LATE MESOZOIC, NON-MARINE CONGLOMERATIC SEQUENCES OF NORTHERN ANTARCTIC PENINSULA (THE BOTANY BAY GROUP)

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ABSTRACT. Non-marine conglomerates (Botany Bay Group), derived from deformed metasedimentary rocks, are of common but local occurrence on the South Orkney Islands and northern Antarctic Peninsula. Successions exposed at Hope Bay (Mount Flora Formation), View Point, Camp Hill (Camp Hill Formation), Downham Peak and Tower Peak (Tower Peak Formation) in northern Antarctic Peninsula are described and discussed here. Indirect evidence suggests an early Cretaceous age for their deposition. The conglomerates lie unconformably on, or are faulted against, the metasedimentary rocks from which they are derived. The dominant lithology is clast-supported conglomerate, the product of debris flow and braided stream deposition on alluvial fans; accompanying sandstones are interpreted as either sheetflood or braided stream deposits. In addition to being the thickest development of such strata (780 m), the succession at Camp Hill is unusual in containing a thick floodplain sequence with fluvial, overbank and lacustrine deposits. Most successions contain interbedded volcanic rocks in the form of accretionary lapilli, crystal lithic and welded tuffs, and are overlain conformably by agglomerates and welded tuffs of the Antarctic Peninsula Volcanic Group. Evidence suggests that the conglomeratic strata accumulated in local fault-bounded basins on an uplifted terrane of metasedimentary rocks and represent a distinct episode between uplift and the onset of calc-alkaline volcanism.

INTRODUCTION

Hope Bay, at the northern tip of Trinity Peninsula (Fig. 1), has played an important part in the establishment of a stratigraphic scheme for the Antarctic Peninsula. It was there that three members of Dr O. Nordenskjöld's 1901–03 expedition endured an enforced winter that provided their geologist, Andersson, with a good opportunity to study the area. Andersson (1906) observed that deformed greywackes (Trinity Peninsula Group) are overlain on Mount Flora (Figs. 2 and 3) by a sequence of conglomerates whose clasts were derived solely from the greywackes. The conglomerates pass up into sandstones and mudstones, the latter containing abundant plant fossils. A preliminary study of the fossil flora was made by Nathorst (1904) who identified numerous ferns, cycadophytes and conifers. Amongst the flora he recognized a waterfern (*Sagenopteris*) from which Andersson (1906) concluded that these fine-grained sedimentary rocks were deposited in a lake. Poorly preserved bivalves, thought to be freshwater forms, were also found (Andersson, 1906; Herbst and Camacho, 1970). The plant collection from Hope Bay was studied in greater detail by Halle (1913) who, by comparison with other floras, especially those of Yorkshire and India, concluded that it was of middle Jurassic age. Andersson (1906) also noted that the upper part of Mount Flora consists of volcanic tuffs. Work on the geology of Hope Bay was not continued until 1945 when a British base was established there. During this period Croft (1947) measured a section through the sedimentary

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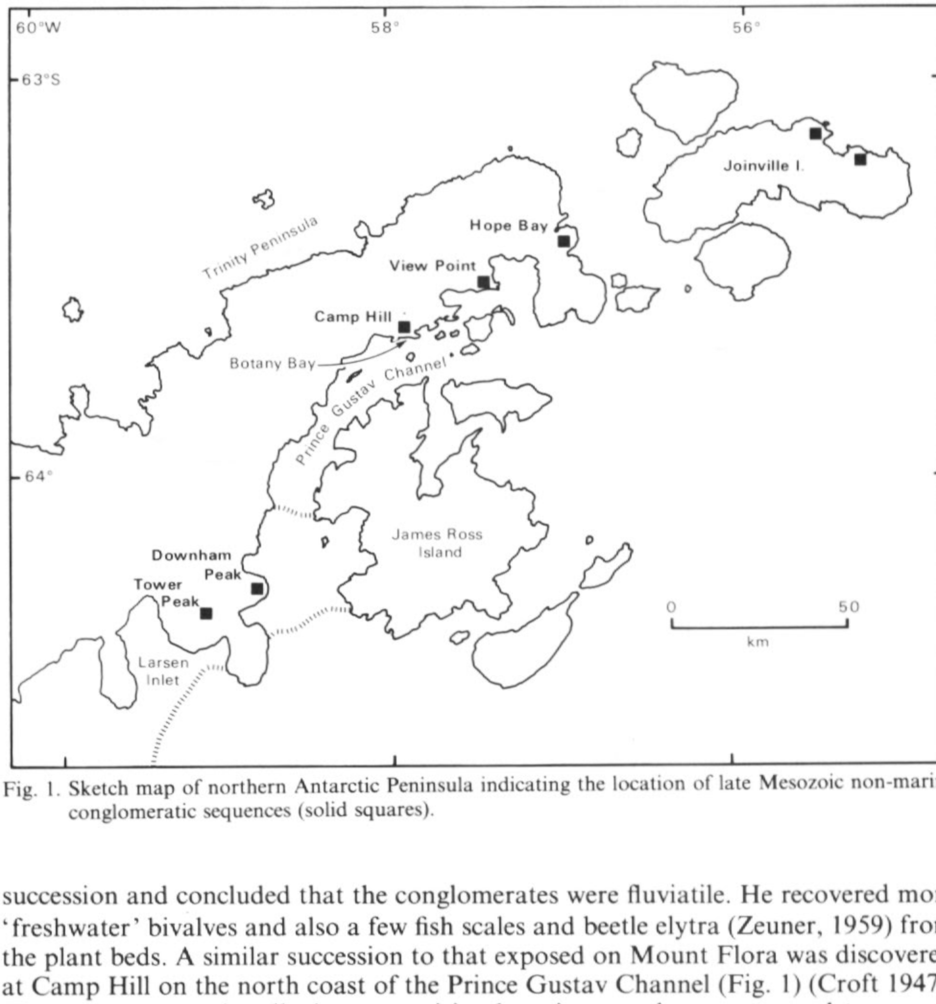

Fig. 1. Sketch map of northern Antarctic Peninsula indicating the location of late Mesozoic non-marine conglomeratic sequences (solid squares).

succession and concluded that the conglomerates were fluviatile. He recovered more 'freshwater' bivalves and also a few fish scales and beetle elytra (Zeuner, 1959) from the plant beds. A similar succession to that exposed on Mount Flora was discovered at Camp Hill on the north coast of the Prince Gustav Channel (Fig. 1) (Croft 1947). The sequence was described as comprising breccias, conglomerates, sandstones and shales, the latter yielding a Jurassic flora the same as found at Hope Bay. The unconformable relationship between the Mesozoic conglomerates and the underlying Trinity Peninsula Group was first noted by Adie (1953).

Stoneley (1952) and Standring (1953) investigated another outcrop of conglomerates and plant-bearing shales, with similar characteristics to the Mount Flora succession, near Downham Peak, 14.5 km to the north of Longing Gap (Fig. 1). Further work on the Mount Flora and Camp Hill successions was carried out by Bibby (1966), and Aitkenhead (1975) found a comparable, essentially conglomeratic, sequence at Tower Peak (Fig. 1). Conglomeratic strata having faulted or unconformable contacts with metamorphic basement rocks also occur on Joinville Island (Elliot, 1967) (Fig. 1) and the South Orkney Islands (Thomson, 1973). An extensive area of generally fine-grained sedimentary rocks in the hinterland to Cape Disappointment was equated with the Mount Flora succession by Fleet (1968).

The middle Jurassic age ascribed to the Mount Flora sedimentary rocks by Halle (1913) has been questioned for some years. In a reassessment of the Jurassic floras

Fig. 2. The north face of Mount Flora, Hope Bay. Light-coloured volcanic rocks form a cap to the darker weathering conglomerates and sandstones (junction is arrowed). The unconformity between the Mount Flora Formation and Trinity Peninsula Group trends across the scree slope (lower arrow). Height of face is about 300 m.

of Argentina and the Antarctic Peninsula, Stipanicic and Bonetti (1970) concluded that the Hope Bay flora was of latest Jurassic, possibly even early Cretaceous age. The same opinion has been expressed by J. M. Schopf (see Elliot, 1975) and Taylor and others (1979). Unfortunately the plant fossils concerned lack cuticle, precluding precise identification and age determination. Identifiable plant microfossils are also absent (T. H. Jefferson, personal communication). The sole occurrence of the terrestrial conglomeratic strata that yield an unequivocal age are those of the South Orkney Islands. A marine intercalation within the alluvial fan conglomerates (Elliot and Wells, 1982) contains olcostephanid and berriasellid ammonites indicative of an early Cretaceous (Neocomian) age (Thomson, 1981). Stratigraphic arguments presented by Farquharson (1983*a*) also favour an early Cretaceous age for this significant tectonostratigraphic group of terrestrial deposits. Typically these rock sequences are overlain conformably by the Antarctic Peninsula Volcanic Group and commonly contain interbedded volcanic beds, particularly in their stratigraphically higher parts. The sedimentary rocks therefore represent a distinct episode of deposition prior to the onset of widespread calc-alkaline volcanism but the time period that separates the two units is probably small. There are only two radiometric ages on Antarctic Peninsula Volcanic Group rocks from the northern Antarctic Peninsula. They are 130 ± 7 Ma (Valanginian-Hauterivian) on a rhyodacite from Hampton Bluffs and 117 ± 4 Ma (Aptian) on a rhyolite from Porphyry Bluffs (Pankhurst, 1982). These ages thus support an early Cretaceous age for the terrestrial arc terrane deposits.

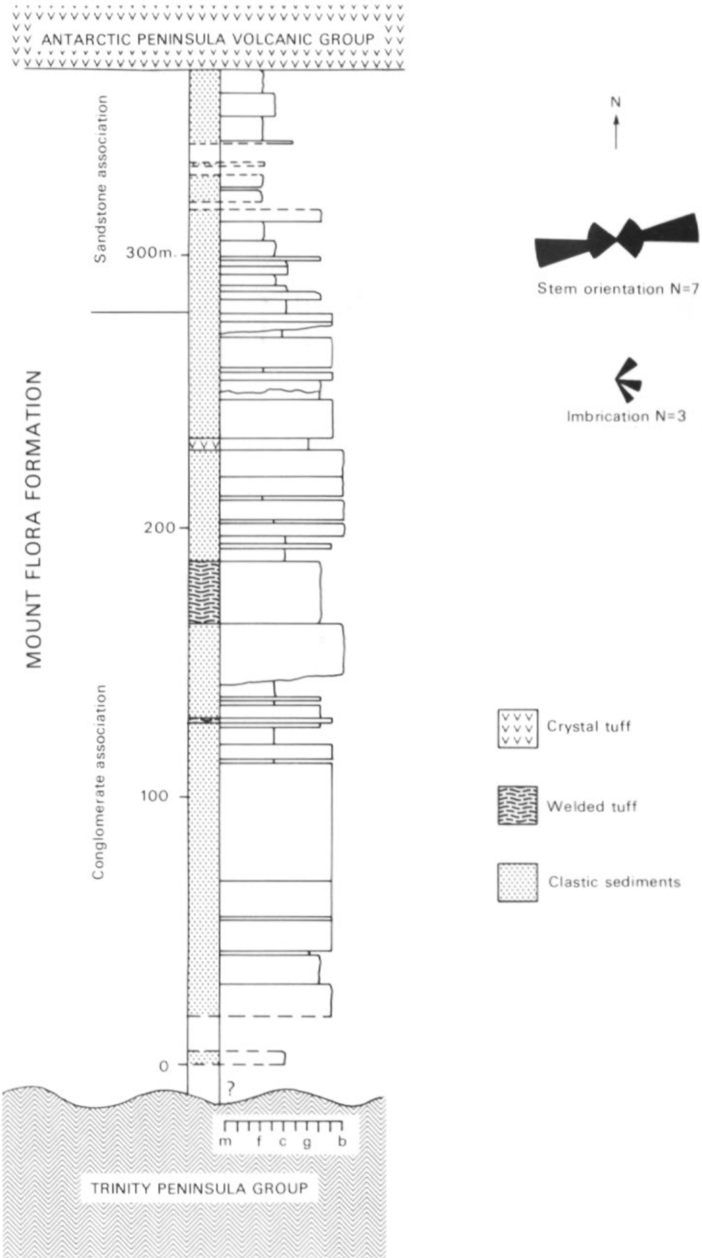

Fig. 3. Generalized, composite section through the Mount Flora Formation as exposed on the north face of Mount Flora, Hope Bay. The grain size scale at the base of the section is (m) mudstone, (f) fine-grained sandstone, (c) coarse-grained sandstone, (g) granule grade, (b) boulder conglomerate.

