

**NEW MIDDLE AND UPPER JURASSIC BELEMNITE ASSEMBLAGES FROM WEST ANTARCTICA (LATADY GROUP, ELLSWORTH LAND): TAXONOMY AND PALEOBIOGEOGRAPHY**

A. Brian Challinor and Dan C.H. Hikuroa

A. Brian Challinor. Department of Earth Sciences, University of Waikato, Private Bag 3105, Hamilton, New Zealand. [b.challinor@actrix.co.nz](mailto:b.challinor@actrix.co.nz)

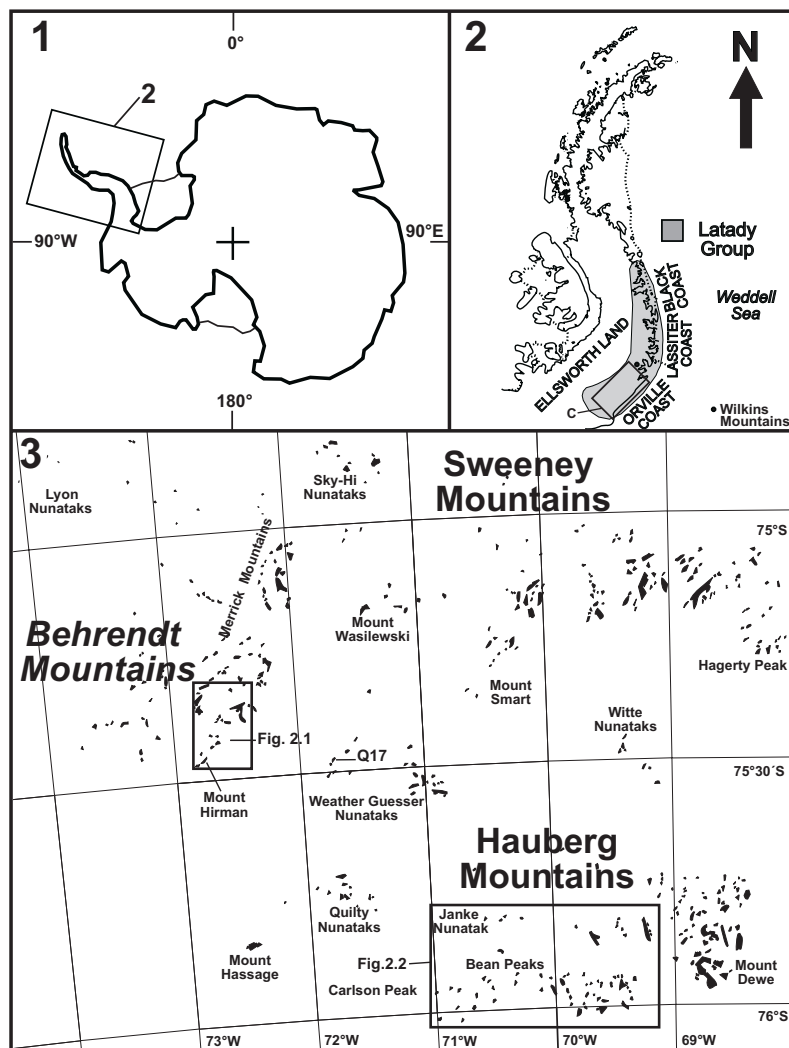
Dan C.H. Hikuroa. Department of Geology, University of Auckland, Private Bag 92019, Auckland, New Zealand (corresponding author). [d.hikuroa@auckland.ac.nz](mailto:d.hikuroa@auckland.ac.nz)

**ABSTRACT**

Six belemnite genera and up to 24 species (some informal) represented mainly by moulds are recorded from the Middle and Late Jurassic Latady Group, Ellsworth Land, West Antarctica. *Belemnopsis* and *Hibolithes* are moderately abundant, *Dicoelites*, *Duvalia*, *Produvalia*, *Pachyduvalia*, and *Rhopaloteuthis* are rare. The assemblages are best described as: a sparse aff. *Brevibelus-Hibolithes* fauna (Bajocian); a *Belemnopsis* fauna with rare *Hibolithes*, Duvaliidae and Dicoelitidae (late Bathonian-Oxfordian); and a more abundant fauna of *Belemnopsis* and *Hibolithes*, with less common Duvaliidae (Kimmeridgian-Tithonian). The Duvaliidae and short grooved *Hibolithes* likely migrated from Madagascar to Ellsworth Land via a trans-Gondwana seaway. Most *Hibolithes* are endemic to the region; they resemble and may be in part conspecific with the New Zealand *Hibolithes arkelli-H. marwicki* group (middle Tithonian). They appeared first in Ellsworth Land and migrated to New Zealand. The *Belemnopsis* are also endemic. One group resembles the New Zealand *Belemnopsis annae-B. stevensi-B. keari* group of the New Zealand Heterian Stage (Callovian to Kimmeridgian) and may have appeared first in Ellsworth Land. A second group of small robust *Belemnopsis* resembles broadly similar forms from the early Callovian and Kimmeridgian of New Zealand. The belemnite occurrences and time distributions suggest that faunal links between West Antarctica and New Zealand, and South America, West Antarctica and Madagascar, existed during the Middle and Late Jurassic.

**KEY WORDS:** Middle and Upper Jurassic; new belemnite assemblages; West Antarctica; taxonomy; paleobiogeography

---



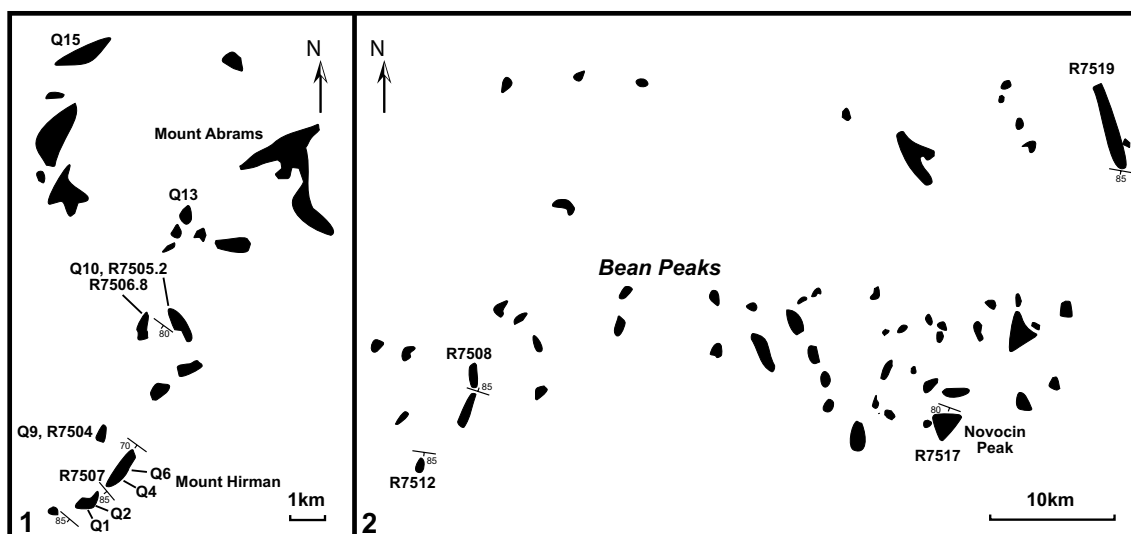
**Figure 1.** Locality maps of the Antarctic Peninsula, Ellsworth Land (1, 2), and the Behrendt, Hauberg, and Sweeney Mountains (3). Map in 3 show detailed outcrop map: shaded areas show all rock outcrops, not exclusively Latady Formation.

## INTRODUCTION

The Witte Nunataks and Hauberg Mountains Formations of Bajocian - Tithonian age comprise two of the five formations of the Latady Group (Hunter 2003; Cantrill and Hunter 2005; Willan and Hunter 2005), and are exposed in the Antarctic Peninsula. They contain faunas dominated by bivalves but also include ammonites, brachiopods, crinoids, polychaete worm tubes, gastropods, rare fish, crustaceans, and belemnites (Stevens 1967; Quilty 1970, 1972a, 1972b, 1978, 1983, 1988; Thomson 1980, 1983; Crame 1982, 1983; Mutterlose 1986; Kelly 1995; Eagle and Hikuroa 2003; Hikuroa 2005; Hikuroa and Kaim 2007). Recent fieldwork in Ellsworth Land and the Orville Coast

(Figure 1) by Hikuroa during the summer field season of 1999/2000 yielded a new collection of fossil material, of which the belemnites comprised a minor part.

The purpose of this paper is to describe the new belemnite material, compare it with previously studied specimens (particularly those of Mutterlose 1986), and consider its biostratigraphic and paleobiogeographic implications. In addition, latex casts of undescribed belemnites collected from the Orville Coast during the 1965-66 field season by Dr. P. Quilty, have been included in the present study. More than 100 specimens are recorded herein from 27 localities in the Behrendt and Hauberg Mountains (Figures 1, 2).



**Figure 2.** Collection sites of belemnite specimens described herein in the Behrendt (1) and Hauberg (2) Mountains, respectively. Those prefixed by Q are from Quilty (1978), and those prefixed by R are from Hikuroa's fieldwork.

## GEOLOGICAL SETTING

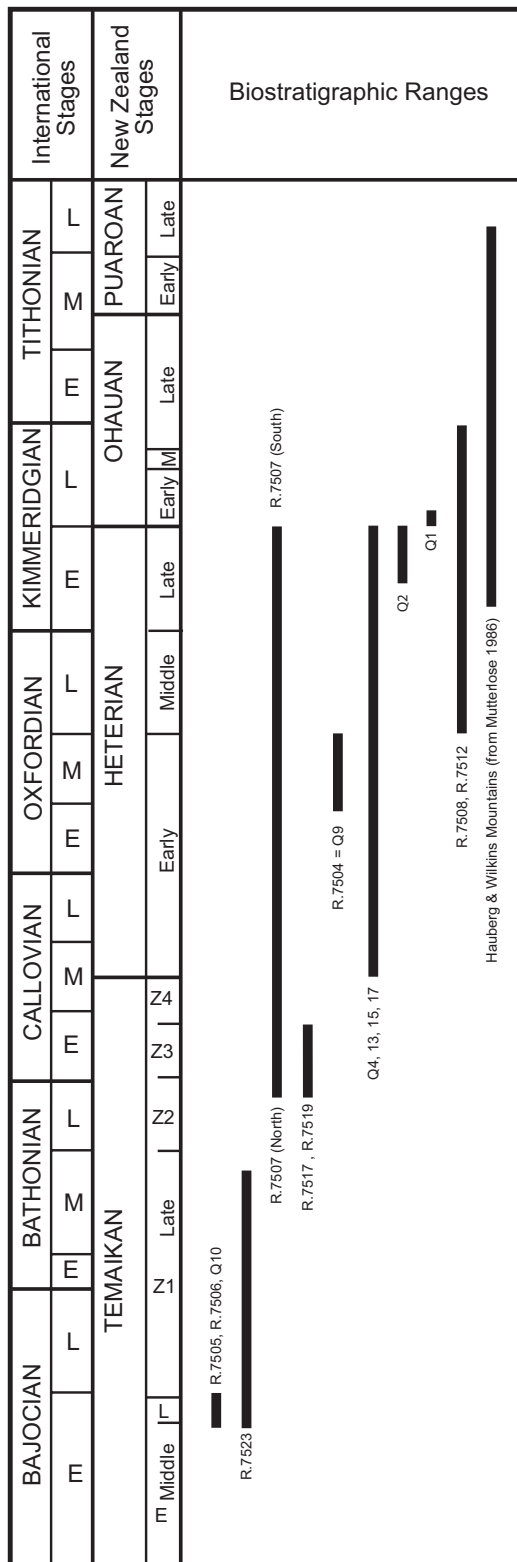
The Latady Group in the southern Antarctic Peninsula is a Jurassic sequence deposited initially in rift basins associated with the early stages of Gondwana breakup (Early and Middle Jurassic). Deposition continued in the Late Jurassic in a larger back-arc basin that formed either in response to subduction along the western margin of the peninsula or thermal relaxation (Willan and Hunter 2005). Rocks of the Latady Group crop out between eastern Ellsworth Land and the southern Black Coast (Figure 1). They comprise a thick (~2.8–6 km) sequence of minor terrestrial, shallow water, and fossiliferous marine sandstones and mudstones (Laudon et al. 1969; Williams et al. 1972; Dalziel and Elliot 1973; Suarez 1976; Quilty 1978; Smellie 1981; Rowley and Williams 1982; Laudon et al. 1983; Rowley et al. 1983; Vaughan and Storey 2000, Vaughan et al. 2002; Hikuroa 2005; Willan and Hunter 2005). Strata of the Witte Nunataks and Hauberg Mountains Formations (Latady Group), crop out in the Witte Nunataks, and the Hauberg Mountains, southern part of Mount Hirman, and Quilty Nunataks respectively (Willan and Hunter 2005, figures 2, 4, 5c,d and Figure 1c).

## MATERIALS AND METHODS

### Preservation of Specimens

Most belemnites studied here have been leached of calcite and, except for occasional calcareous fragments, are present as natural moulds

in dark shale, siltstone, and fine sandstone (Middle Jurassic localities – R.7505, R.7506, R.7507, R.7517, R.7519, Q4, 10, 13, 15, 17), or massive grey decalcified sandstone (Upper Jurassic – R.7504, R.7509, R.7512, Q9), and have been studied as latex casts. They vary from almost entire to small fragments, and range from poorly to moderately well preserved. Latex casts of belemnites do not contain all the necessary information on which to base identifications and descriptions. They rarely provide details of internal structures (apical line position, position of the protoconch, details of phragmocone, development of growth stages, changes in guard shape with ontogeny), and surface lines and grooves are often not well preserved. Many specimens present a view normal to bedding planes, and thus record only the details of one flank. In some instances only the gross form of the guard is preserved, often imperfectly, and for most “taxa” few specimens are available and little indication of specific variation can be obtained. The relationship between apical, stem, and alveolar diameters, one way of describing the cross section (a very valuable feature, reasonably consistent within species; Stevens 1965; Challinor 1979, 1996), is difficult to determine in many instances. Where possible, information on cross section has been obtained from undeformed specimens. Some moulds have clearly been deformed (flattened and/or distorted in other ways), most likely by sediment compaction, and cross section and other data either cannot be assessed.



**Figure 3.** The biostratigraphic ranges of outcrops studied in this project and those of Mutterlose (1986). International correlation based on Campbell (2004), zonation in Temaikān after Hudson (2003).

Belemnite species are identified with maximum confidence when the known taxon has been described from enough material to recognise most or all of the variation present (including ontogenetic variation), and the unknown material consists of several specimens, preferably complete guards. These constraints have not been met during this work. However, belemnites are uncommon and generally poorly preserved in Latady Group rocks, and the localities are remote and are unlikely to be re-visited in the near to medium-term future. Therefore, we believe description of the material at hand to be justified.

