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Late Miocene Asterozoans (Echinodermata) in the James Ross Island Volcanic Group

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Abstract: Asterozoans (Echinodermata) of Late Miocene age (6.02 ± 0.12 Ma) are preserved as external moulds in water-lain tuffs of the James Ross Island Volcanic Group (JRIVG), James Ross Island, Antarctic Peninsula. The asterozoans are complete, and appear to represent specimens suffocated after having been pinioned by rapid sedimentation on the distal fringe of an erupting sub-aqueous tuff cone. Although the coarse nature of the host sediments has obliterated the fine morphological detail of the specimens, at least one suggests evidence of entrainment by a turbidity current. A second shows evidence of detachment of the distal tip of one of its arms. In addition to fossil discoveries from glaciomarine sediments, the volcanic tuffs of the JRIVG represent a new source of fossil data that can be used to interpret the ecology and environment of the Antarctic marine shelf biota during the Neogene.

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Introduction

Opportunities for new Cenozoic fossil discoveries lie in the back-arc basin behind the Antarctic Peninsula, in which James Ross Island is located (Fig. 1). In this area Eocene molluscan faunas from Seymour Island have been extensively documented (Stilwell & Zinsmeister 1992), and Aronson & Blake (2001) have argued that climatically influenced faunal changes can be recognized in Eocene echinoderms from Seymour Island. Extensive molluscan and foraminiferal assemblages have also been documented from rocks of Oligocene and Neogene age in the region. These represent organisms living both during interglacial phases, and in glaciomarine conditions (Jonkers 1998a, 1998b, Jonkers *et al*. 2002). Here we document the discovery of nearly 30 asterozoan specimens from Late Miocene water-lain volcanic tuff deposits of the James Ross Island Volcanic Group (JRIVG) on James Ross Island (Fig. 1). These fossils appear to be external moulds: no skeletal remains are preserved. The discovery represents an entirely new lithofacies for the recovery of fossils in the Neogene of the Antarctic Peninsula region. Although poorly preserved, their presence indicates that careful scrutiny of these rocks might reveal further fossil material, allowing the delineation of environmental effects on a wider range of organisms over a greater stratigraphical range, as well as discerning aspects of changes in community ecology through time.

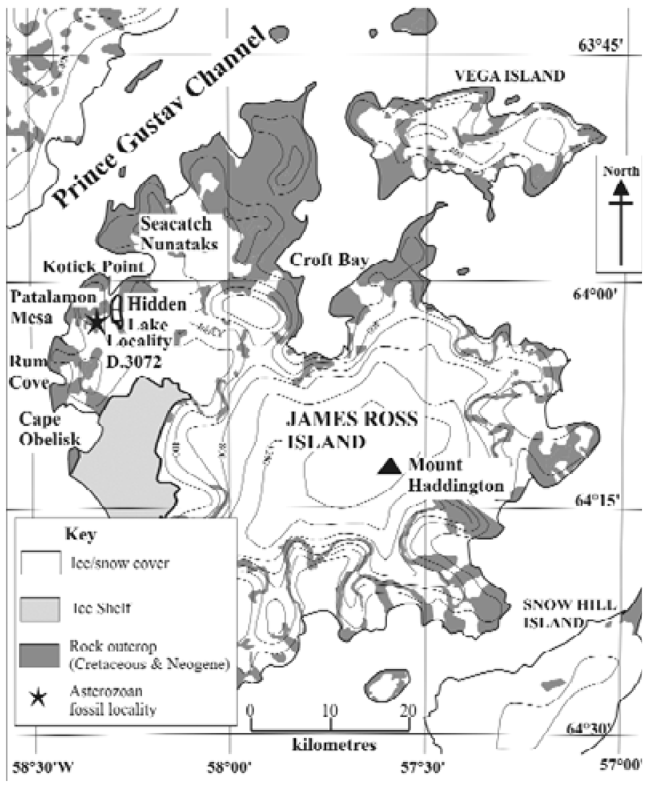

Fig. 1. Geographical map of James Ross Island. The location of the fossil locality lies to the west of Hidden Lake.

