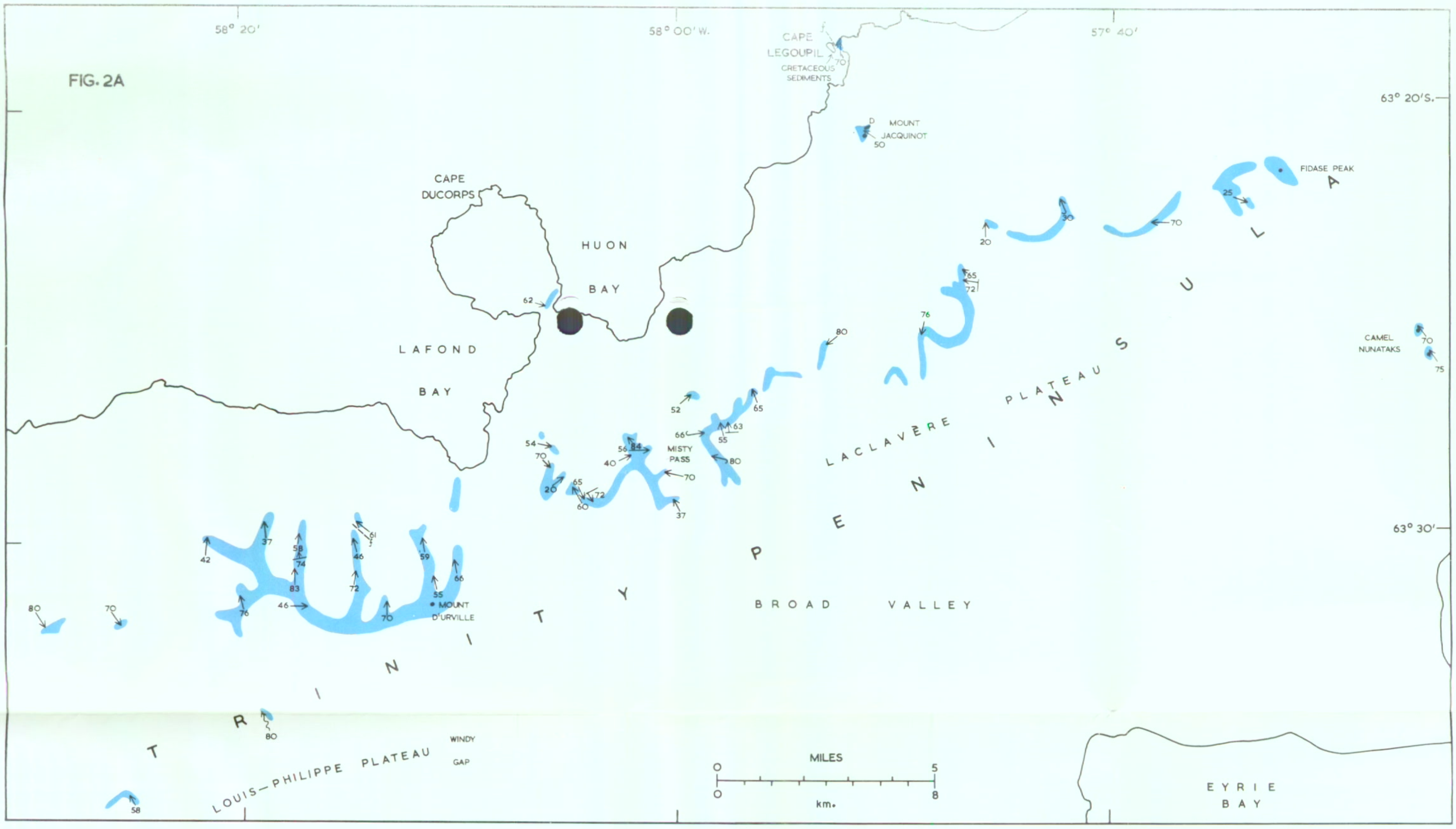
Trinity Peninsula Series

Sediments belonging to the Trinity Peninsula Series are the only exposed rocks in the north-east area, except for the Cape Legoupil sediments and a few dykes. Apart from the plateau edge near Aureole Hills and outcrops near Poynter Col, the Trinity Peninsula Series also occurs at most exposures south-west of Russell West Glacier. Here, the rocks have suffered more intense low-grade regional metamorphism and also have a rather different lithology. Although the maximum recorded thickness of sediments from this side of Trinity Peninsula is 12,000 ft. (3,660 m.), in adjacent areas there are at least 45,000 ft. (13,715 m.) in this sequence (Aitkenhead, 1965).

North-east area

All the rocks in this area are clastic sediments; there are sandstones, siltstones and shales comprising a geosynclinal assemblage which is markedly deficient in basic igneous rocks and in metamorphic rock fragments in the sandstones (Table II). In particular, the absence of basic igneous rocks is anomalous for what might be termed a geosynclinal assemblage but the other characteristics of the sediments indicate such a depositional environment (p. 13). There are localized phyllites and one pebbly mudstone which is described with the pebbly shales from the other area (p. 10). The thickness of these sediments is greater than 12,000 ft. (3,660 m.) in the Mount d'Urville area and there are approximately equal proportions of arenaceous and argillaceous facies.

Fig. 3. a. Trinity Peninsula Series sandstones which dip steeply and are inverted (Fig. 3c); east side of Misty Pass (D.4435).
b. Interbedded sandstones and shales of the Trinity Peninsula Series, in which the sandstones are shattered, whereas the shales are cleaved at a low angle to the bedding; east side of Misty Pass (D.4421).
c. Graded bedding in sandstones showing overturning of the succession. The top of one bed is at the upper end of the hammer shaft and it is succeeded by the base of a younger graded sandstone; east side of Misty Pass (D. 4435).
d. Contaminated quartz-diorite with reaction zones round partly assimilated xenoliths; south-east of Aureole Hills (D.4469).



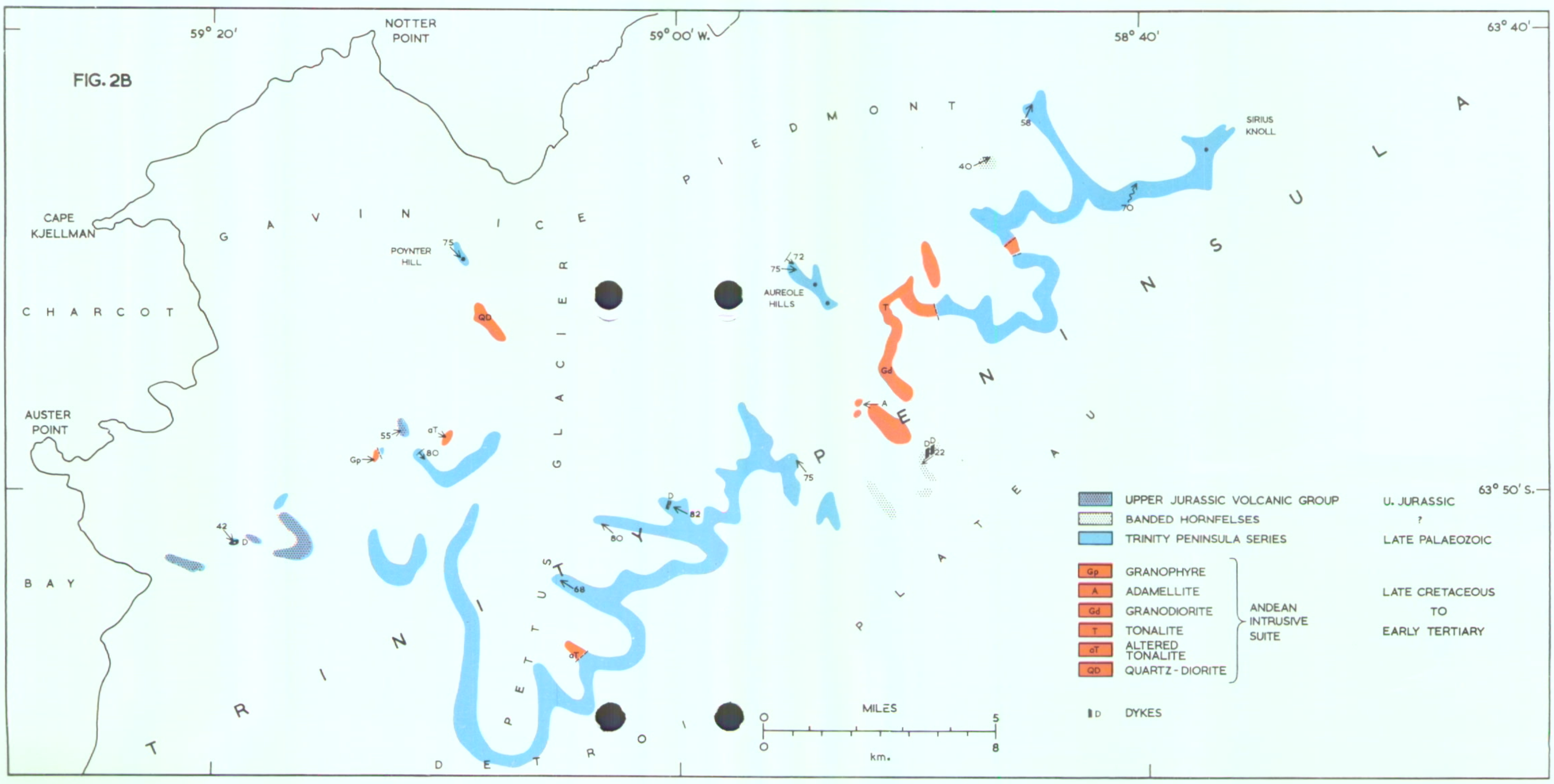


Fig. 2A. Geological sketch map of the area between Fidase Peak and Mount d'Urville.

Fig. 2B. Geological sketch map of the area between Sirius Knoll and Charcot Bay.

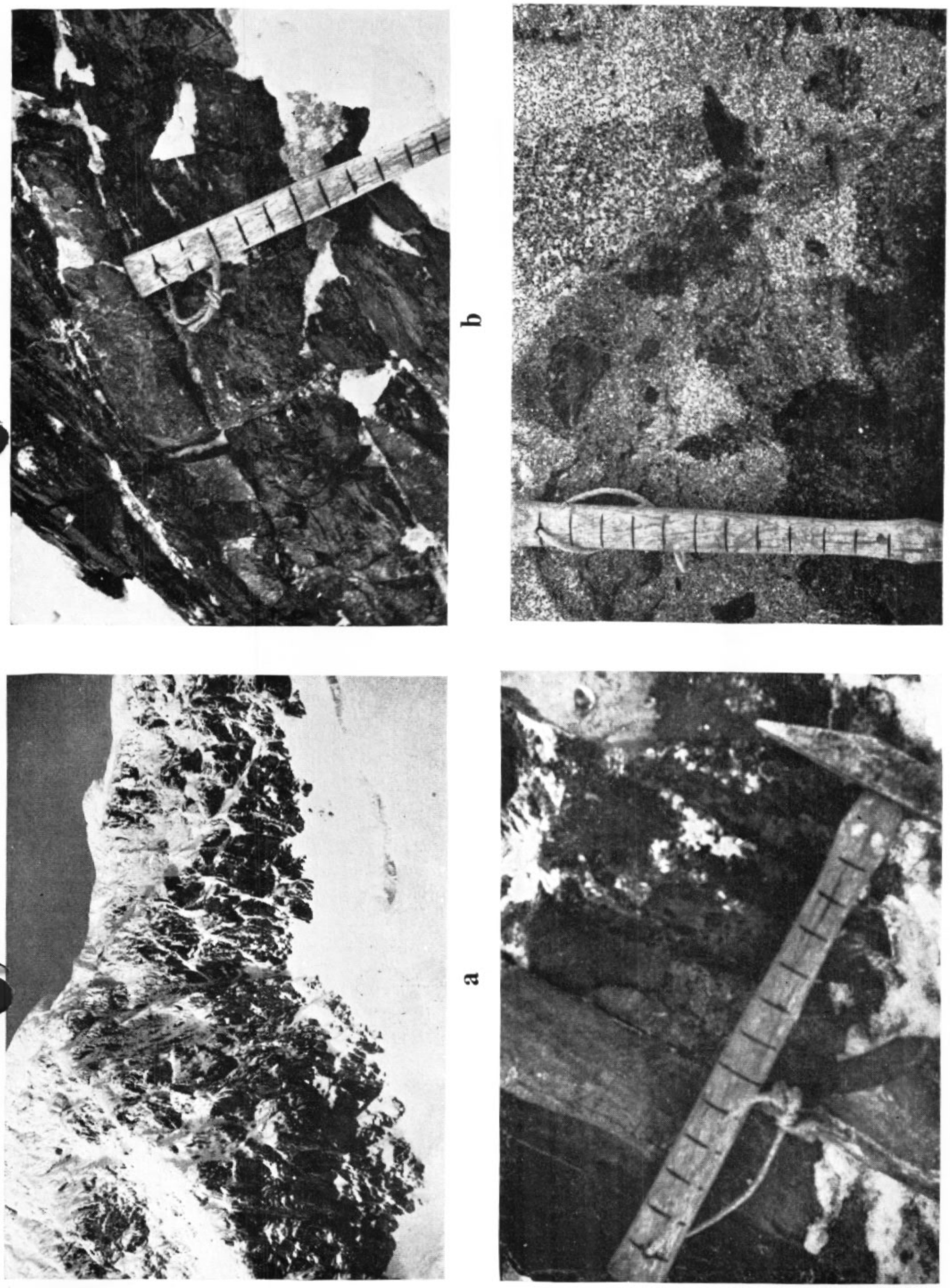


Fig. 3.