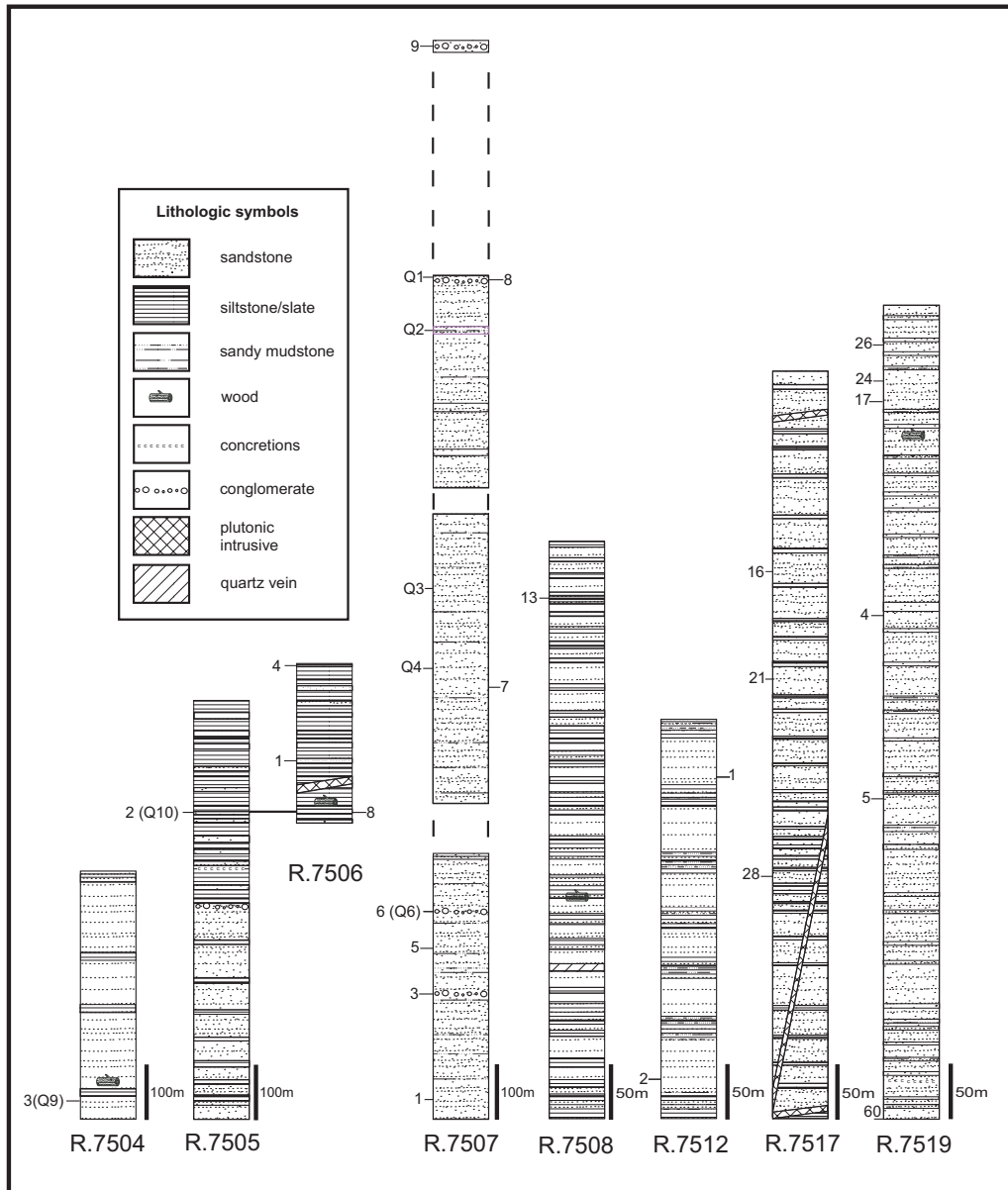
Many specimens are preserved in such a way as to provide few firm-specific identifications, although general appearance allows comparison with known taxa in several instances. Generic placements are thought to be more reliable, although in most specimens some diagnostic criteria are equivocal or missing. Important taxonomic and paleobiogeographic interpretations are based on small numbers of specimens, and/or on poorly preserved material. Given the nature of the record this is unavoidable.

**Material**

Collection locality numbers form two groups. Those prefixed by R (e.g., R.7507.9.4a) are from collections by Hikuroa: R = Rothera Station (base from which work was carried out), 7507 = unique outcrop, 9 = unique horizon within outcrop, 4 = individual fossil sample; where several fossil specimens occur on the same rock sample they are labelled a, b, c, etc. The specimens are deposited at the British Antarctic Survey, Cambridge, UK. Those localities prefixed by Q are collections by Quilty (e.g., Q10 = Quilty Locality 10), and individual specimens from those localities (e.g., UTGD (prefix omitted in text) 87347a) are held in the Geology Department, University of Tasmania, Australia. Collection localities are indicated in Figures 1, 2, and stratigraphic positions of those localities are shown in Figures 3, 4.

**Taxonomy**

Brief descriptions that compare or recognise affinities with known taxa, or under open nomenclature, follow. A list of belemnites of uncertain affinity can be found in the Appendix. The morphology of the belemnite guard and the terminology used to describe it are detailed in Stevens (1965), and that approach is followed here. The meaning of any undefined terms should be self evident, although one needs elaboration. A “mucro” is the

**Figure 4.**

Composite lithostratigraphic columns showing stratigraphic positions of belemnite collection localities (after Hikuroa

terminal, constricted, and drawn out immediate apex (Stevens 1965). A mucro is seen, or inferred to be present, in several specimens described. Its basal part is sometimes present, but its tapering, extended, terminal part is usually replaced by an apical pit. This probably results from failure of the casting medium to penetrate fully into the narrow tapering cavity left by the mucro, the resulting air bubble producing the apical pit.

### Generic Concepts

The generic concepts used in this study are not necessarily identical with those of other workers. Those of *Belemnopsis* and *Hibolithes* have been developed largely from a study of south-western Pacific forms and may be most relevant to them. Only features that have the potential for preservation in casts are discussed. The classification follows Doyle et al. (1994) and is to be the basis of the Coleoidea volume of the *Treatise*.

## SYSTEMATIC PALEONTOLOGY

Order BELEMNITIDA Zittel, 1895

Suborder BELEMNITINA Zittel, 1895

Family PASSALOTEUTHIDIDAE Naef, 1922

Subfamily MEGATEUTHIDINAE Sachs and Naik-  
jaeva, 1967

Genus BREVIBELUS Doyle, 1992 (= *Brachybelus*)

**Type species.**— *Belemnites breviformis* Voltz, 1830. Toarcian-Aalenian.

**Diagnosis.** Guard small, short, and robust. Outline symmetrical and conical to cylindroconical, profile nearly symmetrical, otherwise similar to outline. Apex obtuse to moderately acute, often mucronate. Venter inflated in some species. Transverse sections quadrate, compressed in some species, depressed in others. Apex devoid of grooves or striae. Lateral lines may be well developed, consisting of two weak parallel depressions separated by a well-developed ridge. The phragmocone is ventrally displaced, penetrating about one half of guard. Apical angle c.27° (from Doyle 1992).

aff. *Brevibelus* sp.  
(Figure 5.1-5.4)

**Material.** Three partial latex casts, UTGD87331c, 87320c, 87335b, Locality Q10. Most data is from 87331c, details of apical region from 87320c and 87335b.

**Description.** Guard small, conical, short, robust, laterally compressed, length c. 3 times maximum diameter. Largest specimen (Figure 5.1) 42 mm long, with an estimated 10 mm of the apical region missing. It forms the basis of most of this description. Other specimens are short apical fragments. Widest point on guard anteriorly placed; maximum dorsoventral diameter 14.3 mm, lateral diameter 11.5 mm. Outline symmetrical, weakly conical, widest point at anterior, sides taper regularly towards the apex, more rapidly over terminal 10 mm. Profile asymmetric, more conical than outline. Dorsal surface inflated near mid-guard, apical half of the guard curves more rapidly towards apex. Ventral surface almost straight, not inflated. Cross sections compressed throughout length of guard. Dorsal and ventral surfaces rounded, lateral surfaces more flattened. Lateral lines present near the midline of the guard, preserved as a single wide depression parallel to the ventral surface; visible in the alveolar region, missing over c. 12 mm at mid-guard, then continues towards the apex. Missing section is possibly an artefact of the casting process, or a result of damage to the mould. Alveolus

laterally compressed and deep, penetrating the guard for an estimated 25–30 mm.

**Discussion.** The specimens are broadly similar to Bathonian specimens from New Caledonia illustrated as Belemnitidae (= Passaloteuthididae) gen. et. sp. nov (Challinor and Grant-Mackie 1989) and to New Zealand *Brevibelus* (Toarcian) currently under study.

**Range.** Latest early Bajocian (detailed discussion on inferred age follows taxonomy section).

Suborder BELEMNOPSEINA Jeletzky, 1965

Family BELEMNOPSEIDAE Naef, 1922

Genus BELEMNOPSIS Bayle, 1878

**Type species.**— *Belemnites bessinus* d'Orbigny, 1842. Bathonian.

**Remarks.** Riegraf (1999) argues that the genus *Belemnopsis* Bayle 1878 is invalid on forensic grounds, and that the name should be replaced. The argument for replacement is not accepted here.

**Diagnosis.** Guard moderately elongate and robust, to short and very robust, c. 100 mm long and c. 12-15 mm in maximum diameter; larger and smaller forms known. Cross section at mid-guard and apical region usually depressed, equi-dimensional to compressed anteriorly. Median ventral groove strongly developed, usually extends nearly to the apex, shorter in some taxa. Alveolus short in relation to guard length. Double lateral lines are present, often poorly developed, but more prominent in pre-adult forms. Developmental sequence includes a slender, sometimes strongly hastate, juvenile to early immature guard (our concept).

*Belemnopsis* cf. *B. stevensi* Challinor, 1974  
(Figure 5.7-5.10)

cf. 1965 *Belemnopsis alfurica* Stevens, pl. 5, figures 10-12 only.

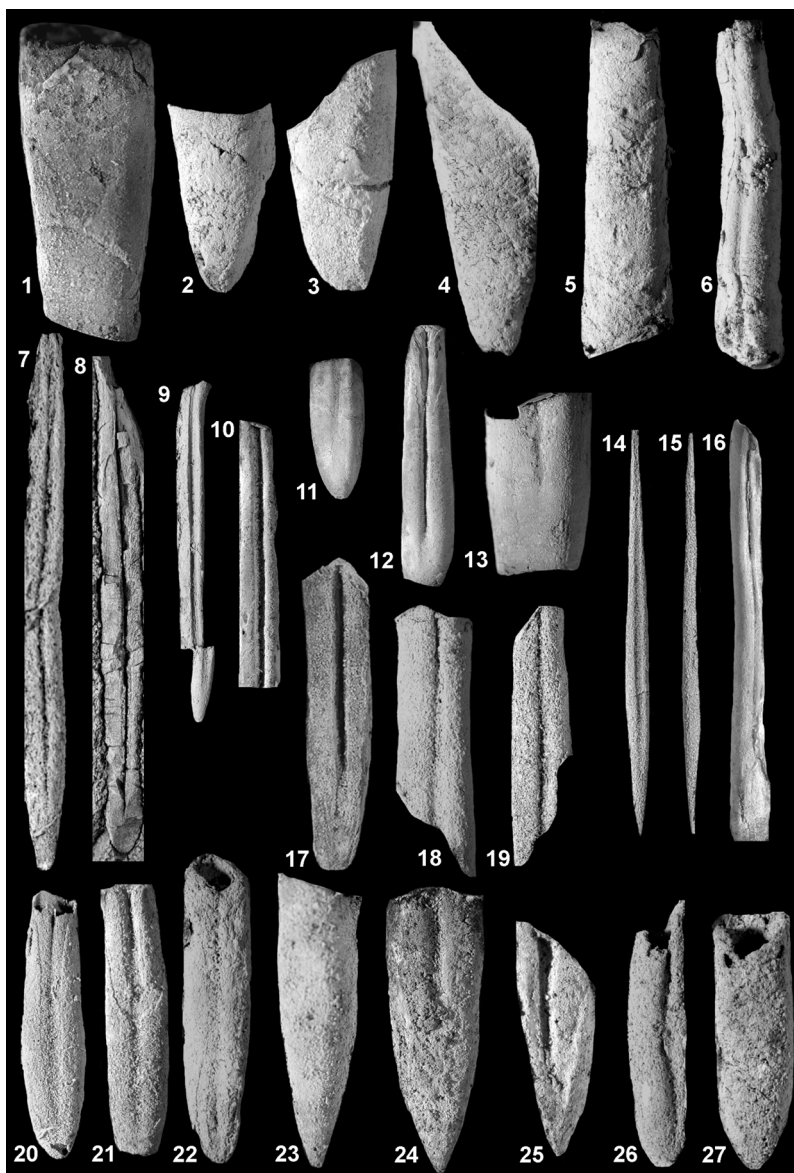
cf. 1965 *Belemnopsis keari* Stevens, pl. 3, figures 7-9; pl. 4, figures 1-3 only.

cf. 1974 *Belemnopsis stevensi* Challinor, figures 8-13.

cf. 1979 *Belemnopsis maccrowi* Challinor, figures 22-42.

cf. 2003 *Belemnopsis stevensi* Challinor p. 87, figures 6-20, p. 88, figures 21-36.

**Material.** Three latex casts and a damaged calcareous specimen. R.7517.16.1 (cast, Figure 5.7), a complete immature guard, ventral surface exposed; R.7517.21.2 (Figure 5.8), a damaged



**Figure 5.1-27.** All specimens are latex casts (except for R.7517.21.2, Figure 5.8, which is a calcareous specimen), coated with ammonium chloride sublimate. Specimens are figured with dorsal or ventral surface facing the camera, and in left or right lateral view (ventral surface facing left or right), and in apical or cross sectional view. The scale for each is stated in the caption. **1-4, aff. *Brevibelus* sp.**, 1, UTGD87331c (locality Q10). Lateral (?left) view, x 1.7. **2, 3**, UTGD87320c. **2**, ventral view, x 2. **3**, lateral (?left) view, x 2. Immediate apex displaced along transverse fracture. **4**, UTGD87335b. Lateral (?right) view, x 1.9. **5-6, *Belemnopsis* (or *Hibolithes*) sp.**, R.7517.28.1. Right lateral and ventral views, x 1, slightly distorted. **7-10, *Belemnopsis* cf. *B. stevensi***, **7**, R.7517.16.1, ventral view of pre-adult, x 1.7. **8**, R.7517.21.2, ventral view of abraded, partly concealed, calcareous, pre-adult (possibly with anterior end uppermost), x 1.3. **9**, R.7504.3.8a, ventral view of pre-adult, x 1.2. **10**, R.7519.5.20, ventral view of pre-adult, x 1.2. **11, *Belemnopsis* sp. A**, UTGD87353c (Q13), view of apical fragment (note very wide, shallow ventral groove), x 1. **12-13, *Belemnopsis* sp. B**, **12**, R.7504.3.146, ventral view of pre-adult, x 1. **13**, UTGD87162b(Q2), adult, (note sudden termination of ventral groove near mid-guard), x 1. **14-15, *Belemnopsis* sp. C**, R.7519.4.3a, b, ventral and ?lateral view of two juvenile specimens, x 2.3. **16, *Belemnopsis* sp. D**, UTGD87356a (Q13), approximately ventral view of crushed specimen, x 1. **17-19, *Belemnopsis* sp. E**, **17**, R.7507.5.1, ventral view, x 1.5. **18**, R.7507.5.2, ventral view, x 1.5. **19**, R.7507.9.9, ventral view, x 1.8. **20-22, *Belemnopsis* sp. F**, **20**, UTGD87058c (Q17), ventral view, x 2. **21**, R.7507.5.8, ventral view, x 2.3. **22**, R.7507.5.7b, ventral view, x 2.3. **23-25, *Belemnopsis* sp. G**, **23, 24**, R.7507.3.6a, left lateral and ventral views, x 2. **25**, R.7507.3.6b, left ventro-lateral view, x 2. **26-27, *Belemnopsis* sp. H**, **26**, R.7507.9.4b, right ventro-lateral view, x 2.5. **27**, R.7507.9.4c, right lateral view, x 2.5.



immature calcareous specimen; R.7504.3.9 (cast, Figure 5.9), a juvenile almost complete guard with anterior region missing; R.7519.5.20, (cast, Figure 5.10), a stem fragment of an immature guard (apical region missing, one flank and ventral surface exposed).

**Description.** Guard elongate, slender to moderately slender. Outline hastate, widest point near mid-guard. Apical region moderately elongate, apex central. Flanks converge anteriorly to produce moderate hastation; anterior flanks usually slightly curved, sometimes straight but converging. Profile similar to outline but apparently less hastate. Cross section uncertain but probably equidimensional or depressed. Ventral groove extends almost to apex, moderately wide and deep, very wide and deep in Figure 5.10.

**Discussion.** Heterian *Belemnopsis* appear near the base of the stage and extend to the top. *Belemnopsis annae*, *B. stevensi* and *B. keari* appear in succession and are stratigraphically separated, except for a short concurrent range zone of *B. stevensi* and *B. keari* in the latest Heterian (Challinor 1979, figure 2). Adults of all three can be recognised by differences in size, hastation, or apical line position. Juvenile and adolescent guards are difficult to differentiate (cf. Challinor 1979, figures 14, 29, 50). All three Heterian taxa were originally included in *Belemnopsis keari* (Stevens 1965). Later work based on new collections and statistical data demonstrated that three different taxa were present (Challinor 1979). The three taxa are collectively referred to later in this paper as the *B. stevensi* group.

