STRATIGRAPHY AND SEDIMENTARY PETROLOGY OF THE ABLATION POINT AREA, ALEXANDER ISLAND

By M. H. Elliott

Abstract. The stratigraphy and sedimentary petrology of 2,100 m. of Upper Jurassic to Lower Cretaceous (Upper Oxfordian–Kimmeridgian to Berriasian) strata in the Ablation Point area of Alexander Island are described. The oldest strata are disturbed and contain an unknown thickness of lavas, agglomerates and breccias. The overlying sedimentary succession consists of conglomerates, arkosic sandstones and shales, with subordinate pebbly mudstones and sedimentary breccias. These rocks are texturally and mineralogically immature, and they could possibly have been derived from the east. Concretions have formed diagenetically in both arkosic sandstones and shales; prehnite, laumontite and chlorite have developed as a result of low-grade load metamorphism. The sedimentary rocks belong to several lithofacies, the areal distribution of which indicates vertical facies changes in this part of the Mesozoic depositional trough.

The Ablation Point area of the east coast of Alexander Island (Figs. 1 and 2) comprises coastal cliffs and mountains between Grotto and Jupiter Glaciers (lat. 70°47′ to 70°56′S.), and between long. 68°21′ and 68°40′W.

Previous investigations

The first investigations of the geology of this area were carried out by W. L. S. Fleming, A. Stephenson and G. C. L. Bertram of the British Graham Land Expedition, 1934–37. They described limestones, calcareous grits and shales, and collected bivalves, brachiopods, belemnites, fish teeth and plant remains. These plants were thought to be comparable to Middle Jurassic plants from the Mount Flora plant beds at Hope Bay, north-eastern Graham Land (Fleming and others, 1938).

Subsequently, V. E. Fuchs and R. J. Adie investigated these cliffs and collected Lower Cretaceous (Aptian) bivalves and annelids (Cox, 1953) and Upper Jurassic ammonites (Howarth, 1958). However, recent work has failed to confirm the existence of Aptian bivalves at Ablation Point. Severe overthrusting from the west, folding and transverse faulting were thought to be responsible for the complex structure of eastern Alexander Island (Adie, 1958).

Since 1961, much detailed palaeontological, stratigraphical and petrological work has been carried out on the Lower Cretaceous sedimentary rocks south of Jupiter Glacier (Taylor, 1965, 1966*a*, *b*, 1967, 1969, 1971*a*, *b*; Horne, 1967*a*, *b*, 1968*a*, *b*, *c*, 1969*a*, *b*; Horne and Thomson, 1967; Thomson, 1967, 1971*a*, *b*, *c*; Horne and Taylor, 1969; Thomson and Willey, 1972).

When the Mesozoic succession of eastern Alexander Island was first subdivided (Adie, 1962), the "Ablation Hook Beds" (subsequently known as the Ablation Point Beds) were regarded as Middle Jurassic despite the presence of Upper Jurassic ammonites (Howarth, 1958) and Aptian bivalves (Cox, 1953). These beds were placed stratigraphically below the Belemnite Point Beds. Horne (1967*b*) included the Belemnite Point Beds stratigraphically *below* the Ablation Point Beds—presumably on the basis of the overall southerly dips and the geographical relationship between Belemnite Point and Ablation Point.

The field work on which this paper is based has demonstrated an apparently conformable succession from the exposed base to the youngest rocks examined at locality AF. Subsequent examination of the ammonites and other molluscan faunas by M. R. A. Thomson and L. E. Willey has indicated that these rocks range from Upper Oxfordian–Kimmeridgian to Berriasian, and that the upper part of the succession may be tentatively correlated with that of locality Z (south of Jupiter Glacier). The faunal sequence is by no means complete, and a considerable part of the Ablation Point succession is so far devoid of stratigraphically useful fossils.

Physiography

The deeply dissected sedimentary block of the Ablation Point area is bounded to the north by Grotto Glacier, southward and westward by Jupiter Glacier and eastward by George VI Sound (Fig. 3). This area comprises four main sedimentary blocks and a number of inter-

Br. Antarct. Surv. Bull., No. 39, 1974, p. 87-113.

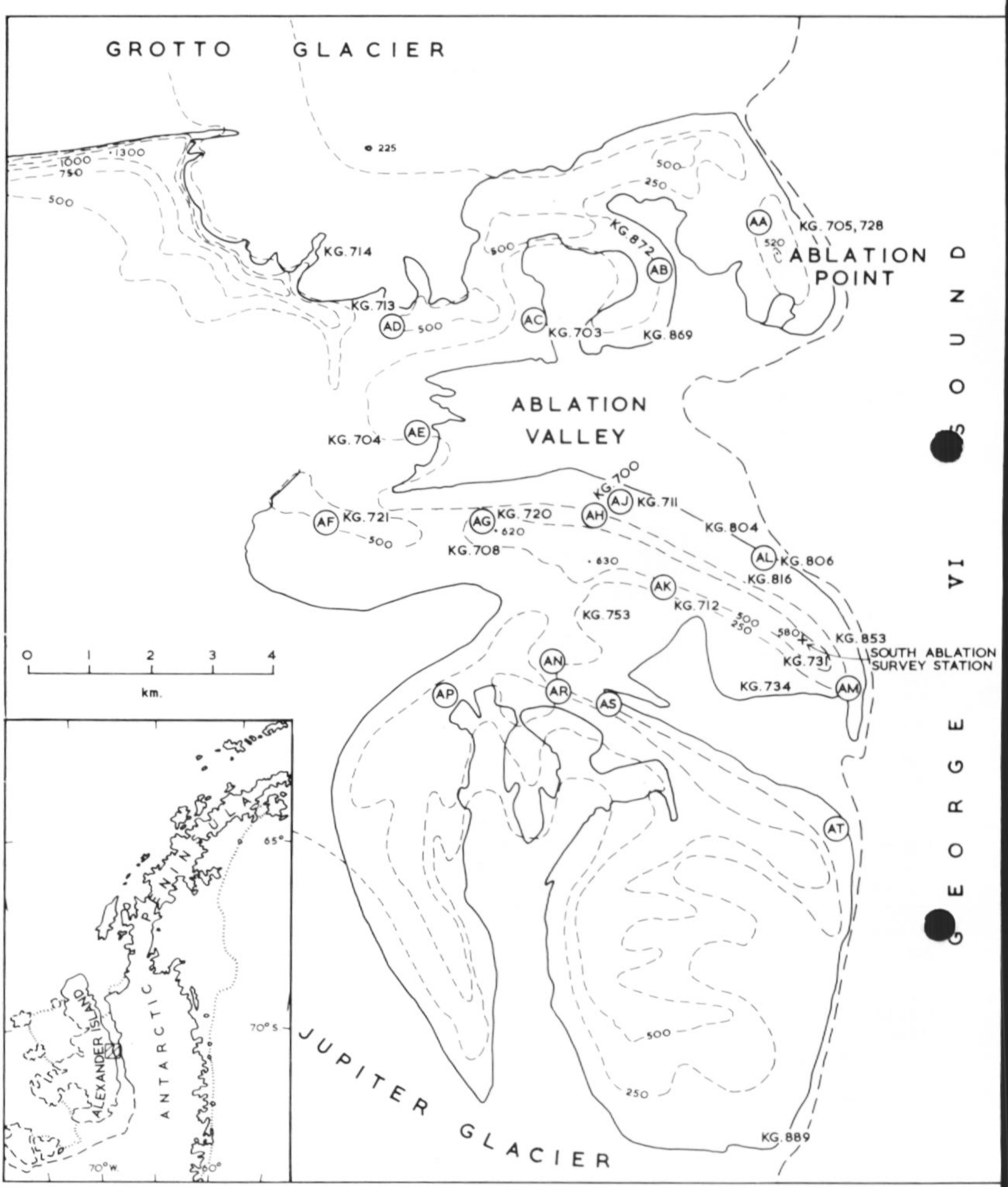

Fig. 1. Topographical sketch map of the Ablation Point area, Alexander Island, showing place-names, locality letters and relevant geological station numbers. The contours are at 250 m. intervals.

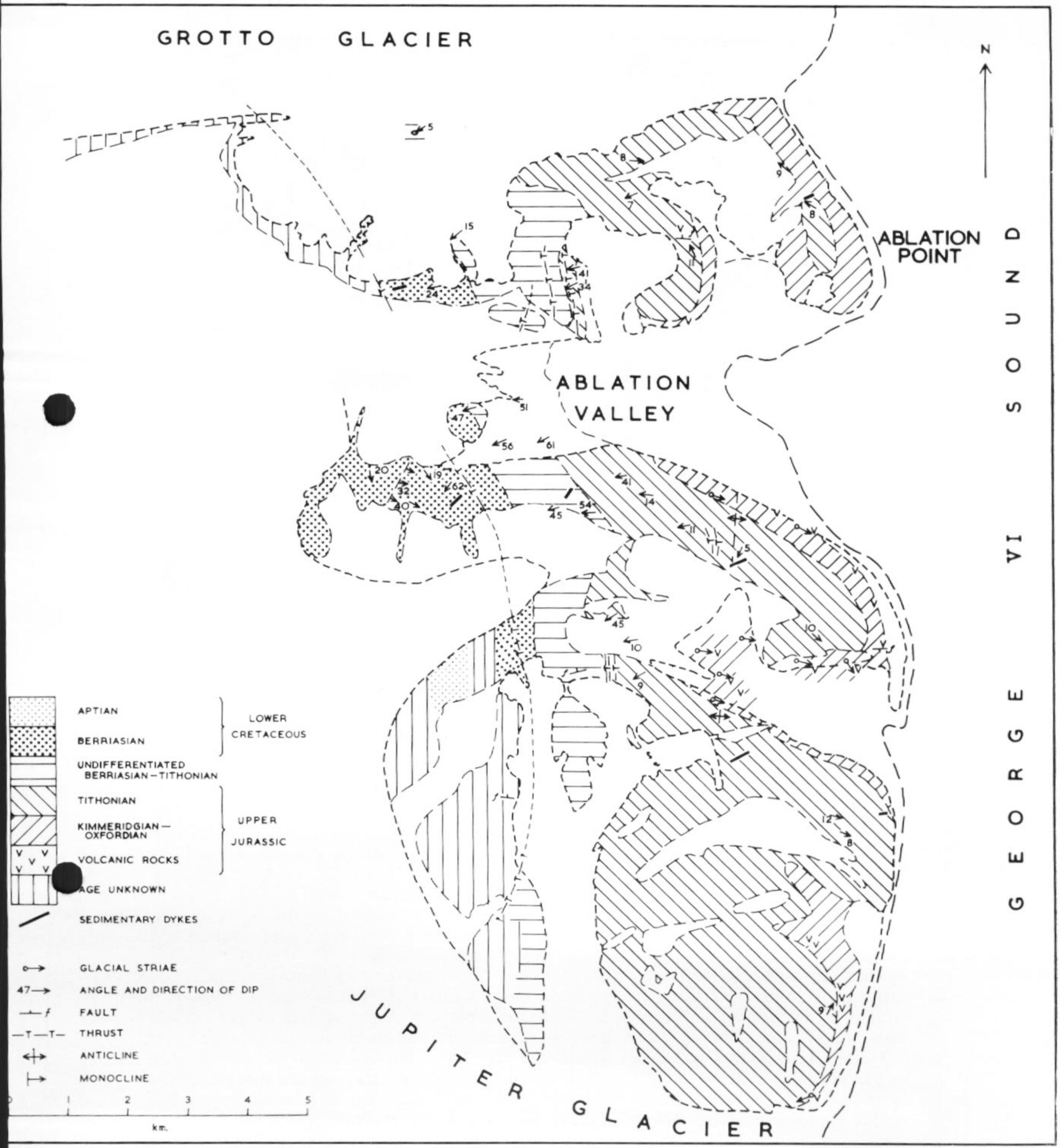

Fig. 2. Geological sketch map of the Ablation Point area, Alexander Island.

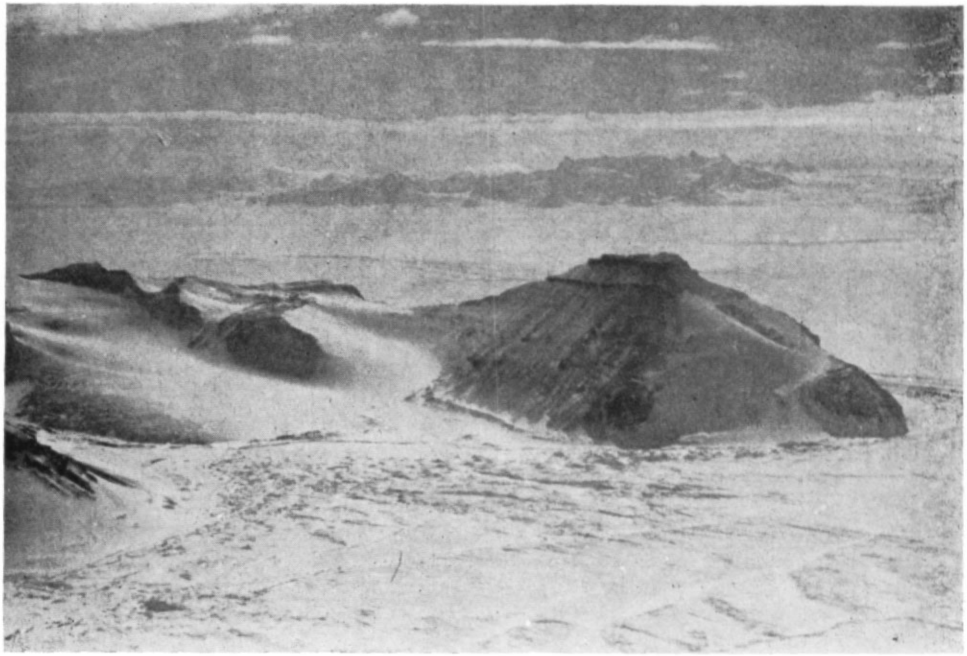

Fig. 3. Ablation Point with pressure ice in the foreground extending into Ablation Valley. George VI Sound and Palmer Land are in the background.

connecting ridges. These blocks have talus-covered north- and east-facing slopes, and steep ice-covered southern slopes. The local topography of the sedimentary blocks can be attributed to both the structure and differential erosion of the various lithologies (Fig. 4a–c). Frost action has played an important part in shaping this landscape. Splitting along joints and cracks has induced extensive block disintegration and minor rock falls occasionally occur. Imbricated screes are widespread and *felsenmeere* are common on ridge summits. Stone stripes, emphasized by the growth of moss on the finer-grained stripes, occur on the south side of Ablation Valley on waterlogged slight to moderate slopes adjacent to permanent ice slabs.

