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Stratigraphy of Tithonian (Ohauan–Puaroan) marine beds near Port Waikato, New Zealand, and a redescription of *Belemnopsis aucklandica* (Hochstetter)

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Abstract Some 1500 m of marine Ohauan and Puaroan strata in the Port Waikato region of New Zealand are restudied in an attempt to resolve lithostratigraphic and biostratigraphic anomalies in published works. New correlations are proposed for some units of the Apotu Group. A lower 650 m siltstone, previously correlated entirely with Kinohaku Siltstone, is here regarded as including the interval Kinohaku Siltstone to **Lower Puti Siltstone** (new member). The Waiharakeke Conglomerate is not represented in the area by coarse sediments. A thin sandstone unit overlying the Lower Puti Siltstone and previously correlated with Waiharakeke Conglomerate is here correlated with the Ruakiwi Sandstone. The overlying 400 m siltstone, regarded previously as the entire Puti Siltstone, is here recognised as a new member, the **Upper Puti Siltstone**. The Coleman Conglomerate is much thicker in the region than mapped, and located higher in the sequence. Biostratigraphy is a key element in correlating the sequence with named units to the south. The sequence is mostly siltstone, but sandstone units provide some lithostratigraphic control. Belemnites are almost the only fossils found in the Late Ohauan and Early Puaroan part of the sequence and are important in the Late Puaroan. Formal belemnite zones, based in part on their stratigraphic distributions in other parts of southwest Auckland, are erected. Occasional ammonites provide tie points that correlate the succession with the standard stratigraphic column for the Tethyan realm. *Belemnopsis aucklandica* (Hochstetter) is redescribed and considered to be of full specific status as is its former subspecies, *Belemnopsis trechmanni* Stevens. Many pre-adult *Belemnopsis aucklandica* differ in form from adults; some have been previously identified in the field as *Hibolithes*. Some earlier identifications of belemnites from the Late Puaroan of Port Waikato are incorrect; most are now included in *Belemnopsis aucklandica*.

Keywords Port Waikato; Ohauan; Puaroan; Tithonian; lithostratigraphy; biostratigraphy; belemnite zones; *Belemnopsis aucklandica*; Lower Puti Siltstone; Upper Puti Siltstone; new stratigraphic names

INTRODUCTION

This study re-examines a sequence of Jurassic beds in the Port Waikato region of southwest Auckland (Fig. 1–3). They comprise the Apotu Group of Kear (1966) and are the youngest and most northerly marine strata of the Murihiku Supergroup (Campbell & Coombs 1966) in the Kawhia Regional Syncline.

The main objectives are to refine and expand an existing biostratigraphy, to re-examine key biostratigraphic indicator fossils, to redescribe lithostratigraphic units and review published correlations, and to redescribe *Belemnopsis aucklandica* (Hochstetter) (new taxonomy) using large previously unavailable collections.

The region studied is located within Sheet R13, New Zealand Map Series NZMS 260, 1:50 000. It is bounded to the north by the Waikato River and to the south by a line running approximately northeast from a point 1 km south of the mouth of Huriwai River, although some specimens of *Belemnopsis aucklandica* from south of this line are included in its taxonomic study.

The stratigraphically lowest beds studied (Late Ohauan *sensu* Meesook & Grant-Mackie 1995) crop out on eastern tributaries to Okahu Stream (Fig. 2). Strata of Early Puaroan age (Challinor 1977, 1999) are centred on Daff Road (Fig. 2), and a Late Puaroan sequence (Challinor 1977) extends westwards along Daff Road (Fig. 2). The Late Puaroan is better exposed south and west of Port Waikato wharf (Fig. 3) and was studied mostly in that area. Late Ohauan and Puaroan Stages correlate with Late Kimmeridgian (youngest part) to Late Tithonian international stages (Stevens 1997).

The base of the Puaroan Stage and of the Mangaoran Substage is now recognised by the first appearance of *Hibolithes arkelli* Stevens (Challinor 1999), although the original position of the base of the stage remains unaltered. The indicator fossil of the Late Puaroan (Mangaoran) Substage (*Belemnopsis aucklandica*) remains unchanged, although the reinterpretation of a single belemnite specimen has altered the extent of the Waikatoan type section (see below). The biostratigraphic units Puaroan Zones A and B (Purser 1952, 1961) are contained wholly within the Waikatoan.

Fieldwork was directed mainly towards fossil collecting, but all opportunities were taken to observe lithology. Exposure is intermittent, particularly in the lower parts of stream valleys in the area covered by Fig. 2. However, enough observations were made to provide a reasonable appreciation of the sequence, although thin units could have been missed.

The first detailed research in the Port Waikato region was that of Purser (1961), although several earlier studies that were less comprehensive, or dealt only in part with the region, had preceded his work. The first observations were those of Ferdinand von Hochstetter who visited the area near the mouth of the Waikato River in 1859, and was the first to

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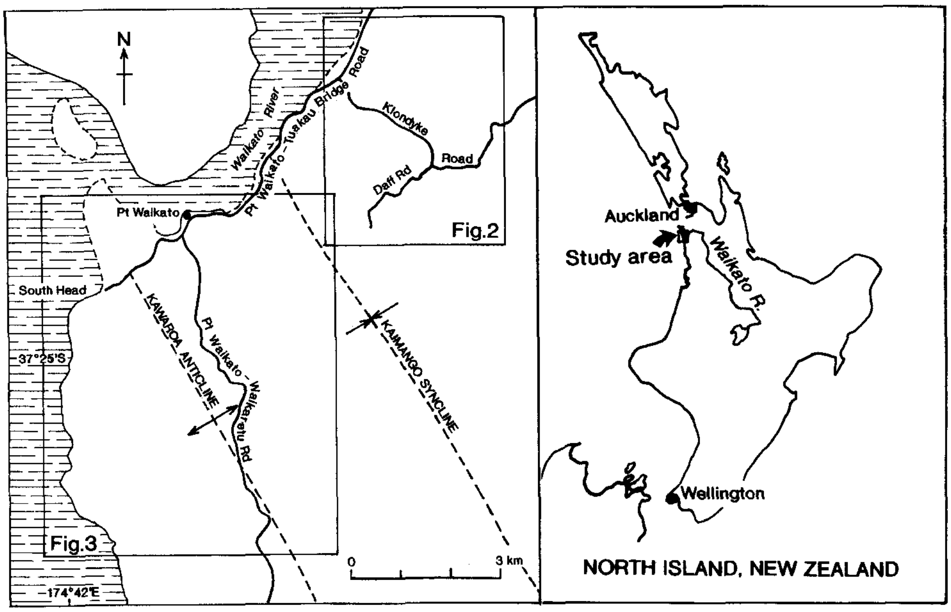


Fig. 1 Port Waikato region and location in North Island of New Zealand. Location of study areas outlined (Fig. 2, 3). Basement rocks are folded sequences of the Murihiku Supergroup. The locations of major fold axes are indicated.

recognise Mesozoic strata in New Zealand (Hochstetter 1864). A selected list of publications on the geology of the region is contained in Rodgers & Grant-Mackie (1978). B. C. Waterhouse remapped the region in 1978.