Based on their small size and shape we interpret the Latady Group *Belemnopsis* cf. *B. stevensi* as immature specimens. The figured specimens (Figure 5.7-5.10) closely resemble the Heterian juvenile and adolescent specimens cited above (note scale of all figured specimens). R.7517.21.2 (Figure 5.8) is a damaged calcareous specimen partly enclosed in matrix (and possibly figured with the apical end uppermost). R.7504.3.9 and R.7519.5.20 (Figures 5.9 and 5.10, respectively) are very strongly grooved. The latter resembles a particularly strongly grooved Heterian specimen (cf. Challinor 2003, figures 24, 25).

Mutterlose (1986) described *Belemnopsis* aff. *keari* from his locality 8 (Bean Peaks Orville Coast) c. 15 km northeast of R.7508. The adult specimen (Mutterlose 1986, figures 6a, b) strongly resembles some adult specimens of *B. stevensi* in size, outline and profile (cf. Challinor 2003, figures 10, 11,

13, 14, 18), but to judge from figure 6a, b, is more depressed in cross section than most (although apparently within the range of variation). The other specimen (figure 6c, d) is a fragment of a juvenile. Mutterlose (1986) considered *B. aff. keari* to be Kimmeridgian in age; the approximate stratigraphic position of his specimens is indicated in Figure 7 by M3. *Belemnopsis* aff. *stevensi* appears slightly earlier in Ellsworth Land than does the *B. stevensi* group in New Zealand.

**Range.** Early Callovian – middle Kimmeridgian.

*Belemnopsis* sp. A  
(Figure 5.11)

**Material.** One latex cast (UTGD87353c, Locality Q13), of the apical region of an adult guard.

**Description.** Fragment 34 mm long; flanks, dorsal, and ventral surfaces curve smoothly towards the centrally placed apex, more rapidly over the terminal 10 mm. Apical region moderately obtuse. Diameters 12.5 mm lateral, 12 mm sagittal; cross section depressed near anterior end. Ventral groove very wide and shallow, terminating almost at the apex.

**Discussion.** The fragment is similar in outline and groove termination position to many New Zealand and Indonesian Upper Jurassic *Belemnopsis*, although its wide shallow posterior groove is atypical. Groove morphology is similar to those of *Belemnopsis gladiatoris* and *B. alexandri*, Berriasian taxa described from Alexander Island, West Antarctica, by Willey (1973).

**Range.** Middle Callovian – early Kimmeridgian.

*Belemnopsis* sp. B  
(Figure 5.12-5.13)

**Material.** Two latex casts, UTGD87162b, locality Q2, is a fragment, apparently of the posterior stem and anterior apical region. R.7504.3.146 is the anterior half of a pre-adult guard, possibly including part of the alveolar region.

**Description.** R.7504.3.146 (Figure 5.12) c. 50 mm long, transversely hastate (posterior diameter c. 9 mm, anterior diameter c. 7.5 mm), slightly sagittally hastate, and cross section is depressed. Ventral groove moderately wide and deep, terminates suddenly, apparently about halfway down the guard. UTGD87162b (Figure 5.13) c. 33 mm long, c. 17 mm in transverse diameter, 16 mm sagittal, cross section depressed. Ventral groove wide, moderately deep, terminates suddenly at mid-fragment.



**Discussion.** Assuming the two specimens are conspecific, R.7504.3.146 is a pre-adult guard. The ventral groove in some specimens of *Belemnopsis sikilyensis* (Middle Oxfordian, Madagascar, Combémoré 1988) terminates in a similar manner to that of these specimens.

**Range.** Latest early Oxfordian – early Kimmeridgian.

*Belemnopsis* sp. C  
(Figure 5.14-5.15)

**Material.** Four latex casts (R.7507.7.19, R.7519.4.a, b, R.7519.26.4) of complete specimens. All are juvenile guards. Description based mostly on R.7519.4.3a which lies on a bedding plane with a ventrolateral surface uppermost. Most of the ventral surface and part of one flank is visible.

**Description.** Very small, slender, hastate, (?early juvenile) guard, 32 mm long and c. 2 mm maximum diameter. Widest point 12–14 mm from the apex. Ventral and lateral surfaces converge to produce an elongate, gently tapering apical region. Guard converges anteriorly to produce a long, very attenuate stem and alveolar region. A long, relatively prominent *Belemnopsis*-like ventral groove extends to within 4–5 mm of the apex.

**Discussion.** Other Latady Group specimens are similar; it is possible that all *Belemnopsis* sp. C may be juveniles of other elongate *Belemnopsis* described. Other similar sized *Belemnopsis* and *Hibolithes* are also present at locality R.7519.

**Range.** Latest Bathonian – early Kimmeridgian.

*Belemnopsis* sp. D  
(Figure 5.16)

**Material.** Two relatively poor latex casts (UTGD87356a, 87357c, Locality Q13). Both are fragments of apparently pre-adult specimens, including the alveolar region (crushed in 87356a), but the apex is missing. Part of the ventral surface, one flank, and part of the dorsal surface of each are visible.

**Description.** Guard slender, elongate, either parallel-sided or slightly hastate, c. 80 mm long, and 7–9 mm in maximum diameter. A narrow, relatively deep ventral groove extends for most of the length of both. Cross-sectional shape is uncertain, but appears to be either laterally compressed or equidimensional. No details of apical region are known, no lateral lines are visible.

**Discussion.** Both specimens are similar in some features to *Belemnopsis mackayi* (Toarcian, New Zealand). Both that taxon and these specimens are slender, elongate, and narrow grooved. However *B. mackayi* is poorly known, and comparisons are made more difficult by the pre-adult state of these specimens, their limited number and incomplete condition. The specimens are much younger than *B. mackayi*.

**Range.** Middle Callovian – early Kimmeridgian.

*Belemnopsis* sp. E  
(Figure 5.17-5.19)

**Material.** Four latex casts (R.7507.5.1, R.7507.5.2, R.7507.9.9, R.7507.9.16), all anterior fragments.

**Description.** Outline slightly hastate and less so in profile. Largest specimen (R.7507.5.2), 35 mm long, 9 mm in transverse diameter posteriorly, 8.5 mm near anterior end. Flanks diverge slightly anteriorly from the point of minimum diameter, suggesting the alveolar region is present but alveolar cavity not preserved. Cross section slightly depressed throughout. Ventral groove moderately wide and deep, extends full length of the fragment, widening but not shallowing posteriorly.

**Remarks.** Specimen R.7507.5.1 is similar in size to R.7507.5.2; R.7507.9.9 and R.7507.9.16 are smaller, but all are similar in form.

**Range.** Early Callovian – late Kimmeridgian.

*Belemnopsis* sp. F  
(Figure 5.20-5.22)

**Material.** Five latex casts (R.7504.3.24, R.7507.5.7b, R.7507.5.8, R.7512.2.3; UTGD87058c, (Q17)).

**Description.** Guard is small, short, robust, typically < 30 mm long, 4–5 times maximum diameter. Outline symmetrical and hastate. Maximum diameter located near mid-guard, usually just posteriorly placed, apical region short and obtuse. Guard tapers anteriorly to produce moderate transverse hastation. Profile hastate, less so than outline, cross section strongly depressed. Ventral groove wide and shallow, and terminates close to apex. Lateral lines are not evident.

**Discussion.** The variation in profile suggests that features derived from more than one taxon may be included in this description. This possibility cannot be further studied with the available material. Specimen R.7507.5.7b (Figure 5.22) differs in profile from the other specimens; its ventral surface is almost flat, dorsal surface at first diverges rapidly

from the apex without curving markedly, then diverges more gradually anteriorly, producing an unusual, wedge-shaped apical profile.

**Range.** Early Callovian – late Kimmeridgian

*Belemnopsis* sp. G  
(Figure 5.23-5.25)

**Material.** 3 latex casts (R.7507.3.6a, b, c), all of apical fragments, 1 poorly preserved. The best preserved is R.7507.3.6a.

**Description.** Longest specimen c. 27 mm long, flanks and dorsal surface converge regularly to produce an elongate apical region with a sharply pointed, dorsally placed apex. Ventral surface more inflated than dorsal surface, converges towards apex earlier than dorsal. Ventral groove moderately wide and deep, terminates close to apex. Cross section at anterior strongly depressed, c. 9.3 mm wide and c. 7.5 mm high.

**Discussion.** It is possible that *Belemnopsis* sp. E and *B.* sp. G are fragmentary specimens of the same taxon. All were found at the same outcrop, although at different horizons. They are all of comparable diameter and have similar ventral grooves. However, the strongly depressed apical regions (sp. G), contrasts with the weakly depressed anterior fragments (sp. E). Guards of *Belemnopsis* are often depressed posteriorly and less depressed anteriorly, but if *Belemnopsis* sp. E and sp. G are conspecific, the difference in cross sectional shape is unusually large. They may conform, particularly *B.* sp. G, to the “European-type *Belemnopsis*” concept of Doyle et al. (1996).

**Range.** Latest Bathonian – early Callovian.

*Belemnopsis* sp. H  
(Figure 5.26-5.27)

**Material.** Two latex casts (R.7507.9.4 b, c), both of apparently almost complete specimens.

**Description.** Guard is short and robust, length about three times maximum diameter. Observed length c. 20 mm, maximum diameter c. 7 mm. Outline slightly hastate, widest point near mid-guard, flanks converge slightly anteriorly. Profile non hastate, dorsal and ventral surfaces subparallel for most of guard length. Apical region short and blunt. Ventral groove strongly developed, relatively wide and deep, extending from alveolar break almost to apex. Cross sections compressed. Alveolus deep, estimated depth one third of guard length.

**Discussion.** The specimens are similar in gross proportions to *Belemnopsis* sp. F, but differ from

that taxon in their compressed cross section and strong ventral groove.

**Range.** Late Kimmeridgian.

*Belemnopsis* (or *Hibolithes*) sp.  
(Figure 5.5-5.6)

**Material.** One cast of the anterior parts of an adult specimen (R.7517.28).

**Description.** Moderately to strongly hastate in outline and profile; dorsal and ventral surfaces and flanks converge steadily towards anterior. Cross section strongly compressed throughout; posterior c. 12.5 x 16 mm; anterior c. 9.5 x 12.5 mm. Moderately narrow, shallow ventral groove extends full length of fragment, weaker at anterior end (the reverse is usually true of *Belemnopsis* and *Hibolithes* – the anterior weakening, and the shallow nature of the groove may be a preservation effect or an artifact of casting). No details of alveolus and apical regions are preserved.

**Discussion.** We are uncertain if this specimen should be placed in *Belemnopsis* or *Hibolithes*. It appears too large and too strongly grooved for *Hibolithes*, and too weakly grooved for *Belemnopsis*. It shares the generally compressed cross section of *Belemnopsis mackayi* Stevens and *B. deborahae* Challinor (Toarcian, New Zealand), although the guard is more hastate and the groove is shallower than is usual in both. *B. compressa* Avias (Bathonian – Callovian, New Caledonia) is similar in cross section and hastation, but the groove is much stronger. The wide, very shallow dorsal alveolar groove that occurs in some specimens of the three taxa compared is not present in our specimen. Given the nature of the groove in those taxa, it would not necessarily be visible in latex casts.

**Range.** Latest Bathonian – early Callovian.

*Belemnopsis* spp.

**Material.** A number of latex casts, all anterior fragments, possibly of several different taxa. The material is inadequate, and they are not described but listed here to complete the record. Specimen UTGD87357a, 87349a, locality Q13; UTGD87367a, 87366c, 87362a, Q9; UTGD87199, 87218a, 87261b, Q4.

Genus HIBOLITHES Montfort, 1808.

**Type species.** - *Belemnites hastatus* de Blainville, 1827. Upper Callovian – Tithonian.

**Diagnosis.** Guard moderately elongate, moderately robust, usually moderately to strongly

hastate, sometimes strongly club-shaped. Widest/deepest part usually in posterior half, sometimes close to the apex. Cross sections depressed, equidimensional, or compressed. Median ventral groove narrow, shallow, occasionally more strongly developed; commences at the alveolar break, sometimes restricted to alveolar and anterior stem regions, sometimes extends to about mid-guard, occasionally into the apical region. Alveolus short compared with guard length. Double lateral lines usually well defined, particularly in the apical half of the guard, less so anteriorly. Juvenile and early immature guard slender, elongate, and strongly hastate (our concept).

*Hibolithes catlinensis* (Hector, 1878)  
(Figure 6.1-6.5)

1965 *Hibolithes catlinensis*, Stevens, p.261, pl.14, figures 1, 2, 6-8, 12, 16-18, text figure 26a, and synonymy therein.

**Material.** Latex casts of eight specimens. Descriptions based mostly on four specimens; UTGD87277a (Q10), (Figure 6.3), an almost complete near adult specimen; UTGD87277b (Q10), (Figure 6.4-6.5), a partly exfoliated adult stem fragment; R.7506.4.1 (Figure 6.1-6.2); anterior half of an adult guard; R.7505.2.106, a pre-adult fragment. Remaining four fragments: R.7505.2.42, 107, 109; R.7506.1.3.

**Description.** The most complete specimen (Figure 6.3) c.110 mm long and c. 12 mm in maximum (dorsoventral) diameter. Most of one flank and dorsal and ventral surfaces of the apical 50 mm of the specimen visible, anterior dorsal and ventral surfaces partly concealed, one flank is completely concealed. Outline symmetrical and strongly hastate. Widest point on guard is c. 20–25 mm from apex. Visible flank converges regularly towards guard midline producing a long very attenuate anterior stem and alveolar region. Profile slightly asymmetric; one surface (? dorsal), slightly inflated near the widest/deepest part of guard. Dorsal and ventral surfaces converge regularly anteriorly to produce strong sagittal hastation. Dorsal and ventral surfaces, and flanks converge regularly towards the partly concealed apex. Cross sections compressed. Dorsal and ventral surfaces and flanks regularly rounded in the apical third of the guard, dorsal and ventral surfaces more acutely rounded than flanks. No details of alveolus, ventral groove, or lateral lines preserved. Figure 6.4-6.5 is a hastate stem fragment c. 25 mm long and c. 9 mm in maximum (dorsoventral) diameter. It is

partly exfoliated, laterally compressed throughout, and a narrow shallow groove extends along its ventral surface. Weak lateral lines are preserved on one flank. Shape and size suggests it is a fragment of the mid or anterior stem regions of an adult.

Figure 6.1-6.2 is the anterior stem region of a large guard, c. 50 mm long, and strongly hastate in outline and profile. Cross section compressed throughout (c. 11.7 mm wide, c. 12.6 mm deep posteriorly, c. 7.2 mm wide, and 8.5 mm deep anteriorly. Compression and hastation both accentuated by exfoliation of anterior surfaces; the remains of an early growth stage project from the exfoliated anterior. A short, partly exfoliated, moderately wide ventral groove extends down the fragment for 20–30 mm. What appears to be the protoconch is preserved at the anterior end.

Specimen R.7505.2.106 is a slender pre-adult guard 75 mm long; part of the apical and anterior regions missing. Part of dorsal and the dorsolateral surfaces of one flank visible, the ventral surface is concealed. No ventral groove visible but lateral lines are evident over much of the visible flank.

**Discussion.** UTGD87277a (Figure 6.3) is a guard less mature than specimens of *Hibolithes catlinensis* figured by Stevens (1965) as plate 14, figure 1-2, 6-8, and more mature than figure 16-18. New specimens currently being studied from southwest Auckland and southeast Otago, New Zealand, are similar in size and morphology. The only apparent difference (and this may be a result of the few specimens available, and of their preservation) is that the ventral groove in Figure 6.1 is shorter than in most adult *H. catlinensis*. *Hibolithes catlinensis* is a long ranging taxon in New Zealand (early Bajocian to late Bathonian, middle and late Temaikan) and is now known to also be present in the Temaikan of New Caledonia (new unpublished data).