Mount Flora Formation

Introduction

The predominantly conglomeratic sedimentary rocks at Hope Bay crop out on the northern part of Mount Flora (Fig. 2) where they dip at 20–40° to the south. The exposed strata are 370 m thick. The base of the succession is nowhere seen but it is inferred to be an unconformity truncating the Trinity Peninsula Group that here comprises arkosic coarse-grained sandstone and rippled siltstone/fine-grained sandstone. Volcanic rocks (ignimbrites with subordinate agglomerates and tuffs) of the Antarctic Peninsula Volcanic Group overlie the sedimentary succession and form a pale weathering cap to Mount Flora (Fig. 2). Volcanogenic deposits also form interbeds within the upper half of the sedimentary section. The name Mount Flora Formation was proposed independently by both Caminos and Massabie (1980) and Elliot and Gracanin (1983) for the sedimentary succession on Mount Flora. It can be subdivided into two distinct parts, a lower conglomerate association (276 m) overlain by a sandstone association (94 m) (Fig. 3). The following description is based on two measured sections, on the north-east, and north-west spurs of Mount Flora taken from the lowest exposed strata up into the Antarctic Peninsula Volcanic Group.

Conglomerate association

The dominant lithology, particularly in the lower part of the succession, is clast-supported cobble to boulder conglomerate (Fig. 4). Matrix comprises 5–30% of the conglomerate and consists of coarse-grained sandstone. The clasts are derived solely from the Trinity Peninsula Group, are subrounded to angular and reach 1.7 m

Fig. 4. Example of a clast-supported conglomerate within the Mount Flora Formation illustrating the poor sorting and random clast orientation. Largest clast is 30 cm long.

across. They typically have no preferred orientation (Fig. 4) but in some beds elongate clasts are parallel to bedding and rarely are imbricated. Bed thickness varies between 5 and 20 m. Bed boundaries are generally flat and sharp; erosional bases are uncommon.

Matrix-supported conglomerates, either of pebble or cobble grade, are uncommon. Graded conglomerates are also rare. Their most common form is as 20–100 cm thick normally graded beds possessing a pebble-rich basal layer which grades upwards into fine- and coarse-grained sandstone. One bed, 1.7 m thick, has an erosive base and is inverse- to normally-graded. Fine- to coarse-grained massive sandstones, 50–150 cm thick, are occasionally intercalated between conglomeratic units. They are generally lenticular and may have a gradational base with the underlying conglomerate; otherwise bed boundaries are sharp.

The conglomerates of the Mount Flora Formation are not wholly characteristic of any particular sedimentary process. Within the clast-supported conglomerates there is a spectrum of clast fabrics from completely random through bedding-parallel to imbricate fabrics. The conglomerates typically occur as laterally continuous units up to 20 m thick but it is likely that these comprise several amalgamated beds whose boundary characteristics are unknown.

Those conglomerates with a random clast fabric are comparable with the deposits of clast-rich debris flows. Theoretical studies (Middleton and Hampton, 1973) and observations on natural subaerial debris flows (Johnson, 1970) have shown that flows of this kind can contain as little as 5% matrix which then acts like a lubricant to clast movement (Rodine and Johnson, 1976; Lowe, 1982). Those conglomerates with an imbricate or horizontal clast fabric are probably the result of bed load deposition by a competent current. Gravel bars within proximal braided streams generate deposits similar to these conglomerates (Smith, 1970; Boothroyd and Ashley, 1975; Rust, 1975). The lack of a true distinction between the two main conglomerate types suggests the operation of a variety of depositional processes varying from debris flows through watery slurries to braided streams (cf. Pierson, 1981).

The rare matrix-supported conglomerates are most likely to be the product of low-stage flow in a braided stream system. Similarly, the normally-graded conglomerates that pass up into sandstone, and the inverse-to-normally graded bed with an erosive base are perhaps a function of fluctuating flow conditions in a braided stream (cf. Allen, 1981). The lenticular sandstone interbeds within the conglomerate association may represent finer grained deposition during the waning stages of a flood event.

The intimate association of cobble- and boulder-bearing braided stream, debris flow and 'transitional' deposits suggests that this lower part of the Mount Flora Formation is the result of alluvial fan sedimentation (see Bull, 1972, for review).

Sandstone association

The sandstone association occupies the uppermost 94 m of the Mount Flora Formation and is dominated by fining-upward cycles (characterized by decreasing grain size) that range in thickness from 2.5–11.5 m (Fig. 5). Occasionally, the fining-upward trend is accompanied by an upward decrease in bed thickness. These fining-upward cycles all possess a clast-supported granule to cobble conglomerate bed at their base. One such bed has an erosive base and two others have an inversely graded basal layer.

The basal conglomeratic unit is overlain by massive sandstones ranging in bed thickness from 0.1 to 5.8 m and in grain size from fine- to coarse-grained sand. These

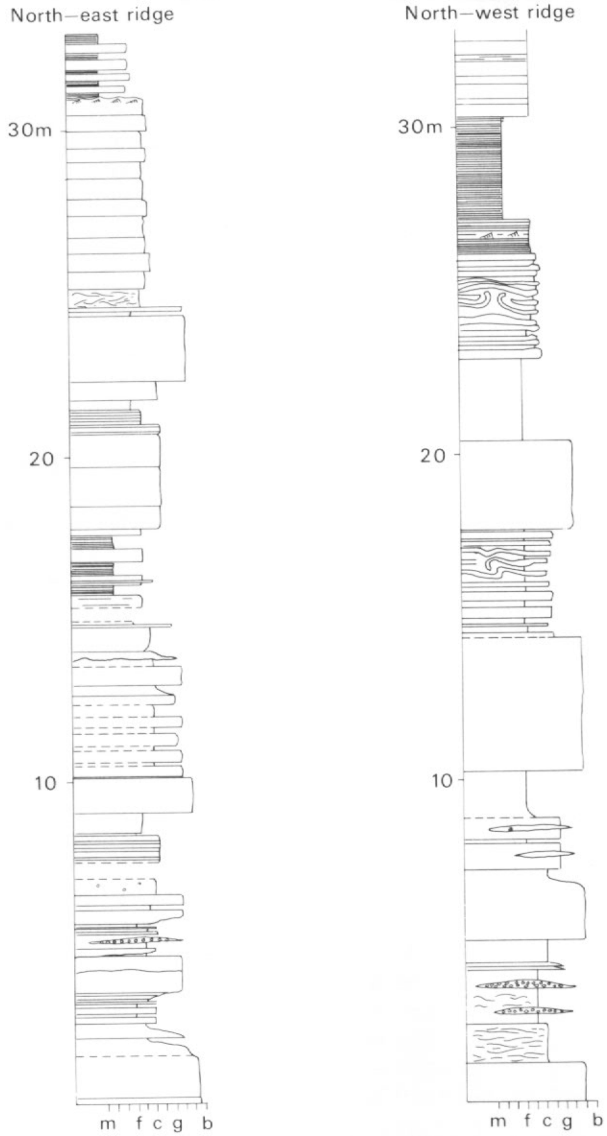

Fig. 5. Sections through parts of the sandstone association to illustrate the fining-upward cycles exposed on the north-east and north-west ridges of Mount Flora.

units may be bedded on a 1-m scale and possess sharp, flat bed boundaries. The following unit is generally a fine- to coarse-grained sandstone laminated on a 2–3 mm scale due to slight grain size variations. The beds reach 2.8 m thick and have sharp flat bounding surfaces.

Towards the top of some fining-upward sequences is a distinctive lithofacies comprising units (0.5–2.7 m thick) of alternating mudstone-siltstone and fine- to medium-grained sandstone beds. Individual beds are laterally continuous and have sharp, flat bases except the sandstones, which are typically loaded into the finer

grained bed beneath. The mudstone-siltstone beds are 2–40 cm thick, typically display a diffuse planar lamination and contain abundant plant fossils including complete leaves. The sandstones are massive or faintly planar laminated, contain sparse laminae of coarse-grained sandstone and also yield plant remains. The finest grained bed within each of these cycles is then overlain by the conglomeratic base of the next cycle.

Interpretation of these fining-upward cycles is hindered by the metamorphic state (biotite grade) of these rocks, which has probably obscured many of the sedimentary structures originally present in the sandstones. Fining-upward cycles are commonly described from alluvial deposits and are generally ascribed to channel incision followed by gradual abandonment (Allen, 1965*a*; Cant and Walker, 1976). However, there are important differences between the sandstone association of the Mount Flora Formation and channel abandonment cycles: the first typically lacks erosive bases and constituent beds are laterally continuous. Repeated flood events within an alluvial fan system would be capable of producing fining-upward cycles as a response to waning flow conditions. Two of the cycles commence with an inversely-graded conglomeratic layer possibly representing increasing flow strength at the start of a flood event. Flood flows of low viscosity and wide extent (sheetfloods; Bull, 1972) under conditions of decreasing strength could be expected to generate sequences comparable to those in the Mount Flora Formation. Cross-bedding is generally scarce in the deposits of such flows. The alternating mudstone/sandstone units that typically form the culmination of the cycles may represent quiet water deposition within standing water left on the fan surface after the flood had subsided. The sandstone might be the result of pulses of coarse material in the tail of the flood or overbank deposits from channellized flows elsewhere on the fan. The possibility of ephemeral lake deposition suggests that the sandstone association may have accumulated within a fan fringe-playa lake setting.

Volcanogenic deposits

Volcanogenic deposits form a small but significant part of the Mount Flora Formation. Sandstones containing abundant accretionary lapilli are occasionally interbedded with conglomerates near the base of the exposed succession. A single ignimbrite 26 m thick forms a pale band across the north face of Mount Flora, approximately half way up the sedimentary sequence (Fig. 6). Higher in the conglomerate association lies a 2.1-m-thick crystal tuff.

The Mount Flora Formation is overlain abruptly by 150 m of volcanic rocks belonging to the Antarctic Peninsula Volcanic Group. The slight discordance between the sedimentary and volcanic rocks, interpreted by Elliot and Gracanin (1983) as an unconformity, may be an illusion caused by the eastward depositional thinning of beds near the top of the Mount Flora Formation. The volcanic rocks comprise tuffs, fine-grained agglomerates and welded tuffs; they display abundant evidence of reworking, commonly in the form of channelling (R. D. Hamer, personal communication).