Purser mapped the Jurassic rocks in terms of biostratigraphic units and, apart from Huriwai Formation at the top of the sequence, did not recognise individual rock units. Formation names were subsequently applied to the sequence studied here by Waterhouse (Takatahi Formation, Kinohaku Siltstone, Waiharakeke Conglomerate, Puti Siltstone). These units were originally erected in the Kawhia region by Fleming & Kear (1960). Younger formations (Coleman Conglomerate, Waikorea Siltstone) were first recognised in the Te Akau district south of Port Waikato by Kear (1966). Waikorea Siltstone underlies Purser's Huriwai Formation, renamed Huriwai Group by Kear (1966) and Huriwai Measures by Waterhouse (1978).

The Upper Ohauan–Puaroan siltstone formations in the Kawhia region (Kowhai Point, Kinohaku and Puti Siltstones) are composed of blue-grey mudstone and siltstone, with minor sandstone, the latter usually thin and fine grained. They are lithologically similar and, in the absence of either their distinctive faunas or the intervening conglomerates, are difficult to differentiate. The conglomerates (Takatahi Formation, Waiharakeke Conglomerate) become thinner and finer grained northwards (Kear 1966; Waterhouse 1978) and are more difficult to recognise in the Port Waikato district.

A biostratigraphic framework for the Ohauan–Puaroan was first developed around the shores of Kawhia Harbour (Marwick 1953; Fleming & Kear 1960). Subsequent work (Stevens 1965; Challinor 1979a; Meesook & Grant-Mackie 1995) concentrated on the same area, partly for reasons of continuity, and partly because the well-exposed shore platforms and cliffs provide fresh, largely unweathered exposures yielding a continuous supply of reasonably well preserved fossils. However, parts of the sequence (Middle and Upper Ohauan and Lower Puaroan) in the Kawhia region are notable for a lack of benthic faunas (Fleming & Kear 1960; Stevens 1965; Meesook & Grant-Mackie 1995). Here, work has tended to concentrate on the remains of free-swimming organisms (ammonites and belemnites). Benthic fossils do not provide a workable biostratigraphic framework above the Middle Ohauan until the later part of the Lower Puaroan.

The situation is similar in the older sequences within the study area. Exposures within the watershed of Okahu Stream (Fig. 2) are not particularly numerous, almost always weathered, and have yielded relatively few fossils. With rare exceptions these are belemnites and occasional ammonites. Fossils of restricted Puaroan age are known from above those of Ohauan age on Okahu Stream (Challinor 1974) and a few more belemnites have since become available. More importantly, studies of the ammonites (Stevens 1997) and belemnites (Challinor 1996, 1999) have been published. These allow a more confident assessment of the fossil succession, age determinations, and lithological correlations.

Belemnites are critical to this study. *Hibolithes* is the only fossil found in any numbers within the Early Puaroan at Port Waikato, and *Belemnopsis aucklandica* is abundant in the early part of the Late Puaroan. Early Puaroan *Hibolithes* have been restudied (Challinor 1999), and this study re-examines *Belemnopsis aucklandica* in an attempt to minimise the possibility of misidentification with some *Hibolithes*. The writer's fossil collections, on which this and other published studies are partly based, will shortly be deposited in the Department of Geology, University of Auckland.

STRUCTURE, LITHOLOGY, AND CORRELATION

The Jurassic rocks of southwest Auckland extend from near Awakino northwards for c. 140 km into the Port Waikato region, where they are downfaulted 2–3 km by the Waikato Fault. They form the core of the Kawhia Syncline (Fleming & Kear 1960). Kaimango Syncline and Kawaroa Anticline are slightly asymmetric folds on the eastern limb of Kawhia Syncline and can be traced northwards to Port Waikato (Fleming & Kear 1960; Purser 1961; Waterhouse 1978).