**Range.** Latest early Bajocian.

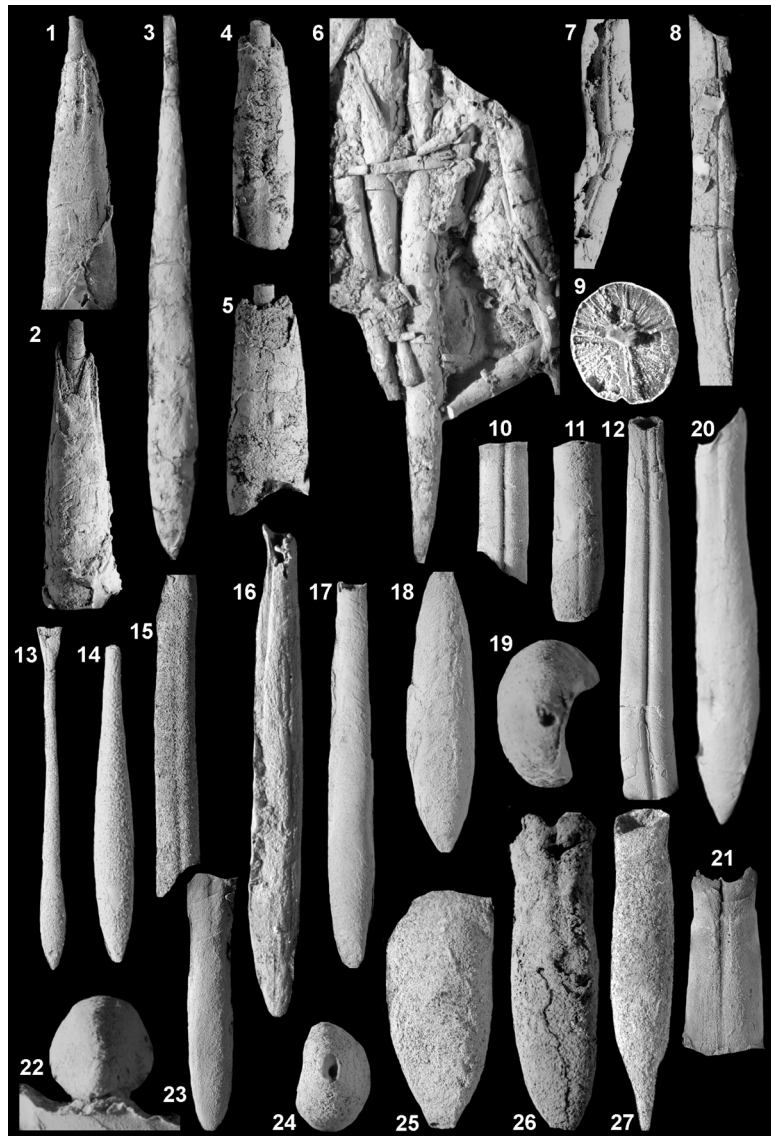
*Hibolithes* cf. *H. marwicki* Stevens, 1965  
(Figure 6.6-6.9)

cf. 1965 *Hibolithes marwicki marwicki* Stevens pl. 18, figures 1-9, 11-17; pl. 19, figures 1-9, 13-18.

cf. 1986 *Hibolithes* aff. *marwicki marwicki* Mutterlose figure 4a, b.

cf. 1999 *Hibolithes marwicki* Stevens, Challinor figures 45-70.

**Material.** Two latex slabs, (R.7508.13.9 and R.7508.13.II (Figure 6.6), with fragments of at least 20 partial specimens, most broken and distorted,



**Figure 6.1-27.** All specimens are latex casts and coated with ammonium chloride. Specimens are figured with dorsal or ventral surface facing the camera, and in left or right lateral view (ventral surface facing left or right), and in apical or cross sectional view. The scale for each is stated in the caption. **1-5, *Hibolithes catlinensis* (Hector)**, **1, 2**, R.7506.4.1, ventral and right lateral views (anterior of specimen exfoliated), **x 1**. **3**, UTGD87277a (Q10), left lateral view, **x 1**. **4, 5**, UTGD87277b (Q10), ventral and left lateral views (eroded ventral groove (**4**), and lateral line depressions (**5**), visible.), **x 1.8**. **6-9, *Hibolithes* cf. *H. marwicki***, **6**, R.7508.13.11, slab with several specimens, partially current aligned, and most viewed laterally, **x 1**. **7**, R.7508.13.11a, view of ventral groove of rightmost specimen (in **6**) **x 2**. **8**, R.7508.13.9, ventral view illustrating ventral groove, **x 2**. **9**, R.7508.13.11b, natural cross section on edge of slab (not visible in **6**), **x 2.5**. **10-12, *Dicoelites* sp. A**, **10, 11**, R.7519.24.51, ventral and dorsal views, **x 2.7**. **12**, R.7519.17.11, ventral view, **x 1.7**. **11-14, *Hibolithes* sp. A**, **13**, R.7519.60.30a, **x 2.1**, **14**, R.7519.60.30b, **x 4.3**. Lateral (?left) views. **15, *Hibolithes* sp. B**, R.7507.9.19. Ventral view, **x 1**. **16-17, *Hibolithes* sp. C**, **16**, R.7504.3.87. Left lateral (approximately) view of crushed specimen, **x 1**; ventral groove visible towards top at left, and eroded, diverging lateral lines towards right over mid and apical regions. **17**, R.7504.3.15. Left lateral view of slightly crushed specimen, **x 1**. **18-19, *Duvalia* aff. *rhopaliformis***, UTGD87397 (Q13). **18**, left lateral view, **x 1.3**. Ventral asymmetry at mid-guard is a casting artifact. **19**, apical view, **x 3**. **20-21, *Hibolithes* aff. *arkelli***, **20**, UTGD 87221d (Q2). Ventral view (**x 1**), with ventral groove weakly visible at top. **21**, UTGD87221a (Q2). Ventral view of alveolar and ?anterior stem region **x 1**; slightly exfoliated anteriorly. **22-23, *Rhopaloteuthis* sp.**, R.7507.1.2. **22**, apical view, **x 3**; **23**, dorsal view **x 1.2**. **24-25, *Duvalia* sp.**, R.7507.9.13. **24**, apical view, **x 1.1**. **25**, lateral (?left) view, **x 1.1**. **26, *Pachyduvalia* aff. *pinguis***, R.7507.9.4a. Left lateral view, **x 1.7**. Eroded lateral line depression more prominent in original. **27, *Pachyduvalia* aff. *agricolae***, R.7507.9.8. Orientation uncertain, **x 1.7**.

semi-aligned on bedding planes. One specimen is almost complete.

**Description.** Guard very elongate, slender, hastate in outline and profile, c. 100 mm long, and 7–8 mm in maximum diameter. Widest and deepest points on the guard are apparently located about one third the distance from apex to anterior. Guard tapers posteriorly to produce an elongate apical region, possibly with some ventral inflation. Apex centrally or slightly dorsally placed. Guard tapers anteriorly to produce an elongate slender stem and alveolar region. A narrow ventral groove, deeply incised into the surface of the guard, is present anteriorly and extends well down the guard (Figure 6.7-6.8). A natural cross section (Figure 6.9) suggests that it may extend into the apical region in some specimens. Cross sections laterally compressed, dorsal and lateral surfaces regularly rounded, ventral surface is maybe slightly flattened.

**Discussion.** The specimens resemble *Hibolithes marwicki* Stevens (middle Tithonian, New Zealand), in their very elongate, slender, hastate form, compressed cross section, and narrow ventral groove (cf. Stevens 1965, pl. 19, figures 1-9; Challinor 1999, figures 40-42, 45-46, 49-50). Mutterlose (1986, figure 4a, b), identified as *Hibolithes* aff. *marwicki* a calcareous specimen similar to this material (and similar to Challinor 1999, figures 45, 46), from his locality 8, also in the Bean Peaks, but some 5 km to the east. The material studied here is poorly preserved, consists of casts, and it is not claimed to be conspecific, although the resemblances to *H. marwicki* are strong.

**Range.** Late Oxfordian – late Kimmeridgian.

*Hibolithes* aff. *arkelli* Stevens, 1965  
(Figure 6.20-6.21)

aff. 1965 *Hibolithes arkelli*, Stevens, pl. 15, 17, 17, figures 1-5, 7, 8; pl. 18, figure 10; text figures 24g, h; 25a-d (see synonymy therein)

?1986 *Hibolithes* aff. *marwicki*, Mutterlose, p. 8-10, figures 6a-b, g-j.

aff. 1999 *Hibolithes arkelli* Stevens, Challinor, p. 381-383, figures 71-93 (see synonymy therein)

**Material.** Two poor quality latex casts (UTGD87221a, d; Q2). One is almost complete, but much of one flank is missing; the other is an alveolar fragment.

**Description.** Guard elongate, outline hastate, moderately robust, largest specimen (Figure 6.20) 81 mm long, 6-7 times maximum diameter. Widest

part posteriorly placed, c. one third the distance from apex to anterior. Stem tapers anteriorly, flanks converging to minimum separation, (presumably at about the position of the protoconch), then diverging anteriorly. They converge posteriorly from widest point producing a moderately elongate apical region with a moderately acute apex. Profile similar to outline but less hastate. Cross section approximately equi-dimensional posteriorly, compressed anteriorly. Median ventral groove moderately wide, shallow, apparently confined to alveolar region and anterior stem. Groove more strongly developed in the anterior fragment, may be poorly reproduced in the complete specimen. No information on alveolus preserved. No lateral lines evident.

**Discussion.** The specimens are generally similar in size, shape, and hastation to the more hastate specimens of *Hibolithes arkelli* (Middle Tithonian, New Zealand) (Challinor 1975, figures 23-24, 36-37), but if the interpretation of cross section above is correct, they are less laterally compressed, and the ventral groove does not extend as far down the guard. However, *H. arkelli* is variable in both these features (Challinor 1975, figures 11-13, 20, 37). Mutterlose (1986, figure 5a, b, g-j) described *Hibolithes* aff. *arkelli* from Bean Peaks (his localities 7, 8), and Wilkins Mountains (loc. 2, 4) Orville Coast, Ellsworth Land. Crame et al. (2000) described a fragment identified as *Hibolithes* aff. *arkelli*, recovered from a bottom trawl in the eastern Weddell Sea. Willey (1973) described *Hibolithes belligerundi* (Tithonian, West Antarctica), *Hibolithes antarctica* and *Hibolithes* sp.nov (Berriasian, West Antarctica) from Alexander Island. All resemble *H. arkelli* in some features. The specimens have some features in common with *H. savornini* (Kimmeridgian-Tithonian, Madagascar, Combémoré 1988). The presence of several similar taxa of Tithonian or Tithonian-Berriasian age in the West Antarctica region and the poor quality of the casts makes identification difficult.

**Range.** Middle – latest early Kimmeridgian.

*Hibolithes* sp. A  
(Figure 6.13-6.14)

**Material.** Two latex casts (R.7519.60.30a, b) of early juvenile growth stages; each lying (apparently on one side) parallel to a bedding plane. R.759.60.30a is complete, R.751960.30b lacks the anterior half.

**Description.** Guard small, slender. R.751960.30a (Figure 6.13) 33 mm long, maximum (sagittal) diameter c. 2.2 mm; deepest point on guard c. 4

mm from apex. Dorsal, ventral, and lateral surfaces converge posteriorly producing a moderately obtuse apical region with a centrally placed apex. Guard contracts anteriorly producing an extremely attenuate stem region c. 1.3 mm in diameter 16 mm from apex and 0.6 mm in diameter 30 mm from apex. Anterior 3 mm distorted into a flattened triangular shape (apparently due to crushing of alveolar region). Cross section in apical region apparently equi-dimensional, compressed anteriorly. No alveolar or other grooves present, no lateral lines seen. The incomplete specimen (Figure 6.14) c. 19 mm long, similar to the posterior half of Figure 6.13 (the long slender anterior region presumably detached before burial or lost during collection).

**Discussion.** The specimens are included in *Hibolithes* solely on their hastate clublike profile. They are two of several juvenile specimens, including *Belemnopsis*, from several horizons at outcrop R.7519.

**Range.** Latest Bathonian – early Callovian.

*Hibolithes* sp. B  
(Figure 6.15)

**Material.** One latex cast (R.7507.9.19) that includes the stem and possibly part of the apical region.

**Description.** Guard slender, hastate, fragment c. 60 mm long. Flanks diverge slightly near the anterior suggesting part of the alveolar region is present. Posterior maximum transverse diameter c. 7.9 mm, sagittal diameter c. 8.2 mm. Minimum (anterior) transverse diameter c. 6.6 mm, sagittal diameter c. 8.2 mm. The cross section slightly compressed throughout. Ventral groove narrow, shallow, extending full length of fragment. It is very weak anteriorly, a region of the guard in which the ventral groove is usually more strongly incised (possibly a preservation effect).

**Discussion.** Almost all New Zealand *Hibolithes* have long ventral grooves (extending to mid-guard or into the apical region). *Hibolithes* sp. B has a long groove, but this feature cannot be evaluated further with the material available. Its cross section is less compressed, it is less hastate, and its ventral groove is not as narrow and well incised as that of *Hibolithes* cf. *H. marwicki* above.

**Range.** Late Kimmeridgian.

*Hibolithes* sp. C  
(Figure 6.16-6.17)

**Material.** Two latex casts (R.7504.3.15, R.7504.3.87), of complete specimens exposed on bedding planes. In the better-preserved specimen (Figure 6.17), one flank and most of the posterior dorsal and ventral surfaces are visible. The dorsal and ventral alveolar and anterior stem regions are partly concealed. The cast appears to be slightly crushed or distorted posteriorly. The other specimen (Figure 6.16) is flattened and distorted, and provides no information on cross section, but both ventral groove and lateral lines are preserved, although poorly.

**Description.** Guard elongate and moderately slender, maximum dorsoventral diameter c. 11 mm, length 90 mm, and c. 8 times maximum diameter. Profile hastate (anterior sagittal diameter c. 6 mm) and asymmetrical, posterior ventral part of guard inflated. Apical region moderately obtuse, apex dorsally placed. Outline hastate, probably more so than profile. Cross section compressed posteriorly, apparently less so anteriorly, although this may be due to distortion. Strong lateral lines and an alveolar groove c. 35 mm long are present on the flattened specimen. The alveolus is shallow and penetrates the guard for about one fifth of its length.

**Discussion.** The better-preserved specimen (Figure 6.17) resembles New Zealand *Hibolithes mangaoraensis* Stevens, 1965 (middle Tithonian, Challinor 1999, figure 11-38), in its ventral inflation and cross section, but both specimens are more elongate and the ventral groove is much shorter (Figure 6.16) than in *H. mangaoraensis*.

**Range.** Latest early – middle Oxfordian.

Family DICOELITIDAE Sachs and Nalnjaeva,  
1967

Genus DICOELITES Boehm, 1906

**Type species.**– *Belemnites dicoelus* Rothpletz, 1892. Upper Jurassic.

**Diagnosis.** Guard moderately elongate and robust, to very elongate and slender, subcylindrical to hastate. Mid-guard cross section slightly to strongly depressed. Median ventral groove moderately narrow, deep, and well incised into guard surface may be wide and deep in robust forms. Extends well into the apical region, sometimes almost to the apex. Median dorsal groove short, shallow, often very weak, usually confined to or near the alveolar region, occasionally extending

further down the guard. May be missing in some adults, more often in pre-adults. Alveolus short in relation to guard length, lateral lines moderately or poorly developed (our concept).

*Dicoelites* sp.  
(Figure 6.10-6.12)

**Material.** Two latex casts (R.7519.17.11, R.7519.24.51), both alveolar/stem fragments.

**Description.** R.7519.24.51 (Figure 6.10-6.11), a slightly hastate fragment c. 20 mm long, midpoint 5.5 mm in transverse diameter, 6 mm in sagittal diameter. Cross section is compressed, prolate, with rounded flanks and dorsal and ventral surfaces. Vague circular markings at anterior end suggest the alveolus is present. A deep and narrow median groove extends long the ventral surface. A short, shallow, narrow, median dorsal groove extends about 10 mm along the dorsal surface, terminates c.10 mm from the anterior (termination prior to the end of the guard may be an individual feature of this particular specimen, or result from damage to the mould). R.7519.17.11 (Figure 6.12), an alveolar/stem fragment 45 mm long. Maximum and minimum lateral diameters are 6.3 and 4 mm; dorsoventral diameters are 5.5 and 4 mm; specimen hastate in outline and profile, cross section depressed. Lateral, dorsal and ventral surfaces regularly rounded. A deep and relatively narrow ventral groove extends the full length of the fragment. No groove visible on damaged dorsal surface of the alveolar region (but the alveolar end suggests a dorsal splitting surface remnant, the "slit" of Krymholz 1992, may be present). Faint lateral lines extend the length of the specimen, they are situated at the midline at its posterior end, and migrate slightly towards the ventral surface in their anterior course.