Discussion

Palaeocurrent measurements from the Mount Flora Formation are scarce (Fig. 3). Three reliable imbrication directions indicate transport of these conglomerates to the east. Plant stems in many of the sandstone beds within the sandstone association are aligned and, assuming that they lie parallel to the current, indicate an easterly or westerly flow direction. Combining the two sets of measurements, it is tentatively suggested that the dominant palaeocurrent direction was towards the east.

Fig. 6. Part of a welded tuff that forms an interbed within the Mount Flora Formation. Lens cap is 5 cm across.

The Mount Flora Formation represents deposition on an alluvial fan situated on a land surface of deformed metagreywackes. Overall, the succession fines upwards, probably as a result of scarp retreat and/or reduction in source terrane relief (cf. Heward, 1978). The lower, conglomeratic part of the formation was deposited by a combination of debris flows and braided streams whereas the sandstone-dominated uppermost 94 m records deposition by repeated sheetflow flood events. At the end of each flood event fine-grained sediment and plant remains accumulated in ephemeral lakes. Volcanism was coeval with sedimentation on the fan, occasionally interrupting clastic deposition with the emplacement of volcanogenic units. Cessation of alluvial fan deposition coincided with, or was the result of, increased calc-alkaline volcanism leading to the development of a thick volcanic succession dominated by welded pyroclastic flow deposits.

View Point Beds

At View Point (Fig. 1) Aitkenhead (1975) described a small exposure of unfossiliferous poorly consolidated conglomerate resting horizontally on steeply dipping greywackes of the Trinity Peninsula Group. The contact is poorly-exposed and its nature, unconformity or fault, is unclear. On reinvestigation, the occurrence was found to comprise three beds. The lowest is a clast-supported conglomerate 3 m thick containing clasts derived solely from the Trinity Peninsula Group. The clasts are very poorly sorted ranging in size from 0.5 to 32 cm, are subrounded to rounded and are set within a medium-grained sandstone matrix. Overlying this with a sharp, flat base is a 1-m-thick bed of green fine- to medium-grained massive green sandstone. The final bed has a maximum thickness of 3 m and an erosive base that cuts out the underlying

sandstone to the east. This unit comprises a pebble, clast-supported conglomerate at the base, which grades up into a matrix-supported conglomerate.

Camp Hill Formation

Introduction

The term Camp Hill Formation is introduced here for late Mesozoic sedimentary strata that unconformably overlie folded metasediments of the Trinity Peninsula

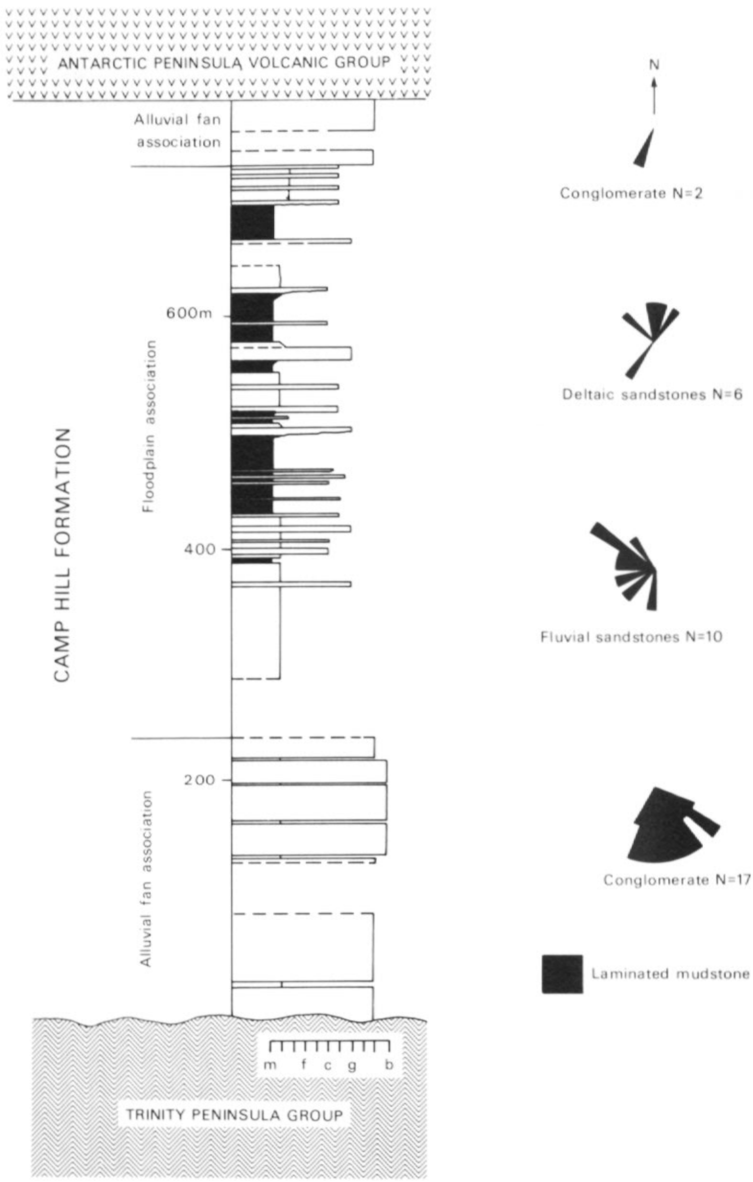

Fig. 7. Generalized section measured through the Camp Hill Formation.

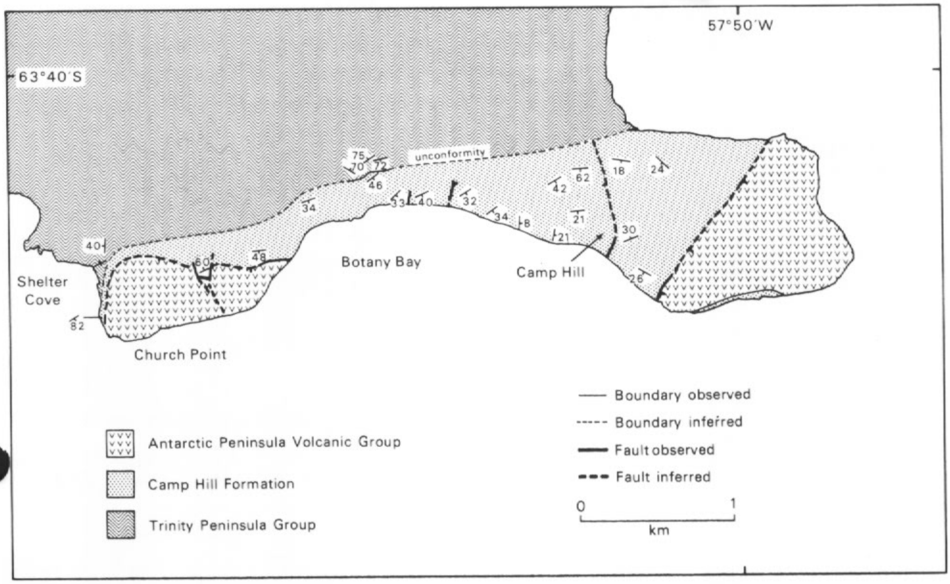

Fig. 8. Geological sketch map of the Camp Hill area. The eastern part of the Camp Hill peninsula is modified from Bibby (1966).

Group in the vicinity of Camp Hill (Figs. 7 and 8). The unconformity is exposed at one locality (Fig. 9); previously this boundary had been mapped as a fault (Bibby, 1966). The top of the formation is exposed to the east of Camp Hill itself where it is overlain conformably by agglomerates and garnetiferous andesites of the Antarctic Peninsula Volcanic Group. The sedimentary rocks extend around the base of Church Point on its northern side and crop out on the eastern shore of Shelter Cove. The volcanic rocks exposed on Church Point were originally mapped as plutonic (Bibby, 1966 Fig. 1); vague stratification is seen on the northern slopes and interbedded granule sandstones are exposed on the summit. These extrusive rocks have a faulted relationship with the sedimentary succession.

The Camp Hill Formation crops out in a southward plunging open syncline whose hinge trends north-north-east and passes through the summit of Camp Hill itself. Most of the area forms part of the western limb whose dip varies from 18 to 46°, although minor folds do give rise to steeper dips in places. The eastern limb has dips of a similar magnitude.

The Camp Hill Formation (Figs. 1 and 7) is the thickest (780 m) of the known terrestrial arc-terrane sequences and comprises a wide range of lithologies. For these reasons work has been concentrated on this locality. On the basis of abundant cross-stratification Adie (1953) concluded that the sedimentary rocks were either fluviatile or estuarine. In contrast, Bibby (1966) interpreted them as being shallow marine.

Although the Camp Hill area is largely scree-covered there is almost continuous exposure along the coast of Botany Bay which allowed a reasonably complete section to be measured; the lateral extent of the section is always limited.

Fig. 9. The unconformity between cleaved metasediments of the Trinity Peninsula Group and overlying cobble conglomerate of the Camp Hill Formation as exposed 2 km west-north-west of Camp Hill. Hand lens is 8.5 cm long.

Facies analysis

Eleven distinct facies were recognized in the measured section through the Camp Hill Formation (Fig. 7). Percentage figures refer to the proportion of the exposed succession that each facies constitutes.

Boulder conglomerate facies 6.9%. The boulder conglomerate facies comprises extremely poorly sorted, sub-angular material having a maximum clast size of 20–110 cm (Fig. 10). The matrix is muddy fine- to medium-grained sandstone and constitutes 5–10% of the bed. Both upper and lower bed boundaries are sharp; the base is not erosional. Bed thickness varies from 1.1 to 9.8 m. Units of this facies wedge out southwards in the cliff exposures to the east of Church Point, although in the measured section all beds appear laterally continuous over the available outcrop width of 35 m. Inverse grading is common. Clast orientation is typically random and elongate boulders may even be perpendicular to bedding. However, vague imbrication was seen in a single bed.

Observations on recent and ancient debris flows have clearly shown that debris laden with coarse material can flow as a viscous mass, resulting in deposits with features identical to those exhibited by the boulder conglomerate facies (Blissenbach, 1954; Bull, 1964; Hooke, 1967; Johnson, 1970). The characteristic features of such deposits are: absence of an erosive base and internal stratification, very poor sorting, vertical clast orientation and a muddy matrix. Debris flows that have given rise to inversely graded deposits are documented by Fisher (1971), Naylor (1980) and Lowe (1982).