Although bounded on the north and south by large glaciers, this area is relatively ice-free except for several small glaciers (up to 2 km. long) with associated terminal and lateral moraines. Widespread evidence of more extensive glacierization in the past includes *roches moutonnées*, polished surfaces, glacial striations and moraines. Some striations occur at up to 170 m. above the present glacier levels.

Relatively snow-free areas are common in the Ablation Point area, the best described being that formerly referred to by the British Graham Land Expedition as "Ablation Valley". Here, a remnant ice slab at the headwall and a small hanging glacier represent the only permanent ice.

These so-called "oases" are probably due to a combination of factors, including deglacierization, lower precipitation, an amelioration of climate (Robin and Adie, 1964, p. 109) and abundant detritus to induce greater localized ablation (Fleming and others, 1938). Similar small-scale "oases" occur throughout the coastal cliffs south of Grotto Glacier.

Melt-water streams and lakes (up to 3·2 km. long) are often well developed, particularly in the pressure troughs in the ice, and in hummocky moraines on the margin of George VI Sound. The lakes, sometimes with a margin of well-sorted fluvial gravel, deepen and extend before rapidly draining in late summer to leave 2–2·7 m. high beach levels *above* normal winter ice level. In one valley, braided streams in well-defined channels 2 km. long and 2 m. wide (Fig. 4d) discharge into a lake.

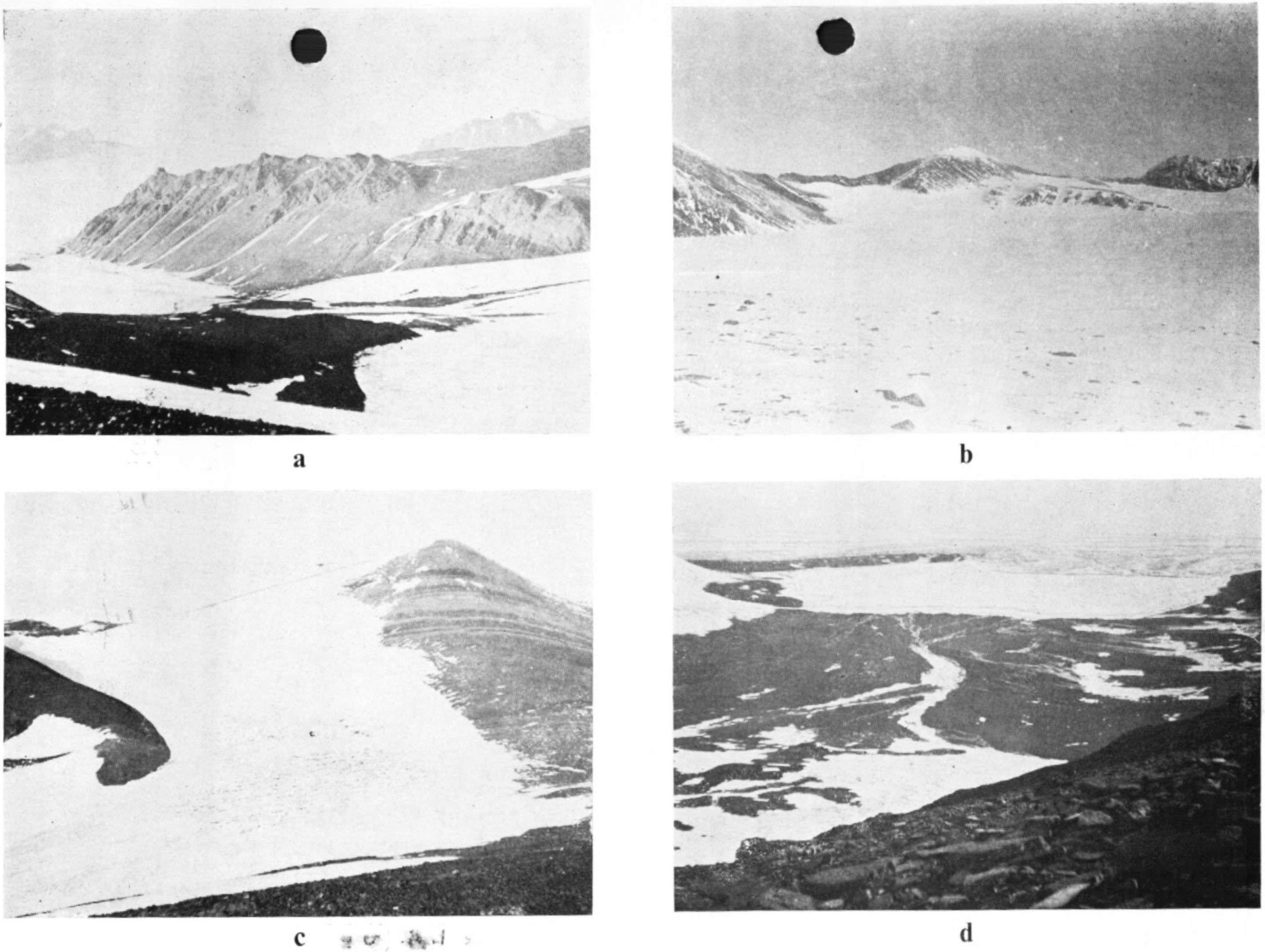

Fig. 4. a. Ridge showing the topographical effect of a thick steeply dipping conglomerate. Jupiter Glacier is in the centre of the photograph.

b. Locality AD viewed from the nunatak in Grotto Glacier. The ridge in the centre is composed of conglomerate.

c. Minor fault with a displacement of 5 m. at locality AR.

d. Braided melt-water stream system. The gravel-covered valley floor has outcrops of glacially striated volcanic rocks. The pressure waves in the ice of George VI Sound are compressed against the moraines.

STRATIGRAPHY

The oldest rocks in the Ablation Point area crop out on the eastern limb of a monoclinal structure and comprise a thick sequence of highly contorted sediments (referred to here as the "disturbed zone") which have not so far been measured stratigraphically. The base is nowhere exposed and the upper boundary is difficult to define, although it is known to occur at different levels below the first easily recognizable marker horizon. This 3 m. thick arkosic sandstone protrudes from the overlying dark mudstones and is easily traceable throughout this area (p. 94) except in the south where it is thinner and largely scree-covered. Some structural observations on the zone are discussed on p. 108.

The "disturbed zone" is best exposed and appears to be thickest (approximately 440 m.) along the east-facing scarp of Ablation Point, whereas in the south of the area (i.e. down-dip) only 150 m. are exposed. There are three main rock types:

i. Volcanic rocks composed mainly of fresh and altered basic lavas (some of which are amygdaloidal), pyroclastic micro-breccias, crystal tuffs and agglomerates.
ii. Polymictic conglomerates and sediments containing variable amounts of volcanogenic material.
iii. Mudstones and sandstones.

The argillaceous sediments, which occupy most of the zone, contain invertebrate fossils, trace fossils, plant fragments and fossilized wood. At several localities, normally bedded sequences occur in the "disturbed zone".

There are pronounced north–south lithological variations within the zone. At Ablation Point and at locality AL, mudstones, siltstones and sandstones are intimately mixed and interbedded with crystal tuffs, vesicular lava (with flow structures), pyroclastic micro-breccias and agglomerates, the volcanogenic material representing the more resistant outcrops. At least two argillaceous dykes, intruded upwards from a similar source bed, occur within the "disturbed zone" on the north-east-facing scarp at Ablation Point. In the valley north of locality AS, the zone crops out as *roches moutonnées* of pyroclastic tuffs and breccias with angular and rounded clasts of volcanic origin which are interbedded and interfolded with grey-green lavas, sandstones and agglomerate. However, at locality AS, the zone is represented only by folded mudstones and subordinate sandstones. In the south of the Ablation Point area, the flat upper surface of at least 40 m. of grey-green agglomerate (possibly laterally equivalent to part of the "disturbed zone") is overlain by normally bedded mudstones and subordinate sandstones. The latter crop out as striated *roches moutonnées*.

The "disturbed zone" (AB_1, AH_1, AJ_1, AS_1; Fig. 5) is only poorly fossiliferous, and contains indeterminate ammonites, belemnites, bivalves, the trace fossils *Chondrites* and what have been referred to as vermicular structures (Taylor, 1967), and plants. The belemnites, which have been identified as *Belemnopsis* cf. *tanganensis* and *B.* cf. *keari* suggests an Upper Oxfordian–Middle Kimmeridgian age (Willey, 1973). In addition, fossils not *in situ* but assumed to have been derived from the "disturbed zone" and of the same age are *Inoceramus haasti*, *I.* aff. *subhaasti* (Thomson and Willey, 1972), *Perispinctes* (*Orthosphinctes*) cf. *transatlanticus* (Howarth, 1958), *Belemnopsis* cf. *gerardi* and *Belemnopsis* cf. *alfurica* (Willey, 1973). Because of the complexity of the "disturbed zone", detailed stratigraphical investigations were commenced immediately above these beds.

Except at locality AH, where a subordinate "disturbed zone" occurs, the overlying sequence is undisturbed (Fig. 5). Because of the apparent differences in the stratigraphical position of the upper boundary of the "disturbed zone", the thickness of the lower part of these sediments, i.e. up to the 3 m. arkosic sandstone, varies from 13 m. at locality AS to 120 m. at locality AH (Fig. 6). Although a more comprehensive fauna occurs at localities AH and AJ, locality AB has been selected as the type locality for these strata as they are better exposed there.

The first 15 m. (AB_2) comprise block-bedded sandstones, cross-bedded sandstones and silty shales with gastropods, perisphinctid ammonites, belemnites, *Entolium* and other bivalves, and plant remains. These are overlain by 16 m. (AB_3) of bioturbated shales with vermicular structures and perisphinctid ammonites interbedded with granular or pebbly sandstones and siltstones up to 50 cm. thick. These contain calcareous concretions, several of which have mineralized tension gashes. Large-scale cross bedding occurs both in the sandstones and silt-

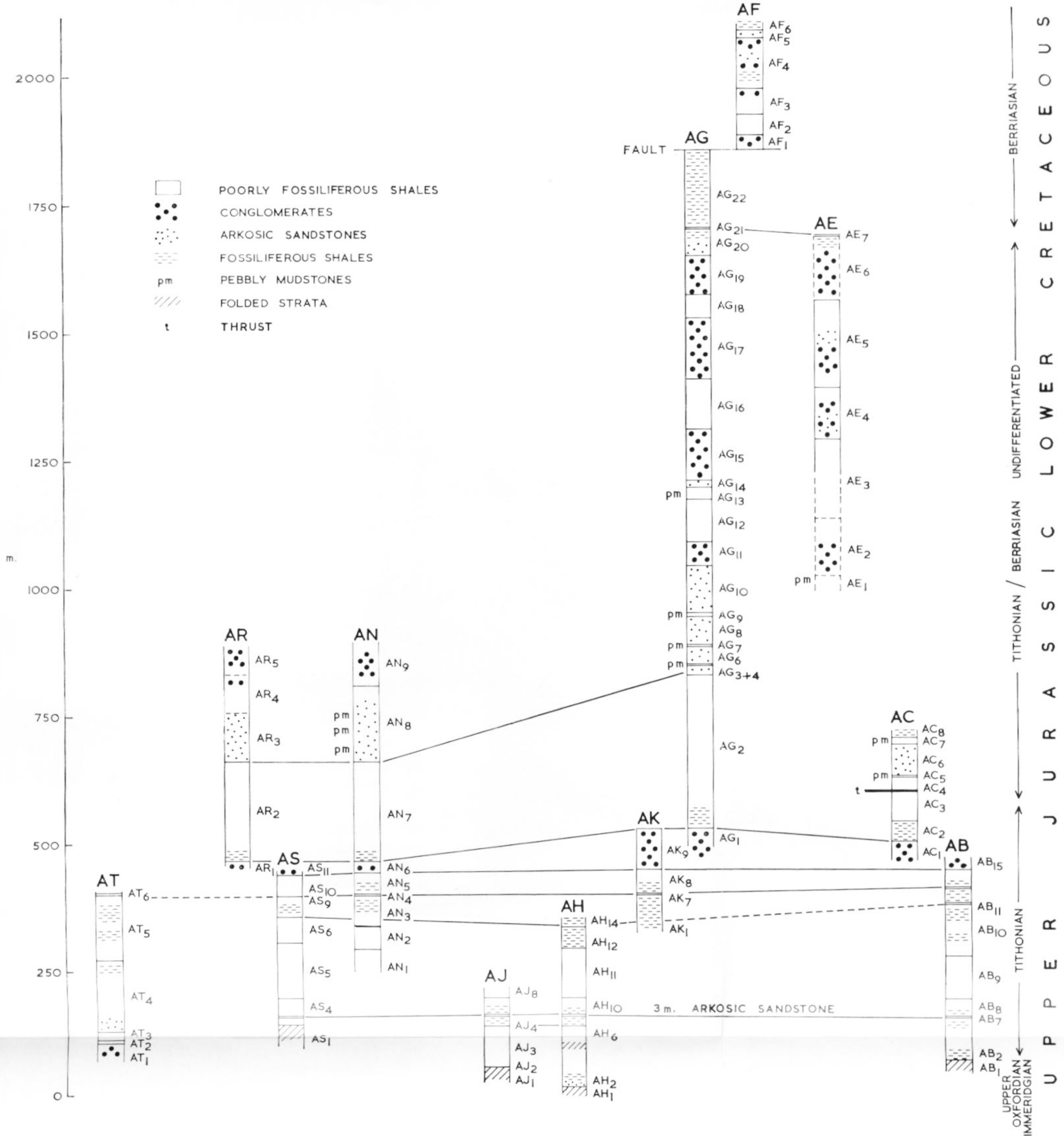

Fig. 5. Diagrammatic representation of the stratigraphical succession in the Ablation Point area except for the Aptian sequence at locality AP. Marker horizons and other rock units are indicated by a locality letter together with a subscript figure.

