SEDIMENTOLOGY, PALYNOLOGY AND STRUCTURE OF HUMPS ISLAND, NORTHERN ANTARCTIC PENINSULA

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Abstract. Approximately 200 m of sediments assigned to the Late Cretaceous Lopez de Bertodano Formation are exposed on Humps Island, northern Antarctic Peninsula. The sequence comprises four sedimentary facies: A, sandstone; B, silty sandstone; C, mudstone; and D, claystone. The facies represent deposition from density currents (Facies A), sedimentation from suspension or dilute density currents, followed by post-depositional reworking by bioturbation (Facies B and C) and sedimentation from suspension of primary air-fall ashes (Facies D). The sequence represents a distinct facies association within the Lopez de Bertodano Formation, with deposition below storm-wave base in an outer shelf setting.

The palynofloras of all samples taken were dominated by dinoflagellate cysts, with smaller proportions of land-derived spores and pollen. The occurrence together of *Isabelidinium pellucidum*, *I. korojonense*, *Ceratiopsis diebelii* and *Odontochitina porifera* is indicative of a Late Campanian to Early Maastrichtian age, by comparison with Australasian sequences. Previous macrofossil biostratigraphy had suggested a Campanian age for the sequence examined.

Localized displacement and tilting on faults has resulted in considerable variation in dip direction, and no consistent dip pattern can be detected. Normal and reverse faults, possibly synsedimentary, showing both an oblique slip component to their sense of movement and possible positive flower structures are also present. This faulting may be related to strike-slip deformation and basin uplift during the Late Cretaceous. Vitrinite reflectivity data from both James Ross Island and Seymour Island also suggests basin uplift, and can be related to a regression and associated eastward progradation of the coastline during the Late Cretaceous.

Introduction

Late Cretaceous sediments exposed on Humps Island, northern Antarctic Peninsula (Fig. 1), previously included in the Snow Hill Island Series of Bibby (1966) are now assigned to the Lopez de Bertodano Formation (Marambio Group) (Rinaldi, 1982; Olivero and others, 1986) (Fig. 1, Table I). These sediments form part of the fill of the Larsen Basin (Macdonald and others, 1988), and are unconformably overlain by the Late Cenozoic James Ross Island Volcanic Group (Nelson, 1975). Although both the ammonite and annelid faunas from Humps Island have previously been described (Spath, 1953; Howarth, 1958, 1966; Ball, 1960; Macellari, 1984), the sedimentology of the sequence has received little study. Recent reconnaissance by British Antarctic Survey geologists showed that the island had a distinctive sedimentary facies association, which was not directly comparable to that within either the Santa Marta or Lopez de Bertodano formations. In addition, structural data given by Bibby (1966, p. 34) have regional implications for the evolution of the Larsen Basin. Bibby (1966) reported a shallow westerly dip on Humps Island, and on the basis of this, implied

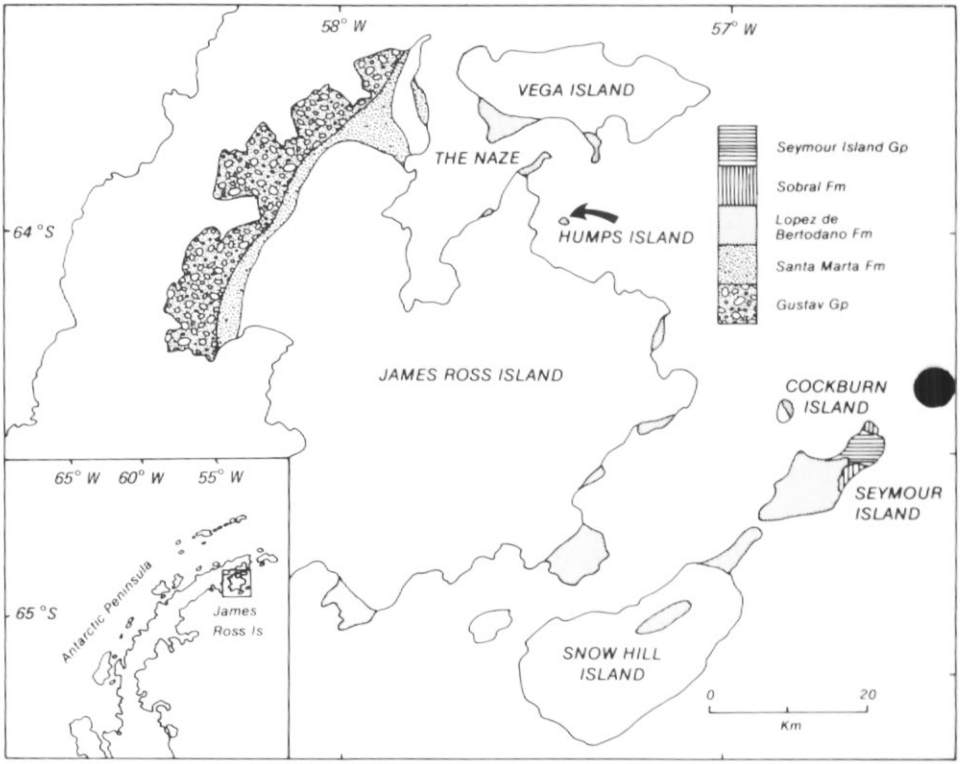


Fig. 1. Sketch map showing the location of the study area, and Cretaceous geology of the James Ross Island area. The Marambio Group is subdivided into its constituent formations: the Santa Marta Formation; the Lopez de Bertodano Formation; and the Sobral Formation. Blank: areas of older or younger rocks, or ice cover.

the presence of large-scale folding within the Cretaceous sequence. However, the significance of these data has remained unclear, because of the lack of sedimentological and stratigraphic data from Humps Island.

The aims of this paper are threefold: (1) to describe and interpret the sedimentary sequence exposed on Humps Island; (2) to examine the palynology of the sequence as a tool to understanding the biostratigraphy; and (3) to re-examine the structural geology of the island, and assess its regional significance.

Regional Setting and Stratigraphy

The Humps Island sequence forms part of the fill of the Larsen Basin, deposited to the rear of an evolving magmatic arc, now represented by the Antarctic Peninsula (Farquharson and others, 1984). Sedimentation within the basin was initiated in approximately the Barremian, with the deposition of a submarine fan–slope apron complex, represented by the Gustav Group of northern James Ross Island (Ineson, 1985, 1987; Ineson and others, 1986) (Fig. 1, Table I). During or prior to the Coniacian–Santonian, partial basin inversion led to shallowing, with deposition in fan-delta and tidally influenced shelf settings (Macdonald and others, 1988; A. G. Whitham pers. comm., 1987).