Cobble conglomerate facies 15.5%. This facies occurs as units with sharp upper and lower boundaries, the latter occasionally being demonstrably erosive. Maximum clast

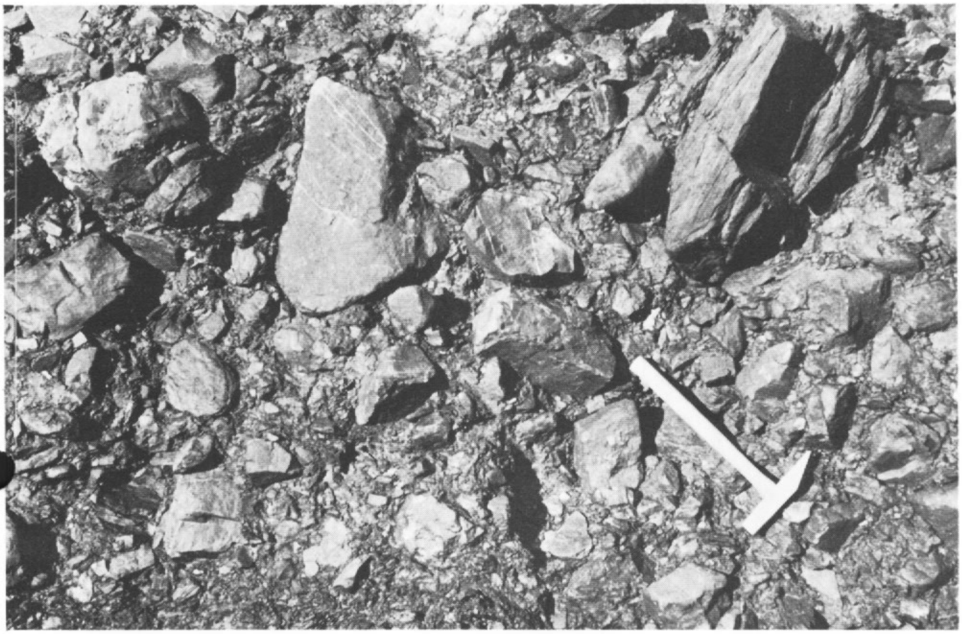

Fig. 10. Boulder conglomerate facies, Camp Hill. The base of the photograph is parallel to bedding. Note the inverse grading and very poor sorting. Hammer is 35 cm long.

size is 3–15 cm although larger clasts are found overlying basal erosion surfaces. The conglomerate is poorly sorted with a clast-supported framework of predominantly sub-angular cobbles. Bed thickness is 0.25–7 m. The matrix, which constitutes 5–20% of the lithology, is typically medium- to coarse-grained sand with up to 5% granules. The clasts are characteristically imbricated, otherwise they appear parallel to bedding. Haematite-coated cobbles are common. The cobble conglomerate facies is divisible into two sub-facies:

i. Sub-facies A

The presence of medium-grained to pebbly sandstone interbeds within the cobble conglomerate is the diagnostic feature of this sub-facies (Fig. 11). Light green to grey-brown in colour, these interbeds range in thickness from 5 to 27 cm. Cross-stratification was occasionally observed and macerated plant material is generally abundant but recognizable leaves and stems are rare. The sandstones generally wedge out over distances less than 15 m and commonly split and rejoin, enclosing lobes of conglomerate. The vertical separation between interbeds is in the range 20–60 cm. Differentiation of the conglomerate into lenticular bodies of varying maximum clast size also occurs in the absence of intervening sandstone interbeds. The size of the lenses is of the order of 2.5 m long by 20 cm thick.

ii. Sub-facies B

This sub-facies lacks sandstone interbeds and the individual beds, which range in thickness from 0.5 to 3 m, tend to be laterally continuous over at least 10 m. A feature of sub-facies B is the presence of thin openwork horizons devoid of matrix frequently

Fig. 11. Cobble conglomerate facies, sub-facies A, Camp Hill. Clast-supported conglomerate containing sandstone lenses. Hammer is 35 cm long.

found between constituent beds. The clasts of sub-facies B tend to be coarser than those of sub-facies A.

The lenticular bedforms, erosive bases, varying grain sizes and imbricate clast orientation of the cobble conglomerate facies imply transport of the sediment as bed load within a fluctuating and generally competent current. The poorly sorted nature of the deposit suggests rapid decline in the power of the flow and subsequent rapid dumping of the material. From the above observations it is concluded that deposition occurred within a braided stream environment. The features of sub-facies B, when compared to sub-facies A, suggest deposition from a more competent current closer to the source of debris. Openwork conglomerate horizons in sub-facies B suggest that either insufficient fines were deposited during waning flow to provide matrix for all the gravel transported during flood stage or that wind deflation or sieving processes occurred. The sandstone interbeds of sub-facies A are interpreted as recording the deposition of fines during waning of the flood that caused development of the gravelly longitudinal bars. Boothroyd and Ashley (1975) noted from Alaskan outwash plains that during falling stage megaripples formed in channels leaving discontinuous sandy lenses a few tens of centimetres in thickness by 5–20 m in length. Similarly, Church and Gilbert (1975) described interbeds of sand preserved within gravel. Openwork gravel horizons similar to those seen in the cobble conglomerate facies of the Camp Hill section have been recorded by Smith (1974) from Kicking Horse River, British Columbia. These too have been ascribed to the results of fluctuating discharge and the availability of fines.

Thin-bedded sandstone facies 2.3%. This thinly-bedded lithofacies consists of well sorted medium- to very coarse-grained sandstone. The bounding surfaces are flat, sharp and non-erosive, and confine laterally prsistent units that range in thickness

from 0.16 to 7.8 m. Rounded clasts of grey green metasiltstone, generally 1–3 mm across, may form up to 5% of the rock. These clasts tend to be tabular and parallel to bedding.

A characteristic of this light-brown sandstone is the presence of abundant petrified wood. Most commonly, the wood is preserved as black, very fine-grained silica with a creamy yellow rind, although some pieces are in the form of coaly material cut by a network of calcite veins 0.5–1 mm wide. The majority of petrified logs, which may measure up to 70 × 25 × 25 cm, lie parallel to bedding and exhibit clear annual growth rings. These logs are distributed throughout the bed. Leaves and stems are sparsely distributed within the beds of this facies, but all those seen are of a robust nature.

The lateral persistence and lack of channelling shown by this facies, are suggestive of deposition by sheetfloods: low-viscosity flows resulting in a layer of well-sorted sand (Bull, 1972).

Siltstone facies 21.9%. Although silt is the dominant sediment within this facies, occasional beds do reach fine sand grade. The brown to black siltstone completely lacks sedimentary structures and occurs in beds 0.5–17 m thick. Characteristic features are the great abundance of well-preserved leaves (Fig. 12) and stems. One tree was observed in growth position. Thin, generally impersistent, coaly horizons up to 4 cm thick are fairly common. Rootlets occur but are rare.

The complete absence of primary sedimentary structures and the fine-grained nature of the sediment indicates deposition in a low-energy environment where material settled out of suspension from stationary or slow moving bodies of water. That the plant material is more-or-less *in situ* is concluded from its exquisite morphological preservation (Fig. 12) and the presence of a tree in position of growth. These conditions and facies relationships indicate a floodplain environment of deposition.

Floodplain sediments accumulate by the fall-out from suspension of fine material in flood-waters that have become slow or stationary having reached low basinal areas close to the river channel. Periodic inundation leads to the interplay between organic and clastic sedimentation. Indeed, incipient coal formation in the siltstone facies requires periods of emergence accompanied by colonization of a flourishing flora followed by clastic sedimentation preventing bacterial decay of the resulting peat accumulation. The abundance of plant growth and coal formation necessitates an environment with a high water table.

Cross-bedded coarse-grained sandstone facies 9.7%. Units of this facies usually have a sharp, erosional base (Fig. 13). The very coase-grained to granule sandstone that overlies the base commonly contains siltstone intraclasts. Units (0.5–5 m thick) of cross-bedded coarse-grained sandstone usually consist of more than one bed, the boundaries of which are always sharp. The sandstones are white, range in grain size from coarse-grained sandstone to pebble conglomerate and are moderately well-sorted.

Low-angle, large-scale trough cross-bedding is the most common stratification type and tends to occur towards the base of the facies. Medium-scale (foreset height 15–20 cm) tabular and trough cross-stratification is commonly developed, generally towards the top of the units. Reactivation surfaces are common in the tabular cross-bedded sandstones. Horizontal bedding is sometimes present and where found forms the highest beds of the unit. The limited nature of the exposures precludes comment on the lateral extent of the sandstone bodies. Poorly preserved stems are occasionally found within this facies, always along partings between beds.

The cross-bedded coarse-grained sandstone lithology overlies either floodplain overbank deposits in the form of the siltstone facies or delta front sediments represented by the coarsening-upward sandstone facies. From this alone it can be

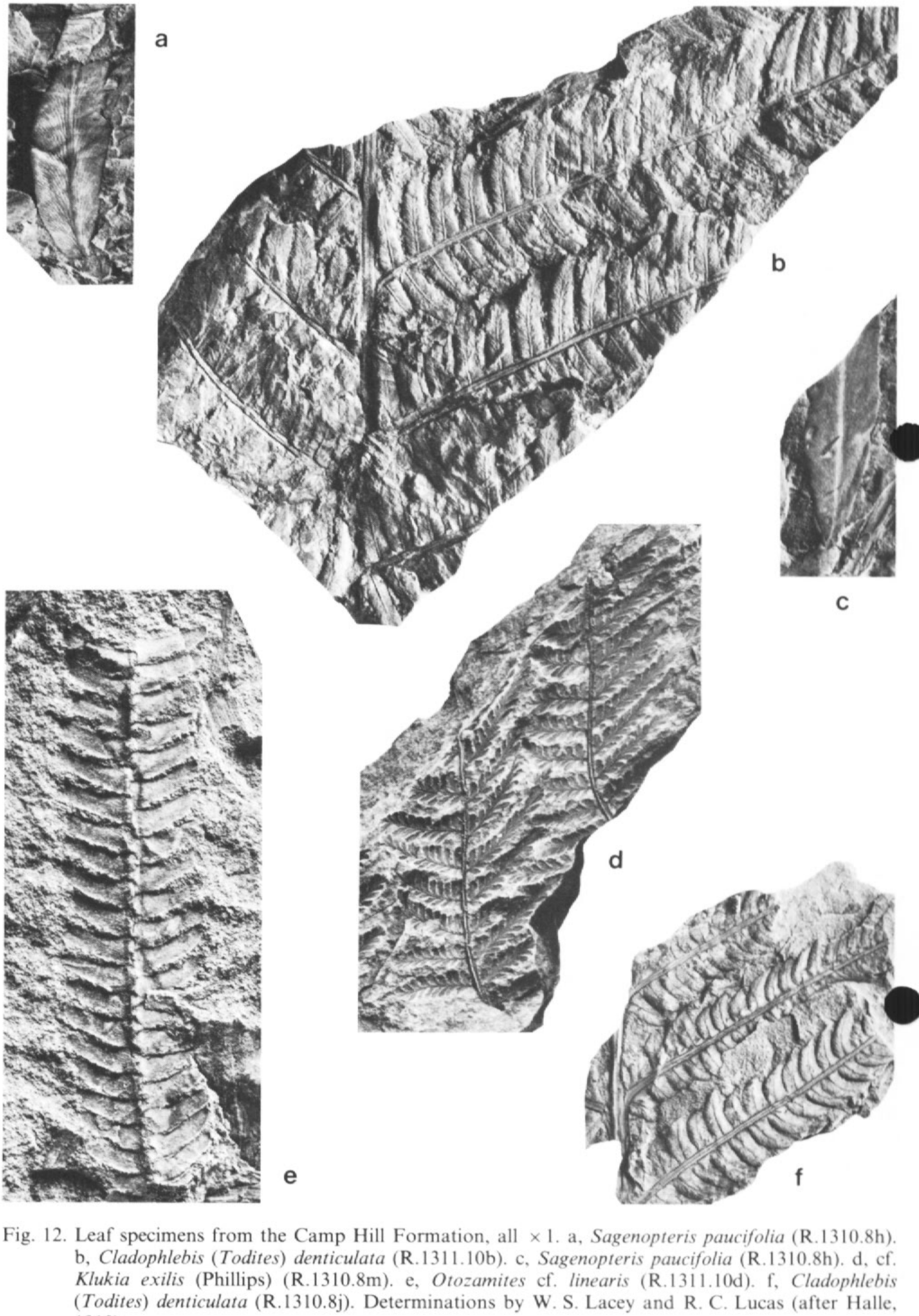

Fig. 12. Leaf specimens from the Camp Hill Formation, all × 1. a, *Sagenopteris paucifolia* (R.1310.8h). b, *Cladophlebis* (*Todites*) *denticulata* (R.1311.10b). c, *Sagenopteris paucifolia* (R.1310.8h). d, cf. *Klukia exilis* (Phillips) (R.1310.8m). e, *Otozamites* cf. *linearis* (R.1311.10d). f, *Cladophlebis* (*Todites*) *denticulata* (R.1310.8j). Determinations by W. S. Lacey and R. C. Lucas (after Halle, 1913).