[face page 92

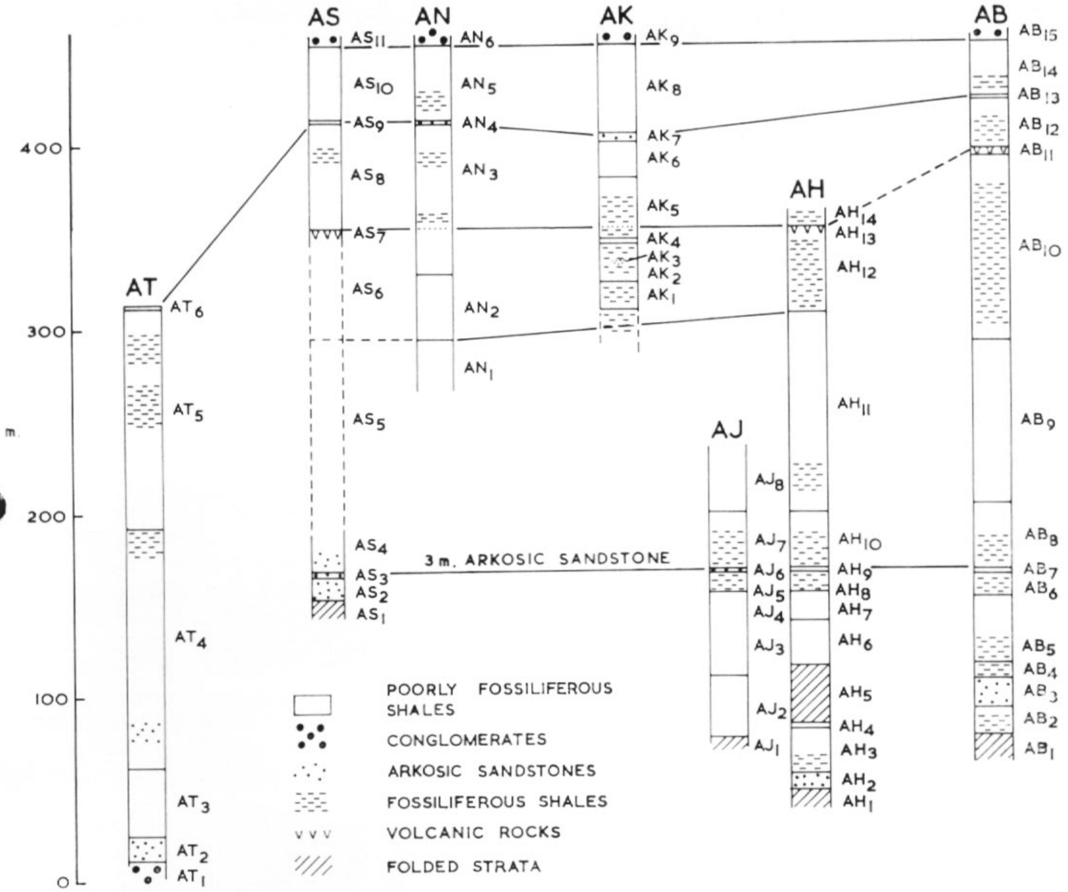

Fig. 6. A detailed stratigraphical section of the Tithonian strata at Ablation Point.

stones. These are succeeded by 3 m. of graded shale-breccias (with a coarse arkosic matrix) and by 5 m. of bioturbated shales and siltstones with *Haploceras* sp. indet., an indeterminate perisphinctid ammonite, the trace fossil *Zoophycos* and vermicular structures (AB_4).

Above these are 15 m. of siltstones, bioturbated silty shales and thin sandstones (AB_5) with phylloceratid and perisphinctid ammonites, 10 m. of sandy shales and an additional 10 m. of silty shales with four concretionary bands containing *Entolium*, *Buchia* and other bivalves. At locality AJ (AJ_5) in beds approximately equivalent to unit AB_6 the ammonite *Virgatosphinctes* aff. *denseplicatus* (*?*) was found *in situ* and *V.* sp. nov. aff. *andesensis* and *Aulocosphinctoides smith-woodwardi* (*?*) occurred in talus derived from the same unit. A further 12 m. of shales (AB_6) with perisphinctid ammonites are overlain by the 3 m. thick cross-bedded yellow arkosic sandstone (AB_7), which represents the first lithological marker horizon in this area. At some localities, the sandstone contains belemnite guards.

The succeeding 35 m. (AB_8) comprise bioturbated shales with indeterminate perisphinctid ammonites, bivalves, *Zoophycos* and abundant vermicular structures, and thinly bedded sandstones characterized by sheet-like burrows of *Zoophycos* parallel or sub-parallel to the bedding. At locality AH (AH_{10}) planispirally coiled *Zoophycos* occur in a silty shale.

The next 90 m. (AB_9) are shales, concretionary shales, siltstones and thinly bedded sandstones; graded bedding occurs at several horizons. At locality AH, where this sequence is 100 m. thick (AH_{11}), the sparse fauna consists of ammonites, including *Haploceras* sp., "*Lytoceras*" sp. indet., *Virgatosphinctes* sp. indet., belemnites, *Inoceramus*, *Buchia*, *Lima* (?) and other bivalves, *Rotularia*, *Chondrites* and *Zoophycos*.

Although the succeeding 100 m. of fossiliferous silty shales, concretions and concretionary bands are exposed at locality AB, they are best described from locality AK where all but the lower 20–25 m. are exposed. The lowest beds in the sequence there consist of 15 m. of shales with small concretions and two 0·5 m. thick concretionary horizons. Many of the upper bedding planes have doggers of hard, often iron-rich siltstone. *Buchia* and *Otapiria* (?) sp., perisphinctid and oppeliid ammonites and belemnites occur in this sequence. These silty shales are overlain by 20 m. (AK$_2$) of coarse arkosic sandstones (with *Hibolithes*), silty shales with perisphinctid and phylloceratid ammonites and occasional concretions up to 4 m. in diameter, and micro-brecciated calcareous shales, one of which contains *Spiticeras s.l.* sp.

Westward along the strike, the arkosic sandstones become thinner and finer-grained, and the concretionary bands become less significant. In one silty shale a lens (AK$_3$) 3 m. wide and up to 20 cm. thick of belemnite guards (*Hibolithes belligerundi*) and *Rotularia* is developed, and above this are relatively unfossiliferous reddish sandstones and siltstones 1 m. thick (AK$_4$), culminating in an horizon containing abundant orientated plants. At approximately equivalent horizons at localities AS (AS$_7$) and AH (AH$_{13}$) are one- and two-acidic ash bands, respectively; these could possibly be contemporaneous with a 3 m. thick basic lava at locality AB (AB$_{11}$). An incomplete decapod cheliped was collected 4 m. above the lava.

The siltstones are overlain by 34 m. (AK$_5$) of fossiliferous silty shales with concretions (up to 4 m. in diameter and containing several species of Radiolaria), two virtually continuous concretionary horizons and ultimately by thin sandstones containing numerous belemnite fragments. One 4 cm. thick sandstone contains abundant bivalves, belemnites and ammonites. The fauna in the shales includes terebratulid brachiopods, perisphinctid and phylloceratid ammonites, a *Lytoceras* encrusted by serpulids (the largest ammonite so far discovered in Alexander Island), belemnites, *Inoceramus*, *Buchia*, *Myophorella*, *Entolium*, *Grammatodon*, *Thracia*, *Pinna* and *Lucina* (?). These fossiliferous strata are overlain by 18 m. of interbedded blocky sandstones with shale fragments and plant remains, and poorly exposed shales containing concretions and bivalves (AK$_6$). The overlying 4 m. thick sandstone (AK$_7$) is characterized by water-worn belemnite guards, macerated plant remains and a considerable quantity of lava fragments.

Above the same arkosic sandstone at locality AN (AN$_4$) are 50 m. of shales (AN$_5$) containing *Blanfordiceras* aff. *wallichi*. The same shales at localities AB, AK and AN are overlain by the first of several thick-bedded conglomerates (AK$_9$), which is 75 m. thick at locality AK but only 20 m. at locality AN (AN$_6$).

Above this conglomerate at locality AC (where it is at least 40 m. thick) is a 2–3 m. thick brecciated and calcite-veined zone and 100 m. of thick-bedded fossiliferous shales (AC$_{2-3}$). In the lower 40 m. (AC$_2$) of these shales at localities AC and AG are *Blanfordiceras* aff. *wallichi*, *Blanfordiceras* sp. juv., "*Berriasella*" *subprivasensis*, *Phyllopachyceras beneckei* (?), *Myophorella*, *Inoceramus*, *Camptonectes*, *Ptilophyllum* and indeterminate wood fragments (collected from the brecciated zone). Several of these shales are bioturbated and there are frequent sandstone partings, some of which are convoluted, whereas others have burrows penetrating into the underlying shale. Vermicular structures are common. Some shales contain concretionary horizons which are usually 5–15 cm. thick although two are 30 cm. thick. The concretions are normally up to 50 cm. long but may reach 3·5 m. in length. The overlying 60 m. of shales (AC$_3$), which have fewer sandstone partings and discrete concretions, are yellow and red rather than grey-black in colour and are abruptly terminated by 2 m. of (?) thrusted sandstones, 20 cm. of which contain orientated belemnite fragments. These are succeeded by 15–20 m. of shales (AC$_4$) sheared by low-angle thrusting, apparently cutting out approximately 100 m. of beds which are more completely exposed at locality AG (AG$_2$). Above AC$_4$ is a 5 m. thick pebbly mudstone (AC$_5$) and 62 m. (AC$_6$) of block-bedded green sandstones which are sometimes convoluted and graded. The sandstones contain cannon-ball concretions and interbedded shales. Trace fossils, particularly *Zoophycos* and *Chondrites* are common, whereas belemnites and small limids occur infrequently. These shales are overlain by 13 m. of pebbly mudstones (AC$_7$) which are succeeded by shales containing brachiopods (AC$_8$). Beds AC$_{4-8}$ are represented at locality AG by beds AG$_{3-9}$ which are punctuated by three pebbly mudstones

(AG_5, $_7$ and $_9$) 2, 5 and 8 m. thick, respectively. The 5 m. thick pebbly mudstone (AG_7) has occasional pebbles up to 5 cm. long, whereas the 8 m. thick bed (AG_9) contains boulders up to 50 cm. long. Several blocks of penecontemporaneous sandstone also occur in this bed.

At locality AG, the green arkosic sandstones described above (AC_6) are followed by 610 m. (AG_{11-19}) of poorly exposed shales with interbedded conglomerates (AG_{11}, $_{15}$, $_{17}$ and $_{19}$), sandstones and pebbly mudstones. As these beds are largely obscured by debris from the conglomerates, the collected fossils may not be truly representative of the overall assemblage but they consist of *Chondrites*, *Zoophycos* and plant remains including *Ptilophyllum*.

A sequence containing a *Bochianites* fauna overlies the 75 m. thick conglomerate (AG_{19}) and continues upwards for 470 m. to form the youngest beds observed on this ridge. The middle part of this sequence is affected by a high-angle fault (Figs. 5, 11 and 12) and the stratigraphical relationships of the sediments above and below the fault at localities AG, AF and AE are uncertain. The strata below the fault, which were examined at localities AD, AE and AG, are traceable northward across an embayment in Grotto Glacier as far as station KG.714, whereas the uppermost strata above the fault only occur at locality AF.

This part of the succession commences with 50 m. of silty shales and sandstones (AG_{20}) and a 1 m. thick silty shale with an abundant molluscan fauna (AE_7 and AG_{21}). The fauna includes *Haplophylloceras strigile* (?), *Belemnopsis alexandri*, *Inoceramus* sp. α, *Camptonectes* (encrusted with serpulids), *Entolium*, *Grammatodon*, *Pinna*, *Pholadomya* (?), *Thracia*, *Myophorella* and astartids, gastropods, *Rotularia* and rhabdocidaroid spines. Several *Pinna* were found in life position. Plant remains include *Ptilophyllum* and *Nilssonia*.

The succeeding 160 m. (AG_{22}) of fossiliferous block-bedded shales are characterized by *Belemnopsis* aff. *uhligi* and *Belemnopsis alexandri*. Concretions frequently occur at the upper bedding planes of individual shale units. The remainder of the fauna consists only of isolated specimens of *Bochianites* aff. *versteeghi*, *Haplophylloceras strigile* (?), *Raimondiceras* sp. nov., *Spiticeras* aff. *spitiensis*, *Inoceramus*, *Grammatodon* and other bivalves, *Chondrites* and vermicular structures. Plant remains are scattered throughout the shales. These beds are abruptly truncated by the fault. Although the sequence above the fault at locality AF seems to be faunally equivalent to the uppermost part of the succession at locality AG, the sediments are more arenaceous and the two localities cannot be satisfactorily correlated lithologically.