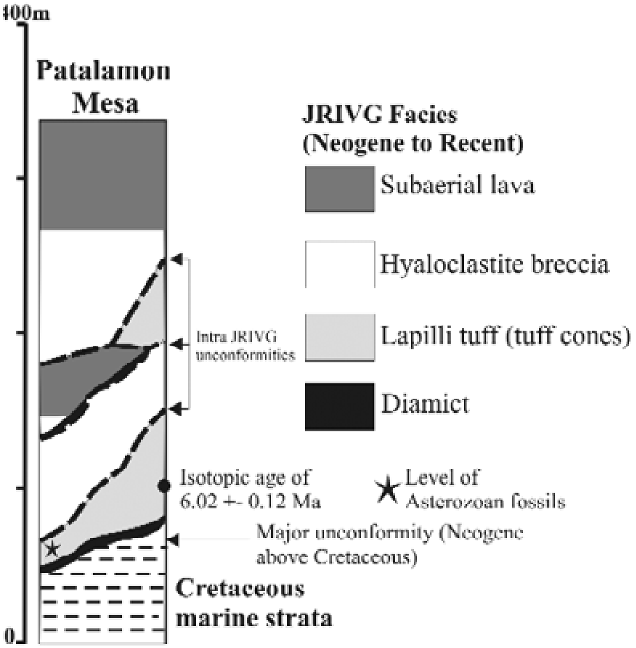

Fig. 2. Schematic vertical section through Patalamon Mesa, western James Ross Island (see Fig. 1 for location), illustrating the local stratigraphical context of the asterozoan-bearing basal lapilli tuff unit. The thickness scale is approximate.

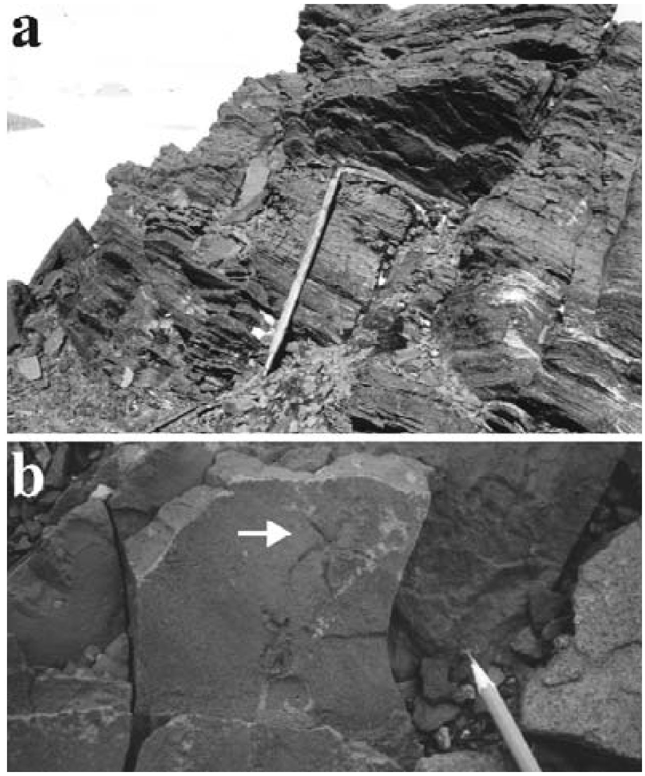

Fig. 3. Volcaniclastic sequence from which the external moulds of the fossil asterozoans have been recovered. West of Hidden Lake, James Ross Island (BAS locality D.3072/DJ.2092. 64°01.9'S 58°20.07'W). **a.** Flaggy sandstones forming the main outcrop; the ice axe is about 50 cm long. **b.** Bedding plane with asterozoan (arrowed); the pencil shaft is about 6 cm long. This specimen is the same as that illustrated in Fig. 5d.