Period	Age		Lithostratigraphy		Environmental Interpretation
TERTIARY	Pli		James Ross I. Volcanic Gp.		Ensialic alkaline volcanism
	Mio				
	Oli		Seymour Is. Group	La Meseta Fm.	Prodelta-delta slope ?Tidal coastline
	Eoc				
	Pal	Tha		Cross Valley Fm.	Delta top
		Dan	Marambio Gp.	Sobral Fm.	Delta complex
CRETACEOUS	Maa			Lopez de Bertodano Fm.	Inner shelf Outer shelf ?Estuarine
	Cmp			Santa Marta Fm.	Tectonically active shallow marine shelf
	San		?	Hidden Lake Fm.	Tidal shelf / fan-delta
	Con				
	Tur		Gustav Gp.	Whisky Bay Fm.	Deep marine submarine fan/slope apron complex
	Cen				
	Alb			Kotick Point Fm.	
	Apt				
	Brm			Lagrelius Point Fm.	

Table I. Age, lithostratigraphy and inferred environmental interpretations for the Cretaceous–Tertiary Larsen basin area (after Ineson and others, 1986; Olivero and others, 1986; Macdonald and others, 1988; Macellari, in press).

Late Cretaceous, dominantly shallow marine sediments have been assigned to the Marambio Group (Rinaldi, 1982; Ineson and others, 1986; Olivero and others, 1986). This unit has been subdivided into three formations; the Santa Marta Formation, restricted to northern James Ross Island; the Lopez de Bertodano Formation, exposed on southern James Ross Island, Humps Island, Vega Island, Seymour Island, Snow Hill Island and Cockburn Island; and the Sobral Formation exposed only on Seymour Island (Rinaldi, 1982; Zinsmeister, 1982; Olivero and others, 1986) (Fig. 1). The Santa Marta Formation represents sedimentation in a tectonically influenced setting, with an upward transition from mid/outer to inner shelf deposition (D. Pirrie, unpublished data). Many of the isolated exposures of the Lopez de Bertodano Formation have received little detailed study and, as yet, cannot be accurately correlated stratigraphically. The lower part of the Lopez de Bertodano Formation exposed on Seymour Island has been interpreted as having been deposited within a shallow marine environment near a delta or estuary; succeeding units represent middle and outer shelf, and inner shelf facies (Barrera and others, 1987; Macellari, in press). This sequence is unconformably overlain by deltaic facies of the Sobral Formation and Seymour Island Group (Zinsmeister, 1982; Macellari, in press).

Sedimentology

Approximately 200 m of sediments are exposed on Humps Island. The base of the sequence is not seen, and the sediments are unconformably overlain by the Late Cenozoic James Ross Island Volcanic Group. A detailed sedimentary log, 136 m thick, was measured through the well-exposed sequence on the south-east side of the island (Fig. 2a, b). Four sedimentary facies can be described on the basis of grain size, sedimentary structure and composition. The remaining ~ 70 m of section is less well exposed, but is predominantly composed of mudstone with rare thin sandstone interbeds.

Facies A: sandstone

Facies A (see Figs 2a, b, 5) is composed of well-sorted, fine- to very fine-grained sandstones, and forms 19% of the measured section. Bed thickness averages 57 cm (range 5–216 cm) with sharp, commonly loaded or fluted lower bed contacts, and sharp planar, rarely gradational, upper bed contacts. The beds are dominantly ungraded or rarely show basal coarse-tail grading, which may be a function of the sediment sorting. Most beds are massive and structureless, but some show indistinct planar lamination, wavy lamination and dish structures. Rare thin, normally graded beds with a massive base and a planar-laminated top also occur. The beds show marked lateral continuity over a distance of approximately ½ km.

Approximately 40% of beds are bioturbated, commonly showing an increase in degree of bioturbation towards the top of the bed. The bioturbation typically appears as an indistinct mottled texture, although the ichnogenera ?*Thalassinoides* and *Zoophycos* are locally recognizable. The sandstones are dominantly composed of quartz, feldspar and glauconite, together with rare mica flakes, lithic volcanic fragments, opaques, pumice and chloritized glass shards. In addition, small angular wood fragments are common within the facies. The glauconite grains are commonly larger than the detrital sandstone grains being on average medium to fine sand grain size. The sandstones are variably indurated, and have sporadic calcareous concretions; when indurated the sandstones have a sparry to microgranular carbonate

