LATE JURASSIC AND EARLY CRETACEOUS BIOSTRATIGRAPHY OF THE FOSSIL BLUFF FORMATION, ALEXANDER ISLAND

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ABSTRACT. A thick (3.6–3.8 km) succession of sedimentary rocks (the Fossil Bluff Formation) in the Ablation Valley–Callisto Cliffs–Planet Heights region of eastern Alexander Island passes through the Jurassic–Cretaceous boundary. It comprises a more or less continuous sequence from a disturbed (slumped) zone, through a conglomerate-dominated interval to a siltstone-dominated one, and finally, into interbedded siltstones and sandstones. One interpretation of this succession is that it represents a progressive regional shallowing event (? from base of slope to inner shelf depths).

The succession spans at least the Kimmeridgian to Aptian stages. It commences with the Middle Kimmeridgian disturbed unit, which is characterized by a suite of belemnopseid belemnites and inoceramid bivalves belonging to the *Retroceramus haasti* species group. This is followed by a Lower Tithonian stage, based on a perisphinctid ammonite-buchiid bivalve fauna, and then an Upper Tithonian one, based on berriasellid ammonites. No precise level can yet be fixed for the Jurassic–Cretaceous boundary, but it probably lies somewhere within the range of *R. everesti* at Callisto Cliffs.

A rich Berriasian fauna has been recognized at four separate localities. This includes ammonites referable to genera such as *Raimondiceras*, *Spiticeras*, *Bochianites* and *Haplophylloceras*, several species of the belemnite *Hibolithes* and a variety of both infaunal and epifaunal bivalves. The topmost levels of the Berriasian fauna are closely associated with two faunal elements that have been used to differentiate the base of the Valanginian stage: the ammonite *Olcostephanus* and the belemnite *Belemnopsis gladiatoris*. Unfortunately, the succeeding levels are poorly fossiliferous and it has not been possible to distinguish the Hauterivian and Barremian stages with any degree of certainty. All that can be said at present is that they are most likely represented by a 700-m interval of siltstones.

The base of the Aptian is defined by a basin-wide spread of aconeceratid ammonites, *Aucellina andina-radiatostriata* species group and *Inoceramus deltoides*. Further aconeceratids, lytoceratids and dimitobelid belemnites (*Tetrabelus willeyi*) characterize the remainder of the Aptian and constitute the youngest fauna in the study region. The topmost beds (at Spartan Cwm) appear to correlate with the lowest levels at Succession Cliffs, immediately to the south. The 600-m section exposed here probably contains the Aptian–Albian boundary.

The faunas examined in this study exhibit a remarkable transition in biogeographic affinities. Whereas the earliest (Kimmeridgian–Tithonian) ones contain many elements that were very widely distributed around the southern margins of the Gondwana supercontinent, the latest (Aptian–Albian) are characterized by a number of groups that are apparently restricted to just the high latitude regions. Such a change can almost certainly be linked with the progressive fragmentation of Gondwana and southward drift of Antarctica and Australasia.

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INTRODUCTION

The Fossil Bluff Formation (FBF) of Alexander Island was one of the first sedimentary units within the Antarctic Peninsula region to be investigated in detail. As a result of a series of field investigations over a twelve-year period (1961–73), the principal features of this major sedimentary formation were clearly established (for a comprehensive review of this early work see Taylor and others, 1979). With an outcrop length of some 240 km, an average width of 20 km and a thickness of approximately 4 km, it was shown to range from Upper Jurassic (Kimmeridgian–Tithonian) to Lower Cretaceous (Aptian–Albian). The clastic sediments comprising it have been taken to represent a sequence of submarine fan and deltaic deposits that built out on the fore-arc (Pacific) margin of the Antarctic Peninsula (e.g. Butterworth, 1985). These accumulated in some form of fault-bounded basin which developed at least partly on top of the metasedimentary rocks of the extensive LeMay Group (which crops out widely in central and western Alexander Island; Burn, 1984; see also Storey and Garrett, 1985).

Comprehensive as these initial studies on the FBF were, they still left a number of significant problems to be solved. One of the most important of these lies in the field of biostratigraphy, where the early indications were that at least part of the Lower Cretaceous marine record may be missing (Taylor and others, 1979, p. 37 and table II; Thomson, 1983*a*). Whereas the Kimmeridgian–Berriasian stages are well represented in the Ablation Valley area (Fig. 1) and the Aptian–Albian at a number of localities between Succession Cliffs and Keystone Cliffs, evidence for the intervening Valanginian–Hauterivian stages was inconclusive. A Valanginian fauna has now been recognized in the former of these areas (Howlett, 1986) and it is important to put this and other new palaeontological collections into a stratigraphic perspective. The Early Cretaceous is now known to have been a time of widespread extensional tectonics associated with the fracturing of central Gondwana (e.g. Dalziel and others, in press) and it is pertinent to enquire whether this activity is reflected in the Antarctic Peninsula sedimentary record. The FBF may hold important evidence of Jurassic–Cretaceous boundary events at high latitudes in the Southern Hemisphere.

During the initial phase of work on the FBF it was noticed that some of the sedimentary successions exposed in the cliffs bordering George VI Sound (Figs 1–3) seemed to extend for a considerable distance inland (i.e. west or south-west). In particular, it was felt that those exposed in the Ablation Valley and Callisto Cliffs regions (Figs 1–3) offered considerable potential for linking Kimmeridgian–Tithonian strata directly to Aptian or Albian ones. Reconnaissance studies by C. M. Bell and A. Linn had shown that ammonites of probable Aptian age occurred at localities in the westernmost parts of these two regions and it has been our aim to incorporate these onto measured stratigraphic sections. In this study we describe the preliminary results of recent field work in the vicinity of both Ablation Valley (by P. J. H.) and Callisto Cliffs (by J. A. C.), and suggest a number of new correlations. To explain the precise lines of section that we followed, it is necessary to discuss briefly the structural geology of the region.

STRUCTURE

The regional dip of the FBF between Belemnite Point and Fossil Bluff (Fig. 1) is to the south-west. However, on a local scale this overall structure is complicated by a series of shallow, open folds and steep, westerly dipping thrust faults. The folds were originally thought to have had essentially north–south axes (Horne, 1967; Elliott,

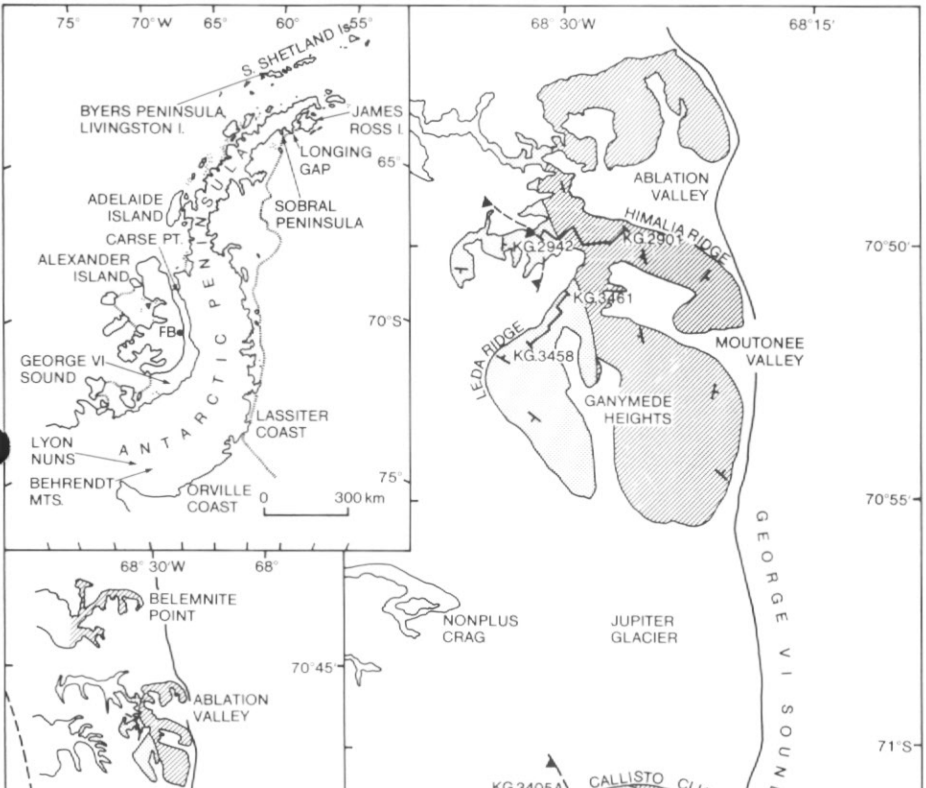

Fig. 1. Locality and sketch geological map of the Fossil Bluff Formation, eastern Alexander Island. Note that further details of locality numbers on Himalia and Leda Ridges are given on the stratigraphic sections presented in Fig. 4.

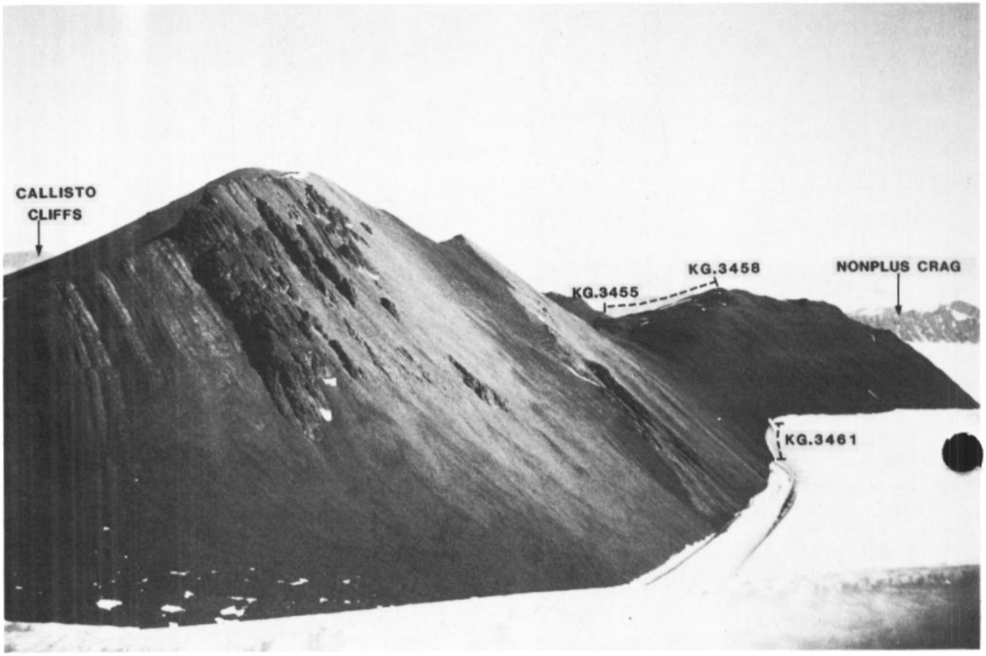

Fig. 2. The northern side of Leda Ridge. The main section runs westward from the col (just right of centre of the photograph) up to the furthest summit. In the foreground are siltstones, sandstones and conglomerates equivalent to the upper half of the Himalia Ridge section (from beneath Conglomerate 2, to above Conglomerate 4). The photograph was taken from Himalia Ridge, looking to the south-west. The ridge is approximately 5 km long.

1974) but it is now apparent that they are aligned more nearly north-west–south-east, a trend parallel to that of the major thrusts (Fig. 1). These two sets of structures are almost certainly genetically related (B. C. Storey, pers. comm. 1986).

In the Ablation Valley area the line of section commences in the core region of an anticline exposed in Himalia Ridge (Fig. 1). Most of the eastern limb of this fold is missing, but a more or less continuous line of section can be traced westwards from locality KG. 2903 (Figs 1, 4). Initially, the beds dip gently (approx. 10°) to the west, but throughout the section the dip increases until near the top (KG. 2934) the beds are steep (60–65° SW). In Moutonée Valley (Fig. 1), this anticline can be traced southwards into Ganymede Heights. The structure is similar to Himalia Ridge, with dips gradually steepening westwards from 15° to 40° south-west. On western Himalia Ridge (just above locality KG. 2942; Figs 1, 4), the section is truncated by a prominent, west-dipping thrust. Approximately 500 m of gently south-dipping sedimentary rocks are exposed above this feature, and these suggest a displacement of 700–800 m. The situation on Leda Ridge (Figs 1, 2) is rather more complicated. At the north-eastern end there is a series of easterly dipping normal faults, and at the south-western end some small westerly dipping reverse faults. Both these cause repetition of the succession, but there is no evidence of any large-scale thrusting, as on Himalia Ridge. The measured section on Leda Ridge starts in the most westerly of the normal-fault bounded blocks (KG. 3461; Figs 1, 4) where the beds dip steeply to the south-west (50–60°). The succession there can be correlated with that on Himalia Ridge (KG. 2934; Fig. 4). Throughout the Leda Ridge section, the dips decrease to approximately 20° south-west at the top (locality KG. 3458).

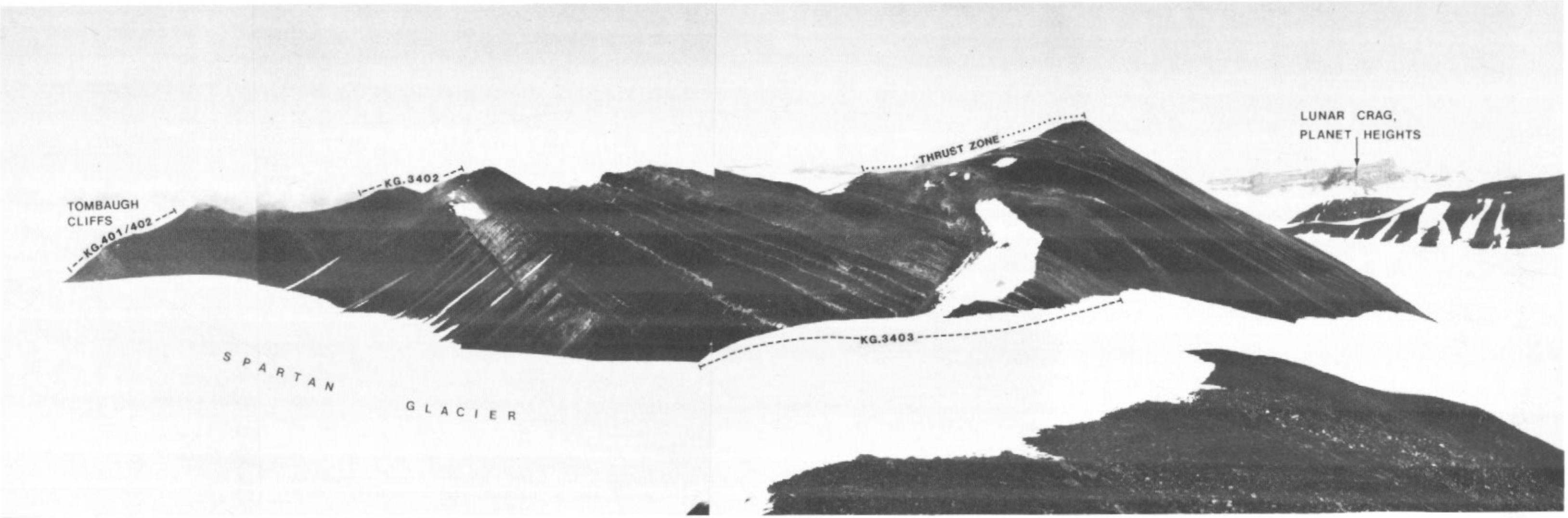

Fig. 3. The south-western flank of Spartan Cwm. The photograph was taken from the western headwall of the cwm, looking in a south-westerly direction. The main cliff-line is approximately 5.5 km in length and exposes some 1750 m of Berriasian–Aptian strata beneath the thrust zone. Pale Tithonian sandstones and conglomerates forming Lunar Crag, Planet Heights can be seen on the extreme right of the photograph.