Geological setting

The late Cenozoic (Late Miocene to Recent) history of the James Ross Basin is represented onshore by the JRIVG. It comprises some 1500 m of alkaline basalts and interleaved sedimentary rocks. The volcanic rocks were erupted largely at Mount Haddington (Fig. 1). The JRIVG dominates the geology of the island (Bibby 1966, Nelson 1975), though it has received relatively scant recent documentation. Previous investigations of the JRIVG suggested its accumulation in a marine setting, but more detailed recent work (Smellie *et al*. 2003, Smellie unpublished data) indicates that most of the volcanic rocks were erupted sub-glacially: in addition to features preserved in the volcanic rocks diagnostic of a glacial environment, each effusive volcanic phase is separated by glacial sedimentary rocks (mainly diamicts) and moulded and striated unconformities consistent with a glacial eruptive environment. The asterozoan-bearing sediments form part of a thin volcaniclastic sequence near the base of the JRIVG (Fig. 2). Additional volcaniclastic sequences occur in the same stratigraphical position at several localities on western James Ross Island, between Rum Cove and Seacatch Nunataks (Fig. 1). These are of similar age, but have so far not yielded any fossils. These sediments were formed during a period of widespread explosive eruptive activity and deposited in a relatively shallow shelf marine setting (Bibby 1966, p. 27, and unpublished information of the authors). $^{40}Ar/^{39}Ar$ isotopic dating of the tuffs (Smellie unpublished data) suggests an age of 6.02 ± 0.12 Ma for the fossil-bearing sequence, placing it within the Late Miocene (for context, see Jonkers *et al*. 2002, fig. 6).

Fossil discovery and nature of material

During 1958 J.S. Bibby made a reconnaissance survey of the JRIVG, including an examination of water-lain volcanic tuffs on the west side of Hidden Lake (Figs 1 & 3a). There, at latitude and longitude 64°01.9'S 58°20.07'W, he discovered more than 20 specimens of fossil asterozoans preserved on a large slab of fine-grained sandstone (Bibby 1966, p. 27). At another locality, about 180 m away from the first, Bibby discovered another specimen. Unfortunately, only two specimens survived the journey back to base. Later, a few specimens were collected from Bibby's first locality in the 1980s by M.R.A. Thomson and six fossils were discovered by one of the present authors (JLS) from the same locality in 2004. The extant BAS specimens, all sourced from Bibby's first locality, are: D.3072.1, D.3072.3, D.3073.1, D.8839.1, and DJ.2092.3 to DJ.2092.6. All of these appear to be external moulds: no specimens are preserved with positive relief and there are no skeletal remains. In all cases only one surface of the external mould is available to us for each specimen. Either the counterpart moulds were not collected, or they were not preserved within the outcrop. The asterozoan specimens were recovered during reconnaissance field investigations, so there is limited information about their taphonomic context, particularly the number of horizons that yield fossils and their relative distribution on the sediment surfaces. Nevertheless, all of the specimens collected by JLS during 2004 were obtained about 2 m above the exposed base of the sequence (Fig. 3a & b), within 3 m laterally and 10 cm vertically of one another, and probably from different bed surfaces. Differences in the lithologies of asterozoan-bearing rock slabs in the BAS collections, and observations associated with the new collection (by JLS), suggest that the material has been sourced from more than one horizon.

Sedimentology and environment

The asterozoans are preserved in a rock sequence about 30 m thick (Fig. 3a), though cropping out only intermittently. Only the basal 15 m is relatively well exposed. The beds are steeply south dipping (70° to vertical) to slightly overturned. The exposures are not *in situ*, but were derived by slumping and creep downslope from prominent crags forming the south-east corner of Patalamon Mesa (Fig. 1). The deposits are mainly khaki-green, flaggy, fine- to medium-grained volcanic sandstones, varying to coarse- and very coarse-grained. Beds are planar, laterally continuous on an outcrop scale (*c*. 20 m) and 0.5 to 8 cm thick, rarely increasing to 12 cm. They have sharp bases and are normal graded or planar laminated. Decimetre-scale ripple cross lamination with well-preserved stoss sides is common and sometimes affects up to 2 m of section. Slumped beds are also present and conspicuous, some associated with possible dewatering structures. Apart from the asterozoans, no other convincing traces of fossils have so far been seen in these rocks, and in the small collection available there is little evidence of bioturbation of the sediments.

These rocks represent a series of water-lain tuffs. The bed continuity, sharp (erosive?) bases, normal grading and abundant planar and ripple laminations suggest deposition from sediment gravity flows, probably turbidity currents that were proximal to source. The preservation of thick stoss side laminae in the prominent ripple bed forms indicates rapid sedimentation from suspension under relatively weak current flow. In Bouma terminology, the deposits are Ta, Tab, Tb, Tbc and Tc turbidites. An abundance of volcanic glass with angular blocky shapes and variable but typically low vesicularity indicate formation in explosive phreatomagmatic eruptions. The absence of non-juvenile clasts suggests that the explosions occurred at a high level, probably in the crater itself (White *et al*. 2003). Similar deposits dominate subaqueous tuff cone successions of