Arenaceous sediments

The dominant rock type is a medium-grained sandstone (p. 7) which often has a conspicuous reddish brown weathered surface. These rocks are generally massive and well bedded, and the individual beds are between 1 and 10 ft. (0·3 and 3·0 m.) thick (Fig. 3a). They may be interbedded with argillaceous rocks, where the individual beds are between 1 and 2 in. (2·5 and 5·0 cm.) thick. An alternation of shale and sandstone in which the beds are less than 1 in. (2·5 cm.) thick also occurs. Sedimentary structures are present at many outcrops and these are described on p. 8.

The sandstones contain quartz, plagioclase and alkali-feldspar grains, igneous, metamorphic and sedimentary rock fragments, and heavy minerals, all set in a very fine-grained matrix composed of quartz, sericite and chlorite (Fig. 4a). The proportions of the different minerals and rock fragments are given in Table II.

Folk's (1959, p. 71) empirical classification of quartz types has been used throughout this paper. The major problem in the classification of quartz in these sediments is that low-grade regional metamorphism may have caused at least some of the undulose extinction, although it is possible that the clay matrix in the sandstones has taken up the deforming stresses and left the sand-sized grains unaffected. Quartz of type 1 is much better represented in the silt-sized grains than in the coarser sizes and, in view of the abundance of type 2 and 3 grains, it is possible that many of the type 1 grains are no more than the other types abraded to a finer size. Type 4 grains (of vein origin) were never seen. Type 5 grains are quite common, whereas type 6 grains are uncommon. On abrasion, all these groups could give rise to type 1 grains. The really distinctive quartz grains belong to type 6, because they include aggregates of small quartz crystals with sutured margins between them and at least some orientation. These grains, of undoubted metamorphic quartz or stretched metaquartzite, occur sporadically and are occasionally quite important. Strain lamellae occur in some of the coarser quartz grains of types 1, 2 and 3. It is likely that these lamellae are an original feature of the quartz rather than ones induced by regional metamorphism. The other part of Folk's classification depends on the type of inclusion. The majority of the grains have a few vacuoles but no microlites. Microlites on their own and completely clear crystals have not been observed. There are a few grains with a number of vacuoles, possibly of hydrothermal vein origin, but the majority of the grains could be derived from any source.

There are three types of plagioclase, though the division between two of them is not clear cut:

i. Untwinned or simply twinned altered plagioclase, the most numerous, includes those grains which are heavily altered to sericite and occasionally epidote. These grains may be totally obscured by alteration products and what twinning there is may be difficult to detect; the composition is in the albite-oligoclase range ($Ab_{88}An_{12}$–$Ab_{94}An_{6}$). Its source is more likely to be volcanic or hypabyssal rather than plutonic, because in the first two environments alteration is often intense.

ii. Multiple-twinned but unaltered grains of oligoclase ($Ab_{75}An_{25}$–$Ab_{85}An_{15}$) (Fig. 4b) are not numerous. They can be distinguished from the first group, because they occur as smaller grains with less alteration in rocks which contain intensely altered plagioclase. The multiple twinning distinguishes these grains from the unaltered ones of type (i). Twinning is on the albite law and occasionally on the combined Carlsbad-albite or the pericline laws; there is evidence that these are plutonic fragments (p. 11).

iii. Chequer-board albite grains are rare and they show little or no alteration to sericite. These also have a plutonic source (p. 11).

There is a small proportion of alkali-feldspar in most of the sandstones. Orthoclase, the commonest, is untwinned, slightly altered to sericite and may have a brown dusting caused by vacuoles (Folk, 1959, p. 81). It is very rarely microperthitic. Microline occurs infrequently as small, slightly sericitized grains.

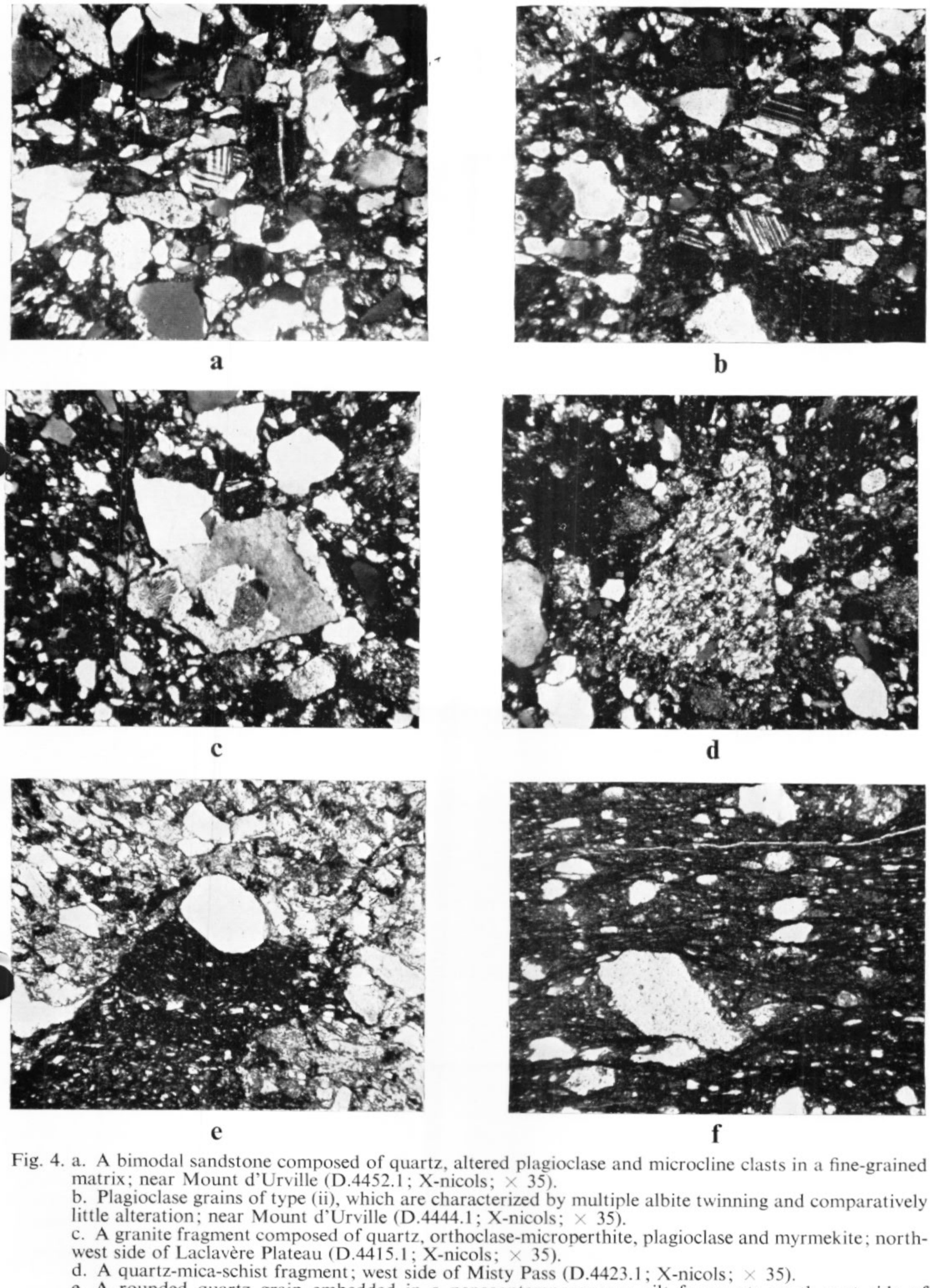


Fig. 4. a. A bimodal sandstone composed of quartz, altered plagioclase and microcline clasts in a fine-grained matrix; near Mount d'Urville (D.4452.1; X-nicols; × 35).
b. Plagioclase grains of type (ii), which are characterized by multiple albite twinning and comparatively little alteration; near Mount d'Urville (D.4444.1; X-nicols; × 35).
c. A granite fragment composed of quartz, orthoclase-microperthite, plagioclase and myrmekite; north-west side of Laclavère Plateau (D.4415.1; X-nicols; × 35).
d. A quartz-mica-schist fragment; west side of Misty Pass (D.4423.1; X-nicols; × 35).
e. A rounded quartz grain embedded in a penecontemporaneous silt fragment; north-west side of Laclavère Plateau (D.4407.1; ordinary light; × 35).
f. Pebbly shale showing sand-sized clasts in a fine-grained matrix which is crossed by numerous shear planes; Aureole Hills (D.4464.1; ordinary light; × 35).

The igneous rock fragments were derived from plutonic and volcanic sources and the former are generally less numerous than the latter. Fragments composed of quartz, plagioclase ($Ab_{92}An_8$), alkali-feldspar and a little mica are the most frequent of all the granitic rocks (Fig. 4c). The plagioclase in all these composite grains is always comparatively unaltered but twinned, and it supports the divisions of the plagioclase group. The rare gneissic fragments are composed of small subhedral crystals of quartz and simply twinned oligoclase crystals. Porphyritic and non-porphyritic rhyolites are the commonest volcanic fragments, and there are also some devitrified rhyolites. The few fine-grained andesite fragments are trachytic in texture.

Metamorphic rock fragments are uncommon and all are quartz-mica-schists with minor variations in the grain-size and mineral proportions (Fig. 4d). The stretched metaquartzite fragments are referred to on p. 4.

The rare sedimentary rock fragments are of cryptocrystalline chert. Compared with the rhyolites they have neither the marked differences in refractive index nor any iron ore. Penecontemporaneous siltstone fragments occur occasionally and at a few outcrops they form a high proportion of the bottoms of sandstone beds. The embedding of grains into the margins of these fragments shows that they were only semi-lithified at the time of their incorporation in the sandstone beds (Fig. 4e).

The commonest heavy minerals are iron ores and their alteration products. Unaltered iron ore is rare; it mostly occurs as titaniferous magnetite or ilmenite, either partially or completely altered to leucoxene and occasionally to sphene. Sphene is widely distributed as small discrete, rarely euhedral, grains. A few grains are twinned and some are pleochroic from pale yellow-brown to pale reddish brown. The grain-size has made it impossible to distinguish sphene from rutile in many instances, but it is probable that the pleochroic grains are rutile. In almost all specimens there are tiny well-rounded zircon grains and bent flakes of detrital muscovite and biotite which is always altered to a brownish chlorite. In a few sandstones there is a little detrital hornblende with a pleochroism scheme α = pale yellow-brown, β = green, γ = brownish green, $\gamma : c = 19°$ and $2V\alpha \simeq 80°$. The mineralogy of the sandstones containing this amphibole precludes an authigenic origin on metamorphism of the rocks. Metamorphic rock fragments tend to be more numerous in specimens containing amphibole grains, and it is likely that this mineral was derived from a metamorphic source. Small colourless garnet grains occur in some rocks and they are always fractured and partially altered to chlorite. There are also a few detrital allanite grains. Authigenic pyrite occurs in only one specimen.