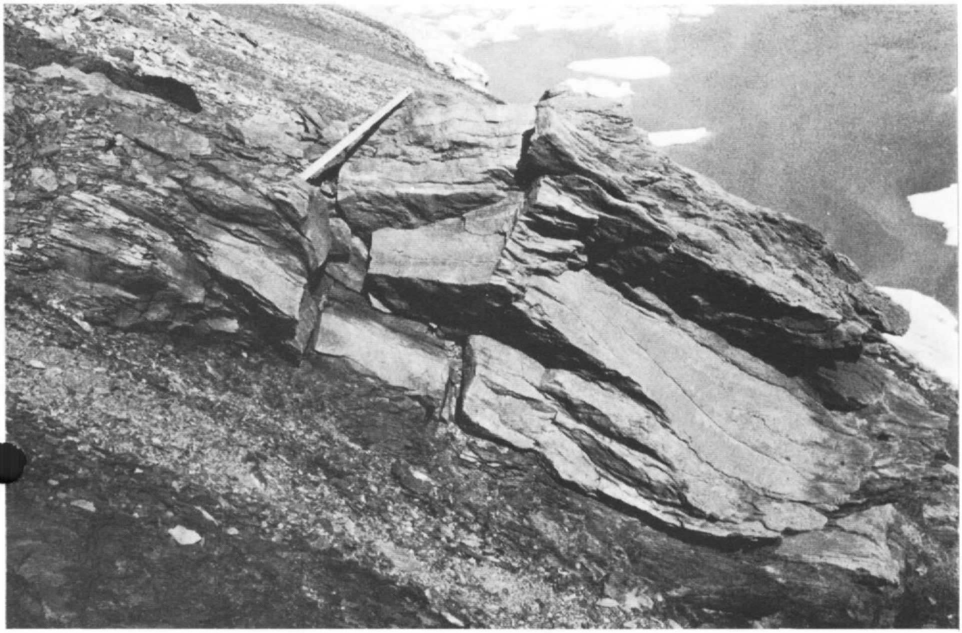

Fig. 13. Cross-bedded, coarse-grained sandstone facies, Camp Hill. Sandstone body with erosional base truncates material of the interbedded coarse- and fine-grained sandstone and siltstone facies. Wooden scale is 40 cm long.

concluded that the cross-bedded sandstones are fluvial bodies, an origin endorsed by the scoured bases and the bedform nature of deposition.

Gravel lens facies 0.6%. Gravel lenses reaching a thickess of 45 cm, and generally wedging out within 4–8 m laterally, are commonly found embedded within the siltstone facies. The gravel is moderately well sorted, has a maximum particle size of 3 cm and possesses a fine- to medium-grained sandstone matrix. In one bed thin sandstone lenses were seen to define foresets. As the gravel lenses only occur within the siltstone facies, it follows that deposition probably took place in the floodplain environment proposed for the latter deposits. It is now well established that coarse gravel can be lifted from a channel and laid down in the form of lobes on the floodplain surface during flood events (Costa, 1974; Ritter, 1975; Stene, 1980).

Interbedded coarse- and fine-grained sandstone facies 3.7%. This facies consists of alternating beds of coarse- and fine-grained sandstone on a centimetre to decimetre scale. The coarser units are generally discontinuous and often convoluted. Well-preserved plant material is lacking but carbonaceous partings are usually very common.

This facies is generally developed between an underlying fluvial sandstone body (cross-bedded coarse-grained sandstone facies) and an overlying siltstone facies unit. This implies that the locus of deposition lay between the river channel and the backswamp area. Levees satisfy this condition. The characteristic feature of levee deposits is the rapid vertical interbedding of coarse and fine sediment (Allen, 1965*b*; Plint, 1983). They also frequently develop soil profiles and support vegetation, sometimes leading to the preservation of plant litter.

Graded coarse-grained sandstone facies 1.3%. This facies typically consists of a basal

coarse-grained sandstone unit up to 30 cm thick which grades upward into fine-grained sandstone and then passes imperceptibly into the siltstone facies. The lower coarse portion always has a sharp, flat and often loaded base and characteristically contains thin, lenticular granule lenses. Small-scale trough cross-bedding is sometimes observed within the fine- to medium-grained sandstone. Stems and leaves are occasionally found on parting surfaces within the bed. Units of this facies are laterally continuous over the width of the outcrop (2–5 m).

The graded coarse-grained sandstone facies occurs solely as sandstone interbeds within the siltstone facies and therefore represents catastrophic spreads of sand over the floodplain surface. A sharp base succeeded by material laid down during an episode of declining flow are consistent with deposition by crevasse splays (Allen, 1965*b*). The in-situ tree, whose base lies in the siltstone facies, is covered by material of the graded coarse-grained sandstone facies and presumably owes its preservation in growth position to rapid deposition of overbank sediment (cf. Jefferson, 1981).

Laminated mudstone facies 24.8%. Although mudstone is the predominant sediment type, grain size varies between mud and fine-grained sand. This facies is characterized by a well developed planar lamination with laterally continuous laminae of constant thickness. Although usually 1–3 mm thick, the laminae range from fractions of a millimetre to 2 cm thick and occasionally display synsedimentary disruption and microfaulting (Fig. 14). Alternation between finer grained black laminae and grey-green coarser laminae is common. The latter horizons sometimes possess loaded bases and commonly grade upwards from fine sand to silt. The laminated mudstone facies is completely devoid of fossils and occurs in units up to 32 m thick.

The absence of current- or wave-induced sedimentary structures, the fine planar lamination and the fine grade of the material involved all indicate deposition from suspension in a low energy environment. As the facies is intimately associated with

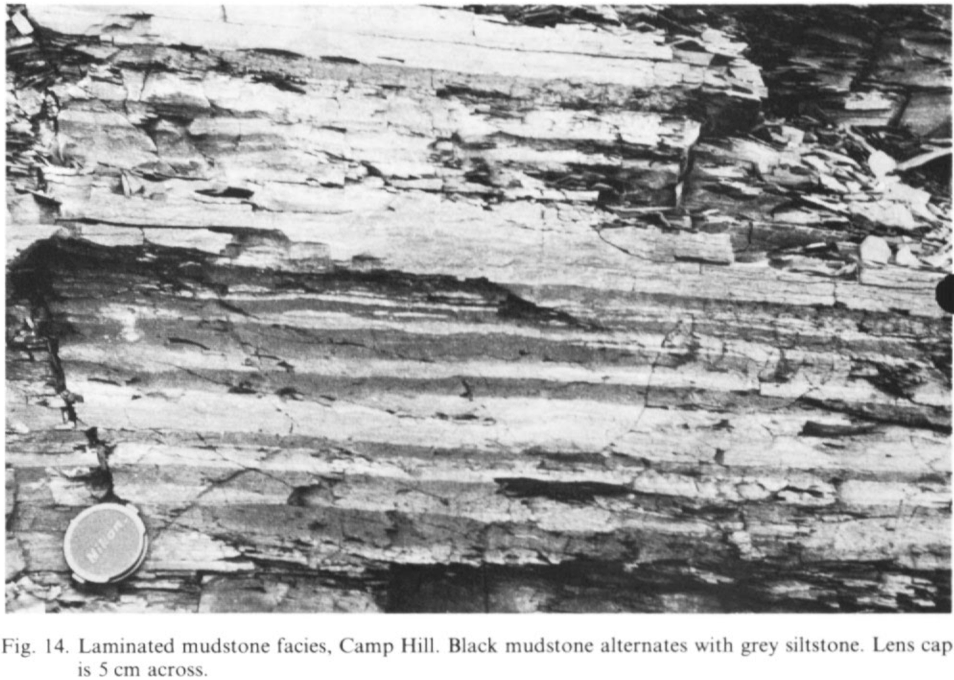

Fig. 14. Laminated mudstone facies, Camp Hill. Black mudstone alternates with grey siltstone. Lens cap is 5 cm across.

units of the siltstone facies, which have been interpreted as backswamp deposits, the most likely environment of deposition for the laminated mudstone facies is within lakes on the floodplain. Graded beds deposited by density underflows are a common feature of lacustrine sedimentation (Kuenen, 1951; Matthews, 1956; Gustavson, 1975; Lambert and others, 1976; Sturm and Matter, 1978).

Graded very coarse-grained sandstone facies 0.7%. Boundaries of this facies are sharp and flat; the lower one is occasionally loaded. Grain size ranges from medium-grained sand to granule grade. The individual units are typically normally graded from granule at the base to coarse sand at the top. Small-scale trough cross-lamination is commonly developed. The only plant remains preserved are scarce stems at the base. Bed thickness varies from a few centimetres to one metre.

The presence of small-scale cross-bedding indicates deposition by migrating subaqueous bedforms under low to moderate flow powers and the upward diminution in grain-size suggests a progressive decrease in the strength of the flow. This facies only occurs in association with the lacustrine laminated mudstone facies. Sedimentation under waning flow conditions by migrating bedforms in a lake environment suggests deposition by underflow density currents. Sturm and Matter (1978) described graded beds varying in thickness from 2 to 150 cm with wood and leaves at the base, intercalated within laminated muds from Lake Brienz, Switzerland. These are the result of river-produced turbidity currents.

Coarsening-upward sandstone facies 5.4%. This facies always overlies the laminated mudstone facies with a gradational base. Above the base, the sandstone gradually coarsens from very fine-grained sandstone up to very coarse-grained or even granule sandstone. Accompanying this increase in grain size is a gradual thickening of the beds comprising the unit. Near the base bed thickness is generally 1–2 cm, but this steadily increases, reaching 30–35 cm at the top. Between the sandstone beds lie siltstone to fine-grained sandstone partings up to 1.5 cm thick. These horizons contain stems which become more abundant upwards. Overall unit thickness is within the range 1–4 m.

This facies displays abundant current ripple cross-lamination (Fig. 15) and cross-bedding indicative of deposition of bedload material by the migration of small subaqueous bedforms. These gradationally-based coarsening- and thickening-upward sandstone sequences that overlie lacustrine mudstone are probably the result of progradation of a marginal lake environment. The lack of wave-induced sedimentary structures and the presence of large-scale planar foresets and trough cross-stratification favours a deltaic rather than a beach origin. These lacustrine deltas are discussed by Farquharson (1982*a*).

Facies associations

The Camp Hill facies fall into two groupings termed the alluvial fan and floodplain associations. The alluvial fan association forms the basal 240 m and uppermost 50 m of the Camp Hill Formation, whereas the floodplain association constitutes the remaining 490 m thick middle section (Fig. 7).