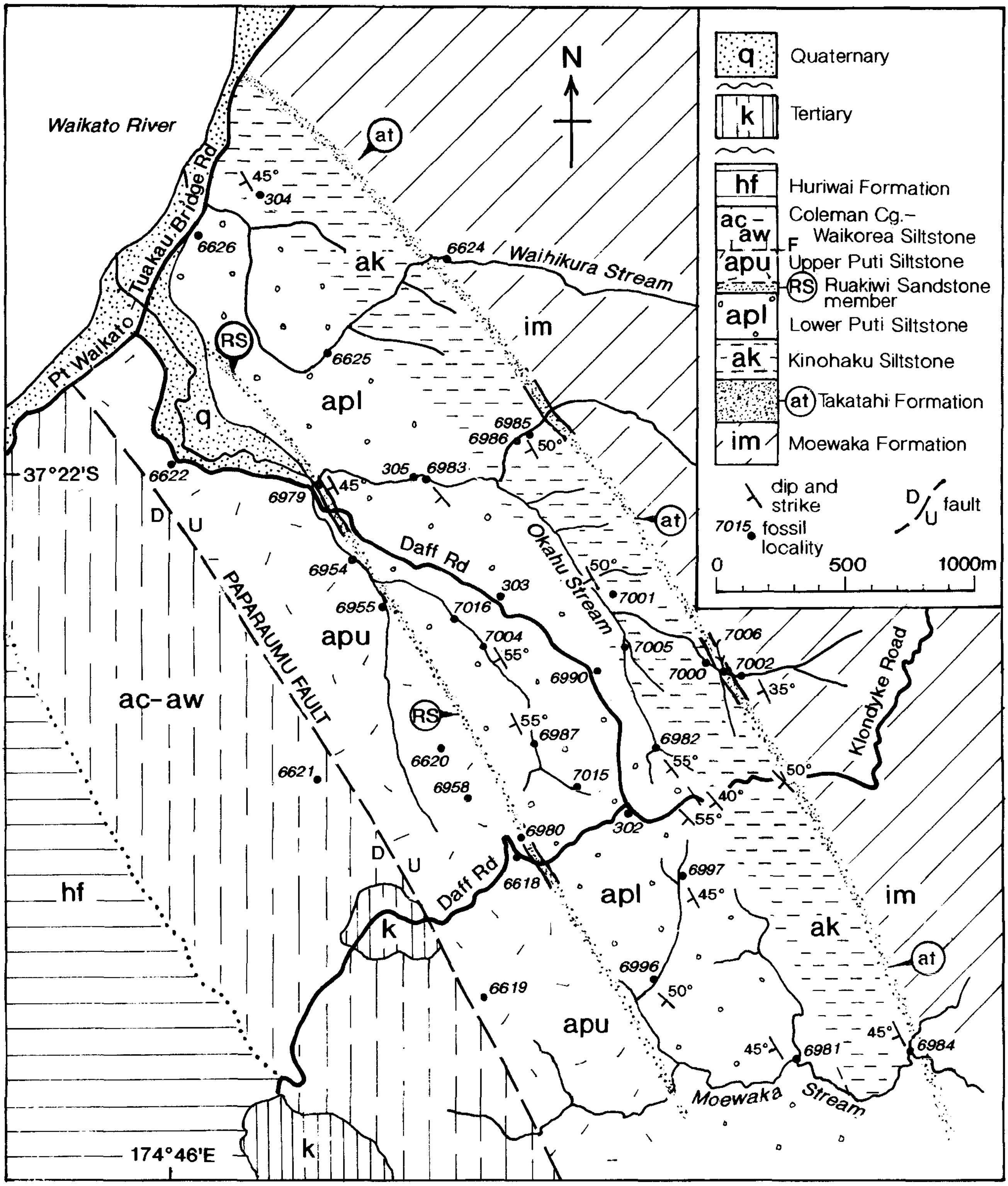


Fig. 2 Geology and fossil localities near Okahu and Moewaka Streams, Port Waikato region. Map based on Purser (1961), Challinor (1974), Waterhouse (1978), and additional fieldwork by A.B.C.

Within the areas studied, the lithology in the lower part of the sequence is mostly mudstone and siltstone with rare medium and fine sandstone. Medium sandstones become dominant in the upper part. There are also common, thin (10–50 mm), pale-coloured rhyolitic tuff beds throughout. The rocks are moderately indurated and weakly metamorphosed.

Beds within the watershed of Okahu Stream are located on the eastern limb of Kaimango Syncline (Waterhouse 1978). They have regional strike of c. 325° and dip westwards at 45–55°, greater than the average regional dip of 30–35° noted on the eastern limb by Purser (1961). All stratigraphic thicknesses and intervals stated herein are approximate. The Takatahi Formation to