Argillaceous sediments

Black shales predominate over siltstones and they either occur alone or are interbedded with the siltstones. Where they are present by themselves, the shales are either massive or in repeated units 1–2 in. (2·5–5·0 cm.) thick. Often the shales are cleaved at a low angle to the bedding (Fig. 3b). The interbedded siltstones and shales may be associated with thin beds of sandstone. Many of these rocks exhibit sedimentary structures (p. 8), which enable the way-up of the beds to be determined.

The finer-grained rocks studied microscopically all fall into the silt class on the grain-size of the quartz. There are a few coarse siltstones, many medium ones and a few fine ones. The finer grades differ most in the amount of micaceous matter and they may in fact grade to the clay classes, but the grain-size of those classes cannot be measured in thin section.

The coarse siltstones reflect the mineralogy of the sandstones (D.4447.1); there are no rock fragments, but in other respects they are finer-grained versions of them. Quartz is the commonest mineral and, although many grains have undulose extinction, it is not possible to classify them into Folk's types because of their grain-size. There is some plagioclase with albite twinning ($An_{90}An_{10}$) and possibly rather more untwinned, as in the sandstones. Chequer-board albite is absent. Orthoclase is present but there may be more which has remained undetected, because the micaceous minerals prevent refractive index comparisons with quartz or plagioclase. There is a high proportion of muscovite or sericite, some of which is authigenic, and a little green or brown chlorite. The accessory minerals include small rounded zircon grains, fragments of brownish sphene or rutile and iron ore which is often altered to leucoxene. Small

TABLE II. MODAL ANALYSES OF 15 SANDSTONES FROM NORTH-WEST TRINITY PENINSULA

Minerals and Rock Fragments			D.4423.1	D.4425.2	D.4429.1	D.4435.1	D.4439.2	D.4444.1	D.4446.1	D.4449.1	D.4452.1	D.4401.1	D.4405.1	D.4407.1	D.4408.1	D.4415.1	D.4417.1
Quartz	Folk's types	1	49	46	49	7	3	52	62	25	15	15	163	23	27	34	39
		2	63	43	36	53	11	56	85	72	116	21	81	91	121	120	148
		3	37	33	78	32	56	83	27	42	59	14	54	102	153	58	68
		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		5	57	38	18	44	6	39	5	8	19	5	5	26	9	7	3
		6	11	0	0	5	0	0	0	0	3	0	0	1	0	0	0
Plagioclase	Types corresponding to text	i	189	201	304	232	74	121	132	268	218	337	141	77	259	270	206
		ii	3	7	14	19	9	29	3	19	32	89	37	2	60	25	13
		iii	0	0	2	0	0	4	0	0	1	14	0	0	0	0	0
Alkali-feldspar	Orthoclase		18	33	26	15	1	0	44	52	56	16	22	38	17	43	11
	Microcline		0	0	0	1	0	0	0	0	0	0	0	1	0	1	2
	Perthite		3	0	2	2	0	0	3	0	0	4	0	1	0	1	0
Igneous rock fragments	Granitic		20	7	9	5	2	3	8	9	32	24	15	18	10	29	19
	Granite-gneiss		0	1	0	0	0	0	0	0	0	1	0	4	0	4	0
	Porphyritic rhyolite		1	11	23	45	0	6	3	11	3	39	0	0	2	12	9
	Rhyolite		20	6	13	44	0	11	16	8	3	70	2	10	16	11	13
	Andesite		1	0	0	1	0	0	0	3	3	8	0	0	1	0	2
Metamorphic rock fragments			24	18	7	9	0	30	0	6	21	2	10	13	1	2	4
Sedimentary rock fragments	Chert		1	0	3	0	0	1	1	6	2	0	0	0	0	0	0
	Penecontemporaneous silt		1	3	7	3	0	0	0	0	5	6	0	1	8	1	0
Heavy minerals	Leucoxene		3	9	8	0	6	7	4	17	11	9	15	4	19	2	6
	Iron ore		3	3	2	0	0	5	3	1	8	0	1	3	0	0	2
	Sphene and/or rutile		2	1	0	0	0	1	0	2	2	2	2	2	0	1	4
	Zircon		0	0	0	0	0	2	0	0	1	0	3	2	0	2	0
	Amphibole		0	1	0	0	0	0	0	0	12	0	0	0	0	0	0
Matrix			494	539	399	483	832	550	604	451	378	324	450	581	297	376	451

1,000 points were counted on each thin section.

[*face page 6*

laths of hornblende occur in one specimen (D.4457.1) and they are similar to those in the sandstones. The matrix is fine silt- or clay-sized. Epidote occurs both as secondary grains and aggregates.

The finer siltstones (D.4449.2), classified as medium silts on the grain-size of the quartz, have lost the distinctive mineralogy of the coarse siltstones. The non-micaceous minerals are dominated by quartz; feldspar may occur in a greater proportion than is apparent from the few identified twinned grains. Small unaltered iron ore grains occur sporadically. The micaceous minerals are muscovite, sericite and chlorite; frequently the flakes are too fine for identification. The proportion varies considerably without much change in the grain-size of the quartz. Minute zircon grains are rare. In some of the finer siltstones there are thin streaks of carbonaceous matter, seldom more than 0·05 mm. long, which may enclose a little pyrite. Granular aggregates of secondary epidote occur in many of the specimens.

Thin-section analysis

Folk's (1954) classification has been used in an analysis of these sandstones. They are considered to be a turbidite sequence in which the clay matrix is a function of the depositional environment and the associated turbidity currents (p. 13). The important factors in this classification are grain-size, composition and textural maturity, the latter defined by the clay content, rounding and sorting. As the sediments are well indurated and slightly metamorphosed, all the data on mineralogy, size distribution and roundness were obtained from thin sections by point-counting.

All grains larger than 0·02 mm. were counted as their respective mineral types, whereas all smaller were counted as matrix without specifying the mineral. All secondary mineral grains and aggregates, which concealed the original mineral, were included in the matrix. The quantitative distribution of the minerals and rock fragments is given in Table II and the classification in Fig. 5.

McBride's (1962, p. 66) method was used to obtain the size distribution from the thin-section data, and the results were plotted as cumulative percentage curves (Fig. 6). The sorting of the samples was derived from these curves by the use of the graphic standard deviation (Folk, 1959, p. 44). The values of σ_G vary from $0\cdot51\phi$ to $0\cdot72\phi$, which indicates that the sand-sized fraction is moderately sorted. The clay matrix has been ignored because it is impossible

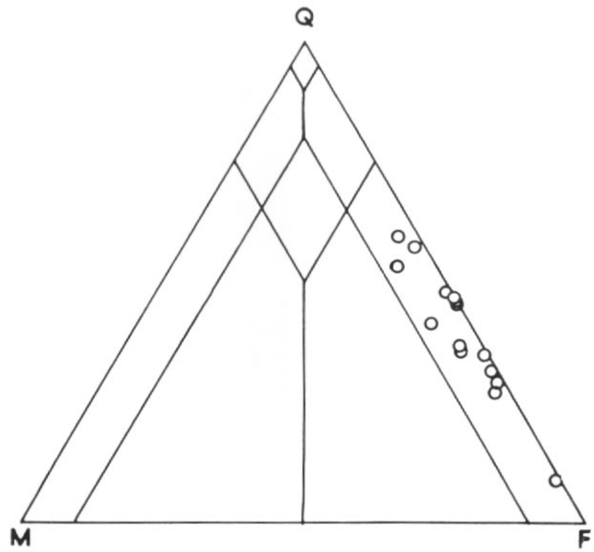


Fig. 5. Classification of 15 sandstones from north-west Trinity Peninsula. Q quartz (less type 6)+chert; M metamorphic rock fragments+quartz of type 6; F plagioclase+alkali-feldspar+igneous rock fragments. All sandstones belong to the arkose clan and are plagioclase-arenites.

to measure the grain-size, so these rocks are in fact bimodal; one mode has been measured, while the other mode lies in the indeterminate fine-silt to clay range.

Many of the grains have been corroded by the clay matrix and their original shape has been modified. A visual estimate of roundness was made by comparison with a standard roundness chart (Powers, 1953, p. 118); this is expressed as a range of roundness classes observed in each sample rather than an accurate quantitative result. The roundness of the sand-sized grains falls in the angular–sub-angular–sub-rounded classes, with the sub-angular class predominant. A few well-rounded quartz grains (Fig. 4e) fall outside this range and these are likely to have been derived from older siliceous sediments in which they had already achieved a high degree of roundness.

Sedimentary structures

In the sediments which have suffered only slight regional metamorphism, sedimentary structures are quite common. The features observed were graded-bedding, current-bedding, slump structures, flute-casts and load-casts. These are useful features for the determination of the way-up of the sediments and in elucidating the depositional environment (p. 13).

Graded-bedding occurs almost exclusively in the sandstones and it varies in type from penecontemporaneous shale fragments (decreasing in number and size upwards from the bottoms of beds) to rather indistinct grading associated with other sedimentary structures. Only in two localities is sandstone–shale grading displayed well. At one locality coarse sand rapidly grades to a medium sandstone which in the top 0·5 in. (1·25 cm.) of the bed grades to a black shale (D.4435.1; Fig. 3c). The thickness of the graded beds is 12–18 in. (30–45 cm.). Similar delayed graded-bedding (Walton, 1956, p. 263) occurs in a coarse siltstone in which the graded units vary in thickness from 1 to 2 in. (2·5 to 5·0 cm.) (D.4447.2; Fig. 7a).

Current-bedding is confined to the siltstones (D.4448.1, 4449.2) but it occurs at many outcrops. The truncated beds rarely exceed 2 cm. in thickness and they are never repeated over more than 6 cm. of sediment thickness.

The slumping of a heavier wet sediment over a less dense sediment was observed at three outcrops. In one example (D.4438.1) the over-riding sediment has picked up small semi-lithified fragments (0·5–1·0 cm. long) of the underlying sediment and incorporated them with

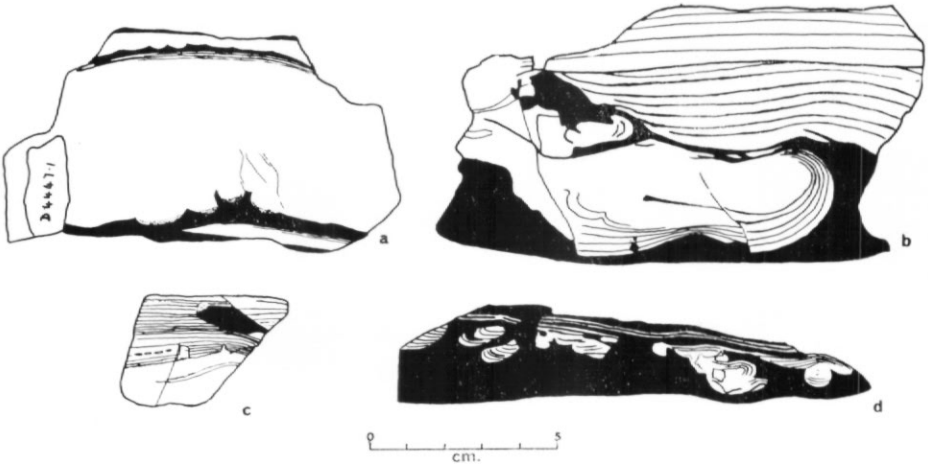


Fig. 7. a. Load-casts and flame structures at the junction between shale (in black) and graded siltstone, of which the coarser grades in the load-casts are stippled; near Mount d'Urville (D.4447.1).
b. Slumping of siltstone over and into mudstone (in black); near Mount d'Urville (D.4457.1).
c. A flute-cast (in black) cut in fine silt and displaced by later micro-faulting; west side of Misty Pass (D.4425.1).
d. Load-casts developed from a thin layer of silt overlying mud (in black); near Mount d'Urville (D.4450.1).