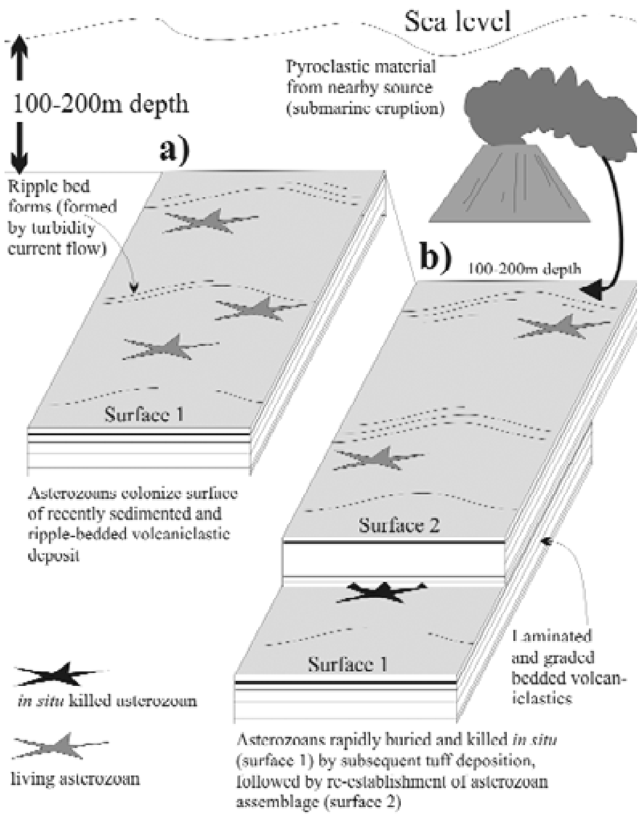

Fig. 4. Cartoon views of the taphonomic setting of the asterozoans in the JRIVG. **a.** Asterozoans moving over a ripple-bedded volcaniclastic sandstone surface, probably formed by turbidity flow during the preceding eruptive event. **b.** Asterozoans entombed by products of the next eruptive event. The coarse nature of the host sediment resulted in a poor representation of the architecture of the animal's exoskeleton (Fig. 5).

Surtseyan type (McPhie 1995, White 1996, Smellie 2001). They are genetically linked mainly to subaqueous jetting and continuous-uprush activity or to collapsing eruption columns (White *et al*. 2003). However, vertical density currents can also be generated from ash fall onto water by destabilization of the ash-loaded water column (Manville & Wilson 2004). The scarcity of tachylite and absence of accretionary or armoured lapilli suggest that the eruption columns lacked a substantial subaerial component, and that they therefore occurred in moderately deep water. Conversely, explosive eruptions would likely be suppressed at water depths of more than a few hundred metres. The fine grain size of the sediments and absence of evidence for wave erosion or wave-induced bed forms (e.g. hummocky cross-stratification) are also consistent with relatively quiet water and depths below wave base (i.e. below *c*. 60 m). Thus, we suggest that original water depths may have been 100–200 m. Similar, but coarser-grained (lapilli-dominated) and more crudely-bedded tephra deposits are better exposed *in situ*, forming the basal few tens of metres of Patalamon Mesa. These are intruded by a coeval columnar plug, which