Above the fault are 30 m. of weathered conglomerates (AF_1), containing a high proportion of plutonic pebbles, and poorly exposed shales (with occasional *Ptilophyllum* fronds), sandstones and conglomerates (AF_{2-4}) 220 m. thick. These are overlain by 15 m. of flag-bedded fine and coarse sandstones (AF_5) which form a cliff or tier near the summit of the ridge. In the upper part of the sandstones is a 1–5 cm. thick bed composed mainly of diminutive *Rotularia* with up to ten individuals per $cm.^2$. Associated with these annelids are *Myophorella*, *Haplophylloceras strigile*, *Chondrites* and *Ptilophyllum*. This sequence culminates in 20 m. of shales with large concretions and arkoses (AF_6) which form the summit of the ridge. An abundant fauna includes *Bochianites* aff. *versteeghi*, *Haplophylloceras strigile* (?), *Hibolithes subfusiformis*, *H. compressus*, *Myophorella*, *Pinna*, *Inoceramus*, *Grammatodon*, *Thracia* and other bivalves. *Ptilophyllum*, *Sphenopteris* and other indeterminate plant remains are also present.

DEPOSITIONAL STRUCTURES

Depositional and post-depositional structures are discussed on the basis of Nagtegaal's (1965) analysis of non-organic sedimentary structures.

Horizontal lamination occurs in shale and arkosic sandstone couplets at localities AB, AC, AG, AH and AJ. As the bedding is regular, the laminations probably represent variations in current strength, seasonal variations in current strength or the supply of detritus.

Cross stratification occurs in many of the arkosic sandstones but it is not characteristic of these rocks. At many localities it occurs as small-scale, multiple-grouped cosets with planar non-erosional lower bounding surfaces. Large-scale festoon bedding is developed in the Tithonian arkosic sandstones and interbedded block-bedded shales at locality AB.

Graded bedding

Normal graded bedding is present in many parts of the succession. At localities AC and AG, it occurs in arkosic sandstones and at locality AH, coarse shale-breccias grade into arkosic sandstones containing small shale fragments. Here, grading probably represents the deposition of heavy fragments from a waning current. Similar graded bedding on a larger scale occurs in the conglomerates which pass up into pebbly arkosic sands and arkosic sandstones.

Graded bedding is widespread in the relatively unfossiliferous Tithonian shales at localities AB, AH, AJ and AS, where thin arkosic sandstones pass up into block-bedded shales. The lower bedding planes of these strata are usually sharp. Some of these apparently poorly fossiliferous sandstones may represent turbidites.

Wash-out channels

Several sizes of wash-out channel occur at various localities in this area. At locality AJ, a wash-out channel is infilled by 30 m. of coarse arkosic sandstones which may have deformed the still unconsolidated adjacent sediments. Alternatively, the deformation may indicate differential compaction. At locality AG (AG_{3-8}), wash-out structures cut down into the arkosic sandstones and less commonly into the underlying shale. The bases are occasionally filled by normally graded pebbly arkosic sandstone. At locality AT, wash-out channels 2–3 m. wide and several centimetres deep are associated with convolute bedding and differential compaction of the arkosic sandstones.

Orientated organic structures

Plant remains are rarely seen to be orientated in the arkosic sandstones and siltstones, probably because exposed bedding planes are seldom more than 5 cm. wide. However, at locality AK, the upper bedding plane of a 20 cm. thick pink arkosic sandstone cropping out over a wide area of the ridge is strewn with orientated *Nilssonia* (*?*) fronds at 022°.

Most of the belemnites in the belemnite and *Rotularia* shell bank at locality AK are current orientated at 014°, whereas those lying up to 90° to this orientation were probably current rolled. Belemnite guards are also orientated at 032° in a coarse arkosic sandstone at locality AC.

POST-DEPOSITIONAL DEFORMATIONAL STRUCTURES

Convolute bedding characterizes many of the coarser rocks, particularly those arkosic sandstones at localities AC, AG and AR. It often occurs as a zone (3–7 cm. thick) in the upper part of otherwise homogeneous arkosic sandstones; the overlying shale is undisturbed. Less well-developed convolute bedding is present in the Tithonian strata at localities AH and AT. In most cases this appears to represent disturbance of waterlogged unconsolidated sediments by weakening currents (Dzulynski and Smith, 1963).

The widespread pebbly mudstones, formed by the deposition of mass-flow sediments, are discussed on p. 100. Their abundance and occurrence in several different facies suggests instability of the sedimentary basin.

Although sandstone dykes occur throughout the Ablation Point area, they are poorly developed compared with those in other parts of the Mesozoic succession (Taylor, 1966*a*). Twelve dykes were examined but more are probably present on the east face of Ablation Point where the higher parts of the cliff face are not easily accessible.

These dykes are 5–50 cm. wide and, whereas several are straight for several hundred metres, others are sinuous and markedly irregular in form and direction. The straight-sided walls of the rectilinear sections and the tabular form of the dykes (even of the apophyses) suggest they were intruded via an open joint system. Although the source beds were not seen, it is probable that the dykes were intruded upwards. At least some of the dykes are post-Berriasian in age.

LITHOFACIES

The sedimentary rocks belong to several lithofacies, each with a characteristic fauna. These lithofacies exhibit few lateral variations but pronounced vertical variations indicate changes in water depth (or shoreline location) during the Upper Jurassic and Lower Cretaceous.

The conglomerates and interbedded arkosic sandstones which characterize the uppermost Tithonian–Berriasian are almost unfossiliferous except for occasional abraded belemnite guards. These shallow-water marine deposits probably represent tidal flats, the conglomerates being deposited during periods of rapid erosion of the adjacent mountain ranges.

Three other lithofacies are characterized by arkosic sediments. The volcanic arkoses in the Upper Oxfordian–Tithonian, which are interbedded with shales and sedimentary breccias, are shallow-water marine deposits laid down close to the shoreline; during these times, the shoreline may have been formed of basic lavas and agglomerates.

The arkosic sandstones at localities AC, AG, AN and AR are characterized by cannon-ball concretions, convolute bedding and wash-out channels; they are interbedded with shales with a sparse bivalve fauna representing a possibly restricted marine environment. At locality AF, the finely laminated arkosic sandstones with abundant plant remains may indicate a tidal-flat environment.

The highly fossiliferous (mainly molluscan) Tithonian sediments consisting of silty shales with abundant calcareous concretions and thin interbedded arkosic sandstones represent a shallow-water marine environment. Sedimentation was sometimes slow, as is indicated by the occasional influxes of coarser arkosic material. A number of arkosic sandstones and siltstones are strewn with plant remains, and a single pink- to red-coloured siltstone suggests that the sea bed may have been totally elevated above sea-level for a short period of time, and underwent subaerial weathering. There is considerable variation in structures and lithology in this part of the sequence between the exposed section, which may indicate some instability at this time.

Concretionary and block-bedded shales characterized by *Belemnopsis* at localities AD and AG probably represent a deeper-water facies. The fauna includes several ammonites and occasional bivalves. No depositional structures were observed and sedimentation is thought to have been continuous. Vermicular structures are abundant in these strata.

Deeper-water conditions are indicated by 35 m. of shales and thin interbedded arkosic sandstones at localities AB, AH and AS. *Zoophycos* is abundant and bioturbation is widespread, whereas molluscan remains are virtually absent. If Seilacher's (1964) bathymetric zonation of trace fossils is a tenable hypothesis, even deeper water may be represented by shales with interbedded graded arkosic sandstones, *Chondrites*, *Zoophycos* and a sparse molluscan fauna. However, in south-eastern Alexander Island, northern Italy and Arkansas (Taylor, 1967, p. 6), *Zoophycos* has been reported from sediments of shallow or intermediate depth of deposition.

Volcanic Rocks

The older volcanic rocks, probably Upper Oxfordian–Kimmeridgian in age, crop out on valley floors and in the basal parts of several cliffs in the east of this area. They occur as lavas, agglomerates and breccias associated with conglomerates, arkosic sandstones and shales containing much volcanic detritus. As these sediments are folded, slumped and generally poorly exposed, the stratigraphical relationship with the volcanic rocks themselves is uncertain. Extensive mineral alteration precludes their use for radiometric dating and palaeomagnetic analysis.

The lavas are petrologically similar to one another. Specimen KG.806.1 consists of sericitized feldspar and augite (some with secondary epidote) set in a groundmass of plagioclase laths and devitrified brown glass. In specimen KG.804.2, the groundmass of feldspar and chloritic glass represents about 85 per cent of the rock; the feldspar phenocrysts have been rolled and the groundmass is flow-banded around them. The vesicles are infilled with an indeterminate, finely divided quartzo-feldspathic mosaic. In specimen KG.889.1, augite (up to 2 mm.) and altered plagioclase feldspar occur in a groundmass of plagioclase laths, augite grains and subordinate magnetite. In specimen KG.853.3, the plagioclase phenocrysts are almost indistinguishable in a flow-structured plagioclase and glass groundmass.

These rocks are epidotized, calcified and chloritized. Calcite is widespread as small crystals in specimen KG.816.1, whereas in specimen KG.869.2 it occurs as large platy crystals and "knots" which may be replacing ferromagnesian minerals. In specimen KG.889.1, the pyroxenes are entirely replaced by calcite and chlorite, and the groundmass is also extensively chloritized. In specimen KG.853.3, sinuous chlorite veins cut the groundmass which contains chloritized ferromagnesian minerals. Chlorite and epidote occur in vesicles in some of these rocks.

The agglomerates and breccias consist of angular lava fragments generally similar to those described above, together with occasional discrete quartz and feldspar fragments, and they are cut by veins of calcite, chlorite, and more rarely quartz. Some of these agglomerates may represent brecciated lavas.

The Tithonian lava (Fig. 7a) is represented by specimen KG.872.1. It comprises plagioclase (An_{67}) phenocrysts (up to 2 mm. long) set in a groundmass of plagioclase (An_{62}) laths, augite, chlorite and minor ilmenite (partly altered to leucoxene). The hand specimen contains iron pyrites crystals and the rock is cut by quartz veins.

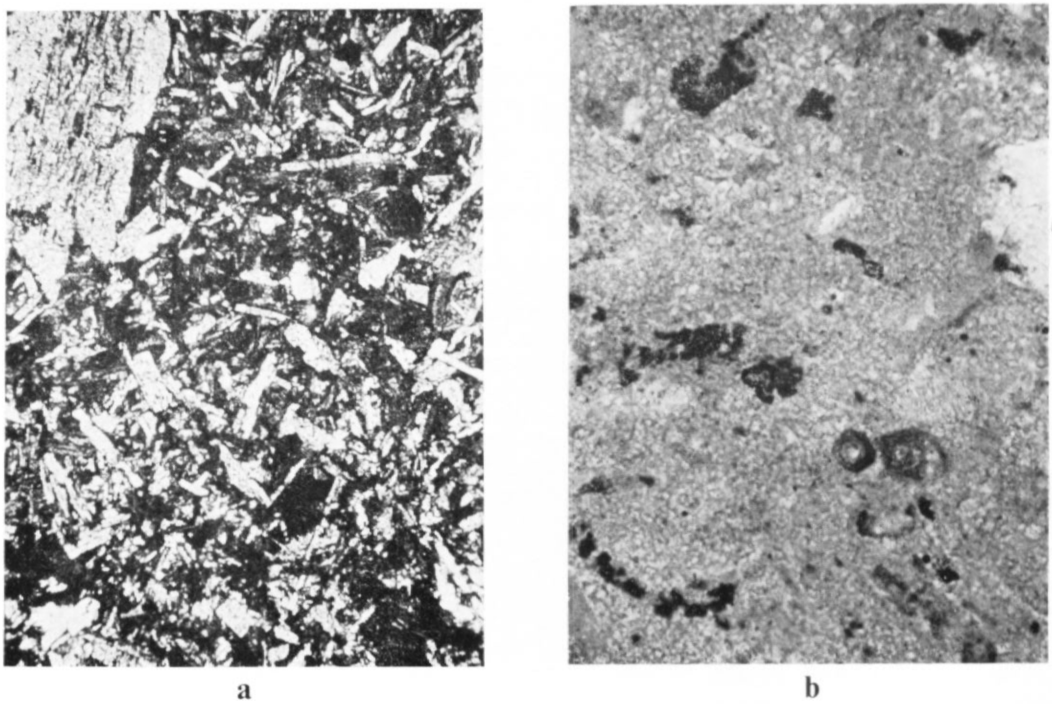

Fig. 7. a. Lava of Tithonian age; the plagioclase occurs in a groundmass of plagioclase, augite, ilmenite and chlorite (KG.872.1; X-nicols; ×27).
b. Indurated recrystallized acidic ash at locality AS (KG.743.2; ordinary light; ×37).

The stratigraphically equivalent acidic ashes at localities AH and AS are white indurated rocks, in beds up to 20 cm. thick, interbedded with fossiliferous shales. The largely indeterminate crystalline groundmass (Fig. 7b) contains angular fragments of quartz and oligoclase. This rock (e.g. KG.743.2) has similar lithology at both of these horizons.

The Upper Oxfordian–Kimmeridgian rocks are basic to intermediate and are comparable with volcanic rocks of a similar age exposed at equivalent latitudes in Palmer Land, where andesites, basalts and tuffs are widespread (Ayling, 1966; personal communications from P. J. Rowe, C. G. Smith and A. C. Skinner). Indurated ashes similar to specimen KG.743.2 are also common in Palmer Land.

SEDIMENTARY PETROLOGY

The 2,100 m. of Upper Oxfordian–Berriasian sedimentary rocks in this area are conglomerates, arkosic sandstones and shales, with subordinate pebbly mudstones and sedimentary breccias.

Textures

The textural and mineralogical immaturity of the sedimentary rocks is indicated by the morphology of the rock and mineral clasts. Thin-section analysis of the sandstones and examination of disaggregated specimens show that most fragments are angular to sub-angular according to Powers's (1953) definition. Most fragments have a low sphericity.

The sedimentary rocks in this area are generally poorly sorted. The best-sorted sandstones are arkosic at localities AF (AF_5) and AG. The "volcanic" arkoses of Upper Oxfordian–Kimmeridgian age are very poorly sorted.