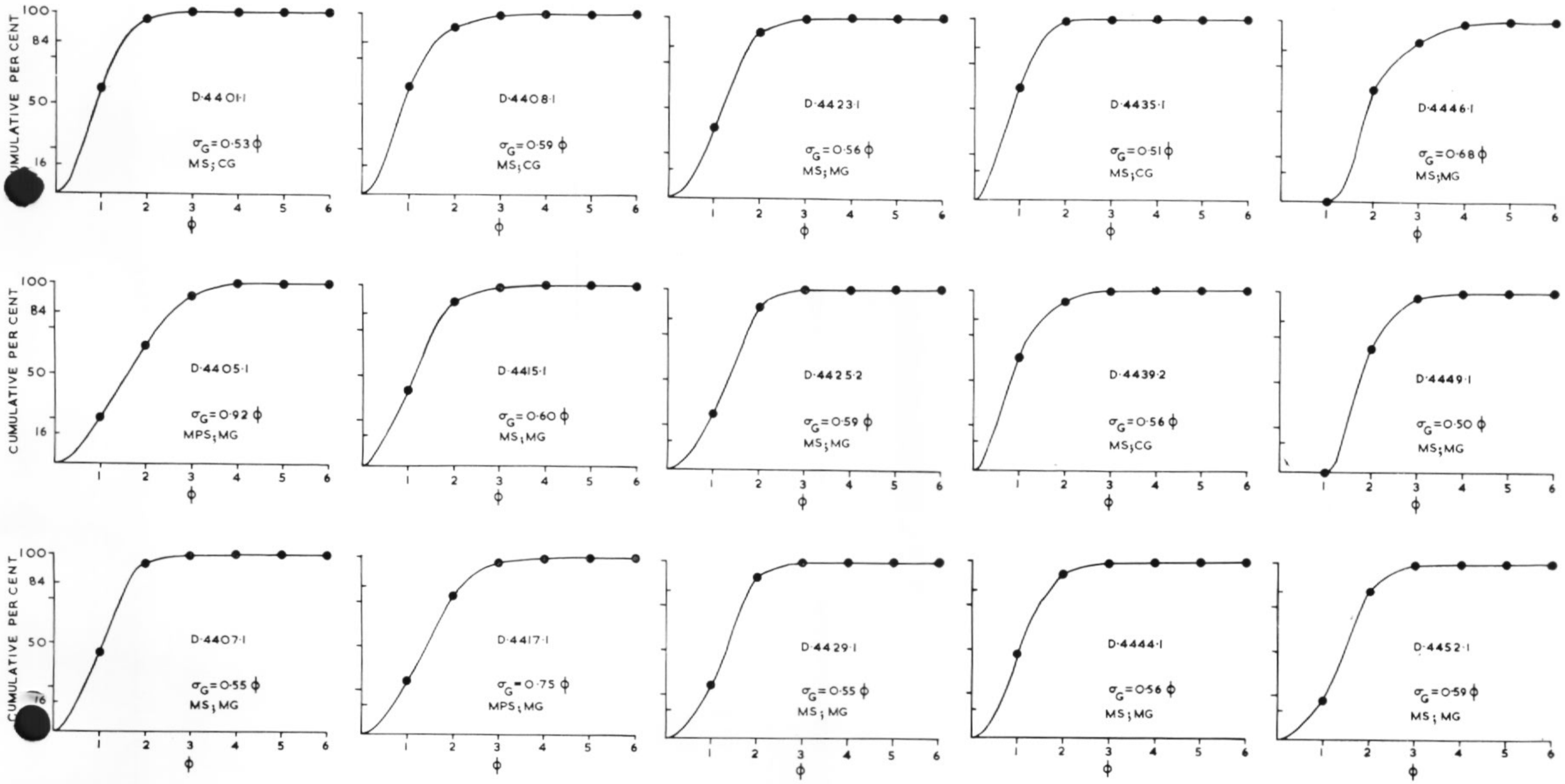


Fig. 6. Cumulative curves from the size-analysis data of the sand-sized fractions of 15 sandstones from north-west Trinity Peninsula. $\sigma_G = (\phi 84 - \phi 16)/2$; MS moderately sorted; MPS moderately poorly sorted; CG coarse-grained; MG medium-grained.

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a homogeneous distribution which reflects the very slight differences in mineral proportions (and hence density) of the sediments. Another example (D.4457.1; Fig. 7b) shows the balling of the over-riding sediment and stringers of the underlying sediment caught up with the slump structures. This is not convolute lamination, because the overfolds are broken up, the structures die out abruptly downwards and may be truncated upwards, and the evenly laminated sediment lies on an erosion surface (Haaf, 1956, p. 192). It is not a flow-cast (Prentice, 1956), because this involves greater current drag than is normally associated with turbidity currents (Kuenen and Prentice, 1957, p. 173).

One flute-cast (Kuenen and Prentice, 1957, p. 173) was seen in fine silt (D.4425.1). A flute was scoured out in fine silt and filled by structureless slightly coarser silt and a small amount of much coarser silt. Later micro-faulting has removed some of the flute-cast (Fig. 7c).

Two examples of load-casts (Shrock, 1948, p. 156; Kuenen, 1957, p. 246) occur and they are described separately, because of the rarity of sole-markings in these sediments. One (D.4447.1, 2; Fig. 7a), already mentioned under graded-bedding, has well-developed load-casts with associated flame structures (Walton, 1956, p. 267). Unequal loading and flow of the mud from beneath the resultant casts produced the flame structures. During compaction the flame structures were bent over and the rock developed planes of weakness into which thin filaments of mud were injected. The top of this graded bed also shows load-casting and flame structures but on a smaller scale. The possibility that these are interference ripple-marks can be ruled out by their irregularity. The other example (D.4450.1; Fig. 7d) shows features similar to an illustration by Shrock (1948, fig. 116). There is no overlying sandstone, some of the casts are attached to the upper surface layers and the rest are detached. All the casts have mud laminae within them, which represents changing conditions during deposition. The convolutions in the casts were caused by slight horizontal slip or flow during their formation and the subsequent compaction of the rock. The detached casts are similar to the slump-balls described by Allen (1963, p. 394). Above the casts there are a few thin laminae of coarser sediment which are parallel to the thin layer joining the top of the attached casts. The absence of any overlying sediment does not imply that there was some which has been removed, because currents strong enough to remove the coarser material would have deposited even coarser sediment. These load-casts must have developed from a thin layer of sediment which was overlying very wet mud. Subsequently, it underwent some horizontal slip and some of the casts were detached and sank into the mud.

South-west area

The more metamorphosed rocks of the Trinity Peninsula Series are phyllites and sandstones, but there are two other rock types: pebbly shales, which have already been recorded (though not described) from the mainland at Cape Legoupil, and greenschists. Phyllites and sandstones form the bulk of the Trinity Peninsula Series outcrops. Regional metamorphism has altered the finer-grained sediments more than the sandstones but the original lithology was a sequence of sandstones, siltstones and shales, which are comparable with the rocks already described; this is considered again on p. 12. It is probable that the argillaceous fraction is greater than the arenaceous one. On the east side of Pettus Glacier the total thickness of these sediments is at least 12,000 ft. (3,660 m.).

Arenaceous sediments

The arenaceous rocks are all medium to fine sandstones (D.4475.1). Most of the beds are 1 to 2 ft. (0·3 to 0·6 m.) thick and they are interbedded with the finer-grained rocks. No depositional feature was seen at any outcrop.

These rocks do *not* possess the typical bimodal texture of the undeformed sandstones (p. 4; Fig. 4a). The clasts are generally smaller and the groundmass has been recrystallized. The quartz and feldspar grains are 0·05–1·0 mm. long. The feldspar composition cannot always be determined because of the absence of twinning but it is in the albite-oligoclase range ($Ab_{88}An_{12}$). The clasts are angular to sub-rounded but metamorphic and metasomatic effects have destroyed their original form. The matrix is composed of quartz, sericite, chlorite and iron ore which is mostly leucoxene after titaniferous magnetite. There are also a few zircon and apatite grains. Two of the specimens contain fragments of a siliceous siltstone, a recrystallized rhyolite and a granite-gneiss. Some of these rocks are traversed by quartz veins and the groundmass may be silicified. There is only one example of secondary calcite (D.4471.1).

Argillaceous sediments

The argillaceous sediments are shales and fine siltstones. The thickness of the beds is masked by the metamorphism and quartz veining. One possible depositional structure takes the form of truncated bedding and this can also be seen in thin section (D.4467.1).

These rocks are dominantly micaceous with variable amounts of quartz, feldspar, iron ore and leucoxene. The micaceous minerals are sericite, muscovite and rare biotite.

Pebbly shales

The three outcrops of pebbly mudstone or shale are widely separated and they occur at Cape Legoupil, Aureole Hills and on the east side of Pettus Glacier. These rocks are termed pebbly mudstones or shales, because almost all the rock fragments visible in the hand specimen fall within the pebble grain-size, but no grain-size analysis has been attempted.

At Cape Legoupil the pebbly mudstone contains sparsely distributed igneous and sedimentary pebbles. It is a small lens which passes into mudstone and is surrounded by shales and sandstones. The pebbly shale at Aureole Hills (D.4464), which is not in contact with any other sediments, is a fissile rock at least 10 ft. (3 m.) thick, carrying pebbles of quartz, igneous rocks and sediments. Most of the pebbles are 1·0–2·5 cm. long by less than 1·0 cm. across, though they may attain a size up to 7·5 cm. by 3·5 cm. On the east side of Pettus Glacier, pebbly shales (D.4471.2) up to 10 ft. (3 m.) thick are interbedded with sandstones about 1 ft. (0·3 m.) thick. The pebbles do not include quartz fragments and they are usually no more than 2·5 cm. long (Fig. 8).

Microscopically, these rocks are characterized by sparsely distributed clasts in a clay- to silt-sized matrix (Fig. 4f). The matrix is composed of quartz, sericite, chlorite and a little iron ore. The clasts in these rocks are similar to those in the sandstones. Quartz grains are the

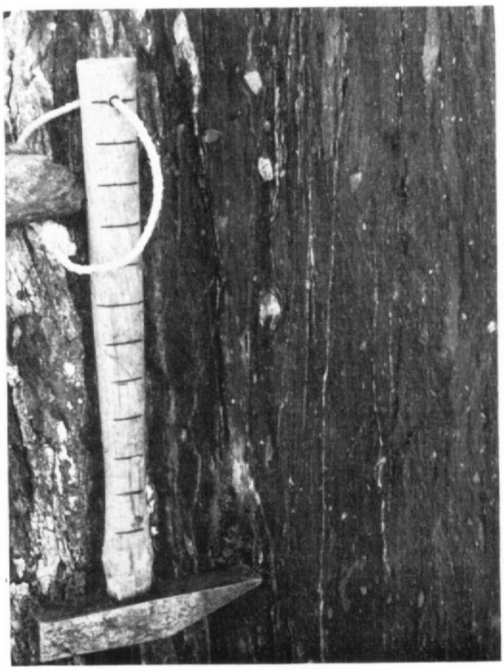

Fig. 8. Sandstone (on the left) and pebbly shale; east side of Pettus Glacier (D.4471).

commonest, and on Folk's classification the majority of them belong to type 3, but there are some composite grains of types 5 and 6. Many of the grains are corroded by the groundmass. The infrequent twinned plagioclase grains are of oligoclase ($Ab_{89}An_{11}$). One of the grains has bent twin lamellae which indicate a foliated source rock. A little leucoxene and a few rounded zircon grains are present. Haematite streaks occur in all specimens, probably replacing pyrite.