**Discussion.** *Dicoelites* occurs in New Zealand (Kimmeridgian and early/middle Callovian, Challinor 1980, and new data), Madagascar (Callovian-Oxfordian, Combémoré 1988), New Caledonia (Bathonian, Challinor and Grant-Mackie 1989), and in South America and West Antarctica (Middle Jurassic, Doyle et. al 1996), but does not seem to be abundant in any of these regions.

**Range.** Latest Bathonian – early Callovian.

Family DUVALIIDAE Pavlow, 1913  
Genus DUVALIA Bayle, 1878

**Type species.-** *Belemnites latus* de Blainville, 1827. Berriasian-Valanginian.

**Diagnosis.** Rostrum of medium size, generally more or less strongly compressed. Apex short, summit often rounded, sometimes mucronate. Transverse section oval or subquadrangular. Dorsal alveolar groove more or less elongated. Lateral lines transversing the flanks. They are generally visible in young rostra and weaken or disappear in adults.

*Duvalia* aff. *rhopaliformis* Combémoré, 1988  
(Figure 6.18-6.19)

aff. 1988 *Duvalia rhopaliformis* Combémoré, p.16, pl. 21, fig. 1.

**Material.** One partial latex cast (UTGD87347a, Locality Q13). The specimen lies on one flank partially embedded in matrix. The posterior half is sufficiently well exposed to provide details of the posterior cross section.

**Description.** Guard hastate, small, moderately slender and strongly compressed. Preserved part of specimen c. 50 mm long, length c. 4.5 times maximum diameter. Maximum transverse diameter situated c. 18 mm from the apex, outline symmetrical, and strongly hastate. Flanks converge anteriorly to produce a moderately elongate stem region, more rapidly posteriorly to produce a moderately obtuse apical region. Dorsal and ventral surfaces taper steadily towards the anterior; converge more rapidly posteriorly producing a slightly dorsally placed, mucronate apex. Profile slightly asymmetrical, ventral surface slightly inflated near the deepest point on the guard. Cross section oval, strongly laterally compressed in the apical half of the guard; transverse diameter near widest point on the guard c. 8 mm, dorsoventral diameter c.11 mm. Cross section apparently more compressed anteriorly. Lateral surfaces of apical region gently rounded, slightly ventrolaterally flattened, dorsal and ventral surfaces are more acutely rounded. Parallel lateral lines, slightly ventrally placed, faintly visible near the midline of the guard towards the anterior. Alveolus not preserved, no certain alveolar groove visible. Short dorsally placed, narrow, weak depression c. 4 mm is length visible at guard anterior.

**Discussion.** The specimen closely resembles *Duvalia rhopaliformis* Combémoré 1988 (late Bathonian, Madagascar,) although the cross section of the latter is apparently less compressed. The short alveolar depression may be a groove remnant or a casting artifact.

**Range.** Middle Callovian – early Kimmeridgian.



*Duvalia* sp.  
(Figure 6.24-6.25)

**Material.** One distorted apical fragment (R.7507.9.13) c. 40 mm long.

**Description.** Outline symmetrical, profile slightly asymmetrical, ventral surface more inflated towards apex. Cross section an irregular oval with moderately rounded dorsal surface, a wider more flattened ventral surface, gently rounded, slightly flattened flanks. One flank is crushed. Guard compressed, maximum dorsoventral diameter c.18 mm, lateral diameter c. 13 mm. Apex mucronate and dorsally placed.

**Discussion.** The cross section, although distorted, resembles that of *Duvalia emeric* (Neocomian, France, Combémoré 1973) in apical view.

**Range.** Late Kimmeridgian.

Genus PACHYDUVALIA Riegraf, 1981.

**Type species.-** *Produvalia (Pachyduvalia) pinguis* Riegraf, 1981. Lower Oxfordian.

**Diagnosis.** Rostrum medium to small sized, hastate or subcylindrical. Cross section variably depressed, subquadratic or subpentagonal. Apical end round with mucro or blunt and excentric, apex closer to dorsal side. Ventral side flat to various degrees. Ventrolateral ridges and longitudinal depressions anteriorly, lateral lines strongly developed. Dorsal alveolar groove short, alveolus up to one third total length of rostrum (interpreted from Barskov and Weiss 1994).

*Pachyduvalia* aff. *pinguis* (Riegraf, 1981)  
(Figure 6.26)

aff.1981 *Produvalia (Pachyduvalia) pinguis* Riegraf, taf. 8, fig. 81, abb. 240 (see synonymy therein).

**Material.** One latex slab (R.7507.9.4), containing the specimen described here (R.7507.9.4a) and several fragmentary *Belemnopsis*. The guard is completely exposed along the dorsal surface and one flank, the ventral surface is almost completely exposed, and one flank is concealed.

**Description.** Guard short, robust, 35 mm long, maximum diameter c. 10 mm. Widest point c. midway along the guard. Outline parallel sided or slightly hastate. Profile asymmetric. Deepest point midway along the guard. Dorsal and ventral surfaces converge anteriorly towards the midline producing slight sagittal hastation, then diverge again. Dorsal and ventral surfaces and flanks converge

posteriorly producing a moderately obtuse apical region. The exposed flank is eroded. Eroded lateral lines extend posteriorly along the midline from the alveolar break and appear to be deflected dorsally near the apex. Apex mucronate and dorsally placed. Cross section compressed. Dorsal and ventral surfaces rounded, visible lateral surface is flattened. Alveolus deep, penetrating c. half the guard length. No alveolar groove visible on preserved part of the guard, dorsal and ventral surfaces identified from the asymmetric profile.

**Discussion.** This specimen resembles *Pachyduvalia pinguis* Riegraf (early Kimmeridgian, Germany) in profile, outline, and, as far as can be seen, in cross section. The strong alveolar groove of *P. pinguis* is not present.

**Range.** Late Kimmeridgian.

*Pachyduvalia* aff. *agricolae*  
(Parona and Bonarelli, 1897)  
(Figure 6.27)

aff.1994 *Produvalia (Pachyduvalia) agricolae*, Barskov and Weiss, p. 93, fig. 6i, j (see synonymy therein).

**Material.** One latex cast (R.7507.9.8) exposed on the surface of a latex slab. Three sides of the specimen are partly or completely exposed, the remaining surface is obscured.

**Description.** Guard short, robust, maximum diameter c. 8 mm, length 40 mm. Widest point c. half-way along the guard. Exposed surfaces converge slightly anteriorly to produce transverse and sagittal hastation. They converge posteriorly towards the apex, at first gradually, and are then drawn out terminally into an extremely long, tapering, centrally placed mucro. Cross section of guard rounded, either compressed (if the completely exposed surface is a flank) or depressed (if the exposed surface is dorsal or ventral). No lateral lines or alveolar groove visible. If originally present the latter may have been restricted to an un preserved part of the guard or may be present on the concealed surface.

**Discussion.** The guard is of unusual, bottle-like shape, and, given the apparent absence of a dorsal groove, is placed in *Pachyduvalia* mostly on gross form. If not so placed it is difficult to know in which taxon it should be included. It resembles *Pachyduvalia agricolae* (late Callovian-early Oxfordian, Crimea), a taxon with similar shape, mucro, and depressed cross section, illustrated by Barskov and Weiss (1994, figure 5i, j). Our specimen

strongly resembles *P. agricolae*, but is slightly more slender and elongate.

**Range.** Late Kimmeridgian.

Genus RHOPALOTEUTHIS Lissajous, 1915  
Type species. *Belemnites sauvanausus* d'Orbigny, 1842.

**Diagnosis.** Rostrum of moderate size, in the form of a club, but sometimes perfectly straight. Transverse section circular, oval, or subquadrangular, but never compressed. Apex more or less elongated, rounded, or mucronate. Dorsal alveolar groove narrow and deep. More or less elongate. Apical line slightly excentric.

*Rhopaloteuthis* sp.  
(Figure 6.22-6.23)

**Material.** One latex cast (R.7507.1.2). Most of the (presumed), dorsal surface and much of the lateral surface are exposed, the ventral surface is concealed.

**Description.** Outline hastate, widest point situated c. 15 mm from apex. Flanks converge regularly posteriorly to produce a moderately obtuse apex, an apical pit suggests a mucro was originally present. Transverse diameter at the widest point c. 8 mm (ventral surface of the cast concealed, dorsoventral diameter cannot be measured). Apical view suggests the specimen is approximately equidimensional, apical cross section subpentagonal. Alveolar region crushed; a shallow, narrow, presumably dorsal groove extends for c. 10 mm down the guard. Alveolar depth uncertain, but alveolus apparently extends into the guard for up to half its length.

**Discussion.** This specimen resembles *Duvalia monsalvensis* (Callovian-Oxfordian, Madagascar) and *Duvalia zaferai* (Oxfordian, Madagascar, see Combémorrel 1988, pl. 21, figure 4, 19), although the dorsal groove in both of these is more extensive and the cross section compressed. Our specimen is robust, its apical cross section is c. equidimensional, and it seems better placed in *Rhopaloteuthis*. We have placed *Pachyduvalia* aff. *pinguis* and *P.* aff. *agricolae* in that genus because of their specific resemblances. *Rhopaloteuthis* sp. is placed in that genus because it conforms better to the generic description and is present in Madagascar at about the same time (Combémorrel 1988).

**Range.** Latest Bathonian.

## DISCUSSION

### Age of Collection Localities

The biostratigraphic ranges of outcrops studied in this project are shown in Figure 3 (after Hikuroa 2005). Detailed composite lithostratigraphic sections in Figure 4 show the stratigraphic positions of belemnite bearing localities (after Hikuroa 2005). Those of Hikuroa (R.750 collections) are considered first, and we correlate those of Quilty (Q1 etc.) with those of Hikuroa (Figures 2, 3, 4). The ranges of belemnite genera or families in the Latady Group are compared with those in New Zealand and Madagascar in Figure 7. Quilty used international stages for some of his localities, but retained the New Zealand Heterian Stage (middle Callovian to lower Kimmeridgian strata, Campbell 2004) for some Upper Jurassic localities he could not correlate with international stages. Where possible we use ages based on ammonites, which we consider most reliable. Otherwise we use bivalves, in particular the retroceramids, which are well constrained biostratigraphically elsewhere in Antarctica (Crame 1982), New Zealand (Stevens 1997, figure 65; Hudson 2003, table 1) and South America (Damborenea 1990, 1996), and also the buchids *Malayomaorica malayomaorica* Jeletzky (Crame 1990; Stevens 1997) and *M. occidentalis* (Jones and Plafker 1977; Jeletzky 1983).

**Outcrop R.7504.** The collection consists mostly of *Belemnopsis*, including *Belemnopsis* cf. *B. stevensi*. *Hibolites* sp. C is also present. The belemnites are not age diagnostic. Based on the presence of the ammonite *Perisphinctes* (*Discosphinctes*) cf. *P. antillarum* (see Quilty 1970, pl. 25, figure 14), the locality is assigned a latest early to middle Oxfordian age (*Perisphinctes-Araucanites* Association in von Hillebrandt et al. 1992, table 12.3).

**Outcrops R.7505 and R.7506.** The collections are from different outcrops but the same stratigraphic horizon and contain the same fauna. Two belemnite forms were collected, aff. *Brevibelus* and *Hibolites catlinensis*, the latter of Bajocian to Bathonian age in New Zealand. The associated fauna includes the ammonites *Stephanoceras* cf. *S. bigoti*, *Teloceras* cf. *T. lotharingicum*, and *Megasphaeroceras* cf. *M. rotundum* (Quilty 1970), and is dated as latest early Bajocian (Humphriesianum Ammonite Zone von Hillebrandt et al. 1992, table 12.2). The belemnites represent an early occurrence of *Hibolites*, not present in the four assemblages recognised by Doyle et al. (1996).



**Outcrop R.7507.** This outcrop has a number of localities that contain a diverse assemblage of localities that contain a diverse assemblage of *Pachyduvalia* (two species), *Duvalia*, *Rhopaloteuthis*, and several species of *Belemnopsis*. The associated faunas are dated as latest Bathonian – early Kimmeridgian; based on the widespread *Retroceramus galoi* (Boehm), *Retroceramus subhaasti* (Wandel) and also *Neocrassina marwicki* (Quilty). The stratigraphically lowest locality R.7507.1 contains *Neocrassina marwicki*, which ranges from latest Bathonian – mid late Kimmeridgian (Hikuroa 2005). *Retroceramus galoi* is recorded from Q2-4 and ranges mid-middle Callovian to early Kimmeridgian (Hudson 2003, table 1). Localities R.7507.3, 5, 6, 7 have no age diagnostic fauna, but as they lie stratigraphically between R.7507.1 and Q4 (see Figure 4), must be younger than latest Bathonian and older than mid middle Callovian. R.7507.7 lies ~40 m below *R. galoi* and is assigned an ?early to middle Callovian age. *Retroceramus subhaasti* occurs concurrently with *R. galoi* at Q2. In the New Zealand stratigraphic sequence the two occur together from mid early Kimmeridgian to latest early Kimmeridgian, and that age is inferred for Q2. Localities Q1 and R.7507.8 and 9 are stratigraphically above Q2, and therefore younger than latest early Kimmeridgian (Figure 4).

**Outcrop R.7508.** The belemnites identified at generic level are all *Hibolithes*, and include *H. cf. H. marwicki* Stevens. Presence of *Malayomaorica malayomaorica* indicates a late Oxfordian – early Tithonian age (Stevens 1997, figure 55). Another species of *Malayomaorica*, *M. occidentalis* (late Kimmeridgian – mid middle Tithonian), is also known from the Hauberg Mountains Formation. *Malayomaorica occidentalis* occurs stratigraphically above *M. malayomaorica* (Jones and Plafker 1977; Jeletzky 1983) restricting the upper range of the latter to late Kimmeridgian. Thus, the age of outcrop R.7508 is late Oxfordian to late Kimmeridgian.

**Outcrop R.7512.** Indeterminate *Belemnopsis*, of no age-diagnostic value, are present. Presence of *Malayomaorica malayomaorica* indicates a late Oxfordian to late Kimmeridgian age.

**Outcrop R.7517.** The belemnites have affinities with *Belemnopsis stevensi*. Based on the presence of *Retroceramus cf. R. stehni* (Hikuroa 2005), *Belemnopsis cf. B. stevensi* at outcrop R.7517 is assigned a latest Bathonian to latest early Callovian age (the range of *R. stehni* see Damborenea 1990, 1996; Hudson 2003).

**Outcrop R.7519.** A diverse assemblage that includes *Hibolithes* sp. A (R.7519.60.30), *Belemnopsis* sp. C (R.7519.4.3; 26.4; 26.13), *Belemnopsis cf. B. stevensi* (R.7519.5.20), *Dicoelites* sp. (R.7519.17.11; 24.51), and indeterminate *Hibolithes* and *Belemnopsis*. Based on the presence of *Retroceramus cf. R. stehni* the fauna is assigned a latest Bathonian to latest early Callovian age.

**Outcrop R.7523.** ?*Belemnopsis* sp. indeterminate. In the absence of any reliable age diagnostic fauna, a latest early Bajocian to late middle Bathonian age is inferred based on the range of the crinoid *Chariocrinus latadiensis* Eagle and Hikuroa (see Eagle and Hikuroa 2003) found in association.

**Q1.** This locality lies stratigraphically above R.7507.8 (Figure 4). It contains *Belemnopsis* sp., and the same genus forms part of the fauna at R.7507. The locality lies stratigraphically above the base of the *R. subhaasti* zone (see discussion for R.7507 above), indicating an early late Kimmeridgian age (Stevens 1997, figure 65).

**Q2.** This locality lies stratigraphically below R.7507.8 (Figure 4). It contains *Hibolithes* aff. *arkelli*, *Belemnopsis* sp. B (UTGD87162b), *Retroceramus galoi*, and *R. subhaasti*. The two bivalves are found concurrently in the New Zealand stratigraphic sequence from mid early Kimmeridgian to latest early Kimmeridgian (Hudson 2003). This locality is older than the middle Tithonian occurrences of *H. arkelli* s.s. in New Zealand.

**Q4.** This locality is stratigraphically higher than R.7507.7. It contains non-diagnostic *Belemnopsis* sp. (UTGD87199). Q4 is dated as mid middle Callovian to early Kimmeridgian as it contains *R. galoi*.