Conglomerates

Conglomerates are important in this succession, being particularly well developed in the uppermost Tithonian and Berriasian part of the sequence. These horizons (up to 100 m. thick) consist of conglomerate lenses interbedded with pebbly arkoses and arkosic sandstones. Although the thickness varies considerably along both strike and dip, individual horizons can be traced over 20 km.^{2}. These conglomerates contain unorientated sub-rounded pebbles, cobbles and boulders up to 4 m. in diameter. The matrix consists of quartz, feldspar, volcanic and plutonic fragments, the relative proportions depending on the stratigraphical position of the conglomerate; the proportion of plutonic fragments increases upwards at the expense of the volcanic content. Because of their large areal extent, their texture and occurrence between marine shales, and the poorly sorted interstitial sandstones, these conglomerates are probably marine.

Arkosic sandstones

Arkosic sandstones, occurring in several lithofacies, are common in parts of the sedimentary sequence. Most of them are 0·2–2 m. thick and are texturally and mineralogically immature to sub-mature. The mineralogy varies throughout the succession, the most significant factor being the replacement of volcanic by plutonic detritus. Several sandstones of Upper Oxfordian–Tithonian age contain a high proportion of re-worked volcanic fragments and are therefore called "volcanic" arkoses.

The arkosic sandstones may be non-laminated, finely laminated, flat-bedded, current bedded, convoluted or graded. Most have a calcitic or chloritic cement, or a quartzo-feldspathic matrix, and some also contain calcareous concretions. Partings and lenses of angular or rounded shale fragments are occasionally present. The lower bedding planes are usually sharp, and macerated, sometimes orientated, plant remains are present on the upper bedding planes. The only invertebrate fossils in the arkosic sandstones are abraded belemnite guards, although the interbedded shales contain ammonites and bivalves.

Argillaceous sediments

Argillaceous sediments are abundant in the Ablation Point area, the commonest being silty shale. These shales, which are usually block-bedded, range from partings in arkosic andstones to beds several metres thick. A stratification based on slight colour differences and rain-size is often evident in thin section. This is often disrupted by bioturbation, notably by vermicular structures, *Chondrites* and *Zoophycos*. The stratification is sometimes due to plant remains which often provide foci for prehnitization. Calcareous concretions are numerous but their apparent facies-controlled distribution is irregular.

The argillaceous sedimentary rocks are immature to sub-mature. They consist of angular grains of quartz and feldspar, small blades of biotite and chlorite and a groundmass of clay minerals. Chlorite is present both as an authigenic cement and as allogenic fragments. Small quantities of prehnite are widely distributed as turbid patches or as rodded networks perpendicular to the fine laminations.

Mass-flow deposits

Pebbly mudstones and sedimentary breccias, similar to those described from California by Crowell (1957) and Alexander Island by Horne (1968*a*), are common in parts of this sedimentary succession.

The sedimentary breccias are up to 2·5 m. thick and comprise angular, sometimes platy, blocks (up to 15 cm. long) of black mudstone in a coarse poorly sorted arkosic matrix. The mudstone fragments are invariably cleanly fractured, indicating that they were consolidated prior to brecciation. They were probably formed by the disruption (possibly triggered by seismic shocks) of a consolidated mudstone or sequence of mudstones interbedded with a re-mobilized arkosic sandstone. These disrupted strata were subsequently deposited down-slope by a strong but waning current. Several of these deposits occur both in the Upper Oxfordian–Kimmeridgian and the lowest Tithonian successions.

By comparison, mudstone breccias infilling conglomeratic channels in the Tithonian shales at locality AG are cut-and-fill features and are genetically unrelated to the breccias described above.

Pebbly mudstones

These occur in the Tithonian–Berriasian strata at localities AC, AE, AG and AN, and in the sedimentary sequence of unknown age in the nunatak and the cliffs on the south side of Grotto Glacier. Pebbly mudstones (2–18 m. thick) are composed of homogeneous, although sometimes convoluted, coarse mudstone or black siltstone enclosing unorientated igneous, plutonic and metamorphic cobbles and rare blocks of penecontemporaneous arkosic sandstone. The exotic cobbles are similar to those in the conglomerates.

The contacts between the pebbly mudstones and the underlying strata are often obscured by talus. Where they have been seen, the pebbly mudstone has often eroded several centimetres into the underlying bed and fragments of this bed are often included in the lower parts of the diamictite. The upper bedding planes are sharp and concordant.

Unlike the pebbly mudstones described by Horne (1968*a*) which were observed to pass latterally into normally bedded conglomerates, arkosic sandstones and mudstones, no such lateral variation was seen in this area.

Concretions

Two types of concretion occur in the Upper Jurassic–Lower Cretaceous succession in this area, i.e. carbonate-cemented cannon-ball concretions in the sandstones, and cement-stone concretions in the mudstones. These concretions are similar to those described from south-eastern Alexander Island by Horne and Taylor (1969).

Cannon-ball concretions. Arkosic sandstones of a Tithonian–Berriasian age at localities AC, AG and AR, and of an unknown age in the cliffs on the south side of Grotto Glacier contain reddish brown concretions to which the term "cannon-ball" has been applied (Horne and Taylor, 1969, p. 19). These occur along distinct horizons in block-bedded arkosic sandstones, and sometimes traces of the bedding lamination pass through the concretions. Most are oblate spheroids or ellipsoids and have a maximum diameter of 40 cm. The contacts between the concretions and the enclosing sandstone are invariably well defined.

Although the cannon-ball concretions consist of clasts, similar to those in the adjacent arkosic sandstones, they contain up to 50 per cent of calcium carbonate cement, whereas the host rock contains only minor amounts of this cement. The finer-grained constituents of the original rock and some larger detrital grains have been replaced by fine-grained calcite, leaving the ferromagnesian and other minerals unaffected. No nuclei of formation were observed.

Cement-stone concretions. Cement-stone concretions are larger and more abundant than the cannon-ball concretions. They are best developed in the fossiliferous Tithonian shales at locality AK, but they also occur in the belemnite-bearing shales at localities AD, AF and AG. However, concretions are rare in those shales believed to represent a deeper-water facies.

The more lensoid concretions are up to 4 m. long (at locality AK) and 2–50 cm. thick. They consist of dense, light grey calcitic or reddish brown, iron-stained calcitic mudstone. Most of the cement-stone concretions are either spherical or elliptical and elongated parallel to the bedding. The contacts with the surrounding mudstones are usually well defined.

Many of the concretions contain ammonites, belemnites, *Myophorella*, *Entolium*, *Inoceramus*, *Buchia*, brachiopods and Radiolaria. Often these fossils are "full-bodied" as are the fossil fish in concretions from the Lower Cretaceous of Colombia (Weeks, 1953).

In thin section, the concretions consist of finely crystalline calcite (and (?) iron carbonate) together with small fragments of quartz, feldspar, epidote and ilmenite (sometimes altered to leucoxene) and an indeterminate matrix.

Origin of the concretions. The presence of full-bodied fossils in many of the cement-stone concretions indicates an early diagenetic formation, i.e. prior to the disintegration of the fossil. Calcium carbonate, derived from dissolved calcareous material, was undoubtedly re-deposited due to the localized alkalinity caused by ammonia and amines released by the decomposition of dead organisms (Weeks, 1953).

It is perhaps significant in this area that concretions are best developed in the fossiliferous and truly *marine* part of the succession, whereas it has been suggested that concretions only occur in anaerobic environments (Weeks, 1953).

The cannon-ball concretions, although formed from interstitial solutions, depend for their development on an availability of sufficient calcium carbonate coupled with high permeability of the enclosing sediments. Organic nuclei were not observed in these concretions, although they have been reported from elsewhere in Alexander Island (Horne and Taylor, 1969, p. 21). A sufficient increase in the alkalinity of the interstitial water was presumably provided by ammonia from the decomposition of organisms which now form the fossil remains in these strata.

SEDIMENTARY MINERALS AND ROCK FRAGMENTS

The modal analyses of 15 arkosic sandstones, siltstones and conglomerate matrices, ranging in age from Tithonian to Berriasian, are given in Table I. A ternary diagram (Fig. 8) illustrates the compositional variation in these sediments. This varies from predominantly volcanic fragments to a quartz and feldspar rock with minor biotite. The cement is unrelated to the composition of the sandstone.

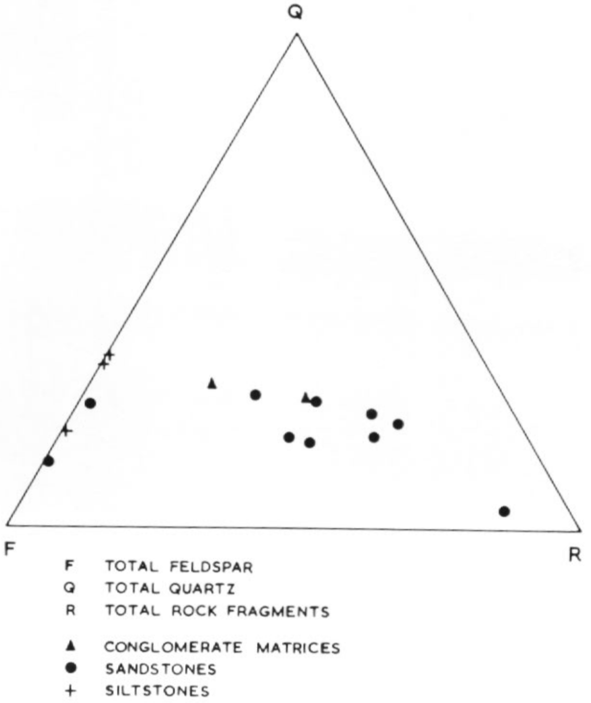

Fig. 8. Ternary composition diagram showing the distribution of 15 conglomerate matrices, sandstones and siltstones from the Upper Jurassic–Lower Cretaceous in the Ablation Point area.

Table I. Modal analyses of Upper Jurassic–Lower Cretaceous arkosic sandstones, conglomerate matrices and siltstones from the Ablation Point area, Alexander Island

	Arkosic sandstones										*Conglomerate matrices*		*Siltstones*		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Quartz	13·5	13·95	8·0	16·33	10·15	10·35	2·7	21·8	14·4	19·5	15·4	19·0	14·0	12·5	20·4
Feldspar	30·15	43·35	14·0	16·0	66·0	10·65	8·8	37·3	32·7	25·3	21·1	35·0	29·0	53·1	41·3
Volcanic fragments	30·6	1·0	28·0	43·0	—	—	62·8	—	—	13·7	10·8	2·0	—	0·2	—
Plutonic fragments	—	—	—	—	—	22·45	—	25·5	37·4	17·9	12·5	13·0	—	0·1	—
Biotite	—	5·15	—	—	5·45	1·15	—	1·3	0·1	—	—	—	1·0	—	2·5
Heavy minerals	—	1·7	tr	5·0	0·03	3·85	—	10·9	0·1	2·6	8·4	3·5	5·0	4·7	14·3
Iron ore	0·75	—	—	—	—	—	—	—	tr	—	—	—	7·0	3·6	6·5
Calcite	—	1·65	6·0	—	17·10	50·06	9·0	—	—	—	31·8	—	44·0	—	—
Prehnite	—	—	—	—	—	—	—	—	3·3	8·4	—	28·0	—	—	—
Chlorite	25·9	—	44·0	19·0	—	—	—	tr	—	—	—	—	—	25·8	16·7
Silicate matrix	—	33·25	—	—	—	—	16·7	3·0	10·4	—	—	—	—	—	—

tr = Trace.

Tithonian	*Berriasian*
1. KG.700.10	9. KG.704.1
2. KG.711.4	10. KG.708.4
3. KG.711.18	11. KG.708.5
4. KG.720.7	12. KG.719.3
5. KG.720.11	13. KG.719.14
6. KG.720.22	14. KG.721.1
7. KG.736.6	15. KG.721.4
8. KG.746.3	

Quartz

Quartz is present in all sedimentary rocks of conglomerate, sand and silt grade, although it only forms 10–20 per cent of the rock. Quartz also occurs predominantly as fragmentary anhedral crystals, 0·01–1 mm. in length, and rarely as rounded or sub-rounded grains. Most of the fragments represent the unstrained parts of single crystals but in the higher parts of the succession, polycrystalline quartz grains indicating a plutonic or metamorphic source are present. In the Tithonian strata, quartz, which was mainly derived from volcanic sources (presumably quartz-porphyries), is embayed and apparently replaced by calcite (Fig. 9a).

Feldspar

The feldspar content ranges from 10 to 66 per cent and the quartz : feldspar ratio varies from 1 : 1 to 1 : 6. Plagioclase comprises 50–90 per cent of the total feldspar and most of the remainder is orthoclase. Minor quantities of myrmekite and perthite also occur.

The feldspars, similar in size to the quartz fragments in the same sediment, are angular to sub-rounded (Fig. 9b). They are often considerably kaolinitized, epidotized and prehnitized, although this is often localized and varies between different stratigraphical horizons. In those arkosic sandstones cemented by calcium carbonate the feldspars are often less altered or even unaltered.

Indigenous rock fragments

Many of the coarser arkosic sandstones and sedimentary breccias contain flakes and pellets of mudstone apparently identical to normally bedded mudstones in the same succession. These sedimentary rocks have been current re-worked and commonly fill wash-out channels.

Exotic rock fragments

Rock fragments occur in many arkosic sandstones and conglomerate matrices, sometimes constituting, as in specimen KG.736.6, the major part of the rock, but others (e.g. KG.720.11) are almost devoid of this detritus.