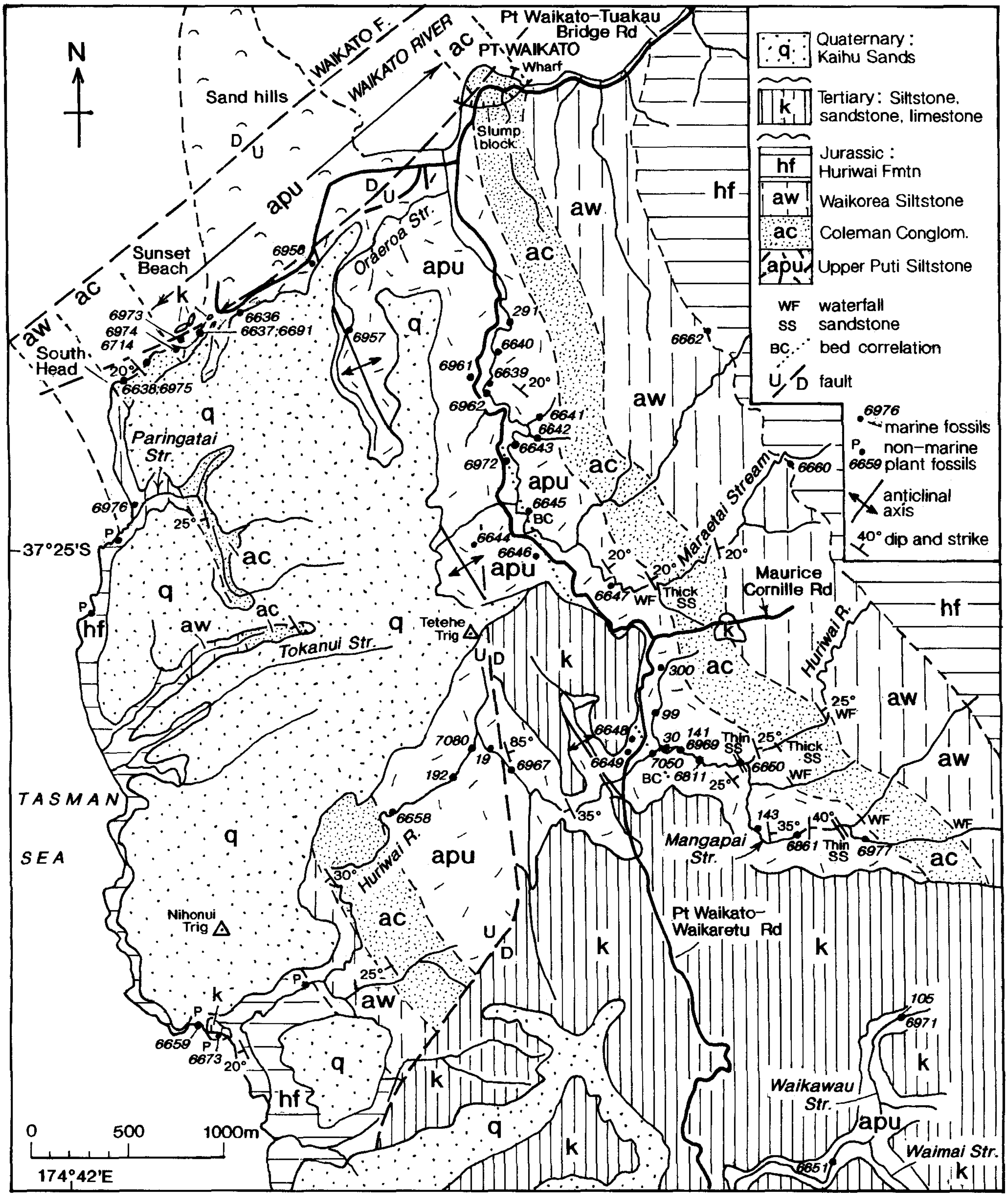


Fig. 3 Geology and fossil localities south and west of Port Waikato. Base map from Purser (1961, map 3). Map based on Purser (1961), Waterhouse (1978), unpublished maps by R. M. Briggs, C. S. Nelson and J. Gillespie (University of Waikato), and additional fieldwork by A.B.C. All localities containing belemnites and ammonites are shown; many also contain *Buchia* spp.

Ruakiwi Sandstone part of the sequence was studied in the area covered by Fig. 2. The Upper Puti Siltstone to Waikorea Siltstone sequence was studied to the west (Fig. 3).

Takatahi Formation

Beds correlated with the Takatahi Formation crop out in the Okahu valley approximately between grid ref. R13/680250 and R13/690238. They comprise 50 m of fine–medium sandstones, each c. 1 m thick, some containing mudstone clasts and separated by thinly bedded siltstone. The formation was observed only on eastern tributaries of Okahu Stream (Fig. 2) and may be lensoidal (Challinor 1974). It was not seen on Port Waikato-Tuakau Bridge Road, Klondyke Road, or Moewaka Stream, and its positions there are indicated by projection along the strike. Its possible position on Waihikura Stream was not visited. The beds are correlated with Takatahi Formation by location immediately above thick siltstones of the Moewaka Formation (Waterhouse 1978), the upper part of which correlates with the Kowhai Point Siltstone at Kawhia Harbour, and by biostratigraphy and sedimentary coarsening to sandstone.

Kinohaku Siltstone to Lower Puti Siltstone

Some 650 m of poorly exposed beds, mostly mudstones and siltstones, with thin, pale-coloured tuffaceous bands and minor thin sandstones and concretionary horizons in the lower part, overlie the Takatahi Formation. They crop out on Okahu Stream and tributaries, on Daff Road, and on Moewaka Stream and tributaries south of Daff and Klondyke Roads (Fig. 2). Fine-grained lithology, position immediately above Takatahi Formation, and biostratigraphy correlate the lower 250 m with Kinohaku Siltstone.

About 400 m of mudstone, siltstone, and rare fine sandstone overlying the Kinohaku Siltstone is here included in the **Lower Puti Siltstone** (new member), correlated with the lower part of the Puti Siltstone of the Te Akau and Kawhia regions. Fine-grained lithology, position immediately above beds correlated with Kinohaku Siltstone, and biostratigraphy support this correlation.

Waiharakeke Conglomerate is present between the Kinohaku Siltstone and Puti Siltstone in the Kawhia and Te Akau regions (Fleming & Kear 1960; Kear 1966) but is apparently not represented by coarse sediments within the area studied. Any fine-grained correlatives of the Waiharakeke Conglomerate within the study area are here included in the Lower Puti Siltstone. The boundaries between the Kinohaku Siltstone and Lower Puti Siltstone indicated in Fig. 2, 10 and 11 are approximately located.

Ruakiwi Sandstone

Waterhouse (1978) mapped thin sandstones on Daff Road (Fig. 2, grid ref. R13/673245 and 680232) as Waiharakeke Conglomerate and correlated the 650 m of beds between Takatahi Formation and his Waiharakeke Conglomerate entirely with Kinohaku Siltstone. The lower 250 m of these beds are here correlated with the Kinohaku Siltstone, and the upper 400 m with the Lower Puti Siltstone.

Waterhouse's Waiharakeke Conglomerate is c. 45 m thick in the region studied and composed of very fine grained sandstones and siltstones. If this sandstone unit correlates with any known formation, it does so with the Ruakiwi Sandstone of the Te Akau region (Kear 1966). This correlation is supported by biostratigraphic data from below, within, and above the unit (see below).

Correlation of eastern and western sequences

Purser (1961) suggested that Kawaroa Anticline plunged gently to the SSE and that the oldest beds exposed in the area covered by Fig. 3 were located in the valley of Oraeroa Stream near the mouth of Waikato River. He correlated these beds with his topmost Ohauan strata (although they were later shown to be high in the Puaroan; Challinor 1974) on the eastern flank of Kaimango Syncline. Kenny et al. (1977) did not accept a southward plunge for the anticline near the mouth of Waikato River and suggested a NNW plunge at c. 2°. Whatever the true inclination is, the plunge is so slight that Purser's correlation is unlikely to require substantial modification. Approximate correlation is accepted here, and there is thought to be no significant stratigraphic interval between outcrops near the Ruakiwi Sandstone in Okahu valley and axial beds of Kawaroa Anticline on Oraeroa Stream.

Upper Puti Silstone

The **Upper Puti Siltstone** (new member), c. 400 m thick, occupies the core of Kawaroa Anticline (Fig. 1, 3). Apart from thin sandstones, particularly near the top, it is composed of siltstones and mudstones. Thin, pale-coloured tuffaceous bands occur throughout. The sequence is moderately well exposed in the Huriwai River valley and at Maraetai Stream (Fig. 3). The Ruakiwi Sandstone, regarded here as the basal member of the Upper Puti Siltstone, apparently does not crop out in Maraetai and Huriwai valleys. No other mappable units were recognised in the Upper Puti Siltstone apart from a bed correlation between the Huriwai and Maraetai valleys (Fig. 3) recognised on paleontological criteria (see below). Fine-grained lithology, stratigraphic position above the Lower Puti Siltstone and below the Coleman Conglomerate, and biostratigraphy correlate the Upper Puti Siltstone with the upper part of the Puti Siltstone of the north Kawhia area (Player 1958) and Te Akau (Kear 1966).