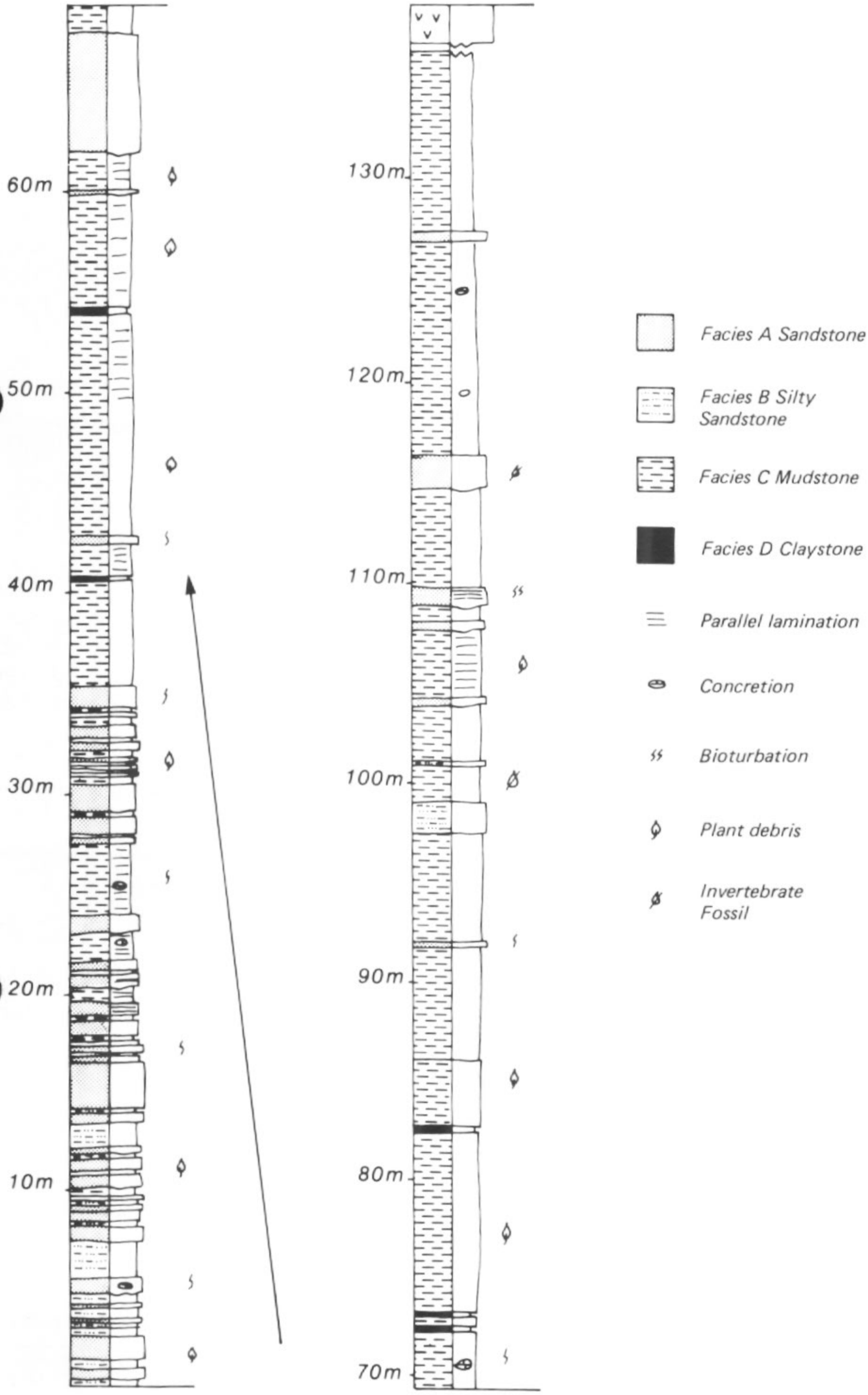


Fig. 2. (a) Sedimentary log through the Lopez de Bertodano Formation sediments exposed on south-east Humps Island. Note the fining-upward trend from a sandstone-dominated to a mudstone-dominated interval.

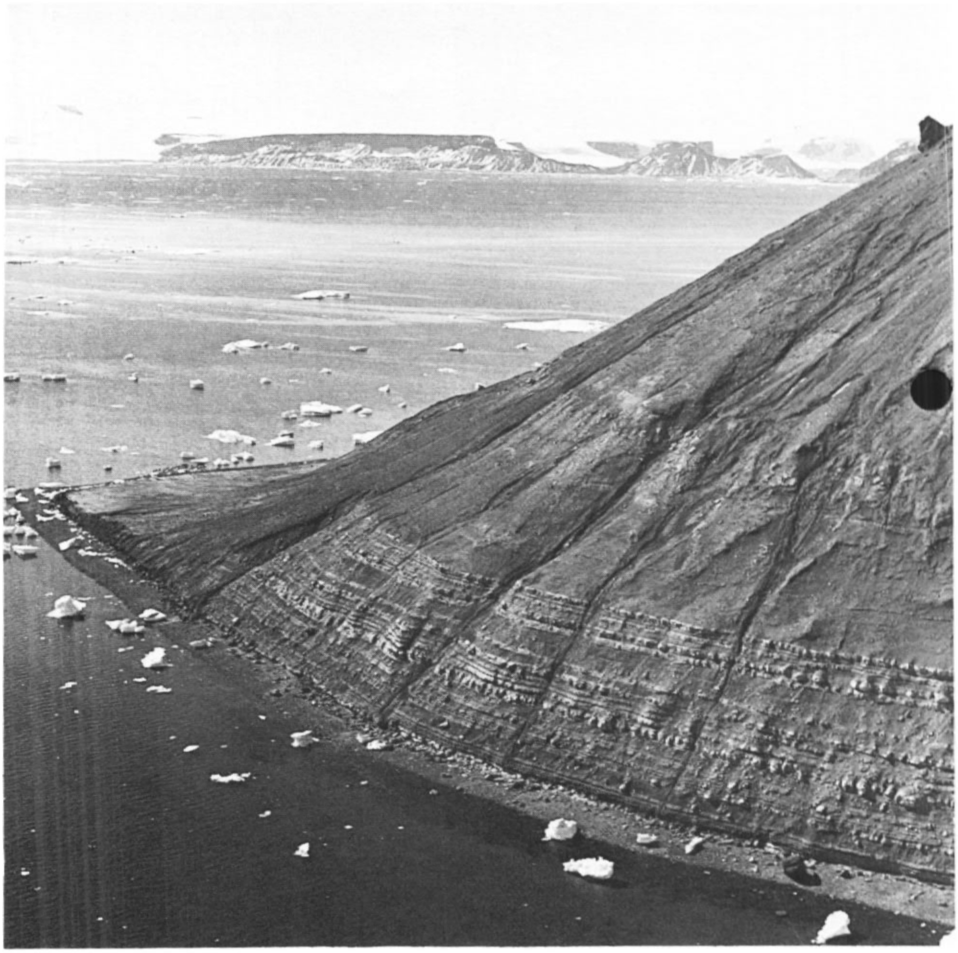


Fig. 2. (b) The main study area on south-east Humps Island (also showing the fining-upwards trend). Oblique air photograph by HMS *Endurance*.

cement. Rare palaeocurrent data based on flute cast orientations, suggest derivation from the west.

The sandstones of Facies A represent rapid deposition from density currents. Their fine grain size, basal coarse-tail grading, dish structures and weak parallel lamination are comparable to the deposits of high density turbidity currents, possibly transitional to liquefied flows (cf. Lowe, 1976, 1982). The presence of dish structures within some of the beds implies rapid deposition, followed by dewatering during compaction (cf. Lowe and Lopicollo, 1974). However, the beds can also be compared to the deposits of density currents related to storm sedimentation within more shallow marine settings (cf. Hamblin and Walker, 1979; Brenchley and others, 1986; Rosenthal and Walker, 1987; Swift and others, 1987). Fine-grained sandstones, showing features analogous to classic turbidites, have been described from numerous ancient shallow marine sequences. Their deposition has been attributed to both turbidity currents (e.g. Hamblin and Walker, 1979), and storm currents (e.g. Swift and others, 1987). Most sandstones attributed to storm sedimentation processes are thinly bedded, although thick bedded units do occur (e.g. Brenchley and others, 1986; Rosenthal and Walker, 1987). The absence of features such as hummocky cross stratification (HCS) within the sandstones may be due to deposition below storm-wave base. Alternatively, Brenchley and others (1986) suggested that parallel laminated sandstone beds lacking HCS may be deposited by offshore directed currents generated by storms, but carrying sediment onto areas of the shelf not directly affected by the storm.

The deposits of turbidity currents and storm-related offshore-directed density currents, deposited below storm-wave base, are hard to distinguish and probably represent a continuum of processes. The sandstones of Facies A may have been deposited by either process.

Facies B: silty sandstone

Facies B, representing 5% of the measured section, is composed of ungraded, poorly sorted, silty very fine sandstone. Bed thickness is on average 48 cm (range 9 cm to 2 m) with mainly sharp planar, rarely gradational bed contacts. The beds are massive, or rarely show indistinct planar lamination. Small disseminated fragments of wood debris are common; large wood clasts are rare. Bioturbation in the form of an indistinct, mottled texture occurs in some beds, and there is a sparse fauna of serpulids and bivalves. Most beds are moderately indurated and small calcareous concretions occur.