Alluvial fan association. This association comprises four facies, namely the boulder and cobble conglomerate, thin-bedded sandstone and siltstone facies. These are interpreted as debris flow, braided stream, sheetflood and overbank deposits respectively. Studies on modern alluvial fans have shown that deposition is dominated by debris flow, braided stream and sheetflood processes (Blissenbach, 1954; Bull, 1964; Hooke, 1967; Bull, 1972). Thus the modes of deposition and grain size of this facies association is concordant with alluvial fan deposition. The siltstone facies is only a

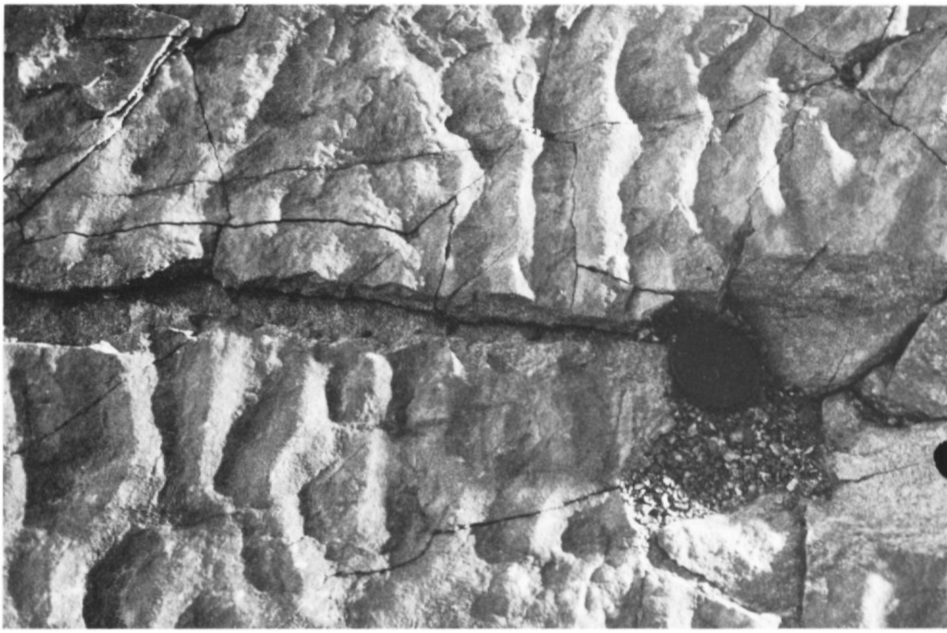

Fig. 15. Inversely graded sandstone facies, Camp Hill. Current ripples with down-current aligned tongues from the basal part of an inversely graded sandstone unit. Lens cap is 5 cm across.

subordinate member of the alluvial fan association, comprising just 6% of the thickness exposed. This is in accord with modern and ancient fans where only thin intercalations of finer material are found (Bull, 1972).

Floodplain association. The floodplain association includes all the facies with the exception of the boulder and cobble conglomerate facies and the thin-bedded sandstone facies. It comprises sediments interpreted as backswamp, river, lake, lacustrine delta and turbidite, and various overbank deposits. Such a collection of intimately related environments indicates that the overall geographic setting is one of a floodplain across which rivers flowed and within which lakes developed.

The dominant lithofacies of the floodplain association is the siltstone facies which constitutes 54% of the measured section. Other overbank deposits are quite common and include gravel spill lobes, crevasse splays and levees. The plant-rich siltstone facies with its incipient coals indicates that the floodplain across which the rivers flowed was well vegetated and possessed a high water table.

The laminated mudstone facies was deposited from suspension in lakes on the floodplain. Occasionally, density underflows carried river-derived sand into the basin giving rise to graded sandstone beds within the mudstone (cf. Dineley and Williams, 1968). Transitions from the laminated mudstone facies up into the plant-rich siltstone facies are often attained by a simple gradation change implying silting up of the lake. Elsewhere, thickening- and coarsening-upward sequences (coarsening-upward sandstone facies) are developed between the two lithologies and clearly represent progradation of a delta over 'basinal' mudstone. These sandstone bodies are of two types: 1) Gilbert-type with steep foresets, and 2) mouth-bar type which lack steep foresets (Fig. 16) (Farquharson, 1982*a*).

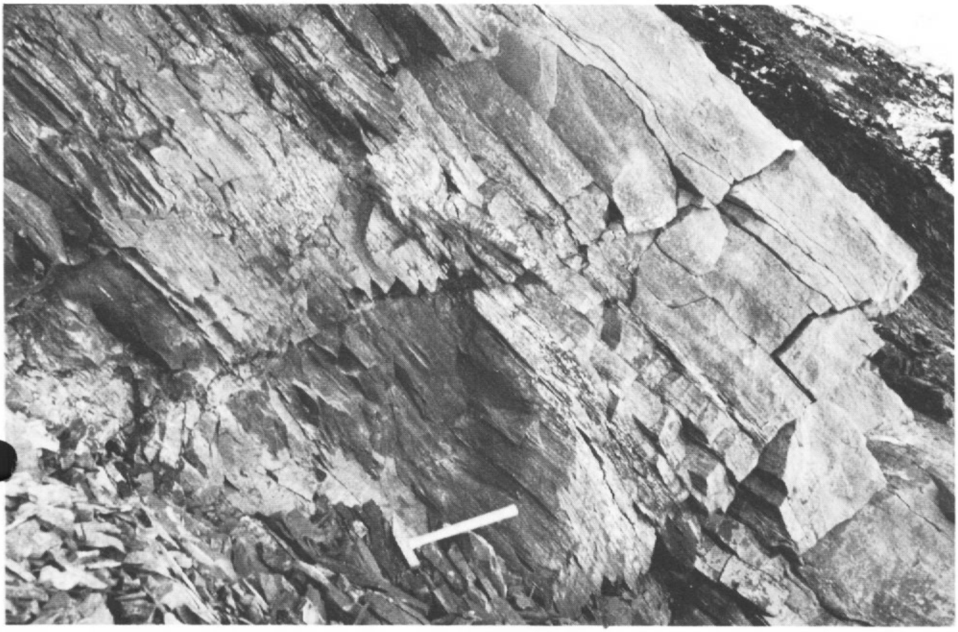

Fig. 16. Inversely-graded sandstone facies, Camp Hill. The upper surface of the sandstone unit is abrupt and followed by further laminated mudstone. The sequence is interpreted as a lacustrine mouth-bar delta abandoned due to avulsion. The hammer is 35 cm long.

Palaeogeography

A generalized section through the sediments preserved at Camp Hill is given in Fig. 7. This representation includes corrections for the small stratigraphic throws imposed by minor faults found in the area. The base of the sequence is delimited by an unconformity with the underlying deformed metagreywackes of the Trinity Peninsula Group. This unconformity is only exposed at one locality (Fig. 9) where it is seen to be topographically irregular on a small-scale, having the appearance of a terrestrial rather than marine unconformity. After allowing for tectonic tilting, the plane of the unconformity has a dip of 40° to the south. This orientation, however, may only be of local extent.

Above the basal unconformity lies material belonging to the alluvial fan association. Overall, this unit shows a crude coarsening-upward cycle overlain by a poorly-exposed fining-upward unit. Thus a symmetrical coarsening- and fining-upward sequence is observed within the alluvial fan deposits at the base of the Camp Hill succession. Coarsening-upward alluvial fan sequences are generally attributable to progradation of the fan (Heward, 1978), although very thick coarsening-upward sequences can be generated by progressively greater movements along a bounding fault (Steel and Wilson, 1975). Fining-upward sequences are generally thought to result from a reduction of source relief and/or scarp retreat. A symmetrical sequence as seen at Camp Hill thus records the development of a fan commencing with progradation as the fan builds out, followed by abandonment. This arrangement of trends has been observed by Ricci-Lucchi (1975) in submarine fan deposits from the Apennines where symmetrical coarsening- then fining-upward sequences are interpreted as representing the progradation and gradual abandonment of fan lobes.

The lower unit of the alluvial fan association is succeeded by a 490 m thick development of the floodplain association. This is essentially an alternation of the siltstone facies and laminated mudstone facies with intercalations of coarser material in the form of overbank, river channel or deltaic deposits. The sequence is capped by 50 m of the alluvial fan association comprising the cobble conglomerate and thin-bedded sandstone facies which crop out on Camp Hill itself.

Half a kilometre to the east of Camp Hill lies a major fault that downthrows predominantly volcanic rocks to the east (Fig. 8). A thin sequence of sedimentary rock exposed at the base of the cliff to the east of the fault is overlain by massive agglomerates, and comprises laminated shales passing up into cobble conglomerates similar to those at the summit of Camp Hill. It is possible that the two sections can be correlated with one another, in which case the volcanic deposits commence only a short distance (a few tens of metres) above the top of the measured sedimentary section. A thin bed about half-way up the Camp Hill section contains accretionary lapilli within a matrix of devitrified glass shards. This is the only evidence that volcanicity was to some extent contemporaneous with sedimentation.

The succession exposed at Camp Hill therefore records a period of subaerial erosion followed by deposition of coarse clastic material on an alluvial fan. Following retreat of the fan, sedimentation became dominated by processes operative within a floodplain environment with low-sinuosity rivers and shallow lakes. Rejuvenation of the source area resulted in the re-introduction of alluvial fan deposits. If the conglomerates to the east of Camp Hill can be correlated with those on Camp Hill then this new phase of alluvial fan development soon gave way to a probably lengthy period of volcanicity represented by the Antarctic Peninsula Volcanic Group.

The coarse lithologies within the Camp Hill section, whether they belong to the alluvial fan or floodplain association, contain clasts derived solely from the Trinity Peninsula Group whose fine- to coarse-grained grey-black arkosic metagreywackes and grey-green metasiltstone with abundant quartz-veining are distinctive lithologies that occur throughout the succession.

Palaeocurrents measured from the imbrication of clasts within the cobble conglomerate facies exposed in the basal alluvial fan association ranged between 134° and 21° with a mean direction towards the south-south-east (vector mean 161°). The palaeocurrent directions of the alluvial fan association at the top of the section fall into the same sector as defined by the lower association (Fig. 7) and suggest that rejuvenation of the alluvial fan was initiated by further movement along a controlling fault scarp. Cross-stratification of the fluvial sandstones yield current orientations between 195° and 338°, with a mean direction towards the west (vector mean 271°). The main trend of floodplain deposition was thus axial to the alluvial fan sedimentation. This organization of marginal and trough deposits is common; for example it has been recognized by Bluck (1978) from the Old Red Sandstone of the Scottish Midland Valley.

Where seen, the plane of the unconformity dips steeply to the south and is concordant with southerly flowing streams associated with alluvial fan deposition along an east-west fault scarp. It is probably significant that the alluvial fan palaeocurrents are perpendicular to the trend of Prince Gustav Channel, a feature long thought to be of faulted origin (Anderson, 1906; Standring, 1953; Bibby, 1966; Farquharson, 1982*a*). It is likely that a fault parallel to that (or those) delimiting the Prince Gustav Channel formed the northern boundary of the Camp Hill alluvial basin. Further evidence for this fault (zone) is discussed by Farquharson and others (in press).

The presence of braided stream, debris flow and sheetflood deposits suggests a moderate to high rainfall with periodic floods. The occurrence of plants with

entire-margined leaves such as *Nilssonia taeniopteroides* within the Camp Hill flora suggests a climatic regime free of frosts (T. H. Jefferson, personal communication). It seems, therefore, that a moist, equable climate is favoured by the available evidence. The same conclusion was reached by Taylor and others (1979) and Jefferson (1981) with respect to late Mesozoic deposits on Alexander Island, 1000 km to the south of Camp Hill.