Coleman Conglomerate

Overlying the Upper Puti Siltstone is a sequence of thick sandstones, siltstones, and minor conglomerate. They are correlated by change in lithology, stratigraphic position, and paleontology with the Coleman Conglomerate of the Te Akau district (Kear 1966).

Coleman Conglomerate is well exposed in cliffs at the southern end of Sunset Beach (Fig. 3). Here it consists, from the base upwards, of poorly bedded medium sandstones with some siltstone and rare fine conglomerate (20 m), thick-bedded medium sandstones (17 m), alternating thin sandstones and siltstones (7 m), thick-bedded sandstones and minor fine conglomerate (13 m), siltstones and thin fine sandstones (22 m), thick-bedded sandstones and minor fine conglomerate (25 m), thinly bedded sandstones and siltstones (35 m), and thick sandstones, more thinly bedded towards the top, with some siltstone in the upper beds. The whole unit is c. 220 m thick.

Abrupt changes of c. 90° in flow directions of Paringatai Stream and Huriwai River to parallel the regional strike indicate the position of Coleman Conglomerate to the south (Fig. 3). Directional changes are presumed to be due to stream control by thick sandstones within the formation. Most of Coleman Conglomerate and overlying formations are concealed on the western limb of Kawaroa Anticline by Quaternary Kaihu Group sands.

The Coleman Conglomerate is also present on the eastern limb of the anticline above Port Waikato wharf, and these outcrops were correlated with those at Sunset Beach by Purser (1961). The base of the formation is indicated to the south by thick sandstones and a waterfall on the upper Maraetai Stream north of Maurice Cornille Road, by thick sandstones on Huriwai River east of R13/f6650, and to the

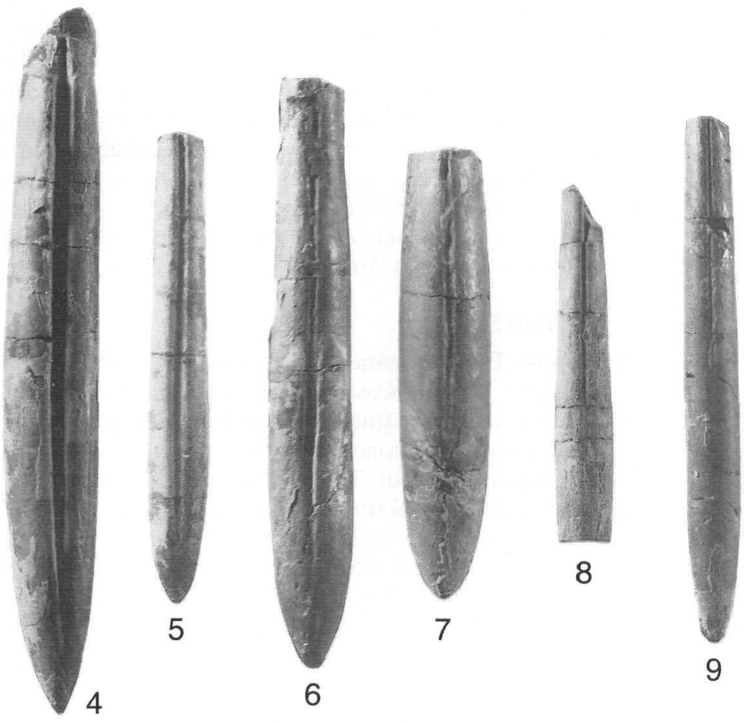


Fig. 4–9 Belemnites from key localities discussed in the text. **4**, *Belemnopsis trechmanni* Stevens, C1861; locality R13/f7000, Kinohaku Siltstone, lower part of taxon range at Port Waikato. **5**, *B. trechmanni*, C1862; R13/f7001, Kinohaku Siltstone, near top of range. **6, 7** *Hibolithes arkelli* Stevens, C1863, C1864; R13/f6982, Lower Puti Siltstone, near base of range at Port Waikato. **8**, *Hibolithes marwicki* Stevens, C1865; R13/f303, Lower Puti Siltstone, near base of range. **9**, *Hibolithes marwicki*, C1866; R13/f7004, Lower Puti Siltstone, near top of range.

Fig. 4–9 (also 19–30, 31–49, 55–82) Belemnites. Specimens figured in ventral view, or in ventral and left lateral view (ventral groove facing camera and facing left), or in transverse or longitudinal section. Ventral and lateral views, and longitudinal sections ×1; transverse sections approximately ×2. Numbers (e.g., C1861) are those of the catalogue of type and figured specimens held in the Geology Department, University of Auckland. In Fig. 19–49, 55–80, a bar indicates the approximate position of the protoconch.

southeast by waterfalls on two southwestward-flowing tributaries to Mangapai Stream. The top is indicated by waterfalls further to the east on upper Huriwai River and Mangapai Stream (Fig. 3). Waterhouse (1978) mapped the base of Coleman Conglomerate much lower in the sequence, particularly on the western limb (c. 150 m), than the position adopted here, and considered the formation to be 45 m thick in the area.

Waikorea Siltstone

Overlying the Coleman Conglomerate and well exposed in the shore platform and cliffs south and west of South Head (Fig. 3) is the Waikorea Siltstone. It consists of 275 m of blue-grey siltstone, grey sandstone and siltstone, with hard carbonaceous sandstone in the upper part. Stratigraphic position and a very sparse marine fauna correlate this unit with Waikorea Siltstone of the Te Akau region (Kear 1966). The top of the Coleman Conglomerate is indicated by the appearance of the non-marine Huriwai Formation with its well-preserved plant fossils. Fragmentary plant remains occur frequently in the Coleman Conglomerate and Waikorea Siltstone.

BIOSTRATIGRAPHY

Late Ohauan Stage

Belemnites (Fig. 4–9) are moderately common and almost the only stratigraphically useful fossils found in the lower part of the sequence studied (Fig. 10). Ammonites occur sparsely, provide some stratigraphic control, and allow overseas correlations to be applied to the local sequence (Stevens 1997). Few other fossils were found. Bivalves become abundant and stratigraphically useful in the upper beds (Purser 1961).

