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# THE GEOLOGY OF THE ABLATION POINT–KEYSTONE CLIFFS AREA, ALEXANDER ISLAND

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## Table II

## DISTRIBUTION OF STRATIGRAPHICALLY SIGNIFICANT MOLLUSCA FROM THE UPPER JURASSIC – LOWER CRETACEOUS SUCCESSION BETWEEN ABLATION POINT AND KEYSTONE CLIFFS

| | | | *Ammonoidea* | *Belemnoidea* | *Inoceramus* | *Other stratigraphically important species* | *Localities* |
|---|---|---|---|---|---|---|---|
| LOWER CRETACEOUS | | **LOWER ALBIAN** | *Phyllopachyceras aureliae*<br>"*Lytoceras*" sp. *β*<br>*Macroscaphites* (*?*) sp.<br>*Pseudothurmannia* cf. *mortiletti*<br>*Hemihoplites* (*?*) sp.<br>*Silesites desmoceratoides* (*?*)<br>*Silesites antarcticus* | | *Inoceramus* sp. *β* | | **X and W** |
| | | | *Eotetragonites* (*?*) sp.<br>*Costidiscus* (*?*) sp.<br>*Antarcticoceras antarcticum*<br>*Callizoniceras* (*?*) sp. | *Dimitobelus macgregori*<br>*Peratobelus oxys* | | | **B** |
| | | **APTIAN** | *Hypophylloceras* sp.<br>*Eotetragonites* sp.<br>*Australiceras* sp.<br>Heteromorphs of "*Ancyloceras*" *patagonicum* group<br>*Aconeceras* aff. *nisoides* | *Dimitobelus macgregori*<br>*Dimitobelus* aff. *macgregori*<br>*Neohibolites minimus* cf. var. *oblongus* | *Inoceramus* aff. *concentricus* | | **A and T** |
| | | | | *Peratobelus* aff. *australis*<br>*Neohibolites minimus* cf. var. *submedius* | | | **T** |
| | | | *Hypophylloceras* sp.<br>*Eulytoceras* aff. *polare*<br>*Lithancylus* (*?*) sp.<br>*Emericiceras* (*?*) sp.<br>*Toxoceratoides* **sp. nov.**<br>Heteromorphs of "*Ancyloceras*" *patagonicum* group<br>*Sanmartinoceras patagonicum* | *Peratobelus* **sp. nov.** (*?*) | | *Aucellina* of the *A. andina/radiatostriata* complex | **T** |
| | | | *Hypophylloceras* sp.<br>*Phyllopachyceras* cf. *baborense*<br>*Phyllopachyceras* sp.<br>"*Lytoceras*" sp. *α*<br>*Eulytoceras* aff. *polare*<br>*Acrioceras* (*?*) aff. *voyanum*<br>*Aconeceras* sp. *α*<br>*Aconeceras* (*?*) sp.<br>*Sanmartinoceras patagonicum*<br>*Theganeceras grande*<br>*Theganeceras* (*?*) sp. | *Neohibolites* cf. *miyakoensis*<br>*Neohibolites minimus* cf. var. *submedius* | | | **AP, D, R, S and N** |
| | | | | | "*Inoceramus*" *trapezoidalis* | | **K** |
| | NEOCOMIAN | **BARREMIAN**<br>\|<br>**VALANGINIAN** | ? | ? | ? | ? | |
| | | **BERRIASIAN** | *Bochianites gracilis*<br>*Phyllopachyceras* (*?*) sp.<br>*Neocosmoceras* aff. *sayni*<br>*Himalayites* (*?*) sp. | *Hibolithes subfusiformis*<br>*Belemnopsis alexandri*<br>*Belemnopsis gladiatoris*<br>*Belemnopsis* aff. *uhligi*<br>*Hibolithes subfusiformis* | *Inoceramus pseudosteinmanni* | *Myophorella* sp. | **Z, K, D and F** |
| | | | *Substreblites* (*?*) sp.<br>*Phylloceras* sp.<br>*Sarasinella* aff. *hondana* | *Hibolithes subfusiformis*<br>*Hibolithes antarctica*<br>*Hibolithes* aff. *marwicki mangaoraensis*<br>*Hibolithes* **sp. nov.** (*?*) | *Inoceramus* sp. *α* | | **Z, C and D** |
| | | | *Haplophylloceras strigile*<br>*Bochianites* aff. *versteeghi*<br>*Spiticeras* aff. *spitiensis*<br>*Raimondiceras* **sp. nov.** | *Belemnopsis alexandri*<br>*Belemnopsis* aff. *uhligi*<br>*Hibolithes subfusiformis*<br>*Hibolithes* cf. *compressus* | *Inoceramus* sp. *α* | *Myophorella* sp. | **AE, AF and AG** |
| UPPER JURASSIC | | **TITHONIAN** | *Phyllopachyceras beneckei*<br>"*Berriasella*" *subprivasensis*<br>*Blanfordiceras* aff. *wallichi* | | *Inoceramus* sp. *γ* | *Myophorella* sp. | **AC and AG** |
| | | | *Calliphylloceras* sp.<br>*Phyllophacyceras beneckei*<br>*Phylloceras* aff. *serum* (*?*)<br>"*Lytoceras*" sp. indet.<br>"*Lytoceras*" **sp. nov.**<br>*Pterolytoceras exoticum*<br>*Haploceras* spp.<br>*Uhligites* aff. *kraffti*<br>Oppeliid **gen. nov.** (?)<br>*Virgatosphinctes* **sp. nov.**<br>*Virgatosphinctes* aff. *mexicanus*<br>*Virgatosphinctes denseplicatus*<br>*Virgatosphinctes* aff. *denseplicatus*<br>*Virgatosphinctes contiguus*<br>*Virgatosphinctes* **sp. nov.** aff. *andesensis*<br>*Virgatosphinctes* cf. *frequens*<br>*Aulacosphinctoides* aff. *sparsicosta*<br>*Aulacosphinctoides smithwoodwardi* (*?*)<br>*Aulacosphinctoides* **sp. nov.** *α*<br>*Aulacosphinctoides* **sp. nov.** *β*<br>"*Spiticeras*" sp.<br>*Corongoceras* cf. *lotenoense*<br>*Andiceras* (*?*) sp. | *Belemnopsis* aff. *uhligi*<br>*Belemnopsis belligerundi* | *Inoceramus* sp. *δ* | *Buchia* cf. *plicata*<br>*Buchia* cf. *spitiensis* | **AB, AH, AJ and AK** |
| | | **KIMMERIDGIAN**<br>\|<br>**UPPER OXFORDIAN** | *Perisphinctes* (*Orthosphinctes*) cf. *transatlanticus*<br>*Pachysphinctes* (*?*) sp. | *Belemnopsis* cf. *alfurica*<br>*Belemnopsis* cf. *gerardi*<br>*Belemnopsis* cf. *keari*<br>*Belemnopsis* cf. *tanganensis* | *Inoceramus haasti*<br>*Inoceramus* aff. *subhaasti* | | **Belemnite Point, Ablation Point and AH** |

These faunas have been identified by M. R. A. Thomson and L. E. Willey.

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## ABSTRACT

SYSTEMATIC stratigraphical investigations in eastern Alexander Island, which began in 1961 and have continued up to the present day, form the basis of this report.

The physiography of the coastal sedimentary belt has been strongly influenced by the overall gentle dip of the rocks and by faulting. Phenomena such as glacial striae and "dry valleys" indicate that considerable deglacierization has occurred since the glacial maximum in the mid-Pleistocene.

A review of previous stratigraphical observations has revealed several inaccuracies and inconsistencies which are discussed in the light of recent research. It is proposed that the term *Fossil Bluff Formation* be used for the whole of the Mesozoic sedimentary sequence (and interbedded lavas) extending from north of Trench Glacier to Stephenson Nunatak, with the proviso that future investigations will probably allow sub-division into at least three units of formation status. That part of the formation between Ablation Point and Keystone Cliffs consists of approximately 4,000 m. of mainly mudstones with subordinate sandstones, conglomerates, pebbly mudstones and tuffaceous sedimentary rocks. The succession contains a varied invertebrate fauna and local occurrences of moderately well-preserved plant material from a nearby shoreline. Fish are also present. The detailed stratigraphy of 27 measured sections and palaeontological studies (mainly on the Cephalopoda) indicate that the age of this part of the sequence ranges from Upper Oxfordian–Kimmeridgian to Lower Albian.

The Mesozoic trough developed adjacent to a rejuvenated (?) Carboniferous geosyncline. The east–west extensions of the Mesozoic succession crop out between the coast and a prominent north–south fault approximately co-linear with the eastern margin of the LeMay Range; west of this fault is a thick sequence of tightly folded (?) Carboniferous sedimentary rocks. A possible eastward extension of the trough is indicated at Carse Point by the occurrence of marine fossils of Upper Jurassic age.

Sedimentation was often rapid and prolonged. Previous facies zonation is difficult to substantiate because facies variations are both synchronous and diachronous, and lateral and vertical. Penecontemporaneous volcanicity in or near the depositional trough is indicated by a wide variety of airborne pyroclastic material. The largely benthonic fauna reflects generally high rates of sedimentation but sporadic occurrences of epifaunas demonstrate periods of reduced sedimentation. The flora and the textural and mineralogical immaturity of the sediments suggest that the late Mesozoic climate was wet and temperate.

Regional correlations indicate that the Jurassic part of the succession shows a much greater correspondence with extra-Antarctic regions than does that of the Lower Cretaceous. Although large-scale thrust/reverse faults have been mapped, west to east overthrusting is not as extensive as originally thought and the disturbed zones (e.g. at Ablation Point, Fossil Bluff and Keystone Cliffs) have probably developed as a result of post-depositional gravity sliding.

# CONTENTS

# I. INTRODUCTION

ALEXANDER ISLAND (Figs. 1 and 2), formerly referred to as Alexander I "Land", "Islands" and "Archipelago", is by far the largest island off the west coast of the Antarctic Peninsula and lies between lat. 69° and 72°30′S., i.e. west of that part of the peninsula known as Palmer Land. The island is approximately 440 km. long, 80 km. wide in the north and 250 km. wide in the south; it is elongated north–south and follows approximately the structural trend of the peninsula. To the east, Alexander Island is separated from the mainland by George VI Sound, an almost straight north–south trough which trends westward at its southern end to join the Bellingshausen Sea. Normally about 30 km. wide, the sound is narrowest

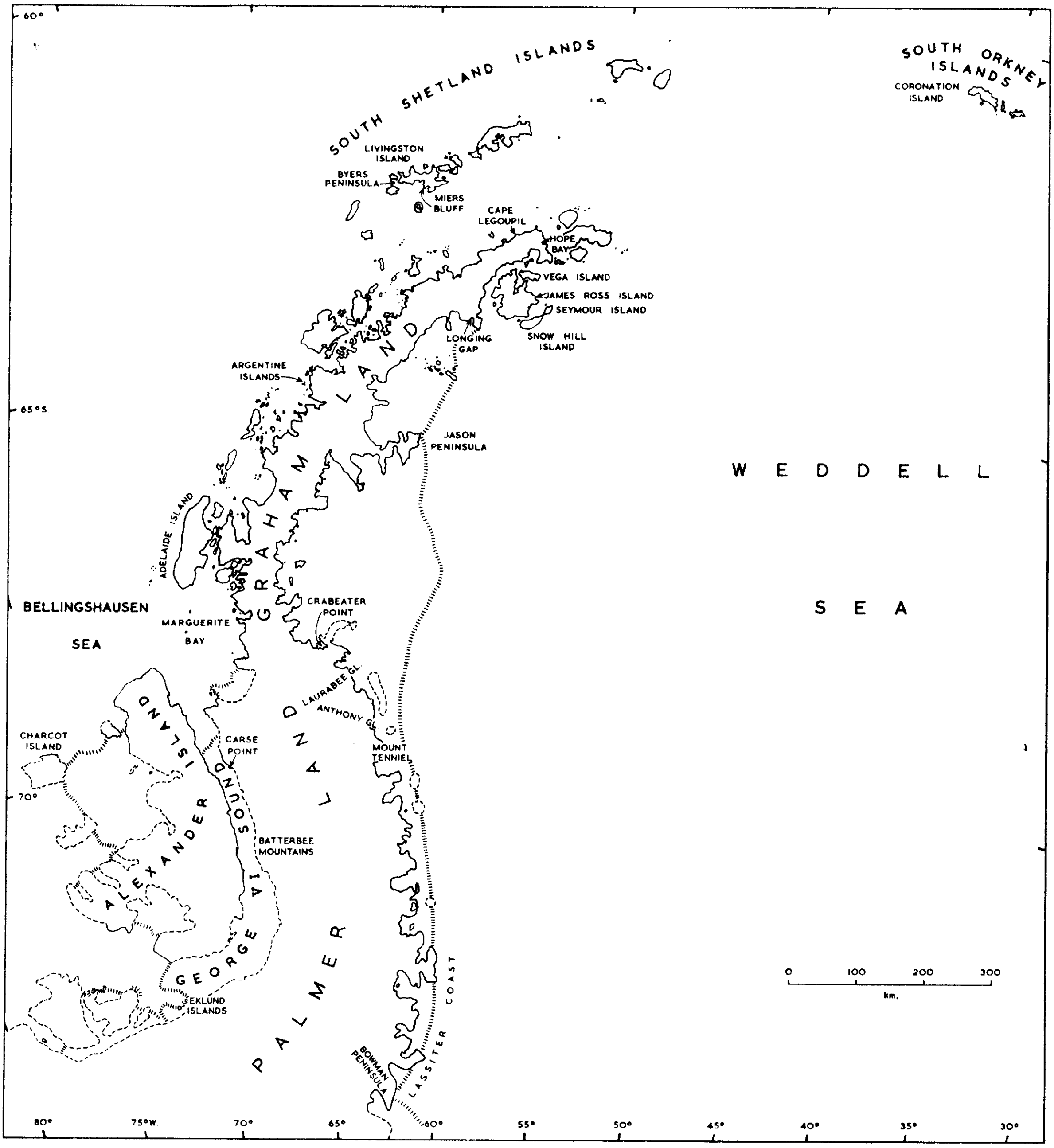

FIGURE 1

Map of the Antarctic Peninsula showing localities mentioned in the text. Eastern Ellsworth Land is situated south of and adjacent to south-eastern Palmer Land. Localities in Alexander Island are shown in Figs. 2 and 3.

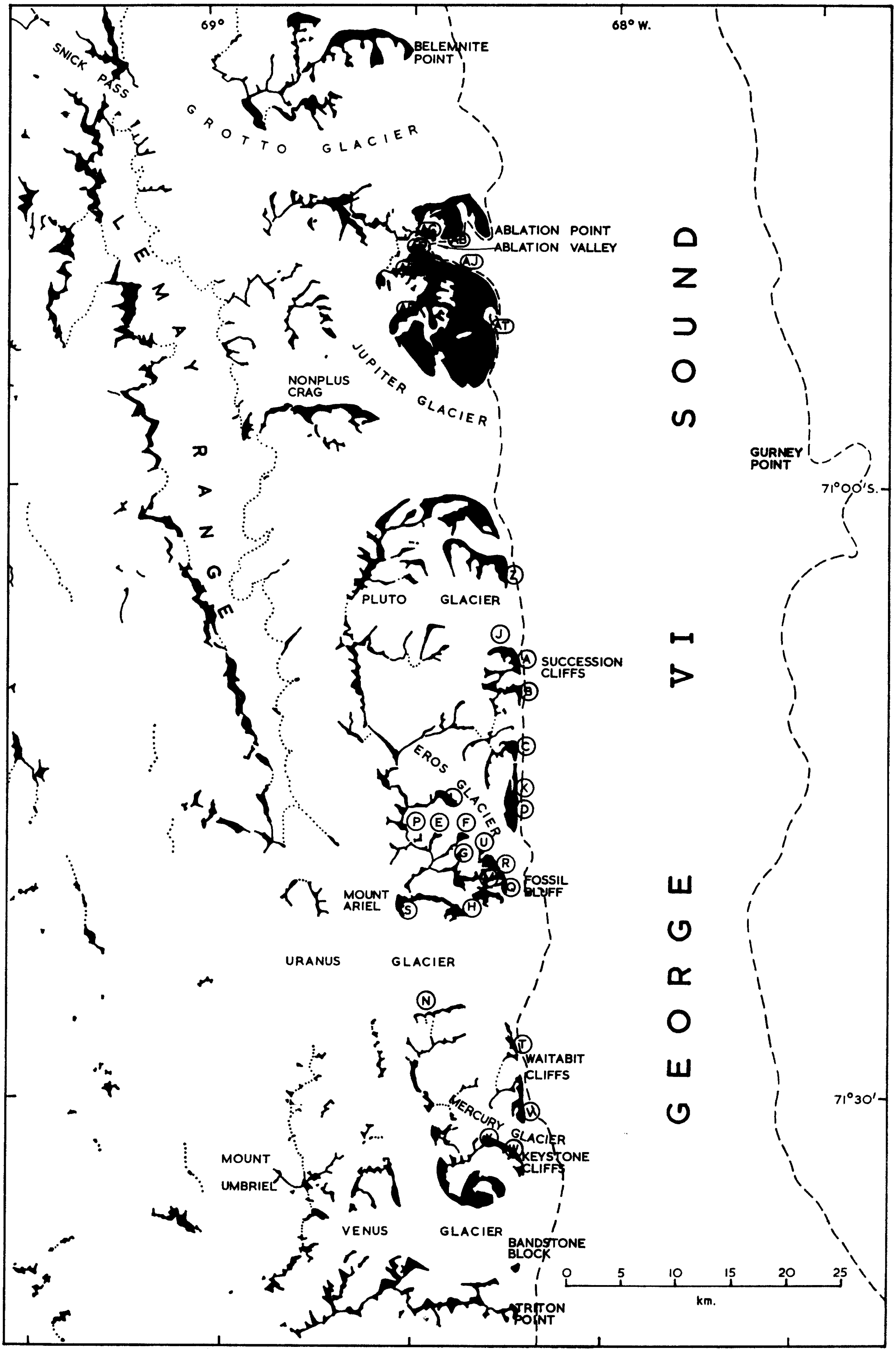

FIGURE 3

Sketch map of part of eastern Alexander Island between Ablation Point and Keystone Cliffs showing the localities where major stratigraphical investigations have been carried out.

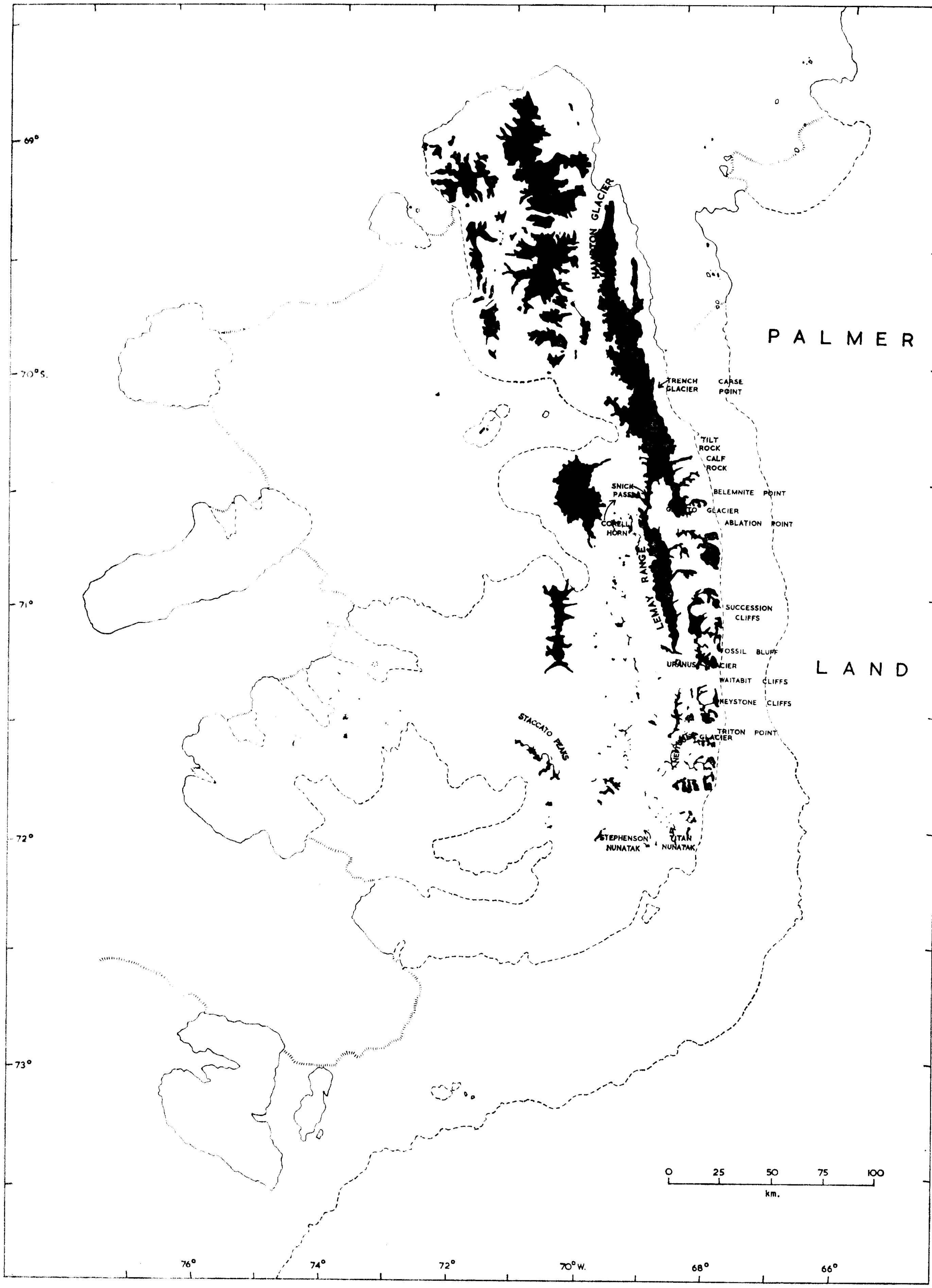

FIGURE 2

**Map of Alexander Island showing the location of the area discussed and localities mentioned in the text.**

(25 km.) in the latitude of Fossil Bluff (lat. 71°19′S., long. 68°16′W.), the site of the British Antarctic Survey field station from which the field work for this report was carried out. All but the northern part of the sound is filled by an ice shelf.

The area described here (Fig. 3) comprises 90 km. of well-exposed coastal cliffs between Ablation Point (lat. 70°48′S., long. 68°22′W.) and Keystone Cliffs (lat. 71°35′S., long. 68°13′W.) and between the coastline and long. 68°45′W.

## II. HISTORY OF INVESTIGATIONS

ALEXANDER ISLAND was discovered in 1821 by T. von Bellingshausen, leader of a Russian expedition, who sighted a prominent cape in lat. 68°43′S., long. 73°10′W. Although pack ice prevented him from approaching closer than 65 km., he later reported sighting a more extensive landmass beyond this cape (and to the west of Graham Land) which he named "Alexander I Land" after the reigning Tsar, sponsor of the expedition.

In the latter half of the nineteenth century and in the first three decades of the present century, there were more sightings by sea and air (useful summaries of which have been given by Mill (1905), Adie (1957*c*, 1958), Searle (1963) and Priestley (1964)), and some pertinent geographical observations were made, notably by Charcot (1911, p. 254), who rightly guessed that the island was large and separated from the mainland by a wide strait. The first geological observations on the sedimentary succession exposed along the eastern coast of the island were made by Hollick-Kenyon, who piloted L. Ellsworth on his trans-Antarctic flight of 1935. When flying approximately alongside the area between Block Mountain and Ablation Point (Fig. 2), Hollick-Kenyon radioed to the British Graham Land Expedition (based at the Argentine Islands) that "the mountains here are sedimentary" (Joerg, 1937, p. 442). Later Joerg (1936, 1937, pl. III), who interpreted Ellsworth's photographs, referred to seemingly continuous stratified rock outcrops between (judging from his map) Block Mountain and the southern margin of Uranus Glacier. More specifically, Joerg (1936, unpublished photograph adjoining fig. 10) referred to sedimentary rocks south of Calf Rock as dipping at 10° to the south-west. This locality may have been Belemnite Point.

This sedimentary succession was first investigated in 1936 by G. C. L. Bertram, W. L. S. Fleming and A. Stephenson of the British Graham Land Expedition (B.G.L.E.), 1934–37, who sledged down George VI Sound as far as lat. 72°30′S., long. 67°18′W., thus proving that Alexander Island was at least 400 km. long. Moreover, when they discovered that the southern limb of the sound trended almost east–west they correctly inferred that "Alexander I Land" was an island.

Stratified cliffs on the eastern coast of Alexander Island were observed as far south as lat. 72°S. (Fleming, 1938, p. 509) and the first fossils were discovered at Fossil Bluff and Ablation Point, the only localities visited by the southern sledge party. At "Fossil Camp" [Fossil Bluff] 48 specimens including numerous poorly preserved molluscs and plants were collected. At "Ablation Camp" [Ablation Point], "limestones",* sandstones and shales were found and nearly 100 specimens were collected including bivalves, brachiopods, belemnites, shark teeth and plants. The belemnites, apparently collected from the lowest strata, are probably Upper Oxfordian to Middle Kimmeridgian in age (Willey, 1973) but the other fossils from this locality and Fossil Bluff are undescribed. Bertram, Fleming and Stephenson also camped beside "cliffs of stratified sedimentary rocks" at the northern end of Succession Cliffs but this locality was not sampled.

In 1940, F. Ronne and C. Eklund of the United States Antarctic Service Expedition (U.S.A.S.E.), 1939–41, sledged to the Eklund Islands and saw George VI Sound terminating in open sea, thus confirming Alexander Island's insularity. "Passing the stratified mountains and the last south-eastern nunatak on Alexander Island" fossiliferous rocks were collected (Ronne, 1945, p. 19) but the present location of this undescribed material is not known. Their geological specimens and field observations were described by Knowles (1945, p. 134), who reported that "well defined low-angle, stratified fossiliferous and sedimentary rock occurs in large outcrops along the western [*sic*] and southern margins of Alexander I Island". The only sedimentary rocks described as being *in situ* were at lat. 72°08′S., long. 68°45′W. (? Titan Nunatak)

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* As no bedded limestones have been found during recent detailed investigations in Alexander Island, the so-called "limestones" discovered by the B.G.L.E. at Fossil Bluff and Ablation Point probably represent the more indurated fine-grained siltstones, lenses of lime carbonate or laumontitized sedimentary rocks which are often white in colour.

where uniform horizontal mudstones, greywackes, arkoses and coarse conglomerate of probable non-marine origin were found together with poorly preserved carbonized plants. These may represent the fossils referred to by Ronne. On Knowles's (1945, p. 135) map this sequence and those sedimentary rocks north of this locality were described as Middle Jurassic in age.

In the summers of 1948–49 and 1949–50 V. E. Fuchs and R. J. Adie of the Falkland Islands Dependencies Survey (F.I.D.S.) made a reconnaissance topographical and geological survey of both coastlines of George VI Sound and their adjacent hinterlands. The results of this investigation have provided the ground work for the more detailed studies currently being undertaken by the British Antarctic Survey (B.A.S.). Most of the eastern coast of Alexander Island was visited and palaeontological collections were made (mainly *in situ*) at several localities between Belemnite Point and Stephenson Nunatak. At Belemnite Point tuffaceous sedimentary rocks with Upper Jurassic belemnites* were discovered, whereas at Ablation Point, Upper Jurassic sedimentary rocks with perisphinctid ammonites were reported interthrust with Aptian sedimentary rocks. Farther south at Succession Cliffs, Fossil Bluff, Waitabit and Keystone Cliffs, siltstones, greywackes and more tuffaceous sandstones contained an abundant mainly molluscan fauna. The gastropods and bivalves were described by Cox (1953), the ammonites by Howarth (1958) and the annelids by Cox (1953) and Ball (1960). The belemnites are currently being described by L. E. Willey but the remainder of Fuchs and Adie's material (e.g. the plants and fish scales) is still undescribed. The stratigraphical implications of these faunas are discussed on p. 11. The area's complex structure was attributed by Adie (1958, p. 11) to severe overthrusting from the west, folding and transverse faulting.

The first detailed geological investigations of the sedimentary succession began in 1961 when B. J. Taylor compiled a detailed measured section at Fossil Bluff. Subsequently, he measured 15 other inter-correlated sections between Pluto and Mercury Glaciers (lat. 71°07′–71°34′S.) (Taylor, 1966*a*) representing a 2,700 m. thick composite succession of Lower Cretaceous (Lower Neocomian–Lower Albian) age. The faunas were found to be more diversified than hitherto known (Taylor, 1965, 1966*a*, *b*, 1967, 1969, 1971*a*, *b*, 1972). The problems involved in correlating these and later stratigraphical sections in south-eastern Alexander Island are discussed on p. 15 (Taylor, 1971*b*).

In 1962, L. C. King made a topographical survey of George VI Sound and Alexander Island from the air and subsequently he (King, 1964) made a number of geological comments on the "late Jurassic–early Cretaceous sedimentary series". The Cretaceous "formations" were reported to be hundreds of feet thick and to crop out at Block Mountain, Lamina Peak, the LeMay Range (or Mountains) (p. 39) and Fossil Bluff. The regional dip was towards the south.

In early 1963, Taylor was joined by R. R. Horne, who carried out structural and sedimentological investigations mainly between Waitabit Cliffs and Triton Point and westward as far as Mount Umbriel. These observations were published by Horne in a general study of the structural geology, sedimentology and palaeoecology of the Mesozoic sedimentary trough (Horne, 1967*a*, *b*, 1968*a*, *b*, *c*; Horne and Taylor, 1969; Horne and Thomson, 1967, 1972).

In 1964, M. R. A. Thomson completed Taylor's measured section at Waitabit Cliffs and compiled a further section of 193 m. at Keystone Cliffs. This work was prematurely terminated by an aircraft crash in December 1964. Subsequent laboratory studies by Thomson have been concerned with the Mollusca (Thomson, 1971*a*, *c*, 1972*a*, 1974; Thomson and Willey, 1972) and inarticulate Brachiopoda (Thomson, 1971*b*).

With the re-introduction of air support in 1967, L. E. Willey attempted to continue Taylor's work north of Pluto Glacier and compiled two measured sections at locality Z (lat. 71°04′S., long. 68°15′W.), where a total stratigraphical thickness of 655 m. was examined. However, in 1968, logistic problems curtailed this work and a precise stratigraphical correlation with Taylor's sections was not achieved.

In 1969–70, M. H. Elliott compiled 11 partly overlapping measured sections in the Ablation Point area comprising a composite stratigraphical thickness of 2,100 m. He also collected ammonites and belemnites from Succession Cliffs and Fossil Bluff. In 1969, C. M. Bell worked with Elliott at Ablation Point and discovered the first of several interstratified lavas (with flow structures) amongst the lowest exposed rocks. In the same year, Bell made some structural observations near locality Z and collected ammonites from moraines near Fossil Bluff. In 1971, Bell completed the stratigraphical work begun by Elliott in the western part of the Ablation Point area.

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* In 1956, L. Bairstow of the British Museum (Nat. Hist.) suggested that at least one specimen of cf. *Belemnopsis* (E.146.1A–C) was Middle or Upper Jurassic in age. This specimen of *Belemnopsis* cf. *tangenensis* is now suggested to be Upper Oxfordian—Middle Kimmeridgian in age (Willey, 1973).

In 1970, A. Linn measured a section at an unnamed outcrop north of locality Z and visited Tilt Rock and a small outcrop north of Transition Glacier where belemnites in a tuffaceous arkose were collected.

## III. PHYSIOGRAPHY

THE area discussed here represents part of a 11–25 km. wide belt of Jurassic and Cretaceous sedimentary blocks bounded on the east by the ice shelf of George VI Sound and on the west by the LeMay Range and Mount Umbriel and its associated peaks (Plates I–III). Although the exposed rock has been glacierized, the relatively flat-lying attitude of the sedimentary rocks, well-developed jointing and rapid weathering have contributed to a generally rounded style of topography. This contrasts strongly with the sharp arêtes and peaks of western Palmer Land where the bedrock is largely of volcanic and intrusive types.

The area is subdivided by Jupiter, Pluto, Eros, Uranus, Mercury and Venus Glaciers but only Uranus Glacier breaches the inland mountain ranges (Fig. 2). The long linear scarp at locality N (Plate IIIb) and stratigraphical proof of faulting between Mount Ariel and Fossil Bluff suggest that some of the glaciers are fault-controlled. Eros Glacier may either be fault-controlled (Grikurov, 1971*a*, fig. 1) or occupy a synclinal structure (Horne, 1967*a*, fig. 1).

In the past, the geology of the hinterland has been partly deduced from the composition of the well-developed moraines (Plate IVa). However, as striated erratics are rare, it is difficult to differentiate between morainic material originating from the hinterland and clasts from the local conglomerates which were possibly derived from Palmer Land (Horne, 1969*a*).

The ice shelf of George VI Sound is laterally compressed by large glaciers and is unusual in being confined on *both* sides by land. At many localities where the ice shelf meets the coastal cliffs and the inland ice, ridges (up to 15 m. high) and troughs of pressure ice often arranged *en échelon* are developed (Plate Id). Some of this pressure represents the eastward movement of glaciers on Alexander Island, notably Grotto Glacier which has a larger and more elevated catchment area than other glaciers. However, most of the pressure along the Alexander Island coast probably represents the westward compression of the ice shelf by the larger glaciers flowing from Palmer Land. As a result of this, these ridges have advanced a short distance up the retreating Jupiter Glacier.

Pressure ice is also associated with many of the "ice calderas" which are relatively common, notably at the foot of the inland ice between Fossil Bluff and locality D where they function as "sumps" for most of the summer melt water draining from the Fossil Bluff area. These "calderas" are oblong or circular bowl-shaped basins up to 2 km. in diameter, often 30 m. deep and floored by angular blocks of ice (Fleming, 1938, p. 512). Tide cracks are also common between the ice shelf and the land ice, and some exude water possibly under pressure due to tidal action.

### 1. *Deglacierization*

Misfit glaciers (e.g. near Ablation Valley (Plate Ic), locality U and Fossil Bluff (Plate IIIa)), striated bedrock and erratics indicate considerable deglacierization since the glacial maximum in the mid-Pleistocene (King, 1964). Stagnant ice in the small glacier at Fossil Bluff is notable for the development of numerous ice pillars caused by differential ablation resulting from an irregular cover of wind-blown rock chips. Hanging cirque glaciers at Waitabit Cliffs (Plate IIIc) may once have acted as overspill channels for ice inland of the cliffs which is now at a lower level than the tops of the cirques.

In the Ablation Point area, rapid glacial retreat is indicated by numerous terminal moraines fronting the present remnant glaciers, by several talus-free areas and by polished and striated *roches moutonnées*. Measurements of 140 striations on erratics at Succession Cliffs and on the bedrock in the Ablation Point area indicate an east–west or west–east ice flow, those at Ablation Valley occurring at an altitude up to 170 m., and 4 km. beyond the present glacier snout.

There are several relatively snow-free areas a few kilometres wide, notably at locality U and near Ablation Valley (Plate Ic), where ". . . glaciated valleys now practically destitute of ice" (Fleming, 1938, p. 512) or "oases" (Robin and Adie, 1964, p. 109) have been described. They probably originated through a combination of factors including minimal precipitation, a more continental climate and the scouring effect of strong winds (Robin and Adie, 1964). In addition, the greater ablation of the ice by the distribution of readily available wind-blown detritus (Fleming, 1938, p. 512) and the absorption of radiation by the dark sedimentary rocks have probably accelerated ice retreat. Relatively snow-free areas of a similar size also occur in the Ellsworth Mountains (Craddock and others, 1964) but neither can be compared in size with the "dry valleys" of eastern Antarctica (Nichols, 1964).

Stone polygons, earth stripes and palsen-like structures occur at several localities. Stone polygons up to 1 m. wide occur on the cliff top at the southern end of Waitabit Cliffs, on screes and lateral moraines at the southern end of locality Z and in the Ablation Point area. Earth stripes are common on slight to moderately steep slopes and some down-slope movement of material is usually evident. Palsen-like structures are developed on the ridge crest of Mount Ariel on 8 cm. of rubble and within a few metres of the melting ice (Plate IVc). These structures are slightly elevated flat-topped mounds with a water-saturated core and an inward gradation of material from coarse to fine. Where they occur on gentle slopes, small-scale lobate slides are developed.

### 2. *Influences on present topography*

The present topography has been determined by the gentle dips (seldom more than 15°) of the sediments, the occurrence of thick-bedded strata and the modifying influences of denudation. The alternation of sandstones and conglomerates with argillaceous sedimentary rocks (Plate VIa–d) usually produces a stepped topography, the thick-bedded sandstones and conglomerates cropping out as steep cliffs, especially at Fossil Bluff, Succession Cliffs, localities L, Z and the Ablation Point area. At locality H, cirque nivation has resulted in a prominent arête (Plate IVb), whereas at Fossil Bluff a pyramidal peak or horn (Plate VIa) has been developed based on several thick-bedded sandstones.

Probably the most important denudation process is frost wedging. Cliffs throughout this area are generally unstable and extensive block disintegration, rock creep, minor rock falls and *felsenmeere* are common. At Fossil Bluff, the removal of parings has left cobbled pavements of hemispherical blocks at several horizons.

Faulting, partly obscured by glacierization, has probably determined the remarkable linearity of the eastern coastline of Alexander Island. The origin of the east–west glaciers, which subdivide the coastal cliffs into a number of discrete blocks (Fig. 2), has been interpreted in several ways. Although Horne (1967*a*, p. 18) inferred that King (1964) "regarded the coastal sedimentary blocks as being separated from each other by grabens", King considered that only Hampton, Grotto and Uranus Glaciers occupy trough faults, whereas some of the smaller glaciers "may originate from a number of causes". Horne (1967*a*, p. 18) suggested that Saturn, Uranus, Grotto and Hampton [*sic*] Glaciers, and (fig. 1) Venus and Neptune Glaciers, were "controlled by oblique-slip faults developed synchronously with the underthrusting and folding of the sediments". Subsidiary faults exposed in the cliff faces have displacements of less than 1 m. and thus have only a modifying influence on the topography, notably in locating some of the gullies and in forming stepped hillsides, especially at localities AH, G, M and Q. Some of these fault planes are accentuated by earth stripes and are widened and deepened by debris slides and melt-water torrents.

Although some gullies represent erosion along fault planes, most are probably joint-controlled and all have subsequently been enlarged by ice wedging, abrading talus and melt-water streams. However, at locality J (Plate IIa), a prominent north–south cleft cutting two thick-bedded sandstones probably represents a fluvial channel formed along the strike of a massive overthrust conglomeratic scarp (p. 56) whose eroded face now stands some distance to the west. The line of the fault crosses the cleft at an acute angle about mid-way along its length. At locality T (Waitabit Cliffs; Plate IIIc), the formation of a large gully is influenced by the presence of a 2·3 m. wide camptonite dyke (Horne and Thomson, 1967). Scree cones are usually developed at the foot of each gully, the more elongated fragments frequently aligning their long axes down-slope. In mid-summer, screes usually have an angle of rest of less than 30° but by early November the *same* cones often have surface slopes of 37°, probably because of ice cementation. Many screes coalesce at the base of gullies as scree aprons. In summer, the gullies represent channels for rushing melt-water torrents (e.g. Succession Cliffs; Plate VIb) carrying large debris in traction and considerable quantities of rock flour in suspension.

### 3. *Melt water*

In summer, considerable quantities of melt water form well-developed "moats" at the foot of the cliffs, less well-defined but more extensive "lakes" partly inundating George VI Sound, and surface and subsurface streams, all of which impede access to the cliffs between late December and January (Plate Ia).

Lakes adjacent to the cliffs subsequently drain into George VI Sound, those at Ablation Point leaving 2·0–2·7 m. high beaches above the normal ice levels. Lakes dammed by glacier ice and pressure ice occur at the southern end of the Ablation Point area. The 2 km. long pressure-ice dammed lake sandwiched between the pressure ridges of George VI Sound and the lower part of Jupiter Glacier is fed by braided melt-water streams flowing across an alluvial fan. Earlier lake levels are indicated by beaches of fluvioglacial "gravel". This ice-dammed lake occurs at the foot of a short valley draining into Jupiter Glacier and is above the level of George VI Sound (personal communication from C. M. Bell).

Wager (1972) suggested that the flooding in George VI Sound "appears to be due to surface contamination by wind-blown rock debris". However, the contributory effect of melt water draining eastward off Alexander Island is probably more significant than he suggested, because melt-water rivers have been observed flowing into George VI Sound south of Fossil Bluff. Wager's implication that the northern limit of melt virtually coincides with the farthest extent of sedimentary rocks is unfounded as these are exposed (at least along the coast) for approximately 35 km. farther northward than is shown on his map (Wager, 1972, fig. 1).