**Q6.** (= R.7507.6, see Figure 4). Dated as younger than latest Bathonian and older than middle Callovian (see above). This locality contains an indeterminate belemnite (UTGD87285a).

**Q9.** (= R.7504.3, see Figure 4). Dated as latest early to middle Oxfordian, based on the ammonite *Perisphinctes (Discosphinctes) cf. P. antillarum* Jaworski (see above). Contains non age-diagnostic *Belemnopsis* sp. (UTGD87366c) and an indeterminate belemnite (UTGD87377a).

**Q10.** (= R.7505.2 and R.7506.8, see Figure 4). Dated as latest early Bajocian based on ammonites (Humphriesianum Zone, see above). Contains aff. *Brevibelus* and *Hibolithes catlinensis*. The latter ranges Bajocian to Bathonian in New Zealand.

The remaining Quilty localities are not correlated with any Hikuroa locality.

**Q13.** Dated as mid middle Callovian to early Kimmeridgian on the presence of *Retroceramus galoi*. Contains *Duvalia* aff. *rhopaliformis* (UTGD87347a), *Belemnopsis* sp.G. (87356a, 87357c), *Belemnopsis* sp. (UTGD87349a, 87353c, 87357a), and an indeterminate belemnite (UTGD87347b). Age possibly Callovian to Oxfordian, based on *Duvalia*. *Duvalia rhopaliformis* (Combémoré 1988) is late Bathonian in Madagascar.

**Q15.** Contains an indeterminate belemnite (UTGD87361d). Dated as mid middle Callovian to early Kimmeridgian based on *R. galoi*.

**Q17.** Contains non age-diagnostic *Belemnopsis* sp. D (UTGD87058c) and *Belemnopsis* sp. Dated as mid middle Callovian to early Kimmeridgian based on *R. galoi*.

#### Belemnite successions in West Antarctica and South America

Doyle et al. (1996) recognised a succession of four belemnite faunas in West Antarctica (Alexander Island and eastern Antarctic Peninsula), and South America (Austral and Neuquen Basins, Argentina). They are: (1) a *Brevibelus-Dicoelites* fauna (Aalenian-Bathonian); (2) a *Rhopaloteuthis-Belemnopsis* fauna (Bathonian-Oxfordian), the *Belemnopsis* being "European type" forms with a markedly hastate outline and strongly depressed cross section, as opposed to the robust, cylindrical, less depressed Gondwana type *Belemnopsis*; (3) a *Belemnopsis* fauna (Gondwana type *Belemnopsis*, Kimmeridgian and Tithonian); and (4) a *Hibolithes* fauna (Tithonian-Berriasian).

Using the ages based on associated faunas for the belemnites studied here, and including the taxa and ages of Mutterlose (1986), the belemnite succession for the Latady Group can be represented by: (1) a sparse aff. *Brevibelus-Hibolithes* fauna (Bajocian); (2) a fauna dominated by *Belemnopsis* but with *Hibolithes* and rare Dicoelitidae and Duvaliidae (Bathonian-Oxfordian); and (3) a *Hibolithes-Belemnopsis* fauna with occasional *Duvalia*, *Pachyduvalia*, and *Produvalia* (Kimmeridgian-Tithonian).

We have described several taxa as having affinities with New Zealand species, but in most instances some differences in morphology are evident. This is not surprising. Belemnite species can be extremely variable in morphology (cf. Jeletzky 1972; Challinor 1975), and variation in the adult is often compounded by changes in shape during ontogeny (many of our specimens are juveniles). Add to this probable intraspecific differences between regional populations (development of

clines), and the sparse nature of the Ellsworth Land material, often limited to single specimens or fragments, and the difficulties are clear. Nevertheless, we are confident that the West Antarctic specimens that we have compared affinities with New Zealand taxa are similar or identical to them.

#### Diversity of Taxa

The large number of taxa recognised may seem unusual or excessive, but the outcrops from which they were collected span much of the Middle and Late Jurassic. The situation is not without precedent. At least 25 belemnite taxa, some undescribed, are present in the New Zealand Toarcian/Aalenian to Tithonian sequence (e.g., Stevens 1965; Challinor 1974, 1975, 1979, 1980, 1996, 1999, 2003 and unpublished data e.g., Hudson 1999). It is possible we have misinterpreted some specimens, recognising them as distinct when they should be included in another described taxon. Conversely, we may have united specimens in a single taxon when they are not conspecific. This is most likely to have happened with *Belemnopsis*, where the material is diverse and fragmentary, but is also possible with other genera.

#### Regional Assemblages

Belemnite assemblages of Latady Group, Madagascar and New Zealand are compared in Figure 7. Chronostratigraphic distributions are based on families (Dicoelitidae (*Conodicoelites* and *Dicoelites*) and Duvaliidae (*Duvalia*, *Pachyduvalia* and *Rhopaloteuthis*) or genera (*Belemnopsis* and *Hibolithes*). Data on Madagascan taxa are from Combémoré (1988); New Zealand from Stevens (1965), and Challinor (1979, 1980, 1999, 2003); Latady Group from Mutterlose (1986) and Hikuroa (2005).

*Belemnopsis* is present in all three regions. Those of Latady Group range from early Callovian to late Kimmeridgian. Two morphological groups are dominant. The first contains *Belemnopsis* cf. *B. stevensi* and *Belemnopsis* aff. *keari* (Mutterlose 1986). This group ranges from early Callovian to late Kimmeridgian, and correlates with the *Belemnopsis annae*, *B. keari* and *B. stevensi* assemblage of the New Zealand Heterian and early Ohauan Stages (middle Callovian to late Kimmeridgian). The second group consists of small robust taxa (*Belemnopsis* sp. D, E, F, G, and H) and are present in the early and middle Callovian, early and late Oxfordian, and late Kimmeridgian. Similar small robust *Belemnopsis* also occur in New Zealand. They are *Belemnopsis rarus* (early

Ohauan = late Kimmeridgian, Challinor 1980, figure 24-33), *B. kiwiensis* (middle Heterian = early Kimmeridgian, Challinor 2003, figure 37-42), and a new undescribed taxon from the early or middle Callovian. All have short stratigraphic ranges and form a very small part of the New Zealand belemnite assemblage during Callovian to Kimmeridgian time. They are not thought to be conspecific with any Latady Group taxon.

Combémoré (1988, pl. 2-11, figure 47) described 10 species of *Belemnopsis* ranging from the late Bathonian to late Tithonian of Madagascar. Most are very large, some have very deep, narrow, long ventral grooves; all can be readily distinguished by several features from New Zealand and Latady Group taxa. We conclude that there are strong affinities between some New Zealand and Latady Group *Belemnopsis* but few between those of Latady Group and Madagascar.

*Hibolithes* is present in the Latady Group, New Zealand, and Madagascar. They range from c. early Bajocian to early Tithonian in Latady Group; from c. early Bajocian to middle Callovian and in the early to middle Tithonian in New Zealand; and from late Bathonian to late Tithonian in Madagascar (and continue into the Early Cretaceous). Latady Group contains *Hibolithes catlinensis* in the Bajocian and the same taxon is present in the Bajocian-Bathonian of New Zealand. *Hibolithes* sp. B (a long grooved New Zealand type taxon) occurs in the late Kimmeridgian, *Hibolithes* aff. *arkelli* in the early Kimmeridgian and early Tithonian, and *Hibolithes* cf. *H. marwicki* in the early Tithonian.

Mutterlose (1986) described *Hibolithes* aff. *marwicki*, *H. aff. arkelli* and *Hibolithes* sp. from his localities 7, 8 (Bean Peaks, c. 15 km northeast of R.7508) and Wilkins Mountains (localities 2, 4). His figured specimens (Mutterlose 1986, figures 4a, b, fig. 5a, b, e-h) are of relatively well-preserved calcareous guards. *Hibolithes* aff. *marwicki* is probably identical with *marwicki* s.s.; *H. aff. arkelli* and *Hibolithes* sp. are morphologically close to *H. arkelli* s.s.

Crame et al. (2000) described a fragment identified as *Hibolithes* aff. *arkelli*, recovered from a bottom trawl in the eastern Weddell Sea. Willey (1973) described *Hibolithes antarctica* and *H. sp. nov.* (Berriasian, West Antarctica) from Alexander Island. The presence of similar taxa of Tithonian or Tithonian-Berriasian age in the region makes confident identification difficult.

Mutterlose (1986, figure 4e, f) also described *Hibolithes* aff. *verbeeki* (Kimmeridgian-Tithonian)

from locality 8 (Bean Peaks). The figured specimen is strongly hastate, with a very depressed cross section and a short ventral groove. It resembles some specimens of *Hibolithes flemingi* Spath (Kimmeridgian-Valanginian, Madagascar, Combémoré 1988). *Hibolithes* sp. C (R.7504.3) is short grooved as are most Madagascan *Hibolithes*.

Combémoré (1988, pl. 12-20, figure 47) described six species of *Hibolithes* from the Bathonian-Tithonian of Madagascar (and others from the Early Cretaceous). Except for *Hibolithes* aff. *verbeeki* and *Hibolithes* sp. C, most Latady Group taxa differ markedly from Madagascan *Hibolithes*. Most of the latter are large, almost all are short or very short-grooved forms, some are strongly hastate and clublike in shape. We conclude that most *Hibolithes* from Latady Group resemble New Zealand taxa, and that one at least (*H. catlinensis*) is conspecific. Two, *Hibolithes* aff. *verbeeki* and *H. sp. C*, resemble Madagascan taxa.

Dicoelitidae are present in all three regions. *Dicoelites* and *Conodicoelites* are present in the Bathonian – Callovian of New Zealand (Hudson 1999, and new unpublished data) and *Dicoelites* briefly in the late Kimmeridgian (Challinor 1980). *Dicoelites* is present in the early Callovian of Latady Group. *Conodicoelites* is not represented in the Latady Group collections studied here, but Stevens (1967) described *Conodicoelites* sp. from Lyon Nunataks c. 0.5° northwest of Mount Hirman. He suggested a Kimmeridgian age, probably based on the similarities to New Zealand *Conodicoelites* (now known to be Bathonian and Callovian in age; Hudson 1999, and new unpublished data). Those from Lyon Nunataks are not conspecific with, but are probably of about the same age as the New Zealand taxa, and with the R.7519.17/24 *Dicoelites* (i.e., Bathonian/Callovian). *Dicoelites* occurs in the late Callovian-early Oxfordian of Madagascar but is rare (Combémoré 1988, pl.1, figure 47) and *Conodicoelites* is apparently absent. The presence of *Conodicoelites* and *Dicoelites* in both New Zealand and Ellsworth Land at about the same time suggests affinities between the dicoelitids of the two regions.

Duvaliidae are not known from New Zealand. They range from late Bathonian to early Kimmeridgian in Madagascar, and reappear in the late Valanginian (Combémoré 1988, pl. 21-23, figure 47). They appear in Latady Group in the late Bathonian (R.7507.1), are present somewhere in the middle Callovian – early Kimmeridgian (Locality Q13, shown arbitrarily as middle Oxfordian in Figure 7), in the late Kimmeridgian (R.7507.9), and in the late

Tithonian (*Produvalia* aff. *neyrivensis*, Mutterlose 1988). The affinities of Latady Group Duvaliidae are clearly with Madagascar.

Passaloteuthid belemnites are present in Latady Group and New Zealand but have not been recorded from Madagascar. *Brevibelus* is present in the Toarcian-Aalenian of New Zealand, a similar age range to the genus in Europe. Aff. *Brevibelus* (Q10) is younger, latest early Bajocian. A taxon resembling *Brevibelus* but larger, is present in the lower Bathonian of New Caledonia (Challinor and Grant-Mackie 1989, the specimens described as Belemnitidae (=Passaloteuthididae) gen. et sp. nov.). Taxa resembling *Brevibelus* occur on Alexander Island, Antarctic Peninsula in the Aalenian-Bathonian, and in Neuquen and Mendoza provinces of Argentina during the Aalenian-Bajocian. However, the name *Brevibelus* is placed within quotation marks, and the stratigraphic ranges are dashed (Doyle et al. 1996, figure 2), suggesting that the data are suspect or the material has not been studied in detail. These data suggest that a taxon resembling *Brevibelus* was present along the southern coast of Gondwana during the Early and early Middle Jurassic. The relationship between *Brevibelus* of New Zealand and aff. *Brevibelus* of Latady Group is not clear.

#### Inter-Regional Assemblages

Provided the ages attributed to the taxa discussed here are correct it is possible to suggest inter-regional migration pathways.

The Duvaliidae originated in Bathonian time (Doyle et al. 1994). They apparently migrated southwards from the central Tethys to Madagascar via an intermittent trans-Gondwana seaway formed during periods of high global sea-level, which initially developed in the early Middle Jurassic. Geophysical and other investigations into the development of that seaway are discussed below. *Rhopaloteuthis* appeared in the Bay of Antarctica (Figure 8, in Latady Group strata) in c. the latest Bathonian, and is present in the Bathonian-Oxfordian of Alexander Island (Doyle et al. 1996).

*Hibolithes* and *Belemnopsis* appeared in the western Tethys in the Bajocian (Riegraf 1980), and presumably followed a similar migration pathway to Madagascar as the Duvaliidae (Combémoré 1988). The origin of the New Zealand late Callovian-late Kimmeridgian *Belemnopsis stevensi* group is uncertain but its constituents possibly evolved from strongly grooved hastate ancestors similar to the Madagascan early Callovian *Belemnopsis andranomavoensis* Combémoré 1988, and *B. late-*

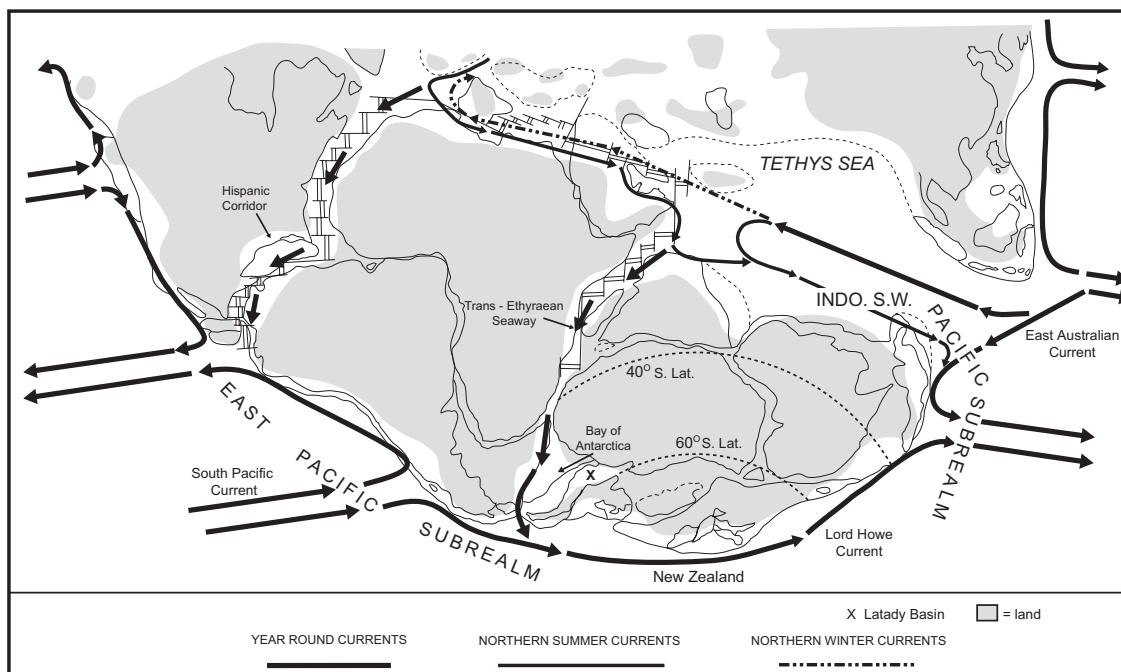
*sulcatus* (d'Orbigny 1845) (see Combémoré 1988). The appearance of *Belemnopsis* aff. *stevensi* in Ellsworth Land (early Callovian) and the *B. stevensi* group in New Zealand (middle Callovian) could be interpreted to indicate migration from Madagascar to Ellsworth Land to New Zealand in that order. But the times of appearance are not greatly different, and could be readily explained by accidents of collection, or by imprecision in the dating methods used by different workers.