Belemnopsis trechmanni (revised taxonomy) occurs within and beneath the Takatahi Formation on an eastern tributary to Okahu Stream (R13/f7002, f7006). *B. trechmanni* extends upwards for c. 200 m (R13/f7000, f7001, f304; Fig. 2, 10) into the overlying siltstones and supports correlation of these beds with the Kinohaku Siltstone. The distribution of *B. trechmanni* in the Takatahi Formation and Kinohaku Siltstone at Kawhia Harbour is similar (Stevens 1965; Challinor 1996).

Locality R13/f7001 also contains the ammonite *Kossmatia pilicosta* Stevens, which appears to range from the uppermost Kinohaku Siltstone to the lowermost Puti Siltstone at Kawhia (Stevens 1997), suggesting that R13/f7001 is located high in the Kinohaku Siltstone. *B. trechmanni* occurs at R13/f304, slightly higher in the formation, and poorly preserved pre-adult belemnite moulds, apparently all *Belemnopsis*, occur at R13/f7005 and a number of unrecorded localities on Okahu Stream between grid ref. R13/682245 and 685241. A similar zone of small belemnites occurs above the *B. trechmanni* zone in the upper Kinohaku Siltstone at Kawhia Harbour (Challinor 1996).

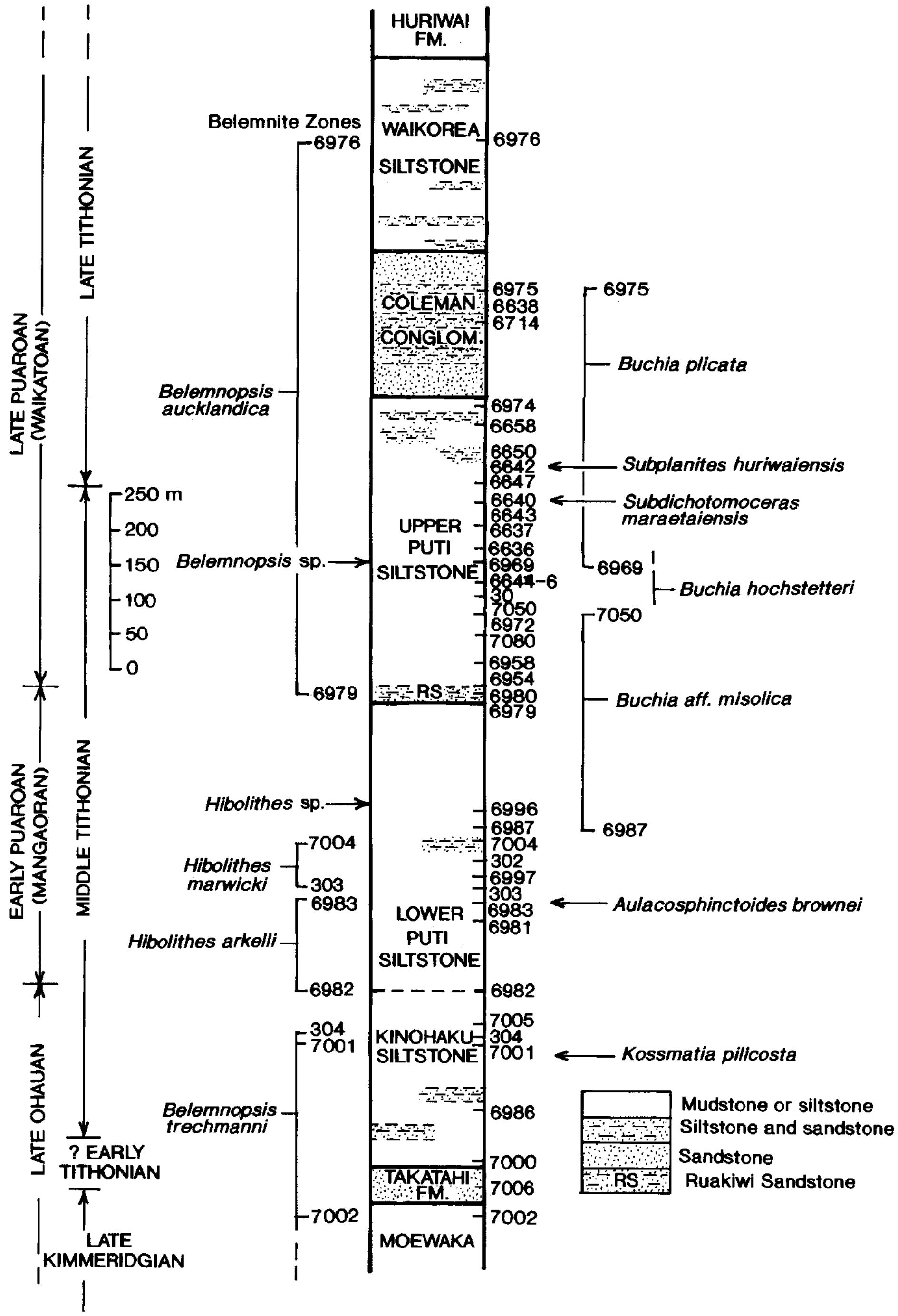


Fig. 10 Composite stratigraphic column for Late Ohauan (part) and Early and Late Puaroan (Mangaoran and Waikatoan) Substages, based on outcrop near Okahu and Moewaka Streams (Fig. 2) and south and west of Port Waikato (Fig. 3). International correlations are from Stevens (1997). RS = Ruakiwi Sandstone. Fossil localities are in approximate relative stratigraphic positions. Known stratigraphic ranges of belemnites and bivalves, and stratigraphic position of ammonite occurrences, are indicated.

No fossils were found within a 50 m thick interval immediately above R13/f7005. These beds are below strata containing *Hibolithes arkelli* and are included in the Kinohaku Siltstone. The formation is 250 m thick in the Okahu valley. A boundary between the Kinohaku Siltstone and the Puti Siltstone cannot be recognised by lithology, but this horizon is thought to be located west of R13/f304, east of R13/f6983, and close to R13/f6982.

The Late Ohauan Stage is correlated with the Middle Tithonian, based on the ammonites *Kossmatia* and *Paraboliceras* from the middle and upper Kinohaku Siltstone at Kawhia Harbour (Stevens 1997).