The silty sandstones of Facies B probably represent the intermixing of thinly interbedded sandstones and mudstones by intense bioturbation (cf. Kuehl and others, 1986). However, some of these beds may represent rapid primary deposition of poorly sorted sediment from suspension, under varying current conditions.

Facies C: mudstone

Facies C, forming 75.5% of the measured section, is composed of mudstone (see Figs 5, 6a). Bed thickness is on average 2.54 m (range 4 cm to 11.20 m). The mudstone forms thick monotonous, dark grey units with sharp bed contacts. The beds are usually massive, or show an indistinct wavy to planar lamination. Small disseminated wood fragments are common, together with a rare macrofauna which includes serpulids and bivalves. Bioturbation is most commonly observed within calcareous concretions, and may therefore be more common than otherwise observed within the unlithified beds.

This facies represents deposition from suspension. The presence of a rare macrofauna, together with bioturbation, suggests deposition under aerobic conditions.

Facies D: claystone

Facies D is represented by only five beds and forms 0.5% of the measured sequence. The beds are composed of a massive yellow to grey, poorly indurated clay. Bed thickness ranges between 5 and 15 cm, with sharp upper and lower bed contacts. No macrofauna or bioturbation occur within the facies. Preliminary XRD data suggest that these beds are dominantly composed of smectite and chlorite, possibly with kaolinite, illite and some K-feldspar.

Beds of Facies D are interpreted as representing altered airfall ashes, probably deposited directly from suspension, following a volcanic eruption. Primary airfall deposits occur sporadically throughout the Santa Marta Formation on James Ross Island (Farquharson and others, 1984), and the Lopez de Bertodano Formation on Vega Island. The clay mineralogy of these beds is comparable to that described for other altered ash beds (e.g. Teale and Spears, 1986).

Facies association and depositional environment

The sedimentary facies exposed on Humps Island represent a distinct facies association within the Marambio Group. The underlying Santa Marta Formation is divisible into two associations, the upper one of which is characterized by massive well-sorted sandstones, cross-bedded sandstones and rare coquinas, along with less common finer-grained interbeds. This association has been assigned to an inner shelf to ?shoreface shallow marine depositional setting (D. Pirrie, unpublished data). The association is typically composed of well-sorted glauconitic quartz-feldspar rich sandstones, in contrast to the underlying association, which is dominated by poorly sorted arkosic and lithic arenites (D. Pirrie, unpublished data). The basal Lopez de Bertodano Formation as exposed on Seymour Island is predominantly composed of massive silty sandstones, yielding a marine fauna of low abundance and diversity. It has been interpreted as representing a nearshore, possibly estuarine depositional setting (Barrera and others, 1987; Macellari, in press).

In contrast, the sequence exposed on Humps Island is characterized by massive sandstones interbedded with mudstones and silty sandstones. The association can be divided into a lower sandstone-dominated interval, fining up over 45 m into an upper mudstone-dominated interval (see Fig. 2a, b, but note that Facies A sandstones also occur throughout). A second thinner, and less well-exposed sandstone-dominated interval occurs near the top of the exposed sequence. A sparse macrofauna occurs throughout the measured section including serpulids, bivalves, ammonites, brachiopods, gastropods, colonial corals and fossil wood (Croft, 1947), and there are signs of bioturbation. This implies a relatively shallow marine, normal salinity depositional environment. In addition, the presence of significant proportions of dinoflagellate cysts within all samples examined is indicative of marine deposition. The preponderance of peridinacean dinoflagellate cysts (i.e. a low gonyaulacacean ratio of Harland, 1973), and the occurrence of woody tissue and miospores, strongly suggests a shelf sea depositional setting. The pollen assemblages are dominated by *Nothofagidites* Potonié 1960, *Tricolpites* Cookson ex Couper 1953 and podocarpacean taxa. Directly comparable assemblages have been interpreted as derived from a mixed angiosperm/gymnosperm rainforest community (Dettmann and Thomson, 1987, pp. 49, 50). The presence of abundant glauconite, commonly larger in grain size than the detrital sanstone components within Facies A, may indicate the *in situ* diagenetic formation of the glauconite within the sandstone beds (cf. Jeans and others, 1982). The formation of glauconite is most commonly observed within shallow marine settings. However, it is still possible that some of the glauconite may be detrital, with its apparent coarser grain size being due to a paucity of other coarse-grained sediment within the source area.

The interbedded sandstone–mudstone association which typifies the Humps Island strata is broadly comparable to a number of depositional settings, ranging from deep marine turbidite systems (e.g. Graham, 1982) to storm-dominated shelf sequences (e.g. Hamblin and Walker, 1979; Brenchley and others, 1986; Rosenthal and Walker, 1987). However the fine grain size of sandstone beds, the abundance of possibly *in situ* glauconite and the associated marine fauna support a shelf-type depositional setting for the Humps Island succession. The association most probably represents deposition below storm-wave base in an outer shelf environment. The sandstone-dominated packets may represent sand lobes within an otherwise low energy shelf, although the absence of sandstone bed amalgamation implies rapid rates of fine-grained sedimentation (cf. Brenchley and others, 1986).

Brenchley and others (1986) suggest that the abrupt appearance of storm-influenced sandstone beds within muddy shelf sequences is a common feature, and may be related to periods of regression. The Facies A sandstones are petrographically directly comparable to the inner shelf sandstones of the upper Santa Marta Formation, the deposition of which is interpreted to be related to a regression during the Late Campanian (D. Pirrie, unpublished data). In addition, Vail and others (1984) suggest that following a sea-level fall and a rapid downward shift in coastal onlap, low stand deltaic and fan facies would be deposited in offshore settings. Such sequences may be comparable to the sandstone-dominated interval on Humps Island.

Stratigraphy

On the basis of ammonite biostratigraphy, the Humps Island sequence was assigned a Campanian age by Spath (1953), refined to Lower to middle Campanian by Howarth (1966). This was based on the presence of a *Gunnarites* dominated ammonite assemblage, also documented from the uppermost levels of the Santa Marta Formation (Spath, 1953; Howarth, 1966; Olivero and others, 1986). Serpulids reported from Humps Island also occur within the lowermost units of the Lopez de Bertodano Formation on Seymour Island (Macellari, 1984); this has a Late Campanian–Maastrichtian age (Macellari, 1986).