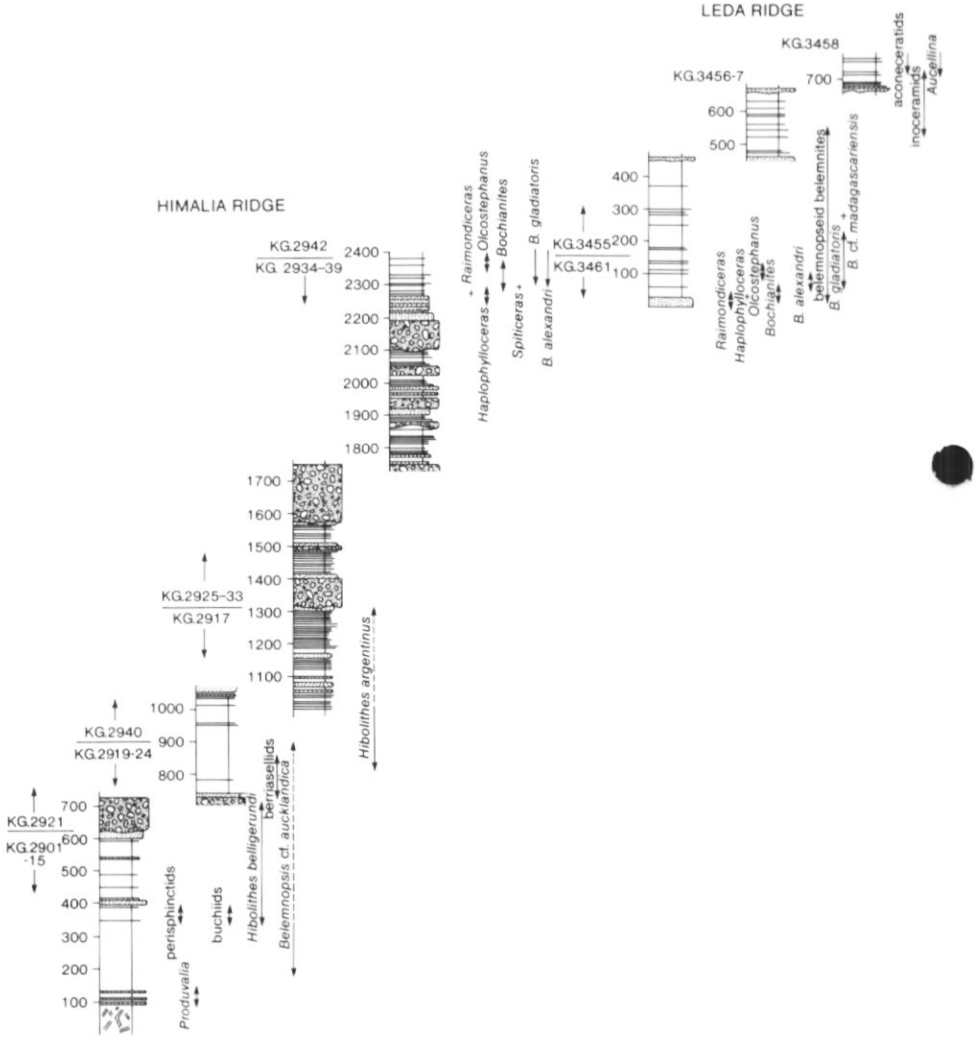

Fig. 4. The Himalia Ridge and Leda Ridge sections. Key faunal elements marked; generalized lithologi range from siltstone to coarse conglomerate; vertical scale in metres. (For disturbed zone faunas se Taylor and others, 1979.)

Strata exposed in the Callisto Cliffs–Planet Heights area define a north-north-west–south-south-east trending synform that plunges gently to the south-east; indeed, it is likely that this is the dominant structure between Jupiter Glacier and Fossil Bluff (Fig. 1). The lowest beds are exposed on the western limb of this fold and a section was measured through them at locality KG. 3404 (Fig. 1). They dip gently (6–9°) north-east into the core region but are abruptly truncated by a steep, westerly dipping thrust zone which is almost coincident with the fold axis. This thrust can be traced southwards from the southern margin of Jupiter Glacier to Succession Cliffs (Fig. 1) and in places reveals a series of spectacular fault structures and ramp anticlines (Taylor and others, 1979; Crame, 1986). The highest beds on the western limb of the synform can be correlated with a low level in the succession exposed in

Callisto Cliffs. Here the beds dip moderately steeply (approx. 40°) to the south-west and a very long section (KG. 2802–3401, Fig. 1) can be measured up the cliffs and onto the ridge at the head of Spartan Glacier (Spartan Cwm). To facilitate ease of access, the highest levels of this section were measured through stratigraphically equivalent beds on the south-western side of Spartan Cwm (KG. 3402 and 3403, Figs 1, 3).

STRATIGRAPHIC TERMINOLOGY

Before describing the sections in detail, it is necessary to discuss briefly the stage terminology that has been employed in Antarctic Jurassic–Cretaceous boundary biostratigraphy. Much confusion still surrounds the use of stage names at this level and it is important to clarify our position.

The problems of precise definition of the latest Jurassic and earliest Cretaceous stages in their type areas have been dealt with extensively elsewhere (e.g. Casey and Rawson (eds.), 1973; Colloque sur la limite Jurassique–Crétacé, 1975; Zeiss, [illegible]83; Jeletzky, 1984; Working Group for the Jurassic/Cretaceous Boundary, 1986). In Antarctica, the scheme used for the Upper Jurassic is based on that employed in New Zealand (e.g. Stevens, 1978; Stevens and Speden, 1978), which is in turn a derivative of the standard Tethyan system. The penultimate stage is the Kimmeridgian and this is divided into two substages, the Lower (which is equivalent to the New Zealand Heterian stage) and Middle (equivalent to the Ohauan) (e.g. Crame, 1982*a*, *b*). So as to avoid possible confusion with the topmost part of the Kimmeridgian succession in England, which is now thought to be Lower Tithonian, no Upper Kimmeridgian is recognized in the Tethyan realm (see Wimbledon, 1980; Westermann, 1984). In both Antarctica and New Zealand the Tithonian follows directly on from the Middle Kimmeridgian and forms the topmost Jurassic stage. The basal Cretaceous stage is the Berriasian and we have tried, wherever possible, to define both it and the succeeding stages using the guidelines outlined by Rawson (1983) and Birkelund and others (1984). We do not use the term Neocomian.

One further point concerning the definition of the Jurassic–Cretaceous boundary should be mentioned here. It is by now fully apparent that it is not a natural stratigraphic division in the sense that it represents an appreciable turnover of taxa on a global scale. The present boundary is largely a matter of historical accident and can only be defined by consensus opinions between systematic and stratigraphic specialists. Perhaps magnetostratigraphy offers the only real prospect for establishing a universal correlation scheme (Ogg and Lowrie, 1986).

DESCRIPTION OF THE SECTIONS

1. *Himalia Ridge*

The lowest 100 m of the section measured on Himalia Ridge (KG. 2902, Figs 1, 4) contain lithologies typical of the 'disturbed zone', which crops out extensively along the eastern margin of the Ablation Valley area (Elliott, 1974; Taylor and others, 1979). At least 440 m thick, this zone is characterized by spectacular intervals (up to 100 m thick) of contorted and disrupted strata that are the direct result of synsedimentary slumping. On Himalia Ridge the dominant lithologies above this 'disturbed zone' are massively bedded mudstones, siltstones (facies 1 of Butterworth, 1985) and subordinate, thinly interbedded fine sandstones (facies 3a of Butterworth, 1985). Intense bioturbation is common, and includes trace fossils such as *Chondrites*, *Zoophycos* and *Planolites*.

Belemnites, which can probably be referred to the genus *Produvalia* Riegraf, were collected between 90 and 150 m (Figs 4, 5a, d). However, macrofossils are genuinely scarce in the lowest levels of the section and no other diagnostic molluscan species were found. Because of the chaotic nature of much of the bedding in the disturbed zone and the occurrence of a number of loose specimens, it has not been possible to subdivide it palaeontologically; traditionally, only a broad late Oxfordian–Kimmeridgian age range has been inferred (Taylor and others, 1979; Thomson, 1979). This age determination is based upon ammonites such as *Perisphinctes* (*Orthosphinctes*) cf. *transatlanticus* (Steinmann), *Pachysphinctes*(?) sp., belemnites such as *Belemnopsis* cf. *alfurica* (Boehm), *B*. cf. *gerardi* (Oppel), *B*. cf. *keari* Stevens and *B*. cf. *tanganensis* (Futterer), and bivalves referable to the *Retroceramus haasti* (Hochstetter) group (Howarth, 1958; Willey, 1973; Thomson, 1979; Crame, 1982*b*). Some evidence that the age may be closer to the upper end of this range is provided by the bivalve fauna. The presence of *R. haasti* suggests a Middle Kimmeridgian (Ohauan) age, as does a possible new species of the oxytomid genus *Malayomaorica*. The latter shows closer affinities to species such as '*Buchia*' *misolica* (Krumbeck) than it does to the earlier (Lower–Middle Kimmeridgian) *M. malayomaorica* (Krumbeck) (Crame, 1983*a*, 1985*a*).

Essentially similar lithologies continue over the next 522 m (localities KG.2901, 2903–5, 2907, 2910, 2912 and 2914, Figs 1, 4) but these are noticeably more fossiliferous. Some of the intercalated sandstones are up to 1 m thick, and at the 120-m level there is a 2.5-m pale arkose that contains some well-rounded pebbles and abraded fragments of belemnite rostra. Although exposure is poor in the top part of this interval, sandstone beds are generally thicker and coarser grained. Perhaps the most striking faunal element in this interval is a perisphinctid ammonite zone which is present between 350 and 400 m (Figs 4, 5b). Species so far identified from this zone include: *Virgatosphinctes* aff. *denseplicatus* (Waagen), *V*. sp. nov. aff. *andesensis* (Douvillé) and *Aulacosphinctoides smithwoodwardi* (Uhlig) (Thomson, 1979). These occur together with several lytoceratids, phylloceratids, and belemnopseid belemnites (e.g. *Belemnopsis* cf. *aucklandica* (Hochstetter) (Fig 5c, g) and *Hibolithes belligerundi* Willey). Bivalves become relatively common in the lower part of this interval too, and in addition to a background fauna of *Myophorella*, *Grammatodon* and *Entolium*, there is a distinct *Buchia* horizon between approximately 340 and 400 m. This is composed of the elongate, narrow forms that may need to be accommodated within a new genus (or subgenus) (= *Australobuchia* of Zakharov, 1981); at present they are still contained in two species groups of the genus *Buchia* (*B. blanfordiana* (Stoliczka) and *B. spitiensis* (Holdhaus) groups; see e.g. Crame, 1982*a*, 1983*a*) (Fig 5e, f). In the upper levels of the 100–622 m interval there are further phylloceratid ammonites (such as *Phyllopachyceras*) and belemnopseid belemnites, though the latter are as yet unidentified.

The *Virgatosphinctes*–*Aulacosphinctoides* ammonite assemblage is undoubtedly Tithonian in age, and there is considerable evidence to suggest that it may be best referred to the Lower Tithonian (Thomson, 1979, p. 31). This agrees well with the age of the *Buchia* fauna, which has been shown to be essentially Lower–Middle Tithonian (Crame, 1982*a*, 1983*a*).

The first of four major conglomerate intervals in the Himalia Ridge section occurs between 622 and 720 m (Fig. 4). These channelized conglomeratic intervals typically thin to both the north and south along strike, and are composed of graded or massively bedded clast-supported conglomerates. Further descriptions of these distinctive lithological units have been given elsewhere (the conglomerate facies of Butterworth, 1985), and it is likely that they can be interpreted as the deposits of mass

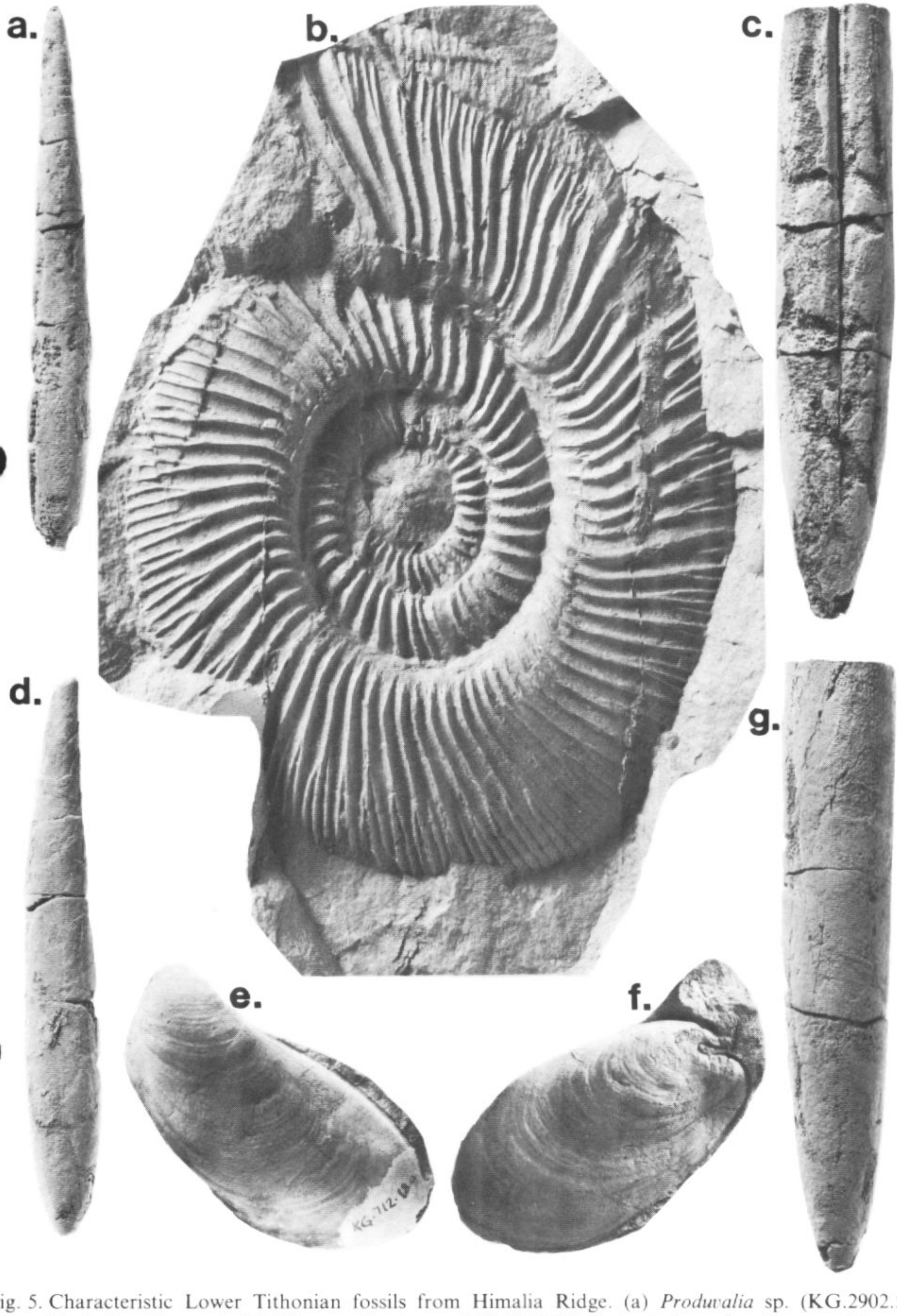

Fig. 5. Characteristic Lower Tithonian fossils from Himalia Ridge. (a) *Produvalia* sp. (KG.2902.55). Ventral outline, × 1. (b) *Virgatosphinctes* sp. (KG.2912.17). Lateral view of a silicone rubber cast from a natural external mould, × 1. (c) *Belemnopsis* cf. *aucklandica* (Hochstetter) (KG.2905.19). Ventral outline, × 1. (d) *Produvalia* sp. (KG.2902.55). Left profile, × 1. (e) *Buchia blanfordiana* (Stoliczka) group (KG.712.18a). Internal mould of a whole specimen viewed from the left, × 1. (f) The same specimen viewed from the right, × 1. (g) *Belemnopsis* cf. *aucklandica* (Hochstetter) (KG.2905.19). Left profile, × 1.

flow processes within major channel systems (P. J. Butterworth, pers. comm. 1987). The only fossils found in the first one came from the topmost 3 m and were mostly abraded fragments. They include berriasellid ammonites, belemnites (*H. belligerundi*) and indeterminate bivalves.