Early Puaroan (Mangaoran) Substage

The belemnite *Hibolithes arkelli* (Fig. 6, 7, 10) was found in the Okahu valley (R13/f6982, f6983) and on upper Moewaka Stream south of Klondyke Road (R13/f6981). Locality R13/f6982 appears to be at the base of the known range of *H. arkelli* at Port Waikato, and R13/f 6981 and f6983 appear to be near the top.

All specimens of *H. arkelli* from Port Waikato (Fig. 6, 7) are corroded and exfoliated to some degree, and in most the alveolar region is crushed. They are fairly numerous through a 40–50 m interval at R13/f6982. Some 30 reasonably complete specimens were found (although only 18 were complete enough to provide statistical data) and fragments of 10–15 more. They are less common at R13/f6983 (5 fragments) and f6981 (2 specimens and 7 fragments) and were found in only a narrow set of beds at both localities. Because of farm development, R13/f6983 no longer exists as a collecting locality.

The original collections from Okahu Stream also include *Aulacosphinctoides brownei* (R13/f6983) and a belemnite fragment identified as *Hibolithes marwicki* (R13/f6982). These associations were used to suggest that the *Hibolithes arkelli* zone on Okahu Stream correlated with that at Puti Point, Kawhia Harbour (Challinor 1974), where all three are associated. Subsequent assessment (Challinor 1977) suggested that the Okahu Stream specimens were closer in form to *H. arkelli* from much lower in the Kawhia Harbour sequence (those localities on Ngapohoi Stream, R15/f8928 and f8929, were at the time thought to be located low in the Puti Siltstone but are now known to be in the topmost Kinohaku Siltstone; Challinor 1999). The presence of what was thought to be *H. marwicki* at R13/f6982 could not be explained (Challinor 1977).

The *H. arkelli* zone is now known to extend through c. 900 m of beds on the western limb of Kawaroa Anticline near Puti Point (Challinor 1999). *Aulacosphinctoides brownei* extends through most of the Mangaoran Substage (topmost Kinohaku Siltstone east of Kawhia Harbour, Challinor 1999; up to middle Puti Siltstone, Stevens 1997). Challinor (1999) re-identified the specimen of *Hibolithes marwicki* from R13/f6982 on Okahu Stream as *H.* cf. *arkelli*. Other small complete specimens now available from the same locality, clearly *H. arkelli*, are similar in groove characteristics and cross-section to the specimen discussed. It is probably *arkelli ss*, although some doubt must remain as it is part of a pre-adult guard, and such specimens can be difficult to identify with confidence (Challinor 1999). The *H. arkelli* zone in the Okahu valley is not restricted to a narrow set of beds as previously thought (Challinor 1974) but extends through an estimated 140 m (see Fig. 10). This implies that correlation of the whole zone with horizons near Puti Point is no longer tenable. Localities R13/f6981 and f6983 may be approximately correlative with Puti Point (see below).

Statistical differences between populations of *H. arkelli* at the base and top of its range at Kawhia are believed to result from evolutionary changes (Challinor 1975, 1999). Accordingly, data from 18 of the best preserved specimens from R13/f6982 at Port Waikato were compared with those from larger samples collected from the top (Puti Point) and base (Ngapohoi Stream) of its known range at Kawhia. This analysis (Table 1) indicates that specimens from R13/f6982 most closely resemble, in postalveolar length, those from the basal zone at Ngapohoi Stream. Their mean lengths are 4.1 mm less than that from Ngapohoi Stream, and 10.4 mm less than that from Puti Point. Some of this can be attributed to a greater proportion of pre-adult specimens in the R13/f6982 sample (see mean *dMax*, Table 1). Four of the 18 specimens (22%) from that locality have a maximum diameter <9 mm. None from Puti Point and only 7% from the Ngapohoi sample have comparable diameters. Small specimens have shorter postalveolar guards than larger ones and this could well produce or contribute to the observed differences.

Table 1 Comparison of some statistical data of *Hibolithes arkelli* from Port Waikato (R13/f6982) and Kawhia region (R15/f8628, f8629, f8928, f8929). Parameters are postalveolar length (*l*), maximum diameter (*dMax*), and index of guard robustness (*l/dMax*).

		Port Waikato R13/f6982	Puti Point R15/f8628/9	Ngapohoi Stream R15/f8928/9
l (mm)	*n*	18	63	60
	$\bar{x}$	49.9	60.3	54.3
	σn-1	7.9	9.9	6.5
dMax (mm)	*n*	18	55	55
	$\bar{x}$	11.0	11.8	11.9
	σn-1	1.8	1.2	1.6
l/dMax	*n*	18	55	55
	$\bar{x}$	4.6	5.1	4.7
	σn-1	0.7	0.8	0.7

Lateral crushing of the alveolar region may also account for some of the discrepancy. Such crushing makes it difficult to determine the position of the protoconch, and if this cannot be accurately located the true postalveolar length cannot be determined (Challinor 1999). Errors in postalveolar length so determined should be random, but operator technique or bias could produce systematic skewing. One or both factors could well produce the 4.1 mm lesser mean length observed compared with the Ngapohoi specimens, but it would seem unlikely to produce a mean length 10.4 mm less than the Puti specimens if both were derived from the same stratigraphic level.

Multivariate statistical techniques reveal other differences between Puti and Ngapohoi populations (Challinor & Turner 1975) but they cannot be applied to the R13/f6982 specimens. The latter are too poorly preserved to provide the sufficiently accurate diametral measurements required. In the absence of more direct evidence, locality R13/f6982 is considered to be approximately correlative with localities R15/f8928 and f8929 at Ngapohoi Stream, and the base of the *Hibolithes arkelli* zone approximately correlative at Port Waikato and Kawhia Harbour. A stratigraphic position for R13/f6982 near the lower boundary of the Mangaoran Substage is supported by the presence of *Belemnopsis* at R13/f7005 and other horizons not far below. *Belemnopsis* is extremely rare in the Mangaoran Substage in other parts of southwest Auckland (Challinor 1977, 1999).

Localities R13/f6626 on Port Waikato-Tuakau Bridge Road and f6625 on the lower Waihikura Stream recorded by Purser (1961) could not be located during this work. Both contain belemnites identified by Purser as *Belemnopsis* sp. Both are within or close to the *Hibolithes arkelli* zone and are possibly misidentifications of that taxon. They would probably not have been recognised as distinct from *Belemnopsis* when Purser's work was completed in 1952.