### 4. *Honeycomb weathering*

Many of the more thickly bedded sandstones exposed to the prevailing winds are characterized by honeycomb weathering. This phenomenon is best developed in a 43·5 m. thick sandstone near the summit of Mount Ariel (Plate IVd). Here, the honeycombs are probably developed in an initially porous sandstone by the interaction of updraughts of snow-charged gusty winds, pore enlargement (resulting from frost wedging by wind-blown snow) and the modifying influence of swirling rock chips. Although many of these honeycombs are filled with wind-blown rock chips of foreign material, other observers have concluded that wind only carries *away* the spalled debris (Van Autenboer, 1964, p. 99) or removes rock flour (Calkin and Nichols, 1971). The location, size and frequency of the honeycombs may depend on a "psammitic component" and on the intensity and direction of wind erosion (Sekyra, 1971).

Elsewhere in Antarctica, honeycomb weathering, observed mostly in crystalline igneous and metamorphic rocks, has been partly attributed to chemical weathering and the concentration of free salts (Wilhelmy, 1958; Riddolls and Hancox, 1968), wind action having only a smoothing or polishing effect (Riddolls and Hancox, 1968). However, Van Autenboer (1964) has emphasized the role played by frost wedging in rocks of this type. Yardangs are developed in sandstones on the back slope of locality Q where gusting winds are particularly prevalent.

# IV. STRATIGRAPHY

## A. PREVIOUS STRATIGRAPHICAL OBSERVATIONS

The first indication of the stratigraphical age of the succession exposed between Ablation Point and Keystone Cliffs was provided by plants collected by the B.G.L.E. at Ablation Point and Fossil Bluff. Since some of these (including a *Ptilophyllum**) and their matrices were considered by Fleming (1938, p. 509) to be "closely matched" with those collected by Nordenskjöld from the Middle Jurassic Mount Flora plant beds at Hope Bay, north-east Graham Land (Halle, 1913*b*), the Alexander Island sedimentary succession was inferred to be Middle Jurassic in age (Stephenson and Fleming, 1940, p. 159). This initial age estimate has subsequently been widely accepted and is now firmly established in the literature. This is unfortunate because these plants have never been systematically described.

Knowles (1945, p. 134) made no comment on the fossils collected by Ronne and Eklund from either Stephenson or Titan Nunataks but he described all of the sedimentary rocks north of lat. 72°08'S., long. 68°45'W. as Middle Jurassic, presumably on the basis of the plants mentioned above. However, recent collections from Stephenson Nunatak suggest that the succession there is (?) Lower Albian in age (see below).

Fairbridge (1952, fig. 10), mainly following Fleming and Knowles, indicated that in eastern Alexander Island Jurassic sedimentary rocks extend southward from approximately lat. 70°30'S. Jurassic sediments were also shown in the vicinity of the Batterbee Mountains but the source of this information is not known.

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* In Patagonia and Antarctica, *Ptilophyllum* commonly occurs in *both* the Jurassic and Cretaceous (Halle, 1913*a*, *b*).

Adie (1957*b*, p. 3) also commented on the "abundant presence" [of plant material] . . . "in the recently discovered Upper Jurassic sediments of Alexander Island" but later he (Adie, 1964*b*, p. 130) referred to the plants at Ablation Point as Middle Jurassic. The flora at Ablation Point was also referred to by Plumstead (1962, p. 11) as Upper Jurassic in age, and that at Fossil Bluff as *both* Upper Jurassic and Upper Jurassic–Lower Cretaceous. Later, she (Plumstead, 1962, p. 13) referred to them collectively as Middle Jurassic. Furthermore, Plumstead (1964, p. 649–50) suggested that these floras were similar to that at Hope Bay which she considered was "characteristic of the Middle Jurassic" . . . or even Lower Jurassic. Plumstead's last interpretation was subsequently adopted by Stevens (1967, p. 347, fig. 2), who indicated the presence of (?) Lower Jurassic plants at the same two localities in Alexander Island.

However, a cursory examination of the fossil faunas collected by Fuchs and Adie indicated that the whole succession was uppermost Middle Jurassic to Lower Cretaceous (Adie, 1952, p. 396); this age estimate was partly based on unpublished data on the belemnites by L. Bairstow. Adie also suggested that the "lower limit" of the Cretaceous was probably demarcated by a 244 m. thick conglomerate which he and Fuchs discovered at the south-eastern corner of Alexander Island [Stephenson Nunatak]. Nevertheless, Adie (1952) suggested that the "presence" of this conglomerate was anomalous because of the apparent absence of an unconformity but later it was said to indicate an "unconformity or disconformity" (Adie, 1957*a*, p. 457, 1958, p. 11). The occurrence of conglomerates referred to by Horne (1969*a*, p. 54, *b*, p. 63) and attributed to Adie (1958, 1964*b*) is not supported by Adie's published observations.

It is now considered that the conglomerate at Stephenson Nunatak may represent the final infilling of the sedimentary trough (Horne, 1969*a*, p. 54) and/or an interstratified conglomerate in the succession. This is supported by the following data:

i. Ammonites of Lower Albian age have recently been collected by C. M. Bell from shales approximately 200 m. *below* the conglomerate at Stephenson Nunatak (Thomson, 1974).
ii. The overall southerly dip and abundant Lower Cretaceous faunas north of Stephenson Nunatak (Cox, 1953; Howarth, 1958).

An initial examination of the ammonites, bivalves, gastropods and annelids collected by Fuchs and Adie (Cox, 1953, p. 5; Spath, 1953, p. 3) showed that most of the sedimentary succession was Lower Cretaceous rather than Middle Jurassic in age and that Aptian sedimentary rocks cropped out at Succession Cliffs, Fossil Bluff, Waitabit Cliffs, Keystone Cliffs and Stephenson Nunatak. However, at Ablation Point, sedimentary rocks containing Aptian bivalves (Cox, 1953) were reported to be interthrust with an Upper Jurassic sequence containing perisphinctid ammonites (p. 38). Additional work on the ammonites (Howarth, 1958) indicated that the Upper Jurassic rocks were probably Upper Oxfordian–Lower Kimmeridgian in age and that the Lower Cretaceous fauna was Aptian; that part containing *Sanmartinoceras* (i.e. at Waitabit Cliffs) was more specifically referred to the Upper Aptian. Howarth's age determinations were subsequently misquoted by Anderson (1965, p. 45), who stated that the ammonites at Succession, Keystone and Waitabit Cliffs were *all* late Jurassic in age.

Because overthrusting from the west was thought to have repeated parts of the succession (Adie, 1952, p. 396, 1957*a*, p. 457), no attempt was made in early reports to subdivide the Upper Jurassic–Lower Cretaceous succession but later Adie (1962, table 3) recognized three units (Table I): the Ablation Hook Beds (Middle Jurassic), Belemnite Point Beds (Upper Jurassic) and Fossil Bluff Series (Lower Cretaceous, Aptian). No thicknesses or descriptions were given and no boundaries between the three units were delineated. Because of their flora, the Ablation Hook Beds were considered by Adie to be equivalent to the Middle Jurassic Mount Flora and Church Point plant beds of north-east Graham Land even though the ammonites indicated an Upper Jurassic age (Cox, 1953; Spath, 1953; Howarth, 1958). Conversely, at Fossil Bluff, where another so-called "Jurassic" flora was reported (Plumstead, 1962, p. 13), Adie included these beds (on the basis of their fauna) in the Lower Cretaceous Fossil Bluff Series. The Belemnite Point Beds, although located north of Ablation Point (formerly Ablation Hook) and apparently stratigraphically below the Ablation Hook Beds, were considered by Adie to be Upper Jurassic in age because of their belemnite fauna. The stratigraphical arrangement of these three units was greatly influenced by the belief that major block faulting, coinciding with east–west glaciers, repeated the succession (personal communication from R. J. Adie).

In 1964, possible unconformities were interpolated between each unit (Adie, 1964*a*, p. 141, table 4) and with a change of place names, the Ablation *Hook* Beds became the Ablation *Point* Beds. Later (Adie, 1964*b*, p. 310) the unconformity between the Belemnite Point Beds and Fossil Bluff Series was not queried

TABLE I

STRATIGRAPHICAL INTERPRETATIONS OF THE MESOZOIC SUCCESSION OF ALEXANDER ISLAND

| | *Adie, 1962* | *Adie, 1964a* | *Adie, 1964b* | *Adie, 1965* | *Horne, 1967b* | *Grikurov, 1971b* |
|---|---|---|---|---|---|---|
| **Lower Cretaceous (Aptian)** | Fossil Bluff Series | ∿∿∿∿<br>Fossil Bluff Series | ∿∿∿∿<br>Fossil Bluff Series | Fossil Bluff Series | Triton Point facies sequence<br>Fossil Bluff facies sequence<br>Ablation Point Beds (in part) | Fossil Bluff Series (including Ablation Point/Ablation Hook Beds) |
| **Upper Jurassic** | Belemnite Point Beds | (?) ∿∿∿∿<br>Belemnite Point Beds | ∿∿∿∿<br>Belemnite Point Beds | Belemnite Point Beds | (?) Ablation Point Beds (in part)<br>(?) Belemnite Point Beds | Belemnite Point Beds |
| **Middle Jurassic** | Ablation Hook Beds | (?) ∿∿∿∿<br>Ablation Point Beds | (?) ∿∿∿∿<br>Ablation Point Beds | Ablation Point Series | | (?) Pre-Aptian conglomerates |

(Table I) and the Aptian fauna, said to occur *only* in the area of Fossil Bluff, was reported to be completely identified and identical to that of Annenkov Island, South Georgia (Adie, 1964*b*, p. 311). The Aptian faunas of Alexander Island and Annenkov Island are compared elsewhere (p. 50). Subsequently, the rock-unit term Ablation Point Beds was superseded by the *time*-rock-unit term Ablation Point Series (Adie, 1965). Skidmore (1972, p. 46), presumably following Adie (1964*a*), referred to the fossiliferous sediments of Alexander Island as Middle Jurassic to Lower Cretaceous (Aptian) in age, whereas Williams and others (1971, p. 148) referred to the same succession as Middle Jurassic *and* Lower Cretaceous.

Horne (1967*b*) placed the (?) Upper Jurassic Belemnite Point Beds stratigraphically below the (?) Middle Jurassic and Aptian Ablation Point Beds [*sic*] on the basis of the overall southerly dip and the geographical relationship between Belemnite Point and Ablation Point. He rejected the term Fossil Bluff Series and proposed a division into two lithofacies: a 4,000 m. thick mainly argillaceous inter-deltaic "Fossil Bluff facies sequence" of Aptian age exposed between Succession and Keystone Cliffs, and a mainly arenaceous deltaic "Triton Point facies sequence" of (?) Aptian age exposed between Keystone Cliffs and Stephenson Nunatak. The latter was estimated to be at least 1,800 m. thick (Horne, 1967*b*, p. 116). Horne (1967*b*, fig. 2) also suggested that the mainly shallow-water sedimentary rocks exposed in the coastal cliffs were traceable westward into a deeper-water "axial" facies.

On a map in the *Antarctic Map Folio Series* (Adie, 1969), the Fossil Bluff Series was shown to extend southward from Succession Cliffs to lat. 71°50'S. and westward as far as the southern end of the LeMay Range and Mount Umbriel. As such, this mainly "Aptian" sequence includes rocks now believed to be (?) Carboniferous and Berriasian to Lower Albian in age.

The Mesozoic stratigraphy of eastern Alexander Island was substantially revised by Grikurov (1971*b*, table 1). The succession was subdivided (in ascending order of age) into the Oscar, Latady[*] and Fossil Bluff Series, and several sedimentary, volcanic and plutonic sequences exposed in Graham Land and its offshore islands were also included. Grikurov included in the Oscar Series the "pre-Aptian" conglomerates of southern Alexander Island (i.e. presumably the so-called "basal conglomerate" at Stephenson Nunatak), whereas the Belemnite Point Beds were incorporated in the Latady Series. In the Fossil Bluff Series, thought to occur mainly in Alexander Island, Grikurov included the Fossil Bluff Series as described by Adie (1964*a*, *b*) and Taylor (1966*a*, 1967) as well as the Ablation Point [Ablation Hook] Beds. Because Grikurov (1971*a*, p. 35) considered the latter were Aptian in age on the basis of the bivalve fauna (Cox, 1953), he concluded that the Upper Jurassic ammonites (Howarth, 1958) were derived. Other successions of comparable age included by Grikurov in his concept of the Fossil Bluff Series are discussed on p. 50.

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[*] The Oscar and Latady Series were named after sequences exposed elsewhere in the Antarctic Peninsula which Grikurov correlated with sedimentary rocks in Alexander Island. The Oscar Series was based on the Upper Jurassic andesite–rhyolite volcanic group of Adie (1962), and the Latady Series referred to the tightly folded Upper Jurassic sedimentary rocks of the Lassiter Coast (Latady Formation; Williams and others, 1971).

Grikurov (1971*a*, fig. 1) indicated that, whereas the Mesozoic sedimentary rocks cropped out at least as far north as Trench Glacier, they only extended westward for 25 km. and were probably faulted against an older sedimentary sequence possibly equivalent in age to the (?) Carboniferous Trinity Peninsula Series of north-east Graham Land. Grikurov indicated several north-north-west trending faults in the area described here. Two faults between Mount Umbriel and the eastern coastline were probably based on a linearity of outcrops. One of them, situated approximately mid-way between Mount Umbriel and Keystone Cliffs, was shown as the boundary between the "Aptian terrigenous sequence" and the upper terrigenous sequence of the Trinity Series [*sic*] (possibly Jurassic (Grikurov and others, 1967, p. 21, table 1) or pre-Mesozoic (Grikurov, 1971*a*)). Since no outcrops of Grikurov's Trinity Series have been found east of Mount Umbriel, the existence of a fault mid-way between this locality and Keystone Cliffs must be considered doubtful. However, it is likely that a fault is present along the western margin of the LeMay Range as mapped by Grikurov (1971*a*, fig. 1).

Probably the same fault which Grikurov (1971*a*, fig. 1) showed extending along the eastern margin of the Mount Umbriel massif was located by C. M. Bell and L. E. Willey in 1973 at an outcrop approximately 8 km. south of Mount Umbriel. This fault, defined by a 10–15 m. wide zone of crushed and slickensided sediments, is almost vertical, trends almost north–south and has a large downthrow to the east of an undetermined amount. West of the fault are apparently unfossiliferous indurated massive grey sandstones and subsidiary dark slaty mudstones. These are sub-vertical and in places isoclinally folded; near the fault the bedding strikes 199° and youngs towards the west. East of the fault is a sequence of relatively undisturbed dark mudstones interbedded with subordinate buff-coloured sandstones showing small-scale ripple cross laminations. The mudstones contain a fauna including *Belemnopsis* aff. *uhligi* Stevens (uppermost Jurassic–lowest Cretaceous; Willey, 1973), *Inoceramus*, ammonite fragments and rare trace fossils including *Chondrites*. Near the fault, these fossiliferous beds strike 027° and dip at 54° to the east, whereas farther away the rocks dip at 18° to the south and strike 091°. The increase in dip towards the fault is probably related to drag against the fault plane. Several minor brecciated and slickensided zones cut these sediments close to the major cataclastic zone.

Similar faulted relationships are probably present in the vicinity of Nonplus Crag along the eastern margin of the LeMay Range (Fig. 4), i.e. virtually equivalent to that shown by Grikurov (1971*a*, fig. 1).

The sedimentary sequence of the hinterland is quite distinct from the Mesozoic succession of eastern Alexander Island. It is more tightly folded, shows cataclastic deformation, is apparently devoid of megafossils and has a higher relief (personal communication from C. M. Bell). These two contrasting sequences are closely juxtaposed and there is no obvious lateral transition between them. However, according to Horne (1969*b*, p. 69), these differences are consistent with the geographical position of his axial facies in the trough "reconstructed on the basis of other evidence". Thus, the structural state of these rocks was "believed to correlate with their depositional environment" and "with the deduced tectonic environment" (Horne, 1967*a*, p. 3).

It is considered here that the petrological evidence referred to by Horne (1967*a*, p. 3, 1968*b*, table 1) for correlating the two sequences is inconclusive and that any petrological similiarities which may exist need only indicate a similar provenance. The only direct evidence for the age of the hinterland sequence is that published by Grikurov and Dibner (1968) and based on fossil spores collected from the Lully Foothills and the western LeMay Range. These were compared with others from the Lower and Middle Carboniferous Donetz and Moscow basins, Kazakhstan and elsewhere.

## B. Fossil Bluff Formation

The geographical and stratigraphical limits of the Belemnite Point Beds, Ablation Point Beds and Fossi Bluff Series have never been defined. It is not yet possible to plot their boundaries on a map even though there are obvious palaeontological differences between, for example, the "Ablation Point Beds" and the "Fossil Bluff Series". It is therefore proposed that, pending more detailed investigations, the whole of the Mesozoic sedimentary sequence (and the interbedded lavas) extending from Trench Glacier to Stephenson Nunatak and as far west as the junction with the hinterland sedimentary sequence should be referred to the *Fossil Bluff Formation*, with the proviso that future work in this area will necessitate further revision, possibly in terms of a Fossil Bluff *group*.

At present, the top and bottom of this formation are undefined but it is known that the succession ranges in age from at least Upper Oxfordian–Kimmeridgian to Lower Albian, and that it is at least 4,000 m. thick. Three major lithological sub-divisions are obvious in the field, but it is not yet possible to define their boundaries precisely. These are:

i. An Upper Jurassic tuffaceous and extrusive sequence exposed at Belemnite Point and the Ablation Point area.
ii. A predominantly argillaceous sequence, ranging in age from Tithonian to Lower Albian, exposed between the Ablation Point area and Keystone Cliffs.
iii. A predominantly arenaceous sequence south of Keystone Cliffs.

Each of these sequences probably constitutes a formation.

It is recommended that the time–rock-unit term Fossil Bluff Series, originally proposed by Adie (1962) for what was assumed to be the Aptian part of the succession, i.e. between Succession Cliffs and Stephenson Nunatak, should be discarded, because it is now known that these sedimentary rocks range in age from the Neocomian to the Lower Albian.

The Fossil Bluff Formation is a mainly shallow-water marine succession ranging in age at least from Upper Oxfordian–Kimmeridgian to Lower Albian. This formation is exposed in many easily accessible cliffs sub-parallel to the regional dip and generally appears to young southward but thrust/reverse faulting at several localities has complicated the succession (p. 55). To date, 29 measured sections represent a composite section of approximately 4,000 m. (Figs. 5 and 6). This figure excludes the Upper Oxfordian–Kimmeridgian part of the succession in the Ablation Point area (the disturbed zone) which is difficult to measure stratigraphically. The total thickness of the Mesozoic succession in Alexander Island is not known but several estimates have been made (Horne, 1967*a*, p. 1, 1969*b*, p. 1; Taylor, 1967, p. 2). Grikurov's (1971*c*, p. 164) criticisms of these estimates are partly confused by his restriction of the term Fossil Bluff Series to the Lower Cretaceous part of the Mesozoic succession, whereas Horne and Taylor included in their estimates the Jurassic succession north of Pluto Glacier and an as yet unmeasured and undated mainly sandstone sequence south of Venus Glacier. Additional measured sections in the Saturn Glacier area suggest that Horne's figure of 8,000 m. may not be a gross overestimate for the composite thickness.

The main rock type is a dark grey, indurated siltstone/mudstone, but thick-bedded sandstones (mainly arkoses) and conglomerates form topographical and lithological units; tuffaceous horizons and lavas are also present. Spectacular sedimentary structures are developed, notably sandstone dykes and "cement-stone" and "cannon-ball" concretions (Horne and Taylor, 1969). Much of this formation contains a diverse flora and marine fauna, the latter dominantly molluscan but including nine animal phyla of which fish are the highest ranked.

The succession will be described in order of decreasing age. Where possible, significant faunal, floral and lithological variations between adjacent sections are emphasized but subordinate differences are excluded.

## C. STRATIGRAPHICAL SUCCESSION

Because only a small proportion of the total sequence has been examined petrographically, all of the rock terms used here are field terms. Whereas most of the sandstones examined are arkoses, many have not been sampled and it may prove misleading to give precise identifications for certain specimens only.

Furthermore, it must be emphasized that the terms "common" and "abundant", or "abundance", for the fauna of the Fossil Bluff Formation relate only to Alexander Island and are *not* meant to imply that the formation is as fossiliferous as, for example, the English Lias. Between locality Z and Keystone Cliffs, the succession was measured to a detail which permitted the recording of beds a few centimetres thick. The less fossiliferous sequence of the Ablation Point area was measured in larger units. This part of the succession is summarized below.

### 1. *Ablation Point area*

The oldest rocks in this area are at least 350 m. of highly contorted sedimentary and subordinate volcanic rocks exposed on the eastern limb of an anticline in the Ablation Point area (personal communication from M. H. Elliott). The base of this disturbed zone is nowhere exposed and the upper boundary is difficult to define, partly because it occurs at different levels below the first easily recognizable marker bed (Fig. 5).

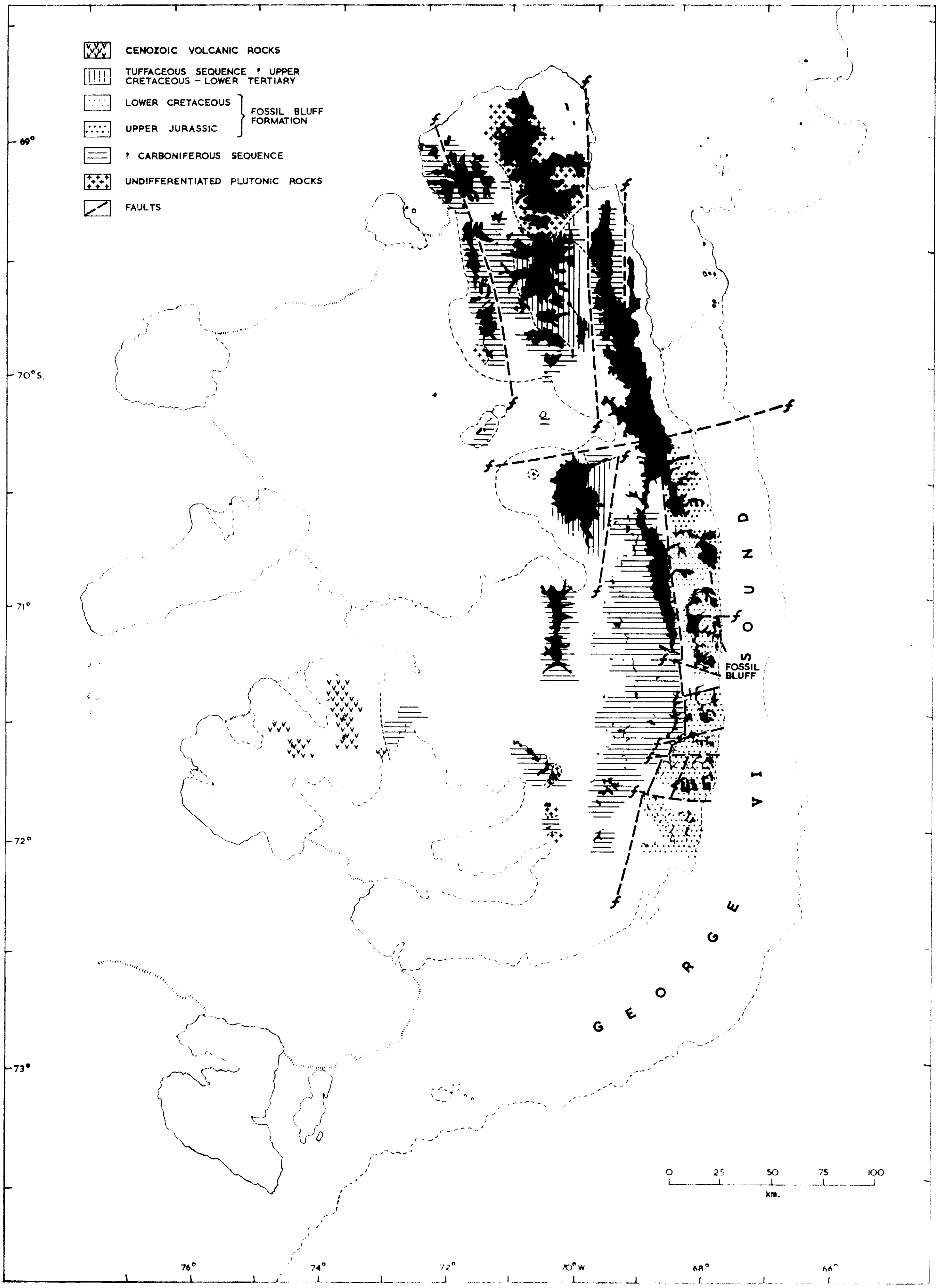

FIGURE 4

Geological sketch map of Alexander Island showing the relationship between the Mesozoic succession and other rock groups. The geology outside the area between Ablation Point and Keystone Cliffs is based on data provided by C. M. Bell.

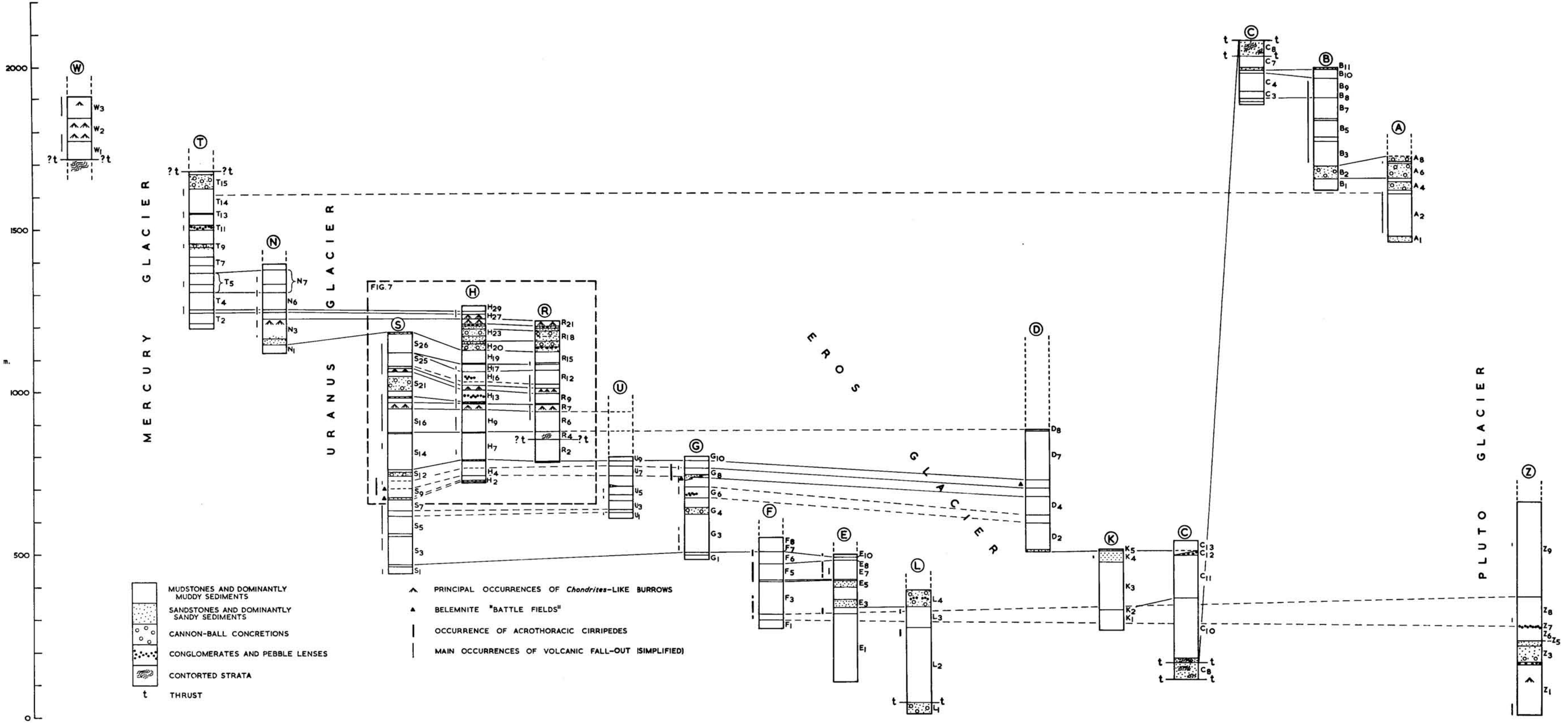

FIGURE 6

**Diagrammatic representation of the measured stratigraphical sections between locality Z and Keystone Cliffs showing the main rock units and their correlation. (Modified after Taylor (1971*b*, fig. 2) and Thomson (1971*c*, fig. 2).)**

The disturbed zone, which is best exposed and thickest along the east-facing scarp of Ablation Point (Plate Ib), consists predominantly of poorly fossiliferous argillaceous rocks together with polymictic conglomerates, tuffaceous sedimentary rocks and volcanic rocks (basic lavas, pyroclastic micro-breccias, crystal tuffs and agglomerates). There are pronounced lithological variations from north to south within this zone and normally bedded sequences occur at several localities. Fossils collected *in situ* (notably belemnites and ammonites) and additional specimens not *in situ* but assumed to have been derived from this zone suggest that these rocks are Upper Oxfordian–Middle Kimmeridgian in age (Howarth, 1958; Thomson and Willey, 1972; Willey, 1973). Some structural observations on this zone are discussed on p. 56.

Above the disturbed zone are approximately 2,100 m. of essentially undisturbed sedimentary rocks subdivisible into a Tithonian sequence approximately 530 m. thick, an undifferentiated Tithonian/Berriasian sequence approximately 1,100 m. thick and a Berriasian sequence at least 470 m. thick.

The lower part of the Tithonian sequence, consisting predominantly of fossiliferous siltstones and silty shales (frequently punctuated by concretionary horizons), has a mainly molluscan fauna. This is composed principally of phylloceratid and perisphinctid ammonites (characterized by a *Virgatosphinctes/Aulacosphinctoides* fauna), belemnites (*Hibolithes* and *Belemnopsis*) and bivalves (notably *Inoceramus*, *Buchia*, *Entolium*, *Myophorella*, *Otapiria* (*?*)) together with trace fossils (*Chondrites*, *Zoophycos* and what have been referred to by Taylor (1967) as vermicular structures) and plants. A 3 m. thick basic lava ($AB_{11}$) and two virtually contemporaneous ash bands ($AS_{7}$ and $AH_{13}$) occur in the upper part of this sequence. The upper part of the Tithonian sequence contains the first of several thick-bedded conglomerates and a late Tithonian ammonite fauna characterized by *Blanfordiceras* and "*Berriasella*".

Overlying these late Tithonian faunas are 1,100 m. of shales, sandstones, thick-bedded conglomerates (up to 140 m. thick) and pebbly mudstones (mainly in the lower part). Although no ammonites or belemnites have been collected from these rocks, they underlie a *Haplophylloceras/Bochianites* ammonite fauna of Berriasian age and must, therefore, be uppermost Tithonian and/or Berriasian.

The Berriasian part of the succession in the Ablation Point area consists of shales, arkosic sandstones and conglomerates. The shales contain an abundant molluscan fauna, notably the ammonites *Haplophylloceras*, *Bochianites*, *Spiticeras* and *Raimondiceras*, the belemnites *Belemnopsis* aff. *uhligi*, *Belemnopsis alexandri* and *Hibolithes subfusiformis* and a variety of bivalves. Plant remains include *Ptilophyllum* and *Nilssonia** (cf. Plate VIIa, e and f).

### 2. *Locality Z*

There are some similarities between the faunas at locality Z (Plate Id) and the *Bochianites* beds of the Ablation Point area, i.e. above unit $AG_{19}$. Several molluscs including *Inoceramus* sp. *a*, *Pseudolimea*, *Myophorella*, *Belemnopsis alexandri*, *Belemnopsis* aff. *uhligi* and *Hibolithes subfusiformis* are common to both areas. However, the remainder of the belemnites and all of the ammonites at locality Z are dissimilar, and *Inoceramus pseudosteinmanni* which occurs in abundance at locality Z has not so far been discovered in the Ablation Point area. In the absence of intermediate measured sections, the considerable distance between these localities (28 km.) is such that any correlation scheme must be tentative. However, future work in this area may make satisfactory stratigraphical correlations possible.

The stratigraphical succession at locality Z consists of two sections totalling 732 m. of sedimentary rocks; these represent a stratigraphical thickness of 655 m. (not 620 m. as reported by Thomson (1971*c*, p. 158)). The lowest exposed beds in these cliffs consist of 156 m. of indurated grey-black siltstones and cream-, grey- or buff-coloured fine, medium and coarse sandstones ($Z_{1}$). The massive siltstones contain nodular and less well aggregated iron pyrites, some of which is surrounded by oxidation haloes. A purplish sheen is also common on weathered surfaces. Iron-stained, sub-elliptical calcareous concretions 15–40 cm. long occur here in large numbers and are orientated with their long axes parallel to the bedding. Several have cores of nodular iron pyrites, plants, belemnite phragmocones or bivalves. Scab-like encrustations of gypsum on weathered surfaces are often associated with these concretions.

The thin- to slab-bedded sandstones are often graded and laminated, and well-developed load casts and flame structures occur adjacent to underlying siltstones. Thin discontinuous siltstones intercalated with slab-bedded sandstones are usually contorted and fragmented. Vitric crystal blebs (Horne and Thomson, 1972, p. 106) occur in the basal 35 m. of unit $Z_{1}$.

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* As yet, it has not been possible to determine whether the plants referred to here as *Nilssonia* (*?*) or *Nilssonia*-like fronds properly belong to *Nilssonia* (a cycad) or *Nilssoniopteris* (a bennettitalean).

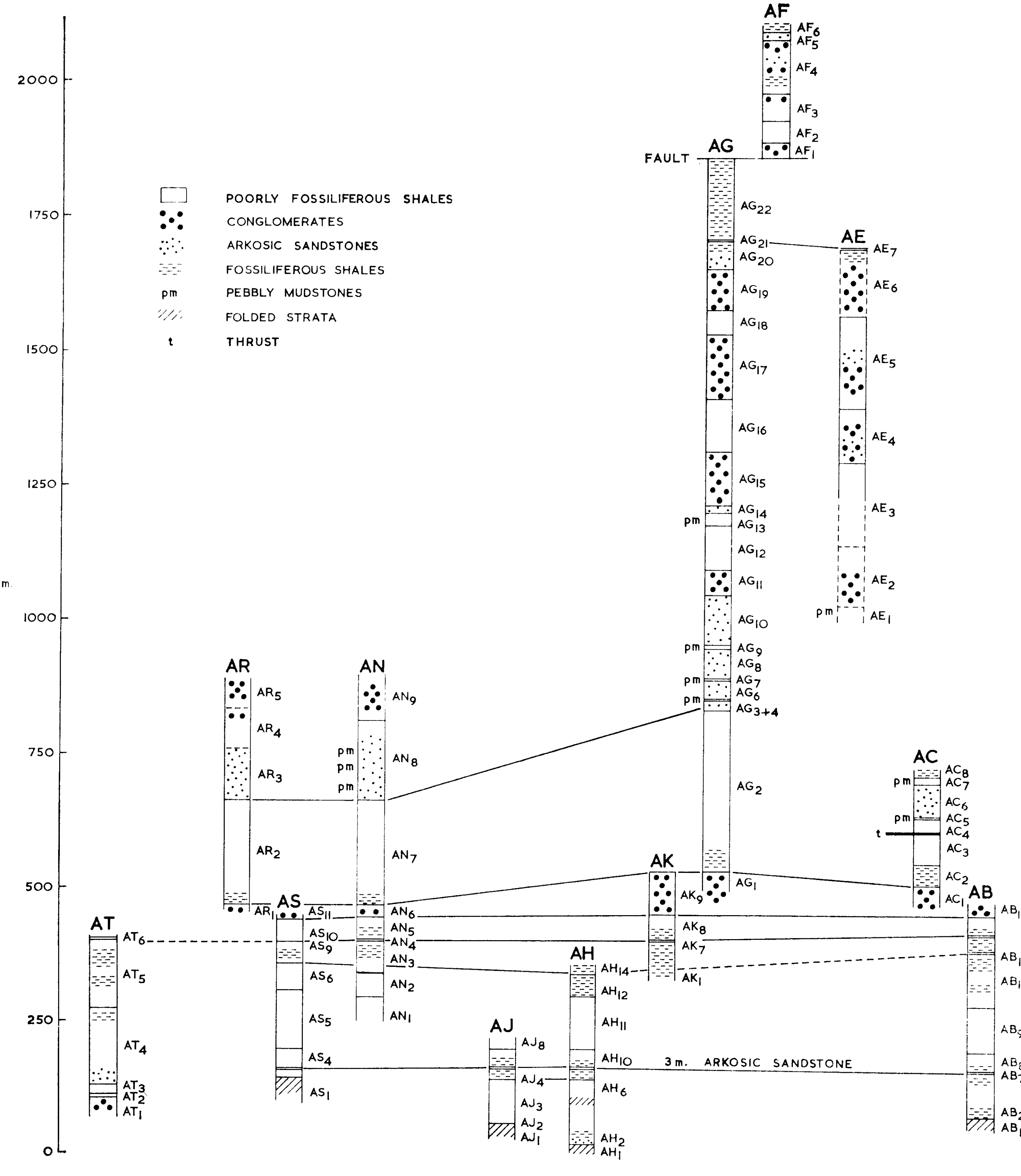

FIGURE 5

Diagrammatic representation of the measured stratigraphical sections in the Ablation Point area showing the main rock units and their correlation (after Elliott, 1974).

A mainly molluscan fauna occurs in these 156 m. of sedimentary rocks. *Aucellina* (*?*), *Entolium* and *Pseudolimea* occur in most beds and several specimens of *Meleagrinella* (*?*) were obtained from the lowermost 25 m. Whereas only one specimen of *Inoceramus* sp. *a* was collected 30 m. above the base of the section, mainly fragmentary internal moulds of *Inoceramus pseudosteinmanni* occur abundantly in localized concentrations above 75 m. Other molluscs present include *Grammatodon*, *Pinna* (sometimes in life position), *Camptonectes* (*?*), *Lucina* (*?*), *Goniomya*, *Substreblites* sp., *Phylloceras* sp. and *Sarasinella* aff. *hondana*. The remainder of the fauna comprises a fish (?) postcleithrum, echinoid spines, smooth turriculate gastropods and other indeterminate shell material. The belemnites *Hibolithes antarctica* and *Hibolithes* sp. nov. (*?*), which first appear in the section at 70 m., ultimately become numerically the most important fossils. *Rotularia* occurs sporadically at most horizons. Widely scattered and locally compacted vermicular structures are common in the siltstones, whereas *Chondrites* usually occurs at the sandstone/siltstone interfaces.

Plant fragments including fronds of *Otozamites* (cf. Plate VIIb), *Pterophyllum*, *Ptilophyllum*, *Nilssonia* (*?*) and a conifer cf. *Elatocladus*, together with large quantities of woody fragments and occasional cone scales, are present in both the argillaceous and arenaceous beds.

Marked lithological and faunal changes occur above 156 m. A discontinuous round-stone conglomerate ($Z_2$) up to 4 m. thick and containing well-rounded boulders up to 2 m. in diameter (composed mainly of granodioritic and dioritic rocks and subordinate metamorphic and volcanic rocks) lies on a slightly eroded and channelled surface. The succeeding 53 m. ($Z_3$) form an almost vertical cliff of massive, grey, iron-stained and laumontitized sandstones which give way in places to a darker calcareous sandstone containing large numbers of *Meleagrinella* (*?*). Lenses of round-stone polymict pebble conglomerate contain clasts, identical in composition to the more massive conglomerate ($Z_2$), which suggest that both rudaceous phases were derived from the same or a similar source area. Several more localized conglomeratic lenses 1–5 m. wide and 0·5–1·0 m. thick may represent narrow infilled wash-out channels.

In the sandstones, cannon-ball concretions (Horne and Taylor, 1969) form conspicuous boss-like protuberances up to 1·5 m. in diameter and they are often reddish brown due to oxidation of ferrous compounds. A large number contain an organic nucleus, often a belemnite phragmocone. Fossils in these sandstones are generally scarce and poorly preserved except in the dark greenish calcareous horizons with *Meleagrinella* (*?*) and in a coquina at 206 m. The coquina, possibly representing a fossil shell bank (p. 48) and traceable over 200 m., contains numerous corbiculid bivalves, together with *Nuculana* (*?*), *Lucina* (*?*), two small species of turriculate gastropod, *Dentalium* and fish bone.

The fauna of the sandstones includes *Pseudolimea*, *Meleagrinella* (*?*) and small indeterminate ribbed pectens. *Hibolithes subfusiformis*, reported from the Ablation Point area, first appears at locality Z associated with *Hibolithes antarctica* and *Hibolithes* sp. nov. (*?*) which remain fairly common. Woody fragments, fronds and pinnae derived from a variety of Bennettitales were also collected from these beds.