Most of the rock fragments are rather larger than the mineral grains and they have as wide a composition range as those in the sandstones. The igneous rock fragments include both plutonic and volcanic types. In the hand specimen there are a few pebble-sized granitic fragments, composed of strained quartz, albite with multiple twinning and comparatively little alteration ($Ab_{92}An_{8}$), orthoclase or orthoclase-perthite, some chequer-board albite (Fig. 10a) and accessories. The mineralogy shows that the strained quartz, alkali-feldspar, plagioclase with multiple albite twinning and chequer-board albite are all derived from a common source. The few granite-gneiss fragments are composed of quartz-plagioclase aggregates. The conspicuous pale grey aphanitic rock fragments are porphyritic and non-porphyritic rhyolites and andesites similar to those in the sandstones, but there is also a plagioclase-porphyry and a metasiltstone. There are a few penecontemporaneous shale fragments and fragments with the same mineralogy as that of the host pebbly shale.

The grain-size of the clasts is variable (p. 10) and the majority of them by number, but not necessarily by weight, are less than 1·0 cm. long. The mineral grains vary in size from 0·02 to 0·55 mm., whereas the rock fragments are larger and range from 0·1 to 1·8 mm. as seen in thin section. Fragments up to 5·0 mm. can only be seen on cut surfaces but above this size they are easily visible in the hand specimen. All the coarser clasts are angular but, with decreasing grain-size, sub-angular fragments occur and finally the mineral grains and smallest rock fragments may be sub-rounded or rarely rounded.

These rocks are texturally immature (Folk, 1954, p. 344). Although no quantitative analysis was attempted, these rocks are bimodal; one mode is centred on the matrix which is probably well sorted, while the other is centred on the clasts which are poorly sorted, thus implying textural inversion.

Although these deposits are till-like, a glacial origin is unlikely, because there is no glacial pavement and there are no striated and faceted clasts or large erratic blocks. The tectonic setting and stratigraphic relations are the most important factors in their interpretation by other hypotheses (Dott, 1961). All the enclosed rock fragments can be matched with types in the sandstones. The Trinity Peninsula Series near Aureole Hills and Pettus Glacier has been regionally metamorphosed and structures such as graded-bedding have not been observed, but these rocks do belong to a sequence of sandstones and shales that can be compared with less deformed sediments to the north-east (p. 12). The general character of the Trinity Peninsula Series is that of a geosynclinal assemblage (p. 13). Turbidity currents are characteristic of such an environment (Folk, 1959, p. 122) and the less deformed sediments have both displaced clastic material in the sandstones and graded-bedding, which are the criteria for such currents (Dott, 1963, p. 118). Dott (1963, p. 113–14) has shown how re-deposition by turbidity currents can produce such sediments. All the available evidence points to the formation of these sediments by re-depositional processes rather than by glacial action.

Greenschists

On the west side of Pettus Glacier, there are widely and sparsely distributed outcrops of a greenschist. Its relationship to the Trinity Peninsula Series is unknown, although sediments similar to those of that series are in contact with it at inaccessible outcrops. The greenschist possesses no structural features but there is some grain orientation in the hand specimen.

The accessible outcrop is composed of a green slightly schistose rock. Microscopically, it is a tremolite-schist (D.4470.1), in which the tremolite forms small colourless laths with a crude parallelism. Granular epidote and sphene are abundant; there is a little quartz, sericite and colourless chlorite, and the rest of the rock cannot be resolved. Only a basic lava or tuff could give the quantity of sphene present; although plagioclase is absent, it may be represented by epidote, sericite and the other unidentifiable minerals. Tremolite in place of actinolite suggests that the iron has passed to other minerals such as epidote.

Correlation

The absence of fossils and marker horizons, and the scattered distribution of outcrops, has made it impossible to correlate the Trinity Peninsula Series rocks from one area to another. Hence the correlation of the sediments of the north-east area with those of the south-west area is rather tenuous. The general attitude of the beds is similar. The lithology of both areas is that of a geosynclinal assemblage of sandstones, siltstones and shales, together with rare pebbly shales and basic igneous rocks. The rocks in the north-east area include two outcrops which have the characteristics of the other area, i.e. quartz veining and stronger regional metamorphism. The features of one of the outcrops (D. 4421) can be attributed to local dynamic metamorphism (p. 23), whereas the other (D.4442) is farther south than the adjacent outcrops, nearer the core of the anticlinorium and does not have the same proportion of sandstone. The degree of regional metamorphism increases from north-east to south-west (Aitkenhead, 1965), and a decrease in the proportion of sandstone would render these rocks more susceptible to deformation. These two facts, together with the fact that the sediments in the north-eastern area are farther away from the core of the anticlinorium, could account for the two somewhat different lithologies encountered in the field.

Metamorphism

The Trinity Peninsula Series has suffered pre-Jurassic regional metamorphism (Adie, 1957, p. 5) and late Cretaceous to early Tertiary thermal metamorphism by the Andean Intrusive Suite (Adie, 1955, p. 4). Regional metamorphism in north-west Trinity Peninsula is low-grade and largely confined to shearing effects, except in isolated outcrops south-west of Sirius Knoll. In that area there has been recrystallization of the matrix of some of the sandstones, and metamorphism of some argillaceous sediments to phyllites and basic igneous rocks to greenschists. There are no visible contacts between the Trinity Peninsula Series and the Andean Intrusive Suite, although there are rocks within the thermal aureole which reach the hornblende-hornfels grade of thermal metamorphism and rocks enclosed in the intrusive masses as xenoliths. Narrow veins of epidote, calcite and prehnite may also be connected with the intrusions, though they may equally well be Jurassic in age.

Regional metamorphism

There is some evidence of a phase of dynamic metamorphism later than the main regional metamorphism, because of the rare occurrence of shear planes cutting folded quartz veins and crossing the schistosity, although this could have been caused by the emplacement of the Andean Intrusive Suite. The dynamic effects of the regional metamorphism are more prominent than mineralogical changes in most rocks.

Near Mount d'Urville and to the north-east, the mineralogical changes are slight. Comparatively coarse sericite flakes are very common but muscovite is only rarely developed. Plagioclase is albitized in many of the rocks and the released calcium has formed prehnite, epidote and calcite. The presence of muscovite suggests that albitization may not have been entirely a diagenetic process but one aided by metamorphism; these rocks are transitional to the lowest sub-facies of the greenschist facies of regional metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 217–24). They cannot be compared with the intermediate stage (the zeolite facies), because of the absence of the critical minerals. South-west of Russell West Glacier, although the dynamic effects are greater, the mineralogical changes are similar, except in two rocks in which recrystallization is complete and biotite has developed. These are quartz-plagioclase-mica-phyllites belonging to the quartz-albite-epidote-biotite sub-facies of the greenschist facies. The greenschist (p. 11), which was probably derived from a basic igneous rock, belongs to the lower sub-facies of the greenschist facies.

The purely dynamic effects of metamorphism are confined to intergranular shearing. In the north-eastern area the medium to fine siltstones never have more than a few, continuous widely spaced shear planes. In contrast, the sandstones and coarse siltstones are more severely sheared, though the shear planes may be poorly defined or discontinuous (Fig. 10b) and are absent from a few rocks. In the outcrops near Mount d'Urville the shearing is at a minimum and this appears to be related to the uniform dip angles and directions, whereas where the latter are variable the shearing is greater. In the south-western area deformation is greater; some of the argillaceous rocks have a strain-slip cleavage (Fig. 10c) and they also include the one example of shear planes crossing the schistosity. Folded quartz veins which are cut by strain-slip cleavage indicate that they were emplaced before the dynamic metamorphism. These veins may be filling tension gashes formed during folding of the rocks. The pebbly shales are characterized by strongly developed, closely spaced and continuous shear planes (Fig. 4f). All the sandstones have undergone some mechanical granulation to give a more extensive matrix and this has probably destroyed many of the shear planes. The shear planes vary between closely spaced and continuous, and widely spaced and discontinuous.

Near Misty Pass there is a small outcrop of metamorphosed shales and sandstones, which are now represented by contorted phyllites and shattered sandstones. It is most likely that this was caused by local faulting, because of the absence of similar rocks in this area.

Thermal metamorphism

Thermally metamorphosed rocks crop out near Aureole Hills and Poynter Col. One of the outcrops near Aureole Hills (D.4469) is described under the Andean Intrusive Suite (p. 22), because the sediments have been completely assimilated and all sedimentary features have been lost.

At the other outcrop, near Aureole Hills (D.4460), the rock is related (on microscopic evidence) to the greenschists on the west side of Pettus Glacier. When cut across the foliation, this black schistose rock shows small white mineral aggregates. Mineralogically, it is a hornblende-quartz-plagioclase-hornfels of the hornblende-hornfels facies of contact metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 205-11). The hornblende forms tightly packed laths 0·1 mm. long which have a poor flow texture round the quartz-plagioclase aggregates. The hornblende with $\gamma{:}c = 24^\circ$ and a pleochroism scheme α = yellow-brown, β = yellow-green and γ = bluish green, is probably sodium-rich. Small unaltered iron ore grains are scattered throughout the amphibole. Some of the aggregates of quartz and plagioclase ($Ab_{70}An_{30}$) enclose calcite and biotite crystals around their rims. The mineralogy suggests that this rock is a thermally metamorphosed greenschist. The original rock was probably a basic lava or tuff which was regionally metamorphosed to a greenschist and then thermally metamorphosed to a hornfels. The quartz-plagioclase aggregates are believed to be metamorphic segregations, and their slightly rotated appearance to be a feature of the clots clearing themselves of inclusions, rather than a dynamic effect.

The other metamorphosed rock (D.4478.2) belonging to the Trinity Peninsula Series is in contact with an altered and metasomatized biotite-tonalite (p. 21). The exact relationship cannot be inferred but it is probably a xenolith. It is a recrystallized quartzo-feldspathic rock which was originally a fine feldspathic sandstone.

Depositional environment and provenance

Depositional environment

This succession of evenly bedded sandstones, siltstones and shales with a thickness of at least 12,000 ft. (3,660 m.) was deposited in a geosynclinal environment, and no features of shallow-water or terrestrial deposition were found. The mineralogy, sedimentary structures and the pebbly shales are all indicative of re-deposition, in particular by turbidity currents.

The sandstones are immature bimodal clastic sediments composed of a coarse fraction of quartz, feldspar and rock fragments set in an argillaceous matrix. The formation of such a sediment, which may carry penecontemporaneous shale fragments showing signs of plasticity at the time of deposition, can only be attributed to high-density turbidity currents in which there was little or no internal abrasion of the suspended sediment (Kuenen and Migliorini, 1950, p. 111). The sedimentary structures could all have been formed by re-deposition. Graded-bedding is the typical structure of a turbidite (Kuenen and Migliorini, 1950) and it is present although not at many outcrops. The sole-markings are flute- and load-casts, both products of scouring and dense coarse sediment overlying less dense finer sediment (Kuenen, 1957, p. 235–42, 246–48). Slumping is not caused by turbidity currents but it is associated with them in many turbidite sequences (Kuenen, 1953, p. 1054–56). Small-scale current-bedding is present at many outcrops and such bedding is characteristic of many graded sequences (Kuenen, 1953, p. 1051–53). The origin of the pebbly shales has been discussed (p. 11) and they are attributed to re-deposition rather than to glacial action. The depositional processes, the great thickness of the sediments and their feldspathic character all point to a geosynclinal depositional environment, i.e. deep-water sedimentation on a rapidly subsiding sea bed with re-deposition of all coarser sediment.

There is little evidence of the characteristics of the coarser fractions of the sandstones and pebbly shales before their re-deposition. The sandstone clasts are moderately sorted and angular to sub-rounded, suggesting deposition by steady currents and little time in an abrading environment before re-deposition. The coarser clasts in the pebbly shales show that, although there was some variation in grain-size, it was either of little importance compared with the volume of sand-size clasts, or the coarser sediment was deposited elsewhere.

Provenance

The mineralogy indicates a variable source terrain composed dominantly of granitic and volcanic rocks with subordinate metamorphic and sedimentary rocks.