In order to re-examine the age of the Humps Island strata, five samples were examined by one of us (J. B. R.) for palynomorphs (see Figs 3, 4). All intervals yielded marine dinoflagellate cyst and land-derived spore/pollen floras. Four samples (D.8673.7, D.8673.8, D.8673.11 and D.8673.12) produced relatively sparse palynofloras, whereas one sample (D.8673.15) yielded a well-preserved, diverse association. In all the samples, dinoflagellate cysts were encountered in higher proportions than spores and pollen. *Ceratiopsis diebelii* (Alberti 1959) Vozzhennikova 1967, *Isabelidinium pellucidum* (Deflandre and Cookson 1955) Lentin and Williams 1977, *Odontochitina porifera* Cookson 1956, *Spiniferites ramosus* (Ehrenberg 1838) Loeblich and Loeblich 1966 and isolated peridinacean endocysts being consistently prominent. The miospore assemblages are dominated by gymnospermous and angiospermous pollen, pteridophyte spores are markedly subordinate.

The dinoflagellate cyst assemblages are indicative of a Late Campanian–Early Maastrichtian age, by comparison with Australasian sequences. *Isabelidinium pellucidum* ranges throughout the Humps Island succession, and is a good marker for the Late Campanian–Early Maastrichtian interval in Australia (Helby and others, 1987; N. Marshall, pers. comm., 1987). The occurrence together of *Ceratiopsis diebelii* (Late Campanian–Early Danian) and *Isabelidinium korojonense* (middle Campanian–Early Maastrichtian) indicates that the interval investigated lies within the *Isabelidinium korojonense* dinoflagellate cyst Zone of Helby and others (1987). This biozone spans the middle Campanian to Early Maastrichtian of Australia and has been independently dated using foraminifera and calcareous nannoplankton (see Helby and others, 1987, fig. 32). The Humps Island samples, except D.8673.8, yielded *Odontochitina porifera*; Helby and others (1987) reported a Santonian to Early Campanian age for this taxon in Australia. Wilson (1984), however, indicated that the

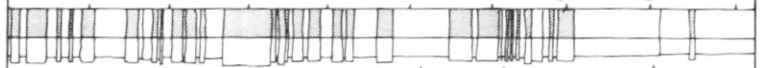
LITHOSTRATIGRAPHY	MARAMBIO GROUP				
	LOPEZ DE BERTODANO FORMATION				
LITHOLOGY	5 – 10 – 15 – 20 – 25 – 30 – 35 – 40 m 				
SAMPLED HORIZON	D.8673.7	D.8673.8	D.8673.11	D.8673.12	D.8673.15
Ceratiopsis diebelii	●	●	●	●	●
Isabelidinium korojonense	●		?	●	●
Isabelidinium pellucidum	●	●	●	●	●
Odontochitina porifera	●		●	●	●
Spiniferites ramosus	●	●	●	●	●
Manumiella? cretacea		●	?	?	
Trithyrodinium vermiculatum					●
Gymnospermous pollen	●	●	●	●	●
Pteridophyte spores	●	●	●	●	●
Nothofagidites spp.	●	●	●	●	
Tricolpites gillii			●		
Biozone	*Isabelidinum korojonense* Zone – Helby and others (1987)				
Chronostratigraphy	late Campanian – early Maastrichtian				

Fig. 3. Range chart of selected dinoflagellate cysts and miospores for the Lopez de Bertodano Formation of Humps Island. Heights given correspond to those shown in the sedimentary log (Fig. 2a).

uppermost occurrence of this dinoflagellate cyst lies within the Maastrichtian of New Zealand. In additon, G. J. Wilson (pers. comm., 1987) has indicated that morphotypes of *O. porifera* with proximally wide, distally tapering horns (as recovered in this study, see Fig. 4f, i), represent the youngest (i.e. Campanian/Maastrichtian) types in a phylogenetic sequence commencing with *Odontochitina cribropoda* Deflandre and Cookson 1955 in the Coniacian/Santonian.

In terms of the New Zealand dinoflagellate cyst biozonation of Wilson (1984), the Humps Island sequence lies within the Campanian–Maastrichtian *Odontochitina porifera* Zone. This scheme has been independently dated by macrofossils and foraminifera (Wilson, 1984, fig. 7). Like the Australian dinoflagellate cyst record, there is a disparity in the New Zealand ranges of forms used to date the Humps Island sequence. According to Wilson (1984, fig. 3), *Ceratiopsis diebelii* has a significantly younger range than in Australia, being confined to the Late Maastrichtian to Danian, hence not overlapping with *Odontochitina porifera*.

Sample D.3122.3, from the east side of Cape Lamb, Vega Island (Fig. 1) is believed to be broadly coeval with the Humps Island sequence, and a probable middle Maastrichtian age was assigned to this locality by Dettmann and Thomson (1987, fig. 2). These authors recognized *Isabelidinium pellucidum* and *Manumiella*? *cretacea* (Cookson 1956) Bujak and Davies 1983 (as *Isabelidinium cretaceum* (Cookson 1956) Lentin and Williams 1977) which are diagnostic of the middle Campanian to Early Maastrichtian *Isabelidinium korojonense* Zone of Australia. In addition, *Chatangiella* cf. *campbellensis* (Wilson 1967) Lentin and Williams 1976, *Isabelidinium* cf. *bakeri* (Deflandre and Cookson 1955) Lentin and Williams 1977, and *Palaeocystodinium granulatum* (Wilson 1967) Lentin and Williams 1976, were recorded from Vega Island (Dettmann and Thomson, 1987), but were not found in the Humps Island sequence. These forms, together with *Manumiella*? *cretacea* suggest a middle–Late Maastrichtian age (*Alterbia acutula* Zone) when compared to the New Zealand dinoflagellate cyst biozonation of Wilson (1984). Dettmann and Thomson (1987) suggested that the Vega Island sample may contain significant levels of reworked Campanian–Early Maastrichtian palynomorphs. These authors reported definite stratigraphical recycling of Early–middle Cretaceous forms, recognized by their darker colour (imparted by a higher thermal maturation level). The Humps Island sequence yielded no perceptibly reworked palynomorphs. The palynofloras from this interval are similar in content to some relatively sparse associations dated as Campanian from James Ross and Vega islands by Askin (1983).

Dettmann and Thomson (1987) noted the similarities of the Antarctic Peninsula and southern Australian Campanian–Maastrichtian dinoflagellate cyst assemblages with the 'Williams Suite' of Lentin and Williams (1980). This is one of three distinctive associations of Campanian peridinacean taxa which was orginally defined as fringing the North Atlantic (with a questionable occurrence in the South Atlantic region; Lentin and Williams 1980, fig. 2).

The pollen and spores encountered from Humps Island cannot further refine the Late Campanian–Early Maastrichtian age indicated by the dinoflagellate cyst assemblages. *Tricolpites gillii* Cookson 1957, a pollen grain, was recovered from D.8673.11 indicating a Coniacian to Early Paleocene age. Overall the miospore assemblages are indicative of the *Tricolporites lillei* Zone (Coniacian: south-east Australia) of Stover and Evans (1973). The occurrence throughout of species of *Nothofagidites* (southern beech pollen) confirms that the Antarctic Peninsula region is well within the *Nothofagidites* phytogeoprovince of Srivastava (1978, 1981). Further discussion on the Campanian–Maastrichtian pollen florule of the region is included in Dettmann and Thomson (1987, pp. 49, 50).