The origin of the long-grooved *Hibolithes arkelli* – *H. marwicki* group is not evident. There appear to be no possibly ancestral taxa in Madagascar. They appear in the early Kimmeridgian of Ellsworth Land (Q2, Figure 7) and disappear in the early Tithonian (M, Figure 7), i.e., earlier than their appearance/disappearance in the middle Tithonian in New Zealand (A, Figure 7). The appearance of *Hibolithes arkelli* and *H. marwicki* (and also of *H. kaimangoensis* Challinor 1966, and *H. mangao-raensis* Stevens 1965) in New Zealand has been interpreted as indicating evolution in a region somewhere adjacent to New Zealand, and subsequent entry into the New Zealand area in a series of migratory events (Challinor 1999). That region of origin is apparently the Latady Basin, or another location within or close to the Bay of Antarctica (Figure 8).

The first appearance of Dicoelitidae is in the Toarcian-Aalenian of western Arctic Canada (Jeletzky 1980), but their major development and radiation appears to have been in and from the western Tethys in c. the Bathonian-Callovian. The origin of the Ellsworth Land dicoelitids is obscure. They are rare in Madagascar and in Ellsworth Land (although that could be due in the latter region to the widely scattered outcrops, Figures 1, 2) but are moderately abundant in New Zealand. A Tethys-Madagascar-Ellsworth Land-New Zealand migratory pathway is possible. Dicoelitidae are present in southern South America in the Callovian (Combémoré 1988) and Aalenian-Bajonian (Doyle et al. 1996). The possibility of a migratory path from western Arctic Canada via the west coasts of the Americas to Ellsworth Land cannot be completely excluded but seems unlikely. We know of no published records of dicoelitids in the western Americas apart from those mentioned, and a western Americas migration would be partly against prevailing ocean currents (Figure 8).

Although rich belemnite assemblages are present in eastern Indonesia (Bajocian to Neocomian, Challinor and Skwarko 1982, Challinor 1991a) and Papua New Guinea (Challinor 1990),





**Figure 8.** Paleogeographic map of the world during the Middle-Late Jurassic (180-135 Ma) after Stevens (1997), showing the position and direction of postulated ocean currents after Parrish (1992).

most are morphologically distinct from New Zealand and Latady Group taxa. Most *Hibolithes* are short grooved; none are similar to *Hibolithes marwicki* or *H. arkelli*. *Conodicoelites* and *Dicoelites* are of distinctive morphology and all are much larger than New Zealand and Latady forms. The *Belemnopsis* are all larger and more strongly grooved than New Zealand and Latady taxa; Oxfordian-Tithonian members are all part of an evolving lineage (Challinor 1989). Some late Kimmeridgian and early Tithonian members of that lineage were originally described as subspecies of New Zealand late Tithonian *Belemnopsis aucklandica* (Hochstetter 1863), but are now regarded as close homeomorphs of the latter. When these morphological differences are considered, an eastern circum-Gondwana migration from Indonesia to New Zealand and then Ellsworth Land also seems improbable for ancestral Latady Group and New Zealand forms, and again would be largely against prevailing ocean currents.

Mutterlose (1986) envisaged migration routes that were similar to some degree. He suggested a trans-Gondwana route for the Duvaliidae (represented by his single specimen of *Produvalia*) during the late Tithonian. He also suggested that *Conodicoelites*, *Hibolithes*, and *Belemnopsis* may have also migrated trans-Gondwana, or alterna-

tively via an eastward circum-Gondwana route, during the Kimmeridgian and early Tithonian.

### PALEOBIOGEOGRAPHY

Faunal links for several different groups at generic, and in some instances specific level, have long been known between West Antarctica/South America and New Zealand during Jurassic time (e.g., Stevens 1963, 1967, 1980, 1989; Willey 1973; Quilty 1978, 1983; Thomson 1981; Mutterlose 1986; Crame 1987; Doyle and Howlett 1989; Damborenea and Mancenido 1992). Challinor (1991b) proposed a South Pacific faunal province based on belemnites, extending from southern South America eastwards along the coast of Gondwana as far as New Zealand, and possibly New Caledonia, during Jurassic time. This South Pacific belemnite faunal province is more extensive in time, but approximately co-extensive in geography, with the eastern part of the late Bajocian to early Callovian East Pacific ammonite realm of Westermann (1981), (now subrealm, Westermann and Hudson 1991), that extended from Arctic Canada along the Pacific coasts of North and South America and West Antarctica as far as New Zealand. This study refines and extends knowledge of belemnite occurrences and relationships within the Jurassic of the South Pacific belemnite province.

The distribution of some Latady Group belemnites suggests they migrated from Madagascar to the Antarctic Peninsula. Migration directly south-west from Madagascar via the Trans-Erythraean Seaway (Figure 8 and Lamare 1936; Arkell 1956; the Gondic Corridor of Krishna 1994 and Gardner and Campbell 2002a, 2002b) would have been the shortest and most direct route. A major transgression occurred in the Callovian (Haq et al. 1987, Haq et al. 1988), and when combined with continental rifting in western Gondwana during the early Middle Jurassic (e.g., Grunow 1993a, 1993b; Studinger and Miller 1999), would have formed a short-lived shallow seaway that acted as a migratory pathway. Recent geophysical investigation suggests that the first oceanic crust formed between Africa and Antarctica around 155 Ma (Jokat et al. 2003). The Trans-Erythraean Seaway acted as a conduit for faunal exchange twice during the Middle Jurassic (Bajocian and Callovian) (Krishna 1994; Gardner and Campbell 2002a, 2002b), before becoming fully established as the Indian Ocean in the Tithonian (Hallam 1983). A number of bivalve taxa, rarer crinoids and a coral also migrated to Ellsworth Land from the north via the Trans-Ethryaeen Seaway (Gardner and Campbell 2002a, 2002b; Eagle and Hikuroa 2003; Hikuroa 2005).

We are confident that the correlations proposed, both in the taxa present and in the timing of biostratigraphic events, indicate migration between West Antarctica/Argentina and New Zealand (and possibly New Caledonia). The concept of a Middle and Late Jurassic South Pacific belemnite province extending eastwards along the southern margin of Gondwana from southern South America through West Antarctica to New Zealand (Challinor 1991b) remains valid. But the new data presented in this paper indicate that trans-Gondwana migrations introduced Tethyan elements to the fauna of southern South America and West Antarctica during the Middle and Late Jurassic.

#### ACKNOWLEDGEMENTS

This paper benefited greatly from two constructive anonymous reviewers. Fieldwork in Antarctica for Hikuroa was supported by the British Antarctic Survey, and passage to the United Kingdom was made possibly by a Claude McCarthy travel fellowship (New Zealand Vice-Chancellor's Committee) and the Trans-Antarctic Expedition Fund. Hikuroa gratefully acknowledges funding from the Foundation of Research, Science, and

Technology (FRST) and Te Mata o te Tau. Thanks are due also to B. Sporli for translations of German text and J. Grant-Mackie for translations of French text. P. Quilty made available collections of belemnites from his 1965/66 field work. This paper contributes to the BAS science SPARC project.

#### REFERENCES

- Arkell, W.J. 1956. *Jurassic Geology of the World*. London, Oliver and Boyd Ltd.
- Barskov I.S. and Weiss, A.F. 1994. The ontogeny and systematics of the Callovian - Oxfordian belemnites *Produvalia* and *Pachyduvalia* from the Crimea, *Paleontological Journal*, 28(1A):81-96.
- Bayle, E. 1878. Explication de la carte géologique de France 4, 1. Fossiles principaux des terrains. Atlas, nationale, Paris.
- Blainville, de H.D. 1827. Memoire sur les Belemnites. Levrault, Paris.
- Boehm. G. 1906. Geologische Mitteilungen aus dem Indo-Australischen Archipel. 1: Neues aus dem Indo-Australischen Archipel. *Neues Jahrbuch für Geologie und Paläontologie. Abhandlungen* 22(B-B): 385-412.
- Campbell, H.J. 2004. Jurassic (Chapter 9), p. 89-101. In Cooper, R.A. (ed.), *The New Zealand Geological Timescale*. Institute of Geological and Nuclear Sciences Monograph 22, Lower Hutt.
- Cantrill, D.J. and Hunter, M.A. 2005. Macrofossil floras of the Latady Basin Antarctic Peninsula. *New Zealand Journal of Geology and Geophysics*, 48:537-553.
- Challinor, A.B. 1974. Biostratigraphy of the Ohauan and lower Puarooan stages (mid-Kimmeridgian to lower Tithonian), Port Waikato region, New Zealand, with a description of a new *Belemnopsis*. *New Zealand Journal of Geology and Geophysics*, 17:235-269.
- Challinor, A.B. 1975. Variation in *Hibolithes arkelli*. *New Zealand Journal of Geology and Geophysics*, 18:804-835.
- Challinor, A.B. 1979. The succession of *Belemnopsis* in the Heterian stratotype, Kawhia Harbour, New Zealand. *New Zealand Journal of Geology and Geophysics*, 22:105-123.
- Challinor, A.B. 1980. Two new belemnites from the lower Ohauan (?Middle Kimmeridgian) Stage, Kawhia Harbour, New Zealand. *New Zealand Journal of Geology and Geophysics*, 23:257-265.
- Challinor, A.B. 1989. The succession of *Belemnopsis* in the Late Jurassic of Eastern Indonesia. *Palaeontology*, 32(3):571-596.
- Challinor, A.B. 1990. A belemnite biozonation for the Jurassic-Cretaceous of Papua New Guinea and a faunal comparison with eastern Indonesia. *BMR Journal of Australian Geology and Geophysics*, 11:429-447.
- Challinor, A.B. 1991a. Revision of the belemnites of Misool and a review of the belemnites of Indonesia. *Palaeontographica A*, 218:87-164.

- Challinor, A.B. 1991b. Belemnite successions and faunal provinces in the southwest Pacific, and the belemnites of Gondwana. *BMR Journal of Australian Geology and Geophysics*, 12:301-325.
- Challinor, A.B. 1996. Belemnites from the upper Ohauan Stage at Kawhia Harbour, New Zealand. *New Zealand Journal of Geology and Geophysics*, 39:211-223.
- Challinor, A.B. 1999. Belemnite biostratigraphy of the New Zealand Late Jurassic Mangaoran (Early Puroan) Substage, and the Puroan Stage revisited. *New Zealand Journal of Geology and Geophysics*, 42:369-393.
- Challinor, A.B. 2003. Synonymy and stratigraphic ranges of *Belemnopsis* in the Heterian and Ohauan Stages (Callovian to Tithonian) in southwest Auckland, New Zealand. *New Zealand Journal of Geology and Geophysics*, 46:79-94.
- Challinor, A.B. and Grant-Mackie, J.A. 1989. Jurassic Coleoidea of New Caledonia *Alcheringa*, 13:269-304.
- Challinor, A.B. and Skwarko, S.K. 1982. Jurassic belemnites from Sula Islands, Moluccas, Indonesia. *Publication of the Research and Development Centre, Indonesia*, Paleontology Series No. 3.
- Combémoré, R. 1973. Les Duvaliidae Pavlow (Belemnitida) du Crétacé Inférieur Français. *Documents de la Laboratoire de Géologie de la Faculté des Sciences de Lyon*, 57:131-185.
- Combémoré, R. 1988. Les bélemnites de Madagascar. *Documents de la Laboratoire de Géologie de la Faculté des Sciences de Lyon*, 104:1-239.
- Crame, J.A. 1982. Late Jurassic inoceramid bivalves from the Antarctic Peninsula and their stratigraphic use. *Palaeontology*, 25:555-603.
- Crame, J.A. 1983. The occurrence of the Upper Jurassic bivalve *Malayomaorica malayomaorica* (Krumbeck) on the Orville Coast, Antarctica. *Journal of Molluscan Studies*, 49:61-76.
- Crame J.A. 1987. Late Mesozoic bivalve biogeography of Antarctica, p. 93-102. In McKenzie, G.D. (ed.), *Gondwana six: stratigraphy, sedimentology and palaeontology*. Geophysical monograph, 41. American Geophysical Union, Washington D.C.
- Crame, J.A. 1990. Buchiid bivalves from the Jurassic-Cretaceous boundary in Antarctica, p. 151-161. In Menner, V.V. (ed.), *The Jurassic-Cretaceous boundary*. Trudy Institut Geologii i Geofiziki Akademiiya Nauk SSSR Sibirscoe Otdelenie.
- Crame, J.A., Arntz, W.E., and Thomson, M.R.A. 2000. A Late Jurassic - Early Cretaceous belemnite dredged from the floor of the Eastern Weddell Sea. *Antarctic Science* 12(1):117-118.
- Dalziel, I.W.D. and Elliot, D.H. 1973. The Scotia Arc and Antarctic margin, p. 171-246. In *The Ocean Basins and Margins*, v.1, The South Atlantic.
- Damborenea, S.E. 1990. Middle Jurassic Inoceramids from Argentina. *Journal of Paleontology*, 64:736-759.
- Damborenea, S.E. 1996. Andean Jurassic Inoceramids as potential bioevent markers for the Austral Realm. *Advances in Jurassic Research*, GeoResearch Forum vols. 1-2:433-442.
- Damborenea, S.E. and Mancenido, M.O. 1992. A comparison of Jurassic marine benthonic faunas from South America and New Zealand. *Journal of the Royal Society of New Zealand* 22:131-152.
- d'Orbigny, A. 1842. Paléontologia Française. Terrains Oolitiques ou Jurassiques. T.1. Masson, Paris.
- d'Orbigny, A. 1845-1847. Mollusques vivants et fossiles ou description de toutes les espèces de Coquilles et de Mollusques. 605 pages, atlas of 36 plates. Paris.
- Doyle, P. 1992. The British Toarcian (Lower Jurassic) belemnites, part 2. *Monograph of the Paleontographical Society*, p.50-79.
- Doyle, P. and Howlett, P. 1989. Antarctic belemnite biogeography and the break-up of Gondwana. In Crame, J.A. (ed.), *Origins and Evolution of the Antarctic Biota*. Geological Society Special Publication 47.
- Doyle, P., Donovan, D.T., and Nixon, M. 1994. Phylogeny and systematics of the Coleoidea. *The University of Kansas Paleontological contributions n.s* 5.
- Doyle, P., Kelly, S.R.A., Pirrie, D., Riccardi, A.C., and Olivero, E. 1996. Jurassic belemnite biostratigraphy of the southern hemisphere: a comparative study of Antarctica and Argentina. *Revista de la Asociacion Geologica Argentina*, 51:331-338.
- Eagle, M. and Hikuroa, D.C.H. 2003. *Chariocrinus* (Crinoidea: Articulata) from the Latady Formation, Behrendt and Hauberg Mountains, Ellsworth Land, Antarctica. *New Zealand Journal of Geology and Geophysics*, 46:529-537.
- Gardner, R.N. and Campbell, H.J. 2002a. Middle to Late Jurassic bivalves of the subfamily Astartinae from New Zealand and New Caledonia. *New Zealand Journal of Geology and Geophysics*, 45:1-51.
- Gardner, R.N. and Campbell, H.J. 2002b. Middle to Late Jurassic bivalves of the genera *Neocrassina* and *Trigonopsis* from New Zealand. *New Zealand Journal of Geology and Geophysics*, 45:323-347.
- Grunow, A.M. 1993a. Creation and destruction of Weddell Sea floor in the Jurassic. *Geology*, 21:647-650.
- Grunow, A.M. 1993b. New Paleomagnetic Data from the Antarctic Peninsula and Their Tectonic Implications. *Journal of Geophysical Research*, 98(B8):13,815-13,833.
- Haq, B.U., Hardenbol, J., and Vail, P.R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235:1156-1167.
- Haq, B.U., Hardenbol, J., and Vail, P.R. 1988. Mesozoic and Cenozoic Chronostratigraphy and cycles of sea-level change, p. 71-108. In Wilgus, C.K., Hastings, B.S., Ross, C.A., Posamentier, H.W., Van Wagoner, J., and Kendall, C.S. C. (eds.), *Sea Level Changes - an integrated approach*, Special Publication 42, Society of Economic Paleontologists and Mineralogists.