Sandstone-dominated lithologies between 720 and 735 m pass up into thick (274 m) fossiliferous siltstones with rare intercalated sandstones (localities KG. 2919, 2923 and 2940, Figs 1, 4). A berriasellid ammonite fauna is present in the 720–860 m interval and previously identified species from this horizon include: *Blanfordiceras* aff. *wallichi* (Fig. 6f), *B.* sp. juv. and '*Berriasella*' *subprivasensis* Krantz (Thomson, 1979). Representatives of *Hibolithes argentinus* Feruglio first occur at 813 m (Figs 4, 6d, e) and a number of incomplete valves of *Retroceramus* sp. were obtained from 913 m. Other bivalves present include *Pinna*, *Grammatodon*, an indeterminate pectinid and possible buchiids (at 751 m). There are scattered occurrences of the serpulid *Rotularia* and local concentrations of both *Chondrites* and plant fragments. The late Tithonian age of the berriasellid ammonite assemblage is supported by the presence of *H. argentinus* (Feruglio, 1936; Leanza, 1967; Thomson, 1979).

Above the 1000-m level there is a distinct change to a complex association of facies and over the next 300 m thick-bedded, massive sandstones, thinly interbedded siltstone/sandstones and massive-bedded siltstones predominate (facies 3b, 2 and 1, respectively, of Butterworth, 1985). Also, there are several sporadic pebbly mudstone horizons (facies 4 of Butterworth, 1985). This change to a complex association of facies is paralleled by a marked decrease in fossils; only trace fossils are at all common (e.g. *Chondrites*, *Planolites* and *Zoophycos*). A poorly preserved ammonite was obtained from 1261 m and a possible specimen of *H. argentinus* from 1301 m.

The second major conglomeratic interval, which is present between 1310 and 1399 m (Fig. 4), is very similar in appearance to the first, except that in this instance there is a gradation into finer-grained lithologies towards the top of the unit. Apart from a minor conglomerate between 1482 and 1507 m, the succeeding 170 m is dominated by massive mudstones and thinly interbedded siltstone–sandstone sequences (facies 1 and 2 of Butterworth, 1985). However, even these finer-grained beds proved to be unfossiliferous and only a single poorly preserved ammonite (?*Uhligites*) was recovered from them. The third, and thickest, of the major conglomerate intervals is present between 1572–1755 m (Fig. 4).

Mixed siltstone, sandstone and conglomerate lithologies (in beds generally < 2 m thick) above 1755 m again yielded a series of trace fossils (*Planolites*, *Chondrites*, *Neonereites* and *Rhizocorallium*) but no macrofossils. A prominent siltstone interval between 2072 and 2100 m (Fig. 4) is followed by the fourth conglomerate (2100–2179 m) which is overlain by fine–coarse grained sandstones with minor interbedded siltstones. Body fossils reappear in these sandstones between approximately 2216 and 2255 m, where there are fragments of belemnopseid belemnites, bivalves and gastropods. Between 2255 and 2384 m there is much better preservation and a number of the finer silty sandstones provided an abundant fauna. This represents the first truly fossiliferous horizon above the 900–1000 m level (Fig. 4).

Bivalves, such as *Pinna*, *Grammatodon*, *Myophorella* and *Pholadomya*, are particularly common in the lowest 30 m of this uppermost interval, where a single specimen of *Inoceramus* cf. *ovatus* Stanton was also obtained (Crame, 1985*b*; Fig. 7d). They are frequently accompanied by serpulids, plant fragments (e.g. *Ptilophyllum*, *Nilssonia*) and numerous trace fossils. Ammonites from the 2268-m level include specimens of *Raimondiceras* and *Haplophylloceras*, whilst the first representatives of the heteromorph *Bochianites* were recorded from 2284 m (Figs 4, 7b, c). Although belemnopseid belemnites are present throughout the interval, the

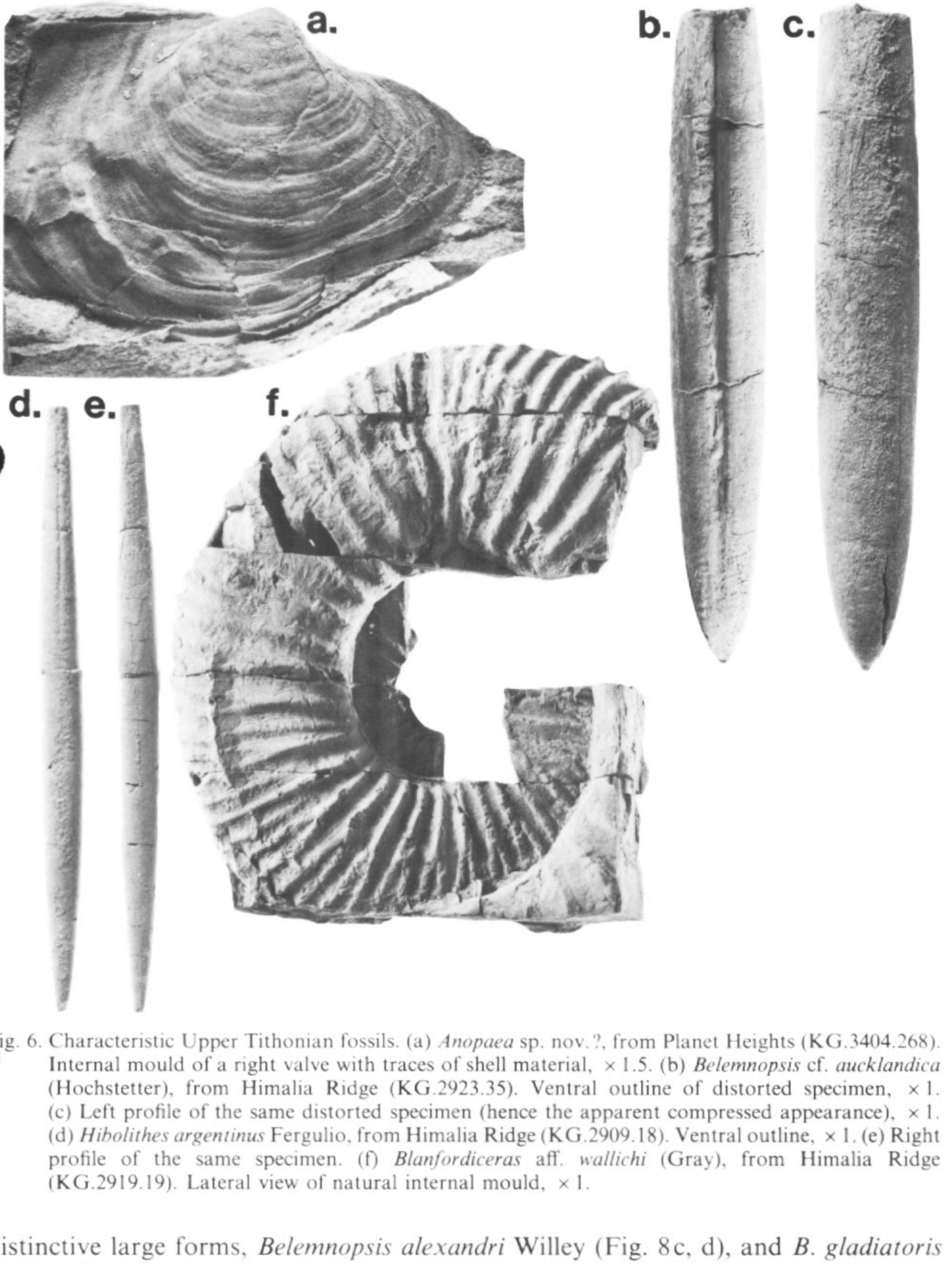

Fig. 6. Characteristic Upper Tithonian fossils. (a) *Anopaea* sp. nov.?, from Planet Heights (KG.3404.268). Internal mould of a right valve with traces of shell material, × 1.5. (b) *Belemnopsis* cf. *aucklandica* (Hochstetter), from Himalia Ridge (KG.2923.35). Ventral outline of distorted specimen, × 1. (c) Left profile of the same distorted specimen (hence the apparent compressed appearance), × 1. (d) *Hibolithes argentinus* Fergulio, from Himalia Ridge (KG.2909.18). Ventral outline, × 1. (e) Right profile of the same specimen. (f) *Blanfordiceras* aff. *wallichi* (Gray), from Himalia Ridge (KG.2919.19). Lateral view of natural internal mould, × 1.

distinctive large forms, *Belemnopsis alexandri* Willey (Fig. 8c, d), and *B. gladiatoris* Willey (Fig. 8a, b), do not occur until 2292 and 2298 m, respectively. They then continue to the top of the section and are frequently found in association with a *Grammatodon–Myophorella–Entolium* bivalve assemblage. *Bochianites* is present to at least 2346 m, and at 2360 and 2377 m specimens of the ammonite *Olcostephanus* were obtained (Howlett, 1986; Fig. 7a). Another stratigraphically important fossil previously collected from these levels is the ammonite *Spiticeras* aff. *spitiensis* (Blanford) from 2290 m (Elliott, 1974; Thomson, 1979).

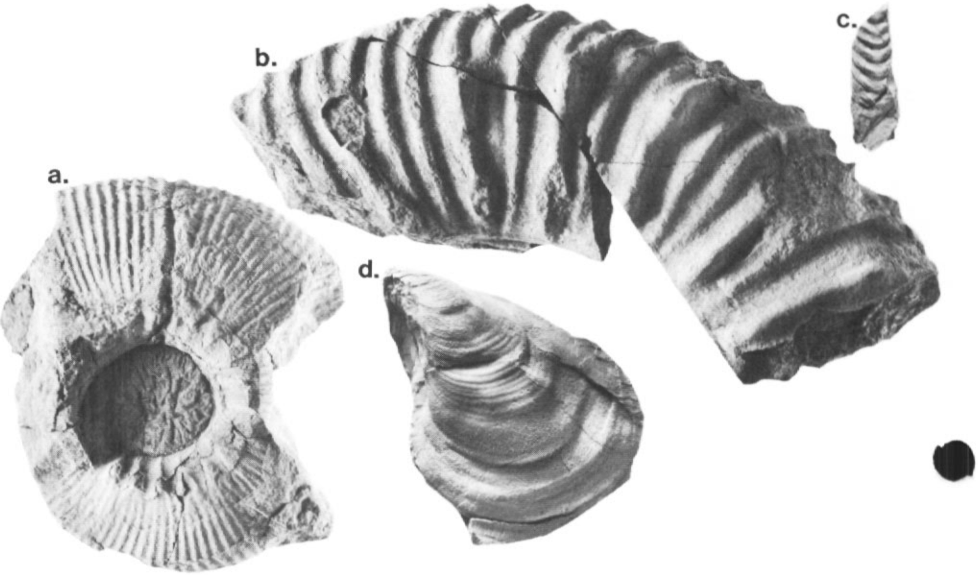

Fig. 7. Typical Berriasian–Valanginian fossils from Himalia Ridge. (a) *Olcostephanus* cf. *guebhardi* (Kilian), (KG.2943.1). Lateral view of internal mould, × $\frac{2}{3}$. (b) *Raimondiceras* sp. nov.? (KG.2934.29). Lateral view of part of an internal mould, × $\frac{2}{3}$. (c) *Bochianites* aff. *versteeghi* (Boehm) (KG.2934.67). Ventral view of a fragment of an internal mould, × $\frac{2}{3}$. (d) *Inoceramus* cf. *ovatus* Stanton (KG.719.15). Internal mould of a whole specimen viewed from the left side, × $\frac{2}{3}$.

The uppermost fauna of the Himalia Ridge section has traditionally been regarded as Berriasian in age (Taylor and others, 1979). This determination is largely based on the age affinities of the *Haplophylloceras–Bochianites–Spiticeras–Raimondiceras* ammonite assemblage (Thomson, 1979), together with supporting evidence from the associated belemnites (Willey, 1973) and inoceramid bivalves (Crame, 1985*b*). Nevertheless, Howlett (1986) has recently suggested that the presence of *Olcostephanus* indicates that the very highest levels are in fact Valanginian in age. This is corroborated by a reinterpretation of the age-range of *Belemnopsis gladiatoris* and its closest allies (Howlett, 1986, p. 75).