Unit $Z_4$ consists of 20 m. of poorly sorted, sometimes graded, dark-coloured sandstones which are locally laminated and load casted. Isolated pebbles in the laminated sequence were probably deposited on a yielding substratum, depressing the subjacent laminae. *H. subfusiformis*, *Gervillella* and a few indeterminate shell fragments occur together with incomplete fronds of *Nilssonia* (*?*), *Otozamites*, *Ptilophyllum*, *Pterophyllum* and a considerable amount of woody material.

Conformably overlying these dark arenites is a 4–6 mm. thick grey siltstone ($Z_5$) containing numerous *Rotularia* and several diminutive turriculate gastropods. This stratum is traceable for several hundred metres.

Above this thin bed are 38 m. of dark-coloured indurated siltstone (containing varying proportions of admixed sand), thin, indurated and soft yellow-weathering sandstones and grey friable shales ($Z_6$). Dark grey ellipsoidal calcareous concretions, generally less than 50 cm. along their major axes, are developed at several horizons within this unit. These concretions contain organic nuclei, notably belemnite phragmocones and bivalves including *Pinna*, apparently in life position.

Vermicular structures are common in the mechanically undisturbed siltstones. Occasionally, larger worm-like traces 1–2 mm. in diameter are developed on the bedding planes, especially in the grey siltstones where they are accentuated by a colour difference and a higher relief. The siltstone/sandstone interfaces and the subjacent sediment are often marked by both multiple and larger branched and unbranched tunnels of a *Chondrites*-like organism.

The fauna of unit $Z_6$ is more varied than that of subjacent units. *Myophorella*, *Modiolus*, *Panopea* and *Pleuromya* first appear in this section; *Entolium*, *Grammatodon*, *Indogrammatodon* and *Rotularia* are common and *Lucina* (*?*), *Pinna*, *Aucellina* (*?*), *I. pseudosteinmanni*, sponge spicules and rhabdocidaroid spines (cf. Taylor, 1966*b*, fig. 8a) are also present. *Hibolithes antarctica*, *H. subfusiformis*, *Hibolithes* sp. nov. (*?*) and a single specimen of *Hibolithes* aff. *marwicki mangaoraensis* occur in the lower part of the unit together with the ammonites *Phyllopachyceras* (*?*) sp., *Neocosmoceras* aff. *sayni*, *Himalayites* (*?*) sp., an indeterminate juvenile (?) phylloceratid and an indeterminate berriasellid fragment. In the upper part of unit $Z_6$, *Belemnopsis gladiatoris* occurs for the first time, ultimately to become the most abundant fossil. The flora includes incomplete fronds of *Otozamites*, *Pterophyllum*, *Ptilophyllum*, cf. *Elatocladus*, cone scales, twigs and quantities of woody fragments.

At a height of 271 m. in the succession there is a distinctive 3 m. thick round-stone pebble conglomerate ($Z_7$) containing broken guards of *Belemnopsis gladiatoris* as well as moulds (in a dark sandy matrix) of *Astarte*, *Myophorella* and *Neithea*. The pebbles are petrologically similar to those of other rudites at locality Z.

The succeeding 90 m. ($Z_8$) are dark-coloured sandy siltstones which gradually become more argillaceous higher in the succession. The lower part of this unit consists mainly of thin- and flag-bedded, yellow-weathering, buff-coloured sandstones separating friable fissile shales containing vitric crystal blebs. The sandstones are generally laminated and load casts, flame structures and groove casts are common. Graded bedding is developed in the coarse beds. Internal load casts or slump balls (Kuenen, 1949, p. 369, fig. 5) occur beneath several of the sandstones and convolute lamination is developed in several sandstone/siltstone beds. Many sandstones pinch and swell before becoming discontinuous laterally. Small-scale normal faulting and low-angle thrusts with throws between a few centimetres and several metres dislocate these beds. Brown- and grey-weathering sub-spheroidal calcareous concretions occur in large numbers throughout the siltstones together with several discontinuous pebble lenses up to 2 m. thick.

The fauna is abundant but not diverse. *B. gladiatoris* and *B. alexandri* are present in the greatest numbers. Only one specimen of *Belemnopsis* aff. *uhligi*, together with the bivalves *Opis*, *Lucina* (*?*), *Aucellina* (*?*), *Entolium* and *Pleuromya*, were collected in the first 4 m., whereas *Grammatodon*, *Indogrammatodon*, *Pseudolimea* and *Rotularia* occur throughout this unit. Multi-branched *Chondrites* and other branched and unbranched burrows occur at the sandstone/siltstone interfaces and vermicular structures (numerically the commonest trace fossil) are ubiquitous. *Palaeodictyon* (*?*) is also present on the upper surfaces of several siltstones (Taylor, 1967, p. 25). The flora includes incomplete fronds of *Ptilophyllum* and *Pterophyllum*, indeterminate pinnae and fragmentary stems.

The succeeding unit ($Z_9$) is composed predominantly of dark-coloured, indurated and lithologically uniform siltstones containing discrete quartz crystals 5 mm. in length and rare vitric crystal blebs. Above 570 m. in the succession, several grey-coloured friable shales (one containing numerous *Zoophycos*-like burrows) occur in the siltstones. Sub-spherical, often laminated, light grey calcareous "cement-stone" concretions (Horne and Taylor, 1969), 8–12 cm. in diameter, are fairly abundant at several horizons in the dark argillaceous beds. A few concretions contain nuclei of nodular iron pyrites, mud balls or bivalves.

The fauna mainly consists of *Belemnopsis gladiatoris* and *B. alexandri* which, although numerous in the lower strata, become scarce and finally disappear at a height of approximately 455 m. in the section. In the upper part, *Hibolithes subfusiformis* and *Bochianites gracilis* occur with several small bivalves including *Grammatodon*, *Indogrammatodon*, *Astarte* and *Pseudolimea*. The sparse and often macerated flora includes woody fragments and indeterminate pinnae. Due to logistic problems, stratigraphical measurements at this locality were terminated approximately 30 m. below the highest exposed beds.

### 3. *Localities C, K and D*

There are some faunal similarities between the succession at locality Z and that at localities K and D and above a major disturbed and thrust zone at locality C (Fig. 6). *Hibolithes* sp. nov. (*?*) has been reported from screes at locality C and it occurs *in situ* with *Belemnopsis gladiatoris* in the vicinity of the lower and middle parts of the sequence at locality D (Willey, 1973). *Lucina* (*?*) and *Palaeodictyon* (*?*) also occur at localities C and K, and *Myophorella* is present at localities K and D, although its vertical distribution is considerably less than that at locality Z.

Although these faunal similarities suggest that the succession at localities C, K and D may be partly equivalent in age to that at locality Z (i.e. Berriasian), no satisfactory correlation scheme can be established at present. Therefore, it is proposed to describe the successions at these three localities separately.

The lowest part of the succession at locality C, which may be early Albian in age, is overlain by a 51 m. thick disturbed zone ($C_8$) comprising at least two major thrusts. The precise stratigraphical relationship of this zone to the sequence above and below is not known although rare echinoid fragments suggest that it represents part of this early Albian sequence.

Thrust above this disturbed zone are 13·7 m. ($C_9$) of siltstones exhibiting disjunctive folding and with a sparse fauna of belemnite guards, *Dentalium*, planispiral annelids (not *in situ*) and limids (likewise not *in situ*). The succeeding 183 m. ($C_{10}$) are represented by grey-black indurated siltstones and cream-coloured tuffaceous sandstones with haloed limonitic nodules and encrustations of gypsum. The fauna consists mainly of belemnite guards, *Rotularia*, turriculate gastropods, *Dentalium*, crinoid ossicles and limids, and more sporadic occurrences of *Inoceramus*, *Pinna*, "terebratelloid" brachiopods, *Aucellina* (*?*), *Nuculana* (*?*), fish teeth and fragmentary opalescent fish bone or crustacean cuticle.* A fish pre-operculum was also collected. Sheet-like burrows of *Zoophycos* occur together with *Palaeodictyon*, which is common at several horizons, and the upper bedding planes of a few siltstones are characterized by an abundance of vermicular structures. Several belemnite guards in the lower part of unit $C_{10}$ have been bored by acrothoracic cirripedes (Taylor, 1965; cf. Plate VIIIb). Fragmentary stems, *Nilssonia*-like fronds, leaves and rare cone scales represent a relatively poor flora.

390 m. above the base of the section at locality C, *Lucina* (*?*) appears for the first time and constitutes a reasonably well-defined zone ($C_{11}$). This is 134 m. thick and composed mainly of indurated siltstones with thin- and flag-bedded sandstones containing "cement-stone" concretions (some with organic or mineralized cores). Belemnite guards and turriculate gastropods (*Rhabdocolpus alexandri*; Thomson, 1971*a*) are found at most horizons, whereas the remainder of the fauna is less common, i.e. *Lucina* (*?*), planispiral and conical *Rotularia*, loosely coiled serpulids, *Dentalium*, ammonites, limids, *Inoceramus*, *Entolium* or *Camptonectes* and fish bone or crustacean cuticle. *Palaeodictyon* is present at several horizons and *Ptilophyllum*- and *Nilssonia*-like fronds, leaves and rare cone scales also occur.

At locality K, the same zone ($K_3$) is much more fossiliferous. Belemnite guards, *Lucina* (*?*), *Rotularia* and *Rhabdocolpus alexandri* are found at most horizons together with numerous *Camptonectes* sp., *Entolium* sp., and more occurrences of decapod cuticle and fish bone including a pre-operculum and possible fish vertebrae. Several identifiable decapods were collected, notably a callianassid propodus and a glypheid cheliped; rhabdocidaroid spines and fragmentary ophiuroid arms occur in the lower part of this unit. Aconeceratid ammonites, *Dentalium* and *Inoceramus trapezoidalis* (Thomson and Willey, 1972) are fairly common throughout the *Lucina* (*?*) zone. Several thin-bedded siltstones are composed almost entirely of vermicular structures, *Chondrites*-like burrows similar to those illustrated by Taylor (1967, fig. 8f) are common and *Palaeodictyon* is abundant at certain horizons. Many of the *Chondrites*-like structures have mudstone cores. There is also a corresponding increase in the flora and *Nilssonia*-, *Nageopteris*- and *Ptilophyllum*-like fronds occur with cone scales, broken stems and detached leaves. At one horizon, a small-scale sinuous sedimentary dyke was injected downwards from a sandstone.

Almost immediately above the *Lucina* (*?*) zone at locality C and underlain by a pebble-bearing mudstone is a 0·6–11·6 m. thick conglomerate ($C_{12}$), which is wedge-shaped in a down-dip direction, i.e. towards locality K (p. 42). Between the clasts, belemnite guards, crinoid columnals, *Entolium* or *Camptonectes*, and spheroidal shale inclusions containing poorly preserved plants were found. Above the conglomerate are 33 m. ($C_{13}$) of siltstones and sandy siltstones with occasional lenses of laminated and microfaulted cream-coloured sandstone and haloed limonitic nodules. *Lucina* (*?*) does not re-appear above the conglomerate but *Aucellina* and *Inoceramus* occur in relative abundance and several *Aucellina* are hinged. In equivalent strata at locality K ($K_4$ and $K_5$) the conglomerate and the overlying siltstones are represented by a mainly arkosic sandstone facies containing a high proportion of plant-rich horizons together with *Aucellina*, *I. trapezoidalis*, *Pinna*, *Myophorella*, *Pholadomya*, *Rotularia*, belemnite guards and phragmocones, large numbers of decapods (*Glyphea* sp. nov.), *Entolium* or *Camptonectes* and numerous limids. The sandstones also contain an unusually large number of fossil-wood fragments, many of which have been bored by *Teredo* (*?*) (Plate VIIIf). At least one decapod has also been bored by a saprotrophic fungus (Taylor, 1971*a*) and several of the belemnites contain bores of acrothoracic cirripedes.

The decapods, together with *Myophorella*, *Aucellina*, *I. trapezoidalis*, belemnite phragmocones and the coarser-grained sandstones are all traceable down dip to locality D ($D_1$). Overlying unit $D_1$ are 365 m.

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* In the field, opalescent decapod cuticle was often distinguished from opalescent fish bone by its tuberculate appearance.

($D_2$–$D_8$) of sedimentary rocks equivalent to those parts of the succession beneath an *Aucellina*/*Inoceramus* coquina at Fossil Bluff ($R_5$), locality H ($H_8$) and Mount Ariel ($S_{15}$). 34·8 and 57·5 m. above the base of the section (i.e. in unit $D_2$), the tail spine of a ray (Myliobatoidea) was found. As at the other four localities, belemnites are ubiquitous for a further 213 m. together with incomplete and often crushed phragmocones (up to 9 cm. long), *Entolium*, *Camptonectes*, *Rotularia* and *Pinna* (frequently in life position). Subsequently, the belemnites temporarily disappear in unit $D_6$ and *Aucellina* becomes the most important fossil in the overlying 155 m. of beds ($D_7$). These units are described on p. 24. Belemnites, probably derived from the middle part of the section at locality D, have been identified as *Belemnopsis gladiatoris* and *Hibolithes* sp. nov. (*?*) (Willey, 1973). *Lamellaptychus* was also found as a scree specimen at this locality (Thomson, 1972*a*, fig. 2a and c).

Lithologically, the upper part of the measured section of locality D (unit $D_7$) differs from equivalent strata at adjacent localities in having numerous, often thin-bedded laumontitized vitric tuffs (p. 42) which are powdery in the hand specimen and light grey or cream in colour. Laumontite represents approximately 60 per cent of these rocks (Taylor, 1966*a*, p. 120, 1967, p. 12; Horne, 1968*c*).

### 4. *Localities L, E and F*

The lowest exposed rocks in the vicinity of Eros Glacier form the basal cliff at locality L ($L_1$) (Plate IXd). The cliff, which is at least 33·5 m. thick, is composed of fine- and medium-grained cream-coloured sandstones and thin- and flag-bedded shales and partly brecciated siltstones. The sandstones are laminated, micro-faulted, convoluted and load casted. Small-scale linguiform and downwardly injected sandstone dykes occur in the basal few metres of the cliff and larger branched dykes striking 231° occupy several fault planes. Brown-coloured cannon-ball concretions contain laminations and textural variations common to the surrounding rocks. The cliff is poorly fossiliferous, although there are more fragmentary plants (including cone scales) than shells which include loosely coiled annelids, paired limid valves and belemnite guards.

Thrust above this basal cliff are 229 m. of grey-black siltstones and cream-coloured sandstones ($L_2$) with "cement-stone" concretions, rare vitric crystal blebs and convolute lamination. Except for belemnite guards, the unit is poorly fossiliferous and there are no significant stratigraphical marker horizons. However, at a height of 106·7 m. above the base of the section, groups of *Aucellina* shells are associated with limids, fish teeth, *Lamellaptychus* (Thomson, 1972*a*, fig. 2b), *Rotularia*, "terebratelloids" and occasional horizons with abundant vermicular structures. In the lower part of unit $L_2$, three horizons of numerous sponge spicules orientated at 170° were found. Higher up in the sequence, crinoid stems occur with poorly preserved ammonites, acrothoracic cirripedes, opalescent skeletal fragments (including a fin ray), *Chondrites*, *Nilssonia*- and *Ptilophyllum*-like fronds and fragmentary stems. The decapod *Schlueteria* sp. nov. was also found 227 m. above the base of unit $L_2$.

In the overlying 63·5 m. ($L_3$), *Rotularia*, "*Terebratella*" and belemnite guards become more numerous and constitute a somewhat indefinite assemblage zone which is traceable to locality E. Several guards are bored by acrothoracic cirripedes. Associated with this zone are large numbers of *Zoophycos*, well displayed in an 8 cm. thick prehnitized stratum where the burrows cut and displace bedding laminations in their path.

In the upper part of unit $L_3$ there is a marked increase in the number of thin- and flag-bedded sandstones which evidently preceded a marked shallowing during which at least 51 m. of thick-bedded sandstones ($L_4$) were deposited. These sandstones, which form an almost vertical cliff, are mainly cream-coloured, laminated, convoluted and cross laminated, and are interbedded with partly brecciated siltstones. Cannon-ball concretions occur sporadically and there are three conglomeratic lenses arranged *en échelon* to one another which have been interpreted as narrow wash-out channels (Horne, 1969*a*). The attitude of much of this cliff is determined by a prominent joint set dipping at 70–80° towards the east-north-east. Small-scale faulting (including step faulting) was observed and upwardly injected sandstone dykes were found in the more accessible parts of the cliff.

Units $L_4$, $L_3$ and part of $L_2$ are traceable to locality E. At the base of the cliffs at locality E are 210 m. ($E_1$) of mainly unfossiliferous, often load-casted, laminated, convoluted and slickensided sandstones and siltstones containing occasional belemnite guards, poorly preserved ammonites, indeterminate tubular structures and fragmentary stems. Iron pyrites nodules (3·0–4·5 cm. in diameter) and haloed limonitic nodules are common, and many of these rocks are red-coloured. One small-scale sandstone pipe was were collected for their acrothoracic cirripedes. All three species occur in the upper part of the section at locality Z and *B. gladiatoris* is probably present in the lower and middle parts of the sequence at locality D (p. 19). Eunicid or chaetopterid polychaetes also occur at locality F at the outer margins of several "cement-stone" concretions (Taylor, 1969).

Small-scale sandstone dykes injected downwards are present 7·6 m. above the base and at the top of the measured section at locality F. Many "cement-stone" concretions in the lower part of the succession are in beds affected by "soft-sediment" deformation but it is not known whether this association is causal or casual.

### 5. *Localities G, U and Mount Ariel (locality S)*

At Mount Ariel and locality G, the terebratelloid/terebratulid junction is not exposed and the first unit of biostratigraphical importance is the crinoid/ophiuroid/rhabdocidaroid assemblage zone ($S_2$). This occurs approximately 22·9 and 16·5 m. above the lowest exposed beds at Mount Ariel and locality G ($G_2$), respectively. As the upper and lower zonal boundaries are often arbitarily defined, its thickness varies between localities; thus the 4·6 m. originally cited (Taylor, 1966*b*, p. 1) represents only those horizons at locality G with large numbers of congregated echinoderms. This zone is best developed at locality G, where the echinoderms have a greater vertical range (30·8 m.) and are more numerous and better preserved than elsewhere in this area (Taylor, 1966*b*). Furthermore, the ophiuroids and crinoids often occur in close juxtaposition.

The succeeding 115 m. ($G_3$) are mainly argillaceous, although thin- and flag-bedded sandstones occur sporadically. Bedding planes of several strata are accentuated by slickensided bands of calcite and quartz. Vitric crystal blebs, limonitic haloes, pebbles, convolute lamination and "cement-stone" concretions were also found. Belemnite guards and *Rotularia* (occasionally congregated) are present throughout unit $G_3$ together with less frequent occurrences of *Entolium* or *Camptonectes*, *Pseudolimea* (?), terebratulids, *Pinna*, *Inoceramus*, crinoids, *Grammatodon*, *Aucellina*, ammonites, belemnite phragmocones, ophiuroids, rhabdocidaroid spines and fish (?) vertebrae. 103 m. above the base of the measured section at locality G, the isopod *Urda* cf. *cretacea* was collected (Taylor, 1972). Bands of compacted vermicular structures up to 2·5 cm. thick are common and *Zoophycos*, *Chondrites*-like burrows and other indeterminate ichnofossils were recorded.

Unit $G_3$ is overlain by a 22·6 m. thick cliff ($G_4$) composed mainly of fine- and medium-grained cream-coloured sandstones and intercalated flag-bedded and partly brecciated shales and siltstones. A prominent joint set striking 243° and dipping at 40° has influenced the reclined attitude of the cliff along parts of the outcrop. Many sandstone interbeds are laminated, convoluted, micro-faulted and studded with cannon-ball concretions which contain laminations common to their host rocks. Where patches of coarse sand occur, belemnite guards and *Rotularia* are particularly common. Two joint sets striking 161° and 067° have produced a tessellated effect on the under surfaces of several undercut horizons within the cliff. At Mount Ariel and locality U, the middle part of unit $G_4$ corresponds to a 10·4–15·9 m. thick well-defined zone of heteromorph ammonites ($S_6$ and $U_2$). Most of the heteromorphs are incomplete. Associated with the heteromorphs are belemnite guards and phragmocones, *Rotularia*, *Inoceramus*, *Entolium* or *Camptonectes*, rhabdocidaroid spines, *Pseudolimea* (?), fish teeth and (?) vertebrae, and *Chondrites*-like burrows.

The sandstone cliff at locality G is overlain by a 28·1 m. thick crinoid zone ($G_5$) consisting of indurated shales and siltstones with vitric crystal blebs, and interspersed with bands of compacted vermicular structures and quartz and calcite veins. Belemnite guards and phragmocones, ammonites, *Rotularia*, crinoids (locally congregated) and fish bone or decapod cuticle are common but *Inoceramus*, *Pseudolimea* (?), rhabdocidaroid spines, fish teeth and sinuous trace fossils are also present. Fragmentary stems, cone scales and *Nilssonia*-like fronds represent an undiversified flora.

Above this crinoid zone is a 33·1 m. thick argillaceous sequence ($G_6$) characterized by turriculate gastropods and a pebble lens with clasts having the lowest mean sphericity (0·71) of all the pebble localities sampled to date (Horne, 1969*a*, p. 57). Convolute lamination and vitric crystal blebs were found together with belemnite guards, *Inoceramus*, *Rotularia*, *Entolium* or *Camptonectes*, rhabdocidaroid spines and more sporadic occurrences of heteromorph ammonites, *Pseudolimea* (?) and fish bone or decapod cuticle.

The crinoid and gastropod zones were not observed at Mount Ariel but at locality U crinoids (in smaller numbers) occur with mecochirid-like decapods *within* a 19·8 m. thick gastropod zone ($U_4$) of *Rhabdocolpus alexandri* and *Amphitrochus* sp. (Thomson, 1971*a*, fig. 2j). *R. alexandri* frequently occurs in groups of up to 19 individuals. Belemnite guards and *Rotularia* (both ubiquitous), *Inoceramus*, *Entolium* or *Camptonectes*, rhabdocidaroid spines, *Grammatodon* (?) and *Palaeodictyon* (?) were also found. Unit $U_4$, which is slightly diachronous with unit $G_6$, may be traceable to locality D ($D_3$).

Overlying unit $U_4$ is a 25·9 m. thick rhabdocidaroid zone ($U_5$) which is confined to locality U, the rhabdocidaroids at locality G occurring mainly within the gastropod zone ($G_6$) and in preceding units. A mainly argillaceous sequence, unit $U_5$ contains vitric crystal blebs, haloed limonitic concretions, convolute laminations, isolated pebbles and a fauna and flora consisting of belemnite guards (and phragmocones), *Entolium* or *Camptonectes* and *Rotularia* (all ubiquitous), *Inoceramus*, *Pseudolimea* (?), opalescent skeletal matter, indeterminate ammonites, (?) fish scales, *Grammatodon* (?), indeterminate branched burrows, leaves, fragmentary stems (numerous at one horizon) and *Ptilophyllum*-like fronds.

In the succeeding 30·5 m. ($U_6$) of mainly dark grey mudstones and siltstones, there are plano-convex lenses of buff-coloured laminated sandstone, ellipsoidal and haloed limonitic concretions and a fauna consisting mainly of belemnite guards (and phragmocones), *Rotularia*, (occasionally in groups) and *Entolium* or *Camptonectes*. *Inoceramus*, indeterminate ammonites, diminutive gastropods, terebratulids and indeterminate branched trails were also recorded but *Pseudolimea* (?) is notably absent in this unit and in corresponding strata at Mount Ariel and localities D, H and G. In an approximately equivalent unit at locality G ($G_7$), vitric crystal blebs occur, terebratulids are commoner, *Aucellina* and *Zoophycos* are present and a few belemnite guards in the uppermost part of the unit have Acrothoracica.

The re-appearance of *Pseudolimea* (?) virtually coincides with the development of a 29·6 m. thick *Pinna* zone ($U_7$) which is traceable to localities D ($D_5$) and G ($G_8$) and less satisfactorily to locality H ($H_4$) and Mount Ariel ($S_{10}$). Sandstone lenses are commoner than in unit $U_6$ and there are discrete clasts up to boulder size. An iron oxide pigmentation characterizes several strata. At locality G and Mount Ariel, the lower part of this zone grades along the strike into well-developed but discontinuous belemnite "battle fields" (p. 47; Plate VIIIa) composed of compacted guards, clasts, wood fragments, numerous annelids, and several molluscs peculiar to these battle fields. The battle fields at Mount Ariel are 1·2 and 4·6 m. thick, respectively.

Apart from *Pinna* (often in life position), the fauna consists mainly of belemnite guards (some with Acrothoracica), *Rotularia* (occasionally grouped), *Inoceramus*, *Aucellina*, *Pseudolimea* (?), terebratulids (numerous and occasionally grouped at locality U but conspicuously absent at locality D), decapods and *Grammatodon* (?) (both at locality D). Several of the best-developed and laterally most extensive *Zoophycos* burrows were found in this part of the succession (Taylor, 1967, fig. 7a, b and f) together with vermicular structures and other more indeterminate ichnofossils.

When traced along the strike, the lower and upper parts of units $G_8$ and $G_7$, respectively, grade into a 16·5 m. thick cliff-like sequence of cross-bedded and convoluted sandstones (1·5 m. thick) and brecciated mudstones containing clasts (up to cobble size), compacted belemnite guards, large numbers of *Zoophycos* burrows and numerous fragmentary stems. This cliff is approximately equivalent to those at locality H ($H_2$) and Mount Ariel ($S_8$).

The gradual diminution in the number of belemnites observed in the preceding units finally culminates at the upper boundary of unit $U_8$ (and corresponding units at other localities). Here, they disappear (albeit temporarily) for the first time in the succession and *Aucellina*, which first appears 16·6–86 m. below the last recorded belemnite, becomes the main faunal constituent in the overlying 90–150 m.

Throughout unit $U_8$, *Rotularia* either singly or in groups of up to 19 individuals, *Pseudolimea* (occasionally hinged) and terebratulids are ubiquitous and *Aucellina*, *Inoceramus*, *Chondrites* and *Zoophycos* are common. Turriculate gastropods are also common at locality G. At locality D ($D_6$), *Entolium* or *Camptonectes*, crinoids, decapods, rhabdocidaroid spines and (?) terebratelloids were also recorded. At Mount Ariel ($S_{11-13}$) and locality G ($G_9$), the succession is more arenaceous and many of the sandstones are convoluted and slickensided. Several horizons rich in plant debris also occur together with isolated cone scales, leaves, fragmentary stems and *Ptilophyllum*- and *Nilssonia*-like fronds.

### 6. *Fossil Bluff* (*locality R*), *locality H and Mount Ariel*

The lowest exposed rocks (3·2 m.) at Fossil Bluff ($R_1$), containing belemnite guards, phragmocones, *Aucellina*, *Rotularia* (singly and grouped), *Pseudolimea* sp. nov. and fragmentary stems, represent the uppermost part of unit $U_8$ and its equivalents.

The succeeding 67·5 m. ($R_2$) consist of indurated grey-black siltstones and thin- and flag-bedded sandstones; some sandstones are load casted, and in an equivalent unit at Mount Ariel a 2·9 m. thick lens of variegated tuffaceous sandstones and argillaceous interbeds characterized by peripheral micro-faulting is developed (Plate Va). Iron pyrites is present as disseminated grains or as nodular crystalline aggregates (often haloed) and encrustations of gypsum are developed between bedding planes and on exposed rock faces.

The fauna is dominated by an abundance of *Rotularia* (frequently grouped), *Aucellina* (numerous and often hinged at certain horizons), *Pseudolimea* sp. nov. (also occasionally hinged) and *Inoceramus*. There are more sporadic occurrences of terebratulids, *Rhabdocolpus alexandri* (locally grouped), poorly preserved and often indeterminate ammonites (including *Phyllopachyceras* (?) sp.), the decapod *Palaeastacus*, *Lamellaptychus*, *Zoophycos*, vermicular structures and indeterminate burrows. *Nilssonia*- and *Ptilophyllum*-like fronds, leaves and fragmentary stems also occur and *Dictyozamites* (?) (Plate VIId) was collected from equivalent strata at locality H.

At 70·7 m. in the Fossil Bluff section, a 1 cm. thick band of veined quartz and calcite (unit $R_3$) (Fig. 7) introduces marked changes to the bedding and the fauna. Along part of the north and north-east-facing scarp the overlying 23·1 m. ($R_4$) (not 79 or 80 m. as cited by Horne (1967*a*, fig. 2)) are massively bedded, strongly deformed (even isoclinally folded) and weakly discordant and represent one of several so-called lubrication zones (Horne, 1967*a*, p. 3) (Plate IXc). The attitude of the east–west striking folds is emphasized by the local almost perpendicular orientation of *Inoceramus*, *Neithea* (?) sp. and leaves. *Neithea* (?) sp. appears to be confined to unit $R_4$ in this part of the succession. Lineated sediment bands within this disturbed zone suggest that some of the sediments were rotated while in a semi-mobile state. One small-scale slightly sinuous sandstone dyke was found in this lubrication zone but its direction of emplacement was not determined.

*Aucellina* is present in the lowest 1·6 m. of unit $R_4$ (together with *Chlamys octoplicatus* and an indeterminate turriculate gastropod) but it then disappears to coincide with the re-appearance of belemnite guards and phragmocones which constitute a well-marked zone. The belemnites are fewer in number at locality H and Mount Ariel, where they occur above, and above *and* below units $H_8$ and $S_{15}$, respectively. The change of bedding at Fossil Bluff also coincides with the appearance of crinoids and *Entolium* sp.

The stratigraphical relationships of the strata immediately above unit $R_4$ are complicated by west to east overthrusting which has cut out progressively higher beds down dip and transposed part of the belemnite zone *above* the *Aucellina*/*Inoceramus* coquina ($R_5$). However, only 2·6 m. of beds appear to be discordant.

The 0·3–3·0 m. thick gypsum-encrusted "rottenstone" or coquina ($R_5$) is composed mainly of compacted *Aucellina* and *Inoceramus* shells. Many of the former are hinged and the *Inoceramus* are large (8 cm.) for this part of the succession. Within the coquina and either immediately above or below it is a distinctive brachiopod fauna of often crushed *Cincta*-like terebratulids and highly spinose forms; both occur only in this part of the succession. The former have been referred to as *Crassatellites*-like bivalves (Taylor, 1971*a*, p. 152). The "rottenstone", which is faunally and lithologically one of the most distinctive units in the whole succession, is traceable to Mount Ariel ($S_{15}$) and localities D ($D_8$), H ($H_8$) and U.

The succeeding 59·5 ($R_6$) to 68·4 m. ($H_9$) is a mainly argillaceous sequence of dark grey siltstones in which convolute bedding is well developed. Nodules of iron pyrites and haloed limonite occur sporadically and repeated small-scale slump faulting (Horne, 1968*a*, fig. 5) is present in one stratum at Mount Ariel (unit $S_{16}$). 14·1 m. above the base of the unit at locality H ($H_9$), a 3·5 m. thick tuff composed of recrystallized shards (Taylor, 1966*a*, fig. 27) grades laterally into mudstones containing an unusually large amount of plant debris. Towards the top of the unit, vitric crystal blebs become commoner at all three localities. Many of the thin- and flag-bedded sandstones are slickensided, laminated and load casted, and flame structures are occasionally present (cf. Plate Vb). Internal load casts occur beneath several of the sandstones and localized "laminar corrugation" (Shrock, 1948, fig. 228) is present at one horizon.

With the disappearance of *Inoceramus* at unit $R_5$ (not re-appearing until unit $T_{14}$ at Waitabit Cliffs) and the sporadic occurrence of *Aucellina* thereafter, the fauna of unit $R_6$ consists mainly of *Pseudolimea* sp. nov., *Lima* sp., *Entolium* sp. (occasionally hinged), *Camptonectes* sp. β and α and *Rotularia* together with fish teeth, indeterminate aconeceratid and (?) lytoceratid ammonites, terebratulids, *Aucellina* (?), gastropods (including *Anchura* (?)), *Ostrea* (at Mount Ariel), indeterminate tubiform structures (Taylor, 1969, p. 77) and hyaline perforate Foraminifera. Bands of vermicular structures, unidentifiable burrows,

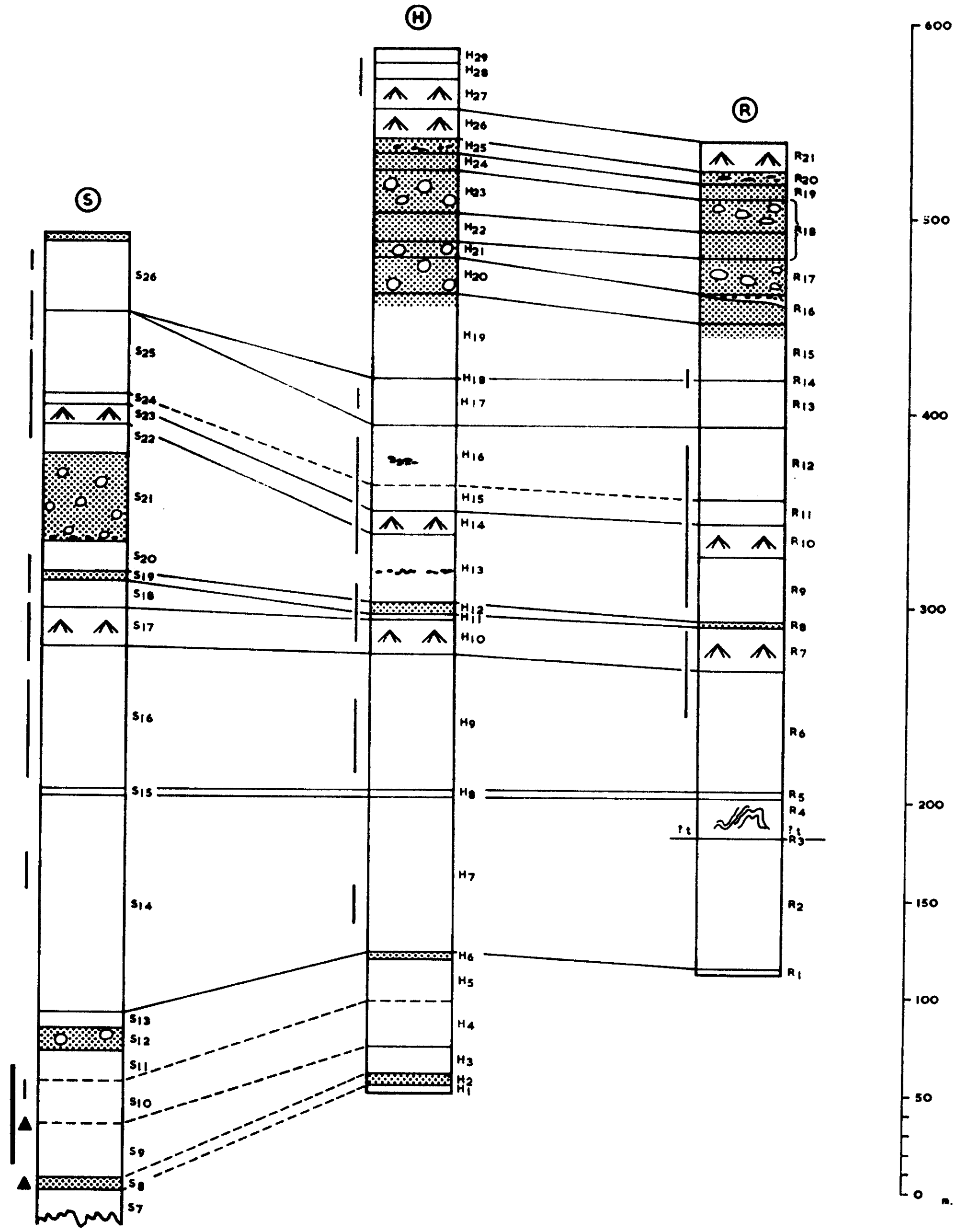

FIGURE 7

Stratigraphical sections at localities S, H and R enlarged to show detailed correlation (see Fig. 6).

*Nilssonia* (*?*), cone scales, stems and leaves occur and several horizons are rich in plant debris. At 156·3 m. in the succession at Fossil Bluff, terebratulids (often grouped), *Chondrites*-like burrows and associated trace fossils (Taylor, 1967, fig. 8e) constitute a useful 22·6 m. thick biostratigraphical zone ($R_7$) that is traceable to locality H ($H_{10}$) and Mount Ariel ($S_{17}$).

A relatively insignificant sequence of sediments (up to 16 m. thick at Mount Ariel; $S_{18}$) separates unit $R_7$ *sensu stricto* from unit $R_8$, a 1·8–2·4 m. thick cream-coloured sandstone forming a distinctive lithological marker bed in this part of the succession. Normal and reverse graded bedding is present, doggers are occasionally developed and the uppermost few centimetres are convoluted. At Mount Ariel, the stratum ($S_{19}$) is the source for several large-scale sandstone dykes.

The succeeding 34 m. in the Fossil Bluff section ($R_9$) is a mainly argillaceous sequence in which convolute lamination (cf. Plate Vc) and laminar corrugation are well developed. Many of the thin- and flag-bedded sandstones are laminated and load casted, and internal load casts occur at several horizons. Vitric crystal blebs are present in most strata and are locally grouped at one horizon, whereas pebbles are more sporadically distributed.

Two significant lithofacies variations occur between unit $R_9$ and equivalent strata at locality H ($H_{13}$) and Mount Ariel ($S_{20-22}$). 16·8 m. above unit $H_{12}$ there is a 3.9 m. thick pebbly mudstone composed of well-rounded clasts of plutonic, volcanic and metamorphic rocks. At Mount Ariel, the pebbly mudstone approximately coincides with the base of a 43·5 m. thick cream-coloured sandstone unit ($S_{21}$). The sandstone, which is almost unfossiliferous, is convolutely laminated and studded with cannon-ball concretions. Pebbles occur near the basal bedding planes of several intercalated siltstones.

Unit $R_9$ is characterized by an aconeceratid ammonite fauna consisting of *Aconeceras* (?) sp. and *Sanmartinoceras* (*Theganeceras*) (?) sp. At several horizons the ammonites are abundant although they are often crushed and distorted. *Rotularia*, occasionally partly replaced by iron pyrites, occurs either singly or grouped together with fish teeth, opalescent skeletal matter, the echinoid (?) *Hemipedina* (Taylor, 1966*b*, fig. 8b–d), ophiuroids, terebratulids, *Lima* sp., *Entolium* sp., *Camptonectes* sp. and indeterminate tubular structures. Bands of compacted vermicular structures, branched burrows and a poorly diversified flora of *Ptilophyllum*- and *Nilssonia*-like fronds, detached leaves, fragmentary stems and cone scales are also present. At Fossil Bluff in a stratum approximately equivalent to the pebbly mudstone at locality H, numerous and almost completely articulated (?) mecochirid decapods are preserved.

Towards the top of unit $R_9$, the aconeceratid ammonites become less common and *Chondrites*-like burrows re-appear in a 16·5 m. thick unit ($R_{10}$) of some stratigraphical importance. The upper half of unit $R_{10}$ overlaps with the lower of two assemblage zones ($R_{11}$) of (?) *Hemipedina* and *Nanonavis* (Taylor, 1966*b*). Although the echinoids also occur at locality H ($H_{15}$) and Mount Ariel ($S_{24}$), the zone is best developed at Fossil Bluff where it is 12·6 m. thick. The zonal boundaries are arbitrarily defined. (?) *Hemipedina* occurs throughout unit $R_{11}$, is commonly grouped (up to 11 individuals) and many of the coronae are complete but compacted. By contrast, *Nanonavis* (formerly referred to as (?) *Parallelodon*; Taylor, 1966*b*), although relatively abundant and often preserved as hinged valves, only occurs at *one* horizon at the top of unit $R_{11}$. Here, it is associated with a somewhat unusual fauna comprising *Ostrea*, the pedunculate cirripede *Cretiscalpellum aptiensis* Withers var. *antarcticum* (Taylor, 1965), the digitate gastropod *Anchura* (?), the inarticulate brachiopod *Discinisca variabilis*, decapods and crinoids.

Overlying unit $R_{11}$ are 41·8 m. ($R_{12}$) of grey-black indurated and occasionally convoluted siltstones and thin, laminated and discontinuous sandstones. Slickensided veins of calcite and quartz, nodular iron pyrites and haloed limonite and crystal blebs (up to 41 mm. long) also occur. In the middle of this sequence at locality H ($H_{16}$) there is a pebble-filled wash-out channel (Horne, 1969*a*, p. 57).