Downham Peak Beds

The occurrence of sedimentary rocks to the south of Downham Peak (Fig. 1) was first reported by Stoneley (1952). There are very few exposures in the area concerned but a wide variety of lithologies were found as in-situ scree. The area is surrounded on three sides by Trinity Peninsula Group rocks and on the fourth by the coast. A fault breccia containing clasts of metagreywacke up to 15 cm across in a matrix of white quartz marks the boundary between the two rock types.

Lithologies identified are:

(1) Clast-supported cobble conglomerate. Very poorly sorted; clasts in size range 3–8 cm. Clasts are subrounded, form 80% of the rock, are set in coarse-grained sandstone matrix and are all derived from the Trinity Peninsula Group. Quartz veins up to 15 cm wide are common.

(2) Crystal lithic tuff. Quartz and garnet crystals and metasiltstone and glassy volcanic clasts in a green glassy matrix.

(3) Fissile grey siltstone with rare coarse-grained sandstone inter-beds. Some units contain sparse plant fossils.

(4) Laminated and bioturbated mudstone.

(5) Granule sandstone. Low angle trough cross-bedding is preserved in some blocks.

Where bedding planes are observed in outcrop they dip at 20° to the south-east.

Tower Peak Formation

After the initial discovery of sedimentary rocks at Tower Peak (Figs. 1 and 17) by Aitkenhead (1975) in 1961 the area was not visited again until 1978/1979 by R. D. Hamer (investigating the Antarctic Peninsula Volcanic Group) and then by the author in February 1980. The predominantly conglomeratic sequence is exposed on the north face of Tower Peak. The formation unconformably overlies cleaved and folded metasiltstone of the Trinity Peninsula Group and passes up conformably into a thick development of agglomerates belonging to the Antarctic Peninsula Volcanic Group. The sedimentary strata dip at 30° to the south-south-east near the base of the succession but become less steeply inclined towards the top where beds dip at 4° to the east. At its thickest point the sedimentary succession is 124 m thick.

The basal 57 m of the sequence comprises massive conglomerates whose bed thickness is probably in the order of 10 m (numerous scree-covered gaps in the sequence make bed delineation difficult) (Fig. 18). The clasts are derived solely from the Trinity Peninsula Group, comprising green metasiltstone (up to 98%), fine-grained metasandstone (up to 20%) and milky vein quartz (up to 5%). They vary from angular–subangular above the unconformity to subangular–rounded towards the top of the basal conglomeratic section. There is no organized orientation of clasts, which are extremely poorly sorted and range in size from several millimetres to 52 cm. Between 5 and 20% of the conglomerate is a silty sandstone matrix. Scarce impressions of plant stems up to 40 cm long were observed at one horizon.

The features of these conglomerates, particularly their lack of clast fabric, grading

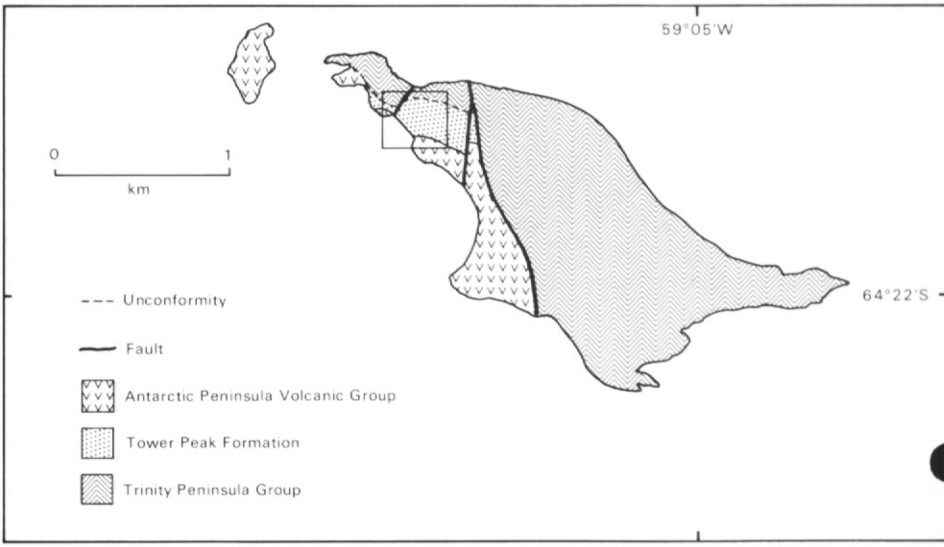

Fig. 17. Geological sketch map of Tower Peak. Boxed area corresponds to that covered by Figure 19.

and stratification are indicative of deposition by a rock-fall or by clast-rich debris flows. The latter process is favoured by the extent (up to 50 m) of those better delineated beds that can be traced laterally.

Immediately overlying the massive conglomerates is a 21-m-thick unit of black, blocky weathering, crystal lithic tuff. The lithology is uniform throughout and comprises 60% clasts (0.05–3 cm across) set within a fine-grained matrix containing abundant quartz and feldspar crystals up to 0.5 mm across. In places the tuff is bedded on a 10–30 cm scale.

The clasts are:

(1) volcanic lithologies, generally with a pale reaction rim and typically comprising phenocrysts in a glassy groundmass (50%)

(2) green divitrified glass (45%)

(3) meta-siltstone and -sandstone (5%)

Rare detrital garnet crystals and petrified wood are also present. Bed boundaries are not exposed but the unit appears to be laterally continuous over at least 100 m. The unit probably represents deposition by a subaerial pyroclastic sediment flow described from recent eruptions of Mount St Helens in Washington (Lipman and Mullineaux, 1981) and the Lesser Antilles (Sigurdsson and others, 1980).

The succeeding 16 m comprises five distinct beds of garnetiferous conglomerate. Maximum grain size ranges from granule to 18 cm. The clasts are subrounded to rounded, predominantly derived from the Trinity Peninsula Group but with up to 10% of volcanic lithologies. The matrix is a coarse-grained white sandstone that constitutes up to 10% of the beds. Garnet, as crystals up to 3 mm across, is abundant, forming up to 5% of a given bed. Discontinuous laminae composed almost entirely of garnet are common. Horizontal stratification due to variation in clast size is a characteristic of these beds as is the orientation of tabular clasts parallel to bedding. One bed has an erosive base. These features, and the segregation of garnet into heavy mineral laminae, are consistent with bed load traction deposition probably within a sheetflood or braided stream system.

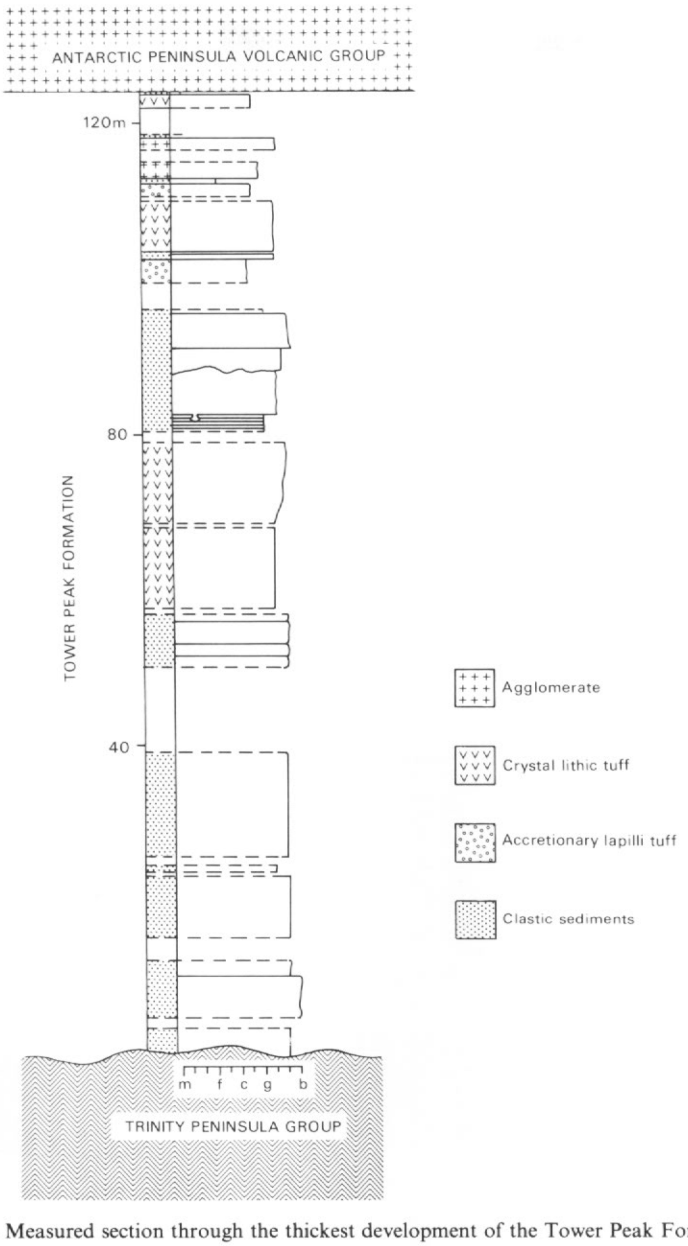

Fig. 18. Measured section through the thickest development of the Tower Peak Formation.

The remainder of the succession (28 m) comprises an alternation between:

(1) fissile, light green very coarse-grained tuffs with abundant accretionary lapilli in beds up to 6.2 m thick,

(2) thin garnetiferous sandstone and pebble conglomerates,

(3) agglomerates, and

(4) 20-cm-thick mudstone beds.

Conformably overlying this succession is massive green agglomerate comprising subangular clasts (50%) up to 10 cm across, of volcanic material and rare metasiltstone embedded in a green, medium-grained tuffaceous matrix.

Near the end of the western ridge that descends from the summit of Tower Peak, beneath volcanic rock described by Aitkenhead (1975) as a laccolith, is another sedimentary section lying unconformably above the Trinity Peninsula Group. The succession here is identical in the sequence of lithologies to that described above but is condensed, the total thickness being 23 m (Fig. 19). The basal clast-supported conglomerate has a maximum thickness of 2 m but wedges out westward against the unconformity. This is overlain by 2 m of black crystal lithic tuff, 6.6 m of garnetiferous conglomerate and finally 15 m of fissile green lapilli tuff. The sequence is capped by 17 m of andesite.