2. *Planet Heights*

The lowest lithological unit exposed on Planet Heights (Figs 1, 9) is a 109-m thick monotonous sequence of massive grey siltstones with minor fine sandstone intercalations (KG. 3404, Fig. 9). These siltstones thicken southwards to approximately twice this figure in the vicinity of Lunar Crag (KG. 3406, Fig. 1). Reconnaissance work in the latter area has established that, in their lowest levels, they contain a distinctive fauna of perisphinctid and possible berriasellid ammonites, belemnites, rhynchonellid brachiopods and large forms of the *Buchia* (?*Australobuchia*) *blanfordiana* and *spitiensis* groups. This fauna has strong Tithonian affinities and correlates well with the 240–400 m level in the Himalia Ridge section (Figs 4, 9). Higher levels of the basal siltstone unit are characterized by a moderately diverse serpulid-belemnite-bivalve fauna in which the following elements are prominent: small *Rotularia*, tiny to medium-sized belemnopseid belemnites, infaunal bivalves (nuculids, astartids, *Pholadomya*), epifaunal bivalves (small oysters,

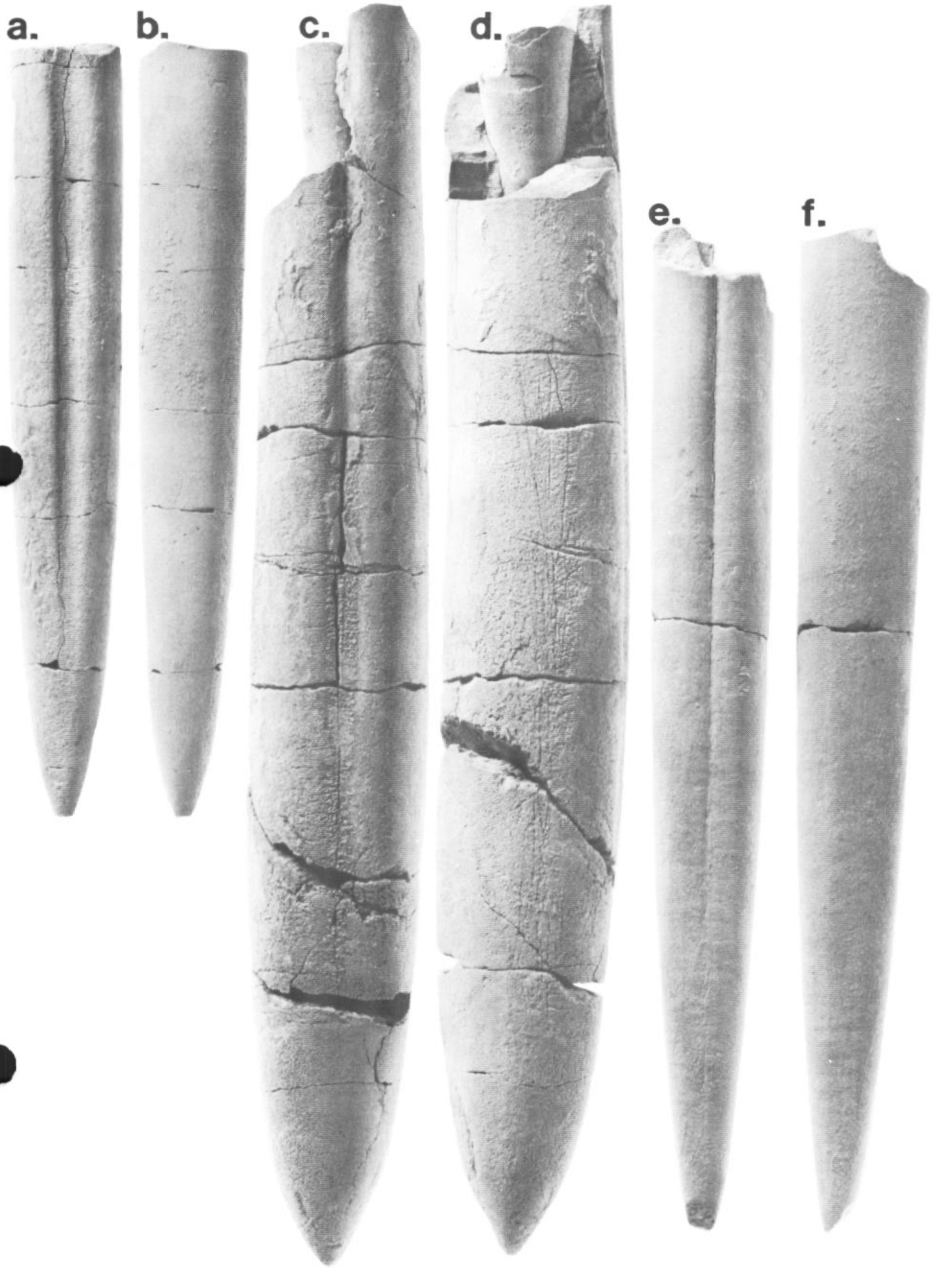

Fig. 8. Characteristic Berriasian–Valanginian belemnites. (a) *Belemnopsis gladiatoris* Willey, from Himalia Ridge (KG.2942.33). Ventral outline, × 1. (b) Left profile of the same specimen, × 1. (c) *Belemnopsis alexandri* Willey, from Himalia Ridge (KG.2942.18). Ventral outline, × 1. (d) Right profile of the same specimen, × 1. (e) *Belemnopsis* cf. *madagascariensis* (Besairie), from Leda Ridge (KG.3455.87). Ventral outline, × 1. (f) Right profile of the same specimen, × 1.

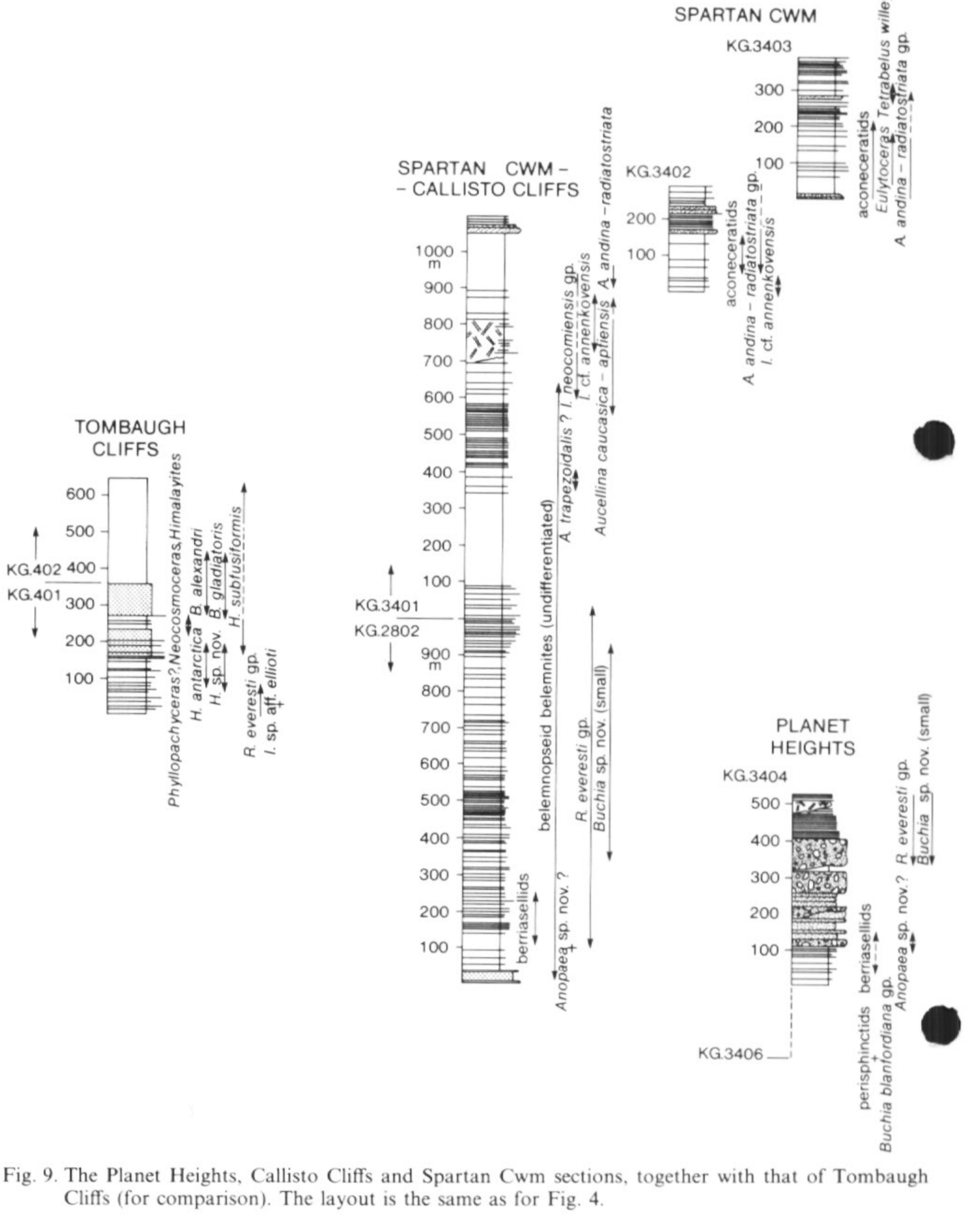

Fig. 9. The Planet Heights, Callisto Cliffs and Spartan Cwm sections, together with that of Tombaugh Cliffs (for comparison). The layout is the same as for Fig. 4.

Grammatodon, *Oxytoma*), and occasional seams of fossil wood fragments. A small ammonite referable to *Corongoceras* was collected from 99 m at KG. 3404 and two specimens of *Blanfordiceras* from an approximately equivalent level at KG. 3406 (Figs 1, 9). The latter agree well with specimens of *B.* aff. *wallichi* obtained from Himalia Ridge (Figs 4, 6).

At the 109-m level on section KG. 3404 (Fig. 9) there is an abrupt coarsening of lithologies and the first in a series of prominent conglomerates appears. These continue over the next 300 m and are directly comparable to the conglomerate-dominated interval above 622 m on Himalia Ridge (Figs 4, 9). At the base there is a 19-m thick pebbly mudstone bed (facies 4 of Butterworth, 1985). Somewhat surprisingly, this was found to contain an abundant and diverse fauna, and it would appear that it may well have been derived. Bivalves are the most conspicuous component of this fauna and include some large and beautifully preserved specimens of *Anopaea* (*A*. sp. nov.? of Crame, 1981; Fig. 6a), *Myophorella*, *Grammatodon*, *Oxytoma*, *Pinna*, *Entolium*, *Pleuromya*, *Thracia*(?), astartids and small oysters. Other elements are small to medium-sized *Hibolithes*, berriasellid fragments, *Rotularia* and several types of small gastropod. The general Tithonian aspect of this fauna is enhanced by the new material assignable to *Anopaea* sp. nov.? This seems to be particularly close to *A. sphenoidea* (Gerasimov) from the Volgian (= Tithonian) of the Russian Platform (Crame, 1981, p. 215).

Succeeding levels are dominated by interbedded massive, pale sandstones (13–20 m thick) and thinner pebbly mudstone beds. Coarse-grained, clast-supported, channelized conglomerates first appear at approximately 181 m but are better exposed between 205 and 218 m (Fig. 9); they closely resemble those already described from Himalia Ridge. A small percentage (probably < 10 %) of the clasts in these conglomerates are intraformational and in one tabular grey siltstone slab an internal mould of a Middle or Upper Jurassic *Retroceramus* was found.

A recessive-weathering interval between 310 and 332 m (Fig. 9) commences with a 6-m thick pebbly mudstone horizon overlain by a uniform dark grey siltstone bearing rusty-brown concretions. The latter is fossiliferous and contains the first occurrences of small phylloceratid ammonites (*Haplophylloceras*?), *Retroceramus everesti* and a new small species of *Buchia* (Figs 9, 10a–c). It has also yielded *Hibolithes*, nuculids, limids, astartids? and a possible smooth inoceramid (*Parainoceramus*?). Massive conglomerates then continue to the 408-m level where there is an abrupt transition to thinner-bedded and finer-grained lithologies (Fig. 9).

Thick-bedded, fine- to medium-grained white sandstones (with sporadic seams of belemnite fragments) predominate for approximately 30 m above the last massive conglomerate where they are interbedded with minor dark siltstones. At higher levels bedding is reduced to the 20–25 cm thick scale and between 438 and 470 m (Fig. 9) there is evidence of large-scale slump folds (7–8 m across). Besides medium–large broken belemnites, the only other fossils recorded in the initial 70 m of this sandstone–siltstone unit were a number of small bivalves.

Above 470 m (Fig. 9) the bedding becomes much finer (generally < 10 cm and occasionally < 5 cm thick) and there is a very regular succession of dark siltstones and pale fine sandstones. These lithologies yielded more belemnites (at least some of which are referable to *Hibolithes*), *R. everesti*, the possible smooth inoceramid and the small new species of *Buchia*. Between 494 and 507 m (Fig. 9) there is a disturbed zone composed of many randomly oriented siltstone and sandstone blocks. Above this disturbed zone there is a repetition of thinly interbedded sandstone/siltstone facies. The fauna up to the 528-m level (Figs 9, 10a–c) consists of *Haplophylloceras*?, *R. everesti*, *Buchia* sp. nov., *Pinna*, *Entolium* and what appears to be a very large anomalodesmatid bivalve.

3. *Callisto Cliffs*

The basal 42 m of this exposure is composed of medium–coarse grained, rarely cross-bedded olive green sandstones interbedded with thin, irregular seams of small-

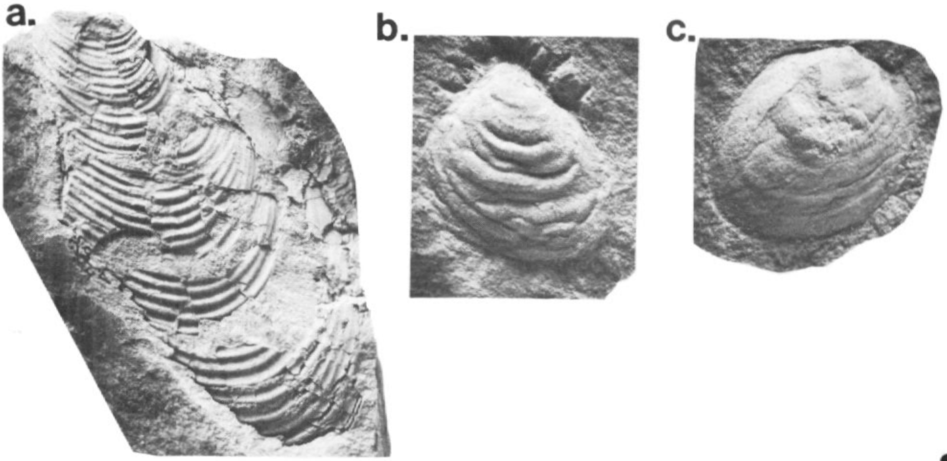

Fig. 10. Jurassic–Cretaceous boundary bivalves. (a) *Retroceramus everesti* (Oppel), from Planet Heights (KG.3404.401). Internal mould of a whole specimen viewed from the left side, × 1. (b) *Buchia* sp. nov. (small form), from the Spartan Cwm region (KG.2803.50). Internal mould of a left valve, × 1.5. (c) *Buchia* sp. nov. (small form), from the Spartan Cwm region (KG.3405.8). Internal mould of a right valve, × 1.5.

pebble conglomerate (section KG. 2802, Figs 1, 9). Thereafter, there is a regular alternation of dark siltstones and pale sandstones up to the 940-m level. Bedding is predominantly in the 10–30 cm range in this interval but there are several extensive sequences of the very thinly interbedded siltstone/sandstone facies, such as between 461 and 534 m (Fig. 9). These match well with the highest levels exposed on Planet Heights. More massive siltstones and sandstones (0.5–1 m range) are only sporadically developed.