- Hallam, A. 1983. Early and Mid-Jurassic molluscan biogeography and the establishment of the central Atlantic seaway. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 43:181-193.
- Hector, J. 1878. On the Belemnites found in New Zealand. *Transactions of the New Zealand Institute*, 10:484-489.
- Hikuroa, D.C.H. 2005. The Fauna and Biostratigraphy of the Jurassic Latady Formation, Antarctic Peninsula. Ph.D. thesis, University of Auckland Library, Auckland, New Zealand.
- Hikuroa, D.C.H. and Kaim, A. 2007. New gastropods from the Jurassic of Orville Coast, eastern Ellsworth Land, Antarctica. *Antarctic Science*, 19(1):115-124.
- Hudson, N. 1999. The Middle Jurassic of New Zealand: a study of the lithostratigraphy and biostratigraphy of the Ururoan, Temaikan and Lower Heterian Stages (?Pleinsbachian to ?Kimmeridgian). Unpublished PhD thesis, University of Auckland Library, Auckland, New Zealand.
- Hudson, N. 2003. Stratigraphy and correlation of the Ururoan and Temaikan Stage (Lower-Middle Jurassic, ?Sinemurian-Callovian) sequences, New Zealand. *Journal of the Royal Society of New Zealand*, 33(1):109-147.
- Hunter, M.A. 2003. A new regional stratigraphy for Eastern Ellsworth Land. In Programme and Abstracts Volume, 9<sup>th</sup> International Symposium on Antarctic Earth Sciences, Potsdam, Germany.
- Jeletzky, J.A. 1965. Late Upper Jurassic and early Lower Cretaceous fossil zones of the Canadian Western Cordillera, British Columbia. *Geological Survey of Canada Bulletin*, 103.
- Jeletzky, J.A. 1972. Morphology and taxonomic status of the Jurassic belemnite "*Rhopaloteuthis*" somaliensis Spath 1935. *Paleontology*, 15:158-183.
- Jeletzky, J.A. 1980. Dicoelitid belemnites from the Toarcian-Middle Bajocian of western and arctic Canada. *Geological Survey of Canada Bulletin*, 338.
- Jeletzky, J.A. 1983. Macroinvertebrate Paleontology, Biochronology, and Paleoenvironments of Lower Cretaceous and Upper Jurassic rocks, Deep Sea Drilling Hole 511, eastern Falkland Plateau, p. 951-975. *Initial Reports of the Deep Sea Drilling Project*, 71.
- Jokat, W., Boebel, T., König, M., and Meyer, U. 2003. Timing and geometry of early Gondwana breakup. *Journal of Geophysical Research*, 108(B9):15 pp.
- Jones, D.L. and Plafker, G. 1977. Mesozoic megafossils from DSDP hole 327A and Site 330 on the eastern Falkland Plateau, p. 845-855. *Initial Reports of the Deep Sea Drilling Project*, 36.
- Kelly, S.R.A. 1995. New Trigonoid bivalves from the Early Jurassic to earliest Cretaceous of the Antarctic Peninsula region: systematics and Austral paleobiogeography. *Journal of Paleontology*, 69(1):66-84.
- Krishna, J. 1994. Origin of the Gondic (Trans-Gondwana) Corridor: the ammonoid evidence, p. 1091-1099. In Ninth International Gondwana Symposium, Geological Survey of India.
- Krymholz, G.Y. 1992. Slits in the rostra of belemnites. *Paleontological Journal (translated from Paleontologicheskaya Zhurnal)*, 26(3):124-127.
- Lamare, P. 1936. Recherches géologiques dans les Pyrénées basques d'Espagne. *Mémoire Société géologique France (NS)*, v. 14.
- Laudon, T.S., Lackey, I.L., Quilty, P.G., and Otway, P.M. 1969. Geology of eastern Ellsworth Land (sheet 3, eastern Ellsworth Land). In Bushnell, V.C. and Craddock, C. (eds), *Geologic maps of Antarctica*. American Geographical Society Antarctic Map Folio Series, 12.
- Laudon, T.S., Thomson, M.R.A., Williams, P.L., Milliken, K.L., Rowley, P.D., and Boyles, J.M. 1983. The Jurassic Latady Formation, Southern Antarctic Peninsula, p. 308-314. In Oliver, R.L., James, P.R., and Jago, J.B. (eds.), *Antarctic Earth Science*. Australian Academy of Science, Canberra.
- Lissajous, M. 1915. Quelques remarques sur les Bélemnites Jurassiques. *Bulletin Société Histoire naturelle, Mâcon*, 1-32.
- Montfort, de P. 1808. Conchyliologie systematique, et classification methodique des coquilles; offrant leurs figures, leur arrangement generique, leurs descriptions caracteristiques, leurs noms; ainsi que leur synonymie en plusieurs langues. *Coquilles univalves, cloisonnes*, 1.
- Mutterlose, J. 1986. Upper Jurassic belemnites from the Orville Coast, Western Antarctica, and their paleobiogeographical significance. *British Antarctic Survey Bulletin*, 70:1-22.
- Naef, A. 1922. Die Fossilien Tintenfische. G. Fischer, Jena.
- Parona, C.F. and Bonarelli, G. 1897. Fossili Albiani d'Escragnoles del Nizzardo e della Ligurias occidentale. *Paleontographica Italia*, 2:53-112.
- Parrish, J.T. 1992. Jurassic Climate and Oceanography of the Pacific Region, p. 365-379. In Westermann, G.E.G. (ed.), *The Jurassic of the Circum-Pacific - International Geological Correlation Programme Project 171*, Cambridge University Press.
- Pavlov, A.P. 1913. Les cephalopods du Jura et du crétacé inférieur de la Sibérie septentrionale. *Same*, 21(4):1-68.
- Quilty, P.G. 1970. Jurassic ammonites from Ellsworth Land, Antarctica. *Journal of Paleontology*, 44:110-116.
- Quilty, P.G. 1972a. Middle Jurassic brachiopods from Ellsworth Land, Antarctica *New Zealand Journal of Geology and Geophysics*, 15:140-147.
- Quilty, P.G. 1972b. *Pentacrinites* and (?)*Apiocrinus* from the Jurassic of Ellsworth Land, Antarctica. *Neues Jahrbuch für Geologie und Paläontologie Monatsheft*, 8: 484-489.

- Quilty, P.G. 1978. Late Jurassic bivalves from Ellsworth Land, Antarctica: their systematics and paleogeographic implication. *New Zealand Journal of Geology and Geophysics*, 20:1033-1080.
- Quilty, P.G. 1983. Bajocian bivalves from Ellsworth Land, Antarctica. *New Zealand Journal of Geology and Geophysics*, 26:395-418.
- Quilty, P.G. 1988. *Cycleryon* Glaessner (Crustacea, Decapoda) from the Jurassic of Ellsworth Land, Antarctica. *Journal of Paleontology*, 64(2):619-622.
- Riegraf, W. 1980. Revision of the Swabian Jurassic belemnites. *Palaeontographica Abteilung A: Palaeozoologie-Stratigraphie*, 169:128-206.
- Riegraf, W. 1981. Revision of the Swabian Jurassic belemnites. *Palaeontographica Abteilung A: Palaeozoologie-Stratigraphie*, 173:64-139.
- Riegraf, W. 1999. Taxonomic status of the belemnite genus *Belemnopsis* Bayle 1878. *Paläontologische Zeitschrift*, 73(1):59-76.
- Rothpletz, A. 1892. Die Perm-, Trias-, und Jura-Formation auf Timor und Rotti im Indischen Archipelago. *Palaeontographica*, 39(2):57-106.
- Rowley, P.D. and Williams, P.L. 1982. Geology of the Northern Lassiter Coast and Southern Black Coast, Antarctic Peninsula, p. 339-348. In Craddock, C. (ed.), *Antarctic Geoscience*. The University of Wisconsin Press, Madison.
- Rowley, P.D., Vennum, W.R., Kellogg, K.S., Carrara, P.E., Boyles, J.M., and Thomson, M.R.A. 1983. Geology and plate tectonic setting of the Orville Coast and eastern Ellsworth Land, Antarctica, p. 245-250. In Oliver, R.L., James, P.R., and Jago, J.B. (eds.), *Antarctic Earth Science*. Australian Academy of Science, Canberra.
- Sachs, V.N. and Naljaeva, T.I. 1967. On the systematics of Jurassic and Cretaceous belemnites (in Russian). In: Sachs, V.N. (ed.), *Problems of paleontologic substantiation of detailed Mesozoic stratigraphy of Siberia and the Far East of USSR*. Materials for the 2nd International Colloquium on the Jurassic System, Luxembourg, July 1967: 6-27. Leningrad (Nauka) (Systematics).
- Smellie, J.L. 1981. A complete arc-trench system recognised in Gondwana sequences of the Antarctic Peninsula region. *Geological Magazine*, 118:139-159.
- Stevens, G.R. 1963. Faunal realms in Jurassic and Cretaceous Belemnites. *Geological Magazine*, 100(6):481-497.
- Stevens, G.R. 1965. The Jurassic and Cretaceous belemnites of New Zealand, and a review of the Jurassic and Cretaceous belemnites of the Indo-Pacific region. *New Zealand Geological Survey Paleontological Bulletin* 36.
- Stevens, G.R. 1967. Upper Jurassic fossils from Ellsworth Land, West Antarctica, and notes on Upper Jurassic biogeography of the southwest Pacific region. *New Zealand Journal of Geology and Geophysics*, 10:345-393.
- Stevens, G.R. 1980. Southwest Pacific faunal palaeobiogeography in Mesozoic and Cenozoic times: a review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 31:153-196.
- Stevens, G.R. 1989. The nature and timing of biotic links between New Zealand and Antarctica in Mesozoic and early Cenozoic times, p. 141-166. In Crame, J.A. (ed.), *Origins and Evolution of the Antarctic Biota*. Geological Society Special Publication 47.
- Stevens, G.R. 1997. The Late Jurassic Ammonite fauna of New Zealand. *Institute of Geological and Nuclear Sciences monograph 18 (New Zealand Geological Survey Paleontological Bulletin 74)*. Institute of Geological and Nuclear Sciences Limited, New Zealand.
- Studinger, M. and Miller, H. 1999. Crustal structure of the Filchner-Ronne shelf and Coats Land, Antarctica, from gravity and magnetic data: Implications for the breakup of Gondwana. *Journal of Geophysical Research*, 104(B8):20379-20394.
- Suarez, M. 1976. Plate tectonic model for southern Antarctic Peninsula and its relation to southern Andes. *Geology*, 4:211-214.
- Thomson, M.R.A. 1980. Late Jurassic ammonite faunas from the Latady Formation, Orville Coast. *United States Antarctic Journal*, 15:28-30.
- Thomson, M.R.A. 1981. Mesozoic ammonite faunas of Antarctica and the breakup of Gondwana, p. 269-275. In Cresswell, M.M. and Vella, P. (eds.), *Gondwana Five* (selected papers and abstracts of papers presented at the Fifth International Gondwana Symposium).
- Thomson, M.R.A. 1983. Late Jurassic ammonites from the Orville Coast, Antarctica, p. 315-319. In Oliver, R.L., James, P.R., and Jago, J.B. (eds.), *Antarctic Earth Science*. Australian Academy of Science, Canberra.
- Vaughan, A.P.M., and Storey, B.C. 2000. The eastern Palmer Land shear zone: a new terrane accretion model for the Mesozoic development of the Antarctic Peninsula. *Journal of the Geological Society, London*, 157:1243-1256.
- Vaughan, A.P.M., Kelley, S.P., and Storey, B.C. 2002. Mid-Cretaceous ductile deformation on the Eastern Palmer Land Shear Zone, Antarctica, and implications for timing of Mesozoic terrane collision. *Geological Magazine*, 109(4):465-471.
- Voltz, M. 1830. Observations sur les bélemnites. *Memoire Societe Histoire Naturelle Strasbourg*, 1:1-70.
- von Hillebrandt, A., Smith, P., Westermann, G.E.G., and Callomon, J.H. 1992. Ammonite zones of the circum-Pacific region, p. 247-272. In Westermann, G.E.G. (ed.), *The Jurassic of the Circum-Pacific*. Cambridge University Press, Cambridge.
- von Hochstetter, F. 1863. Neu-Seeland. Cotta, Stuttgart.
- von Zittel, K.A. 1895. Grundzüge der Palaeontologie (Palaeozoologie), Oldenbourg, München.

- Westermann, G.E.G. 1981. Ammonite biochronology and biogeography of the Circum Pacific Middle Jurassic. In House, M.R. and Senior, J.R. (eds.), *The Ammonoidea*. Systematic Association Special Volume 18.
- Westermann, G.E.G. and Hudson, N. 1991. The first find of Eurycephalitinae (Jurassic Ammonitina) in New Zealand and its biogeographic implications. *Journal of Paleontology*, 65(4):689-693.
- Willan, C.R. and Hunter, M.A. 2005. Basin evolution during the transition from continental rifting to subduction: Evidence from the lithofacies and modal petrology of the Jurassic Latady Group, Antarctic Peninsula. *Journal of South American Earth Sciences*, 20:171-191.
- Willey, L.E. 1973. Belemnites from southeast Alexander Island: II. The occurrence of the family Belemnopseidae in the Upper Jurassic and Lower Cretaceous. *British Antarctic Survey Bulletin*, 36:33-59.
- Williams, P.L., Schmidt, D.L., Plummer, C.C., and Brown, L.E. 1972. Geology of the Lassiter Coast area, Antarctic Peninsula – preliminary report, p. 143-153. In Adie, R. J. (ed.), *Antarctic Geology and Geophysics*. Universitetsforlaget, Oslo.

## APPENDIX

**Belemnites of Uncertain Affinity**

The following specimens cannot be identified at the generic level. Brief descriptions are included to complete the record.

**Specimens UTGD87347b (Locality Q13).**

Two apical fragments, each c. 45 mm long, both with what appear to be very wide shallow grooves extending to near the apex (cf. UTGD87220a). One 60 mm fragment of stem and part of the ?apical region with no visible grooves. One flank of the specimen is concealed.

**Specimen UTGD87347d (Q13).**

One apical fragment 30 mm long, one flank preserved, no groove or lateral lines visible.

**Specimen UTGD87361d (Q15).**

One apical fragment 35 mm long. All surfaces are visible. No groove is visible but what appear to be faint, ventrolaterally placed lateral lines are present on one flank. Cross section appears compressed.

**Specimens UTGD87220a (Q4).**

A latex slab with parts of 18 poorly preserved specimens. Both apical and anterior fragments are present. The specimens include:

1. Two small ?anterior fragments with *Belemnopsis* or possibly *Hibolithes*-type ventral grooves; two partial specimens 40–50 mm long, both including the apex, with what appear to be either (1), very wide, shallow surface grooves extending over much of the fragment (cf. UTGD87347b), or (2), eroded lateral lines, or (3), ventrolateral apical grooves extending down the guard.
2. One apical fragment 45 mm long, with an inflated ventral surface and a compressed cross section. No grooves or lateral lines visible. Two large anterior fragments. One is 35

mm long and preserved with one flank visible, the other 10 mm long and preserved in the round. Both are 10–12 mm in diameter and both lack surface grooves. The shorter fragment is strongly laterally compressed.

**Specimens UTGD87293b (Q10).**

Two partial casts of apical regions, each with one flank visible, both c. 35 mm long. Both are ventrally inflated. No surface grooves visible.

**Specimen UTGD87308b (Q10).**

One apical fragment 40 mm long, maximum diameter c. 8.5 mm, ventral surface appears inflated. What appear to be faint lateral lines present on posterior mid flank. Cross section ?compressed.

**Specimen UTGD87285a (Q6).**

One apical fragment 35 mm long, c. 6 mm in maximum diameter. A possible short ventrolateral apical depression, continued anteriorly as faint lateral lines, is present. Possibly a passaloteuthid.

**Specimen UTGD87267b (Q10).**

One apical fragment 40 mm long and c. 9 mm in maximum diameter, with one flank exposed. Ventrally(?) placed lateral lines visible over much of fragment.

**Specimen R.7519.17.4.**

A small sagittally hastate(?) specimen c. 20 mm long and 5 mm in maximum diameter, one flank of which is exposed. No ventral or other groove is visible. A conical structure, partially detached from the anterior end, may be a cast of part of the alveolus.

**Specimens R.7508 13.8, R.7508.15.35.**

A number of small specimens lying parallel to a bedding plane. A second larger, juvenile(?) specimen, consisting of an apical and stem fragment. No surface grooves visible, but their general appearance suggests *Hibolithes*.