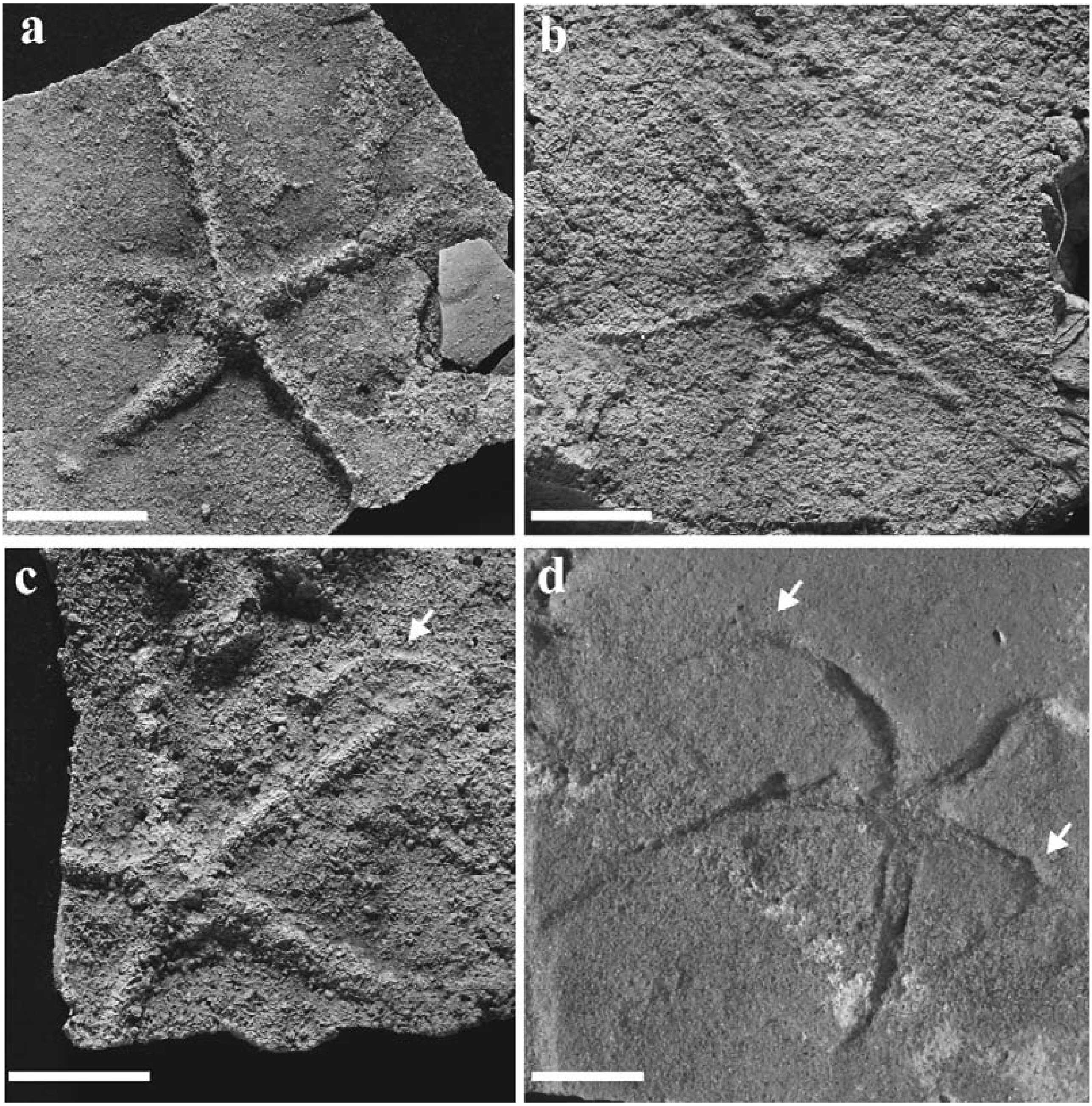

Fig. 5.a. Latex cast (showing dorsal surface?) of asterozoan fossil BAS D.3072.3. **b.** Silicon rubber cast of fossil BAS D.3073.1 (surface uncertain). **c.** Silicon rubber cast (surface uncertain) of fossil BAS D.3072.1. The distal tip of the arm at '2 o'clock' appears to have been detached, and lies slightly displaced to the 'north' (arrowed). The flexibility of this arm may suggest an ophiuroid. **d.** External mould, specimen BAS DJ.2092.6, showing possible current entrainment (from right to left in the image), probably within, or at the base of, a turbidity-current. The arms of this specimen are curved (arrowed), suggesting an ophiuroid affinity, though the curvature may simply be an effect of current entrainment. Scale bars are 1 cm.

provided the isotopic age for the sequence. These crudely-bedded tephra deposits are a more proximal equivalent to the asterozoan fossil beds. They probably formed part of the subaqueous tuff cone edifice itself, whereas the fossiliferous beds were probably deposited on the distal flanks. The presence of a nearby erupting centre provides an attractive explanation for the numerous interbedded slump deposits in the asterozoan-bearing deposits, which could have been triggered by seismic and percussive effects of violent phreatomagmatic explosions.