A sketch of the north face of Tower Peak is given as Fig. 19. There is a conspicuous

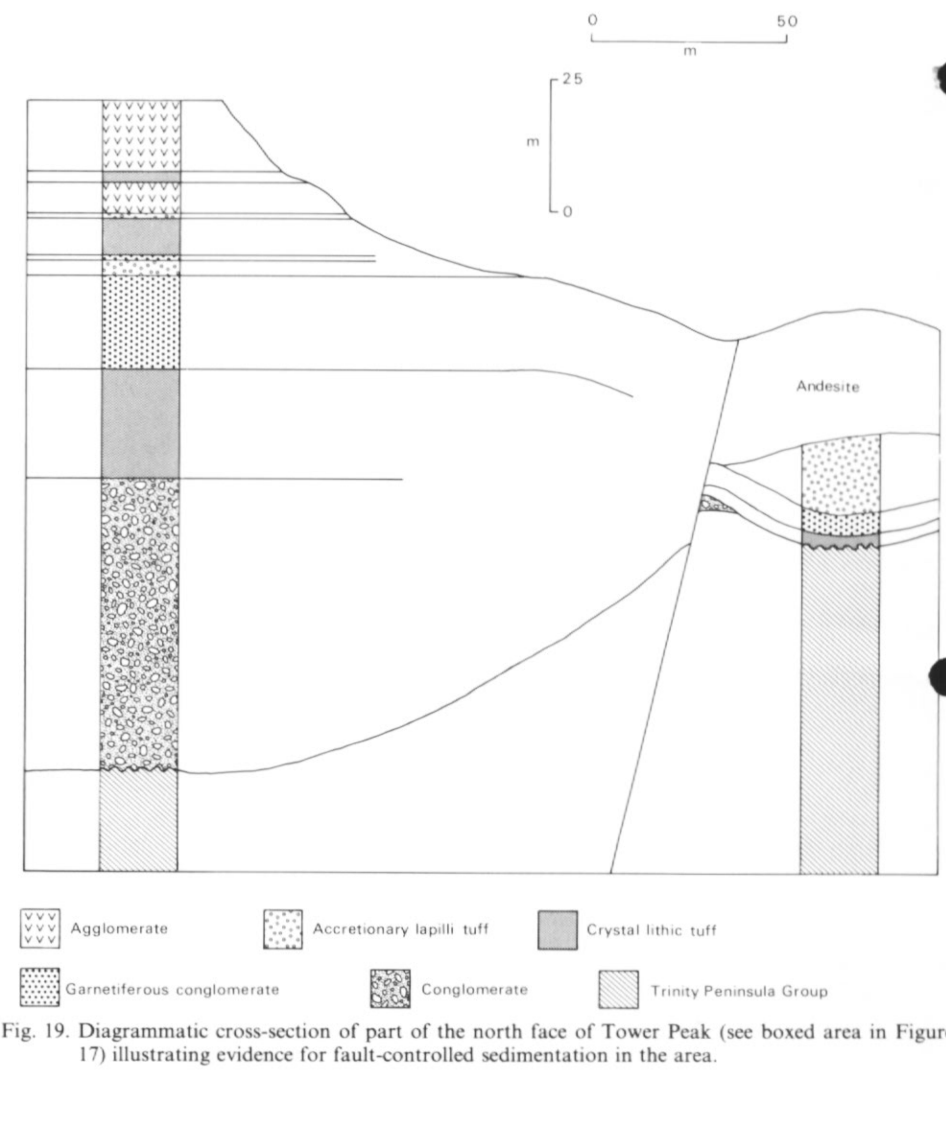

Fig. 19. Diagrammatic cross-section of part of the north face of Tower Peak (see boxed area in Figure 17) illustrating evidence for fault-controlled sedimentation in the area.

lack of outcrop where the break between the two sequences must occur but it is clear that a fault with a downthrow of about 10 m to the east must pass through this area. Movement along this fault (downthrow to the east) prior to, or during, sedimentation is the best explanation for the thickness changes observed. This fault probably formed part of the boundary to the alluvial basin.

A 5-m-thick succession of conglomerate and plant-bearing fine-grained sandstone was found by R. D. Hamer (personal communication) near to the summit of the nunatak 2 km north of Tower Peak. The sedimentary strata lie sandwiched between the Trinity Peninsula Group and Antarctic Peninsula Volcanic Group. Attenuation of the succession compared to the 124-m-thick sequence on Tower Peak strengthens the notion that the alluvial deposits are preserved in steep-sided hollows on the Trinity Peninsula Group land surface.

Joinville Island

A description of the conglomeratic rocks that occur along the north-east coast of Joinville Island and on Patella Island was first published by Elliot (1967). This work was based largely on the unpublished field data of J. S. Bibby, A. J. Standring, N. Aitkenhead and P. H. H. Nelson. In 1978 landings were made in the area from R/V *Hero* by Elliot and others (1978). The unconformity separating the conglomerate beds from the underlying Trinity Peninsula Group was observed at several localities around Ambush Bay. The conglomerates are massive or poorly stratified; finer-grained beds are rare and volcanic interbeds apparently absent. The upper boundary of the Botany Bay Group in this area is not seen.

South Orkney Islands

Two distinct units of conglomeratic strata are exposed in the South Orkney Islands. Neither the base nor top of the Powell Island Conglomerate are seen; it has a faulted contact with the Greywacke-Shale Formation from which it is largely derived. In contrast, the Spence Harbour Conglomerate is derived from the Scotia metamorphic complex which it is seen to overlie unconformably (Thomson, 1973). The top of the Botany Bay Group in the South Orkney Islands is not seen and volcanic interbeds are absent although volcanic clasts have been observed within the conglomerates. Elliot and Wells (1982) have interpreted these deposits as the products of coalescing alluvial fans banked against fault scarps. A fossiliferous sandstone (Matthews Island sandstones) within the Spence Harbour Conglomerate represents a short-lived shallow marine incursion (Elliot and Wells, 1982). Ammonites from this unit indicate an early Cretaceous (Neocomian) age of deposition (Thomson, 1981).

Petrography and Provenance

The composition of representative sandstone samples from the succession at Hope Bay, Camp Hill and Tower Peak were determined by point-counting (3500 points per slide; 0.05-mm spacing). These analyses plot in the lithic arenite field of Dott (1964) (Fig. 20). Many of the samples contain more than 15% matrix and are thus lithic greywackes. The mineralogy of the arc-terrane deposits is relatively simple. The major components are metagreywacke rock fragments and strained quartz crystals derived from the Trinity Peninsula Group. Feldspar is scarce, varying in amount from 0 to 8.6% and is slightly more abundant at Hope Bay than Camp Hill or Tower Peak. With the exception of two specimens from near the top of the Camp Hill succession,

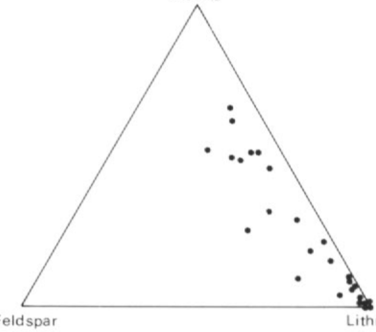

Fig. 20. Plots of sandstone modal analyses on a quartz (monocrystalline), feldspar and total rock fragment triangle. The sandstones are from Hope Bay, Camp Hill, Downham Peak and Tower Peak.

volcanic lithoclasts are either absent or rare. Other components are traces of zircon and detrital muscovite and small quantities of opaque grains.

The conglomerates comprise clasts of meta-siltstone and greywacke and vein quartz and it is clear that they too represent debris derived from a 'basement' terrane of deformed Trinity Peninsula Group metasediments. Despite such a provenance varying degrees of contemporaneous volcanism were associated with each of the terrestrial arc-terrane successions. At Hope Bay several ignimbrites and tuffs punctuate the upper half of the sedimentary succession. Contemporaneous volcanism was less important at Camp Hill where only a single glass shard deposit with accretionary lapilli interrupts the 780-m-thick sequence of clastic sediments. Crystal lithic tuffs and accretionary lapilli tuffs interspersed within the Tower Peak Formation indicate the existence of significant coeval volcanism. A striking feature of the granule sandstone and pebble conglomerates towards the top of the Tower Peak sedimentary sequence is their content of red almandine garnet, up to 14% in the point-counted thin-sections. Sometimes they form laminae of almost 100% garnet within the host rock. These garnets are detrital and are probably of volcanic origin, garnet being a widespread constituent of the Antarctic Peninsula Volcanic Group (Hamer and Moyes, 1982).

Replacement of matrix and feldspar crystals by calcite is a common phenomenon in the sedimentary rocks from Camp Hill and Tower Peak but is uncommon in the Hope Bay deposits. Feldspar crystals at all localities, if not replaced by calcite, are typically sericitized. Most samples from the Mount Flora Formation at Hope Bay contain abundant metamorphic biotite that has grown within the matrix. The development of biotite is probably a response to contact metamorphism associated with intrusion of a quartz-diorite pluton that crops out less than 1 km from Mount Flora. Metamorphic biotite is absent from the Camp Hill and Tower Peak sediments, which are 35 and 8 km respectively from the nearest exposed plutons. The higher grade of metamorphism at Hope Bay compared to Camp Hill and Tower Peak is reflected in greater induration and poorer preservation of plant remains.

Conclusions

Outcrops of non-marine, mainly conglomeratic, sedimentary rocks derived from deformed metasedimentary rocks are of common but local occurrence from the South Orkney Islands south to Larsen Inlet (Fig. 1). They have many points in common and form a significant tectono- and litho-stratigraphic unit in the northern Antarctic Peninsula; the Botany Bay Group. Their main characteristics are:

(1) They lie unconformably on, or are faulted against, deformed metagreywackes of the Trinity Peninsula Group on the Antarctic Peninsula and Joinville Island. In the South Orkney Islands they lie on the local 'basement' of Scotia metamorphic complex and Greywacke-Shale Formation (Thomson, 1973).

(2) Clasts within the conglomerates are derived solely from the basement metasedimentary rocks now exposed in the immediate vicinity.

(3) Conglomerates, largely clast-supported, are the dominant lithology particularly towards the base of the sequences. Plant-bearing sandstone, siltstones and mudstones typically form the higher parts of the sequences.

(4) The conglomerates are the result of deposition by debris flows and braided streams on alluvial fans (Elliot and Wells, 1982; Farquharson 1982*a*). Accompanying sandstones are interpreted as either sheetflood or braided stream deposits. The succession at Camp Hill is unusual in containing a thick floodplain sequence with fluvial, overbank and lacustrine deposits (Farquharson, 1982*a*).

(5) Most of the sedimentary succession (except those on Joinville Island and the South Orkney Islands (Elliot and Wells, 1982)) contain interbedded volcanic deposits, most commonly towards the top of the successions. These deposits are accretionary lapilli, crystal lithic, and welded tuffs.

(6) The sedimentary successions at Hope Bay, Camp Hill and Tower Peak are overlain conformably by agglomerates and ignimbrites of the calc-alkaline Antarctic Peninsula Volcanic Group (Hamer, 1983).

(7) The basins within which these successions accumulated were generally fault-controlled. Evidence for this is found on the South Orkney Islands (Elliot and Wells, 1982) and at Camp Hill (Farquharson, 1982*a*) and Tower Peak.

Farquharson (1983*a*) has argued on the basis of the sedimentary successions in the northern Antarctic Peninsula that the late Mesozoic evolution of the area can be described in terms of two distinct periods of volcanic arc development. Evidence from the Nordenskjöld Formation (Farquharson, 1983*b*) indicates that, during late Jurassic (Kimmeridgian to Tithonian) and possibly earliest Cretaceous times, although a magmatic arc was active in the area, there was no appreciable subaerial landmass and fine-grained sediments were able to accumulate over a wide area.

The Botany Bay Group represents accumulations, predominantly on alluvial fans, within fault-bounded basins. The sedimentological evidence combined with the presence of coeval calc-alkaline volcanism indicate deposition on an emergent magmatic arc. The probable early Cretaceous age of the Botany Bay Group and the late Jurassic to earliest Cretaceous age of the Nordenskjöld Formation indicate that uplift must have occurred sometime in the early Cretaceous. This timing of events is coincident with the first influx of coarse detritus into the accompanying back-arc basin during Hauterivian or Barremian times (Farquharson, 1982*b*). It can be concluded that the alluvial sequences accumulated in fault-bounded basins on an uplifted area of metasedimentary rocks and represent a distinct episode between uplift and the onset of volcanism. The alluvial basins were probably of quite local extent and may not be exactly contemporaneous, particularly as the initiation of volcanism is unlikely to have been synchronous over such a large area.

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