The lithic clasts consist of volcanic, plutonic and metamorphic rocks. The volcanic clasts, usually of lava (Fig. 9c), include microlitic, vesicular, vitric and vitrophyric fragments. The vesicles in the fragments (Fig. 9d), which have an indeterminate brown groundmass, are infilled with chlorite and epidote, and they were probably derived from an eroded vesicular tuff. The pilotaxitic or hyalopilitic subhedral to euhedral feldspar microlites were probably derived from intermediate types of lava. Basaltic lavas are represented by clasts containing intergranular and ophitically arranged plagioclase laths. Fragments, which were originally vitric or vitrophyric, have been recrystallized to form phyllosilicates, zeolites, feldspars, silica minerals or combinations of these in microcrystalline aggregates. Although shards occur in the Fossil Bluff area (Taylor, 1966*a*; Horne, 1968*b*), they have not been observed in the Ablation Point area.

The plutonic rock fragments are represented by gabbroic, granodioritic and granitic clasts. Many grains include myrmekitic feldspar.

Fragments of a metamorphic origin include gneissose quartzo-feldspathic rocks with orientated biotite flakes, and an amphibolite fragment consisting of hornblende and feldspar. In specimen KG.711.2, a metamorphosed siltstone clast probably represents an episode of contact metamorphism in the source area.

Ferromagnesian minerals

Although rapid erosion and sedimentation may have favoured the survival of the labile minerals, significant quantities are only encountered in the Berriasian strata. This is attributed to a rarity of micas and hornblende in the volcanic rocks probably representing the source rocks for the lower parts of the succession.

Biotite, probably derived from plutonic and metamorphic sources, usually comprises less than 1 per cent of the detrital fraction in the sandstones, although in specimens KG.711.4 (an arkosic sandstone) and 720.11 (a concretion) it forms 5 per cent of the rock. Biotite occurs in

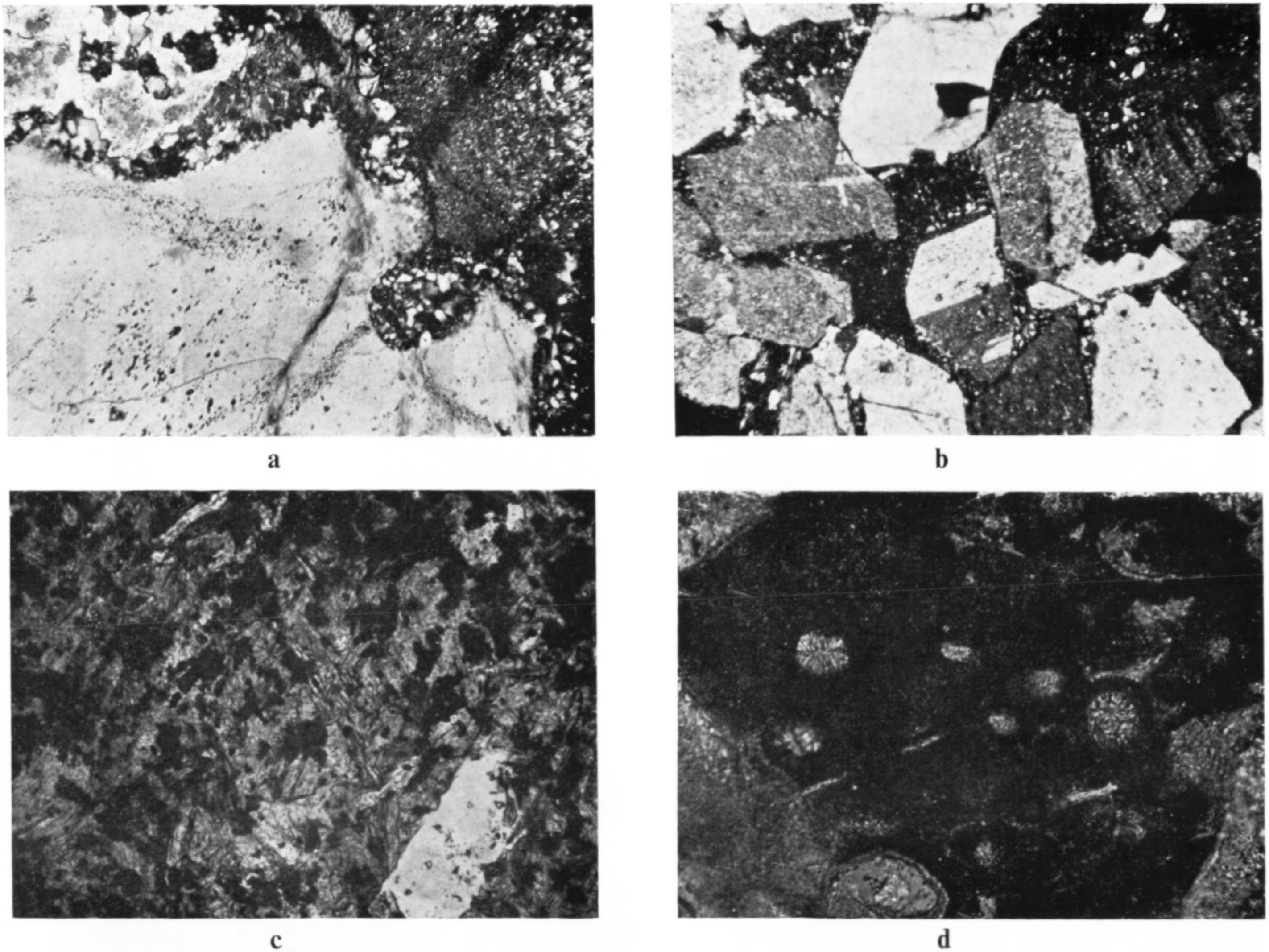

Fig. 9. a. Quartz fragment rimmed by a quartzo-feldspathic matrix (KG.723.1; X-nicols; ×107).
b. Immature plagioclase feldspars in an arkosic sandstone with a chlorite cement (KG.723.1; X-nicols; ×37)
c. Haem[illegible]te-rich volcanic fragment from an arkosic sandstone at lo[illegible]y AL (KG.706.1; ordinary light; ×107).
d. Vesicular tuff fragment (KG.700.13; ordinary light; ×260).

elongated plates, sometimes with bleached margins, and it is usually bent or broken. This distortion is the result of compaction before cementation of the sediment (Davies, 1967) and the other clastic particles often impinge on the biotite. The distribution of the biotite does not appear to be stratigraphically controlled.

Small amounts of *hornblende* occur in the Berriasian strata both as discrete fragments and as components of amphibolitic clasts. The source of these amphiboles may be metamorphic or plutonic.

Insignificant amounts of *augite* were probably derived from volcanic rocks similar to those cropping out in the Ablation Point area.

Other minerals

Although the conditions of sedimentation would also have favoured the survival of heavy minerals, these only become common in the Berriasian strata.

Excluding those ferromagnesian minerals already listed, there are minor amounts of magnetite (locally abundant in specimen KG.721.4), sphene, zircon, apatite, chlorite and muscovite. The grains are all of first-cycle igneous and metamorphic origin. These minerals are characterized by the same immaturity as the other detrital minerals in the succession and are thus directly related to the composition of the source area.

PROVENANCE

Horne (1968*b*, p. 80) suggested that the Lower Cretaceous sediments of south-eastern Alexander Island were derived mainly from the igneous and metamorphic complex exposed in Palmer Land in approximately the same latitudes. Lithofacies variations in the Ablation Point area support a similar conclusion. Furthermore, the sedimentary succession indicates a change from a predominantly volcanic provenance to one characterized by plutonic and metamorphic rocks.

The predominance of volcanic detritus in the Upper Oxfordian–Tithonian part of the succession indicates that the source area in the Upper Jurassic was composed almost entirely of volcanic rocks. There are several volcanic rock types, some similar to those exposed in the lowest parts of the succession. These similarities suggest that the sediments were derived in part from this local volcanic sequence. Later in the Tithonian, a massive influx of argillaceous material, representing a deepening of the trough, probably buried most of these volcanic rocks.

Subsequently, in the latest Tithonian and earliest Berriasian the developing geanticline in the vicinity of Palmer Land, which probably maintained its elevation throughout the period of sedimentation (Horne, 1969*b*, p. 74), resulted in the deposition of massive conglomerates and arkosic sandstones. These consist of an increasingly high proportion of plutonic and metamorphic rocks, but volcanic clasts remain important. The plutonic rocks range from gabbros to granites and the metamorphic rocks include hornblende-schists and gneisses. Many of the acid plutonic rocks are fresh in appearance.

Most of the plagioclase, orthoclase and weakly strained quartz was probably derived from granitic–granodioritic rocks. The occurrence of apatite, sphene and magnetite suggests a similar derivation. The biotite may be partly plutonic and partly metamorphic in origin, whereas the epidote, hornblende and chlorite was derived from a metamorphic terrain.

Proposed source area

The volcanic rocks exposed in Palmer Land are typically altered porphyritic lavas, tuffs and agglomerates. Some of the tuffs are identical to those at localities AH and AS, and many of the lavas are similar to the detrital fragments in the Tithonian sedimentary rocks.

The plutonic rocks cropping out in Palmer Land at the present time are gabbros, diorites, granodiorites and granites, many probably belonging to the Andean Intrusive Suite. Although no specimens have been correlated satisfactorily, and no radiometric dates are available for determining the age of the intrusive rocks represented by the detritus in the conglomerates in the Ablation Point area, it is possible that intrusions occurred in the provenance area in Upper Jurassic times. Horne (1968*a*) advocated general instability in the Palmer

Land area during the Mesozoic. Highly folded Jurassic sediments intruded by Cretaceous plutons have been reported from eastern Ellsworth Land (Laudon and others, 1969) and (?) Jurassic rocks cut by (?) Cretaceous plutons have been described from the Lassiter Coast (Williams and others, 1971). The features of instability observed in the Ablation Point area may be related to movements associated with these events.

The metamorphic rocks at present exposed in Palmer Land include gneisses, schists and amphibolites of an uncertain age. Clasts of similar rocks occur in the conglomerates which crop out in the Ablation Point area.

Because of a general similarity between the detritus in the Upper Jurassic–Lower Cretaceous sediments and the volcanic, plutonic and metamorphic complex of Palmer Land, it appears that Palmer Land represents the degraded source area for these sediments (Horne, 1969*b*, p. 74).

Cementation and Diagenesis

The conglomerates and arkosic sandstones have a calcium carbonate, chlorite or prehnite (Fig. 10a) cement, or a (?) quartzo-feldspathic matrix. Occasionally, two cements occur in the same rock. There is no apparent correlation between the type of cement and the mineralogy of the sediment or its lithofacies. The prehnite was probably formed during subsequent low-grade load metamorphism. The mudstones are cemented by finely divided clay or chlorite minerals, which are replaced in the concretions by calcite or, less commonly, prehnite. Although quartz occasionally occurs as veins, secondary quartz is rare; it is in optical continuity with detrital quartz grains in specimen KG.711.4.

Although the presence of convolute bedding and mass-flow structures in these sediments indicates that they were not lithified for some time after deposition, this semi-consolidated condition did not inhibit diagenesis. Many of the rock and mineral fragments, particularly those in the lowest parts of the succession, were coated with iron ore (Fig. 10b) or chlorite prior to cementation. This phenomenon may indicate a degree of chemical weathering in a sub-tropical to tropical climate before deposition.

Many of the arkosic sandstones and conglomerate matrices have a calcareous cement (Fig. 10c) which is either finely crystalline or in the form of poikilitic plates enclosing the often dissolved and embayed detrital clasts (Fig. 9a). Where concretions occur, the unorientated calcite has replaced the matrix prior to solution and replacement of the quartz and feldspar clasts, and ultimately the rock fragments and ferromagnesian minerals. A sequence of "volcanic" arkoses at locality AL shows a similar progressive replacement by calcium carbonate. In specimen KG.706.13, the arkosic sandstone is traversed by thin calcite veins, whereas in specimen KG.706.1 there are additional small calcite patches. In specimens KG.706.3 and 11, the calcite patches have been enlarged by selective replacement of the quartz and feldspar, and the sequence culminates in a rock type represented by specimen KG.706.12, in which most of the volcanic rock fragments have been replaced.

A finely crystalline quartzo-feldspathic matrix (Fig. 9b) is present in many of the arkosic sandstones, often filling pores where it is associated with chlorite. After cementation, calcite was subsequently introduced into some of these rocks, e.g. specimen KG.711.4.

Iron minerals

In specimen KG.703.38 (a bioturbated calcareous silty shale), a haematite vein is surrounded by an aureole of calcite-free sediment, and in specimen KG.706.11 there is an apparent lateral migration of iron through the rock in advance of the calcite replacement. The ferromagnesian minerals in a trachytic fragment in specimen KG.706.12 have also been replaced by iron ores, and in specimens KG.712.15 and 720.45 the chambers of Radiolaria are filled with haematite.

Chlorite

Chlorite, as a detrital mineral (often in the form of penninite), occurs as small isolated flakes in the arkosic and argillaceous rocks. In its authigenic form, it is often associated with calcite, prehnite and the quartzo-feldspathic matrix.