The fauna of unit $R_{12}$ consists predominantly of *Rotularia* (either single or grouped), *Entolium* or *Camptonectes* and aconeceratid ammonites (numerous at certain horizons) together with indeterminate heteromorphs, *Aucellina* (?), *Hemipedina* (?), *Lima* or *Pseudolimea*, decapods and fish teeth. At locality H ($H_{16}$) and Mount Ariel ($S_{25}$), the ammonites are less common, whereas *Rotularia* is more commonly found grouped and there are horizons with abundant *Entolium* or *Camptonectes*.

286.2 m. above the base of the Fossil Bluff section (i.e. at the base of unit $R_{13}$) and at approximately equivalent stratigraphical positions at locality H (the base of $H_{17}$) and Mount Ariel (the base of $S_{26}$), three significant zones commence, i.e. those of *Anchura* (?) *antarctica* (together with smaller numbers of *Anchura* (?) sp. *a* (Thomson, 1971*a*)), *Discinisca variabilis* (Thomson, 1971*b*) and a third of heteromorph ammonites including *Acrioceras* (?) aff. *voyanum* (Thomson, 1971*c*, cf. fig. 3j). The heteromorph zone, the least significant biostratigraphical unit of the three, is best developed at locality H where it is at least 21·2 m. thick.

Throughout the 49·2 m. of units $R_{13}$–$R_{15}$, *D. variabilis* and *A.* (?) *antarctica* are extremely common but both disappear below the overlying arenaceous phase, presumably in response to a change in the environment. A palaeocurrent study of *A.* (?) *antarctica* proved inconclusive. Several of the smaller inarticulate brachiopods were found apparently attached to plant fragments (Thomson, 1971*b*, fig. 7a and b).

Both zones, which are traceable to locality N ($N_1$), are subdivided unequally at Fossil Bluff and locality H by an upper *Hemipedina* (?)/*Nanonavis* zone ($R_{14}$ and $H_{18}$). However, at Mount Ariel, this same zone coincides with the beginnings of the *A.* (?) *antarctica* and *D. variabilis* zones, i.e. at the base of unit $S_{26}$. The upper *Hemipedina* (?)/*Nanonavis* zone differs from the lower one in that, whereas the echinoids are less abundant, *Nanonavis* is commoner and has, at Mount Ariel, a greater vertical range (15·2 m.).

(often with a purplish tarnish). More sporadic occurrences of the decapod *Enoploclytia* sp., *Pleuromya* (in life position), *Lingula*, loosely coiled serpulids, branched *Chondrites*-like burrow systems and *Nilssonia*- and *Ptilophyllum*-like fronds have been recorded. In approximately equivalent horizons at locality N ($N_3$), the decapod *Palaeastacus terraereginae* was found *in situ* and a scree specimen of *Palaeastacus foersteri* sp. nov. (bored by a saprotrophic fungus) may have been derived from the same horizon. In the upper half of unit $H_{26}$ there are two beds characterized both by devitrified lapilli and by unusual stellate burrows and less regular cuneiform structures. Typically, these strata are pitted due to preferential weathering of the lapilli. Two similarly bioturbated beds occur in the lower part of unit $H_{27}$ and three of these four beds are traceable to Fossil Bluff and locality N. At locality N lapilli have only been recorded from one bed, whereas at Fossil Bluff they have been collected from one stratum but probably they occur in all three.

The succeeding 16 m. ($H_{27}$) coincide with the development of a crinoid zone, which is traceable to locality N ($N_4$), and the re-appearances of *Anchura* (*?*) *antarctica* and *Entolium*. There are more sporadic occurrences of hyaline calcareous Foraminifera, turriculate gastropods, heteromorph fragments, (?) phylloceratid and lytoceratid ammonites (including *Eulytoceras* aff. *polare*), *Lingula* cf. *subovalis*, *Pleuromya*, the decapod *Trachysoma* aff. *ornatum*, fish teeth and a flora of *Ptilophyllum*- and *Nilssonia*-like fronds and detached leaves. The upper bedding plane of the crinoid zone virtually coincides with the brief (7·8 m.) appearance of limids ($H_{28}$) which also occur at locality N ($N_5$) and at the northern part of Waitabit Cliffs ($T_3$).

The remaining 18·4 m. at locality H ($H_{29}$) represent the uppermost part of the measured section. Dark grey siltstones and mudstones containing vitric crystal blebs and occasional clasts occur together with a fauna composed predominantly of *A.* (*?*) *antarctica*, *Entolium* or *Camptonectes*, (?) aconeceratid and heteromorph ammonites, *Rotularia*, the diminutive gastropods *Turritella alexandra* sp. nov. (Thomson, 1971*a*, fig. 2b–d) and *Rhabdocolpus alexandri*, crinoids, *Pholadomya* (in life position) and *Pleuromya* (often hinged). *Lingula*, *Lamellaptychus* (Thomson, 1972*a*, fig. 2d), *Aucellina* (*?*), leaves, cone scales, fragmentary stems and *Ptilophyllum*- and *Nilssonia*-like fronds have also been recorded.

### 7. *Locality N and Waitabit Cliffs* (*localities T and V*)

The uppermost parts of the *A.* (*?*) *antarctica* and *D. variabilis* zones at locality H and a much-reduced development of the thick-bedded sandstone facies are all traceable to locality N ($N_1$ and $N_2$). The strata of stellate burrows, the crinoid zone ($N_4$) and the re-appearance of *Rotularia* in large numbers, which characterize the upper part of the succession at locality H, also occur at locality N at approximately the same stratigraphical levels and *Aucellina* may also be present in these beds. However, none of these biostratigraphical units was observed at Waitabit Cliffs where the equivalent strata ($T_1$ and $T_2$) contain numerous "cement-stone" concretions, particularly in the lowermost 18·3 m. ($T_1$) (Horne and Taylor, 1969, fig. 8a–c) and a 31·3 m. thick zone of turriculate gastropods ($T_2$).

Nevertheless, the lowermost part of the measured section at Waitabit Cliffs can be correlated with localities N and H by the zone ($T_3$) of *Lima* or *Pseudolimea*. At locality H, *Pinna* was found only once in the lower part of the section, but at locality N and Waitabit Cliffs, the upper boundary of the limid zone virtually coincides with the beginnings of a *Pinna* zone. This zone is best developed at locality N, where it is 138·7 m. thick and continues to within 8 m. of the top of the measured section.

The upper bedding plane of the limid zone at locality N and Waitabit Cliffs also marks the beginnings of a 50·3 m. thick aconeceratid zone ($N_6$), which is more easily recognizable and stratigraphically definable at Waitabit Cliffs ($T_4$). Both specimens of *Sanmartinoceras patagonicum* collected from the screes at this locality were probably derived from this zone together with *in situ* specimens of *Aconeceras* sp. *a* (from locality N). In the uppermost part of the aconeceratid zone at locality N, there is a 15·2 m. thick echinoid zone.

The aconeceratid zone is punctuated by slickensided calcite and quartz veins and by thin beds of compacted vermicular structures. Vitric crystal blebs, localized convolute lamination and nodules of iron pyrites also occur. The remainder of the fauna consists of *Rotularia* (singly or rarely grouped), *Entolium* or *Camptonectes*, *Aucellina* (rarely grouped), *Pinna*, and more sporadic occurrences of *Anchura* (*?*) sp., turriculate gastropods, loosely coiled annelids, limids, crinoids and decapod cuticle. Fish remains include teeth, (?) spines and a parasphenoid. *Nilssonia*-like fronds, (?) cone scales, stems and leaves have also been recorded.

Between the aconeceratid zone and the re-appearance of belemnites in the succession are 58·1 ($T_5$) to 69·5 m. ($N_7$) of predominantly argillaceous rocks of which the upper 19 m. are thin- and slab-bedded sandstones. The sandstones are usually slickensided, laminated, load casted, convoluted and unfossiliferous. The fauna in the argillaceous beds is similar to that of the aconeceratid zone with the exception of rare occurrences of *Nanonavis* and doubtful scaphopods. Towards the top of this unit the aconeceratids re-appear, although not in such large numbers as in unit $T_4$. At Waitabit Cliffs, the fauna is less abundant, probably because of poorer exposure. Only three *Pinna* were recorded, no limids were observed and *Rotularia* was less common. The overlying beds (unit $N_8$), which represent the uppermost part of the measured section at locality N, consist of 18·8 m. of sandstone and subordinate grey-black siltstones and mudstones. This unit is best described from Waitabit Cliffs ($T_6$).

Unit $T_6$ is 22·9 m. thick and consists of block- to thick-bedded dark grey to black mudstones and sandy mudstones, some of which are load casted and graded. They contain concentrations of iron pyrites surrounded by oxidation haloes. Poorly cemented and indurated sandstones punctuate the sequence. This unit is characterized faunally by the sudden re-appearance of belemnites after an apparent absence from the succession over a thickness of about 500 m. *Entolium*, small belemnites including *Peratobelus* sp. (*?*) nov. (Willey, 1972, fig. 4a–e), and *Rotularia* occur in almost every bed, and *Sanmartinoceras patagonicum* is common in the lower half of the unit. Less frequent occurrences of other fossils make the total fauna a varied one: *Nanonavis*, *Pinna*, *Pleuromya* (sometimes in life position), *Thracia*, *Hypophylloceras* sp., *Eulytoceras* aff. *polare*, *Toxoceratoides* sp. nov., *Lamellaptychus* (Thomson, 1972*a*, fig. 2e), (?) scaphopods, crinoid ossicles, echinoid fragments, crustacean appendages, and fish teeth and scales. Macerated plant fragments occur throughout the unit. In the lower part of this unit at locality N ($N_8$), *Peratobelus* sp. (*?*) nov. is associated with another decapod zone (composed mainly of *Mecochiris* sp.) and relatively large numbers of (?) chirocentrid fish scales. Terebratulids, loosely coiled annelids and incomplete fish (?) spines also occur.

The lower 10·7 m. of unit $T_7$ are characterized by shaly and silty mudstones which contrast with the more massive beds below. A varied fauna, particularly rich in *Discinisca variabilis* and *Anchura* (*?*) sp. *β*, constitutes an assemblage zone. Other relatively common fossils include *Lingula* aff. *beanii* and plant fronds; *Nanonavis*, *Entolium*, small turriculate gastropods, *Emericiceras* (*?*) sp., large heteromorph ammonites, *Sanmartinoceras patagonicum*, crinoid ossicles, *Rotularia* and vermicular structures also occur. Many fish scales and one quadrate were found. The succeeding 14·6 m. are generally lighter in colour and contain a higher proportion of sand-grade material. In the middle are 3 m. of mottled sandstone with rust-coloured spheroidal concretions up to 60 cm. in diameter. The silty mudstones contain calcareous muddy nodules and small cannon-ball concretions. The mottled sandstones are characteristically unfossiliferous but the siltstones contain *Aucellina* and *Sanmartinoceras patagonicum*, together with occasional small turriculate gastropods, *Anchura* (*?*) sp. *β*, *Panopea*, *Thracia*, fish teeth and plant fragments.

Unit $T_8$ (Plate VId) represents a marked change in fauna and lithology. It consists of approximately 30 m. of highly pyritiferous silty shales which are poorly cemented and weather easily so that much of this unit is scree-covered. The sand content increases upwards and there is a complete transition into the overlying sandstones of unit $T_9$. At various levels the shales are rich in calcareous muddy nodules, some of which coalesce into tabular bed-like layers covering several square metres. The fauna is almost entirely limited to small turriculate gastropods (notably *Rissoina* sp.) and an occasional *Lingula*. *Toxoceratoides* sp. nov. and a few friable carbonized logs also occur. *Anchura* (*?*), ammonite fragments and plant fronds are present in some of the nodules but not all of them have organic cores. In the middle of this monotonous unit is a 1·5 m. thick mottled sandstone which locally exhibits current bedding.

The succeeding 11·2 m. ($T_9$) consist of thick beds of creamy white, mottled, laumontitized sandstone containing large spheroidal concretions and intercalated subsidiary black siltstones. One such siltstone is conspicuous for its small but macroscopic white feldspar crystals and a variety of microscopic axiolitic structures (Horne and Thomson, 1972, fig. 5b–d). Except for trace fossils, the sandstones are largely unfossiliferous but a belemnite and a few twig impressions were found at the base of one bed. About 0·5 km. north of the camptonite dyke-controlled gully (Plate IIIc), where the upper part of this section was measured, the sandstones contain carbonized logs bored by *Teredo* (*?*). *Aucellina* and belemnites occasionally occur in the interbedded siltstones.

The typically greenish to reddish weathering mudstones of unit $T_{10}$ are 40·5 m. thick and are notable for the presence of *Aucellina* in relatively large numbers. The weathering colour and bright yellow and red patches on rock faces are due to oxidized iron pyrites. Sandy layers in the mudstones sometimes show small-scale cross bedding and convolute lamination, and some discrete sandstones are feeders for small-scale sedimentary dykes. The fauna is dominated by *Aucellina*, small belemnites and vermicular structures but *Rotularia* is also relatively common in the lower part of the unit. *Sanmartinoceras patagonicum* appears to range no higher than about 10 m. above the base of this unit. Other fossils occur only occasionally and include *Nanonavis*, *Pinna*, *Entolium*, *Panopea*, crustacean appendages, fish scales and plant fragments. An articulated specimen of the decapod *Palaeastacus* cf. *sussexiensis* was collected from screes derived from this unit.

The sedimentary rocks of unit $T_{11}$ differ from others so far discovered in south-eastern Alexander Island in consisting of an extensive deposit of mudstone conglomerate. This is 16·2 m. thick at northern Waitabit Cliffs (locality T) and more than twice that about 6·5 km. farther south (locality V). Poorly cemented and indurated sandstones also occur. The characteristically greenish mudstone clasts (enclosed in a matrix of silt or sandy mudstone) are lithologically identical to many mudstones examined elsewhere in the sequence, even to the presence of vermicular structures. Sometimes the clasts account for as much as 70 per cent of the total rock. Pebbles of igneous and metamorphosed sedimentary rocks occur sporadically in addition to small black calcareous concretions (Horne and Taylor, 1969, p. 29) and vitric crystal blebs. Fossils are rare but *Aucellina*, ammonite fragments, *Neohibolites minimus* var. *submedius*, *Peratobelus* aff. *australis* and *Rotularia* have been recorded.

The succeeding 35·2 m. ($T_{12}$) consist of block- to thick-bedded black mudstones with thin discontinuous laminae of fine-grained, indurated greenish sandstone and sporadic vitric crystal blebs. The sequence is punctuated by thin but persistent poorly cemented sandstones, some of which show well-developed internal load casts. The monotonous lithology is matched by the faunas. *Inoceramus* (*I.* aff. *concentricus* and *Inoceramus* sp. indet.), appearing for the first time in the measured sequence at locality T, is present in relatively large numbers together with *Aucellina*. Small belemnites (including *Neohibolites minimus* var. *oblongus*) and *Rotularia* occur sporadically and a single rhynchonellid brachiopod was obtained from near the base of the unit. Trace fossils include vermicular structures and a *Neonerites*-like form which appears to be characteristic of these strata; plant remains occur as woody fragments only.

1·8 m. of indurated sandstones with thin shales ($T_{13}$) separate the mudstones of unit $T_{12}$ from a similar sequence above. The sandstones, containing a high proportion of iron pyrites, are bright yellow on weathered surfaces and have yellow encrustations of gypsum, thus forming an easily recognizable marker bed.

The overlying 74·4 m. ($T_{14}$) are predominantly mudstones, broadly similar to those of unit $T_{12}$ except that the proportion of thin greenish sandy laminae increases until, at some levels, they account for nearly 50 per cent of the sequence. Vitric crystal blebs also occur. About 12 m. below the top of the unit, the mudstones are replaced by poorly cemented, almost white sandstones and muddy sandstones but, before the thick mottled sandstones of unit $T_{15}$ are reached, the rocks revert to black somewhat shaly mudstones. *Inoceramus* is again common throughout this unit, but *Aucellina* is less frequent and apparently absent at several levels. Two zones of mudstones containing ammonites occur about 35 m. above the base and also at the top of the unit; in the lower zone are *Hypophylloceras* sp., *Eotetragonites* and *Aconeceras* aff. *nisoides*, whereas the ammonite fauna in the upper mudstone appears to be limited to *Eotetragonites* and heteromorph fragments. A cirripede tergum was collected at the base of unit $T_{14}$ and *Nuculana*, *Entolium* and (?) scaphopods occur in the topmost shaly mudstone.

Unit $T_{15}$ represents a thicker development (44·2 m.) of the type of sandstones included in unit $T_9$. These are followed by mudstones ($T_{16}$) similar to those of units $T_{12}$ and $T_{14}$ but only 9·2 m. are exposed before the sequence is interrupted by a (?) thrust. The thick mottled sandstones display a variety of sedimentary features including mud-flake conglomerates, small-scale slumps with intra-formational micro-faulting, and shock-produced collapse structures (Plate Vd). Cannon-ball concretions are well developed and frequently reach diameters of 1 m. or more; these tend to be slightly ellipsoidal but smaller examples (about 30 cm. across) are almost perfectly spherical. Southward along the eastern face of Waitabit Cliffs, the sandstones of unit $T_{13}$ gradually finger out and are largely replaced by mudstones at locality V. This replacement is all but completed when the unit is abruptly truncated by a "slump" plane about 1 km. from the southern end of the cliffs (Plate Xa). Only *Aucellina* and *Inoceramus* have been collected from the uppermost mudstones ($T_{16}$).

### 8. *Succession Cliffs (localities A and B) and the lower 148 m. at locality C*

The sedimentary succession exposed at Succession Cliffs (localities A and B; Plate IIa and b) and the lowermost 148 m. at locality C (Plate IIc and d) represents some of the youngest Mesozoic rocks so far

Besides the zonal fossils, units $R_{13}$ and $R_{15}$ have a varied fauna consisting of *Rotularia* (rarely grouped), *Aconeceras* sp. *a*, *Entolium* or *Camptonectes* together with more sporadic occurrences of turriculate gastropods, *Lingula* cf. *subovalis* (Thomson, 1971*b*, cf. fig. 2b), indeterminate tubiform fossils (Taylor, 1969), indeterminate decapods, fish teeth and scales, vermicular structures, and large branched burrows (frequently at or near the upper bedding planes). *Nilssonia*- (Plate VIIe) and *Ptilophyllum*-like fronds, leaves, and fragmentary stems have also been recorded. Many of the more fissile and ferruginous strata in these units contain juvenile or small (possibly dwarfed) *Pholadomya*-like bivalves, limids and diminutive oxycone ammonites.

Towards the top of unit $R_{15}$ (and corresponding units at the other localities), the often fissile siltstones and shales become progressively more arenaceous, and at unit $R_{16}$ a radical change of conditions takes place during which at least 78 m. of sandstones were deposited in the Fossil Bluff area. These sandstones form three prominent cliffs beneath the summit of the pyramidal peak (locality M) overlooking Fossil Bluff, three cliffs at locality H, a high cliff capping locality Q and the lowest cliff at locality N.

The lowest cliff at Fossil Bluff is 14·6 m. thick (unit $R_{16}$) and is composed of grey-coloured medium- and coarse-grained sandstones which weather to a pale brown. The sandstones, which coarsen upwards, are poorly fossiliferous and usually unlaminated, although cross bedding is present along parts of the outcrop. In the lower part of the cliff, angular mudstone flakes occur probably indicating slight erosion of the sea bed, and medium-sized pebbles have been found 6·1–9·1 m. below an overlying conglomerate. The upper bedding plane of this unit is defined by a prism-shaped pebble conglomerate (Horne, 1969*a*, fig. 2a and b) which, at one point, rests directly on cross-bedded sandstones dipping at 25° to the north-north-east. The conglomerate is thickest (2 m.) at the eastern end of locality M and it thins both along the strike (i.e. westward) and down dip towards locality Q, where it is only 0·58 m. thick. The morphology and petrology of this conglomerate have been described by Horne (1969*a*).

Numerous and locally grouped indeterminate bivalve shells have been found at several horizons together with the gastropods *Vanikoropsis* (*?*) sp. (Thomson, 1971*a*, fig. 2i), *Anchura* (*?*) sp. indet. and an indeterminate scalid (?). *Lingula*, *Chondrites*-like burrows, casts resembling those of a lugworm, and incomplete *Nilssonia*- and *Ptilophyllum*-like fronds and fragmentary stems have also been recorded. This thick-bedded sandstone is traceable to locality N ($N_2$) where it is 17·2 m. thick.

Overlying the lowest cliff are 18·6 m. of fine- and medium-grained cream-coloured sandstones ($R_{17}$) with irregular patches of coarser sand. Convolute bedding is common and often associated with cannon-ball concretions and lenses of identical brownstone. There is every gradation from cannon-balls within brownstone lenses to discrete spheroids. Along parts of the outcrop, the sandstones are laminated and small-scale convolutions and downwardly injected sandstone dykes occur. At locality H, the sandstones are only 8·1 m. thick ($H_{21}$), although the lithologies are the same.

Above these sandstones and forming a middle cliff are 30·5 m. ($R_{18}$) of shales, siltstones and buff-coloured sandstones which are divisible into two units. The first (14·4 m.) forms a virtually perpendicular cliff of alternating shales, siltstones and sandstones with sporadic scatterings of coarser sand and a few well-rounded pebbles. *Entolium* sp. occurs together with incomplete gastropods, indeterminate bivalves and relatively large, branched *Chondrites*-like burrows. Shells are comparatively rare but there are large quantities of partly carbonized stems, incomplete *Ptilophyllum*- and *Nilssonia*-like fronds, cone scales, leaves and lenticellular bark.

The second unit, which is 15·6 m. thick, is separated from the first by a 10 cm. thick band of calcite, quartz and brecciated rock fragments. The sandstones, shales and siltstones representing this unit form a moderately reclined cliff which is set back from the more vertical cliff below. Cannon-ball concretions and lenses of an identical reddish brown sandstone are common and rare fragmentary stems are the only fossils.

Above these almost unfossiliferous strata are 7·6 m. (unit $R_{19}$) of sandstone terraces which have been accentuated by differential weathering and erosion. At one point along the contact with unit $R_{18}$, the sandstones are cross bedded and dip at 16° towards the east-north-east. *Pleuromya*-like bivalves in life position and indeterminate gastropods occur together with large numbers of partly carbonized stems and *Ptilophyllum*-like fronds. The sandstones are overlain by a further 6·9 m. ($R_{20}$) of sandstones and a "re-worked" conglomerate which is traceable to locality H. Several clasts in the conglomerate are entire but most of them have been disaggregated and assimilated into the matrix.

The strata above this conglomerate are best exposed at locality H. The lower 15 m. ($H_{26}$) of grey-black siltstones contain numerous "cement-stone" concretions and large numbers of well-preserved *Entolium* sp.

recognized in south-eastern Alexander Island (p. 37)—even though their present geographical position would suggest otherwise. Evidently, their stratigraphically low position compared with the measured section to the north at locality Z and the apparently anomalous relationship between Succession Cliffs and the upper part of the succession at locality C is due to overthrusting and a possible east–west fault along Pluto Glacier.

Three ammonite specimens (*Eotetragonites* sp., *Aconeceras* aff. *nisoides* and *Australiceras* sp.) were collected from screes beside the northern block of Succession Cliffs (locality A). *Eotetragonites* sp. (resembling Upper Aptian and Albian forms (Thomson, 1971*c*, 1974)) and *A.* aff. *nisoides* have also been found *in situ* near the top of the section at Waitabit Cliffs ($T_{14}$). A new heteromorph *Antarcticoceras antarcticum*, obtained from the screes at locality B, has also been collected from Stephenson Nunatak (p. 37).

The lowest exposed strata at locality A are 16·5 m. of mainly orange-coloured micaceous sandstones ($A_1$) containing concretions and scattered pebbles. In the thin-bedded, laminated and convoluted parts of the unit there are several small-scale sandstone dykes. These exhibit down-dragged laminae and the "U" bending and inversion of fragmented siltstone interbeds. The laminae consist mainly of heavy minerals, notably sphene, epidote, magnetite, zircon, apatite and allanite. Thin bituminous lenses, numerous carbonized stems and several belemnite guards are also present. The unit as a whole coarsens upwards.

Unit $A_2$ consists of 131 m. of indurated grey-black siltstones and cream-, grey- or buff-coloured fine- and medium-grained sandstones. Several of the sandstones are laminated, convoluted, load casted and discontinuous laterally. "Cement-stone" concretions, nodules of iron pyrites, vitric crystal blebs, pebbles and pebble lenses occur periodically throughout this unit. There are also eight crystal tuffs composed predominantly of plagioclase and hornblende together with devitrified lapilli and recrystallized shards. The pronounced green colour of these beds is due to the lapilli and the lithic fragments. Tension gashes are common in this unit, particularly in the uppermost part.

Belemnite guards (including those of *Dimitobelus macgregori* and *D.* aff. *macgregori* (Willey, 1972, fig. 3d and 3a–c) are present in almost every stratum and *Aucellina* is common, particularly at certain horizons where it is locally grouped. In the lower part of unit $A_2$, *Entolium* sp. and *Entolium* or *Camptonectes*, *Pinna* (often in life position), *Pseudolimea* sp. and *Rotularia* occur sporadically. However, in the upper part, *Rotularia* (rarely grouped) is more common together with fish fragments, opalescent skeletal matter (probably fish), turriculate gastropods and poorly preserved ammonites including heteromorphs. The fish fragments consist of teeth, scales, vertebrae, fin rays, a supercleithrum or angulum, subopercula and interopercula. The flora consists only of fragmentary stems.

*Inoceramus* sp. appears for the first time in unit $A_3$ 149 m. above the base of the section. This unit is 10·5 m. thick and consists mainly of friable grey-black mudstones and thin-bedded, often cream-coloured sandstones containing vitric crystal blebs, "cement-stone" concretions and haloed limonitic concretions. Belemnite guards, *Aucellina*, ammonites, turriculate gastropods, larger pagodiform gastropods (Thomson, 1971*a*, fig. 5c), *Rotularia* (including loosely coiled forms), echinoid spines, fish teeth and fragmentary plant stems were found.

Unit $A_3$ is overlain by 23·8–25·9 m. ($A_4$) of mainly cream-coloured laminated, convoluted and honeycombed sandstones studded with brown or reddish weathering cannon-ball concretions; many of these concretions are arranged along ill-defined bedding planes (Horne and Taylor, 1969, fig. 3). This unit crops out as a cliff whose upper and lower limits are sharp and linear. Within the convoluted horizons, brecciated shale fragments and downwardly intruded small-scale sandstone dykes occur.

Overlying unit $A_4$ are 12·8 m. ($A_5$) of predominantly fissile grey-black siltstones and shales with thin-bedded cream-coloured sandstones, "cement-stone" concretions, vitric crystal blebs and small-scale intrusive phenomena. The fauna, which is not abundant, consists mainly of *Inoceramus*, *Aucellina*, belemnite guards, *Aconeceras* aff. *nisoides*, *Rotularia* and opalescent skeletal matter. Stem fragments were also found. The uppermost 1·8 m. of unit $A_5$ are mainly arenaceous.

Unit $A_6$ consists of 45 m. of cream-coloured, laminated, convoluted and honeycombed sandstones with cannon-ball concretions. The sandstones form a reclined cliff whose attitude is probably governed by an east–west joint set dipping at 34° to the north. Intercalated shales, containing belemnite guards, gastropods and either *Inoceramus* or *Aucellina*, are usually brecciated and convoluted and several are downwardly intruded by small-scale linguiform sandstone dykes up to 13 cm. deep.

Overlying unit $A_6$ are 5·5 m. ($A_7$) of often fissile and poorly fossiliferous grey-black siltstones and thin-bedded sandstones with vitric crystal blebs, "cement-stone" concretions and a fauna of belemnite guards, *Aucellina*, *Inoceramus*, incomplete ammonites and planispiral annelids. Partly carbonized stems were also recorded. These beds are succeeded by a cliff at least 16·8 m. thick (unit $A_8$) of a cream-coloured, laminated, convoluted and honeycombed sandstone studded with cannon-ball concretions averaging 1·2 m. in diameter. Most of the concretions exhibit the same textural variations (e.g. an increase in grain-size) as the host rock. Many of the intercalated siltstones and shales are brecciated. The upper boundary of this unit was not encountered along the line of section. Down dip, the lower of the three sandstone cliffs pinches out but the upper two cliffs thin and converge to form the basal cliff at locality B ($B_2$).

The 38·5 m. thick sandstone cliff at locality B ($B_2$) (Plate VIc) represents a prominent lithological and topographical marker bed. Individual sandstones, often laminated, convoluted, micro-faulted and honeycombed, become discontinuous or change lithologically across the outcrop. Flame structures occur at one horizon but directional implications are confused by apparent reversible inclinations of the mud streaks. The only fossils (carbonized plant fragments and *Aucellina* (*?*)) are found in the flag-bedded siltstones, many of which are brecciated. Cannon-ball concretions up to 1·6 m. long and 1 m. high are common and often arranged along bedding planes. The attitude of unit $B_2$ is influenced by east–west joints dipping perpendicularly and at 34° towards the north. Towards the top of the cliff, interbedded siltstones become more dense. The cliff is succeeded by 305 m. ($B_{3-10}$) of siltstones and thin-bedded sandstones.

The first 75·5 m. ($B_3$) of this siltstone–sandstone succession consist mainly of dark grey siltstones and subordinate sandstone interbeds; some of the latter are micro-faulted and convoluted. Vitric crystal blebs are common throughout, whereas "cement-stone" concretions occur abundantly only in the lower half of the unit. The fauna consists predominantly of belemnite guards, *Aucellina*, *Rotularia* and, in the lower one-third of the unit, *Inoceramus*, together with incomplete ammonites and gastropods, *Pseudolimea* (*?*), sponge spicules, opalescent skeletal matter and sporadic occurrences of *Nuculana*. In the uppermost 12 m. of unit $B_3$, *Entolium* sp. and several indeterminate pectinids were recorded. Fragmentary stems were also found.

The succeeding 14·2 m. ($B_4$) consist of indurated grey-black siltstones, continuous and discontinuous sandstone interbeds and internal load casts of sandstone. Vitric crystal blebs occur throughout and tension gashes are common. "Cement-stone" concretions also occur at one horizon. This unit is characterized faunally by the ammonite *Callizoniceras* (*?*) sp., *Entolium* (*?*) sp. and other pectinids and by nuculanids which together may constitute a stratigraphically significant assemblage zone for future work in this area. Belemnite guards (and phragmocones), *Aucellina* (*?*), *Pseudolimea* (*?*), *Rotularia* and fragmentary stems were also found.

The overlying 51 m. ($B_5$) of indurated dark siltstones and thin-bedded sandstones contain "cement-stone" concretions and more lensoid bodies of limestone up to 3 m. long and 0·6 m. thick (Horne and Taylor, 1969, p. 26). Vitric crystal blebs and tension gashes occur in most strata and two crystal tuffs composed predominantly of plagioclase, hornblende and green-coloured lithic fragments were found. Many beds are mottled due to the piping-down of a pale-coloured calcareous tunnel sediment into subjacent siltstones containing numerous *Chondrites*-like burrows (Taylor, 1967, fig. 9c). Belemnite guards are virtually ubiquitous, whereas the remaining fauna is more sporadically distributed, i.e. *Aucellina*, ammonites, *Entolium*, *Rotularia*, nuculanids, indeterminate gastropods and fish (?) scales. There is a paucity of fossils at several horizons.

The almost unfossiliferous 17·7 m. representing the upper part of unit $B_5$ is followed by 7·6 m. of beds ($B_6$) characterized by numerous *Aucellina* shells which are locally congregated. The upper part of unit $B_6$ also coincides with the beginning of an *Inoceramus* zone which continues throughout unit $B_7$. Belemnite guards, ammonites, *Rotularia* and stems also occur and mottling, probably caused by bioturbation, is present. Lithologically, unit $B_6$ is characterized by three beds of green-weathering crystal tuff and less significantly by vitric crystal blebs.

The 65·5 m. thick *Inoceramus* zone ($B_7$) consists of grey-black indurated siltstones and thin-bedded sandstones, many of which wedge out down dip. Vitric crystal blebs and "cement-stone" concretions are common and there are six beds of greenish weathering crystal tuff. *Inoceramus* and *Rotularia* are common throughout unit $B_7$ and *Aucellina* (locally grouped), *Entolium* (*?*) and diminutive gastropods (*Procerithium* sp. and fig. 5a in Thomson (1971*a*)) are present in the upper part together with isolated occurrences of *Pinna*, nuculanids, (?) scaphopods and fish teeth. The ammonite *Costidiscus* (*?*) sp. was also found at three horizons in unit $B_7$.

The temporary disappearance of *Inoceramus* in the overlying units ($B_{8-11}$) approximately coincides with the development of the first of two echinoderm zones, the re-appearance of *Pseudolimea* (*?*) and the extension of a *Procerithium* zone first developed in the upper part of unit $B_7$. Units $B_{8-11}$ are traceable to locality C, where they represent the lowest exposed beds beneath the first of several major thrusts.

Units $B_{8-11}$, which are 89·9 m. thick, are characterized by two echinoderm zones of *Epiaster* (*?*) (Taylor, 1966*b*), both of which are best developed at locality C, where they are 9·9 and 50·4 m. thick, respectively. The disappearance of *Inoceramus* at locality B virtually coincides with the appearance of *Epiaster* (*?*) ($B_8$), which is represented by only one specimen compared with its common occurrence in 9·9 m. of beds at locality C. This zone is overlain by 57 m. ($B_9$) of mainly indurated grey-black siltstones with occasional thin-bedded sandstones containing tension gashes, vitric crystal blebs, "cement-stone" concretions and a fauna composed mainly of *Pseudolimea* (*?*), *Procerithium* (locally grouped), belemnite guards and less frequent occurrences of ammonites (probably of "*Ptychoceras*" sp.), *Aucellina*, *Entolium* (*?*), *Rotularia*, fish teeth, fish vertebrae and *Chondrites*-like burrows. Fragmentary stems and plants have also been recorded.

The upper *Epiaster* (*?*) zone at locality B ($B_{10}$), which is 26·8 m. thick, is only represented by two separate occurrences but this may be due to poor exposure. These rocks are more arenaceous than in unit $B_9$ and are ultimately overlain by at least 6·1 m. of buff-coloured, medium- to coarse-grained and laminated sandstone ($B_{11}$) which is probably equivalent to unit $C_6$.

Units $B_{8-11}$ are represented at locality C by units $C_{1-6}$ which are more fossiliferous overall, notably in the numbers of diminutive gastropods (*Procerithium*) and the occurrence of the ammonite "*Ptychoceras*" sp. Unit $C_6$ is overlain by a further 33·8 m. of beds ($C_7$) forming the greater part of the upper *Epiaster* (*?*) zone. Indurated dark grey siltstones and subordinate thin-bedded sandstones (with internal load casts) are characterized by "cement-stone" concretions, occasional "chert" bands and a fauna consisting mainly of *Procerithium*, *Pseudolimea* (*?*), *Entolium* or *Camptonectes* and "*Ptychoceras*". Belemnite guards, *Aucellina* (*?*), (?) scaphopods, indeterminate bivalves, (?) nuculanids, fish teeth, scales, opalescent skeletal matter and *Rotularia* also occur. Stems and fronds were found at several horizons. Unit $C_7$ is terminated by a prominent thrust.

### 9. *Keystone Cliffs* (*localities W and X*)

The sedimentary sequence measured at Keystone Cliffs overlies a thick zone of disturbed beds (Plate IIId) and cannot be satisfactorily correlated with other parts of the succession examined so far. The base of the disturbed zone is not exposed but at the north-eastern corner it forms a large part of the cliff face and is at least 200 m. thick. The boundary between it and the overlying undistorted sequence is a flat plane of contact which dips steadily westward until, about 2·5 km. up Mercury Glacier, the disturbed beds disappear below the ice level. Some of these beds can be matched lithologically with units $T_{11}$, $T_{13}$ and $T_{15}$ at Waitabit Cliffs but they are much less fossiliferous and only *Inoceramus* and *Aucellina* have been found. Other units rich in *Chondrites*-like burrows are similar to some examined in the overlying undistorted sequence. Structures in the disturbed zone include folds and sediment wedges, the origins of which are discussed on p. 58.

The base of the undistorted sequence is difficult to determine on the outcrop even though it is obvious from a distance. A few zones of movement are present in the measured sequence but these are parallel to the bedding and appear to have no significant effect on the stratigraphical succession. For the most part, the fauna and lithology are monotonous and more varied faunas are restricted to particular beds.

Unit $W_1$ consists of 32 m. of hard grey to black mudstones with thin sandy lenses. The mudstones are generally massive but in places they may become shaly and are interbedded with thin beds of unindurated sandstone. Towards the top of these beds, black calcareous nodules rich in Radiolaria (Horne and Taylor, 1969, p. 29) and calcareous concretions occur with increasing frequency together with oxidized concretions of iron pyrites and occasional vitric crystal blebs.

Two movement zones, occasionally chaotically bedded, occur 23·8–27·3 m. above the base of the section and in the top 2 m. of the unit. *Inoceramus* and *Aucellina* are common throughout, whereas *Silesites antarcticus* (Thomson, 1974, pl. Vg–j) is restricted to the basal 5 m. and sporadic occurrences in the upper beds. *S.* aff. *vulpes* was found in association with *S. antarcticus* at locality X at a level probably equivalent to the base of the measured section. *Phyllopachyceras aureliae* and "*Lytoceras*" sp. β occur with *Silesites* in the lower part of the unit. Brachiopods, echinoids, small belemnites, *Rotularia*, rare (?) fish remains and cirripede terga complete the fauna. Twig moulds and one damaged *Ptilophyllum*-like frond (Plate VIIa) were the only plant remains found.

The succeeding 94 m. ($W_2$) are notable for their sudden decrease in the variety and quantity of the fauna and also for the presence of turbidite-filled troughs. The sequence largely consists of dark to medium grey mudstones containing small black nodules (similar to those referred to above), and calcareous concretions up to 2 m. long and 30 cm. thick. Vitric crystal blebs are relatively common 58–78 m. above the base of the section. Sand-grade material usually occurs in thin bands or lenses but 91 m. above the base of the section there is a discrete 1·2 m. thick sandstone. Small belemnites are relatively common but *Aucellina*, *Inoceramus* and *Rotularia* also occur sporadically. Since gastropods and crinoid columnals have been recorded only from turbidite beds filling small channels (about 0·5 m. deep), they are believed to be exotic. Numerically, the commonest fossils are *Chondrites*-like radiating and branched burrows which have been found extensively at two horizons: 70–76 and 93–105 m. above the base of the section.

Unit $W_3$ is 67·7 m. thick and lithologically similar to unit $W_2$ except for the greater proportion of thin unindurated sandstones which occur at intervals of about 10 cm. These rocks are eroded easily and much of this unit is therefore scree-covered. Calcareous nodules up to 1 m. long commonly occur in bands and the top of the measured section is marked by such a band whose upper surface bears numerous poorly preserved ammonite moulds. Vitric crystal blebs occur throughout. *Inoceramus* is commoner than in unit $W_2$ and *Aucellina*, although not very persistent, is sometimes found in large numbers on a few bedding planes. Belemnites have been recorded at only two horizons, *Rotularia* occurs sporadically and one occurrence of *Proscala* (?) sp. was observed (Thomson, 1971*a*, fig. 2h). About 150 m. above the base of the section some mudstones contain a varied but poorly preserved ammonite fauna which includes *Pseudothurmannia* cf. *mortilleti*, *Hemihoplites* (?) sp., *Macroscaphites* (?) sp. and *Silesites desmoceratoides* (?). *Chondrites*-like burrows are extensively developed at some levels.

The section measured is incomplete and there is approximately twice as much again of easily accessible sedimentary outcrop. The sequence gradually becomes more sandy upwards until it is almost entirely composed of pale-coloured sandstones, such as are exposed in a prominent rounded peak at locality X (Plate IIIc).

## V. AGE OF THE SEDIMENTARY SUCCESSION

EARLY estimates of the age of the sedimentary succession have already been outlined (p. 10), detailed discussions have appeared in papers on *Inoceramus* (Thomson and Willey, 1972), the Ammonoidea (Thomson, 1971c, 1974) and Belemnoidea (Willey, 1972, 1973), and further information will be published together with the systematic studies that are still in progress. The distributions of the stratigraphically important species are summarized in Table II and they are briefly discussed below.

Largely because of logistic problems, none of the fossil collections made so far in south-eastern Alexander Island are comprehensive, although initially they were at least assumed to be representative. Despite the considerable amount of material, laboratory studies indicate that in many cases the collections are not even wholly representative. It is thus impossible to delineate the boundaries between the stages recognized with any degree of precision.