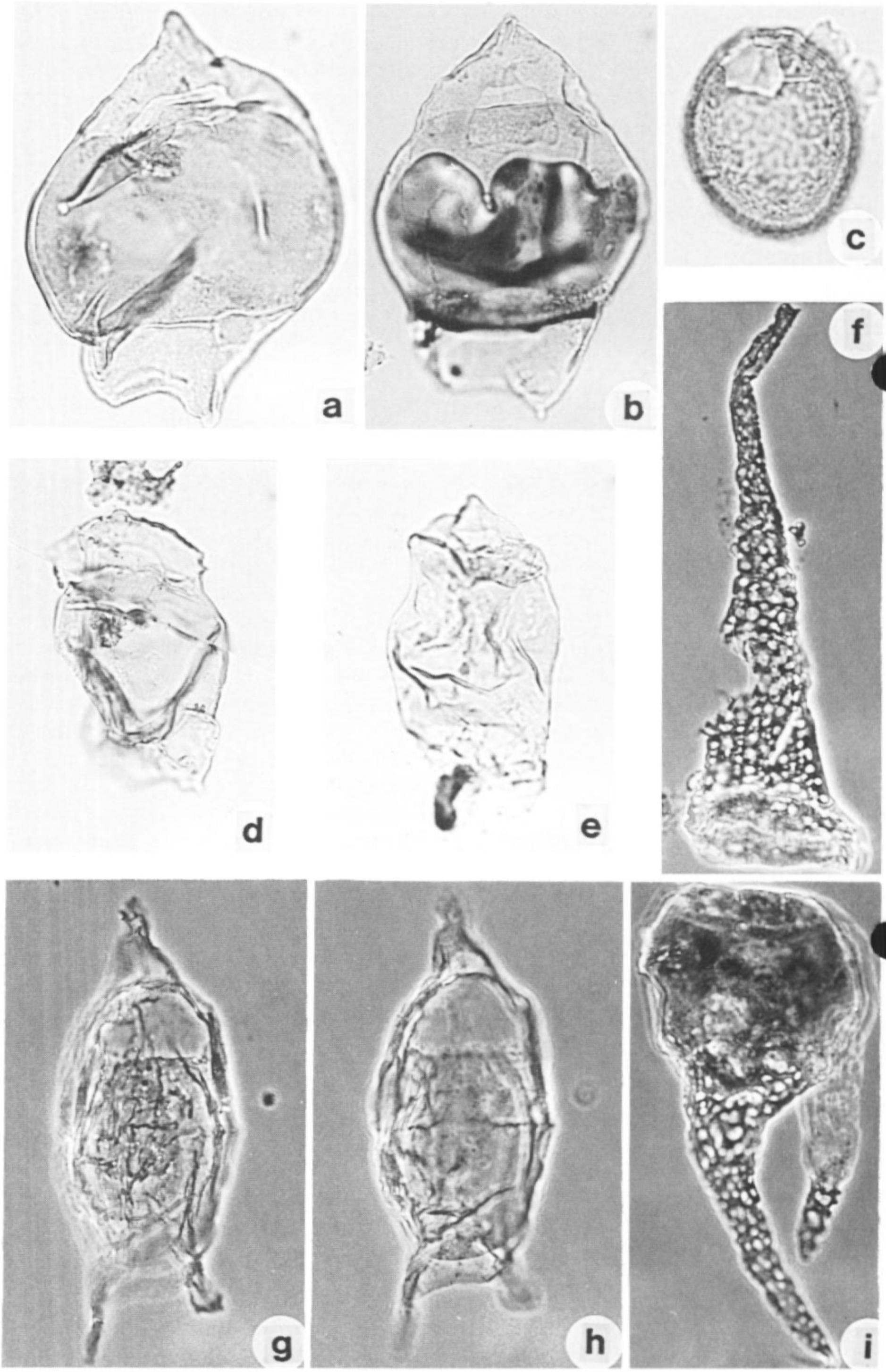


Fig. 4. For legend see opposite.

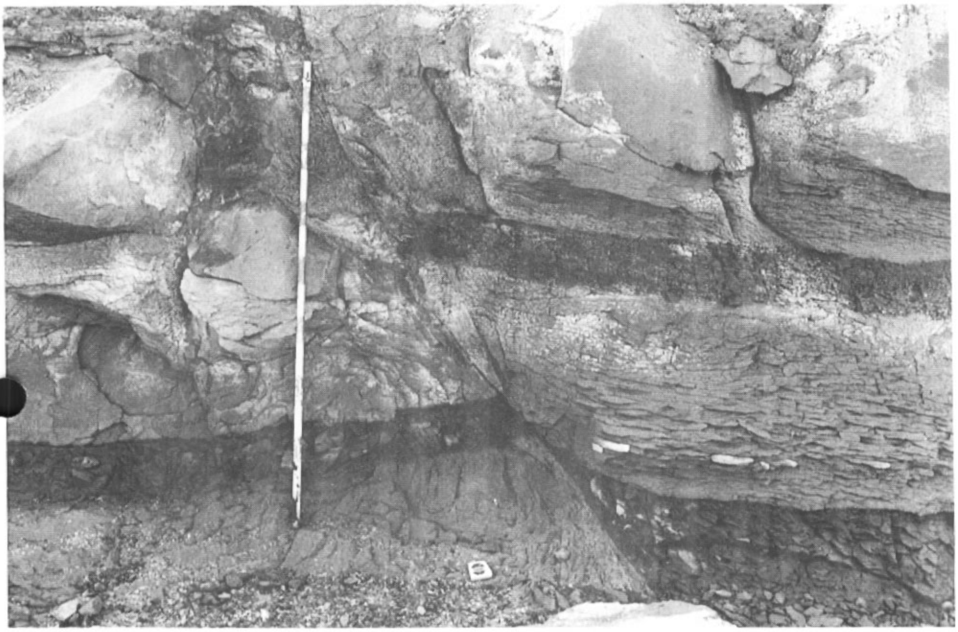


Fig. 5. Possible synsedimentary reverse fault within interbedded sandstones (Facies A) and mudstones (Facies C), south-east Humps Island. Measuring staff = 1.5 m.

Structural Geology

The Marambio Group sediments characteristically show a gentle, south-easterly dip throughout the James Ross Island area. However, Bibby (1966) reported a shallow westerly dip on Humps Island, and implied the presence of a broad, shallow asymmetric syncline in the vicinity of the Naze (with the Humps Island beds representing the eastern limb of the fold). Rinaldi (1982), on the other hand, suggested that the Marambio Group was not folded, but had a monoclinal structure.