Asterozoan fossils

As traditionally defined, the Asterozoa includes starfish

(Asteroidea) and brittlestars (Ophiuroidea). Asteroids have a flattened flexible body and their arms are typically two to three times the diameter of the central area, with which they merge (Bell 2004, p. 55). Ophiuroids typically have a central disc and long slender arms with pinnate lateral spines (Bell 2004). The asterozoan skeleton consists of thousands of discrete ossicles linked in a dermal layer at the surface of the body. After death, most asterozoans suffer rapid destruction (see Blake 2000, Salamon & Zaton 2004, Twitchett *et al*. 2005), hence their sparse fossil record as complete specimens. Asterozoans are also known as trace fossils, typically preserved on the underside of sandstone beds (Bell 2004 and references therein) which cast excavations made in underlying mudstones.

There are two possible interpretations for the nature of the asterozoan fossils in the JRIVG (Fig. 5a–d): either the specimens represent trace fossils formed by excavation activity into the underlying sediment; or, the asterozoans represent external moulds of specimens rapidly buried by sediment. The specimens from the JRIVG show no evidence for repeated and overlapping burrowing, which is typical for trace fossils of shallow surface excavations made by asterozoans (Bell 2004 and references therein). None of the asterozoan specimens in the JRIVG are preserved as trace fossil casts on the undersides of sandstone beds, a typical mode of preservation for asterozoan trace fossils (e.g. Bell 2004). Indeed, the absence of mud-grade lithologies within the tuffs makes this mode of preservation unlikely. At least one asterozoan specimen suggests some limited entrainment by a turbidity current (Fig. 5d), which has repositioned the distal ends of three of its arms into the direction of current flow. A second specimen shows detachment of the distal tip of one of its arms, again perhaps as a result of current entrainment (Fig. 5c). As trace fossils are unlikely to show such structures, this suggests that the asterozoans are preserved as external moulds of specimens entrained and entombed very rapidly within water-lain volcanic tuffs (Figs 4 & 5a–d). Similar rapid burial processes are invoked to explain the preservation of complete asterozoans elsewhere (Blake 2000, Radwański 2002, Salamon & Zaton 2004). Nevertheless, because the tuffs are relatively coarse-grained, and because of the porous nature of the rock, the moulds of the specimens that are available to us preserve comparatively limited morphological information. Gross morphology and indications of ossicular form suggest class level affinities for the specimens, as well as specimen status at the time of final entombment (i.e. only one specimen seems partially disassociated, Fig. 5c).

The most complete specimens have a maximum diameter of about 4 cm, including the arms, which are generally intact. Casting of the fossils with silicon rubber has failed to provide information about the architecture of the skeleton. One of the specimens has flexed arms that might be considered more typical of an ophiuroid (Fig. 5d), though this might be a taphonomic effect, as this specimen appears to have been entrained by a turbidity current. The morphology of other specimens (Fig. 5a–c) is also ambiguous. That of Fig. 5a is suggestive of an asteroid, with cylindrical arms, and possible mid-arm keels for those two arms positioned at 5 and 11 o'clock. In contrast, those specimens of Fig. 5b & c are suggestive of ophiuroids, with narrow cylindrical arms and a central disc.

The presence of asterozoans in the JRIVG, and the sedimentology, supports the argument that the water-lain tuffs at Hidden Lake were deposited in a marine environment, though some ophiuroids can tolerate brackish water. The sedimentology of the tuffs suggests rapid deposition of material during eruptions, probably with periods of intermittent quiescence similar to other tuff cones (cf. Smellie 2001, White *et al*. 2003). This suggests that the asterozoans may have been opportunistic, invading an environment subject to periodic instability, which excluded many other benthic marine organisms: there is no evidence for other faunal activity in these sediments. Presumably the asterozoans colonized the seabed during periods of relative quiescence, but were entombed by subsequent ash depositional events (Fig. 4). Despite periodic catastrophes for these animals, the presence of asterozoans at several horizons suggests the persistence of the fauna in this area for some time.

Conclusions

Water-lain volcanic tuffs of the JRIVG at Hidden Lake, James Ross Island, represent a new source of fossil data from the Neogene rock sequence of the Antarctic Peninsula. The fossils reported here represent a rare Cenozoic occurrence of asterozoan animals (possible ophiuroids and asteroids). Although poorly preserved, their presence indicates that careful scrutiny of these volcaniclastic rocks might yield further fossil material, allowing the delineation of environmental effects on a wider range of Antarctic fossil organisms over a greater stratigraphical range, as well as identifying changes in community ecology through time.

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