### 1. *Upper Oxfordian–Kimmeridgian*

Relatively undiverse often poorly preserved faunas from the disturbed zone of the Ablation Point area (and from the tuffaceous sedimentary rocks at Belemnite Point) contain species probably ranging in age from Upper Oxfordian to Middle Kimmeridgian. The dating of the *Inoceramus* species (Thomson and Willey, 1972) was based on early accounts of their occurrences in Indonesia and New Zealand. However, a recent revision of the associated belemnites from these two areas suggests that in Indonesia *I. haasti* occurs in the Lower Tithonian and *I. subhaasti* in the Middle Kimmeridgian (Stevens, 1965, p. 139, table 13), whereas in New Zealand, both occur in the Middle Kimmeridgian although *I.* cf. *subhaasti* appears to be the earlier (Stevens, 1965, p. 31, fig. 13). Nevertheless, in Alexander Island there is no evidence from the associated cephalopods (Table II) to suggest that the occurrence of *I. haasti* in the disturbed zone ranges as high as the Lower Tithonian.

### 2. *Tithonian*

Proven Tithonian sedimentary rocks have only been recognized in the eastern half of the Ablation Point block between Grotto and Jupiter Glaciers. The Tithonian ammonite faunas are dominated by species of *Virgatosphinctes* and *Aulacosphinctoides*. Strong affinities with the Himalayan Spiti Shale forms and less marked similarities with Mexican and South American faunas are evident. Both Upper and Lower Tithonian faunal elements may be present but collecting is not yet detailed enough to subdivide the stage satisfactorily in Alexander Island. The latest Tithonian faunas, represented in the 50 m. or so above and below conglomerate $AG_1$, are characterized by the absence of *Virgatosphinctes* and *Aulacosphinctoides* and by the appearance of "*Berriasella*" and *Blanfordiceras*. These late Tithonian species were foreshadowed by the appearance of *Corongoceras* about 75 m. below the base of conglomerate $AG_1$ at locality AK. Recent collections of *Buchia* in the Ablation Point area were confined to the Tithonian part of the sequence, although earlier collections may have been obtained from the Upper Oxfordian–Kimmeridgian sequence.

As yet, belemnites are of little direct stratigraphical value because the only identifiable species are one new form (*Hibolithes belligerundi*) and *Belemnopsis* aff. *uhligi*, which ranges higher in Alexander Island (Berriasian) than previously known species of the *B. uhligi* complex (Kimmeridgian–Tithonian) (Stevens, 1965, p. 207).

### 3. *Berriasian*

a. *Ablation Point*. Above the *Blanfordiceras* fauna of the Ablation Point area are approximately 1,300 m. of largely scree-covered shales, sandstones and conglomerates from which no ammonites or belemnites have been collected. However, sedimentary rocks 50–100 m. above conglomerates $AE_6$ and $AG_{19}$ at localities AE and AG, and at the top of the section measured at locality AF, contain ammonite faunas rich in *Haplophylloceras strigile* (?) and *Bochianites* aff. *versteeghi*. In northern India, *H. strigile* was considered to be Upper Tithonian in age (Uhlig, 1910), and in Indonesia both this species and *B. versteeghi* have been reported from Jurassic–Cretaceous transition beds (Boehm, 1904). In view of the great thickness of sedimentary rocks between these faunas and the late Tithonian *Blanfordiceras* fauna, and the additional occurrence of *Spiticeras* aff. *spitiensis* and *Raimondiceras*, it seems reasonable to date this sedimentary sequence as Berriasian.

The belemnites are of little diagnostic value but the occurrence of *Hibolithes subfusiformis*, *Belemnopsis alexandri* and *B.* aff. *uhligi* provide a measure of correlation with the sequence at locality Z, where the ammonite faunas are different.

b. *Locality Z*. The poorly preserved ammonites at locality Z were initially interpreted as Upper Tithonian–Berriasian in age (Thomson, 1971*c*). Although the sequence at locality Z cannot be directly correlated on a bed-to-bed basis with that examined in the Ablation Point area (Fig. 5), the belemnites (Willey, 1973) and some bivalve species (Thomson and Willey, 1972) are similar to those in the Berriasian sequence of Ablation Valley (localities AE, AF and AG) (p. 17). Therefore, the whole sequence at locality Z is now considered to be Berriasian.

c. *Other localities*. Belemnites (*Belemnopsis gladiatoris*, *B. alexandri* and *B.* aff. *uhligi*) and a fragmentary ammonite, *Spiticeras* sp. (not unlike *S. damesi* (Steuer)) indicate a Berriasian age for the mudstones and overlying massive conglomerates west of the fault at locality J. Although no ammonites have been collected from localities D and F (Table II) and from above the major thrusts at locality C, belemnites suggest that the sedimentary rocks here are approximately equivalent in age (Fig. 6) to those at locality Z.

### 4. *Aptian*

Initially, an Aptian or Upper Aptian age was given to specific localities exposed along the coast between Succession Cliffs and Keystone Cliffs (Cox, 1953; Howarth, 1958). This age estimate was extended by Taylor (1965, 1966*a*, *b*, 1967) to other localities on the coast and in the interior. Thus, the whole of the Mesozoic succession between Succession Cliffs and Keystone Cliffs was equated within the rather narrow time limits of the Aptian (Thomson, 1967, p. 13) or Upper Aptian (Taylor, 1967, p. 2). Although work on the ammonites (Thomson, 1971*c*, 1974) has shown that some of the localities cited by Taylor have Aptian faunas, the succession at localities in Eros Glacier (p. 38) can no longer be regarded as Aptian.

The Aptian faunas of Alexander Island, like those of Australia and Patagonia, lack hoplitid ammonites which might provide a close zonal link with the faunas of Europe and the Malagasy Republic. In Alexander Island the Aptian ammonite faunas are characterized by aconeceratids and by a variety of heteromorphs

TABLE II

DISTRIBUTION OF STRATIGRAPHICALLY SIGNIFICANT MOLLUSCA FROM THE UPPER JURASSIC – LOWER CRETACEOUS SUCCESSION BETWEEN ABLATION POINT AND KEYSTONE CLIFFS

| | | | *Ammonoidea* | *Belemnoidea* | *Inoceramus* | *Other stratigraphically important species* | *Localities* |
|---|---|---|---|---|---|---|---|
| LOWER CRETACEOUS | | LOWER ALBIAN | *Phyllopachyceras aureliae*<br>"*Lytoceras*" sp. β<br>*Macroscaphites* (*?*) sp.<br>*Pseudothurmannia* cf. *mortiletti*<br>*Hemihoplites* (*?*) sp.<br>*Silesites desmoceratoides* (*?*)<br>*Silesites antarcticus* | | *Inoceramus* sp. β | | X and W |
| | | | *Eotetragonites* (*?*) sp.<br>*Costidiscus* (*?*) sp.<br>*Antarcticoceras antarcticum*<br>*Callizoniceras* (*?*) sp. | *Dimitobelus macgregori*<br>*Peratobelus oxys* | | | B |
| | | APTIAN | *Hypophylloceras* sp.<br>*Eotetragonites* sp.<br>*Australiceras* sp.<br>Heteromorphs of "*Ancyloceras*" *patagonicum* group<br>*Aconeceras* aff. *nisoides* | *Dimitobelus macgregori*<br>*Dimitobelus* aff. *macgregori*<br>*Neohibolites minimus* cf. var. *oblongus* | *Inoceramus* aff. *concentricus* | | A and T |
| | | | | *Peratobelus* aff. *australis*<br>*Neohibolites minimus* cf. var. *submedius* | | | T |
| | | | *Hypophylloceras* sp.<br>*Eulytoceras* aff. *polare*<br>*Lithancylus* (*?*) sp.<br>*Emericiceras* (*?*) sp.<br>*Toxoceratoides* **sp. nov.**<br>Heteromorphs of "*Ancyloceras*" *patagonicum* group<br>*Sanmartinoceras patagonicum* | *Peratobelus* **sp. nov.** (*?*) | | *Aucellina* of the *A. andina/radiatostriata* complex | T |
| | | | *Hypophylloceras* sp.<br>*Phyllopachyceras* cf. *baborense*<br>*Phyllopachyceras* sp.<br>"*Lytoceras*" sp. α<br>*Eulytoceras* aff. *polare*<br>*Acrioceras* (*?*) aff. *voyanum*<br>*Aconeceras* sp. α<br>*Aconeceras* (*?*) sp.<br>*Sanmartinoceras patagonicum*<br>*Theganeceras grande*<br>*Theganeceras* (*?*) sp. | *Neohibolites* cf. *miyakoensis*<br>*Neohibolites minimus* cf. var. *submedius* | | | AP, D, R, S and N |
| | | | | | "*Inoceramus*" *trapezoidalis* | | K |
| | NEOCOMIAN | BARREMIAN – VALANGINIAN | ? | ? | ? | ? | |
| | | BERRIASIAN | *Bochianites gracilis*<br>*Phyllopachyceras* (*?*) sp.<br>*Neocosmoceras* aff. *sayni*<br>*Himalayites* (*?*) sp. | *Hibolithes subfusiformis*<br>*Belemnopsis alexandri*<br>*Belemnopsis gladiatoris*<br>*Belemnopsis* aff. *uhligi*<br>*Hibolithes subfusiformis* | *Inoceramus pseudosteinmanni* | *Myophorella* sp. | Z, K, D and F |
| | | | *Substreblites* (*?*) sp.<br>*Phylloceras* sp.<br>*Sarasinella* aff. *hondana* | *Hibolithes subfusiformis*<br>*Hibolithes antarctica*<br>*Hibolithes* aff. *marwicki mangaoraensis*<br>*Hibolithes* **sp. nov.** (*?*) | *Inoceramus* sp. α | | Z, C and D |
| | | | *Haplophylloceras strigile*<br>*Bochianites* aff. *versteeghi*<br>*Spiticeras* aff. *spitiensis*<br>*Raimondiceras* **sp. nov.** | *Belemnopsis alexandri*<br>*Belemnopsis* aff. *uhligi*<br>*Hibolithes subfusiformis*<br>*Hibolithes* cf. *compressus* | *Inoceramus* sp. α | *Myophorella* sp. | AE, AF and AG |
| UPPER JURASSIC | | TITHONIAN | *Phyllopachyceras beneckei*<br>"*Berriasella*" *subprivasensis*<br>*Blanfordiceras* aff. *wallichi* | | *Inoceramus* sp. γ | *Myophorella* sp. | AC and AG |
| | | | *Calliphylloceras* sp.<br>*Phyllophacyceras beneckei*<br>*Phylloceras* aff. *serum* (*?*)<br>"*Lytoceras*" sp. indet.<br>"*Lytoceras*" **sp. nov.**<br>*Pterolytoceras exoticum*<br>*Haploceras* spp.<br>*Uhligites* aff. *kraffti*<br>Oppeliid **gen. nov.** (?)<br>*Virgatosphinctes* **sp. nov.**<br>*Virgatosphinctes* aff. *mexicanus*<br>*Virgatosphinctes denseplicatus*<br>*Virgatosphinctes* aff. *denseplicatus*<br>*Virgatosphinctes contiguus*<br>*Virgatosphinctes* **sp. nov.** aff. *andesensis*<br>*Virgatosphinctes* cf. *frequens*<br>*Aulacosphinctoides* aff. *sparsicosta*<br>*Aulacosphinctoides smithwoodwardi* (*?*)<br>*Aulacosphinctoides* **sp. nov.** α<br>*Aulacosphinctoides* **sp. nov.** β<br>"*Spiticeras*" sp.<br>*Corongoceras* cf. *lotenoense*<br>*Andiceras* (*?*) sp. | *Belemnopsis* aff. *uhligi*<br>*Belemnopsis belligerundi* | *Inoceramus* sp. δ | *Buchia* cf. *plicata*<br>*Buchia* cf. *spitiensis* | AB, AH, AJ and AK |
| | | KIMMERIDGIAN – UPPER OXFORDIAN | *Perisphinctes* (*Orthosphinctes*) cf. *transatlanticus*<br>*Pachysphinctes* (*?*) sp. | *Belemnopsis* cf. *alfurica*<br>*Belemnopsis* cf. *gerardi*<br>*Belemnopsis* cf. *keari*<br>*Belemnopsis* cf. *tanganensis* | *Inoceramus haasti*<br>*Inoceramus* aff. *subhaasti* | | Belemnite Point, Ablation Point and AH |

These faunas have been identified by M. R. A. Thomson and L. E. Willey.

together with phylloceratids and lytoceratids, few of which can be matched at all closely with species described from elsewhere. These faunas have been collected from localities AP (see below), A, the top of D, and from R, H, S, N and T. Two broad sub-divisions can be recognized.

At localities AP, D, R and H rich aconeceratid faunas containing species of *Aconeceras* and *Theganeceras* occur. The stratigraphical position of a specimen of *Sanmartinoceras patagonicum* from the screes at locality H is unfortunately unknown. A Lower rather than Upper Aptian age for these faunas (Thomson, 1971*c*, 1974) is emphasized by the occurrence of the heteromorph *Acrioceras* (*?*) aff. *voyanum* which has marked Neocomian affinities.

Only one ammonite has been collected *in situ* from locality N and none from equivalent zones at locality T. In the middle part of the section at locality T (units $T_6$ to the base of $T_{10}$), the only aconeceratid ammonite is *Sanmartinoceras patagonicum*. *Sanmartinoceras* was once regarded as indicative of the Upper Aptian or even Lower Albian but the evidence for this has been questioned (Waterhouse and Riccardi, 1970; Thomson, 1971*c*, 1974) and it is now concluded that it may also occur in the Lower Aptian. The belemnites *Peratobelus* aff. *australis* and *Peratobelus* sp. (*?*) nov. at locality T also characterize the Aptian sediments here.

### 5. *Lower Albian*

The *Eotetragonites* faunas of Succession Cliffs (locality A) and Waitabit Cliffs (locality T) probably represent the uppermost part of the Aptian or the Lower Albian. Although they are apparently undiagnostic, the silesitid/desmoceratid faunas of locality B must be younger in age since they occur stratigraphically above those of locality A; these are considered to be Lower Albian. A previous report suggesting the occurrence of the Upper Neocomian at locality B (Thomson, 1971*a*, p. 45) was based on a preliminary examination of the *Silesites*-like appearance of still doubtful specimens of *Callizoniceras* (*?*) sp., and the occurrence of *Costidiscus* (*?*) sp.

Poorly preserved fragments of *Eotetragonites* have recently been obtained from the screes at locality B, and a new genus of heteromorph, *Antarcticoceras antarcticum* (Thomson, 1974), from the same locality is of particular significance since it has also been collected from Stephenson Nunatak. The occurrence of *Peratobelus oxys* at the southern end of locality B (Willey, 1972, p. 39) is problematical. Published data suggest that in Australia it is restricted to the Aptian in beds below *Dimitobelus macgregori* (Albian–Cenomanian). However, at locality B, *P. oxys* may extend into the Albian because recent investigations show that *D. macgregori* probably occurs throughout the succession at this locality.

The ammonite faunas at Keystone Cliffs also have a strong Neocomian (? Barremian) appearance (Thomson, 1971*a*, *c*), yet it now seems probable that they may correlate with the Lower Albian faunas of Succession Cliffs (Thomson, 1974). The re-interpretation of the "thrust zone" beneath the ammonite-bearing sequence at Keystone Cliffs as essentially a gravitational slide or slump phenomenon (p. 58) lessens the possibility of there being any substantial reversal of stratigraphy in the sequences above and below it. Field evidence suggests that the Keystone Cliffs faunas are essentially in their correct stratigraphical position, i.e. above the late Aptian–Lower Albian beds in the upper part of the sequence at Waitabit Cliffs. Thus *Inoceramus* sp. *β* is probably Lower Albian rather than (?) Barremian as previously suggested (Thomson and Willey, 1972, p. 11, table II).

### 6. *The problem of the Neocomian*

Although apparently continuous successions between rocks of known Berriasian and Aptian ages are exposed (Fig. 6), no faunas diagnostic of the Valanginian–Barremian are known to occur. The following sequence occurs at locality AP, 8 km. south-west of Ablation Point:

| | |
|---|---|
| Mudstones with aconeceratid ammonites | (Lower Aptian) |
| 300 m. of siltstones with *Substreblites* at the base | (Berriasian) |
| ———————— *Reverse fault* ———————— | |
| Siltstones (largely obscured by scree) | |
| Conglomerate equivalent to unit $AG_{19}$ | (Berriasian) |

The bed with *Substreblites* presumably represents part of the thick sequence at locality Z where the ammonite also occurs. It is conformably overlain by approximately 300 m. of siltstones, passing up into more siltstones containing an aconeceratid fauna, which is indistinguishable from that at the top of locality D and the lower part of the cliffs at Fossil Bluff. The 300 m. of siltstones contain undiagnostic bivalves and serpulids and two as yet unsampled belemnite horizons. This sequence must represent either the greater part of the Neocomian or contain an undetected gap in sedimentation of considerable duration.

As yet there is no field evidence suggesting that any of these sediments have been faulted out. It is doubtful whether the reverse fault in the Berriasian part of the sequence at locality AP cuts out much of the succession because at localities AG and AF 200 m. of mudstones containing a *Haplophylloceras/ Bochianites* fauna are repeated above and below the *same* fault (Fig. 5).

No ammonites have been collected *in situ* from localities C (upper part), K, D, L, E, F and G, all of which lie stratigraphically below the Aptian sequences of Fossil Bluff and Waitabit Cliffs with their typical aconeceratid faunas. Since a minimum of 600–700 m. of sedimentary rocks are involved and belemnites from localities D and F have Neocomian affinities, it is probable that at least part of this sequence must be pre-Aptian in age.

### 7. *So-called Aptian faunas of Ablation Point*

The anomalous association of Upper Jurassic (Upper Oxfordian–Lower Kimmeridgian) ammonites (Howarth, 1958) and bivalves identified with the Aptian species *Aucellina radiatostriata* (Cox, 1953), from the north face of the hook at Ablation Point, was originally ascribed to the effects of thrusting. However, more recent observations suggest that thrust faulting in this area is not on a sufficiently large scale to cause such a juxtaposition of faunas, and the presence of Aptian sediments at Ablation Point itself is not only unproven but must be considered as highly doubtful.

This locality has not been examined in detail during recent investigations because the cliffs bordering Ablation Valley are more readily accessible and suitable for measuring stratigraphical sections. Nevertheless, the disturbed zone in the lower part of the cliffs at Ablation Point proper, and at the base of the cliffs on the south side of Ablation Valley, is probably laterally equivalent to those beds from which the "mixed" faunas were obtained. Although some small-scale thrust faulting is apparent, most of the structures in this zone probably represent the re-mobilization of partly consolidated sediments by slumping. No Lower Cretaceous (Aptian) fossils have been collected during recent investigations and, furthermore, a re-examination by M. R. A. Thomson of the previously collected "*Aucellina radiatostriata*" specimens (housed in the British Museum (Nat. Hist.)) casts doubt on their identification.

These specimens are not as well preserved as those from known Lower Cretaceous localities to the south and only general buchiid affinities can be confirmed. Numerous well-preserved specimens of *Buchia* have now been collected from the Ablation Valley area and it is probable that the so-called examples of *Aucellina* (Cox, 1953) from Ablation Point are species of *Buchia*. Apart from its smaller size, one recently collected left valve of *Buchia* (KG.731.2) is virtually identical to a plaster cast from the type of *Buchia spitiensis* var. *extensa* (Holdhaus, 1913, pl. XCVII, fig. 12a) housed in the British Museum (Nat. Hist.). Several narrowly elongate right valves ornamented only with regular concentric threads may also belong either to this variety or to *B. plicata* (Zittel). These only differ from Cox's apparently worn specimen of *Aucellina alexandri* (Cox, 1953, p. 8, pl. I, fig. 11) in their better preserved ornament. *B. spitiensis* var. *extensa* occurs in the Chidamu Beds of the Spiti Shales (Kimmeridgian–Tithonian) and *B. plicata* in the Lower Tithonian of New Zealand (Fleming, 1959).

Only one identifiable ammonite, *Pachysphinctes* sp., has recently been obtained from the disturbed zone. Its Kimmeridgian age is consistent with the general Upper Oxfordian–Middle Kimmeridgian age suggested by the bivalve and belemnite faunas (Table II).

## VI. DEPOSITIONAL ENVIRONMENT AND PALAEOGEOGRAPHY

ALTHOUGH the sedimentology and palaeogeography of this area have already been described or referred to in several previous papers (Taylor, 1966*a*, 1971*a*; Horne, 1967*a*, 1968*a*, *b*, 1969*a*, *b*; Thomson, 1971*b*), the following account gives additional information, notably on the regional extent and morphology of the Mesozoic trough and the palaeoecology as deduced mainly from the bottom fauna.

### 1. *Morphology of the trough prior to tectonism*

The first published accounts of the morphology of the Mesozoic trough by Horne (1967*a*, 1969*b*) were based on data from previous workers and on his own observations between Waitabit Cliffs and Triton

Point and westward as far as Mount Umbriel. Mesozoic sedimentary and subordinate pyroclastic rocks were thought to occupy a narrow linear trough orientated north–south and about 7,750 km.$^2$ in area. This was bounded eastward by a geanticlinal area of basement rocks and westward by an intermittently active volcanic archipelago (Horne, 1967*a*, p. 1). The eastern shoreline of the trough was thought to coincide approximately with the present linear coastline of eastern Alexander Island.

All of the palaeocurrent directions and gravity-controlled structures suggested that the bottom of the trough sloped westward and, although its western edge had not been located, the trough was thought to be at least 30 km. wide (Horne, 1969*b*, p. 63), i.e. extending as far as the eastern margin of the LeMay Range.

However, in the western foothills of the LeMay Range, Grikurov (personal communication to R. R. Horne) recorded steeply dipping and isoclinally folded sedimentary and pyroclastic rocks locally overturned to the east. These rocks, which Horne (1967*a*, p. 9) conceded might belong to a different, probably earlier, depositional cycle, were considered by Grikurov and others (1967) to be structurally and lithologically similar to the (?) Carboniferous Trinity series [*sic*] of north-east Graham Land. However, Grikurov and others (1967) acknowledged that the upper part of this "older sequence" might be *Jurassic* in age. Subsequently, myospores from sedimentary rocks on the northern and western sides of the LeMay Range (west of Pluto Glacier) were identified with Lower and Middle Carboniferous forms from eastern Europe (Grikurov and Dibner, 1968). It has also been suggested that part of this older sequence is Upper Carboniferous to Permian in age (Grikurov, 1971*c*, p. 164).

While acknowledging the occurrence of these myospores and the difficulties involved in determining the age of this older sequence, Horne (1969*b*, p. 69) maintained that the apparently unfossiliferous sandstones exposed in the ridge trending north–south through Mount Umbriel, i.e. co-linear with the LeMay Range, were the deeper-water equivalents of his Cretaceous shelf facies—because of their similar mineralogy, provenance and volcanogenic components and because their lithologies, textures and depositional structures were consistent with their geographical position in the trough as conceived by Horne.

More recent information on the areal extent of the Mesozoic sedimentary trough by C. M. Bell and A. Linn seems to reinforce Grikurov's (1971*a*) conclusions. The known Mesozoic outcrop extends at least 15 km. north of Transition Glacier and it is bounded westward by a sequence of structurally distinct sediments (personal communication from C. M. Bell) through a line approximately between Mount Edred, Nonplus Crag and the eastern margin of the LeMay Range. No field evidence has yet been obtained to support King's (1964, p. 60) observation that the LeMay Range is "crowned with *Cretaceous* strata disposed in folds like corrugated iron". Therefore, in Alexander Island the outcrop of Mesozoic sediments north of Venus Glacier is only 15 km. wide. The discovery of Upper Jurassic Mollusca by N. G. Culshaw at Carse Point, Palmer Land, suggests either a coastal embayment or a 30 km. extension of the Alexander Island Mesozoic trough into this area (p. 53). South of Venus Glacier and the north–south trending fault located by C. M. Bell and L. E. Willey (p. 13), outcrops of Mesozoic sediments indicate that the trough is at least 23 km. wide. Observations by Grikurov and Bell seem to support Adie's original suggestion that the Mesozoic trough developed adjacent to a rejuvenated (?) Carboniferous geosyncline (Adie, 1962, p. 33, 1963, p. 458) affected by a late Triassic–mid-Jurassic orogeny. This orogeny is well documented in the South Orkney Islands (Grikurov and others, 1967), the Antarctic Peninsula and Marie Byrd Land (Horne, 1969*b*, p. 74).

### 2. *Sedimentary environment and provenance*

Horne (1967*a*) argued a case for subdividing the sedimentary trough into three parallel "structural" and lithofacies zones.

i. A 1–5 km. wide coastal zone of shelf facies trending along the length of Alexander Island.
ii. A 16 km. wide central neritic zone culminating in the outer or western edge of the shelf in long. 68°31′W. (and characterized by diamictites).
iii. A western zone representing a deep-water axial-turbidite facies.

East–west lithological changes were interpreted as synchronous facies variations, the "facies zone indicators" were said to be well-defined and "localities where features of one zone are transitional into the succeeding one" were frequent. Subsequently, Horne (1969*b*) recognized five lithofacies which were considered to be synchronous from east to west, i.e. deltaic, inter-deltaic, shelf, shelf-edge and axial facies. Although their boundaries were not delineated on a map (Horne, 1969*b*, fig. 1), approximate positions were suggested by palaeoform lines (indicating the "deltas" and shelf edge), and by references to their occurrence in his text.

Horne (1969*b*, p. 61) recognized that, because of a constant southerly "stratigraphic tilt", facies patterns along the length of the trough at any point in time cannot be determined. However, he suggested that "on structural, petrological and palaeontological grounds the strata cropping out from east to west (or normal to the trough axis) are considered to be approximate lateral equivalents, and their lithological and faunal contrasts to be synchronous facies variations". No palaeontological evidence was cited but the structural and petrological data were outlined (Horne, 1967*a*, p. 3, 1968*b*).

Although this facies concept described the general pattern of sedimentation in the Mesozoic of eastern Alexander Island, a critical review of available information suggests that some points of detail need to be amended, e.g. the reliability of synchronous east to west facies changes as predicted by Horne and the practicability of a scheme based solely on lithofacies or rock units irrespective of time. The most suitable traverse to re-examine these data is that between Fossil Bluff, locality H and Mount Ariel where approximately 400 m. (Figs. 6 and 7) are common to all three sections, and where stratigraphical marker beds are particularly common.

According to Horne (1969*b*, fig. 6), Fossil Bluff lies within his inter-deltaic facies, whereas Mount Ariel would appear to be situated close to the shelf edge (Horne, 1969*b*, fig. 1). Such a traverse might be expected to show a westward decrease in the number of fossil genera and individuals, and fewer instances of cross lamination and current bedding (Horne, 1969*b*, p. 67). Despite an almost bed by bed correlation, none of these variations was observed in the field, and present collections even suggest that there is an *increase* in genera towards Mount Ariel. Thus, the "inter-deltaic" sequence at Fossil Bluff in Aptian times (Horne, 1969*b*, fig. 6) appears to have extended much farther westward than was previously envisaged. Likewise, the "inter-deltaic" sandstones or (?) deltaic sandstones at the top of the Fossil Bluff sequence can be traced westward as far (11 km.) as Mount Ariel and southward (11 km.) to locality N.

Although a continuous succession is also exposed between Fossil Bluff and locality P, the sequence at locality P is stratigraphically about 400 m. lower, and Lower Neocomian rather than Aptian. Similarly, at Triton Point, the sequence is probably no older than Lower Albian, whereas about 20 km. to the west, belemnites suggest a Lower Cretaceous (Berriasian) age. Thus, whereas Horne's palaeogeographical map in "late Aptian" times is an illustration of his facies concept, late Aptian sediments are only known to occur in parts of this area.

Pebbly mudstones may delineate a Mesozoic shelf edge in the interior parts of eastern Alexander Island (Horne, 1969*b*, fig. 1), but their occurrence at locality H and at Ablation Point in rocks probably corresponding to the "coastal" zone is apparently anomalous. It is clear that such deposits by themselves are not indicative of a shelf edge. No directional data are available for any of the pebbly mudstones recorded from Alexander Island.

Detailed stratigraphical sections described in this paper demonstrate that, at some localities, rocks representing all of Horne's facies (including every combination of lithology, sedimentary structure and faunal variant) can be found superimposed, with the possible exception of his "axial" facies. Although quartz : feldspar ratios in sandstones were said to vary smoothly across the facies zones (Horne, 1967*a*, p. 3), the ratios in the sandstones at Waitabit Cliffs show a range almost completely encompassing those for the rest of the area (Horne, 1968*b*, table I). The validity of relating east to west mineralogical variations to a horizontal scheme in diachronous strata perhaps spanning 15–20 m. yr. (Lower Neocomian to Lower Albian) is also questioned. Similarly, the variation in the ratio of stable to unstable constituents as shown by Horne's (1968*b*, table I) analyses is *not* "smooth across the facies zones" (Horne, 1967*a*, p. 3).

Although only *one* agglomerate had been found (Horne, 1968*b*), the area west of Mount Umbriel mapped by Grikurov (1971*a*) as "Trinity series" was thought by Horne (1969*b*, fig. 1) to have been the site of a volcanic archipelago or landmass in Lower Cretaceous times. The large size of the pyroclastic material in this agglomerate suggests the close proximity of a volcanic centre (Horne, 1967*b*, p. 54), which may have expelled some airborne material into the depositional trough. However, there is no evidence for an extensive extrusive area west of Mount Umbriel (Bell, 1973, p. 11). Additional evidence for contemporaneous volcanicity in or near the depositional trough is indicated by a variety of ejectamenta (Taylor, 1966*a*, 1967; Horne and Thomson, 1972) but their provenance has not yet been proved.

The Mesozoic shoreline of eastern Alexander Island was probably near the present-day coastline and a shelf edge existed some distance to the west (Horne, 1969*b*), but the distribution of sedimentary facies between these two boundaries appears to be far more complex than originally envisaged. Much of the succession seems to correspond to a variable shelf facies or to Horne's "inter-deltaic" facies. Additional current and down-slope directions other than those used by Horne (1969*b*, fig. 1) indicate a strong north to south component, i.e. parallel to the trough axis. More detailed east–west stratigraphical traverses and petrological sampling of established marker beds should be undertaken before an alternative facies scheme is proposed.

Most of the detrital fraction in the sedimentary sequence was probably derived from a landmass to the east (Taylor, 1966*a*; Horne, 1968*b*, 1969*a*, *b*), situated either in the present-day George VI Sound or in Palmer Land. The great volume of this sediment suggested to Horne (1969*b*, p. 74) that the elevation of this geanticlinal source area was maintained throughout the period of sedimentation. This is supported by evidence (below) of an active zone along the eastern side of the present-day Palmer Land during the late Jurassic to early Cretaceous, i.e. at a time virtually coinciding with the deposition of the Mesozoic succession of eastern Alexander Island.

This period of tectonism has so far been recorded at three localities. In eastern Ellsworth Land, deposits containing marine faunas ranging up to early Kimmeridgian in age (Laudon and others, 1969) are intruded by post-folding early Cretaceous dykes and by Middle Cretaceous plutons (Halpern, 1967). A similar late Jurassic–early Cretaceous period of folding is indicated in the Lassiter Coast area (Williams and others, 1971), where (?) Middle Cretaceous plutons intrude a late Jurassic geosynclinal succession (Williams and Rowley, 1971). The full northward extent of these Lassiter Coast sedimentary rocks is not yet known. However, possibly equivalent are some of the slaty rocks of the east coast of Palmer Land, described by Adie as possibly Trinity Peninsula Series (Adie, 1957*b*), and the more tightly folded sequence exposed on the plateau margin of eastern Palmer Land between Lurabee and Anthony Glaciers (Knowles, 1945, fig. 1) and at Mount Tenniel (personal communication from A. C. Skinner). Knowles's suggestion that the mainly slaty succession between Lurabee and Anthony Glaciers was (?) Jurassic was based on an overall lithological similarity between these and the Jurassic sequence in north-east Graham Land (Knowles, 1945, p. 145). The close juxtaposition of Jurassic sedimentary rocks on the Lassiter Coast with others on Bowman Peninsula, referred to the Trinity Peninsula Series (Adie, 1957*b*), suggests two possible interpretations, i.e. at least some of the "Trinity Peninsula Series" south of Kenyon Peninsula is Jurassic, and/or Jurassic sedimentation in eastern Palmer Land took place in or adjacent to a rejuvenated (?) Carboniferous geosyncline as in Alexander Island.

A later stage of the same late Jurassic to early Cretaceous orogeny may be represented at Crabeater Point (Fig. 2), where sedimentary rocks of probable Neocomian age are much more strongly folded (Thomson, 1967) than the Upper Cretaceous succession of north-eastern Graham Land.

This tectonic episode in Palmer Land probably caused a state of general instability in the Alexander Island area throughout much of the Upper Jurassic–Lower Cretaceous. This is demonstrated by many slump-shear structures, mass-flow deposits, sedimentary dykes and particularly by the massive conglomerates of latest Jurassic–earliest Cretaceous age in the Ablation Point area.

### 3. *Lithological evidence for rates of sedimentation*

The palaeogeographical implications of the syn- and post-depositional structures and of the textural and mineralogical immaturity of these sedimentary rocks have already been discussed (Taylor, 1966*a*; Horne, 1968*a*, *b*, 1969*a*, *b*). Therefore, it is intended only to reconsider the evidence for both rapid and relatively slow rates of sedimentation as shown by the alternation of coarse and fine sediments, and to examine in more detail than hitherto (Horne, 1969*b*) the palaeoecological implications of the fauna, notably the benthos.

Because of late Jurassic–early Cretaceous uplift near the depositional trough, there are many coarse, often poorly sorted boulder-conglomerates in the succession, notably those in the middle part of the succession in the Ablation Point area. In the upper part of Ablation Valley, these conglomerates comprise about one-third of the total thickness of exposed rocks. The lowest conglomerate ($AG_1$), which is traceable along the strike for 10 km. and down dip for at least 2 km., contains a higher percentage of volcanic clasts than the other conglomerates in the area (personal communication from C. M. Bell). As some well-rounded boulders measured by Bell were 4 m. in diameter, it is unlikely that they had been transported far from the shoreline. These conglomerates and their associated diamictites and wash-out channels indicate a much higher instability and rate of erosion of the source than elsewhere in this area. This may have coincided with the initial stage in the uplift of south-eastern Palmer Land.

The only other conglomerate north of Venus Glacier comparable in coarseness and thickness with those in the Ablation Point area occurs at locality J (Horne, 1969*a*, fig. 2c and d) as part of an as yet uncorrelated overthrust block (p. 56). It is 70 m. thick and is divisible into two lithofacies, a lower pebbly-sandstone facies 35 m. thick and a coarser polymict conglomeratic facies containing boulders (some of siltstone) up to 1·5 m. in diameter.

Although all of the conglomerates and associated sandstones indicate *proximity* to a shoreline, the only definite shoreline so far discovered, the overall configuration of which is known, lies between localities C and K. At locality C a 1–12 m. thick conglomerate, which is traceable from east to west for 1 km. and represents what was probably an offshore bar or shoal, grades down dip into cross-bedded intertidal sandstones containing *Myophorella* and an abnormally large number of bored fossil-wood fragments (Plate VIIIf). By contrast, the blanket-type conglomerate in the upper part of the succession at Fossil Bluff (Horne, 1969*a*, fig. 2a and b) is much thinner (0·5–2·0 m. thick) and the phenoclasts are embedded in a sandy matrix representing about one-third of the volume of the deposit. This conglomerate and its subjacent sandstones may have been the site of a delta (Horne, 1969*b*, fig. 1) which extended as far west as Mount Ariel and south to locality N (p. 40).

Pebbly mudstones along Horne's diamictite zone suggest further re-mobilization and rapid deposition below the shelf edge. The significance of similar deposits in the Ablation Point area is less obvious. Pebble-filled wash-outs, indicating rapid erosion and deposition, also occur in the Ablation Point area and at localities Z, M, G, H, L and Waitabit Cliffs (Taylor, 1966*a*; Horne, 1968*b*, 1969*b*).

It is difficult to assess the lithological evidence for normal or even relatively slow rates of sedimentation. However, the deposition of 1,100 m. of sediment in the Aptian suggests virtually continuous sedimentation.

### 4. *Airborne volcanic material*

Although the airborne volcanic material in the succession has been described (Taylor, 1966*a*; Horne, 1968*b*, *c*; Horne and Thomson, 1972), its regional and stratigraphical distribution have not been adequately discussed. Because only a part of the succession has been sampled petrologically, the distribution of vitric shard deposits (laumontitized or unlaumontitized) is not known with certainty. Thus the suggestion that they "comprise a large proportion of the sedimentary material" in the Aptian (Adie, 1971, p. 139) is not borne out by Horne's (1968*b*) published observations.

Between Succession and Keystone Cliffs, only two localized and unlaumontitized vitric-shard deposits have so far been recorded. At locality H, a 3·4 m. thick tuff (Taylor, 1966*a*, fig. 27) grades laterally into siltstones containing sandstone concretions and abundant fronds. Uncored ovate greenish pellets resembling devitrified lapilli occasionally occur between the shards together with more abundant Radiolaria. The shards are mainly of (?) sanidine and prehnite. At Succession Cliffs (locality B), a bed at least 3 cm. thick contains loosely compacted shards and more irregular macroscopic greenish pellets (see below). More numerous laumontitized vitric-shard deposits, some of them graded (Taylor, 1966*a*, fig. 30; Horne, 1968*b*; Horne and Thomson, 1972, fig. 2a) and bioturbated (Taylor, 1967), occur in the uppermost part of the measured section at locality D (unit $D_7$). The localized occurrence of these deposits, probably due to prevailing winds, may have contributed to increasing the thickness of unit $D_7$ compared with similar units at adjacent localities (e.g. $H_5$).

By contrast, the vitric crystal blebs (up to 4·1 cm. long) are common throughout parts of the succession (Fig. 6), notably Succession Cliffs (localities A and B), Mount Ariel, Waitabit and Keystone Cliffs. They are most abundant in one horizon at Fossil Bluff (not station KG.2 as reported by Horne and Thomson (1972, p. 106)) and are absent or rare in the measured sections at localities C, D, E, F, K and L. Thus, vitric-crystal blebs first appear in quantity in the upper part of the Neocomian and thereafter intermittently throughout the Aptian and Upper Aptian or lowermost Albian (where they are particularly common). They have not been recorded from the Ablation Point area.

There are at least three occurrences of devitrified lapilli. No stratigraphical data have been given for the first and earliest occurrence at locality D (Horne and Thomson, 1972, fig. 5a)* but it may be present at Fossil Bluff at a height of 70 m. in the measured section. The other known occurrences are confined to the upper parts of the succession at Fossil Bluff ($R_{21}$) and locality H ($H_{24}$ and $H_{25}$) and to an equivalent sequence at locality N (upper part of unit $N_3$). At Fossil Bluff there are three unusual strata characterized by

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* Horne and Thomson's (1972) station KG.91 is marked too far to the north and should be located at locality D (Fig. 3), not locality C.

stellate burrows (Taylor, 1967, fig. 8i) and less regular cuneiform structures. Although lapilli were collected from only one of these bioturbated beds, they probably occur in all three. The uppermost 4 cm. of the 2·9 m. thick bed is typically pitted due to differential weathering of the often macroscopic, ovate greenish lapilli, many of which are cored and unbroken. There are approximately 250 lapilli/cm.$^2$. At locality H, lapilli occur in the upper few centimetres of two beds in unit $H_{25}$ and in one stratum at locality N. These beds are bioturbated in the same way as those at Fossil Bluff. As the lapilli-bearing strata are virtually contemporaneous, they represent geographically the most extensive deposits of airborne pyroclastics discovered so far. The occurrences of uncored greenish pellets referred to above may also represent lapilli. Axiolitic structures of the type described and illustrated by Horne and Thomson (1972, fig. 5b and c) occur not only in the matrices but *within* several of the lapilli.

This aerially transported "fall-out" material may have been derived from several sources. Some of it may have come from near the site of the agglomerate whose matrix appeared to be identical in composition to that of the pyroclastic material described elsewhere in the succession (Horne, 1968*b*, p. 78). The agglomerate is situated approximately 37 km. south-south-west of Fossil Bluff (Horne, 1969*b*, fig. 1). Other possible source areas include Adelaide Island (where at least part of the (?) Upper Jurassic stratified volcanic and sedimentary rocks (Dewar, 1970) may be Lower Cretaceous (p. 53)) and Palmer Land, where volcanic rocks associated with sediments of possible Cretaceous age have been mapped (Adie, 1971, p. 139). According to Moore and Peck (1962, p. 191), most occurrences of lapilli are deposited within a few kilometres (probably within 6 km.) of the vent. However, all of the lapilli discussed by these authors are larger (2·0–5·6 mm.) than those described here.

### 5. *Some palaeoecological implications of the fauna*

There is some evidence for high and slight or suspended sedimentation and considerably more to suggest that much of the benthos was capable of overcoming any adverse effects of rapid sedimentation—other than catastrophic deluges such as those induced by turbidity currents. This evidence is discussed below.