Where dip measurements are obtainable on Humps Island, they are highly variable. This variation is controlled primarily by localized tilting and disturbance due to faulting. No evidence for the folding proposed by Bibby (1966) could be corroborated by our field studies and the sequence may show horizontal bedding. However, the faulting may have important implications for the structural evolution of the basin during the Late Cretaceous.

Fig. 4. Peridinoid (a–e, g, h) and ceratioid (f, i) dinoflagellate cysts from Humps Island; magnification, all figures × 500. Photomicrographs (f–i) taken with phase contrast. (a, b) *Isabelidinium pellucidum* (Deflandre & Cookson 1955) Lentin & Williams 1977, note the bicavate cyst organization and the lati-deltaform I (2a) periarchaeopyle, both from sample D.8673.11. (c) *Trithyrodinium vermiculatum* (Cookson & Eisenack 1961) Lentin & Williams 1976, note the thick autophragm and the 3I (1–3a) archaeopyle, sample D.8673.15. (d, e) *Isabelidinium korojonense* (Cookson & Eisenack 1958) Lentin & Williams 1977, note the prominent shoulders and the iso-omegaform I (2a) periarchaeopyle. (d) Sample D.8673.7. (e) Sample D.8673.12. (f, i) *Odontochitina porifera* Cookson 1956, an operculum (f) and a loisthocyst, note the perforate apical and antapical horns, (f, i) both from sample D.8673.7. (g, h) *Ceratiopsis diebelii* (Alberti 1959) Vozzhennikova 1967, note the longitudinal striations on the periphragm – high focus – (g) and the large steno-deltaform periarchaeopyle – median focus – (h) sample D.8673.15.

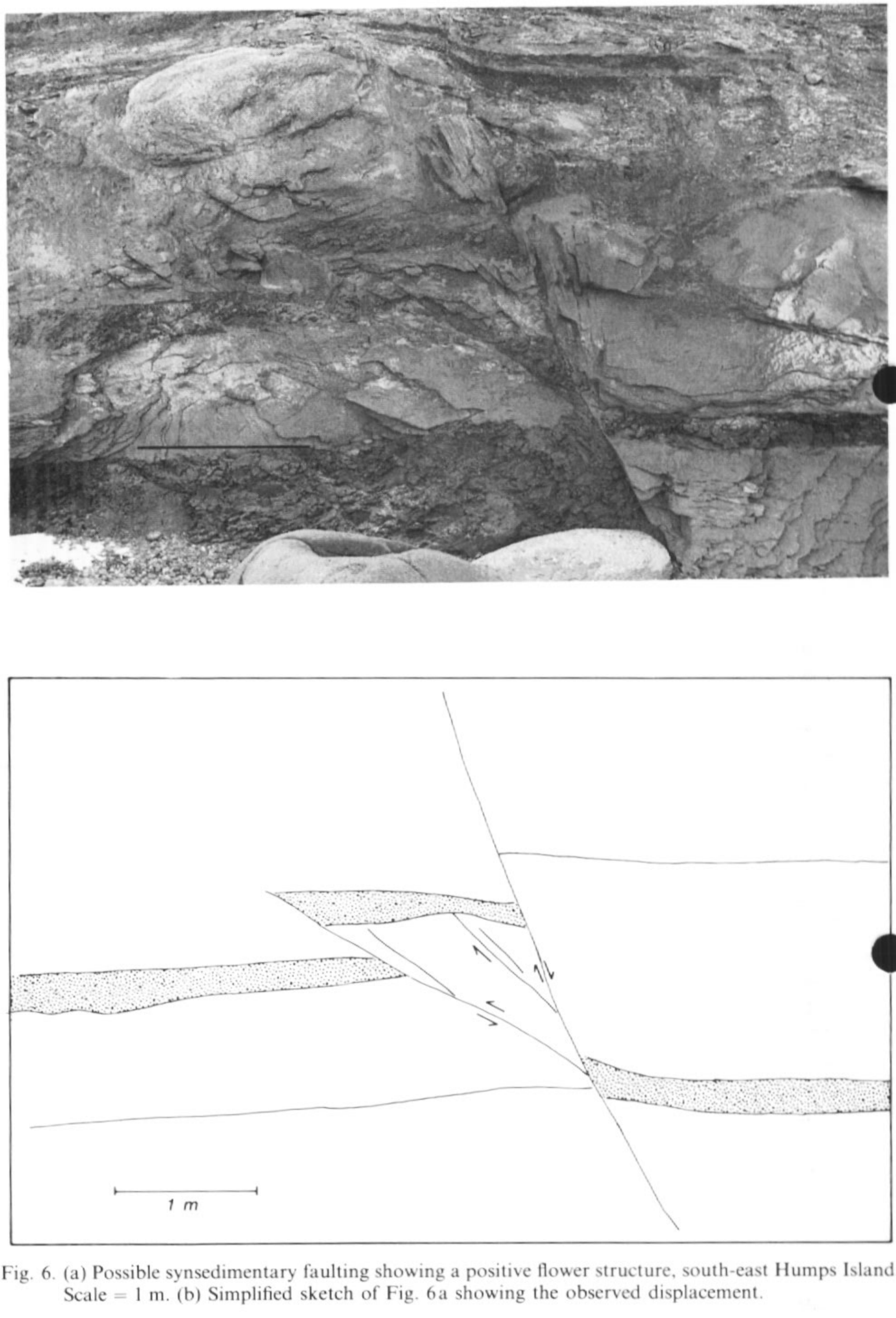


Fig. 6. (a) Possible synsedimentary faulting showing a positive flower structure, south-east Humps Island. Scale = 1 m. (b) Simplified sketch of Fig. 6a showing the observed displacement.

Within the lower sandstone-dominated interval, faulting is both abundant and well exposed (Figs 5, 6). This faulting dies out vertically, and may be synsedimentary although this cannot be confirmed. Reverse faults are most common, although normal faults do occur with downthrows both to the north-west and south-east. The faults are orientated north-east–south-west, and typically have small displacements, ranging between 30 and 122 cm. Rarely, larger faults with throws up to approximately 20 m are present. Where measurable, slickensides on fault planes show an oblique slip component to the sense of displacement. Within the mudstone-dominated interval, displacement on the high-angle faults is hard to determine, with the fault planes commonly marked by calcite or quartz veining. Many of the faults show marked changes vertically in both the angle of hade and degree of displacement, and die-out over a distance of 2–5 m. In addition, several faults define possible positive flower structures (Fig. 6). Rare, thin sandstone dykes, orientated 115–295°, also occur.