Berriasellid ammonites, which can probably be referred to the genus *Blanfordiceras*, occur between approximately 100 and 260 m at KG. 2802 (Fig. 9). Various belemnopseid belemnites occur throughout the section, though many are still unidentified. However, *Hibolithes belligerundi* has been found at 100 m, *Belemnopsis* cf. *aucklandica* between 222 and 232 m, and *H. argentinus* further up the section of 305–380 m (Fig. 6 b–e). *Anopaea* sp. nov.? is prolific between 91 and 99 m and other early inoceramids are probable precursors of the *R. everesti* group (91–255 m, Fig. 9; see Crame, 1982*b*). The latter is a consistent feature of the upper half of the section (503–1040 m), where it occurs in association with the new small species of *Buchia* (338–935 m) and the ammonite *Haplophylloceras* (?481–921 m).

From the foregoing palaeontological data it is apparent that the uppermost levels of Planet Heights (KG. 3404) and the main face of Callisto Cliffs (KG. 2802) are approximately equivalent to the 1200–2300 m interval on Himalia Ridge (Figs 4, 9). However, no precise correlations can be made between these two regions as they differ sharply in lithofacies and are sparsely fossiliferous. Some indication that the topmost levels of section KG. 2802 can be directly correlated with the top of the Himalia Ridge section is provided by the pronounced change in lithologies seen there. Between 937 and 1015 m (Fig. 9) there is a prominent pale zone comprising massive fine- to coarse-grained sandstones bearing large, spherical, rusty brown concretions and thin seams of pebble–cobble conglomerate. Reconnaissance observations indicate that this pale zone can be traced westwards onto the narrow ridge connecting Callisto Cliffs and Planet Heights (KG. 3405A, Fig. 1). Here, conglomerates are even more strongly developed and there are two distinct channelled intervals (10–15 m thick) of cobble–boulder, matrix-supported conglomerate. Moving in the other direction, the same zone can be traced into the lower levels of Tombaugh Cliffs (KG. 401, Figs 1, 3) where massive pale sandstones and minor conglomerates are well developed between 156 and 233 m (= units Z_2–Z_4 of Willey, 1972; Taylor and others, 1979).

On the very summit of Callisto Cliffs (1015–1037 m, KG. 2802; Fig. 9) there is a 22-m sequence of micaceous siltstones that yielded a prolific, bivalve-dominated fauna. *Retroceramus everesti* features prominently in this assemblage, together with types such as *Grammatodon*, *Myophorella*, *Pinna*, *Entolium*, astartids and anomalodesmatids. A variety of belemnopseid belemnites from this unit includes the distinctive *Belemnopsis alexandri* and there are phylloceratid ammonites referable to *Haplophylloceras*. Altogether, a correlation with the 2255-m level (or above) on Himalia Ridge is indicated on the one hand, and with interval Z_6 (233–271 m) at Tombaugh Cliffs on the other (Figs 4, 9). The latter unit, which consists of dark siltstones with minor fine sandstones, has also yielded *Phyllopachyceras*? sp., *Neocosmoceras* aff. *sayni* Simionescu, *Himalayites* sp., an indeterminate berriasellid, *Belemnopsis gladiatoris*, *Hibolithes antarctica*, *H. subfusiformis* (Raspail), *H.* aff. *marwicki mangaoraensis* Stevens and *Inoceramus* sp. aff. *ellioti* Gabb (Willey, 1973; Crame, 1985*b*). This fauna is consistent with a Berriasian–Valanginian age.

4. *Spartan Cwm*

Section KG. 3401, which extends around the north-western rim of Spartan Cwm (Fig. 1), is a direct vertical continuation of section KG. 2802. It commences with 81 m of intermittently exposed massive siltstones with intercalated minor pale sandstone units. The latter are generally less than 30 m thick, but may locally reach up to 70 cm, and include small lenses of pebbles. At the 69-m level (Fig. 9) there is a prominent 1.2-m bed of medium–coarse grained dark green sandstone that contains scattered pebbles and numerous large belemnites. These are the predominant faunal element in this initial interval, with *B. alexandri* being especially common (Figs 8c, d, 9).

The following 320 m in KG. 3401 is composed of a remarkably uniform dark siltstone/mudstone and the lack of any resistant beds gives this interval a distinctive concave weathering profile which can be traced from the upper levels of Tombaugh Cliffs (93–294 m [= Z_9], KG. 402; Willey, 1972) through Spartan Cwm to the base of Leda Ridge (see below). Large, rusty-brown, tabular concretions (up to 0.75 m across) are present throughout this lithology but it has few other distinguishing features. It has yielded a sparse belemnite assemblage, *Chondrites*-like trace fossils and two specimens of *Anopaea* (366–390 m level) which are perhaps closest to *A. trapezoidalis* (Thomson and Willey) (Crame, 1981) (Fig. 11e).

Between 400 and 450 m (Fig. 9) a number of thin sandstone beds occur in succession and these are accompanied by a sparse belemnite–small bivalve assemblage. There is then a marked change to a stepped-scarp topography which reflects the presence of a 117-m thick pale-coloured unit. This lithology also forms a prominent marker horizon which can be traced from the top of Tombaugh Cliffs (just above the top of section KG. 402) through the north-western corner of Spartan Cwm to the western extension of Callisto Cliffs (KG. 3405A, Fig. 1). It is characterized by pale, fine-to-very-fine sandstones which are intensely bioturbated with grey siltstones. This slight, but nonetheless significant, increase in grain size is accompanied by a much richer fauna in which infaunal bivalves are particularly common. These

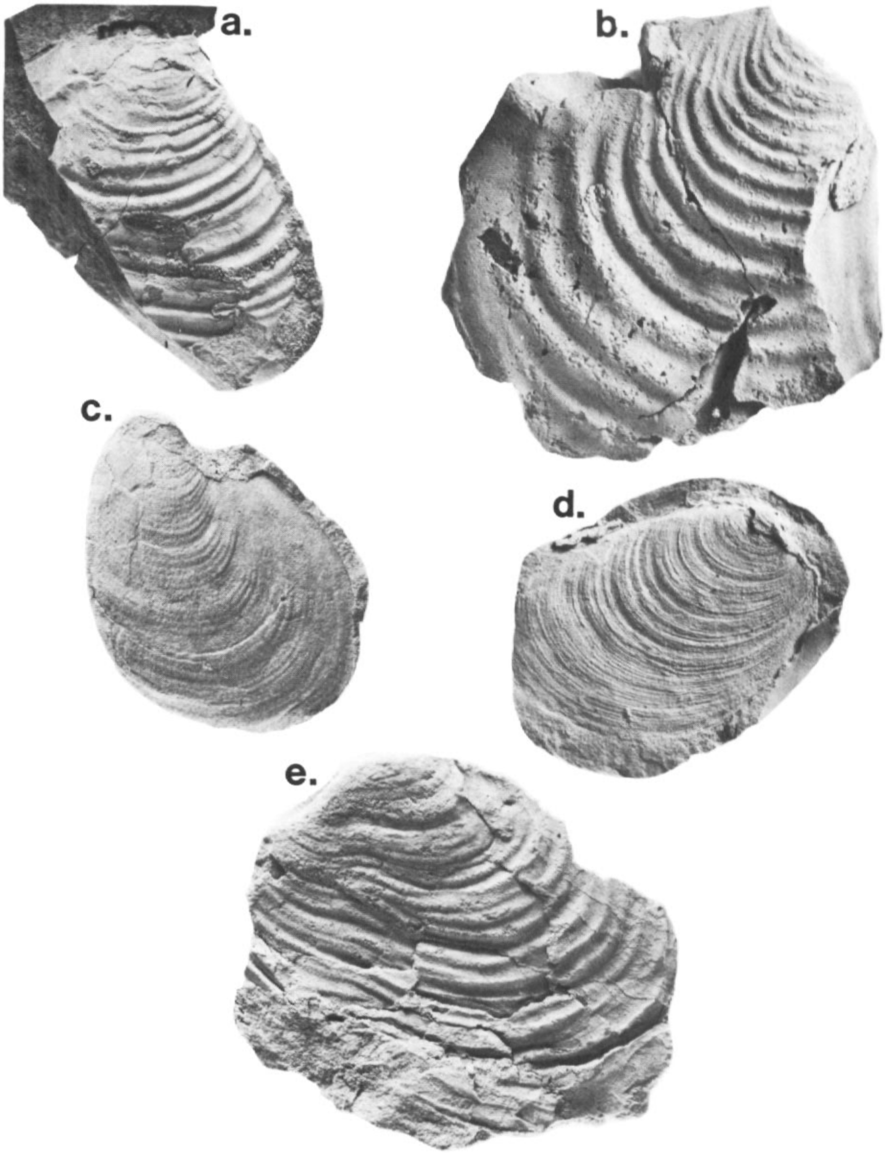

Fig. 11. Possible Hauterivian–Barremian bivalves from the Spartan Cwm area. (a) *Inoceramus neocomiensis* d'Orbigny group (early form), (KG.3401.431). Incomplete internal mould of a right valve, × 1. (b) *Inoceramus neocomiensis* d'Orbigny group (early form), (KG.3401.360). Incomplete internal mould of a right valve, × 1.5. (c) *Aucellina caucasica* (Abich) – *aptiensis* d'Orbigny group, (KG.3405.68). Internal mould of a left valve, × 1.5. (d) *Aucellina causica* (Abich) – *aptiensis* d'Orbigny group, (KG.3405.86). Rubber peel from the external mould of a right valve, × 1.5. (e) *Anopaea trapezoidalis* (Thomson and Willey) (KG.3401.78). Incomplete internal mould of a whole specimen viewed from the left side, × 1.5.

include nuculids, astartids, *Myophorella* and several types of anomalodesmatid; there are also epifaunal genera such as *Grammatodon*, *Entolium* and a possible smooth inoceramid (*Parainoceramus*?). Small- to medium-sized belemnopseid belemnites are also present and between 543 and 555 m (Fig. 9) two lytoceratid ammonites were obtained. The same interval also yielded the first representatives of a very finely ribbed oxytomid/buchiid which may be referable to *Aucellina*. Preliminary observations suggest that it may in fact be assignable to the *A. caucasica* (Abich)–*A. aptiensis* d'Orbigny species group (G. A. Lee, pers. comm., 1986; Fig. 11c, d).

Above 567 m (Fig. 9) there is a return to more massive, darker siltstones and minor thinly interbedded sandstones which are much less strongly bioturbated. Notable faunal changes in this interlude include the introduction of members of the *Inoceramus neocomiensis* d'Orbigny group (591–603 m) and the disappearance of belemnopseid belemnites (663 m) (Figs 9, 11a, b). Increasing stratal disruption towards the 700-m level marks the presence of a major disturbed zone. This approximately 100-m thick zone consists of a mass of jumbled blocks (often 5–10 m across) and contorted strata which alternate with discontinuous seams of *in situ* beds. Most of the blocks are of intraformational lithologies but there are also a few exotic sandstones that cannot be easily matched with any beds lower in the section. Both the possible *Aucellina* and the early representatives of the *I. neocomiensis* gp. continue into the disturbed zone and the latter is joined by a very irregularly ribbed inoceramid that shows some resemblance to *I. annenkovensis* Crame (1985*b*) from Annenkov Island (Fig. 9). Other components of the fauna are: phylloceratid ammonites, *Entolium* and *Rotularia*.

Although there is no abrupt change in faunal composition across the disturbed zone, there is a marked decrease in abundance. The regularly bedded grey–green siltstones above the 800-m level (Fig. 9) contain a sparse fauna comprising the following types: *Inoceramus* (especially the form with very irregular ribbing), *Aucellina*?, *Entolium*, *Rotularia* and a small brachiopod. A few soft, poorly lithified sandstone beds occur between 856 and 868 m, where there are also occasional discrete patches of pale, fine sands which have been bioturbated into the dark siltstones. Two larger phylloceratid ammonites were collected from this interval, and from 865–890 m the first specimens of *Inoceramus deltoides* Crame (*I. neocomiensis* gp.) were obtained (Figs 9, 12a). The latter occur together with specimens that can almost certainly be referred to the *Aucellina andina* Fergulio–*radiatostriata* Bonarelli and Nágera species group (Fig. 12b, e), and a general correlation of this interval with the 100–120 m level in section KG.2800 at Fossil Bluff (Crame, 1978; = loc. R of Taylor and others, 1979) is indicated. Between 900 and 1040 m (Fig. 9) the section is largely scree-covered, but patches of *in situ* grey siltstone can be detected and there are many loose specimens of *I. deltoides* and *Aucellina* in the float. At 1040 m there is an abrupt change to a resistant 18-m cliff of massively bedded dark green sandstones.

The line of section was transferred to locality KG.3402 on the southern flank of Spartan Cwm (Figs 1, 3, 9). This was easily accomplished by tracing the olive-green sandstone band, which forms a prominent topographic feature. At the new locality the beds directly beneath these sandstones are better exposed, and immediately to the south-east of KG.3402 (Figs 1, 3) there is a disturbed zone equivalent to that seen at 700–800 m in section KG.3401 (Fig. 9). It, too, passes up into regularly bedded grey siltstones and it is at the base of these that section KG.3402 commences. These initial beds are also characterized by a sparse *Inoceramus–Aucellina–Rotularia* fauna, together with a probable heteromorph ammonite and a few plant fragments. Between 42 and 48 m (Fig. 9) there is a fairly sharp change to a darker grey siltstone which is more massively bedded and resistant to erosion. This lithological change is