The evidence for high or abnormally high sedimentation consists mainly of absences or rare occurrences of organisms. However, these could have been deterred by environmental factors other than sedimentological ones. Fossils are rare in the conglomerates, and shelf faunas such as corals and sponges which require very restricted salinity and turbidity ranges are absent and rare, respectively.

Although belemnite guards bored by acrothoracic cirripedes (Taylor, 1965) are locally abundant (p. 47), they do not occur in the belemnite "battle fields" of the Fossil Bluff area, which approximately coincide with an acrothoracic cirripede zone (Fig. 6). This suggests that, providing other environmental conditions conducive to cirripede settlement remained fairly constant, the "battle fields" were rapidly buried before infestation could take place. Considering the numerous shells in the succession, the rarity of epizoans is a further indication of rapid sedimentation.

By contrast, periods of slight or suspended sedimentation are represented by delicate ophiuroids, crinoids (Taylor, 1966*b*), almost completely articulated decapods (notably thin-shelled mecochirids), shell banks of *Aucellina* and *Buchia* (p. 45) and "reefs" of *Rotularia*. Sporadic epifaunas also occur, i.e. encrusting serpulids on ammonites (Thomson, 1973, pl. Ih and IVg), decapods (Taylor, 1979), bivalves, wood fragments and cobbles in wash-out deposits, a bryozoan on a belemnite guard, cirripede borings in belemnite guards (Taylor, 1965) and small discinid brachiopods attached to plant debris and a *Lingula* shell (Thomson, 1971*b*). One small colony of discinids was also found attached to a gastropod (Plate VIIIc). Quiet undisturbed sedimentation coupled with almost no mechanical re-working is demonstrated by the unusual occurrence of *Panopea* (in life position) in a *Pinna* (also in life position) (Plate VIIId).

The preservation of articulated Crustacea is often attributed to rapid burial. However, the occurrence of boring thallophytes in several decapod cuticles suggests that, providing the borer was not completely heterotrophic, these decapods must have lain uncovered long enough for the thallophyte spores to settle and proliferate (Taylor, 1971*a*, p. 297).

By contrast, an analysis of the benthos suggests that most were free-living forms capable of overcoming many adverse effects of high rates of sedimentation (Horne, 1969*b*, p. 70). Most of the Bivalvia were active forms, capable of swimming, or crawling on or burrowing into the sediment of the sea bed.

*Entolium*, common in south-eastern Alexander Island (particularly in the Lower Cretaceous part of the sequence), epitomizes the extreme bivalve shell form considered by Yonge (1936) as necessary for the development of the swimming habit, i.e. it has very thin, flat equilateral valves. The pectinid *Camptonectes* has a sub-circular shell outline, but a well-developed byssal notch below the anterior auricle of the right valve is indicative of byssal fixation for at least part of its life. However, several well-known examples of living byssus-attached species can also swim when necessary (Jackson, 1890; Kaufmann, 1969; Stanley, 1970) and *Camptonectes* possesses features observed in swimming pectinids (Stanley, 1970, p. 31, 41), i.e. a wide umbonal angle and a relatively broad convex shell.

Although it is probable that some of the Alexander Island species of *Lima* were capable of swimming, it is difficult to determine this on shell form alone. The pronounced asymmetry of the valves in some species may even have inhibited swimming, and some living species are known to remain byssally attached throughout life. The effect of the taxodont dentition on rapid opening and closing of the valves and hence on the potential swimming abilities of the related *Pseudolimea* is unknown; but the heavy and inflated shell of the commonest species suggests that they probably could not swim.

Fossil "*Trigonia*" is usually regarded as indicative of a shallow-water environment and the presence of *Myophorella* in the Ablation Point area and localities Z and K provides confirmatory evidence of this. As there is only one living genus of the once great trigoniacean lineage, little is known of their mode of life. The present-day *Neotrigonia* has a powerful foot which is capable of quite "athletic" movements (Fleming, 1964, p. 198), and in the aquarium it has been observed to behave as an "infaunal suspension feeder which lives with the posterior shell margin at or slightly above the sediment surface" (McAlester, 1966).

Burrowing forms, a common constituent of many of the bivalve faunas, include *Panopea*, *Pleuromya*, *Pholadomya*, *Thracia* and *Lucina*. *Panopea* and *Pleuromya* commonly occur in life position in sandy or silty mudstones, with their hinge axes vertical and with the elongated posterior parts of the shell directed upwards. Among the types present, these genera possess the shell form best adapted for burrowing and they almost certainly penetrated the farthest into the sediment. This deep penetration coupled with limited *mechanical* re-working of the sediment probably accounts for their frequent fossil occurrence in life position.

*Thracia* is unusual in that it has an inequivalve shell with the smaller left valve nestling just inside the larger right one. An inequivalve shell form in living Bivalvia is almost always associated with a life position resting on its side. Like the morphologically similar *Cochlodesma* (Allen, 1958), *Thracia* burrows into the sediment of the sea bed and then lies with its commissure in the horizontal plane; feeding and respiration are carried out via a pair of mucus-lined tubes extending to the sediment–water interface. The shallow-burrowing *Nuculana* occurs only rarely.

Although known sedentary byssus-attached species are less varied than the active forms, they occasionally occur in considerable numbers. *Pinna*, commonly found in life position, has a mode of life which has been carefully studied (Yonge, 1953). Despite its sessile existence, a study of Liassic occurrences in England led Hallam (1960) to conclude that the genus even favoured conditions of high sedimentation. Once established, *Pinna* cannot withdraw from the sediment, but the rapidity with which it can repair a damaged shell (Yonge, 1953, p. 361) suggests a possible mechanism for keeping pace with sedimentation, assuming that the soft parts were able to grow fairly rapidly. However, specimens from Alexander Island rarely exceed 10 cm. in length. The discovery of a living *Pinna* completely covered with epibonts (Boekschoten, 1967, p. 315) indicates that some of these bivalves are capable of living free on the sea bed. Whether this example was uprooted or had lain free all of its life is not known.

Although some limids (widely reported elsewhere nesting in "fissures") may have been derived from crevice habitats near the coast, others probably occupied spaces within the root bundles of aquatic plants (Kaufmann, 1969, p. *N*151) close to the location where they now occur.

The elongated shell form of the various species of the *Grammatodon* group suggest an exposed byssus-attached mode of life rather than a partly buried one (Stanley, 1970, p. 90). As even free-burrowing arcids are sluggish, large numbers of this group at particular horizons suggests times of reduced sedimentation during which hard grounds may have developed. Because paired valves are common in such horizons, they can only have undergone minimal transportation.

Numerically most important Mesozoic bivalves in Alexander Island are the Buchiidae, *Buchia* (Upper Jurassic–lowest Cretaceous) and *Aucellina* (Upper Neocomian–uppermost Aptian or earliest Albian). Both have a closely similar external morphology, i.e. a strongly inequivalve shell consisting of a deeply convex, oblique left valve with an enrolled umbo, and a smaller, flatter right valve with an anterior byssal notch. The almost *Gryphaea*-like form* of the shell might suggest that buchiids lay loose on the sea floor with

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* Many *Buchia* species show a striking resemblance to *concentricus* group *Inoceramus* and have often been misidentified with that genus. Inequivalve inoceramids are generally considered to have been loose-lying sedentary forms.

their flat right valves uppermost, and Fleming (1959, p. 892) has already considered the possibility of such a mode of life for *Buchia plicata*, a large species with a strongly inflated left valve. However, he seemed unprepared to extend this hypothesis to the Buchiidae as a whole. The presence of a byssal notch indicates an attached mode of life during at least part of their lives, but its small size in large examples of such species as *Buchia plicata* casts doubt on the effectiveness of byssal attachment in adult individuals.

Imlay (1959, p. 156) considered that *Aucella* [ = *Buchia*] "apparently thrived on hard bottoms in shallow, much agitated waters" and cited its scarceness in thick siltstone units, "except for widely separated thin, coquinoid layers", as evidence of this. Similar layers of *Buchia* occur in the Ablation Point area and *Aucellina* coquinas are present at Fossil Bluff. Scattered articulated specimens in localized parts of the succession (notably at Ablation Valley and Succession Cliffs) may have been torn off nearby hard grounds or could be examples adopting a *Gryphaea*-like mode of existence in soft sediment.

As most buchiids in Alexander Island occur as isolated valves (usually the flatter and lighter right valves) it is possible that they were transported some distance from their habitat. Such a markedly inequivalve shell type would lend itself to the mechancis of current sorting, the right valve travelling the farthest.

*Inoceramus*, another typically Mesozoic bivalve, occurs commonly in parts of the succession; its absence elsewhere has already been discussed (Thomson and Willey, 1972). The genus *sensu lato* is morphologically diverse and widely varying modes of life have been suggested for its various forms at different times, e.g. active benthonic, sedentary and loose-lying, byssus fixed and even swimming (Sornay, 1966). *Inoceramus* is well known as a facies breaker and for the widely differing environments it could inhabit (e.g. Reeside, 1957); the Alexander Island specimens are generally too poorly preserved to warrant a speculative discussion as to their modes of life.

Imlay's (1959, 1961) observations in Alaska indicated that *Buchia* and *Inoceramus* never occurred in the same bed, whereas in Alexander Island there are many instances of associated *Aucellina* and *Inoceramus*. However, it is possible that in some cases, at least one genus was transported.

The ecological significance of the inarticulate Brachiopoda has already been discussed (Thomson, 1971*b*) but the occurrence of articulate forms at localities AC and AK in the Ablation Point area and at several localities in the vicinity of Fossil Bluff (notably D, L, R, H and S) has some bearing on the present discussion. Although Rudwick (1970, p. 91) has suggested that some Palaeozoic strophomenids might have been able to "swim", the articulate brachiopods are essentially a sessile group. Their attached mode of life suggests that they could not tolerate high rates of sedimentation and their occurrence in the present succession may be interpreted in several ways:

i. They indicate periods of reduced sedimentation or non-sedimentation.
ii. They were washed into the area of deposition.
iii. They were attached to algae, floating logs, etc. (Rudwick, 1970, p. 77) not preserved in the fossil state.

It is possible that at different times and places all three mechanisms were operative.

Brachiopods from locality AK occur on ammonite shells in a position of attachment (Plate VIIIe). The ammonite conches, presumably of dead individuals, would have provided a hard substratum which also kept the brachiopods above the level of any accumulating sediments. Their relatively large size (2 cm. or more in length) implies periods of slow sedimentation but their occurrence in a position of apparent attachment indicates that they were probably finally overcome by sediment and buried *in situ*.

It is likely that many of the brachiopods scattered throughout the mudstone and siltstone sequences were transported, if only because the sea bed would probably have been unsuitable for attachment. The modern terebratulid *Chlidonophora* has a long pedicle, with rootlets which pierce Foraminifera shells in the deposits of the sea bed, enabling it to anchor itself in soft sediments (Rudwick, 1970, p. 78, fig. 62). Thus, the possibility of some fossil species being able to do the same must always be borne in mind. However, the chances of substantiating this (i.e. finding some trace of the modified pedicle) are minimal. Although small groups of brachiopods at Fossil Bluff containing up to 12 individuals could represent small communities originally attached to algae, they may also indicate aggregations of individuals washed together by current action; the occurrence of *Rotularia* and small turriculate gastropods in similar accumulations (up to 19 individuals) favours the latter interpretation.

### 6. *Trace fossils*

Trace fossils (mainly feeding burrows) are abundant in the more argillaceous parts of the Mesozoic succession of eastern Alexander Island (Taylor, 1967). However, only a few types have so far been discovered compared with other areas rich in ichnofossils, e.g. the Fort Hays Limestone Member of the Niobrara Chalk (Upper Cretaceous) of west-central Kansas (Frey, 1970).

Tracks and trails (other than those referred to by Horne (1969*b*, p. 70)) are uncommon but burrows of what are generally assumed to have been lithophagic organisms, i.e. *Chondrites*, *Zoophycos* and vermicular structures, occur throughout parts of the succession. The nutrients to support these burrowing organisms were probably derived mainly from the abundant benthos and rich vegetation.

Although anaerobic conditions may have existed from time to time, and from place to place, at or just below the water–sediment interface (Horne and Taylor, 1969, p. 30), high ratios of sediment-ingesting organisms are thought to indicate that the associated sediments were well aerated as sub-surface oxygenation is enhanced by re-working (Seilacher, 1964, p. 303). Furthermore, the abundant endobenthos probably increased the porosity and incoherence of the sediments which remained in a thixotropic state for a considerable period of time after deposition.

The only form of *Zoophycos* so far recorded from eastern Alexander Island is the flat non-spiraled type (Taylor, 1967) supposed to indicate waters below effective wave base down to bathyal depths in non-turbidite areas (Frey, 1970, p. 23). In Alexander Island, the frequent occurrence of these planar burrows in sediments either immediately preceding or succeeding a thick-bedded sandstone (e.g. beneath unit $L_4$ and in equivalent strata at locality E) suggests that here the ichnofossil preferred a relatively shallow-water environment. The first appearance of *Zoophycos* in the Eros Glacier area virtually coincides with a sudden increase in fauna, notably of *Rotularia* and terebratelloids. However, thereafter there are no significant compositional or numerical changes in the invertebrate fauna indicating why *Zoophycos* occurs in such well-defined ichnofacies (Taylor, 1967, fig. 6), and why it disappears above unit $R_5$.

Contrary to Taylor (1967, p. 25), *Palaeodictyon* (?) is common only at localities K and C (where the last-recorded occurrence of the ichnogenus could be used in correlation). It is also found more sporadically at localities Z, D and U. As *Palaeodictyon* is usually thought to represent a deep-water facies, its occurrence along what was probably the eastern shoreline of the Mesozoic trough (Horne, 1969*b*) is problematical.

Because the ichnofaunas (notably *Chondrites*) are remarkably uniform laterally, no significant (and synchronous) differences in bathymetry based on ichnofacies can as yet be demonstrated on a regional scale either east–west or north–south. However, there are local variations usually associated with the thick-bedded sandstones where, predictably, most *spreitenbauten* are steeply inclined or perpendicular to the bedding.

Throughout the Upper Jurassic–Lower Cretaceous of eastern Alexander Island, changes in ichnofacies directly or indirectly related to bathymetry and/or food supply occurred. In the area discussed here, a predominantly *Chondrites* ichnofauna at locality Z is equivalent at localities L and E (if existing correlations are substantially correct) to an almost unfossiliferous, possibly poorly oxygenated sequence with no trace fossils. This sequence is followed by several *Zoophycos* facies (with associated *Chondrites*) and by three stratigraphically important *Chondrites* ichnofacies. *Chondrites* also occurs at Succession and Keystone Cliffs. It is unlikely that these fluctuations in ichnofacies represent major changes in palaeobathymetry. Both *Chondrites* and the tabular form of *Zoophycos* (with its relatively simple burrow structure) probably preferred quiet water conditions. Although it has been suggested by Horne (1969*b*, p. 70, figs. 9 and 10a and b) that the numerous and relatively large tubular burrows in the Triton Point area (Taylor, 1967, fig. 9a) indicate accumulation of unstable sediment by rapid currents of fresh or brackish water, a high-energy marine environment may also have been compatible with these burrowers.

Although belemnite guards (and more rarely enclosed phragmocones) bored by post-mortal acrothoracic cirripedes were said to occur throughout the succession (Taylor, 1965, p. 41), it is now known that they are confined to six main ichnofacies and three isolated occurrences (Fig. 6). Furthermore, even within these ichnofacies bored guards usually represent only a small fraction of the total belemnite population. At locality F (and less notably at locality E), the Acrothoracica have a considerable stratigraphical range, whereas elsewhere they are less common (locality G) or absent (Succession Cliffs) even though belemnites are present in virtually every stratum. Because the belemnites were often inadequately sampled, it is difficult to determine how many hosts are involved. However, at locality F, there are two or possibly three hosts, i.e. *Belemnopsis alexandri* and either *B. gladiatoris* or *B.* aff. *uhligi*, or both. Recent work by L. E. Willey on the belemnites at this locality shows that the Acrothoracica here are probably Berriasian rather than Aptian in age (Taylor, 1965, fig. 3a–c; Newman and others, 1969, p. 252).

At locality H, the absence of bored guards stratigraphically equivalent to those at Mount Ariel and locality G may be a sampling error. However, their absence at localities U and D, within approximately the same stratigraphical boundaries, is probably ecological. The presence of several horizons rich in plant debris at locality G and the greater frequency of sandstones and *Zoophycos* burrows at Mount Ariel and locality G suggest a different, possibly shallower environment here compared with localities U and D. Shell borers are generally restricted to shallow-water marine environments (Seilacher, 1969, p. 718).

### 7. *Belemnite "battle fields"*

In the fossil record it is often difficult to distinguish between instances of mass mortality (commonly reported in present-day marine environments) and the effects of current sorting, because the two phenomena frequently produce similar effects, i.e. shell banks.

At Ablation Point, locality D, Fossil Bluff and Mount Ariel (Plate VIIIa), there are one or more discontinuous shell banks up to 5 m. thick composed of densely packed belemnite guards; these have sometimes been referred to in the literature as belemnite "battle fields". The best is developed at Mount Ariel where the largest of two banks is up to 1·2 m. thick and 17 m. long.

The presence of abnormally large numbers of pebbles, cobbles, wood fragments, (?) re-worked "cementstone" concretions and brecciated siltstone blocks in these banks, and the parallelism of individual guards suggest that wave sorting and/or current action has taken place. However, the presence of both juvenile and adult guards in these shell banks suggests that winnowing may only have modified a deposit resulting from some form of catastrophic death.

Both natural endogenous and external factors may have caused the mass mortality of these belemnites. Present-day squids (e.g. *Loligo*), which are considered analogous to fossil belemnites, are gregarious spawners and at least one species (*Loligo opalescens*) dies after spawning (Brongersma-Sanders, 1957, p. 960). In one such instance, it was reported that "the sea bottom for about 100 yards was littered with dead or dying squids" (Lane, 1957, p. 128).

Alternatively, whole shoals of belemnites might have died through some environmental factor such as waterbloom (Gunter and others, 1948; Bary, 1951; Mstislavsky and Kochenov, 1961), pressure waves caused by seaquakes or abnormally large amounts of $H_2S$ associated with volcanism. Annual, often catastrophic mass mortality of squids coinciding with an enormous increase of phytoplankton occurs along the Chilean coast (Brongersma-Sanders, 1957, p. 981). Although penecontemporaneous volcanism in the vicinity of the depositional trough in eastern Alexander Island lends some credence to the possible effects of seaquakes and abnormal amounts of $H_2S$, it is unlikely that a nektonic animal would be smothered by showers of airborne volcanic ash as was inferred by Adie (1962, p. 33; 1964*a*) to account for the abundance of belemnites at Belemnite Point. Indeed, it has been emphasized that the injurious effects of volcanism have previously been exaggerated and often misinterpreted for something else, notably waterbloom which may be a side effect of volcanism (Brongersma-Sanders, 1957, p. 943). Certainly, there is no indication that the "battle fields" at Ablation Point, Fossil Bluff and Mount Ariel were formed as a result of ash showers. Abnormal changes in sea temperature are known to induce catastrophic death amongst squids, notably during the winter of 1929 when abnormally low temperatures in the Adriatic Sea caused the mass mortality of numerous *Sepia officinalis* (Brongersma-Sanders, 1957, p. 949).

In the Middle Fernie (Middle Bajocian) of Canada, concentrations of belemnites similar to those in Alexander Island may have been formed exclusively by wave sorting in shallow water (Frebold, 1957). However, in the Jurassic and Cretaceous of New Zealand, some form of mass mortality (either as a physiological after effect of spawning or some external factor) is thought to have preceded some winnowing of the smaller guards (Stevens, 1965, p. 56).

Local abundances of Radiolaria, often coinciding with a high tuffaceous content in the sediments, may represent either mass mortality due to influxes of toxic chemicals associated with the volcanism (Horne and Thomson, 1972, p. 108), or to a sudden "bloom" caused by the introduction of silica from the same source (Katz and Watters, 1966, p. 340; Horne and Taylor, 1969, p. 27).

### 8. *Abnormal salinities*

The presence of conglomerates and deltaic-type sandstones, and the postulated occurrence of river deltas (Horne, 1969*b*), suggest that at several times during the Upper Jurassic and Lower Cretaceous areas of reduced salinity would have developed locally around estuaries. It is also probable that sand bars and spits accumulated from the coarser detritus transported into the sea, resulting in the formation of areas of restricted or lagoonal sedimentation. Sediments comprising the nunataks at the south-eastern corner of the island were considered by Knowles (1945, p. 141) to be non-marine; likewise Fuchs and Adie (Adie, 1952) deduced from the occurrence of both plants and invertebrates that the sediments farther north were deposited in a littoral or estuarine environment. However, it is difficult to indicate specific examples of such conditions on faunal grounds. The light-coloured deltaic-type sandstones and the conglomerates are either sparsely fossiliferous or unfossiliferous but whether this faunal paucity is the result of reduced salinity, the high-energy environment, or both, is not clear.

A deposit which might represent brackish water conditions is a 2–3 cm. thick shell bed at locality Z. It occurs at the top of a 53 m. thick mottled sandstone and marks the base of 20 m. of muddy sandstones and sandy mudstones passing up into a more normal mudstone sequence. The shell bed, consisting mainly of small smooth corbiculid bivalves, also contains smaller numbers of *Nuculana*, *Lucina* (?), two species of gastropod and *Dentalium*. A band of dirty greenish sandstone immediately beneath the shell bed contains *Meleagrinella* (?), and *Gervillella* occurs in the muddy sandstones immediately above. Apart from an obvious marine influence, suggested by *Dentalium*, and the variety of species present, the shell bed proper strongly resembles the brackish water corbiculid beds of the Purbeck and Wealden in southern England (Casey, 1955). Thus, it is possible that this corbiculid bed represents a short period of brackish water conditions in an environment of fluctuating salinities, during which deltaic-type sedimentation was being replaced by fully marine conditions.

In discussing the Mesozoic faunas of south-eastern Alexander Island, Horne (1969*b*, p. 70) recalled a long-recognized criterion of brackish water conditions: high population density coupled with low specific variety, and he implied that "almost monotypic shell beds of *Inoceramus* or of *Aucellina*" might be examples of this. Hallam (1969, p. 13) suggested a similar origin for the *Buchia*-, *Inoceramus*-, and *Gryphaea*-rich beds of the Jurassic in the Boreal Region. However, as there are many instances when buchiids and *Inoceramus* are truly marine, their occurrence in beds of low diversity need not necessarily imply brackish water conditions. Other factors which may account for their abundance in sediments rich in terrigenous clastics (Hallam, 1969, p. 16) are turbidity and a plentiful supply of food as in Alexander Island.

At Waitabit Cliffs there are approximately 30 m. of sandy shales ($T_8$) which become increasingly arenaceous upwards until they pass with complete transition into true sandstone. The shales are characterized by abundant iron pyrites which has resulted in the development of yellowish gypsum encrustations on exposed surfaces and in open joints, and this suggests that the beds accumulated under somewhat stagnant conditions. This is confirmed by the impoverished fauna, for the most part restricted to occasional specimens of *Lingula*, small turriculate gastropods including *Rissoina*, and small smooth bivalves. Definite marine species (*Anchura* (?) and ammonites) are limited to a few horizons only and usually occur in concretions. These pyritiferous sandy shales are thought to have accumulated in a restricted lagoonal environment (Horne and Taylor, 1969, p. 30), where the water was generally brackish; the truly marine species were probably washed in sporadically.

Another possible example of brackish water conditions occurs at locality E. Here, the lower part of the succession (the first 184 m. of unit $E_1$) consists of almost unfossiliferous mudstones and intercalated sandstones characterized by numerous and relatively large (30–45 mm. in diameter) nodules of iron pyrites and encrustations of yellowish gyspum. Trace fossils, often indicative of well-aerated sediments, are scarce.

### 9. *Palaeoclimate*

Some idea of the palaeoclimate of eastern Alexander Island in the Upper Jurassic–Lower Cretaceous is suggested by certain petrological observations, by the type of flora present, by the occurrence of *Discinisca* and *Lingula* and by palaeotemperature studies on belemnite guards of a similar age and species from the Indo-Pacific region.

Horne (1969*b*, p. 71) suggested that rapid derivation of texturally immature sand and silt from plutonic rocks (as reported in eastern Alexander Island) typified areas characterized by warm, periodically wet climates. Certainly, the occurrence of deltaic-type sediments and the relatively abundant flora indicate a moderately heavy rainfall in the source area.

Bedded limestones are absent from the present succession and some climatic significance has been attributed to their absence from successions elsewhere (Arkell, 1956, p. 616). However, as has been emphasized by Craig (1961, p. 218), precipitation of limestone depends not only on temperature but also on the amount of clastic material being deposited—as in eastern Alexander Island.

In any analysis of the palaeoclimate of a region, considerable caution should be exercised in assessing the palaeoclimatological significance of the fauna and flora, especially of extinct groups or those whose supposed extant counterparts may be living in significantly different geographical environments. A classical example of altered distributions is the common Jurassic bivalve assemblage of *Trigonia*, *Astarte* and *Pholadomya* when compared to their present-day descendants (Arkell, 1956, p. 616). Nevertheless, it is possible to make a general analysis.

The source area at least adjacent to the coast supported a rich, mainly bennettitalean flora which presupposes suitable soil and climatic conditions to support this luxuriant plant growth. The general similarity between many fossil Bennettitales and living cycadophytes (e.g. the resemblance of *Ptilophyllum* to *Zamia*) suggested to several palaeobotanists that the fossil Bennettitales thrived in climates not significantly different from those of living cycadophytes, i.e. tropical or sub-tropical. In the case of Alexander Island, Seward (Stephenson and Fleming, 1940, p. 165) suggested that at least one of the fossil plants collected by the B.G.L.E. indicated a climate "which was almost sub-tropical". Likewise, Plumstead (1964, p. 651) inferred that the Jurassic "cycads" and conifers of the Mount Flora plant beds were so closely related to living cycadophytes that they must have grown under similar climatic conditions.

However, recent investigations by Harris (1969, p. 1) have shown that any phylogenetic connections between the Bennettitales and the Cycadales must be remote. Furthermore, as living cycadophytes are only a remnant of a previously more variable group, it is possible that in the past they occupied a much wider geographical and climatological range. Whereas fossil Bennettitales in Alexander Island undoubtedly indicate a climate considerably warmer than that at present, it may be misleading to infer from these as yet systematically undescribed plants that this climate was warmer than temperate.

Palaeoclimatologically, the fauna is less diagnostic. From among the nine animal phyla represented the only climatically significant fossils (apart from the belemnite guards) are *Discinisca* and *Lingula*. As even these now live in both temperate and warm waters, it can only be inferred from their presence in south-eastern Alexander Island that the sea-water temperature was warmer than that at the present day (Thomson, 1971*b*).

Of some possible significance in the palaeoclimatology of eastern Alexander Island are the belemnite guards which have yet to be examined isotopically. Although it is generally accepted that anomalous oxygen-isotope determinations do occur (Longinelli, 1969; Spaeth and others, 1971), minimal values, i.e. those representing the least possible isotopic exchange, indicate approximate ranges of sea-water temperatures. Formerly, belemnites were thought to indicate relatively cool waters (Bergquist and Cobban, 1957, p. 873; Peterson, 1958, p. 128) but it has since been demonstrated by Stevens (1965) that different belemnite subfamilies and perhaps different genera possessed different temperature tolerances.

Analyses of comparable belemnite faunas (containing similar genera and species) from the Upper Jurassic and Cretaceous of Australia and New Zealand (both of which may have been in similar latitudes to Antarctica in the Mesozoic) indicate a temperature low of approximately 12° C in the Aptian, with higher temperatures in the Upper Jurassic and Albian (Clayton and Stevens, 1968; Stevens and Clayton, 1971).

Although Ludbrook (1966, p. 25) suggested that the palaeotemperatures from the Australian belemnites of the Great Artesian Basin may have represented water temperatures existing at depths in excess of 198 m., Lowenstam and Epstein (1954, p. 243) concluded that most belemnites inhabited near-shore waters. This conclusion is supported by growth-ring analyses indicating well-defined seasonal fluctuations not expected to occur at depths substantially below sea-level (Dorman and Gill, 1959, p. 91; Clayton and Stevens, 1965, 1968). On the basis of mean annual sea-water temperatures, Clayton and Stevens (1965) suggested that the Australian and New Zealand belemnites may have lived in an area similar to that existing today between lat. 41° and 48° S. where the climate ranges from temperate to cool temperate. Palaeomagnetic evidence for any given locality often appears to contradict palaeotemperature data for the *same* locality. This apparent anomaly may be due to variations in the trend of major oceanic currents (Stevens and Clayton, 1971, p. 879), and/or a lack of ice caps in the Mesozoic with a less marked climatic zonation than the present day.

# VII. REGIONAL SETTING AND COMPARISONS

## A. South Georgia, Annenkov Island and Western Antarctica

The Upper Jurassic and Lower Cretaceous marine sequence of south-eastern Alexander Island forms only one of several isolated Mesozoic successions exposed in the sub-Antarctic islands of South Georgia and Annenkov Island, and the peninsula region of western Antarctica (Fig. 1; Table III). The stratigraphical and palaeontological relationships of these areas to that described here are briefly discussed below.

### 1. *South Georgia and Annenkov Island*

South Georgia is largely composed of a thick flysch-like succession of graded shales, sandstones and conglomerates. This is structurally complicated but it has been divided into two main lithological sequences: the Sandebugten type and the Cumberland Bay type (Trendall, 1959). Few fossils have been found which give any precise indication of age but a possible acanthoceratid ammonite from Prince Olav Harbour (Salomon, *in* Heim, 1912) and a doubtful "*Posidonia*" from Moraine Fjord (Andersson, 1906) indicate a Mesozoic age for the Cumberland Bay type sediments. On the south coast of the island, the supposed upper parts of this sedimentary sequence are interbedded with spilitic lavas, and Adie (1964*a*, *b*) has reported fossiliferous Aptian sediments from this part of the succession. These fossils have not yet been described.

A poorly preserved Mesozoic fauna of supposed Aptian age has been described from similar sedimentary rocks on Annenkov Island off the south-western coast of South Georgia (Wilckens, 1947). The fauna includes fish remains, cirripedes, ammonites, bivalves and echinoderm fragments, but the stratigraphically most important species are:

*Aucellina radiatostriata* Bonarelli and Nágera
*Puzosia matheroni* (d'Orbigny) (*?*)
*Tropaeum* (*?*) *antarcticum* Wilckens
*Georgioceras kohllarseni* Wilckens
*Sanmartinoceras* cf. *patagonicum* Bonarelli.

Although it has been equated with the Aptian fauna of Fossil Bluff (Adie, 1963, p. 459, 1964*b*, p. 311), a more cautious view of the supposed similarities is advocated here as only *Aucellina radiatostriata* has been positively identified from both areas. *Sanmartinoceras* cf. *patagonicum* from Annenkov Island is based on extremely poor material (Wilckens, 1947, pl. 3, fig. 6a and b) and the tentative identification of *Georgioceras* from Fossil Bluff (Howarth, 1958, pl. I, fig. 3) has not been substantiated by the collection of more specimens—even though the young stages of *Georgioceras* have a distinctive style of ornament (described in great detail by Wilckens (1947)) that would make it easily recognizable if found again.

Doubts concerning the Upper Aptian age assigned to the Annenkov Island fauna were expressed by Casey (1961, footnote on p. 56) who observed that:

i. *Georgioceras* Wilckens has a "style of sculpture seen more frequently in the Neocomian Crioceratitidae than in the Ancyloceratidae".
ii. "'*Puzosia matheroni* (d'Orbigny)?' . . . looks more like a Hauterivian *Plesiospiticeras*".

Thus, evidence for the supposed faunal similarities between Alexander Island and Annenkov Island must await the collection of further material from the latter locality.

### 2. *South Orkney Islands*

Poorly preserved faunas including fish teeth, small gastropods, bivalves, belemnites and echinoderms have been obtained from Gibbon Bay and Rayner Point on Coronation Island. At Gibbon Bay they occur in a thin bed of sheared black shales (Matthews, 1959, p. 435) lying between the "basement complex" and a thick conglomerate. At Rayner Point the fossils occur in calcareous grit boulders within the conglomerate. These faunas have been examined by several palaeontologists who have suggested that they are Mesozoic, probably Cretaceous. As the belemnites might be a species of *Belemnopsis*, a late Jurassic–earliest Cretaceous age is indicated (Willey, 1973). The faunas, notable for the small size of their constituent forms, show no obvious resemblance to any other Antarctic fauna yet described. Poorly preserved Mesozoic ammonites and bivalves have also been collected from Matthews Island (Thomson, 1971, p. 56).

## TABLE III

### N ATTEMPT AT CORRELATING THE MAIN OCCURRENCES OF JURASSIC AND LOWER CRETACEOUS SEQUENCES OF THE ANTARCTIC PENINSULA AND ADJACENT AREAS. THE STRATIGRAPHICAL EXTENT OF THE UPPER JURASSIC VOLCANIC GROUP IS LEFT IN DOUBT. HORIZONTAL ALIGNMENTS OF FORMATIONS BETWEEN AREAS IMPLIES APPROXIMATE AGE EQUIVALENCE ONLY

| | *Livingston Island* | *North-eastern Graham Land* | | *Graham Land especially Adelaide Island* | *Alexander Island* | *Palmer Land* | | | *Eastern Ellsworth La* |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Carse Point* | | *Lassiter Coast* | |
| **lbian** | | | | | — — — ? — — —<br>Succession Cliffs<br>Waitabit Cliffs<br>? Keystone Cliffs<br>Stephenson Nunatak | | | | |
| **ptian** | | Pebbles in Stoneley Point Conglomerate of James Ross Island | | | Area east of Eros Glacier and south to Waitabit Cliffs. Localities south-west of Ablation Point | | | | |
| **arremian** | | | | ? Strongly folded black shales of Crabeater Point | — — — ? — — — | | | | |
| **auterivian** | | | ? | | ? | | ? | | |
| **alanginian** | | | | | — — — ? — — — | | | | |
| **erriasian** | Shoreline deposits of western Byers Peninsula | | | | West end of Ablation Valley. Locality Z | | | | |
| **thonian** | | | | | Ablation Valley area | Pyritiferous shales at base of volcanic sequence | | Volcanic sequence of Mount Poster | |
| **immeridgian** | | Loose fossils in James Ross Island group and sediments at eastern end of Longing Gap | Upper Jurassic Volcanic Group | Water-lain tuffs at base of 3,000 m. volcanic sequence on Adelaide Island | Tuffaceous sediments of Belemnite Point and disturbed zone of Ablation Point area with basal lavas | | Upper Jurassic Volcanic Group | Strongly folded sediments of Latady, Scaife and Wilckens Mountains<br>— — — — — — | — — — — — —<br>Belemnite faun<br>Lyon Nunatak<br>— — — — — — |
| **xfordian** | | | | | — — — — — —<br>? | | | | Ammonite faunas of southern Behrendt Mountains |
| **allovian** | | | | | | | | | — — — — — — |
| **athonian** | | | ? | | | | ? | | — — — — — — |
| **ajocian** | | ? Mount Flora plant beds and underlying conglomerates. Botany Bay and Oscar II Coast sequences | | | | | | | Ammonite fauna of southern Behrendt Mountains |
| **re-Bajocian** | | | | | | | | | (?) Plant beds of Mount Neuner |

### 3. *Livingston Island*

A sedimentary sequence on Byers Penninsula, formerly thought to be Miocene (Hobbs, 1968), has subsequently yielded marine faunas of Tithonian to Neocomian age (González-Ferrán and others, 1970; Tavera, 1970). Although published illustrations (Tavera, 1970) suggest that the faunas are poorly preserved, they seem to bear little resemblance to those of Ablation Point even though they must be of a similar age. The only comparable species is *Spiticeras* (*Spiticeras*) cf. *spitiensis*, but even this is probably not conspecific with the species referred on p. 36 to *Spiticeras* aff. *spitiensis*.

Detailed stratigraphical information (Valenzuela and Hervé, 1971) suggests that the ammonites occur at only two levels and in a much thinner sequence than in Alexander Island. The faunas are of considerable palaeogeographical importance because they are closely associated with terrestrial plant beds (González-Ferrán and others, 1970) and the whole sequence must have been deposited close to the Mesozoic shore.

### 4. *North-eastern Antarctic Peninsula*

Around the periphery of James Ross Island and on some adjacent islands (Vega, Snow Hill, Seymour, Cockburn and Humps Islands) are exposures of a thick sequence of marine Upper Cretaceous (Campanian) sedimentary rocks (Bibby, 1966).

However, the presence of earlier Mesozoic marine deposits in the James Ross Island group is inferred from the discovery of:

i. A loose fragment of the Upper Jurassic ammonite *Perisphinctes* cf. *transatlanticus* at Hidden Lake (Spath, 1953, p. 3, pl. XII, fig. 5).
ii. Lower Cretaceous *Aucellina andina* in a pebble from the Stoneley Point Conglomerate of James Ross Island (Bibby, 1966, p. 8).

Other bivalves and perisphinctid ammonites of Upper Jurassic age have been collected at Longing Gap (Bibby, 1966, p. 8). Thus, these few remnants represent what must have been relatively extensive deposits in north-eastern Antarctic Peninsula, equivalent in age to those so well-developed in eastern Alexander Island.

### 5. *Cape Legoupil*

A thick sequence of folded greywackes, arkoses, sandstones, conglomerates, argillites and pebbly mudstones from Cape Legoupil and offshore islands in Bransfield Strait (Halpern, 1964, 1965) has been radiometrically dated as Cretaceous on a dyke cutting the sediments and a diorite pebble from a pebbly mudstone. Poorly preserved bivalves from Kopaitic Island, tentatively identified as *Platopis* sp. (hitherto known only from the Northern Hemisphere), were thought to support this age determination. However, lithologically and structurally, the Legoupil Formation is more comparable with the Trinity Peninsula Series of the northern Antarctic Peninsula and the Miers Bluff Formation of Livingston Island (Elliot, 1965, p. 2, 1966, p. 41; Dalziel and Elliot, 1973, p. 193), both of which are late Palaeozoic in age.

Three latex casts of fossil bivalve hinges in the British Museum (Nat. Hist.) are labelled as having been prepared from specimens collected in the Cape Legoupil area. Two notable features are the stout, obscurely bifid, median triangular tooth in the left valve and the presence of a buttress behind the anterior adductor muscle scar. These characters and other details of the dentition suggested to M. R. A. Thomson that these bivalves compared most favourably with some of the Permo-Triassic Myophoriidae, particularly *Myophoria* Bronn and *Neoschizodus* Giebel.

### 6. *Adelaide Island and the Upper Jurassic Volcanic Group*

The basal part of a 3,000 m. thick sequence of stratified volcanic rocks on Adelaide Island has yielded an Upper Jurassic fauna of fragmentary ammonites and bivalves (Thomson, 1972*b*). One of the bivalves (*Inoceramus* aff. *subhaasti*) also occurs in the disturbed zone at the base of the marine sequence exposed in Ablation Valley (p. 35), where it is considered to be Upper Oxfordian or Kimmeridgian in age. Marine micro-fossils and trace fossils have also been found in water-lain tuffs of a similar age in south-west Adelaide Island (Thomson, 1969).

Marine fossils also occur in Upper Jurassic sediments containing a high proportion of tuffaceous material at Belemnite Point (Adie, 1962), and in sedimentary volcanic rocks at Carse Point, mapped as Upper Jurassic (p. 53). Curtis (1966, p. 49) inferred that current-bedded tuffs and volcanic agglomerates on the Graham Coast were deposited in water close to the shoreline. Therefore, it seems likely that at least on the western side of the Antarctic Peninsula, the Upper Jurassic Volcanic Group contains a considerable amount of water-lain tuffaceous marine sediments, and it is probable that more fossiliferous localities will be discovered.

On the east coast of the Antarctic Peninsula, volcanic rocks of an equivalent age contain plant beds but no marine fossils have yet been recognized. Several thin sections of fine-grained water-lain volcanic rocks of supposed Upper Jurassic age (collected by A. F. Marsh) were examined by M. R. A. Thomson for marine micro-fossils but none was found.

Although volcanic sequences can accumulate rapidly, the widespread distribution of the Upper Jurassic Volcanic Group in the Antarctic Peninsula and the localized thick successions suggest that these rocks may not be confined to the narrow time limits of the Upper Jurassic (Table III). The Upper Jurassic and Lower Cretaceous marine sedimentary rocks of eastern Alexander Island contain considerable quantities of penecontemporaneous volcanic debris (Adie, 1957*a*, p. 457; Taylor, 1966*a*; Horne and Thomson, 1972) and lavas are interbedded in the marine sequence as late as the Tithonian (p. 17). It is therefore possible that some of these volcanic sequences exposed in Graham Land range as high as the Lower Cretaceous (Dalziel and Elliot, 1973, p. 203). Conversely, a downward extension of the age of this volcanic sequence is apparent from radiometric dates obtained from correlated rocks on Jason Peninsula; apparently unaltered andesites (Adie, 1971) have been dated at about 165 m. yr. (Middle Jurassic) and basalts (Rex, 1971) at 156 m. yr. (Upper Jurassic) and 186 m. yr. (late Triassic).