The granitic rocks include some granite-gneisses but intrusive rocks are by far the most numerous. The latter are postulated from the plutonic fragments, the independent alkali-feldspar, the chequer-board albite and the unaltered plagioclase. The scarcity of metamorphic fragments means that the strained quartz was probably derived from granitic rocks. There are more plutonic than gneissic fragments, so it is probable that the quartz was derived from sheared plutonic rocks rather than from true gneisses. Alkali-feldspar is generally in excess of unaltered plagioclase and both are smaller in grain-size than the quartz.

Fragments of extrusive rocks are generally more numerous than granitic ones and altered plagioclase is far in excess of unaltered oligoclase, so volcanic rocks must have formed at least as large a source area as the plutonic ones. Porphyritic and non-porphyritic rhyolites far exceed the proportion of andesite fragments, but volcanic quartz has not been proved. This suggests that the abundant altered plagioclase was derived from easily weathered rocks such as tuffs. The larger grain-size of the altered plagioclase compared with the unaltered plagioclase, together with the relative size of the latter and quartz, suggests that either the source was closer to the depositional area or the original plagioclase was coarser.

Quartz-mica-schists and stretched metaquartzites, and the presence of detrital garnet and amphibole, are all evidence of metamorphic rocks in the source area. Garnet was probably derived from pelitic schists, and amphibole from either metamorphosed calcareous sediments or metamorphosed basic igneous rocks. The detrital amphibole points to a metamorphic terrain close to the depositional basin.

The sparse chert fragments show that in the source area there were either some orthochemical sediments or *ortho*quartzites, because the latter often include a proportion of these fragments (Folk, 1959, p. 78, 126). These sediments may have formed a thin veneer on the stable granitic rocks. The rare occurrence of well-rounded quartz among dominantly sub-angular grains also indicates a sedimentary source, which must have included terrigenous siliceous rocks, probably *ortho*quartzites. Quartz grains with a high degree of roundness in immature sandstones are almost always re-worked from older sediments.

The provenance of these sediments was probably a high, rapidly eroding landmass composed of intrusive, extrusive, metamorphic and sedimentary rocks. Farthest from the basin of deposition, there were sheared plutonic rocks together with some true gneisses, all overlain by thin terrigenous and orthochemical sediments. Nearer, possibly, there were volcanic rocks ranging in composition from intermediate to acid, dominantly rhyolitic and possibly including pyroclastic rocks to account for the abundant altered plagioclase. Nearest to the depositional basin was a narrow belt of metamorphic rocks that provided the detrital amphibole.

The relative ages of some of these rocks may be inferred from the early Palaeozoic volcanic and intrusive rocks, and the Basement Complex, which occur farther south (Adie, 1954; Goldring, 1962). The early Palaeozoic volcanic rocks are dominantly andesitic, whereas the intrusive rocks are intermediate to acid in composition. The latter include rocks with strained quartz crystals but, since the age of the stress is unknown, the granitic source could be either or both the Basement Complex and the Palaeozoic intrusions. The volcanic source was probably early Palaeozoic. The metamorphic rocks are either earliest Palaeozoic or Basement Complex, because they represent a period of regional metamorphism which must be earlier than the unmetamorphosed sediments in this area.

Banded Hornfelses

Along the plateau edge east and south of Aureole Hills, a few outcrops are composed of banded hornfelses. The only extensive outcrops are south of Aureole Hills (D.4465, 4466) where the thickness of the hornfelses is at least 500 ft. (153 m.) (Fig. 9). The banding in the

Fig. 9. Quartz-plagioclase-porphyry dykes (light grey) cutting gently dipping banded hornfelses (darker grey with prominent, near-horizontal banding); south of Aureole Hills (D.4465).

accessible rocks has a low dip (22°) to the south-west and it is apparently uniform over a very wide area, including the inaccessible outcrops (D.4466). The only other recorded dip is 40° to the north-east at station D.4461. The accessible rocks do not possess any obvious sedimentary features, although the banding could be interpreted as bedding.

The mineralogy of these rocks, their attitude in the field and the type of metamorphism they have undergone, are all quite different from that of the adjacent Trinity Peninsula Series, which dips steeply and is composed of regionally metamorphosed sandstones, siltstones and shales. At the head of Victory Glacier and on the ridge trending north-west from Mount Bradley (both on the south-east side of Detroit Plateau), Aitkenhead (1965) has recorded rocks which are different in mineralogy and field occurrence to the adjacent Trinity Peninsula Series. On the Mount Bradley ridge there are at least 2,000 ft. (610 m.) of metamorphosed sediments.

Petrography

The hornfelses (D.4465) have individual quartzo-feldspathic and ferromagnesian bands 0·1–0·4 mm. thick. They are quartz-plagioclase-chlorite-hornfelses with a granoblastic texture in the quartz-plagioclase-rich bands and a poor schistosity in the chlorite-rich bands.

In the former there are a little alkali-feldspar and micaceous minerals, whereas the latter are composed of penninite, biotite, sericite and muscovite, with a little quartz and plagioclase ($Ab_{68}An_{32}$). The penninite with enclosed rutile or sphene was derived from biotite. Zircon, sphene and iron ore are accessory.

The banded rocks at the other accessible outcrops have been metamorphosed by the Andean Intrusive Suite. At one outcrop (D.4463) the hornfels is a xenolith in tonalite but at the other (D.4461) it is not in contact with any other rocks. Both the centre of the xenolith and the latter are very similar; the banding is more pronounced, from 1·0 to 6·0 mm. wide, and consists of equal proportions of light and dark bands. These hornfelses have a granoblastic texture with some poekiloblastic alkali-feldspar and amphibole. There is some segregation of the minerals into bands but it is not as clear-cut as in the other hornfelses; the quartz-plagioclase ($Ab_{59}An_{41}$) bands include some pyroxene and epidote, whereas the chlorite-biotite bands include hornblende. The grain-size of the quartz is larger in the former, 0·1–1·0 mm. as opposed to 0·02–0·10 mm. A little of the colourless pyroxene, probably diopside, is intergrown with green hornblende. Strings and aggregates of pistacite occur in the chlorite-biotite bands but more prominently with the pyroxene. There is accessory zircon, iron ore, sphene and apatite. The xenolith (D.4463.3) has a pale actinolite in place of the hornblende, less epidote and more sphene. The high proportion of epidote in specimen D.4461.1 is probably an original compositional difference. The xenolith margin is a quartz-plagioclase-biotite-hornfels with a lepidoblastic texture of biotite and chlorite. Quartz and plagioclase ($Ab_{62}An_{38}$) have a granoblastic texture and a grain-size between 0·2 and 0·3 mm. The small irregular orthoclase crystals may be poekiloblastic and partly metasomatic. The rock is cut by shear planes along which biotite is chloritized, the adjacent feldspar sericitized and the quartz strained. The difference in composition compared with the centre of the xenolith must have been caused by reaction with the host magma in order to attain mineralogical equilibrium.

Metamorphism

The quartz-plagioclase-chlorite-hornfelses properly belong to the hornblende-hornfels facies of contact metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 205–11), because the chlorite was derived from biotite. They could have been derived by thermal metamorphism of a succession of alternating laminae of argillaceous and quartzo-feldspathic sediments, the chlorite being a later alteration product of biotite. Alternatively, the foliation could have been induced by metamorphic differentiation (Turner, 1941) during regional metamorphism of impure sandstones. The unstrained quartz could indicate later thermal metamorphism which converted the schists to quartz-plagioclase-biotite-hornfelses; later retrograde metamorphism would have chloritized the biotite.

The pyroxene- and amphibole-bearing rocks of the hornblende-hornfels facies have been derived by metamorphism of rocks similar to the quartz-plagioclase-chlorite-hornfelses. The association of pyroxene with amphibole indicates an original compositional difference. The co-existence of epidote and andesine is a result, not of hydrothermal alteration because the rock as a whole lacks alteration, but of high load-pressure and some stress (Turner and Verhoogen, 1960, p. 546), and this is supported by the presence of strained quartz. These rocks are transitional between the hornblende-hornfels and almandine-amphibolite facies of regional metamorphism (Fyfe, Turner and Verhoogen, 1958, p. 228–32).

Origin

It is most unlikely that these rocks are Trinity Peninsula Series sediments brought into their present position by thrusting (p. 22). It is equally unlikely that they are impure sandstones *in situ*, which are contemporaneous with or later than the Trinity Peninsula Series and which have undergone metamorphic differentiation, because there is an abrupt change in attitude in the field and in rock assemblage in adjacent outcrops; there are no stages intermediate between possibly granulated and reconstituted impure sandstones and the sheared sandstones and argillites of the Trinity Peninsula Series.

It is more likely that the banded hornfelses should be correlated with the post-Trinity Peninsula Series sediments at the head of Victory Glacier and elsewhere. North-west of

Detroit Plateau they are pre-Upper Jurassic in age, if the quartz-plagioclase-porphyry dykes (p. 18) which cut them were intruded at that time. There is no evidence of the metamorphic differentiation of impure sandstones, because these features are absent from the correlated outcrops. It is therefore concluded that these rocks were derived from an alternating succession of thin laminae of argillaceous and quartzo-feldspathic sediments. The source rocks are unlikely to have been the Trinity Peninsula Series, because of the high proportion of feldspar. They could, however, represent the erosion products of a period of renewed uplift of the landmass from which the Trinity Peninsula Series was derived. The depositional environment must have been very stable for a considerable time to allow deposition of such a thickness of evenly bedded sediments.

Upper Jurassic Volcanic Group

Pyroclastic rocks which probably belong to the Upper Jurassic Volcanic Group form a few isolated outcrops near Poynter Col. There are no contacts with any other rocks and the age is only inferred from other intermediate to acid volcanic rocks which are of known Upper Jurassic age.

Dykes of probable Jurassic age cut both the banded hornfelses south of Aureole Hills and the Trinity Peninsula Series south of Poynter Col and east of Pettus Glacier.

Pyroclastic rocks

All the extrusive rocks are lithic crystal tuffs, which are stratified at only one outcrop (D.4479) where there are several beds 3–4 ft. (0·9–1·2 m.) thick dipping steeply eastwards, but the contacts are very irregular and possibly only a local feature. These beds grade sharply at the top into fine-grained non-lithic tuffs. The visible rock fragments vary in size and composition from one outcrop to another; they are of igneous and sedimentary types, including a few phyllites of the Trinity Peninsula Series.

The pale bluish grey to black tuffs enclose accidental xenoliths, most of which are less than 5·0 mm. long and sub-angular, although some are angular or sub-rounded. The matrix enclosing the xenoliths has a dacite composition. The phenocrysts (up to 2·0 mm.) of quartz and altered plagioclase ($Ab_{60}An_{40}$–$Ab_{75}An_{25}$) are corroded by the groundmass which is an aggregate of very fine-grained (0·020–0·002 mm.) quartz and feldspar with a little leucoxene and yellowish green chlorite.

All the rock fragments in the thin sections are of volcanic types, and only one specimen (D.4483·1) contains an accessory xenolith similar to the matrix of the rock. The accidental xenoliths are porphyritic, non-porphyritic and vesicular andesites and dacites, a few dacite crystal-tuff fragments and rare devitrified dacite glass fragments.

Hypabyssal rocks

South of Aureole Hills a series of quartz-plagioclase-porphyry dykes cuts the banded hornfelses (D.4465) (Fig. 9). These dykes are 20–30 ft. (6–9 m.) thick and 100–200 ft. (30·5–61 m.) apart, and all dip steeply eastwards. They are pale bluish grey flinty rocks with feldspar phenocrysts and biotite clots in an aphanitic base. Microscopically, plagioclase and quartz phenocrysts (up to 4·0 mm.) are set in a groundmass with a granitic texture but also with granophyric, graphic and vermicular intergrowths of minerals (D.4465.4). The plagioclase has a composition range from $Ab_{76}An_{24}$ to $Ab_{84}An_{16}$ to untwinned albite. Some crystals are heavily corroded and replaced by quartz, but elsewhere they have an albite rim and occasionally a border of quartz and alkali-feldspar in either vermicular or graphic intergrowth. The groundmass plagioclase has similar properties. Most of the quartz is in the groundmass as separate crystals and as intergrowths with alkali-feldspar. Biotite occurs in the groundmass as small flakes and needles, and clots of laths, with associated magnetite and slight alteration to green biotite and chlorite. There is a little accessory allanite.