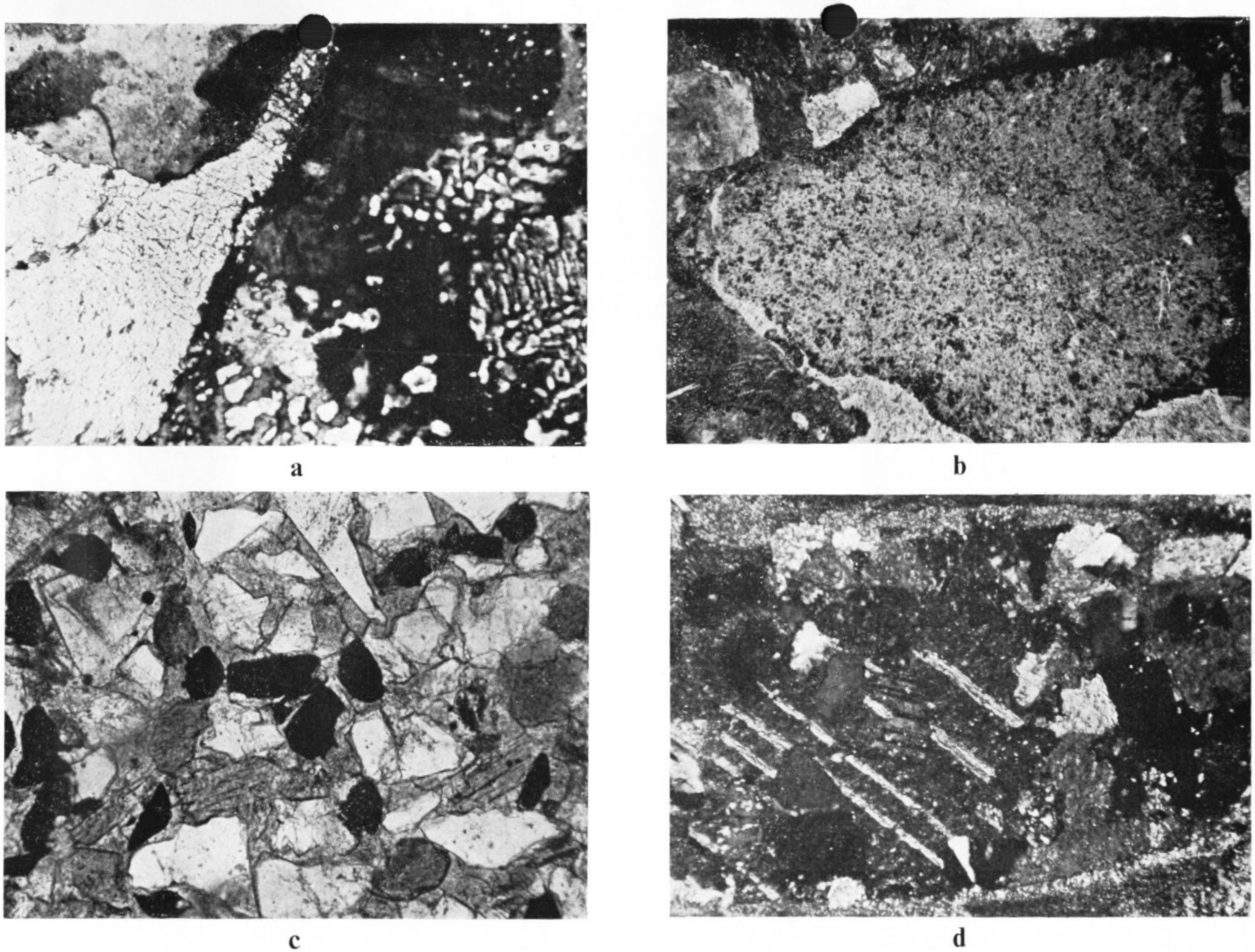

Fig. 10. a. Prehnite cement in a conglomerate (KG.719.3; X-nicols; ×37).
b. Lava fragment probably coated by haematite prior to deposition of the clast (KG. 754.5; ordinary light; ×37).
c. Magnetite-rich arkosic sandstone cemented by calcite (KG.720.30; ordinary light; ×107).
d. Calcite and prehnite infilling *Rotularia* chambers (KG.704.5; X-nicols; ×107).

Zeolite facies

In the Upper Jurassic–Lower Cretaceous succession of the Ablation Point area no relationships have been observed between the postulated stratigraphical environment of the sediment and the qualitative and quantitative development of authigenic silicates. As in south-eastern Alexander Island, prehnite and calcite often occur in association (Fig. 10d) (Taylor, 1966*a*, 1967), whereas calcite and laumontite are generally antipathetic (Horne, 1968*c*).

The relationship between the authigenic minerals and calcite, and the stratigraphical alternation of prehnite and laumontite, seems to invalidate the concept of transitional zeolite assemblages as proposed by Coombs and others (1959). Dickinson (1962), working on Jurassic tuffaceous marine sedimentary rocks in Oregon, and Watters (1965), discussing the Yahgan Formation of Navarino Island, southern Chile, reached a similar conclusion. Nevertheless, the experimental data of Coombs and others (1959) suggest that these minerals demonstrate that during burial the host rocks were heated up to 300–350° C at a pressure of up to at least 3,000 bar (Fyfe and others, 1958).

The development of these authigenic minerals depends on the initial composition of the sedimentary rocks, their physical properties and the connate waters. The critical factor appears to be the initial composition as shown by the prehnitization of the calcic cores of the plagioclase and of silty shales rich in carbonaceous plant remains. As these authigenic minerals can co-exist, their formation is influenced neither by silica deficiency nor saturation (Coombs and others, 1959).

As many of the Upper Jurassic–Lower Cretaceous sedimentary rocks were deposited rapidly, are texturally immature and may have been initially porous (several arkosic sandstones are devoid of clay matrices), prehnitization and zeolitization may have been accelerated. Furthermore, the abundant calcium in these rocks and in the connate waters (mostly re-deposited either as cement or as concretions) would have favoured the formation of calc-silicates such as prehnite and laumontite rather than sodic silicates such as albite; albite occurs only when the sodium content of the connate waters is relatively high (Lerbekmo, 1963).

STRUCTURAL GEOLOGY

The Ablation Point area lies within the tectonic framework previously described for Alexander Island (Horne, 1967*a*). This area consists of two major structural blocks (Figs. 2 and 11) separated by a major thrust. The eastern block is represented by a deeply dissected monoclinal structure (with a north–south axis) composed of lavas and sedimentary rocks ranging in age from Upper Oxfordian–Lower Kimmeridgian to Berriasian. This structure is affected locally by thrusts (usually westerly dipping) and is extensively deformed where the lower parts of the succession are exposed. In the west, the block is overthrust by a southerly dipping sequence of Aptian and Berriasian rocks. In the Grotto Glacier area, this block consists of locally thrust and folded arenaceous sedimentary rocks of unknown age.

The lower part of the eastern block is composed of volcanic rocks and sedimentary rocks of Upper Oxfordian–Kimmeridgian (and possibly Tithonian) age which have been structurally deformed. This deformation is demonstrated by anticlines and synclines, by post-depositional slump shearing and cataclasis, and possibly by the intrusion of sedimentary dykes. However, there are thick undeformed sequences within these disturbed strata and the prominent disturbed zone is itself overlain by an essentially flat-lying Tithonian succession. Horne (1967*a*, p. 3) suggested that these disturbed beds (together with similar disturbed zones at Fossil Bluff and Keystone Cliffs) represent "lubrication zones" for post-Aptian thrusting. At present, the age of the disturbed strata and the overlying concordant sediments is not known with any degree of certainty but it is likely that the "soft-sediment" deformation structures represent Kimmeridgian–Tithonian earth movements. The sediments deposited on these deformed beds were themselves subsequently subjected to minor tectonism; this is shown by the disturbances at locality AH and the sedimentary breccias which characterize this part of the succession.

The dip on the western limb of the monoclinal fold gradually increases to 60° at locality AG, but decreases again before disappearing beneath the Berriasian block of locality AF (Fig. 12). This steeply dipping limb is seen throughout this area and a similar structure crosses the

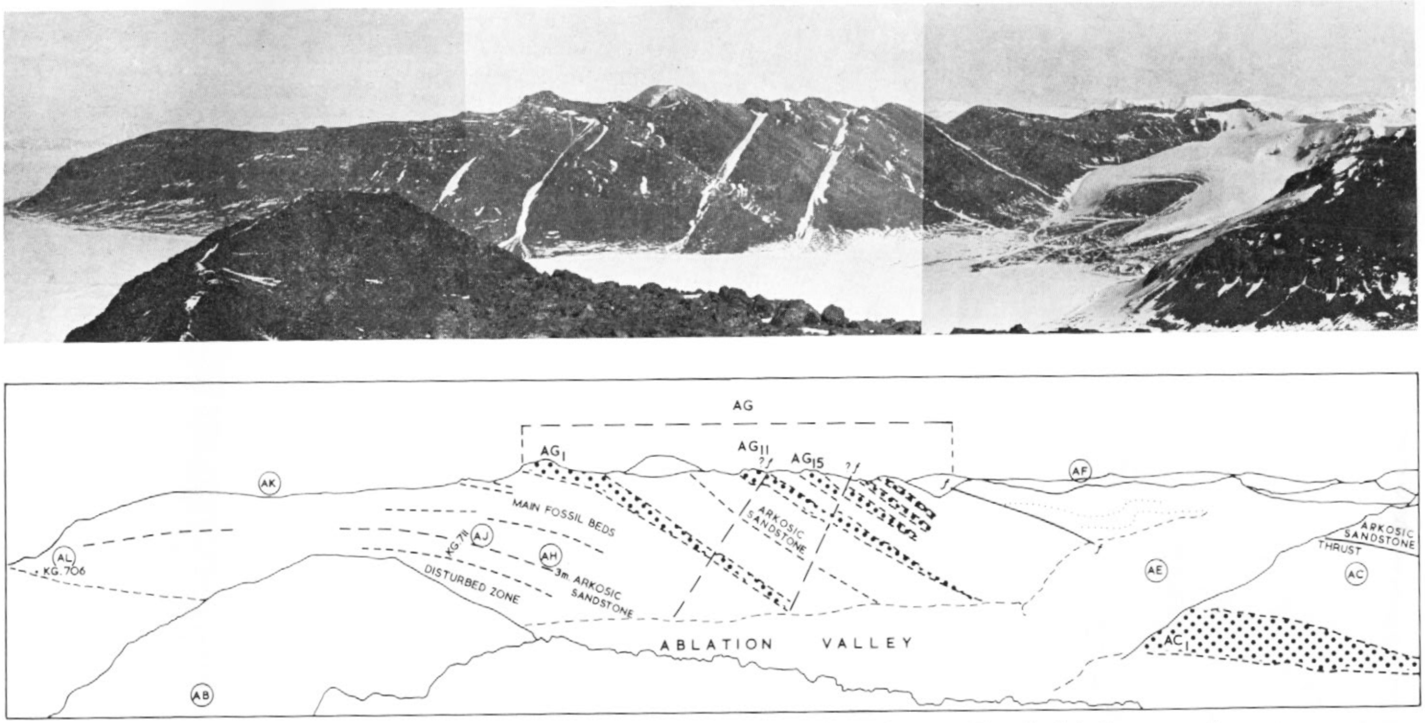

Fig. 11. Ridge south of Ablation Valley showing the structure of the Ablation Point area. The stipple indicates conglomerates.

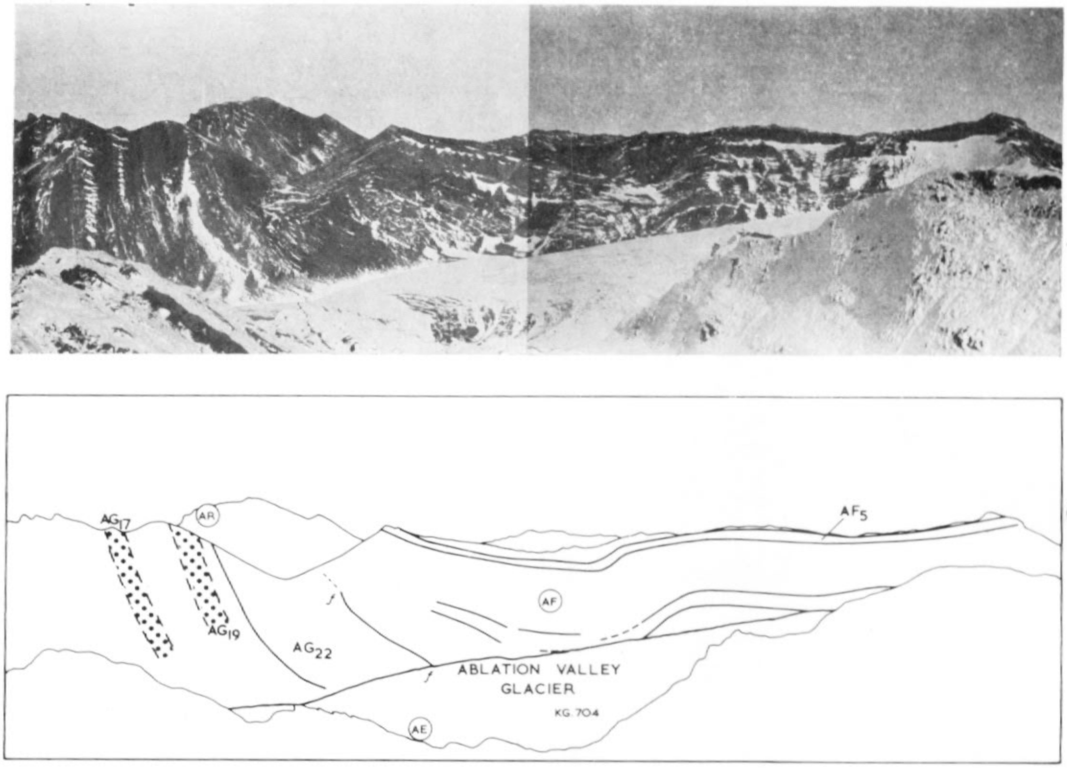

Fig. 12. Ridge (localities AF and AG) of Berriasian sedimentary rocks, showing the structure of the western structural block of the Ablation Point area. The stipple indicates conglomerates.

hinterland of Belemnite Point 10 km. to the north. The dip on the truncated eastern limb of this major fold rarely exceeds 10°.

The western (and hence stratigraphically higher) parts of this block are cut by thrusts dipping westward at up to 50° and parallel or sub-parallel to the strike. These thrusts, which may have compensated the folding, are not traceable across this area and the displacements on them are usually small. However, approximately 100 m. of shales are cut out by a thrust at locality AC, and an additional but inaccessible thrust at this locality also appears to have cut out a thick part of this sequence. At localities AK and AN, several minor imbricate thrusts repeat part of the Tithonian succession, while at locality AN another such thrust dips at 35° to the west and strikes 127° in sedimentary rocks which dip at 25° to the west and strike 107°. Slight thrusting and imbrication on a 10–15° easterly dipping plane striking 137° also occurs at locality AT, where a displacement of several centimetres was observed. At locality AG, an easterly dipping thrust in a conglomerate (AG_1) has a displacement of about 10 m. (Fig. 13).