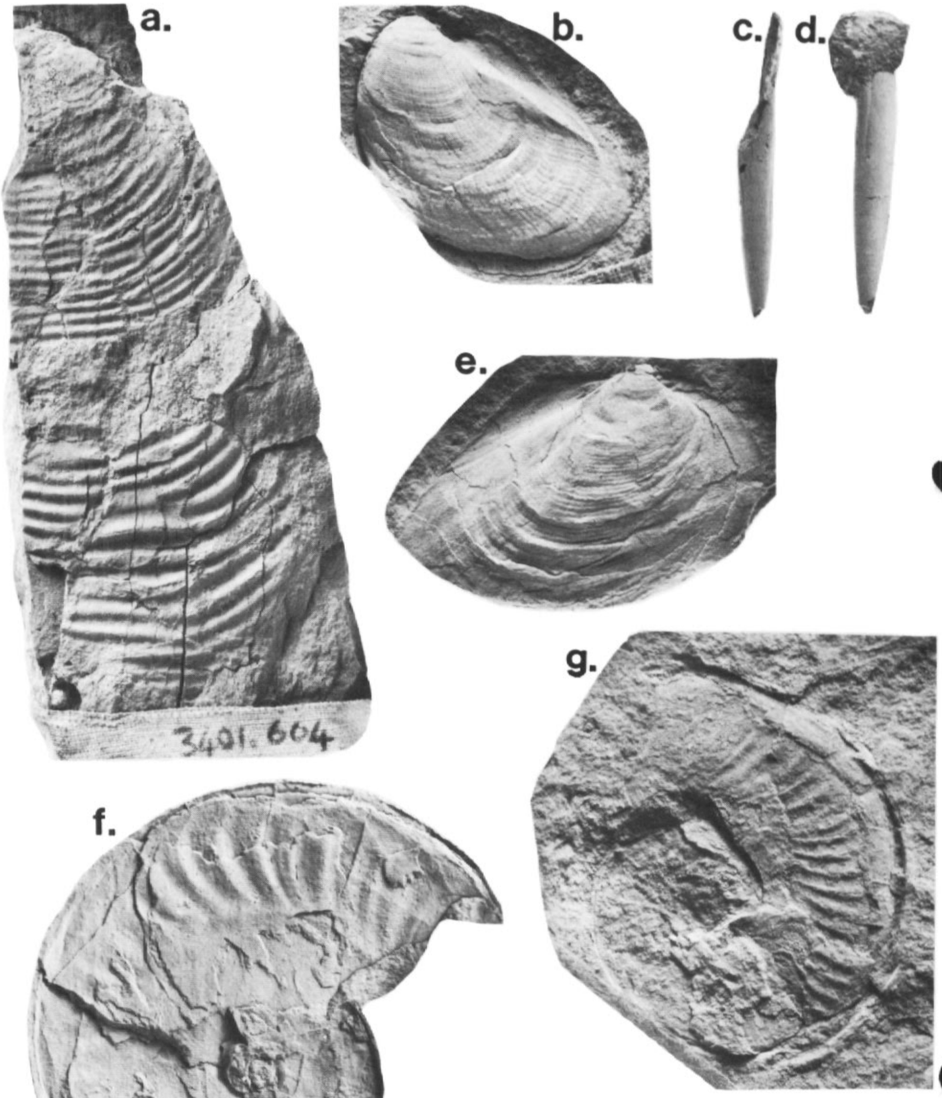

Fig. 12. Characteristic Aptian fossils. (a) *Inoceramus deltoides* Crame, from Spartan Cwm (KG.3401.604). Internal mould of an incomplete left valve, × 1. (b) *Aucellina andina* Feruglio-*radiatostriata* Bonarelli and Nágera group, from Spartan Cwm (KG.3403.11). Internal mould of a left valve, × 1.5. (c) *Tetrabelus willeyi* Doyle, from Spartan Cwm (KG.3403.229). Ventral outline, × 1. (d) Left profile of the same specimen, × 1. (e) *Aucellina andina* Feruglio-*radiatostriata* Bonarelli and Nágera group, from Spartan Cwm (KG.3402.60). Internal mould of a right valve, × 1.5. (f) *Sanmartinoceras* (*Sanmartinoceras*) *patagonicum* (Bonarelli), from Spartan Cwm (KG.3403.107). Lateral view of natural internal mould, × 1. (g) *Sanmartinoceras* (*Theganeceras*) sp., from Leda Ridge (KG.3458.140). Lateral view of natural internal mould, × 2.

accompanied by the incoming of aconeceratid ammonites and the *A. andina-radiatostriata* gp. (Fig. 12b, e–g), and is thought to be equivalent to approximately the 868–900 m interval in KG. 3401 (Fig. 9). Over the succeeding 20 m the blocky siltstones contain thin seams of intensely bioturbated pale sandstones and a prolific ammonite–*Aucellina* assemblage.

Exposure breaks down somewhat above 69 m (Fig. 9), but it is apparent that the principal lithology is a grey siltstone with minor intercalated soft recessive-weathering sandstones. The fauna, which is much less abundant than before, seems to show a slight increase in the proportion of benthonic elements. Such a trend is confirmed between 105 and 162 m (Fig. 9) where ammonites are rare and the commonest elements are aporrhaid gastropods, nuculid, arcid, mytilid and lucinid-type bivalves, tiny echinoids and brachiopods (*Discinisca*). A slight but significant increase in sediment grain size occurs together with these faunal changes and a general shallowing trend is inferred. Indeed, sandstones become much more prominent above the 162-m level and both sedimentary and faunal evidence suggests that they can be linked to a regional shallowing event (P. J. Butterworth, pers. comm., 1987). Being more resistant to erosion, they form a series of pyramidal peaks along the southern rim of Spartan Cwm which are directly comparable to similar features at Fossil Bluff (e.g. 320–426 m in section KG. 2800 – Crame, 1978; beds R_{16}–R_{20} of Taylor and others, 1979).

The dark olive-green sandstones at KG. 3402 occur between 162 and 176 m (Fig. 9). They are predominantly poorly sorted, fine–coarse grained with rare pebbles, and occur in beds up to 5 m thick. They appear to be largely unfossiliferous, although one loose large heteromorph ammonite resembling *Australiceras*? sp. (cf. Thomson, 1974) probably comes from this interval.

The succeeding 80 m of pale beds (Fig. 9) is dominated by a variety of thinner-bedded sandstones and minor siltstones. The initial 42 m is composed of fine–medium grained thinly bedded (< 20 cm) sandstones with off-white to deep rusty brown colourations. In places these have been intensely bioturbated to form a fine mottled texture. Between 219 and 241 m (Fig. 9) more massive sandstones with discontinuous pebble seams are present, and these have weathered into distinct flaggy sheets. Over the next 15 m in section KG. 3402 (241–256 m, Fig. 9) there is a return to thinly interbedded siltstones and fine–medium sandstones. These have a very distinctive blotchy appearance due to intense bioturbation). Above 256 m the siltstones become much more massive and are interbedded with a sequence of sharply defined pale sandstones.

At this point the line of section was transferred back into the south-west corner of Spartan Cwm (section KG. 3403, Figs 1, 3, 9) where the siltstone–pale sandstone sequence is more accessible. Here, it is composed initially of a massive grey–black siltstone containing only minor pale sandstones (generally < 10 cm thick). Apart from occasional white blotchy patches due to bioturbation of fine sands, these siltstones are extremely uniform and frequently weather into massive rounded bosses and pillars. They yield a moderately diverse fauna composed of aconeceratid ammonites (including *Sanmartinoceras*; Fig. 12f, g), lytoceratids (principally *Eulytoceras*), *Aucellina* (Fig. 12b, e), anomalodesmatids (*Thracia*, *Cuspidaria*, etc.), *Entolium*, *Pinna* and *Rotularia*. Above 72 m (Fig. 9) a number of thick (2 m +) coarse–very coarse grained pale sandstones occur. Unfortunately, many of these higher sandstones are soft and recessive-weathering and it is not always possible to determine their true nature and extent. The general impression is that they become slightly more numerous up to the 200-m level (Fig. 9) and this may be the reason for the apparent replacement of the ammonite fauna by a small–bivalve one.

The base of a prominent 68-m pale zone is located at the 215-m level (Fig. 9). This consists initially of fairly thinly (< 30 cm) interbedded dark siltstones and pale sandstones which are in places intensely planar laminated. At 232 m, much more massive white sandstones are present and over the next 35 m these alternate with thinner units of planar-laminated or intensely bioturbated siltstone–sandstone. A distinguishing feature of these units is the presence of very large (2 m+) sub- to well-rounded concretions. These are particularly prominent in the pale massive sandstones where they weather out to form giant 'cannonballs' very similar to those seen in Succession Cliffs (e.g. unit B_2 of Taylor and others, 1979). These beds contain a sparse bivalve assemblage.

Above 267 m (Fig. 9), there is a return to thinner-bedded siltstones and sandstones and between 274 and 283 m there is a small scarp composed predominantly of planar-bedded orange coloured sandstones (fine–medium grained). Resistant massive concretions are still present, however, and close to the top of the scarp there is a small conglomerate seam containing occasional plutonic clasts of boulder size. Between 283 and 285 m there is a recessive band of coarse white sandstone which grades up into a massive siltstone. The latter, which is very similar to the lower, blocky, grey–gre[illegible] siltstones, is at least 12 m thick and moderately fossiliferous. A reasonably diverse bivalve assemblage includes nuculids, mytilids, *Aucellina*, *Entolium* and anomalodesmatids (e.g. *Pleuromya*, *Thracia*), but more characteristic is a series of small dimitobelid belemnites referable to *Tetrabelus willeyi* Doyle (1987) (Fig. 12c, d). These are the first belemnites to be encountered since the loss of the belemnopseids at 663 m in section KG. 3401 (Fig. 9).

Siltstones alternating with soft recessive-weathering sandstones can be traced up to 315 m (Fig. 9), but unfortunately exposure is very intermittent above this level. At least two massive pale cannonball sandstones occur between 315 and 326 m and there is then a return to moderately thinly bedded units up to approximately 345 m (Fig. 9). The topmost levels of the section consist of further heavily weathered massive cannonball sandstones interbedded with thinner siltstone–sandstone intervals.

If the dating of the composite section has hitherto been comparatively straightforward, it becomes much less so for these higher levels in Spartan Cwm (i.e. sections KG. 3401–3403, Fig. 9). As the 1015–1037 m level in section KG. 2802 correlates with 2255 m (or above) on Himalia Ridge, it is apparent that the base of KG. 3401 (and thus Z_6 at KG. 401, Tombaugh Cliffs) should now be regarded as Valanginian. However, no further age-diagnostic fossils are encountered until approximately 868–900 m in KG. 3401 (= 42–48 m, KG. 3402; Fig. 9) where the initial representatives of the prolific aconeceratid ammonite – *I. deltoides–A. andina/radiatostriata* fauna were encountered. These have usually been regarded as indicating an Aptian age, but a recent study of heteromorph ammonites from equivalent and higher levels at localities further south suggests that they may be somewhat older (Thomson, 1983*a*). In particular, an *Acrioceras–Crioceratites* fauna from 286–335 m at Fossil Bluff (= R_{13-15} of Taylor and others, 1979) strongly suggests a Hauterivian–Barremian age (Thomson, 1983*a*).

The above comments notwithstanding, it has also been argued that the age-ranges indicated by the bivalves are in reasonably close agreement with those of the regularly coiled ammonites (Crame, 1983*b*, 1985*b*). For example, both *I. deltoides* and the *A. andina/radiatostriata* gp. have strong Aptian affinities which accord well with those normally attributed to the aconeceratid genera *Aconeceras*, *Theganeceras* and *Sanmartinoceras* (there is a possibility that these genera could range down into the Upper Barremian; Thomson, 1974; Kennedy and Klinger, 1979). Higher levels still in the FBF are characterized by inoceramids such as *Birostrina*? cf. *concentrica*

(Parkinson), *I.* cf. *anglicus elongatus* Pergament and *Anopaea* sp. nov. aff. *mandibula* (Mordvilko), and these, taken in conjunction with the presence of ammonites such as *Eotetragonites* sp. and *Ptychoceras* sp., strongly suggest an Albian age. *Tetrabelus willeyi* from 285–297 m in KG.3403 (Fig. 9) is Aptian, as are further dimitobelids (*Peratobelus* cf. *oxys*; Doyle, 1987) from Succession Cliffs (see below). It should also be pointed out here that aconeceratids, ancyloceratid heteromorphs and certain problematical regularly coiled ammonites (e.g. *Silesites* aff. *antarcticus* Thomson and '*Pseudothurmannia*' cf. *mortilleti* (Pictet and Loriol)) have a probable Albian age on James Ross Island (Thomson, 1984; Ineson and others, 1986).

There is a minor stratigraphic discontinuity across the disturbed zone (700–800 m, KG.3401, Fig. 9), and there is possibly another one at the base of the prolific aconeceratid–*Aucellina* zone (42–48 m, KG.3402, Fig. 9). Nevertheless, all the indicators are that this section is essentially complete and the interval between the well-defined Valanginian base and Aptian top must be regarded as undifferentiated Hauterivian–Barremian. The base of the Aptian is provisionally set at 865 m in KG.3401 (= 42–48 m in section KG.3402; Fig. 9).

5. *Leda Ridge*

The basal 30 m of the Leda Ridge section (Figs 1, 2, 4) consists of highly bioturbated brown silty sandstones interbedded with minor pale, fine-grained sandstones (> 50 cm thick). Towards the top of this unit there is a gradation into uniform siltstones and throughout there is an abundant molluscan fauna. This is bivalve-dominated and includes representatives of the following genera: *Pinna*, *Pholadomya*, *Grammatodon*, *Entolium* and *Myophorella*. With ammonites referable to *Raimondiceras*, *Bochianites* and *Haplophylloceras*, it is obvious that a general correlation can be made with the topmost (1015–1037 m) levels of Callisto Cliffs (KG.2802) and Himalia Ridge (KG.2934; 2250–2985 m), and lowermost (0–81 m) levels of section KG.3401 (Figs 4, 9).

The overlying 420 m comprises bioturbated massive dark grey siltstones with occasional thin, fine-grained sandstone interbeds (generally < 20 cm thick). This siltstone, which is intensely shattered in places and contains rusty-brown tabular concretions (> 2 m in length), correlates well with the 81–400 m interval in KG.3401 and unit Z_9 (= 93–294 m) at Tombaugh Cliffs (KG.402) (Figs 4, 9). It is slightly more fossiliferous here, with belemnopseid belemnites being particularly well represented. The latter include *B. alexandri*, *B. gladiatoris*, *B.* cf. *madagascariensis* (Fig. 8a–f) and as yet unidentified specimens of *Hibolithes* and *Belemnopsis*, whilst in the lowest 100 m of this unit representatives of both *Bochianites* and *Olcostephanus* (Fig. 7b, c) were obtained. Occasional small bivalves (mostly *Grammatodon*) were the only benthonic elements found in these siltstones.

At the 450-m level (Fig. 4) there is a sharp, erosionally based 7-m thick, pebble-to-medium-grained, red-brown, massive sandstone. This sandstone forms a prominent topographical feature that can be traced along the flanks of Leda Ridge. The sandstone contains many belemnite rostra (mainly ?*Belemnopsis*), bivalves (mostly *Grammatodon* and *Myophorella*), some gastropods and plant material. The top of this sandstone, displays a well-developed fining-upward cycle, over 4 m, back into siltstone. This change is accompanied by an increase in the number of bivalves (including the introduction of *Pinna*) and a decrease in belemnites. In the uppermost part of the sandstone there are also a few poorly preserved ammonites.

Between 457 and 657 m (Fig. 4) there is a return to uniform grey siltstone lithologies. However, these beds are characterized by a distinctive belemnite–bivalve fauna and it is clear that they can be matched with approximately the 567–700 m interval in section KG. 3401 (Fig. 9). Belemnites, formerly attributed to *Neohibolites* (Willey, 1973), but which may now have to be reassigned to another genus, occur up to 555 m (Fig. 4), and at 525 m the first representatives of the *Inoceramus neocomiensis* group (Fig. 11a, b) were recorded. The latter became the dominant element in an assemblage which also includes *Grammatodon*, *Pinna* and occasional phylloceratid ammonites.

Above 657 m (Fig. 4), there is a further prominent 10-m sandstone unit which, like the one at 450–457 m, has a sharp, erosional base and a normally graded top. However, fossils are lacking in this bed, apart from a few serpulids (*Rotularia*) and plant fragments. There is then a return to the uniform dark siltstone lithology which continues to the top of the section (667–780 m). Up to the 700-m level, *Inoceramus* is the commonest fossil, but thereafter *Aucellina* (= *A. andina-radiatostriata* gp.) largely replaces it (Figs 4, 12b, e). At the 740-m level, aconeceratid ammonites (mostly *Sanmartinoceras*) enter the succession and they are accompanied by a few, large phylloceratids, *Entolium* and small limids. The highest belemnites recorded were probably belemnopseids from 555 m (Fig. 4).