The dyke margin (D.4465.3) has a finer-grained matrix with a granoblastic texture composed of quartz and feldspar with a little biotite, penninite and unaltered iron ore. Some of the penninite is in clots with quartz and a little zircon and epidote.

The granoblastic groundmass implies later thermal metamorphism and hence the dykes are pre-Andean and probably Upper Jurassic in age, because quartz-plagioclase-porphyries on the east coast of Graham Land are of that age. The age relations also imply that the banded hornfelses into which the dykes are intruded, are earlier than the Upper Jurassic.

The other dykes cutting the Trinity Peninsula Series are a quartz-porphyry (D.4473.2) and a porphyritic andesite (D.4482.4) which is similar to many of the accidental xenoliths in the tuffs. There is one other dyke (D.4409.1) cutting the Trinity Peninsula Series: a microgabbro, which is probably Tertiary in age.

Andean Intrusive Suite

Plutonic rocks of the Andean Intrusive Suite crop out south-west of Russell West Glacier. There is one large intrusion in the plateau edge south and south-east of Aureole Hills, and there are several small outcrops near Poynter Col and one east of Pettus Glacier.

Evidence either for the order of intrusion or for the age is absent, except that it is later than the Trinity Peninsula Series and the quartz-plagioclase-porphyry dykes, which are probably of Upper Jurassic age. Adie (1955, p. 4, 21–35) has presented evidence for a late Cretaceous to early Tertiary age and a basic to acid order of intrusion.

The intrusions show little range in composition. An augite-biotite-granodiorite occurs near Poynter Col; the main intrusion close to Aureole Hills is a tonalite but to the south an adamellite, and a pink granophyre crops out near Poynter Col. Near Aureole Hills there are inaccessible dark intrusive rocks, which may be more basic, and some accessible contaminated rocks. Altered intrusive rocks crop out near Poynter Col and Pettus Glacier.

Contamination

Near Aureole Hills and Poynter Col the intrusions enclose sedimentary rafts and they show signs of contamination. The assimilation of argillaceous sediments probably belonging to the Trinity Peninsula Series must have been considerable, because in apparently normal plutonic rocks there are numerous pale pink garnet crystals which probably belong to the almandine-spessartine series (D.4463.1, 4468.1). Many of the altered rocks contain metasomatic quartz and alkali-feldspar. The assimilation of sedimentary rocks could account for some of the metasomatism, because at one outcrop (D.4469; Fig. 3d) the contaminated host rock, which has metasomatic alkali-feldspar, is intimately associated with the remnants of a xenolith.

The sedimentary rafts may reach 150 ft. by 50 ft. (46 by 15 m.) in the outcrops near Aureole Hills, but there are also small xenoliths. The latter have two important aspects: some have sharp contacts and have been thermally metamorphosed (D.4463.2), whereas others have been partially assimilated and have diffuse contacts (D.4469.2). The host of the latter xenoliths has a marked development of biotite and the xenoliths are almost unrecognizable as sedimentary rocks. These two aspects may reflect compositional differences rather than the effects of thermal metamorphism, and this is supported by the two sedimentary types in this area. The accessible xenoliths near Aureole Hills are either the banded hornfelses (p. 16) or almost completely assimilated rocks. The latter were probably Trinity Peninsula Series sediments because of their mineralogy, the proximity of those sediments and the probable derivation of the garnet in the plutonic rocks. The xenolith in the altered tonalite south of Poynter Col (D.4478.2) is a metasomatized feldspathic sandstone with a clay matrix, and it probably belongs to the Trinity Peninsula Series. Some of the inaccessible xenoliths near Aureole Hills have the appearance of the Trinity Peninsula Series sediments which crop out near Sirius Knoll and Pettus Glacier.

Shearing stress

The main intrusion near Aureole Hills has been subjected to strong shearing stress after crystallization, as shown by the compound quartz grains with strong undulose extinction and finely embayed (0·02–0·10 mm. across) recrystallized contacts between individuals (Fig. 10d), the plagioclase with bent and spindle-shaped polysynthetic glide twin lamellae (Vance, 1961, p. 1108) (Fig. 10e), the bent biotite and the shattered garnet crystals (p. 20). The twinning and zoning in the plagioclase is related to the shearing stress. In the contaminated rocks which

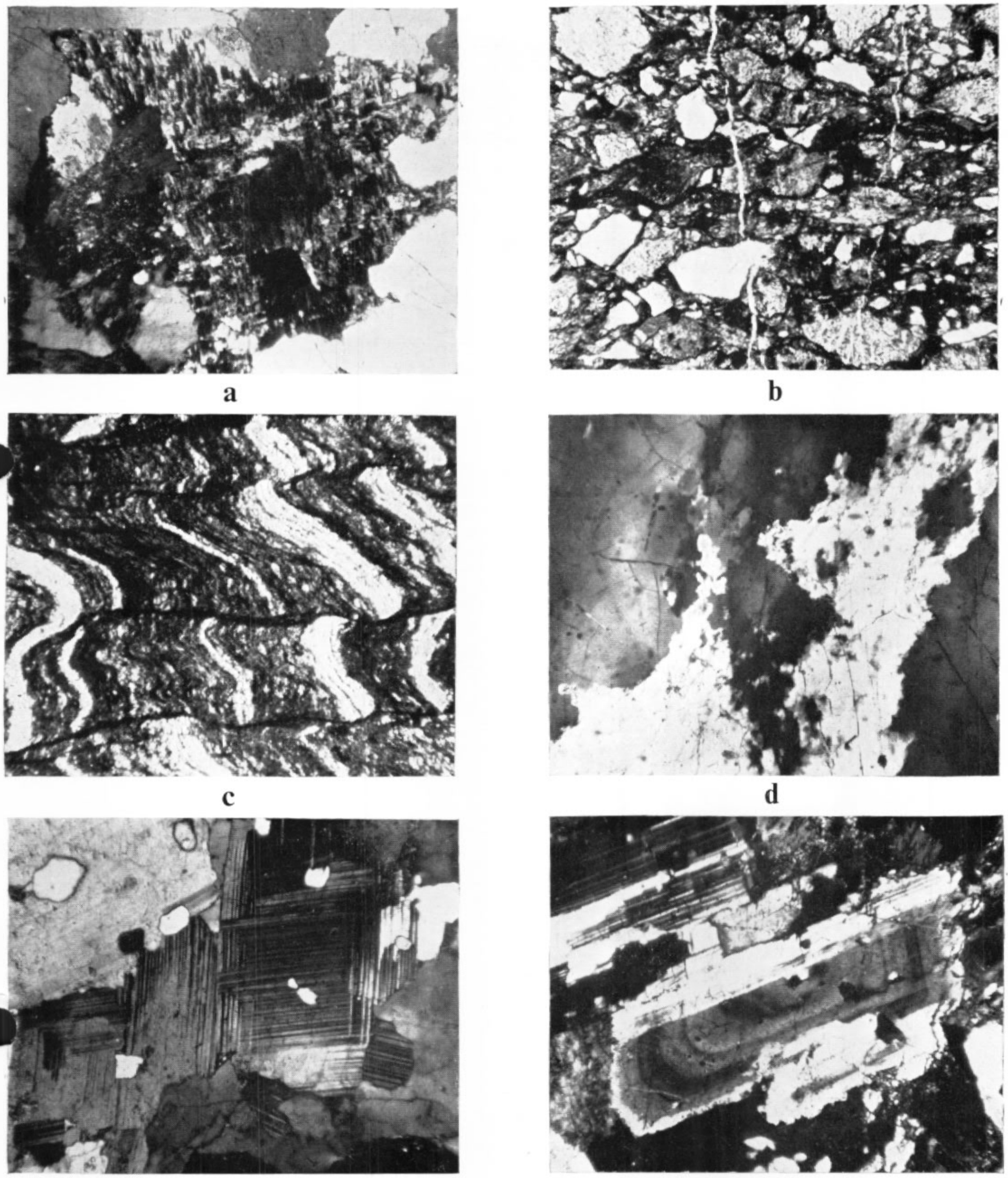

Fig. 10. a. Chequer-board albite in a granite pebble in pebbly shale; Aureole Hills (D.4464.4; X-nicols; × 35).
b. Poorly defined and discontinuous intergranular shear planes in a sandstone; west side of Misty Pass (D.4425.2; ordinary light; × 35).
c. Strain-slip cleavage in quartz-mica-schist; near Poynter Col (D.4485.1; ordinary light; ×35).
d. Composite quartz crystals with finely embayed margins between individuals and with undulose extinction; south-east of Aureole Hills (D.4468.1; X-nicols; × 35).
e. Polysynthetic glide twinning in plagioclase; east of Aureole Hills (D.4463.1; X-nicols; × 35).
f. The partial replacement of zoning by multiple albite twinning in one half of a plagioclase crystal; Poynter Col (D.4477.1; X-nicols; × 35).

possess a high proportion of biotite (D.4469.2A, B) the stress is taken up by the quartz and biotite, and the plagioclase has more primary twin lamellae and synneusis twins (Vance, 1961, p. 1099, 1107) than the unaltered plutonic rocks. The latter seldom exhibits primary twinning but many have multiple albite twinning and a few show polysynthetic glide twinning. The zoning in crystals with multiple albite twins is related to the twinning. In the tonalite (D.4463.1) there is a marked tendency for twinning to be absent from crystals with strong zoning across the whole of them, and for well-defined twins to occur in crystals without zoning. Intermediate stages, in which zoning occurs in one set of twin lamellae only (D.4468.1; Fig. 10f), are present in all specimens. These features suggest that the replacement of the zoning and primary twinning by secondary twinning was caused by internal re-distribution aided by stress (Emmons, 1953, p. 41–54).

Petrography

The unaltered plutonic rocks comprise the main intrusion and a few isolated outcrops. The tonalite and adamellite forming the main intrusion have many features in common and the plagioclase properties of the granodiorite are also similar. Modal analyses of these rocks are given in Table III.

TABLE III. MODAL ANALYSES OF THREE PLUTONIC ROCKS FROM NORTH-WEST TRINITY PENINSULA

	Specimen Number		
	D.4477.1	D.4463.1	D.4468.1
Quartz	19·1	37·7	30·6
Alkali-feldspar	15·1	1·6	29·8
Plagioclase	50·2	50·0	34·7
Myrmekite	—	0·1	0·1
Augite	6·5	—	—
Hornblende	0·7	—	—
Uralite	2·9	—	—
Muscovite	—	—	0·6
Biotite	3·5	9·7	2·6
Chlorite	*	0·5	1·2
Iron ore	1·7	*	*
Accessory minerals	0·3	0·4	0·4
Plagioclase composition	An_{49}	An_{38}	An_{27}

* Present but not recorded.

D.4477.1 Granodiorite; south of Poynter Col.
D.4463.1 Tonalite; east of Aureole Hills.
D.4468.1 Adamellite; south-east of Aureole Hills.

The tonalite (D.4463.1) has a medium-grained granitic texture composed of plagioclase ($Ab_{62}An_{38}$) and quartz crystals (up to 2·5 mm.) with interstitial biotite and orthoclase. Zoning in plagioclase crystals is restricted to the margins which may be untwinned. Some of the plagioclase contains quartz and orthoclase inclusions, some is replaced by those minerals and some has myrmekite borders with orthoclase. A little iron ore, apatite and garnet occurs with the biotite flakes and clots. The garnet is rounded and cracked, and some of the cracks are filled with penninite formed at the same time as the slight chloritization of the biotite.

The adamellite (D.4468.1), also with a medium-grained granitic texture, is composed of quartz, plagioclase and orthoclase. The plagioclase, zoned from $Ab_{73}An_{27}$ to $Ab_{88}An_{12}$, has been corroded by quartz and orthoclase, and some has albite rims which cut across both the twinning and zoning. Some contacts between alkali-feldspar crystals, or with plagioclase, are separated by small grains of plagioclase and a little quartz. There is a little replacement of the orthoclase by myrmekite. Very rarely the quartz is in vermicular intergrowth with the orthoclase-perthite. Biotite, which is partially altered to chlorite and iron ore, and muscovite form separate flakes as well as composite clots. Slightly pink garnet is a prominent accessory and may be enclosed in feldspar and quartz.