This block contains several normal faults (Fig. 4c) with small displacements (up to 10 m.) which have been accentuated by differential weathering and erosion.

The contact between the two major structural blocks differs from one locality to another. At locality AG and probably in the south-western ridge (Fig. 4a), there is a single high-angle fault, whereas at localities AP, AD, station KG.714 and in the cliffs overlooking Grotto Glacier the contact is a thrust or series of imbricate thrusts. A southerly pitching monocline (Fig. 12) with a vertical disparity of 50–75 m. between the limbs is a major feature of the Berriasian block at locality AF. However, this flexure is evidently localized as it does not occur at localities AD and AP.

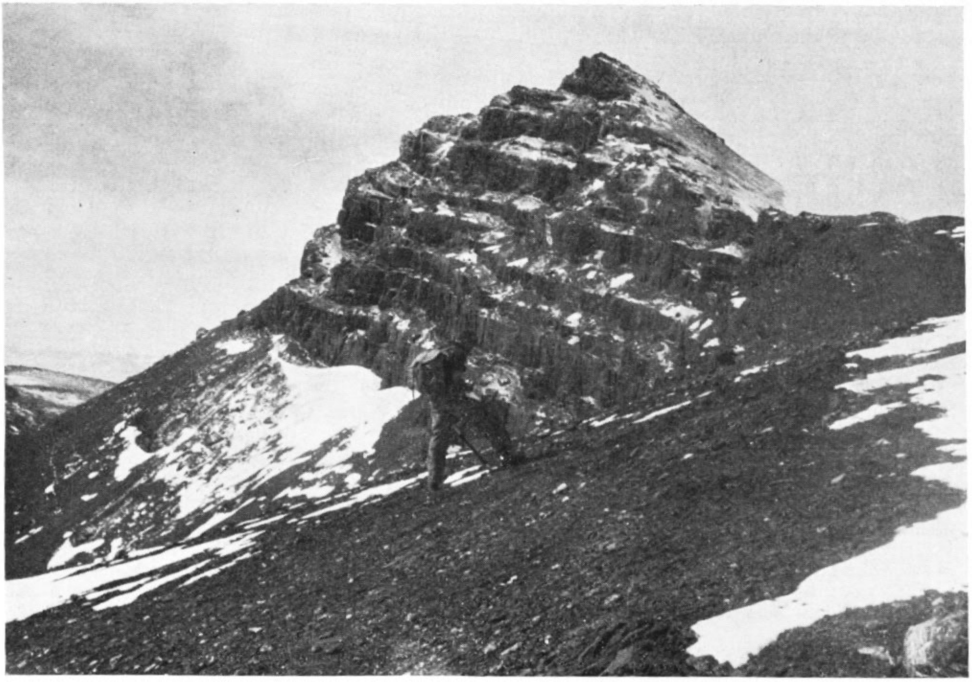

Fig. 13. Thrust in conglomerate at locality AG. The displacement is about 10 m.

The linearity of the cliffs forming the southern margin of Grotto Glacier and those between locality AC and the southern face of Ablation Point may indicate the presence of oblique-slip faults as in other parts of eastern Alexander Island (Horne, 1967). Although there is no stratigraphical evidence for the presence of these postulated faults, the large size of the features would indicate that glacial erosion has considerably emphasized these "fault lines".

Joints are common, particularly in the indurated shales. Their directions appear to be related to larger-scale structures indicating regional north-west to south-east compression. The sedimentary dykes were probably intruded into a well-developed joint system. The abundance of joints has led to gully formation and the rapid erosion of the shales which are often severely fractured.

Discussion and Conclusions

Observations on the stratigraphy and sedimentary petrology of this area indicate numerous similarities between the Upper Jurassic–Lower Cretaceous succession at Ablation Point and the Lower Cretaceous successions in other parts of south-eastern Alexander Island.

The stratigraphical work has indicated a conformable sequence of sediments 2,100 m. thick in the Ablation Point area. The identification of the molluscan fauna by M. R. A. Thomson and L. E. Willey has shown that the sequence ranges from Upper Oxfordian–Kimmeridgian to Berriasian, and has also suggested a tentative correlation between the upper part of this sequence and the Lower Cretaceous sedimentary sequence at locality Z. This largely conformable stratigraphical sequence indicates that the structure, at least in this area, is less complicated than previously believed (Adie, 1964).

It has become evident that the Ablation Point area is sedimentologically similar to the Lower Cretaceous parts of the Mesozoic succession. The composition of the rocks differs only in the higher proportion of volcanic detritus in the older sedimentary rocks. The Ablation Point area is characterized by thick conglomerates of uppermost Tithonian–Berriasian age, and pebbly mudstones are apparently more common than in the area studied by Horne

(1969*b*). This is probably due to the effects of the Upper Jurassic–Lower Cretaceous orogeny described from Ellsworth Land (Laudon and others, 1969) and the Lassiter Coast (Williams and others, 1971).

The general similarity of the sedimentary rocks, their concretions and their prehnitization suggest that both the Ablation Point area and the remainder of south-eastern Alexander Island have suffered a similar post-depositional history and had a similar palaeogeography.

ACKNOWLEDGEMENTS

I am grateful to members of the British Antarctic Survey for assistance with the field work during which these rocks were collected. Thanks are due to Professor F. W. Shotton for making available the facilities of the Department of Geology, University of Birmingham, and to Dr. R. J. Adie for advice during the course of this work. I am grateful to Dr. B. J. Taylor and C. M. Bell for critical discussion of this work, and to Drs. M. R. A. Thomson and L. E. Willey for the identification of ammonites, belemnites and bivalves discussed in this paper.

MS. received 6 July 1972

REFERENCES

ADIE, R. J. 1958. Geological investigations in the Falkland Islands Dependencies since 1940. *Polar Rec.*, **9**, No. 58, 3–17.

————. 1962. The geology of Antarctica. (*In* WEXLER, H., RUBIN, M. J. *and* J. E. CASKEY, *ed. Antarctic research: the Matthew Fontaine Maury Memorial Symposium*. Washington, D.C., American Geophysical Union, 26–39.) [Geophysical monograph No. 7.]

————. 1964. Stratigraphic correlation in west Antarctica. (*In* ADIE, R. J., *ed. Antarctic geology*. Amsterdam, North-Holland Publishing Company, 307–13.)

AYLING, M. E. 1966. *The geology of the "St. Valentine's" area, and related observations in the Batterbee Mountains, Palmer Land.* M.Sc. thesis, University of Birmingham, 119 pp. [Unpublished.]

COOMBS, D. S., ELLIS, A. J., FYFE, W. S. *and* A. M. TAYLOR. 1959. The zeolite facies, with comments on the interpretation of hydrothermal syntheses. *Geochim. cosmochim. Acta*, **17**, Nos. 1/2, 53–107.

COX, L. R. 1953. Lower Cretaceous Gastropoda, Lamellibranchia and Annelida from Alexander I Land (Falkland Islands Dependencies). *Falkland Islands Dependencies Survey Scientific Reports*, No. 4, 14 pp.

CROWELL, J. C. 1957. Origin of pebbly mudstones. *Bull. geol. Soc. Am.*, **68**, No. 8, 993–1009.

DAVIES, D. K. 1967. Origin of friable sandstone–calcareous sandstone rhythms in the Upper Lias of England. *J. sedim. Petrol.*, **37**, No. 4, 1179–88.

DICKINSON, W. R. 1962. Petrogenetic significance of geosynclinal andesitic volcanism along the Pacific margin of North America. *Geol. Soc. Am. Bull.*, **73**, No. 10, 1241–56.

DZULYNSKI, S. *and* A. J. SMITH. 1963. Convolute lamination, its origin, preservation, and directional significance. *J. sedim. Petrol.*, **33**, No. 3, 616–27.

FLEMING, W. L. S., STEPHENSON, A., ROBERTS, B. B. *and* G. C. L. BERTRAM. 1938. Notes on the scientific work of the British Graham Land Expedition, 1934–37. *Geogrl J.*, **91**, No. 6, 508–28.

FYFE, W. S., TURNER, F. J. *and* J. VERHOOGEN. 1958. Metamorphic reactions and metamorphic facies. *Mem. geol. Soc. Am.*, No. 73, 259 pp.

HORNE, R. R. 1967*a*. Structural geology of part of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 11, 1–22.

————. 1967*b*. *The geology of part of south-eastern Alexander Island.* Ph.D. thesis, University of Birmingham, 164 pp. [Unpublished.]

————. 1968*a*. Slump-shear structures and mass-flow deposits in the Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 17, 13–20.

————. 1968*b*. Petrology and provenance of the Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 17, 73–82.

————. 1968*c*. Authigenic prehnite, laumontite and chlorite in the Lower Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 18, 1–10.

————. 1969*a*. Morphology, petrology and provenance of pebbles from Lower Cretaceous conglomerates of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 21, 51–60.

————. 1969*b*. Sedimentology and palaeogeography of the Lower Cretaceous depositional trough of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 22, 61–76.

————. *and* B. J. TAYLOR. 1969. Calcareous concretions in the Lower Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 21, 19–32.

————. *and* M. R. A. THOMSON. 1967. Post-Aptian camptonite dykes in south-east Alexander Island. *British Antarctic Survey Bulletin*, No. 14, 15–24.

HOWARTH, M. K. 1958. Upper Jurassic and Cretaceous ammonite faunas of Alexander Land and Graham Land. *Falkland Islands Dependencies Survey Scientific Reports*, No. 21, 16 pp.

LAUDON, T. S., LACKEY, L. L., QUILTY, P. G. *and* P. M. OTWAY. 1969. Geology of eastern Ellsworth Land (Sheet 3, eastern Ellsworth Land). (*In* BUSHNELL, V. C. *and* C. CRADDOCK, *ed.* Geologic maps of Antarctica. *Antarct. Map Folio Ser.*, Folio 12, Pl. III.)

LERBEKMO, J. F. 1963. Petrology of the Belly River Formation, southern Alberta foothills. *Sedimentology*, **2**, No. 1, 54–86.

NAGTEGAAL, P. J. C. 1965. An approximation to the genetic classification of non-organic sedimentary structures. *Geologie Mijnb.*, **44**, Nr. 10, 347–52.

POWERS, M. C. 1953. A new roundness scale for sedimentary particles. *J. sedim. Petrol.*, **23**, No. 2, 117–19.

ROBIN, G. DE Q. *and* R. J. ADIE. 1964. The ice cover. (*In* PRIESTLEY, R. E., ADIE, R. J. *and* G. DE Q. ROBIN, *ed. Antarctic research*. London, Butterworth and Co. (Publishers) Ltd., 100–17.)

SEILACHER, A. 1964. Biogenic sedimentary structures. (*In* IMBRIE, J. *and* N. NEWELL, *ed. Approaches to paleoecology*. New York, London, Sydney, John Wiley and Sons, Inc., 296–316.)

SPATH, L. F. 1953. The Upper Cretaceous cephalopod fauna of Graham Land. *Falkland Islands Dependencies Survey Scientific Reports*, No. 3, 60 pp.

TAYLOR, B. J. 1965. Aptian cirripedes from Alexander Island. *British Antarctic Survey Bulletin*, No. 7, 37–42.

————. 1966*a*. *The stratigraphy and palaeontology of the Aptian of the central east coast of Alexander Island.* Ph.D. thesis, University of Birmingham, 245 pp. [Unpublished.]

————. 1966*b*. Taxonomy and morphology of Echinodermata from the Aptian of Alexander Island. *British Antarctic Survey Bulletin*, No. 8, 1–18.

————. 1967. Trace fossils from the Fossil Bluff Series of Alexander Island. *British Antarctic Survey Bulletin*, No. 13, 1–30.

————. 1969. Small tubiform fossils from the Lower Cretaceous of Alexander Island. *British Antarctic Survey Bulletin*, No. 21, 71–78.

————. 1971*a*. Thallophyte borings in phosphatic fossils from the Lower Cretaceous of south-east Alexander Island, Antarctica. *Palaeontology*, **14**, Pt. 2, 294–302.

————. 1971*b*. Stratigraphical correlation in south-east Alexander Island. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 149–53.)

THOMSON, M. R. A. 1969. *Some aspects of the Lower Cretaceous palaeontology and stratigraphy of south-east Alexander Island*. Ph.D. thesis, University of Birmingham, 175 pp. [Unpublished.]

————. 1971*a*. Gastropoda from the Lower Cretaceous sediments of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 25, 45–58.

————. 1971*b*. Inarticulate Brachiopoda from the Lower Cretaceous of south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 25, 85–94.

————. 1971*c*. Ammonite faunas of south-eastern Alexander Island and their stratigraphical significance. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 155–60.)

————. *and* L. E. WILLEY. 1972. Upper Jurassic and Lower Cretaceous *Inoceramus* (Bivalvia) from south-eastern Alexander Island. *British Antarctic Survey Bulletin*, No. 29, 1–19.

WATTERS, W. A. 1965. Prehnitization in the Yahgan Formation of Navarino Island, southernmost Chile. *Mineralog. Mag.*, **34**, No. 268, 517–27.

WEEKS, L. G. 1953. Environment and mode of origin and facies relationships of carbonate concretions in shales. *J. sedim. Petrol.*, **23**, No. 3, 162–73.

WILLEY, L. E. 1973. Belemnites from south-eastern Alexander Island: II. The occurrence of the family Belemnopseidae in the Upper Jurassic and Lower Cretaceous. *British Antarctic Survey Bulletin*, No. 36, 33–59.

WILLIAMS, P. L., SCHMIDT, D. L., PLUMMER, C. C. *and* L. E. BROWN. 1971. Geology of the Lassiter Coast area, Antarctic Peninsula: preliminary report. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 143–48.)