Although the lithological match is not precise, it is apparent that the Leda Ridge section is equivalent to approximately the lower 868 m of section KG. 3401 in Spartan Cwm (Figs 4, 9). Its base is well dated by the *Raimondiceras–Bochianites*–bivalve assemblage as Berriasian–Valanginian and the top, by the incoming of aconeceratids, as Aptian (see above). Both the massive sandstone units (at 450–457 m and 657–667 m) mark the sites of breaks in the sequence, but these are not thought to mark excessive periods of time. For example, at least two belemnite species continue uninterrupted across the lower sandstone.

STRATIGRAPHICAL DISCUSSION

Although the precise nature and extent of the disturbed zone at the base of the succession is uncertain, it may now be better to regard it as essentially Middle Kimmeridgian (Ohauan) in age. Such a decision is based partly on the age affinities of its fossil content and partly on the absence of the Oxfordian–Lower Kimmeridgian faunas that are known to occur at a number of other Scotia arc–Antarctic Peninsula localities. For example, a distinctive bivalve fauna, comprising elements such as *Jeletzkiella falklandensis* Jones and Plafker, *Malayomaorica malayomaorica* (Krumbeck) and *Retroceramus galoi* (Bohm), can be traced from the eastern Falkland Plateau to the Orville and Lassiter Coasts and eastern Ellsworth Land (Jones and Plafker, 1977; Quilty, 1977; Crame, 1983*a*; Jeletzky, 1983); however, it is not present in the FBF. No precise level can be fixed for the Kimmeridgian–Tithonian boundary, but a useful field guide may be the top of the disturbed zone (i.e. 100 m, Figs 4, 13).

Two distinct, ammonite-dominated faunal assemblages characterize the Tithonian strata and can, perhaps, be used as the basis of a twofold division of this stage (following Enay, 1972; Imlay, 1980; Jeletzky, 1984). The first of these is dominated by the perisphinctid genera *Virgatosphinctes* and *Aucalosphinctoides* (Figs 4, 5b, 9) and can be assigned to the Lower–Middle Tithonian (= Lower Tithonian of the above authors). Such a determination is compatible with the known age-ranges of associated *Buchia* (or *Australobuchia*) species. There is then a short but nonetheless distinct gap from the overlying berriasellid fauna (Figs 4, 9). This is provisionally taken to be late Tithonian, an age supported by the occurrence of both *Hibolithes argentinus* and *Anopaea* sp. nov.?

Some objections might be raised to the foregoing division on the grounds that

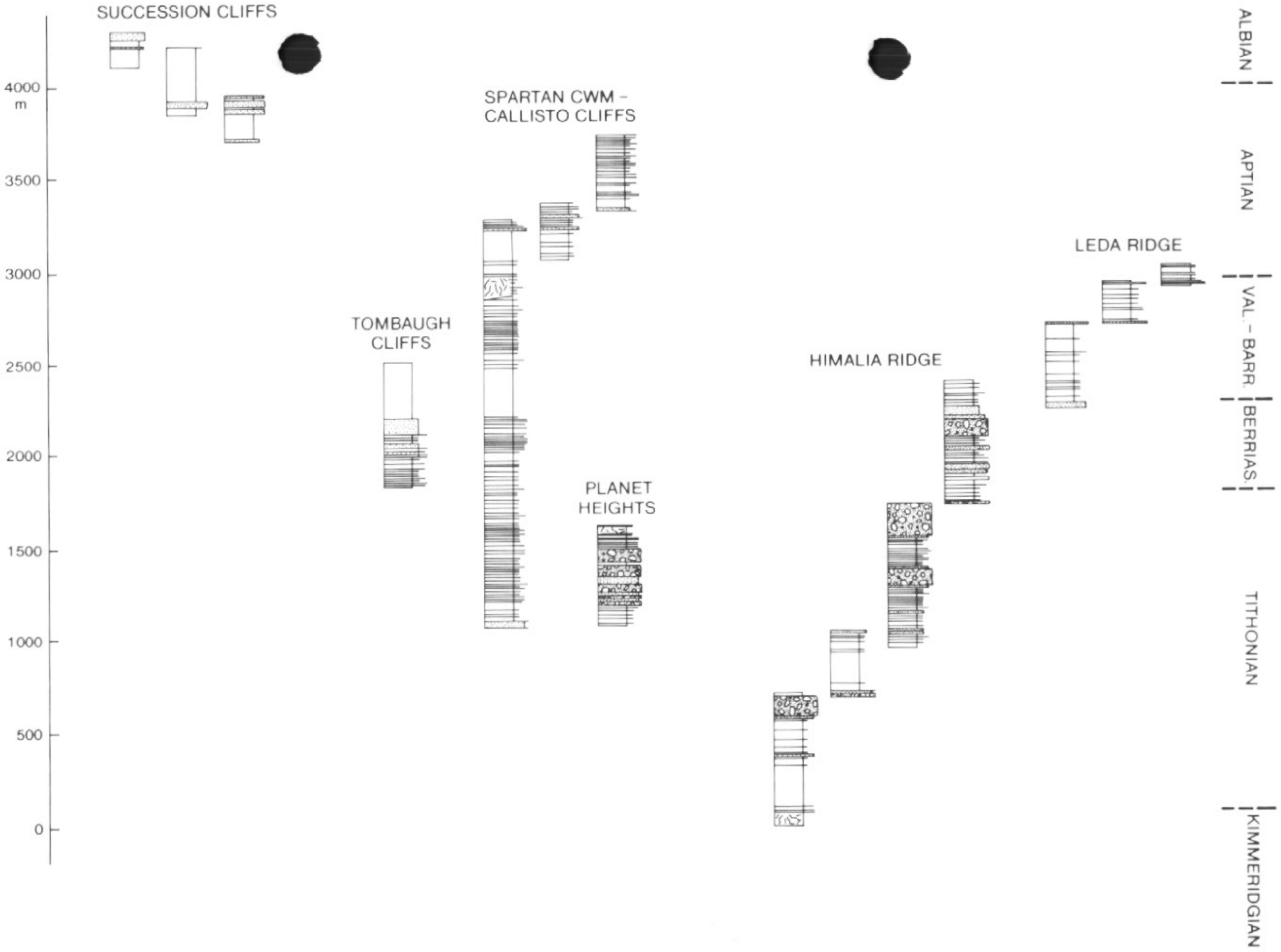

Fig. 13. Stratigraphical correlations between the sections described in the text, together with Tombaugh Cliffs and Succession Cliffs. The scale along the left side of the diagram indicates the height in metres above the base of the Himalia Ridge sections. The stage boundaries along the right of the diagram are only approximate. VAL.–BARR. is an abbreviation for Valanginian–Barremian and BERRIAS. for Berriasian. The symbols are the same as for Figs 4–9.

proven Berriasian occurs very much higher in the Himalia Ridge section (2250 m, Fig. 4); by implication, either the Upper Tithonian or the Berriasian could be represented by disproportionately long stages. Nevertheless, it should be borne in mind that the bulk of the sediments between 1300 and 2200 m (Fig. 4) are extremely coarse-grained and it is likely that they were deposited comparatively rapidly (within a complex channel system, and perhaps at the base of the continental slope; P. J. Butterworth, pers. comm., 1987). It may actually be better to define the Jurassic–Cretaceous (or J–K) boundary within the finer-grained and more fossiliferous succession at Callisto Cliffs (section KG. 2802, Fig. 9). It has previously been argued (Crame, 1982*b*) that, as *Retroceramus everesti* has a Tithonian–Berriasian age-range, the most likely position for the boundary is within the upper 200–300 m of KG. 2802 (Figs 9, 13). At present, this is the only macrofaunal basis for placing the J–K boundary and it is hoped that greater resolution will eventually be provided by micropalaeontology.

The lower levels of the prolific siltstone-associated fauna which first appears at 2255 m on Himalia Ridge, 0–30 m on Leda Ridge, 1015–1037 m at Callisto Cliffs (section KG. 2802) and 233–271 m (Z_6) at Tombaugh Cliffs (section KG. 401) (Figs [illegible] 9) are well dated (by ammonites, belemnites and bivalves) as Berriasian. However, it has recently been shown that the uppermost levels of this fauna, containing *Olcostephanus* and *B. gladiatoris*, are now better regarded as Valanginian (Howlett, 1986), and it would appear that the incoming of the latter species may serve as a useful datum between the two stages. Thus the base of the Valanginian is set at 2298 m on Himalia Ridge, 48 m on Leda Ridge and 260 m (Z_6) on Tombaugh Cliffs (Figs 4, 9, 13).

Even though there are some breaks in the overlying succession (such as at 450 and 657 m on Leda Ridge, Fig. 4), it is unlikely that they are of any more than local significance. Unfortunately, no diagnostic Hauterivian fossils have yet been found, but it is hoped that further taxonomic studies on belemnopseid belemnites, inoceramid bivalves (especially *Anopaea trapezoidalis* and its allies) and microbiota may reveal their presence. There is probably greater scope for establishing the presence of the succeeding stage, the Barremian. Representatives of the *Aucellina caucasica-aptiensis* group (which first appear at 543–555 m in KG. 3401) would seem to be of this age, as may be both early members of the *I. neocomiensis* gp. (first appearance at 591–603 m, section KG. 3401) and belemnites formerly referred to *Neohibolites* (up to 555 m on Leda Ridge) (Fig. 4). The latest representatives of the *I. neocomiensis* group (*I. deltoides*; 865–890 m, KG. 3401) and members of the *Aucellina andina-radiatostriata* group (865–890 m, KG. 3401) could also be at least partly late Barremian in age (Figs 4, 9, 13).

The base of the Aptian is here taken to be the abrupt incoming of the aconeceratid ammonites (42–48 m, section KG. 3402; 740 m on Leda Ridge; Figs 4, 9, 13), which can be regarded as a basin-wide event. This level correlates with 215 m at Fossil Bluff (R_9 of Taylor and others, 1979, fig. 6) and the early aconeceratid-dominated fauna with occasional heteromorphs (e.g. 42–176 m, KG. 3402; Fig. 9) is thought to be equivalent to approximately 215–320 m (i.e. R_{9-15}). Higher faunas, such as the aconeceratid-lytoceratid (*Eulytoceras*)–*Aucellina* assemblage from 0–72 m in section KG. 3403 (Fig. 9), are equivalent to high in the Fossil Bluff succession (H_{27}, i.e. approximately 429 m) and low levels in Waitabit Cliffs (T_6, i.e. approximately 160–180 m; Taylor and others, 1979, fig. 6). The specimens of *Tetrabelus willeyi* (dimitobelids) from 285–297 m in KG. 3403 (Figs 9, 12c, d) also indicate a direct correlation with the lower levels of Waitabit Cliffs (T_6).

The succession in section KG. 3403 (Figs 1, 9) ends in the core of a shallow syncline associated with a major thrust zone (Crame, 1986). The axial trend (151°) and plunge (15–20°) of this fold strongly suggest that the topmost beds in this sequence are equivalent to those exposed in the lowest levels at Succession Cliffs. In fact, the lowest unit (A_1) at the latter locality comprises 16.5 m of orange micaceous sandstones (with concretions and scattered pebbles; Taylor and others, 1979) which match well with the 274–283 m interval in KG.3403 (Fig. 9). It is succeeded by 131 m of interbedded grey–black siltstones and cream–buff sandstones (with concretions) ($= A_2$) which are lithologically equivalent to the topmost (283–390 m) levels in section KG.3403. Such a correlation is strengthened by the presence of dimitobelid belemnites (*Peratobelus* cf. *oxys* (Tennison-Woods); Doyle, 1987) but absence of *Birostrina*? cf. *concentrica* (a common fossil in the upper levels of Succession Cliffs; Crame, 1978, 1985*b*). Unfortunately the Aptian–Albian boundary cannot yet be accurately located in the Succession Cliffs section (localities A–C of Taylor and others, 1979), and all that can be said at present is that it most likely lies above the 148-m level (Fig. 13). The presence of *B.*? cf. *concentrica*, further dimitobelid belemnites and tetragonitid, desmoceratid and silesitid ammonites suggests that there may well be a substantial thickness of Albian strata here (Thomson, 1983*a*; Crame, 1985; Doyle, 1987). It is even possible that the uppermost levels of Succession Cliffs represent some of the youngest strata in the entire Fossil Bluff Formation (Taylor and others, 1979, pp. 31, 37).

As detailed correlations of the FBF with other Upper Jurassic–Lower Cretaceous sedimentary sequences in the Antarctic Peninsula region have already been made (Taylor and others, 1979; Crame, 1982*b*; Thomson, 1983*b*), only a brief synopsis will be given here. The most extensive of these sequences is the Middle–Upper Jurassic Latady Formation which crops out on the south-eastern flanks of the peninsula (e.g. Thomson, 1983*b*, fig. 8). Ranging in age from Bajocian–Kimmeridgian in the Lyon Nunataks–Behrendt Mountains region to Kimmeridgian–early Tithonian on the Orville and Lassiter Coasts, it may well be at least as thick as the FBF. However, Upper Tithonian faunas are only known from its southern extremity (Thomson, 1983*c*) and it may be that there is no more than approximately 500 m of stratigraphic overlap between these two major units (Crame, 1982*b*, p. 593). Similarly, marine horizons within the Antarctic Peninsula Volcanic Group at both Carse Point and Mount Bouvier, Adelaide Island (Fig. 1) correlate with a very low (basal 500 m) level in the FBF (Crame, 1982*b*; Thomson, 1983*b*).

Considerably more potential exists for detailed correlations with Jurassic–Cretaceous boundary sequences exposed at the northern end of the Antarctic Peninsula (Fig. 1). These are contained within the Nordenskjöld Formation and associated conglomeratic deposits on the north-eastern flank of the peninsula, and the Byers Formation of western Livingston Island, South Shetland Islands (Fig. 1). The Nordenskjöld Formation, which is perhaps the best-known of these units, is at least 500 m thick and possibly considerably more (Farquharson, 1983*a*). It comprises a regular alternation of dark, organic-rich radiolarian mudstones and thin pale ash-fall tuffs (Farquharson, 1982, 1983*a*, *b*), although more recent observations suggest that a number of other lithological types may also be present (Whitham, 1986). At the type locality of Longing Gap, perisphinctid ammonites and inoceramid bivalves referable to the *R. haasti* group indicate a Kimmeridgian–early Tithonian age (Farquharson, 1983*a*). Further loose macrofossils from both Sobral Peninsula and James Ross Island include berriasellid and spiticeratid ammonites, *R. everesti* and an unusual large form of ?*Buchia*. These almost certainly signify that the Nordenskjöld Formation extends into at least the Berriasian (Farquharson, 1983*b*; Crame, 1984).

Although there is undoubtedly a major stratigraphical break between the

Nordenskjöld Formation and the basal (Barremian–Aptian) volcaniclastic conglomerates of James Ross Island (Farquharson and others, 1984), these two units may be much more closely linked (in a temporal sense) on the Sobral Peninsula Fig. 1). Here, Farquharson (1983*a*, p. 7) postulated the existence of an unconformity between a 550-m sequence of Nordenskjöld Formation beds and a thick (750–1000 m) succession of volcaniclastic sandstones and conglomerates of probable Hauterivian–Barremian age (see also Farquharson, 1982; Farquharson and others, 1984). Unfortunately, very few macrofossils have yet been collected from this locality.