Because the andesite–rhyolite volcanic group of Hope Bay conformably overlies plant beds dated by Halle (1913*b*) as Middle Jurassic, it has been widely accepted that these volcanic rocks were Upper Jurassic in age. If Rao's (1953) re-assessment of the age of the plant beds as Lower Jurassic is valid, then the volcanic sequence could equally well be Middle Jurassic in age. Yet a third interpretation follows from a critical review of the same plant beds and the related Rajmahal floras of India by Stipanicic and Bonetti (1970, p. 109, table II), who concluded that the flora of the Hope Bay plant beds is uppermost Jurassic, in which case the andesite–rhyolite volcanic group would be Lower Cretaceous in age.

The term "Upper Jurassic Volcanic Group" has proved useful for referring to predominantly intermediate to acid volcanic sequences throughout the Antarctic Peninsula, which were all thought to be of the same age (i.e. Upper Jurassic). As it is probable that these rocks span a time of greater duration than Upper Jurassic, a new name, having no chronological significance, would be preferable.

### 7. *Crabeater Point*

A poorly preserved fauna from this isolated locality was tentatively assigned a Cretaceous age (Thomson, 1967), although it was not comparable with known Antarctic Cretaceous faunas. On a re-examination of the heteromorph ammonite (Thomson, 1967, fig. 6), an early Cretaceous age seems most probable. Associated with this internal mould fragment is an external mould showing an openly coiled shell form resembling a hoop. The loose coiling and simple non-tuberculate ribs recall two European Hauterivian–Barremian species, *Moutoniceras moutonianum* (d'Orbigny) and *M. annulare* (d'Orbigny), except that both of these are even more openly coiled than the Antarctic species. Although *M. annulare* is the closest match, it has constrictions which have yet to be demonstrated in the specimen from Crabeater Point.

### 8. *Carse Point*

At the foot of the exposed cliffs of Carse Point, beneath a thick succession of volcanic rocks, there is a thin sequence of black pyritiferous shales. These contain a late Jurassic molluscan fauna of bivalves, ammonites and belemnites, probably equivalent in age to part of the tuffaceous sequence in the disturbed zones at Belemnite and Ablation Points. The belemnites (species of *Belemnopsis* and *Hibolithes*) occur in Alexander Island but the ammonites (*Kossmatia* spp.) have not yet been recorded there. *Belemnopsis* was also found in a coarse-grained tuff in the overlying volcanic sequence.

### 9. *Lassiter Coast*

A thick sequence of strongly folded black siltstones and shales in the Lassiter Coast area (Williams and Rowley, 1971; Williams and others, 1971) contains rich ammonite and bivalve faunas indicating a late Jurassic age (Middle–late Kimmeridgian = Middle Kimmeridgian–Lower Tithonian in the sense used here). Faunal identifications by R. W. Imlay, of the United States Geological Survey, suggest that the ammonite faunas are slightly earlier than the Tithonian ones of Alexander Island, although they also contain species of *Aulacosphinctoides*. The presence of *Inoceramus haasti* and *I. subhaasti* in the Kimmeridgian and lowest Tithonian part of the sequence implies a possible correlation with parts of the disturbed zone of the Ablation Point area where similar forms also occur (Thomson and Willey, 1972).

The uppermost part of the sequence is represented by dacitic and andesitic volcanic rocks at Mount Poster. From their stratigraphical position, these can be no older than Lower Tithonian and could even be early Cretaceous in age.

### 10. *Ellsworth Land*

At several localities in eastern Ellsworth Land, notably the Behrendt Mountains, a thick sequence of structurally complicated sedimentary rocks is folded about west-north-west trending axes (Laudon and others, 1969; Laudon, 1971). These contain varied marine faunas (Stevens, 1967; Laudon and others, 1970; Quilty, 1970, 1972*a*, *b*) ranging from Middle to Upper Jurassic in age, and a Lower to Middle Jurassic flora is present at Mount Neuner. Three ammonite faunas (Bajocian, Callovian and Oxfordian) have been distinguished (Quilty, 1970) and belemnites from Lyon Nunataks may be as late as Kimmeridgian in age (Stevens, 1967). Most of this sequence pre-dates the succession described here under the Fossil Bluff Formation but the bivalve genera present (Laudon and others, 1969) are broadly similar to those from eastern Alexander Island. However, the Ellsworth Land sedimentary rocks appear to contain more volcanic detritus than those of the Fossil Bluff Formation except perhaps for the earlier (Upper Oxfordian–Kimmeridgian) part of the formation represented by the disturbed beds at Ablation Point. Furthermore, fossils are apparently commoner in coarser-grained sedimentary rocks than in south-eastern Alexander Island.

## B. EXTRA-ANTARCTIC REGIONS

The concept of the Antarctic Peninsula as a more southerly extension of the South American Andes is a long-held one and the present separation of the two, together with the fragmentation of the Scotia arc, may be conveniently explained by the mechanism of continental drift. Since the exact drift path of each fragment of the Scotia arc is still unknown, postulated reconstructions of the precise way in which the Antarctic Peninsula and Patagonian South America were once joined differ appreciably (cf. Barker and Griffiths, 1972; Dalziel and Elliot, 1973). The most comprehensive geological comparison of these two areas to date is that of Dalziel and Elliot (1973). Among their conclusions they noted that the tectonic situation of Alexander Island is analogous to that of South Georgia and Navarino Island, i.e. they are all parts of the Pacific "hinterland" of the Andean and western Antarctic cordilleras, or "Antarctandes" as they are sometimes called. This agrees with Horne's (1967*a*, 1969*b*) interpretation of the Alexander Island Mesozoic sedimentary trough as a back trough formed along the margin of present-day Palmer Land (or cordillera).

In addition to their similar tectonic setting, the Yahgan Formation of Navarino Island (Katz and Watters, 1966), the Cumberland Bay type sediments of South Georgia (Trendall, 1953, 1959) and the Fossil Bluff Formation of eastern Alexander Island also resemble each other in the great thickness of sedimentary rocks present, their tuffaceous content and the broadly similar ages of all three formations. However, the Fossil Bluff Formation differs in two important respects: it is many times more fossiliferous and it is not known to be intruded by plutonic rocks. In view of the widely accepted geological similarities between Patagonia and the Antarctic Peninsula, the faunal comparisons between these two regions are disappointing.

The sparsely fossiliferous Yahgan Formation contains *Inoceramus pseudosteinmanni*, as do the sediments of locality Z (Thomson and Willey, 1972). However, the more fossiliferous Upper Jurassic–Lower Cretaceous sequences of west-central Patagonia, in the vicinities of Lago San Martín (Bonarelli and Nágera, 1921; Leanza, 1970) and Lago Argentino (Feruglio, 1936, 1949), apparently contain relatively few forms in common with the Fossil Bluff Formation. Initially, systematic descriptions of Lower Cretaceous fossils from Alexander Island (Cox, 1953; Howarth, 1958; Ball, 1960) indicated that the following species (almost half the total number identified) were also common to Patagonia:

*Aucellina andina*
*Aucellina radiatostriata*
"*Pecten*" cf. *argentinus*
*Sphaera* (?) *striata*
*Ancyloceras patagonicum*
*Sanmartinoceras patagonicum*
*Rotularia australis*
*Rotularia callosa*.

The subsequent collection of many more specimens from Patagonia (e.g. ammonites; Leanza, 1970) and Alexander Island has failed to disclose a proportionate increase in the number of species common to both regions, and earlier, widely reported accounts of the similarities between the "Aptian" faunas of these two areas (e.g. Cox, 1953, p. 5; Adie, 1963, p. 456) thus seem to have been exaggerated. However, these differences may still be apparent ones and could largely be a reflection of collection failures. For example, no counterparts of the rich echinoderm (Taylor, 1966*b*) and decapod crustacean (Taylor, 1979) faunas of Alexander Island have yet been reported from Patagonia, whereas the bivalve *Maccoyella* and the ammonite *Aioloceras*, both of which occur in Patagonia and Australia, have not yet been recognized in Alexander Island.

Because Upper Jurassic belemnites in South America are poorly known, any comparison with the belemnites from the Upper Oxfordian–Kimmeridgian–Tithonian of Alexander Island is naturally biased towards regions other than South America. These faunas therefore appear to be most closely related to those of East Africa, India, Indonesia, Australia and New Zealand (Willey, 1973). However, the close similarities shown by the earliest Cretaceous belemnites of Alexander Island to those of Patagonia (see below) suggest that a good correlation with South American Upper Jurassic belemnite faunas is possible once they become better known.

The Tithonian *Virgatosphinctes*/*Aulacosphinctoides* ammonite faunas of the Ablation Point area are broadly similar to others of similar age in the Malagasy Republic (Collignon, 1960) and the Himalayas (Uhlig, 1910). However, the occurrences of *V.* sp. nov. aff. *andesensis*, *V.* aff. *mexicanus* and isolated specimens of *Corongoceras* (?) *lotenoense* and *Andiceras* (?) sp. also indicate a South American influence. In the uppermost Tithonian, *Blanfordiceras* aff. *wallichi* is related to species typical of the Malagasy Republic, the Himalayas and Indonesia, whereas "*Berriasella*" *subprivasensis* is a South American species. Species of *Buchia* have only been re-collected in the Tithonian part of the sequence (although early collections appear to have come from the disturbed zone) and a preliminary examination suggests that they are closely related to *Buchia spitiensis* and/or *B. plicata*, which also occur in the Himalayas, Indonesia and New Zealand.

Except for the *Haplophylloceras*/*Bochianites* fauna of Ablation Valley (also represented in the Himalayas and Indonesia), the earliest Cretaceous ammonites so far collected are too poor for comparison (Thomson, 1974), whereas the belemnites are of considerable value. These show similarities to species from East Africa, India, Indonesia, Australia, New Zealand and also Europe. One species, *Belemnopsis gladiatoris* (Willey, 1973), is conspecific with *Belemnites* (*Belemnopsis*) *patagoniensis* (Feruglio, 1936; *non* Favre, 1908) from the Lago Argentino area of Patagonia, and both occur in association with similar *Hibolithes* faunas. *Myophorella* in the Tithonian and Berriasian of Alexander Island compares favourably with South American and South African forms.

The Aptian ammonite faunas (Thomson, 1971*c*, 1974) apparently show no strong relationships with any particular extra-Antarctic region, and in many cases species have been compared with examples from the diverse European faunas for the want of comparable faunas in the Gondwana continents. Nevertheless, a free marine connection with Patagonia and Australia is indicated by the occurrence of such genera as *Sanmartinoceras* and *Aucellina* in all three areas. Species of the belemnite genus *Peratobelus* (Willey, 1972) compare closely with the distinctive Australian forms, whereas *Neohibolithes* species resemble those of Japan and Europe. It is possible that some of the large heteromorph ammonites from the Malagasy Republic and Australia (*Australiceras* and *Tropaeum*) may have their equivalents in Alexander Island but the Antarctic specimens are too fragmentary for detailed comparison. Lower Albian *Dimitobelus* show strong affinities with examples from New Guinea, Australia and New Zealand but there are no Gondwana equivalents of the *Eotetragonites* fauna.

From amongst the decapod fauna, the Glypheidae and Erymidae resemble those from the Aptian and Upper Albian of Queensland and some dispersal from Antarctica to south-eastern Australia may be inferred (Taylor, 1979). However, many of the other decapods either resemble European forms (*Trachysoma* aff. *ornatum*) or have no Southern Hemisphere counterparts and must of necessity be compared with Northern Hemisphere (mainly European) forms, often from the *Upper* Cretaceous.

## VIII. STRUCTURE

THE structural geology of most of this area has already been described and interpreted by Horne (1967*a*). The north–south fold axes have not complicated the interpretation of measured sections and faunal sequences in the coastal exposures, but the effects of thrust faults and disturbed zones are more important. Their probable modifications to an apparently simple succession and the origin of the disturbed zones are discussed below.

### 1. *Western margin*

In Fig. 4, the western margin of the Mesozoic sedimentary belt in Alexander Island is shown diagrammatically as a north–south-trending fault, an interpretation in partial agreement with that of Grikurov (1971*a*, fig. 1). Because of inaccuracies in the topographical map (Searle, 1963), it is probable that the curved boundary at the head of Jupiter Glacier on Grikurov's map is apparent rather than real. The fault's existence was previously inferred from the high topographical position of tightly folded (?) older rocks immediately west of the Upper Jurassic–Lower Cretaceous sequence and from the significantly different structures of these two sequences (personal communication from C. M. Bell). The fault has now been located approximately 7 km. south of Mount Umbriel at the head of Venus Glacier (p. 13) and air photographs suggest that it may be exposed near the western end of Nonplus Crag.

South of Venus Glacier, the outcrop of the Mesozoic sequence is considerably wider than it is to the north. It appears that the southern part of this area has been displaced along a fault or fault system situated in Venus Glacier (Fig. 4). This is shown by the east–west offsetting of the major north–south fault in this area; this displacement has been omitted by Bell (1973, fig. 3).

### 2. *Ablation Point area*

a. *Ablation Point.* Ablation Point (Plate IXa) and the coastal cliffs just south of Ablation Valley are notable for the development of chaotically bedded and folded sedimentary and subordinate volcanic rocks at least 350 m. thick, referred to as a disturbed zone.

The "weird fold structures" in this zone were first ascribed by Adie (1964*a*, p. 152) to the effects of "severe repeated overthrusting from the west", and they were later interpreted by Horne (1967*a*) as representing a "lubrication" zone related to overthrusting. Early palaeontological studies (Cox, 1953; Howarth, 1958) supported a complexly interthrust origin for this zone, since it appeared to contain both Upper Oxfordian–Lower Kimmeridgian ammonites and Aptian bivalves. The similarity of this and other comparable zones in eastern Alexander Island to "syn-sedimentary" slump zones in Patagonia (Scott, 1966) was considered by Horne (1967*a*, p. 6) to be superficial. However, a recent study at Ablation Point has revealed structural and sedimentological evidence supporting a gravitational "sedimentary" or slump origin for many of the incorporated structures (personal communication from C. M. Bell).

There is also some palaeontological evidence which could be used in support of the same argument. Because the supposed Aptian bivalves collected from the north face of the hook at Ablation Point (Cox, 1953) are *Buchia*s of probable Kimmeridgian–Tithonian age (p. 38), it is unnecessary to invoke complex interthrusting here. Furthermore, all available evidence indicates that the sediments of the disturbed zone are essentially of the same age (Upper Oxfordian–Kimmeridgian; p. 35) and that they are all older than the overlying Tithonian.

b. *South Grotto Glacier.* 10 km. west of Ablation Point on the southern margin of Grotto Glacier is an apparently impersistent zone of disturbed sediments (Plate IXb) overlying a strongly discordant reverse fault. The fault is probably equivalent to that examined at the head of Ablation Valley (locality AF; p. 38) and also at locality AP (p. 37). It has a displacement of several hundred metres on the south side of Grotto Glacier but at localities AF and AP the amount of movement is unknown. No disturbed bedding is associated with the fault at localities AF and AP but the sediments are intensely brecciated. However, immediately below the fault plane at Grotto Glacier, drag folds indicate relative movement of the western block upward and eastward. Imbricate structures are also well-developed here in a thick bed of mudstone interbedded with a more sandy sequence. The incompetent deformation in this sequence and in the crumpled beds of the disturbed zone above is comparable in many ways with that seen at Ablation Point.

### 3. *Pluto Glacier to Uranus Glacier*

a. *Succession Cliffs.* At locality J, at the northern end of Succession Cliffs (Plate IIa), a steep, westerly dipping reverse fault has juxtaposed a poorly fossiliferous Berriasian sequence (capped by a 70 m. thick conglomerate) against an Upper Aptian–Lower Albian sequence. The conglomerate is not exposed in the coastal cliffs of localities A and B, and the nearest lithological equivalents are those conglomerates in the sequence between the fossiliferous Tithonian and Berriasian sediments of the Ablation Point area. Movement along this fault is at least equivalent to the thickness of sediments exposed above it at locality J (300 m.) and it is probably considerably more. The fault has been traced along a line about 0·5–1·0 km. west of the coastal exposures of Succession Cliffs and on a spur between localities B and C (Plate IIb), finally emerging into George VI Sound about 1 km. south of locality C. 147 m. above the base of the section measured at locality C (Fig. 6; Plate IIc) are 51 m. of chaotically bedded sandstones and interbedded, strongly sheared shales. Disjunctive folding is well developed in the upper part of the zone and there are at least two thrust planes with significant west to east dislocations.

7·5 km. south of Succession Cliffs, at locality D, small-displacement reverse faults with a north–south trend have displaced sandstone dykes cutting the sequence. The relative movement on the western side of the faults is upward and eastward.

b. *Locality L.* At locality L (Plate IXd), on the western side of Eros Glacier, a thrust has superposed at least 350 m. of mainly dark shales on a sequence of light-coloured sandstones interbedded with flaggy shales and siltstones. The thrust plane dips at 27° to the west and overthrusting towards the east is clearly indicated by drag folds and small-scale imbricate shears. Since the sandy beds are poorly fossiliferous and no fossils have been collected from the shales above the thrust which might give a precise age to the sediments, the stratigraphical importance of this thrust is difficult to assess.

c. *Fossil Bluff.* A 23 m. thick, slightly discordant disturbed zone in the cliffs just south of the Fossil Bluff field station (Plate IXc) has been briefly described and illustrated by Horne (1967*a*, fig. 2). The sediments involved are mostly broken into disorientated blocks, sometimes with the bedding vertical, but in other instances they are recumbently folded about west–east axes. No obviously cataclastic breaks have been observed within the zone but there is a 10 cm. thick calcite/quartz vein at its base. One of several sandstone dykes in this area cuts the disturbed zone but whether this originates from it is uncertain because of the scree cover. The zone is traceable northward in the cliffs behind the field station towards locality U. A comparison between the successions at Fossil Bluff and locality H indicates that the disturbed zone is probably wedge-shaped, tapering to locality H, and that it has had an insignificant effect on the stratigraphy of these areas.

### 4. *Waitabit Cliffs*

Along the southernmost 0·8 km. of Waitabit Cliffs (Plate Xa) the sediments in the upper part are affected by three successive dislocations (i–iii; Plate Xa), which repeat the succession.

The lowest and most extensive of these (i) is a thick (up to 3 m.) zone of brecciated mudstones. It is apparently concordant with the bedding for much of its extent, but northward it becomes strongly discordant and curves upward to transgress a considerable thickness of sediments; these are equivalent to units $T_{10}$–$T_{15}$ at locality T. At the southern end of the cliffs, this zone dips south-westward beneath a snow ridge and it is not exposed in a gully situated behind and parallel to the cliff face. The second dislocation plane (ii), marked by a 3 cm. thick calcite-veined crush zone, is apparently concordant with the bedding. Its southward extent is limited by a third plane (iii) which overrides it. Plane iii is strongly discordant and cuts down through the sedimentary sequence towards the south; in the gully behind the cliff face it completely cuts out plane ii. No basal cataclastic zone is present but much of the overlying sedimentary sequence appears to be jumbled and brecciated (Plate Xa, top centre). A possible sandstone dyke (d) occurs near to this (?) brecciated region.

In the top of the cliff at the northern outcrop of plane i is a block of banded mudstones quite different from those in the main body of the disturbed mass. The sediments have been folded and (?) dislocated in a style similar to that observed in the disturbed zone at Keystone Cliffs (see below). The mechanics involved in the emplacement of this exotic block are not yet understood.

Apart from this block, the sediments involved in the disturbed complex are all equivalents of some of those in the stratigraphical section measured at northern Waitabit Cliffs ($T_{10}$–$T_{14}$). Although it was not possible to measure the disturbed complex, some of the sedimentary units appear to be abnormally thick compared with the sequence at locality T (Fig. 6). This suggests that more as yet undetected dislocation planes are present.

The top of this disturbed sequence is approximately co-linear with a thinner (5–10 m.) and more extensive zone to the north. Here, dips and strikes may vary considerably both vertically and laterally, and the beds appear to be arranged in large slabs and wedges which are sharply delineated from adjacent ones. This zone, which has been traced northward to the northern end of southern Waitabit Cliffs, is probably responsible for the thrust-like structure at the top of the section measured at locality T (Fig. 6).

### 5. *Keystone Cliffs*

At Keystone Cliffs (Plate IIId) is a spectacular disturbed zone, second only to those at Ablation Point and Belemnite Point. It has been interpreted by Horne (1967*a*) as a "lubrication" zone over which a thick sequence of virtually undeformed sediments has been thrust eastward. Structures developed in this zone are largely of two types: folds with sub-horizontal axes (Plate Xb; Horne, 1967*a*, fig. 3a) and large sediment wedges (see below).

The best folds are developed in the area shown in Plate Xb (locality W). All of them demonstrate the peculiar feature mentioned by Horne, i.e. they close against the cliff and appear to adhere to it. A 3 m. thick bed of indurated mudstones at locality X contains several tight recumbent folds with sub-horizontal axes. In places, mudstones may have flowed around folded sandstone but elsewhere the close jointing gives the rock a brecciated appearance. The very elongated and flattened form of the folds suggests that they were formed under strong horizontal shear.

However, most of this zone consists of variously orientated large slabs or wedges up to tens of metres thick and hundreds of metres in lateral extent composed of bedded mudstones and minor sandstones. Where the contact between any two wedges is exposed, it is generally sharp and unbrecciated; in some cases, wedges appear to have been "fused" together. Other structures include sandstone dykes and one instance of sandstone "rafts" in a complex of tilted mudstone wedges.

This zone exhibits some important differences from that at Ablation Point, notably a lack of boudinage- and imbricate-like structures. However, their absence is probably due to the non-occurrence of suitable massive beds at Keystone Cliffs rather than a difference in the mechanics of formation. In both of these zones the upper limit is sharply and evenly demarcated by the base of a thick sub-horizontal sedimentary sequence, and both contain beds which are tightly folded about sub-horizontal axes.

Because comparable structures in the disturbed zone at Ablation Point are now thought to have been formed by slumping or gravitational sliding (rather than by easterly overthrusting), a similar origin is suggested for the disturbed zone at Keystone Cliffs. There are several indications that the sediments involved were only partly lithified when deformation occurred, for example, the absence of fracture cleavage in the tight fold formed in a now highly indurated sandstone (Horne, 1967*a*, fig. 3a) and of brecciation in rock bluffs composed of separate, variously orientated slabs or wedges. Although sub-vertical faults and low-angle breccia planes are present, these can often be shown to post-date the structures in the disturbed zone.

Except for some mudstones rich in *Chondrites*, most of the sedimentary rocks in this disturbed zone can be matched with those from the upper part of the sequence measured at locality T. This suggests that the disturbed zones of Keystone Cliffs and southern Waitabit Cliffs represent parts of the same large-scale structure. As ammonites from the undeformed beds above the disturbed zone at Keystone Cliffs resemble European late Neocomian species, a possible Barremian age for these beds has been advocated (Thomson, 1971*c*; Thomson and Willey, 1972, table II). However, it is doubtful whether there has been any thrust faulting at Keystone Cliffs of sufficient magnitude to emplace Upper Neocomian strata on top of the Aptian. The appearance of the ammonites is deceptive and additional palaeontological evidence (Thomson, 1974) now suggests an approximate correlation between the measured sections at localities W and B, i.e. the undeformed strata of Keystone Cliffs are probably Lower Albian in age and in their correct stratigraphical position.

### 6. *Synthesis*

In addition to large-displacement reverse/thrust faults at southern Grotto Glacier, Succession Cliffs and probably Eros Glacier (locality L), numerous examples of slickensided planes and small-scale faults (with a displacement of a few metres or less) clearly indicate that west to east overthrusting has affected the Mesozoic sequence of eastern Alexander Island. Some of this movement is detectable in the disturbed zones at Keystone Cliffs and possibly at Fossil Bluff. At southern Grotto Glacier a disturbed zone occurs in close association with a thrust fault.

It now seems that the effects of east to west overthrusting are less extensive and intensive than was previously envisaged (Adie, 1964*a*, p. 152; Horne, 1967*a*; Thomson, 1971*c*, p. 160). It is thought that the disturbed zones were formed when the sediments were incompletely lithified, possibly as a result of some form of gravitational sliding or slumping; later, thrust faulting may have utilized them as zones of weakness. The time of the folding and thrusting of the Mesozoic sequence cannot yet be precisely dated but it must have been between the Middle Cretaceous and a period of camptonite dyke intrusions during the Miocene (Horne and Thomson, 1967; Rex, 1970). At locality D, the thrusting post-dates the injection of sandstone dykes.

## IX. SUMMARY

Geological investigations associated with the Mesozoic sedimentary succession in eastern Alexander Island are traced up to the present and the more important discoveries are summarized. Some of the east–west glaciers subdividing the area between Ablation Point and Keystone Cliffs into a block topography may be fault controlled. The generally rounded topography of the Mesozoic sedimentary rocks contrasts strongly with the sharp arêtes and peaks of Palmer Land. Features of deglacierization include misfit glaciers, striated bedrock and "dry valleys". Several factors, including gentle dips, well-developed jointing and the thick-bedded strata have had a modifying influence on the present topography. Large-scale faulting has probably determined the remarkable linearity of the eastern coastline of Alexander Island, whereas minor faulting has influenced the location of several gullies.

A critical review of previous stratigraphical observations reveals certain inaccuracies and inconsistencies which have been perpetuated in the recent literature. An attempt has therefore been made to correct these and to express current ideas.

The eastern coastal belt of Alexander Island, from north of Trench Glacier to Stephenson Nunatak, is composed of a thick, mainly marine sedimentary succession, with interbedded lavas in the northern part. Present studies indicate that this sequence varies in age from Upper Oxfordian–Kimmeridgian to Lower Albian but parts of the area have still not been visited. The term *Fossil Bluff Formation* is proposed for this sequence, with the proviso that future investigations will probably allow sub-division into at least three units of formation status, when the term "Fossil Bluff group" would be more appropriate.

Detailed stratigraphical work suggests that, despite possible collecting omissions, the fauna in the Aptian part of the succession is more diverse and more abundant than elsewhere. The measured part of the succession is about 4,000 m. thick. Although the dominantly southerly or south-westerly dip suggests a continuous succession younging southward, thrust/reverse faulting has repeated the succession at some localities.

The Fossil Bluff Formation is thought to have accumulated in a north–south trough, developed adjacent to a rejuvenated (?) Carboniferous geosyncline (Adie, 1962). The present outcrop of this formation is not considered to extend as far west as was envisaged by Horne (1969*b*). Much of Horne's "axial facies" is now thought to be part of a separate, strongly folded older (?) Carboniferous sedimentary sequence bounded on the east by a major north–south fault approximately co-linear with the eastern margin of the LeMay Range. South of Venus Glacier, this fault is offset by several kilometres to the west. An easterly extension of the Alexander Island trough or a coastal embayment is indicated by the discovery of fossiliferous sedimentary rocks (probably of Upper Jurassic age) at Carse Point on Palmer Land.

The sedimentary environment and provenance of the Mesozoic succession are discussed and synchronous facies variations are described. There is no evidence for an extensive contemporaneous extrusive area west of Mount Umbriel (Bell, 1973, p. 11), although one agglomerate was recorded by Horne (1969*b*) south-east of this locality. Elsewhere, lavas and tuffaceous sedimentary rocks are developed, predominantly in the lower part of the Upper Jurassic sequence exposed at Ablation Point. A more widespread indication of penecontemporaneous volcanicity at many localities is airborne material consisting of vitric crystal blebs, lapilli and glass shards.

Lithological evidence for high rates of sedimentation includes massive conglomerates, notably in the Ablation Point area. Pebbly mudstones and pebble-filled wash-out channels are further indications of re-mobilization and rapid deposition of sediments at several localities. The great thickness of argillaceous rocks in this succession indicates that almost continuous sedimentation must have occurred to account for the accumulation of 1,100 m. of sediment in the Aptian.

The absence or rare occurrence of certain organisms also suggests high rates of sedimentation but other factors, such as reduced salinity, may have been partly responsible. The absence of acrothoracic borings in belemnite guards from belemnite "battle fields" is such an example. By contrast, periods of slight or suspended sedimentation are represented by beds of delicate ophiuroids, crinoids, almost completely articulated decapods (with saprotrophic borings in their cuticles), shell banks of *Aucellina* and *Buchia*, "reefs" of *Rotularia*, sporadic epifaunas encrusting a variety of substrata and by cirripede borings in belemnite guards.

Many of the benthonic Mollusca, e.g. *Entolium*, *Camptonectes*, *Thracia*, *Pleuromya* and *Panopaea*, were mobile forms probably capable of overcoming the adverse effects of high rates of sedimentation. Instances of deposits suggesting accumulation under abnormal salinities (e.g. brackish water and restricted lagoonal environments) have been recorded. No major changes in palaeobathymetry can as yet be determined from the distribution of trace fossils (particularly *Chondrites* and *Zoophycos*) in Alexander Island. In the six main acrothoracic ichnofacies, bored guards usually represent only a small fraction of the total belemnite population. At one locality, two or possibly three hosts are involved.

Several shell banks composed mainly of belemnite guards are thought to indicate some form of catastrophic death of belemnite shoals. The local abundance of Radiolaria, often coinciding with a high tuffaceous content in the sediments, is believed to be due to the effects of either toxic chemicals associated with the volcanism or to a sudden "bloom" caused by the introduction of silica from the same source.

During the Upper Jurassic and Lower Cretaceous, the coastline around the Alexander Island trough supported a rich flora which presupposes suitable soil and climatic conditions for its development. Although it has been previously suggested that this flora indicated a tropical or sub-tropical environment, it is now believed that only a temperate climate can be postulated from these, as yet, systematically undescribed plants. A relatively warm wet climate is indicated by the textural and mineralogical immaturity of the sediments.

Among the varied fauna, only *Lingula*, *Discinisca* and the belemnites appear to have some palaeoclimatic significance. Present-day examples of these brachiopods live in temperate and sub-tropical seas. Oxygen-isotope determinations on comparative belemnite faunas from Australia and New Zealand also indicate that the water was warmer in the Mesozoic trough than it is around Alexander Island today.

A review of the Fossil Bluff Formation on a regional basis enables comparisons to be made with several areas of western Antarctica, the sub-Antarctic islands of South Georgia and Annenkov Island and extra-Antarctic regions. The Jurassic part of the sequence shows a much closer correspondence with extra-Antarctic regions than does the Lower Cretaceous. Previous correlations are discussed in the light of recent discoveries and the necessity for further investigations is emphasized.

After its final infilling, the area described here was subjected to east–west compression (Horne, 1967*a*), causing gentle folding and thrusting. Fault displacements vary from a few metres or less to several hundred metres at southern Grotto Glacier and Succession Cliffs. Disturbed zones, notably at Ablation Point, Fossil Bluff and Keystone Cliffs are believed to have developed primarily as a result of post-depositional gravity sliding or slumping.

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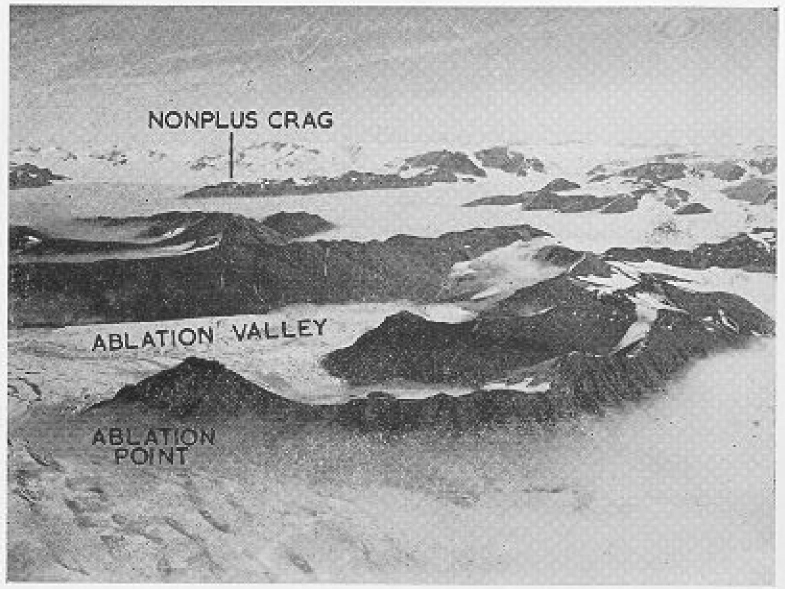
## PLATE I

a. Oblique air view looking south-westward across Ablation Point to Nonplus Crag (middle distance) and the LeMay Range (background). Melt-water pools can be seen in George VI Sound (bottom left) and low cloud, typical of late December and January, is building up round the coastal cliffs and in the lower parts of the glaciers. The LeMay Range is composed of tightly folded (?) Carboniferous sedimentary rocks, whereas all the rocks between the foreground and Nonplus Crag belong to the marine Upper Jurassic–Lower Cretaceous succession.

b. Air view of Ablation Point showing the complicated deformation of the sedimentary rocks rich in tuffaceous material in the lower part of the sequence. The upper beds are flat-lying and apparently undisturbed.

c. Air view looking westward into an Antarctic dry valley approximately 3 km. south of Ablation Valley. Note the advanced stage of deglacierization and the melt rivers issuing from the remnants of glacier ice.

d. Oblique air view of locality Z showing a sequence of mudstones and pale sandstones. The general topography is rounded and much of the rock is scree-covered. In the foreground are linear pressure ridges arranged *en échelon* to one another and parallel to the cliff.



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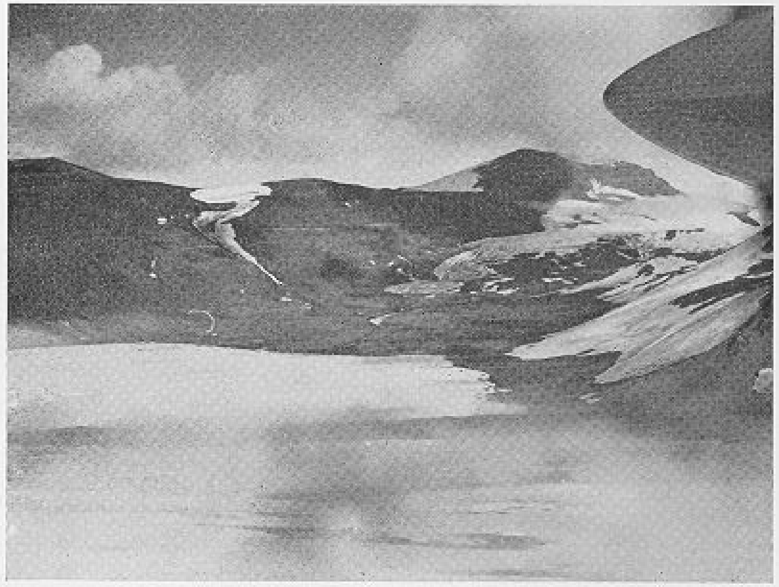

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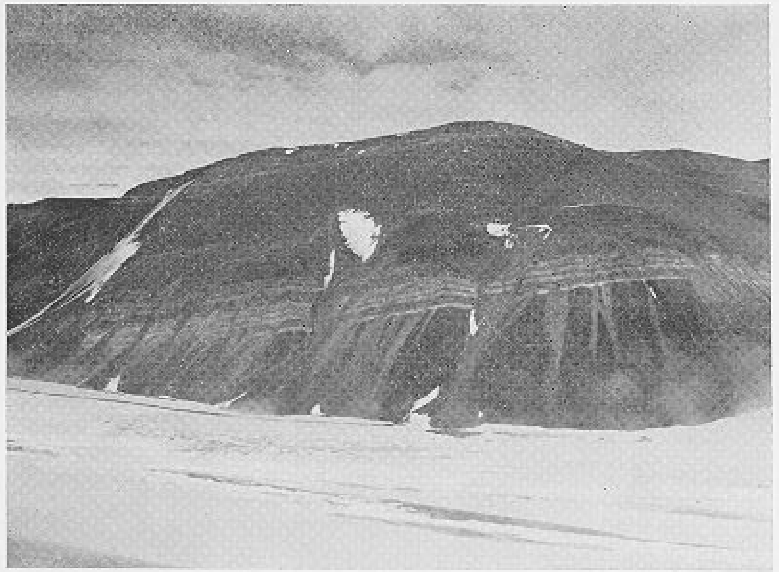

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PLATE I

# PLATE II

a. Oblique air view looking south-westward towards Succession Cliffs (locality A). Locality J (right) is capped by massive conglomerates and separated from the coastal cliffs by a major reverse fault. In the upper left is locality L.

b. Oblique air view looking south-westward towards Succession Cliffs (locality B) showing the linearity of the coastal cliffs. A major reverse fault between localities B and C is indicated (pecked line). Localities in Eros Glacier and near Fossil Bluff are also shown.

c. Oblique air view looking almost due west towards locality C showing pale-coloured Lower Albian sediments (below arrows) overthrust by probable Neocomian sediments. Melt-water pools are developed in George VI Sound.

d. Oblique air view looking south-westward over localities C and K into part of Eros Glacier. The Fossil Bluff area, Uranus Glacier and locality N are also shown.

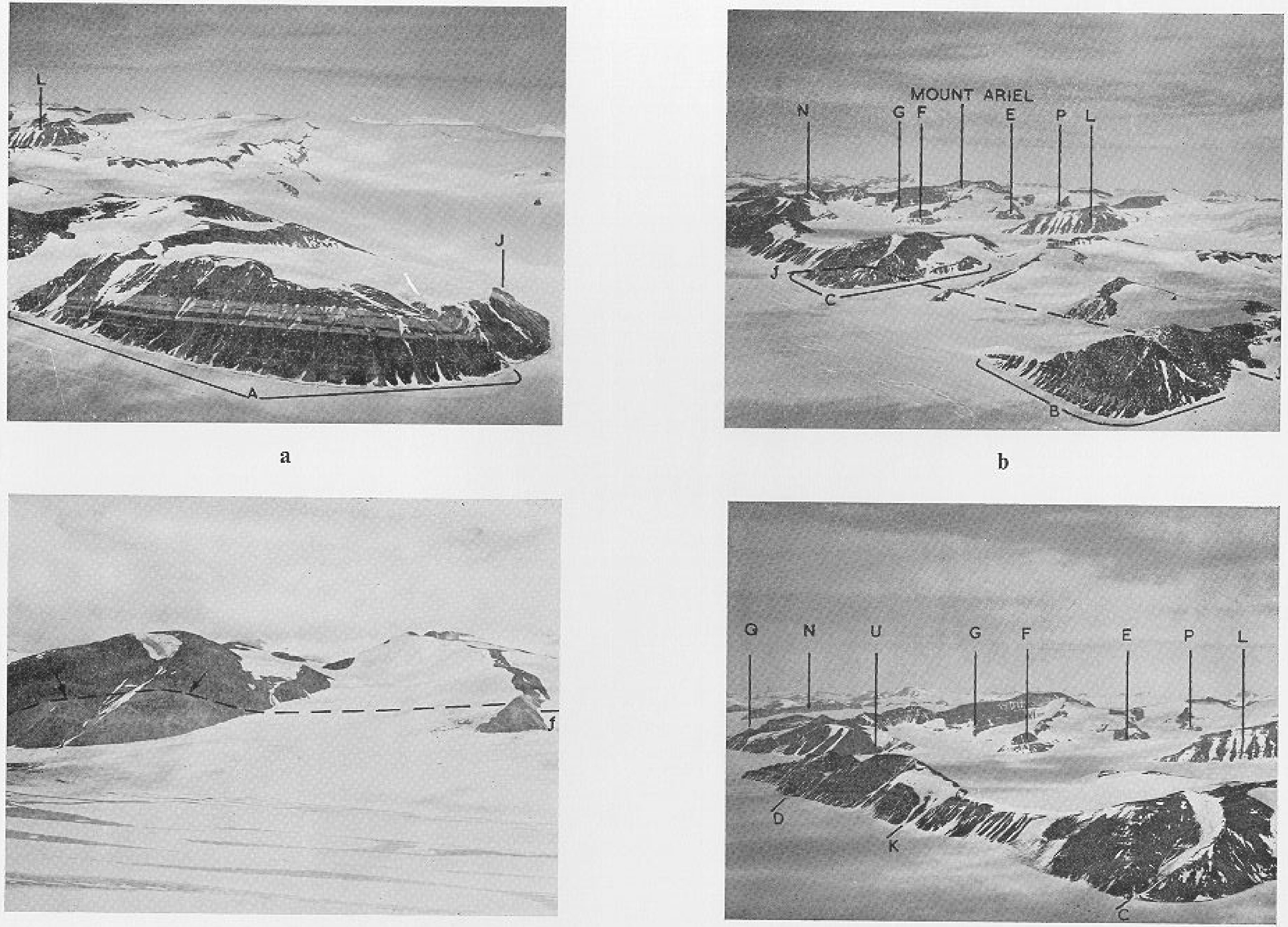

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PLATE II

## PLATE IV

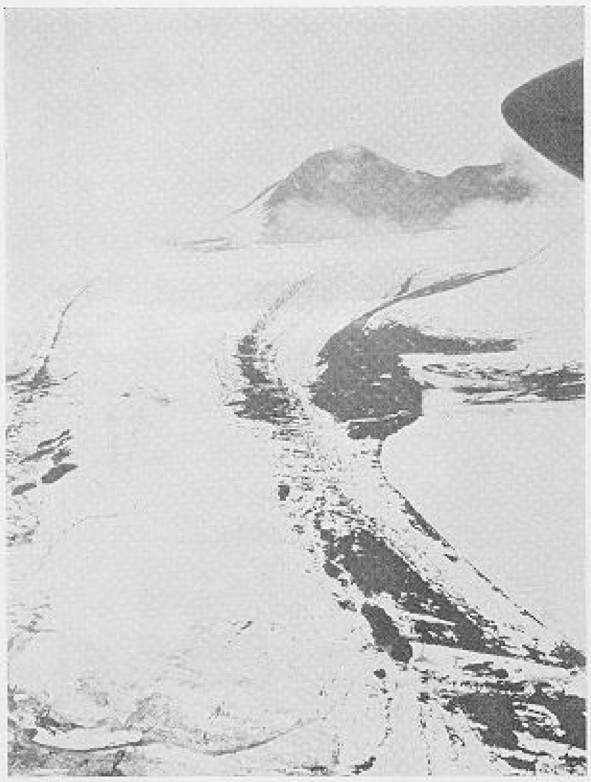
a. Oblique air view of lateral moraines on the northern side of Uranus Glacier. The eastern end of Mount Ariel is in the distance.

b. A prominent arête representing the summit at locality H. Palmer Land is on the horizon.

c. Palsen-like structures (with water-saturated cores) developed within a few metres of melting ice near the summit of Mount Ariel. Where these structures occur on slight slopes, small-scale lobate slides occur. The chisel is 15 cm. long.

d. Honeycomb weathering in a 43·5 m. thick sandstone (with "cannon-ball" concretions) near the summit of Mount Ariel. The sandstone is exposed to the prevailing winds.