Recent structural work in the Antarctic Peninsula region has recognized the importance of strike slip deformation (Nell and Storey, in press), and suggested that this deformation may have controlled the development of the sedimentary basins along the eastern margin of the Antarctic Peninsula (Storey and Nell, 1988). Macdonald and others (1988) suggest that, during the opening of the Weddell Sea, strike slip or oblique slip movement along the Antarctic Peninsula may have occurred during Middle Jurassic–Early Cretaceous time. The possible positive flower structures and oblique slip component within the faulting observed on Humps Island may be indicative of this deformation, and, if so, suggests that it continued into at least the Late Cretaceous. In addition, the presence of possibly synsedimentary faulting within the Hidden Lake and Santa Marta formations on northern James Ross Island, and the Lopez de Bertodano Formation on Vega Island suggests that deformation may have occurred sporadically throughout the Santonian to Campanian/Maastrichtian within the Larsen basin area. The strike-slip deformation suggested by the faulting on Humps Island may be related to a phase of compression and basin uplift during the Late Campanian–Maastrichtian.

Discussion

The presence of outer shelf sediments of Late Campanian to Maastrichtian age on Humps Island is of considerable significance to the understanding of the palaeogeography of the area during this time interval; assuming that the exposed sediments have not been tectonically displaced relative to one another, and that they still occupy their initial depositional configuration. However, until the Humps Island succession can be accurately correlated stratigraphically with the well-documented Marambio Group sediments exposed on northern James Ross and Seymour islands, the palaeogeography of the area will remain unclear.

Previous models of basin evolution during the Late Cretaceous suggest the presence of a wide shelf area which was affected by a regression and eastward progradation of the coastline during the Late Campanian (Thomson and others, 1983). This model explains the presence of shallow marine deltaic or estuarine facies within the basal Lopez de Bertodano Formation on Seymour Island (Barrera and others, 1987; Macellari, in press). The significance of the outer shelf sediments on Humps Island, west of Seymour Island, is dependent on the regional correlation of the Humps Island strata. On the basis of the currently accepted palaeogeography of the region, the Humps Island strata occur closer to the inferred western margin of the basin than the basal Lopez de Bertodano Formation sediments exposed on Seymour Island. Although the nature and location of the eastern margin of the basin is unknown, there is no evidence to suggest the presence of a landmass or significant basin high in the vicinity of Seymour Island during the Late Cretaceous. Assuming that the accepted palaeogeography of the region is correct, and that the Humps Island and basal Seymour Island strata are direct age equivalents, then the Humps Island strata should represent a shallower marine setting than the basal Lopez de Bertodano Formation. This is clearly not the case, which suggests that the two localities are not direct age equivalents.

If, however, the Humps Island succession is older than the basal Lopez de Bertodano Formation exposed on Seymour Island, then it may represent the more offshore equivalent to the Santa Marta Formation. The basin uplift suggested by the faulting on Humps Island may be related to the eastward progradation of the coastline, leading to the deposition of the deltaic to estuarine facies of the Lopez de Bertodano Formation on Seymour Island. Low vitrinite reflectivity values throughout the Santa Marta Formation on James Ross Island, and within the Lopez de Bertodano Formation on Seymour Island, suggest that the area has undergone minimal post-depositional burial (Barrera and others, 1987; A. G. Whitham and J. E. A. Marshall, pers. comm., 1987). This can best be explained by a period of basin uplift following deposition, with little net sedimentation close to the basin margin during the Maastrichtian to Early Cenozoic. In addition the presence of beach facies within the La Meseta Formation on Seymour Island (Zinsmeister, 1987) implies that the Cretaceous sequence now exposed on northern James Ross Island formed part of an uplifted land mass by at least Eocene times.

On the basis of the data currently available, the Humps Island strata may best be considered as representing the offshore equivalent to the Santa Marta Formation. However, it must be stressed that, until the stratigraphy of the region is more fully understood, this interpretation should be regarded as provisional.

In addition to the tectonic control on palaeogeography during the Late Cretaceous, sea-level fluctuations may also be important. Haq and others (1987) suggest that the global eustatic sea-level curve shows a transgression during the Santonian–Campanian followed by a regression during the Late Campanian–Paleocene. This is comparable to that seen within the Santa Marta Formation, with the recognition of a transgressive to regressive pulse (D. Pirrie, unpublished data). A second transgressive–regressive pulse can also be recognized during the Maastrichtian to Paleocene Lopez de Bertodano Formation (Macellari, in press), and this is comparable to the sea-level curve for the Magallanes basin in southern South America (cf. Riccardi, 1987). The Humps Island sandstone beds may be related to the observed regression at the top of the Santa Marta Formation (cf. Vail and others, 1984). Brenchley and others (1986) have suggested that the abrupt appearance of storm-influenced sandstones within muddy shelf sequences may be associated with periods of regression.

The occurrence together of *Isabelidinium pellucidum*, *I. korojonense*, *Ceratiopsis diebelii* and *Odontochitina porifera* is indicative of a Late Campanian–Early Maastrichtian age for the Humps Island sequence. All the samples examined lie within the Campanian/Maastrichtian *Isabelidinium korojonense* dinoflagellate cyst Zone of Helby and others, 1987. Previous work on the ammonite biostratigraphy of the sequence had suggested a lower to middle Campanian age (Howarth, 1966).

The possibility of strike-slip deformation within the Larsen basin area has previously been proposed (Storey and Nell, 1988; Nell and Storey, in press). The faulting on Humps Island is younger than that previously suggested for the area (Macdonald and others, 1988), and the possibility that strike-slip deformation has played a more continuous role in the basin evolution cannot be discounted. Although the most intense deformation described from the basin is restricted to a narrow zone along its eastern margin (Macdonald and others, 1988; A. G. Whitham and J. E. A. Marshall, pers. comm., 1987), the presence of faulting on Humps Island suggests that the structural evolution of the basin is likely to be more complex than previously envisaged.

Conclusions

(1) Approximately 200 m of Late Cretaceous sediments, currently assigned to the Lopez de Bertodano Formation, are exposed on Humps Island.

(2) The sedimentary sequence can be divided into four distinct facies, deposited by both density current and suspension sedimentation processes. Altered airfall ashes indicate the occurrence of contemporaneous arc volcanism.

(3) The facies association and associated fauna represent deposition within an outer shelf setting, with sedimentation at all times below storm-wave base.

(4) A Late Campanian–Early Maastrichtian age is assigned to the sequence on the basis of the macrofauna and palynoflora. All samples examined lie within the Campanian/Maastrichtian *Isabelidinium korojonense* dinoflagellate cyst Zone of Helby and others (1987).

(5) Westerly dip measurements and inferred large-scale folding proposed by Bibby (1966) are not confirmed. Localized disruption of the dip is due to fault displacement.

(6) Normal and reverse faults showing possible positive flower structures and an oblique slip component are present. They may be indicative of the previously speculated phase of strike-slip deformation within the basin.

(7) Basin uplift during the Campanian–Maastrichtian related to this deformation may be important in the understanding of the palaeogeography of the Larsen basin during the Late Cretaceous–Early Cenozoic. In addition, global and local sea-level fluctuations may be an important control on sedimentation within the basin during this time.

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