The Byers Formation of Byers Peninsula, western Livingston Island represents a complex sequence of interbedded volcanic and sedimentary rocks which is at least 425 m thick. Although accurate mapping and correlation have been consistently hampered by poor exposure and intense local faulting, it is thought that the marine sedimentary rocks of the formation were deposited in approximately Kimmeridgian–Valanginian times (Valenzuela and Hervé, 1971; Covacevich, 1976; Pankhurst and others, 1979; Smellie and others, 1980; Askin, 1983; Crame, 1984). The lowest lithostratigraphic unit, the Mudstone Member, comprises at least 105 m of dark mudstones with occasional thin pale tuff bands that matches well with Nordenskjöld Formation from localities such as Longing Gap and Sobral Peninsula (Farquharson, 1983*a*). Such a correlation is strengthened by a Kimmeridgian–Lower Tithonian molluscan assemblage which includes: perisphinctids (especially a finely ribbed form resembling *Subplanites* and *Pectinatites*), berriasellids such as *Berriasella behrendsi* Burckhardt, oppeliids, belemnopseids (*Belemnopsis* and *Hibolithes*), inoceramids referable to the *R. haasti* group and *Arctotis australis* Crame (Tavera, 1970; Covacevich, 1976; Smellie and others, 1980; Crame, 1984, 1985*a*).

There is some evidence to suggest that the Mudstone Member grades directly into the overlying Mixed Marine Member (Crame and Farquharson, 1984). The latter, which is at least 320 m thick, appears to be characterized by an initial (116 m) coarse-grained interval in which rusty-coloured volcaniclastic conglomerates (> 3.5 m thick), sandstones and thin intercalated lavas predominate. These are succeeded by a siltstone-dominated interval and the sequence terminates in interbedded lavas and agglomerates (Crame, 1984, fig. 2B; Crame and Farquharson, 1984). A basal fauna from the section through the Mixed Marine Member has yielded *Bochianites*, berriasellid-type fragments, a small (juvenile?) *Inoceramus* and a new buchiid (previously identified as *Otapiria* sp. nov. 1; Crame, 1984). Some 120 m above this level spiticeratid ammonites appear for the first time, together with probable berriasellids and an almost smooth mytilid or inoceramid (*Parainoceramus* of Crame, 1984). The uppermost levels of the member are characterized by further specimens of *Bochianites*, oppeliids, a second distinctive buchiid/monotid and an *Inoceramus* belonging to the *I. ovatus* group. Overall, a Berriasian age is suggested for this unit, although it is possible that it both ranges down into the Tithonian and up into the Valanginian (Smellie and others, 1980; Crame, 1984). The stratigraphic position of a Valanginian fauna described by Covacevich (1976) from the south-eastern flank of Byers Peninsula has yet to be accurately established.

In summary, the probable Kimmeridgian–Valanginian age range for the Byers Formation indicates that it is directly comparable with, for example, the entire Himalia Ridge section of the Fossil Bluff Formation (Fig. 4).

Some Biogeographical Considerations

Whenever regional comparisons of the FBF are attempted, it is readily apparent that it is much easier to correlate the lower (Kimmeridgian–Tithonian) levels than the uppermost (Aptian–Albian) ones (e.g. Taylor and others, 1979; Crame, 1982*a*, *b*; Thomson, 1983*b*). The reason for this lies in the fact that, whereas the Upper Jurassic faunas can be related to a broad faunal province that covered much of the Southern Hemisphere mid- and high latitudes (the so-called Indo-Pacific province of many authors – see below), their Aptian–Albian counterparts have much less wide-ranging affinities. It has generally been assumed that, in the late Jurassic, comparatively warm waters would have been able to penetrate to high latitudes, and that the more or less continuous shelves around the southern Gondwana margins would have been populated by a homogeneous fauna (e.g. Gordon, 1974; Stevens, 1980). In marked contrast, by the Aptian–Albian new seaways were developing between the component Gondwana continents and both Antarctica and Australasia had shifted southwards into higher latitudes (e.g. Smith and Briden, 1977, maps 33–35). Migration routes were now disrupted and significant centres of endemism began to emerge (e.g. Fleming, 1967; Stevens, 1980). It has been postulated that one such centre lay over western Antarctica (Thomson, 1981; Crame, in press) and the Fossil Bluff Formation may hold a very valuable record of the transition from cosmopolitan to restricted faunas.

The earliest faunas of the FBF certainly seem to have had very widespread affinities. The perisphinctid ammonites can be linked with wide-ranging forms (Thomson, 1979) and the belemnites largely fall within the *Belemnopsis uhligi* group, which has been recorded from the Himalayas, Indonesia, New Zealand, western Antarctica, southern Argentina and the Falkland Plateau (Stevens, 1965, 1973*a*; Willey, 1973; Jeletzky, 1983). Typical associates of this group in the Lower–Middle Kimmeridgian are bivalves such as members of the *R. galoi* and *R. haasti* groups and *Malayomaorica malayomaorica* (Crame, 1982*a*, *b*, 1983*a*). However, it is apparent that these bivalve types are uncommon (and possibly absent) in both southern South America and the Himalayas, and a faunal province defined on essentially benthonic elements stretches around the Gondwana margins from only approximately Patagonia to the Indonesian region (Crame, in press, fig. 2). This is, in essence, the Maorian (or '*I. galoi*') province of Freneix (1981), Quilty (1981) and Hayami (1984). Some evidence that it may be divisible into sub-provinces (or endemic centres) is provided by the occurrence of bivalves such as *Jeletzkiella falklandensis*, *Arctotis australis*, *Malayaomaorica occidentalis* and *M*. sp. nov.? in the western Antarctic region (Crame, in press).

Ammonites of the subfamily Virgatosphinctinae (i.e. species of *Aulacosphinctoides* and *Virgatosphinctes*), buchiids (*B. blanfordiana* and *B. spitiensis* groups) and inoceramids such as *Anopaea stoliczkai* (from Belemnite Point) all suggest that very broad distribution patterns around the Gondwana margins continued into the Lower–Middle Tithonian (e.g. Thomson, 1981, fig. 1b; Crame, in press, fig. 3). Indeed, it is even possible that a circular migration path around the India–Australasia–Antarctica block was accomplished by means of an oceanic link between the latter continent and South Africa (e.g. Enay, 1973; Hallam, 1975; Thomson, 1981). Such a connection is certainly suggested by the occurrence of ammonites such as *V. denseplicatus*, *V. contiguus* and *V.* cf. *frequens* in both the Spiti Shales and FBF (Thomson, 1979, 1981).

That these very broad faunal connections persisted into the Upper Tithonian is evidenced by the distribution of both berriasellid ammonites and bivalves such as

Retroceramus everesti (Thomson, 1979, 1981; Crame, 1982*b*). Nevertheless, it should be stressed here that there are again some indications of restricted ranges on the western margins of circum-Gondwana (Indo-Pacific) province. Endemic belemnite species within the Belemnopseidae are known from the Malagasy Republic, Patagonia (Stevens, 1965, 1973*a*; Riccardi, 1977), and the FBF (*Hibolithes belligerundi*; Willey, 1973) and it appears that the circum-Gondwana belemnite links established in the Kimmeridgian may have been substantially reduced by the Late Tithonian (Stevens, 1965, 1973*a*). *Anopaea* sp. nov.? and the new small species of *Buchia* may also be unique to the FBF.

In comparison with the Kimmeridgian–Tithonian, the Berriasian–Valanginian palaeontological record of the Southern Hemisphere is much less well understood. There are far fewer fossiliferous localities of this age, especially in the higher latitudes, and only very tentative biogeographic reconstructions can be attempted. Some indications that the very broad 'circum-Gondwana' distribution patterns persisted across the J–K boundary are provided by ammonite genera such as *Spiticeras*, *Himalayites*, *Raimondiceras*, *Olcostephanus*, *Haplophylloceras* and *Bochianit*[illegible] (Leanza, 1981; Rawson, 1981; Thomson, 1981), together with bivalves like *R. everes*[illegible] (in the upper part of its range; Crame, 1982*b*). Nevertheless, there are also signs that the FBF faunas may have been becoming steadily more isolated. There are again endemic belemnopseid belemnites, such as *B. alexandri* Willey, as well as species such as *B. gladiatoris* which indicate links with southern South America and the Malagasy Republic (Willey, 1973; Howlett, 1986). The occurrence of *I.* cf. *ovatus* and *I.* sp. aff. *ellioti* can be matched with those of certain other inoceramids in the Antarctic Peninsula–Scotia arc–Patagonia and it is becoming increasingly apparent that a small-scale radiation of *Inoceramus*- and *Parainoceramus*-like forms occurred in this region at this time (Crame, 1984, 1985, in press). So far, this is the only significant inoceramid centre-of-origin recognized in the Berriasian–Valanginian of the Southern Hemisphere.

Of the various faunal elements in the FBF that may be Hauterivian–Barremian in age, only the possible members of the *Aucellina caucasica–A. aptiensis* group have regional correlatives (in arctic Canada, Jeletzky, 1964). Neither the various representatives of the *I. neocomiensis* group nor the *Anopaea* resembling *A. trapezoidalis* have any close Southern Hemisphere counterparts and the same may well be true of the belemnites formerly referred to *Neohibolites*. All that can be said at present is that there is an apparent trend towards faunal isolation in the Hauterivian–Barremian interval of the FBF and this agrees with a general trend in the western Antarctica–Scotia arc–Patagonia region (Crame, in press).

In the succeeding Aptian–Albian stages there is a much more comprehensive foss[illegible] record and detailed comparisons can be made between key Southern Hemisphere high latitude localities. Perhaps the most striking feature to emerge from analyses to date is that the cephalopod faunas now show signs of marked differentiation. In particular, the belemnite family Dimitobelidae has been clearly demonstrated to be restricted to high latitude regions (Stevens, 1973*b*; Doyle, 1985, 1987, in press). Strong connections between eastern Australia and western Antarctica are indicated by such belemnites as *Dimitobelus praelindsayi*, *D. diptychus*, *D. stimulus* and *Peratobelus* cf. *oxys* (Doyle, 1987, in press). Further links between Australia, New Zealand, Antarctica and Patagonia are suggested by a distinctive group of aconeceratid and heteromorph ammonites (Day, 1969; Thomson, 1974, 1981), and inoceramid and oxytomid bivalves (Crame, 1985*b*, in press). Prominent among the latter are members of the *Aucellina andina-radiatostriata* group.

Although there are still many substantial gaps in the records and much taxonomic work remains to be done, there is a distinct impression that the marine invertebrate faunas of the western Antarctic became progressively isolated during Jurassic–Cretaceous boundary times. From a Kimmeridgian condition where many species and species groups can be traced considerable distances around the Gondwana margins, there appears to have been a marked retraction to much higher latitude affinities in the Aptian–Albian. The changes in the various faunal groups do not appear to have been synchronous, for there is some evidence to suggest that bivalves became more restricted before belemnites, and both these groups in turn may have preceded the ammonites (whose acme of differentiation may well have been in the Campanian–Maastrichtian Kossmaticeratidae; Thomson, 1981). Fuller documentation of this faunal response to the fragmentation of Gondwana remains a major goal of Antarctic Late Mesozoic palaeontology.

CONCLUSIONS

1. An extremely thick sequence of FBF sedimentary rocks is exposed in the [illegible]blation Valley–Callisto Cliffs–Planet Heights region of eastern Alexander Island. Correlations presented in this study suggest that the total thickness here lies between 3.6 and 3.8 km. A further 600 m of strata exposed at Succession Cliffs can be added to this figure. No major breaks have been recognized in this sequence and there is every prospect that it may reflect a substantial record of marine sedimentation across the Jurassic–Cretaceous boundary. As such, it is a potentially useful Antarctic reference section.

2. The earliest faunas, associated with the disturbed zone in the Ablation Valley region, are probably best regarded as Middle Kimmeridgian in age. The Kimmeridgian–Tithonian boundary can be placed at the top of the disturbed zone and the latter stage is subdivided into two. The Lower Tithonian is characterized by a perisphinctid-buchiid assemblage (together with certain belemnopseid belemnites) and the Upper by a suite of berriasellid ammonites and belemnites such as *Hibolithes argentinus*. The boundary between them is placed at 720 m on Himalia Ridge (Figs 4, 13).

3. At present, there is no firm macrofaunal basis for defining the Jurassic–Cretaceous boundary in the FBF. It is here placed within the upper 200–300 m of the Callisto Cliffs section (KG.2802), within the range of *Retroceramus everesti*. Micropalaeontological analyses currently in hand may provide greater resolution.

4. The Berriasian fauna recognized at the base of the Leda Ridge section, top of Himalia Ridge and Callisto Cliffs sections and low in Tombaugh Cliffs (Figs 4, 9, 13) may be best regarded as Late Berriasian. It is closely associated, in its uppermost levels, with certain Valanginian indicator species, and the boundary between these two stages has been set at 48 m on Leda Ridge, 2298 m on Himalia Ridge and 260 m on Tombaugh Cliffs (Figs 4, 9).

5. The Hauterivian–Barremian interval is the least well-defined one in the entire sequence. There are, as yet, no diagnostic Hauterivian macrofossils and only a few tentative Barremian ones are known. However, this time interval is represented by as much as 700 m of strata in the Spartan Cwm area (section KG. 3401, Figs 9, 13) and it is hoped that further taxonomic studies of belemnopseid belemnites and inoceramid bivalves may reveal some age-diagnostic forms.

6. The base of the Aptian is well defined by the sudden influx of aconeceratid ammonites, *Aucellina andina-radiatostriata* and *Inoceramus deltoides*. This level is set at *c*. 740 m on Leda Ridge and 865–890 m in section KG. 3401, Spartan Cwm (Figs 4, 9, 13).

The Aptian stage extends through the topmost levels of the Spartan Cwm section (where it is characterized by further aconeceratids, lytoceratids and dimitobelid belemnites) and into the lower levels of Succession Cliffs. The Aptian–Albian boundary can probably be placed at the latter locality somewhere above the 148-m level (Fig. 13).

7. Whereas the sedimentary record across the J–K boundary at the northern end of the peninsula is characterized by an abrupt lithological change (from a mudstone-tuff sequence to volcaniclastic conglomerates), that in eastern Alexander Island is broadly gradational. There is some evidence to suggest that the passage from a disturbed zone (at the base of the sequence) to interbedded siltstones and sandstones (at the top) may have been the product of a single regional shallowing event.

8. Whereas many elements within the earliest (Kimmeridgian–Tithonian) faunas had very widespread affinities within the Southern Hemisphere, the latest (Aptian–Albian) faunas appear to have been much more restricted. Both nektonic and benthonic molluscan species suggest that, by the end of the Early Cretaceous, a distinct high-latitude faunal province can be traced from southern South America, through western Antarctica to New Zealand and eastern Australia.

Such a change in biogeographic configurations can almost certainly be linked to the fragmentation of Gondwana and southward drift of Antarctica and Australasia (e.g. Stevens, 1980; Howarth, 1981, figs 13.9 and 13.12). It is hoped that fuller documentation of the faunas encountered in this study will enable this fundamental shift in faunal affinities to be scrutinized more closely.

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