The granodiorite from Poynter Col (D.4477.1) is composed of equigranular subhedral crystals of plagioclase, augite and biotite, with interstitial quartz and alkali-feldspar. The plagioclase (up to 2·5 mm. long) is zoned from $Ab_{51}An_{49}$ to $Ab_{77}An_{23}$ but some has untwinned albite-oligoclase rims. There are a few xenocrysts zoned from $Ab_{31}An_{69}$ to $Ab_{77}An_{23}$. The oscillatory zoning in the core is inherited and the normal zoning round it was caused by the crystallization of the host magma. The augite (1·0 mm. long) may show simple twinning on (100) and polysynthetic twinning on (001), and some has the diallage structure of iron ore flakes. There is strong marginal alteration to pale yellow-green fibrous uralite and in a few crystals one set of twin lamellae has been replaced. A little magmatic brownish green hornblende is present together with some biotite, iron ore and apatite. Quartz and orthoclase are interstitial and allotriomorphic; graphic intergrowths of the two are rare and orthoclase replaces the rims of some plagioclase crystals. Zircon is a rare accessory mineral.

The pink granophyre (D.4480.1) from near Poynter Col is a medium-grained rock with, microscopically, conspicuous granophyric intergrowths (up to 4·0 mm. across) of quartz and heavily sericitized microperthite. Outside the intergrowths, the granitic texture is composed of quartz, microperthite and albite crystals. Magnetite, alkali-amphibole and zeolite are accessory. The amphibole, with a pleochroism scheme α = pale yellow-brown, β = green to deep green, γ = olive-green to brownish deep green and $\gamma : c = 20°$, could be hastingsite.

South-east of Aureole Hills the accessible rocks in the main intrusion are altered quartz-diorites and contaminated rocks. The other altered rocks form isolated outcrops on the east side of Pettus Glacier (D.4474.1) and near Poynter Col (D.4478.1).

The altered quartz-diorite (D.4469.1) is a metasomatized rock, now a hornblende-chlorite-granodiorite. The quartz and plagioclase (0·3 to 0·7 mm. long) tend to occur in separate clots and the metasomatic orthoclase has a poor poekiloblastic texture. The plagioclase has a composition range of $Ab_{50}An_{50}$–$Ab_{54}An_{46}$. Many crystals are euhedral but when they are in contact with orthoclase which may replace them, marginal zoning to albite gives a subhedral outline. Alternatively, either a little myrmekite or small granular albite crystals may separate the two feldspars. Where orthoclase is absent, the plagioclase has neither albite rims nor myrmekite. The single, broad, slightly ragged amphibole laths, one of which has a pyroxene morphology, are either of pale brown hornblende or of pale green amphibole which always rims and may replace the hornblende. The separate penninite encloses sphene, epidote and iron ore, and was derived from biotite. Potash metasomatism may have been caused either by the assimilation of sedimentary rocks or the release of potassium following alteration of biotite, or both. The effects of shearing stress are shown by the quartz and the chlorite derived from biotite.

The altered tonalite from Pettus Glacier (D.4474.1) has a coarse pseudo-graphic texture of heavily altered plagioclase and quartz (up to 2·5 mm.); quartz is rarely pseudo-ophitic and dactyloidal to feldspar, which suggests replacement. There is a little micrographic quartz and sericitized orthoclase. A few plagioclase crystals have clear albite rims. The slightly brownish chlorite includes cross-sections with an amphibole morphology, whereas the penninite, densely packed with lines of rutile or sphene, was derived from biotite. A little epidote and leucoxene are associated with the chlorite and there is accessory apatite and allanite.

The other altered tonalite (D.4478.1) has crystals of two distinct grain-sizes, about 0·5 mm. and 1·0–2·0 mm., and a poor granitic texture of subhedral to anhedral quartz and plagioclase ($Ab_{88}An_{12}$). The sericitized orthoclase encloses quartz, replaces plagioclase, fills interstices and is metasomatic. Most of the biotite has been altered to penninite and other secondary minerals. There is accessory magnetite and apatite.

South of Aureole Hills, the intrusion has been contaminated by the assimilation of sedimentary rocks (D.4469). The uncontaminated host rock is a metasomatized quartz-diorite (p. 21), and the assimilated xenolith is a distinctly foliated rock composed of quartz, plagioclase (0·5–2·0 mm.) and biotite. The subhedral plagioclase ($Ab_{48}An_{52}$–$Ab_{52}An_{48}$) includes a few highly altered, more basic xenocrysts ($Ab_{34}An_{66}$ zoned to $Ab_{51}An_{49}$). A few synneusis twins and some oscillatory zoning are present, which show that the plagioclase crystallized from a melt. There is a little glide twinning which was contemporaneous with the straining and recrystallization of the quartz and the bending of the biotite. The biotite is slightly altered to penninite and magnetite. A little apatite and magnetite are accessory.

The transition to the endogenous zone is irregular and biotite-rich streaks occur before passing to a more uniform medium-grained rock composed of the same essential minerals and a little metasomatic orthoclase, which is poekiloblastic to plagioclase. The texture is a poor granitic one and considerable stress has been superimposed on the quartz and biotite as in the exogenous zone. The plagioclase (1·0–2·0 mm. long) has more basic cores ($Ab_{38}An_{62}$–$Ab_{51}An_{49}$) but more acid outer rims ($Ab_{59}An_{41}$–$Ab_{68}An_{32}$).

There is no sign of the original size or shape of the xenolith. The heterogeneous distribution of the minerals and the evidence for the crystallization of the plagioclase from a melt suggest that by the time the xenolith had been completely assimilated the magma was in the process of crystallizing, and the diffusion of the exogenous material could not take place. Since the assimilation of argillaceous sediment usually generates garnet, the original material was probably quartzo-feldspathic and on assimilation in a quartz-diorite it would result in rocks composed mainly of quartz, feldspar and micas.

Structural Geology

The sparse distribution of outcrops in north-west Trinity Peninsula precludes any detailed structural analysis. The Trinity Peninsula Series forms most of the outcrops, and in the Misty Pass area and to the north-east the dip is variable both in amount and direction. At some of the outcrops the beds are steeply dipping and inverted. In the Mount d'Urville area the dip has a uniform direction away from Louis-Philippe Plateau and is between north and north-north-west. There is a slight diminution in the high dip angle away from the plateau but it is not well defined. None of the beds are inverted. Near Sirius Knoll the rocks dip steeply in a northerly direction, and in the extensive outcrops on the east side of Pettus Glacier it is towards the north-west. The rocks dip east at Aureole Hills and south-east near Poynter Col. Although the dip direction departs considerably from the trend elsewhere, these eastward-dipping rocks are assigned to the Trinity Peninsula Series on their mineralogy and regional metamorphism.

These rocks form part of one limb of a huge anticlinorium, of which 45,000 ft. (13,715 m.) are exposed on the south-east side of Trinity Peninsula, but the only possible sign of large-scale folding within this limb lies in the variable dip values near Misty Pass and the easterly and south-easterly dipping rocks at Aureole Hills and near Poynter Col. The main axis of the anticlinorium is to the south-east of this area, on the basis of the relationship of the cleavage dip to the bedding dip. The more metamorphosed rocks south-west of Russell West Glacier may have numerous minor folds which have a short-limb height (Matthews, 1958) up to 6 in. (15 cm.), but there is a dominant bedding-dip direction at any one outcrop. The axes of the minor folds trend in the strike direction of the rocks and plunge a small amount to either side of the horizontal.

The banded hornfelses near Aureole Hills dip gently south-westwards but they have not undergone regional metamorphism similar to that of the adjacent Trinity Peninsula Series. This indicates that they are either later than the regional metamorphism, or that they are Trinity Peninsula Series sediments derived from some distance and represent part of an allochthonous nappe. The latter is unlikely considering the general structural character of the Trinity Peninsula Series which does not include thrusting in this area.

The isolated Jurassic pyroclastic rocks do not provide any conclusive dip angles and directions.

After the regional metamorphism of the Trinity Peninsula Series, there has been no intense folding, though there may have been warping caused by the Andean intrusions.

The presence of faults is difficult to determine. From the dip and strike of the rocks at Cape Legoupil, it is probable that there is a major fault between the mainland and the offshore islands, where the sediments are locally dynamically metamorphosed. Apart from Cape Legoupil, direct evidence of faulting is absent, except for one locality near Mount d'Urville where a small but abrupt change in dip angle and direction occurs. From physiographic, geophysical (Allen, in press) and geological evidence, it is possible that Misty Pass is a structural feature and probably the line of a fault trending north-west. The phyllites and shattered sandstones at Misty Pass (D.4421) can be attributed to local dynamic metamorphism. The geophysical evidence indicates a fault with a downthrow of about 1 km. to the north-east, and this could account for the variable dips recorded in the Misty Pass area.

The overall structural pattern is of steeply dipping strata forming one limb of a pre-Jurassic anticlinorium, with later overlying rocks which are gently dipping, because of the intrusion of the late Cretaceous to early Tertiary plutons. Finally, there may have been late Tertiary block-faulting.

Conclusions

In this area the only evidence of rocks older than the (?) Carboniferous Trinity Peninsula Series sediments lies in the mineral and rock fragment composition of the sandstones and pebbly shales. The landmass from which they were derived was composed of sheared granitic rocks, volcanic deposits and subordinate metamorphic and sedimentary rocks. The sheared intrusive rocks could be either Palaeozoic or Precambrian in age, but the volcanic and sedimentary rocks are probably Palaeozoic, whereas the gneisses and metamorphic rocks are Precambrian or earliest Palaeozoic.

The Trinity Peninsula Series is a sequence of unfossiliferous geosynclinal sediments composed of sandstones, siltstones, shales and a very small proportion of pebbly shales and greenschists. On the available evidence, correlation between outcrops is impossible, because of the absence of fossils and the repetitive lithology. There are at least 12,000 ft. (3,660 m.) of sediments in north-west Trinity Peninsula. The lithology, sedimentary structures and the microscopic texture of the sandstones are all indicative of re-deposition of the sand-sized and coarser fractions in deep water by turbidity currents. The depositional basin was probably parallel to the present distribution of the sediments but the direction of the landmass from which they were derived is unknown. Some evidence of crustal tension is the presence of volcanic rocks, but this was followed by compression which caused folding and regional metamorphism of the sediments. The sediments form one limb of an anticlinorium whose major axis is to the south-east. Complex small-scale folding occurs at some outcrops. The metamorphism is mainly dynamic and it is expressed by intergranular shearing, except in those sediments which have been regionally metamorphosed to the greenschist facies.

The banded hornfelses from near Aureole Hills are younger than the regional metamorphism of the Trinity Peninsula Series but they are older than the Upper Jurassic Volcanic Group. The alternation of argillaceous and quartzo-feldspathic sediments is evidence of deposition in very stable conditions and this may represent renewed erosion of the landmass from which the Trinity Peninsula Series was derived. They have been thermally metamorphosed by both Upper Jurassic quartz-plagioclase-porphyry dykes and Andean intrusions.

During the Upper Jurassic there was a period of crustal tension and vulcanicity which involved the deposition of pyroclastic beds and the intrusion of dykes.

The uplift of the Trinity Peninsula Series and the Jurassic rocks was accompanied by intrusion of batholiths along the core of the uplifted area and also by gentle folding or tilting. The intrusions are intermediate to acid in composition and, although the order of intrusion cannot be demonstrated in this area, it is likely to have been basic to acid. Post-crystallization shearing stress has affected both twinning and zoning in the plagioclase, and garnet crystals in the acid members are the result of the assimilation of argillaceous sediments. Thermal metamorphism of the country rocks does not exceed the hornblende-hornfels grade and the aureoles are not extensive.

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