PLATE IV



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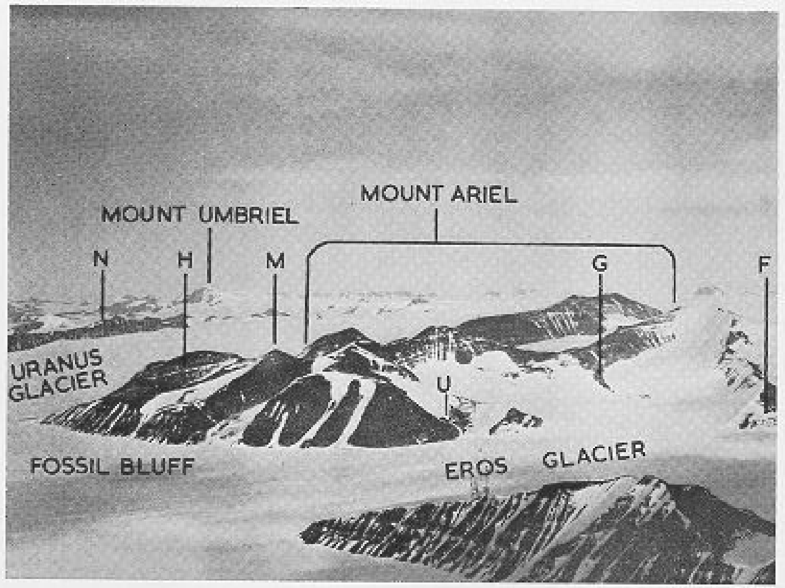
## PLATE III

a. Oblique air view looking south-westward across locality D and Eros Glacier towards the Fossil Bluff area, Mount Ariel (middle distance), Uranus Glacier and locality N. The relatively snow-free area at locality U is also shown. The mountain ranges on the horizon are composed of tightly folded (?) Carboniferous sedimentary rocks.

b. 5 km. long cliffs (locality N) along the southern margin of Uranus Glacier as seen from locality H (left foreground). The linearity of these cliffs may be fault-controlled. The prominent peak in the distance right of centre is Mount Umbriel. The eastern end of Mount Ariel is on the right.

c. Oblique air view looking south-westward at Waitabit Cliffs (localities T and V). Keystone Cliffs (localities W and X) can be seen on the left with the paler sandstone facies of the Venus Glacier area beyond. Note the two hanging cirque glaciers (g) and the large dyke-controlled gully (arrowed).

d. View southward across Mercury Glacier to Keystone Cliffs from the summit of southern Waitabit Cliffs. The pecked line delineates the top of the disturbed zone.



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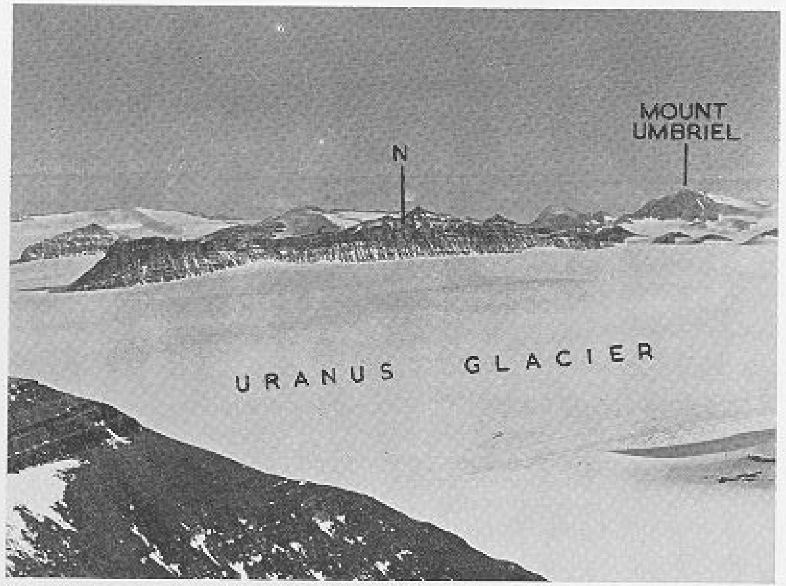

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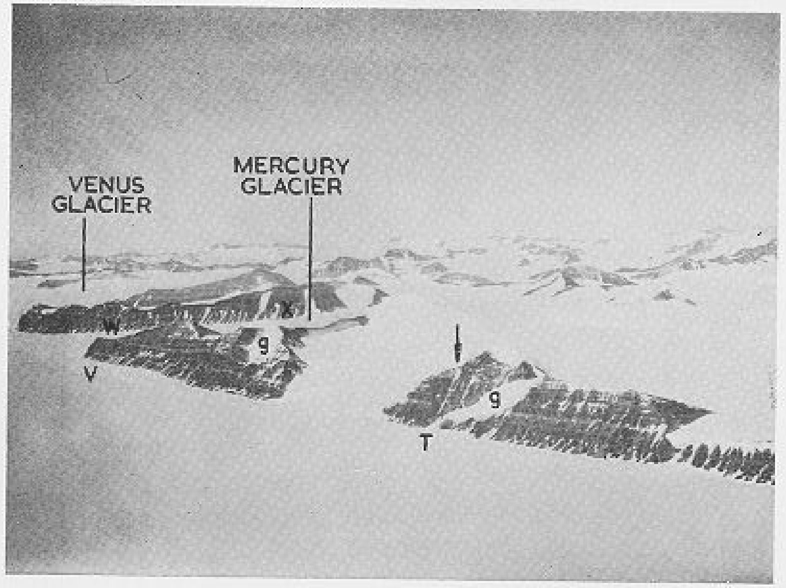

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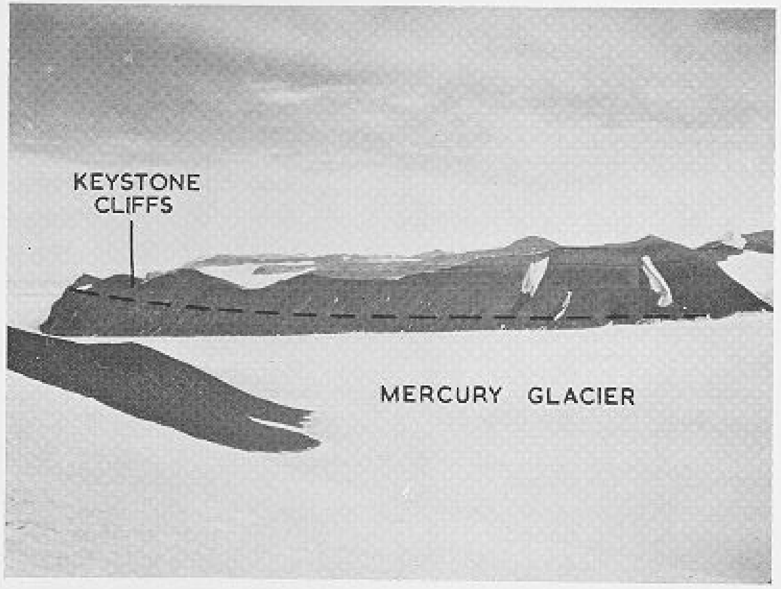

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PLATE III

# PLATE V

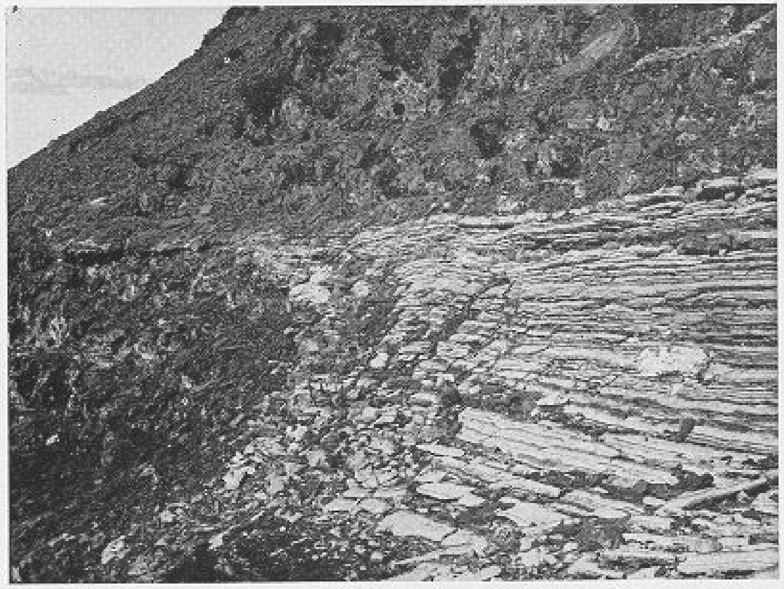
a. Indurated black mudstones at Mount Ariel passing laterally into a 2·9 m. thick lens of variegated tuffaceous sandstones and argillaceous interbeds. The lens, which extends 62·5 m. along the strike, is characterized by peripheral micro-faulting.

b. Load casts and associated flame structures in a loose and mainly laminated sandstone block comprising part of a prominent cliff at locality P; ×0·2.

c. Convolute lamination in several flag- and slab-bedded cream-coloured sandstones representing part of a prominent cliff at locality P. The peaked anticlines and broadly rounded synclines in the thickest sandstone resemble deformed ripple marks. The fine mottles probably represent foci of prehnitization; ×0·07.

d. A collapse structure in mottled sandstones of unit $T_{15}$ near the top of northern Waitabit Cliffs. The structure is of limited lateral extent and the bedding in the right-hand part of the outcrop is undisturbed. The staff is graduated in 1 ft. (30 cm.) divisions.

PLATE V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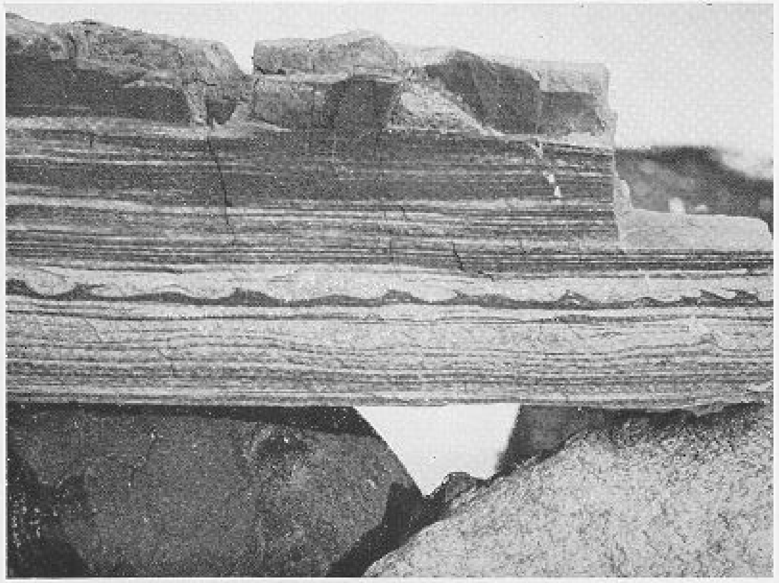
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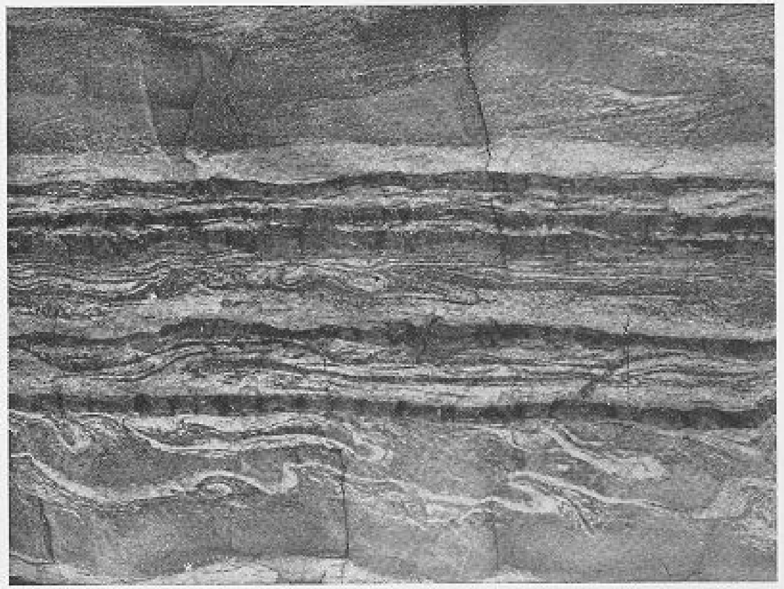
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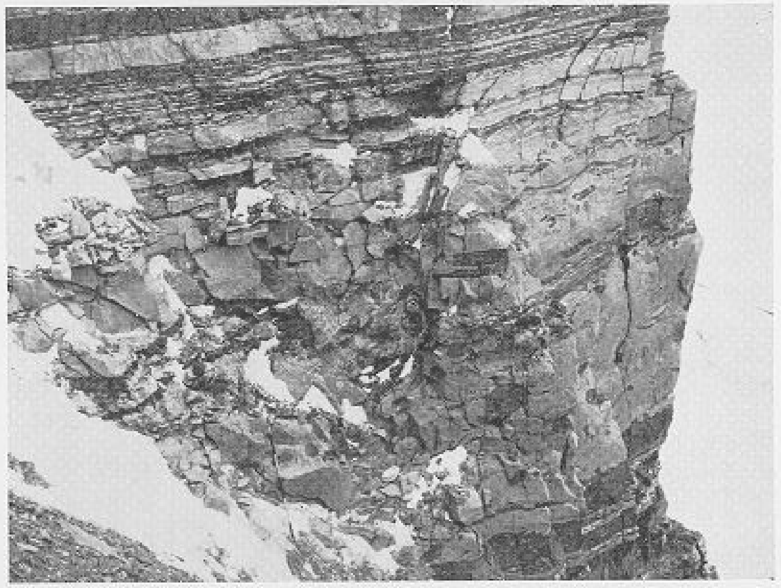
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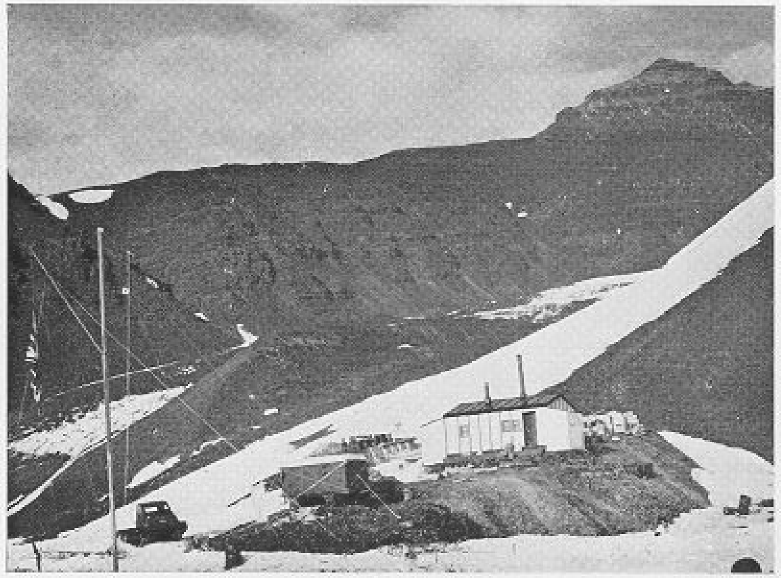
# PLATE VI

a. View looking west towards the field station at Fossil Bluff in summer. The considerable extent of well-exposed and often easily accessible sedimentary rocks (dipping at 9° to the south-south-east) is evident. Behind and to the left of the hut is an ice-covered moraine along the margin of a small glacier. The stepped pyramidal peak or horn on the skyline consists mainly of thick-bedded sandstones, some with "cannon-ball" concretions. The disjointed appearance of the lowermost sandstone is due to faulting.

b. Part of Succession Cliffs (locality A) showing prominent buttresses of mainly argillaceous rocks interbedded with thick-bedded cream-coloured sandstones containing "cannon-ball" concretions. Gully erosion by melt-water torrents is prevalent here in summer. The cliffs are 365 m. high.

c. A geological camp site beside the southern block of Succession Cliffs (locality B). The thick-bedded and pale-coloured sandstone cliff containing "cannon-ball" concretions is 38·5 m. thick.

d. Part of the southern end of Waitabit Cliffs showing a mainly argillaceous succession punctuated by thick-bedded cream and yellow-coloured sandstones. The rocks comprising the lower half of the cliff dip at 20° towards the west. A sandstone dyke (arrowed) cuts the succession obliquely. On the far left is the eastern end of Keystone Cliffs.



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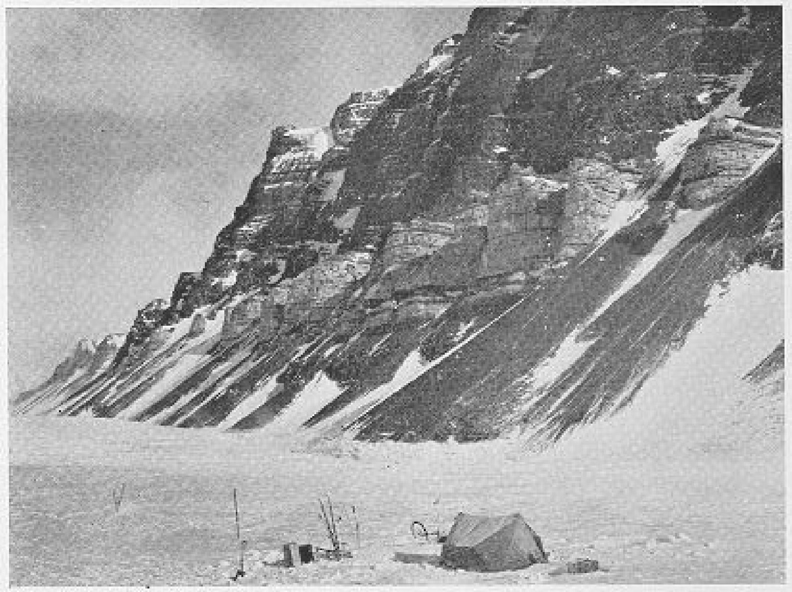

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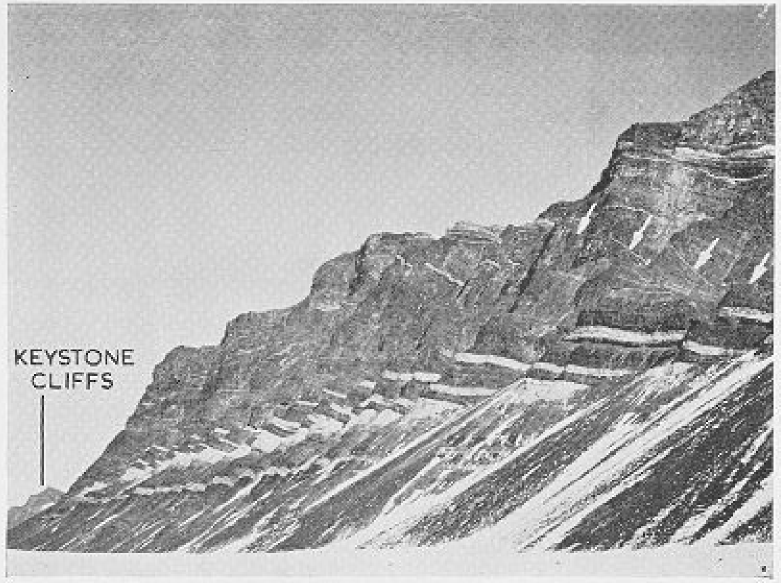

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PLATE VI

## PLATE VII

Representative leaves from the marine mudstones of the Fossil Bluff Formation.

a. *Ptilophyllum* (*?*); locality W; ×1. (KG.106.16)

b. *Otozamites* (*?*); locality H; ×1·6. (KG.2.172)

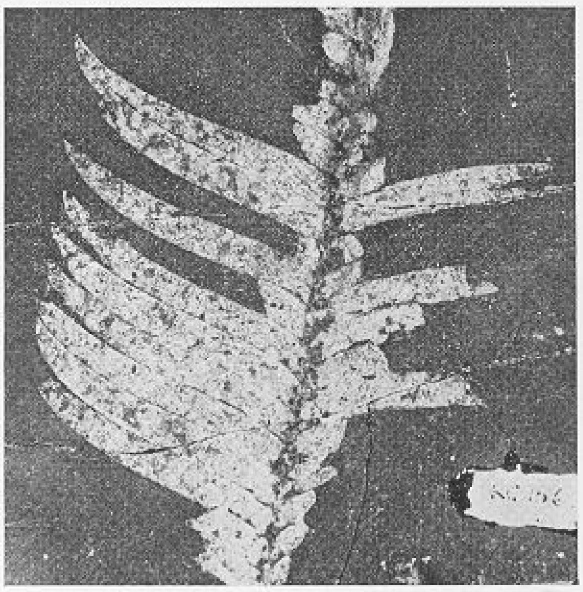
c. Indet. bennettitalean (?); locality R; ×0·7. (KG.1.745)

d. *Dictyozamites* (*?*); locality H; ×1·6. (KG.2.14)

e. *Nilssonia* (*?*); locality R; ×1·5. (KG.1.618)

f. *Nilssonia* (*?*); locality T; ×1. (KG.103.118)

# PLATE VII



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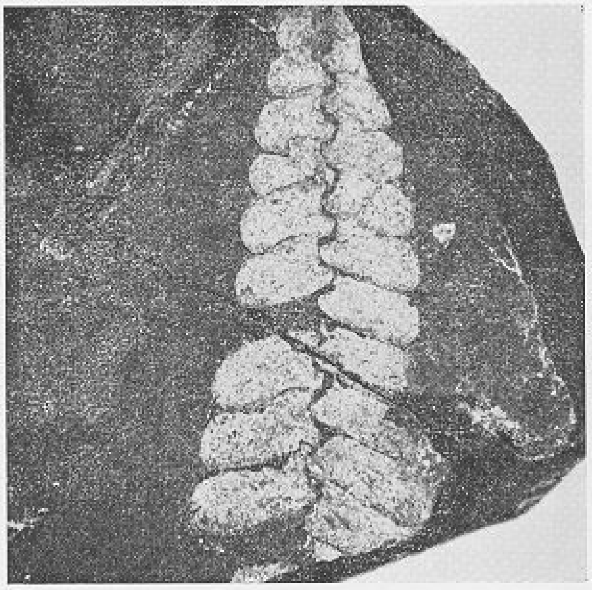

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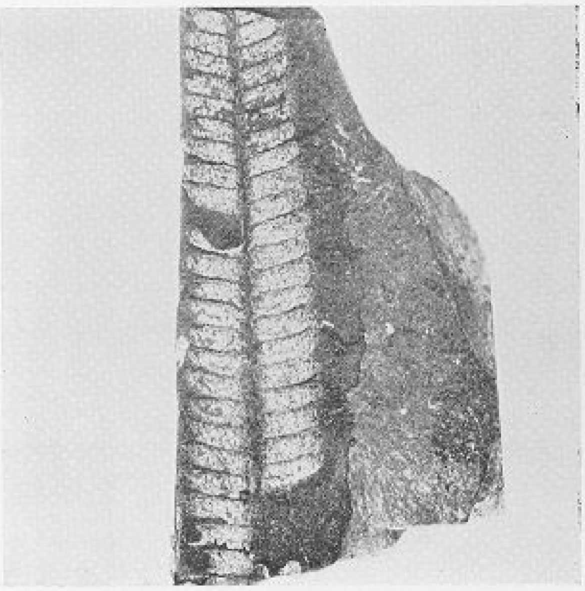

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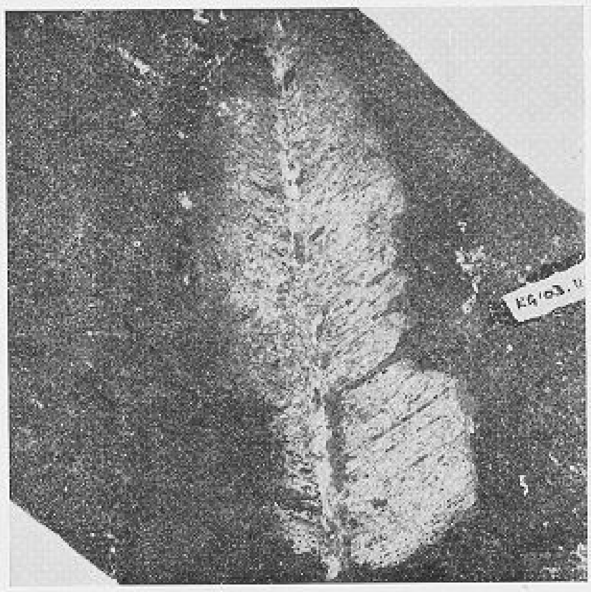

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## PLATE VIII

a. Part of a 1·2 m. thick belemnite "battle field" at Mount Ariel showing numerous compacted guards together with phenoclasts, concretions and brecciated intercalations (arrowed). The hammer shaft is 34 cm. long.

b. Transverse thin section through the rostrum of *Belemnopsis gladiatoris* showing four acrothoracic cirripede borings; locality F; ×6. (KG.13.11)

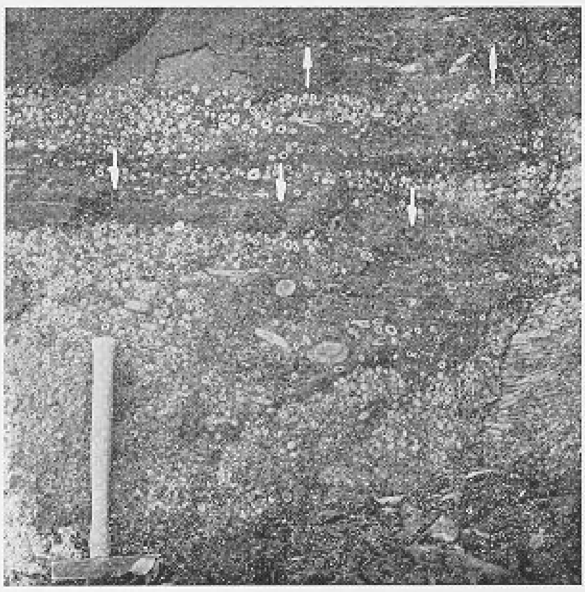
c. Small colony of the inarticulate brachiopod *Discinisca variabilis* attached to a gastropod shell; locality T; latex cast, coated, ×3·5. (KG.103.91)

d. *Pinna* sp., found in life position, containing *Panopea* sp. also in life position. The *Pinna* was probably burrowed post mortem; locality Z; ×1·3. (KG.401.650)

e. Rhynchonellid brachiopods in position of growth on a shell fragment of a giant ammonite, *Lytoceras*; Ablation Valley; coated; ×1·6. (KG.712.91)

f. Transverse thin section through a fossilized wood fragment showing a "*Teredo*" boring complete with bivalved shell. The boring has been subsequently filled with calcite; locality K; ×4·7. (KG.18.30)

PLATE VIII



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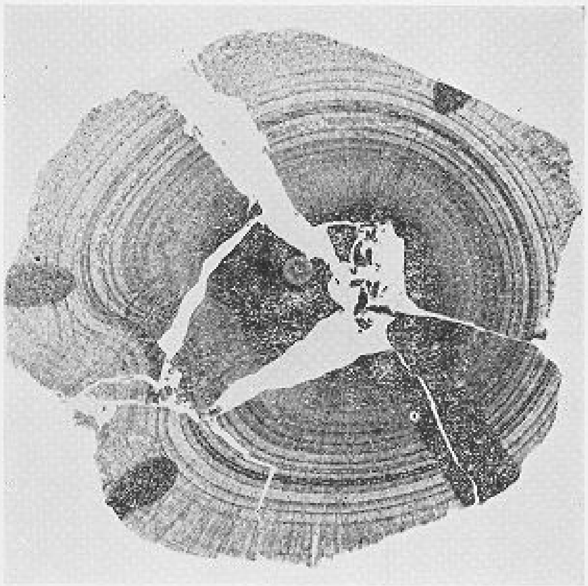

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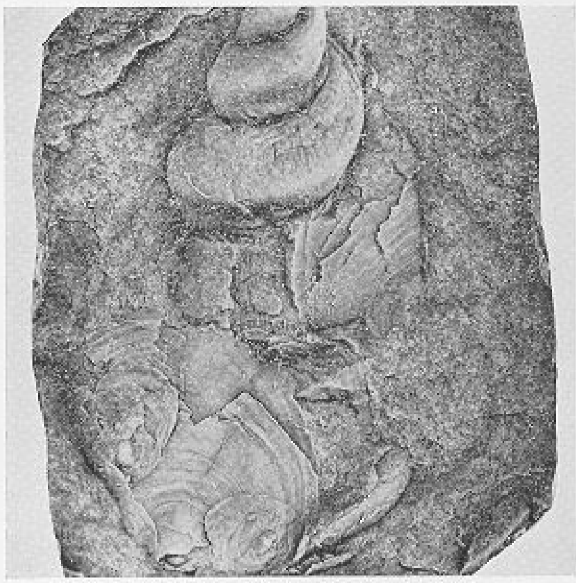

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# PLATE IX

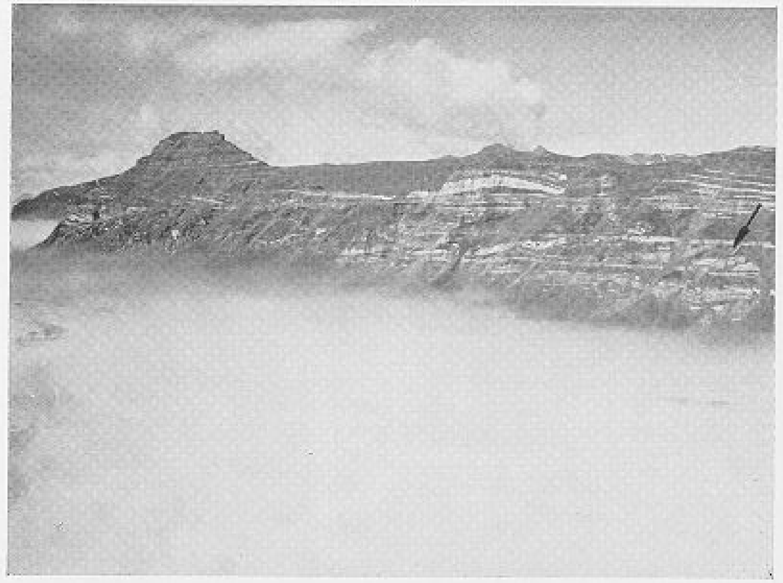
a. Air view looking south-west towards Ablation Point (left) and adjacent cliffs on the southern margin of Grotto Glacier. The lower tuffaceous sequence which is either Upper Oxfordian and/or Kimmeridgian in age has been intensely deformed by "gravitational sliding" or slumping, whereas the overlying Tithonian strata are little disturbed. Imbrication of a thick sandstone can be seen on the right (arrowed).

b. Cliffs on the southern side of Grotto Glacier 10 km. west of Ablation Point. A large-scale north–south reverse fault (pecked line) displaces a thick sequence of sandstones (pale coloured) by several hundred metres towards the east.

c. A 23 m. thick disturbed zone at Fossil Bluff (locality R). Note the rapid variations of dip and strike of the beds affected by the disturbance. The sandstone peak (centre) is locality Q.

d. A westerly dipping thrust/reverse fault (pecked line) at locality L displacing a mudstone sequence disconformably on top of well-bedded sandstones. The movement is from west to east but its amount is unknown.

PLATE IX



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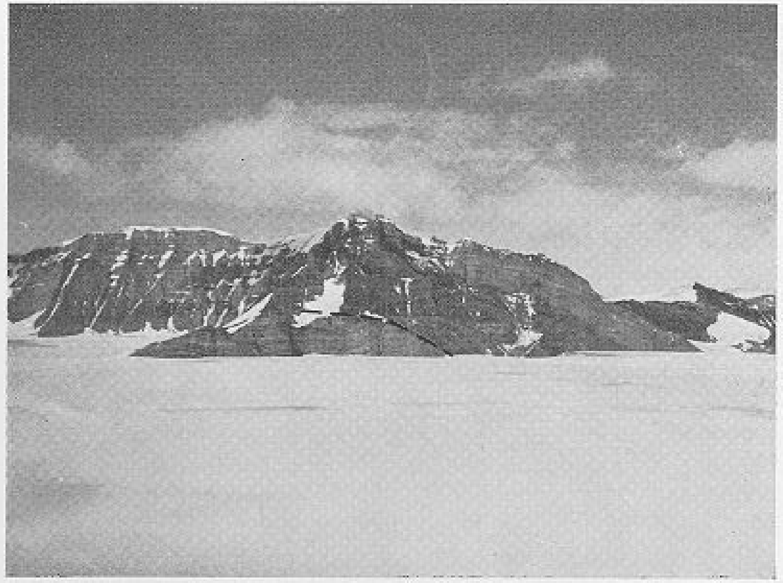

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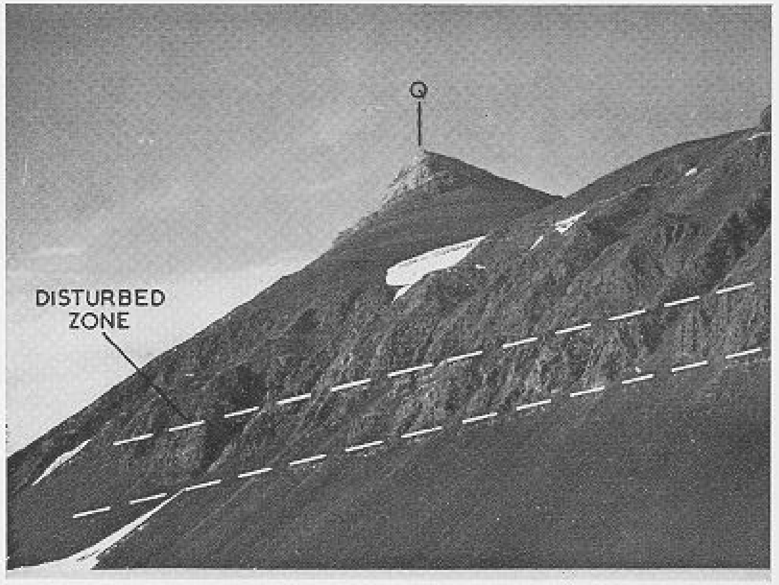

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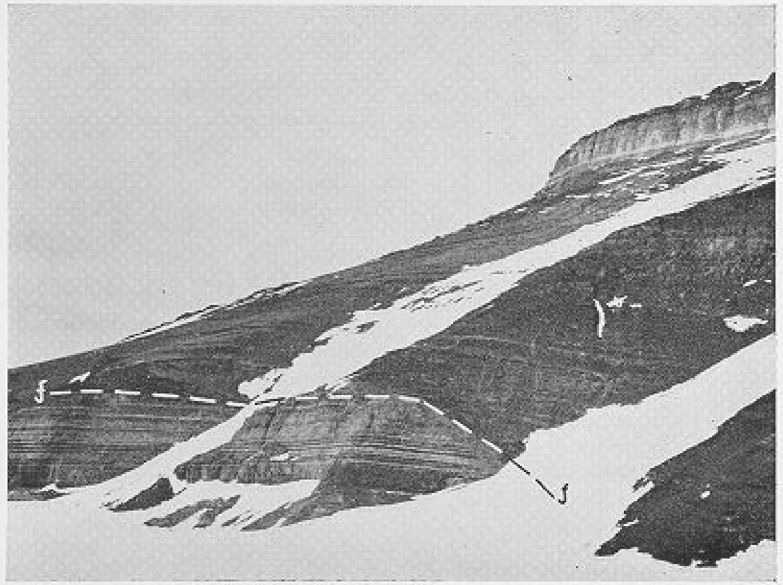

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# PLATE X

a. Panorama of southern Waitabit Cliffs (locality V) showing what is believed to be the lateral equivalent of the disturbed zone at Keystone Cliffs. The sedimentary sequence has been repeated by movement along three major planes (i–iii) of which (i) and (ii) are accompanied by localized brecciation and may have been affected by late-stage thrusting. The sediments in the upper part of the cliffs (right) contain a silesitid fauna similar to that of unit $W_1$ at Keystone Cliffs immediately above the disturbed zone there.

b. Panorama of part of the disturbed zone at Keystone Cliffs (locality W). Sedimentary rocks are crumpled about sub-horizontal axes into folds which appear to adhere to the cliff face. The sequence in the upper part of the cliff is flat-bedded and apparently undisturbed.

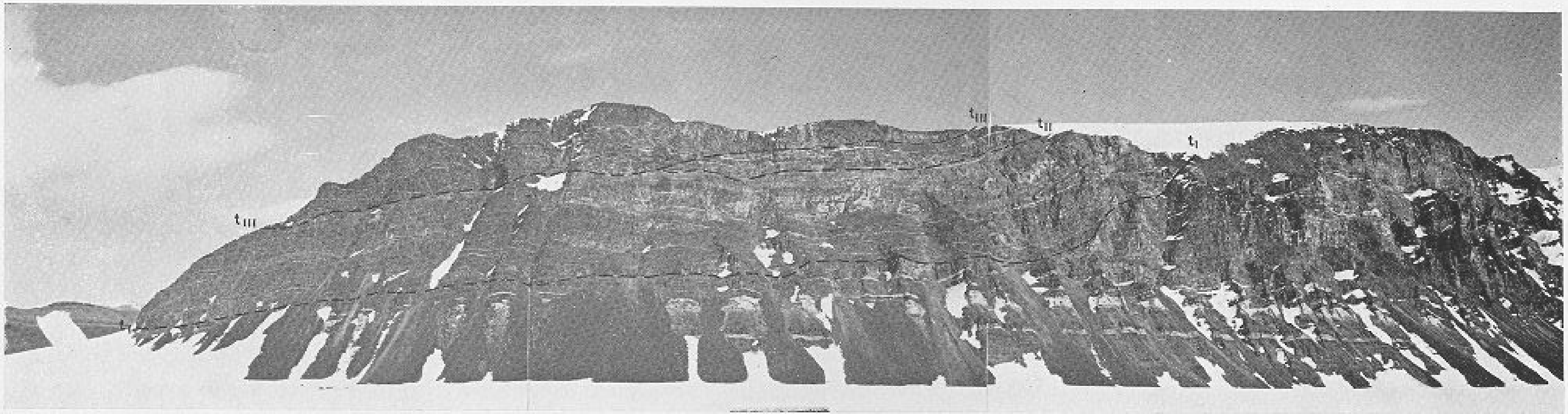

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PLATE X