Immediately above the youngest beds containing *Hibolithes arkelli* lie c. 100 m of sediments containing scattered *Hibolithes marwicki* (Fig. 8, 9, 10) and *Hibolithes* sp. Single well-preserved specimens of *H. marwicki* are known from R13/f7004 and f303, and well-preserved natural moulds from which good casts were prepared, from f302 and f7016 (the latter a float locality). These are all long forms of the taxon and are similar to those at Puti Point, Kawhia Harbour (Challinor 1999). A small mid-stem fragment with dimensions, cross-section, apical line position, and ventral groove characters typical of *H. marwicki* was collected at R13/f6997 on a south-flowing tributary of Moewaka Stream. R13/f303 and f6997 are stratigraphically just above R13/f6983 and probably correlate with horizons near Puti Point.

Indeterminate *Hibolithes* occur at R13/f305 at Okahu Stream just above f6983, and at f6990 on Daff Road. Small fragments of a pre-adult belemnite were found at R13/f6996 south of Daff Road. This specimen, originally identified as a juvenile *Belemnopsis* (Challinor 1974), was used to position the eastern limit of the type section of the Waikatoan Substage (Challinor 1977). Better knowledge of Early Puaroan *Hibolithes* has led to a reinterpretation of this specimen as a juvenile *Hibolithes*, not unlike *H. marwicki*. Firm identification is not possible because similar *Hibolithes* distinct from *H. marwicki* occur stratigraphically well above *H. marwicki* near Puti Point and on Oparau River northeast of Kawhia Harbour (Challinor 1999). R13/f6996 is the youngest *Hibolithes* locality found in the Port Waikato region.

As a result of the reinterpretation above, the eastern limit of the type section of the Waikatoan Substage is here relocated some 350 m westwards from its original position (to grid ref. R13/666252 approximately where the Port Waikato-Tuakau Bridge Road crosses Okahu Stream) and c. 150 m stratigraphically higher in the sequence. This approximates to the stratigraphic position of the oldest known *Belemnopsis aucklandica* in the area.

Buchia (or *Malayomaorica*) aff. *misolica* and ?*Lytoceras* were collected from R13/f6987 in the 1970s but the specimens cannot now be located. The stratigraphically lowest known occurrences of *Buchia* aff. *misolica* are at Puti Point, Kawhia Harbour, where it is associated with *Hibolithes arkelli*, *H. marwicki*, *Aulacosphinctoides brownei*, and other ammonites and bivalves. R13/f6987 is apparently above this level.

Based on occurrences of the ammonites *Uhligites*, *Aulacosphinctoides*, and *Kawhiasphinctes* at Kawhia Harbour, Stevens (1997) correlated the lower half of the Puti Siltstone (up to at least the stratigraphic level represented by Puti Point and Motutara Peninsula) with the Middle Tithonian. On this basis, the Early Puaroan Substage is of Middle Tithonian age.

Late Puaroan (Waikatoan) Substage

Belemnopsis aucklandica was found within (R13/f6979 and f6980) and just above (R13/f6954 and f6955) the sandstones correlated by Waterhouse (1978) with Waiharakeke Conglomerate. *Belemnopsis aucklandica* is not known from Waiharakeke Conglomerate in other regions of southwest Auckland. Some 800 m of sequence in which only *Hibolithes* is known occur above Waiharakeke Conglomerate on the western limb of Kawaroa Anticline on the north shore of Kawhia Harbour (Challinor 1999). *Belemnopsis aucklandica* occurs in the upper part of the Puti Siltstone at least 700 m above Waiharakeke Conglomerate in the region north of Kawhia Harbour (Player 1958; Stevens 1965). Kear (1966) recorded profuse *B. aucklandica* from the 80 m thick Ruakiwi Sandstone some 370–600 m below the top of the Puti Siltstone in the Te Akau region. The sandstone mapped by Waterhouse (1978) at Port Waikato as Waiharakeke Conglomerate, is provisionally correlated here with the Ruakiwi Sandstone member of the Puti Siltstone.

There is one record of *Hibolithes arkelli* in the Ruakiwi Sandstone (Stevens 1965; Kear 1966), but Challinor (1977) suggested that this was probably a misidentification based on poorly preserved material (fragmentary corroded juvenile specimens and moulds). Some pre-adult *Belemnopsis aucklandica* can be misidentified as *Hibolithes* (see below).

The base of the Waikatoan Substage is indicated by the first appearance of *Belemnopsis aucklandica* (Challinor 1977), and this is approximately coincident with the mapped position of the Ruakiwi Sandstone in the valley of Okahu Stream (Fig. 2).

Locality R13/f6958 (Upper Puti Siltstone) was the stratigraphically highest collected in the Okahu valley during this work. It contains *Belemnopsis aucklandica.*

Purser (1961) collected from a number of localities in the west of the Okahu valley stratigraphically above the Ruakiwi Sandstone. He recorded *Buchia hochstetteri* and *Belemnopsis* sp. at R13/f6618, f6619 and f6622; *Belemnopsis* sp. at f6620 (all Upper Puti Siltstone); and *Buchia plicata* and *Belemnopsis* sp. at f6621 (probably Coleman Conglomerate). The base of Purser's Puaroan A zone passes through R13/f6618 and f6620. Purser also recorded localities at Te Karamu Stream south of the area covered by Fig. 2 and at a slightly higher stratigraphic position than R13/f6618 and f6980. He identified *Buchia hochstetteri* and *Belemnopsis* sp. at f6631, f6632, and f6633.

Waterhouse (1978) recorded R13/f6915 and f6916 with *Buchia* aff. *misolica* and f6932 with *Buchia* aff. *misolica* and belemnites on the same length of Te Karamu Stream. Some of these localities are probably identical with those of Purser. *Buchia* aff. *misolica* was not recognised as distinct from *B. hochstetteri* when Purser's work was published (1961), and the *B. hochstetteri* zone is known to be thin (see below). Many *B. hochstetteri* recorded by Purser in the lower part of his Puaroan A are likely to be *Buchia* aff. *misolica. Belemnopsis aucklandica* from R13/f6952 and f6953 at Te Karamu Stream (possibly identical to some of the localities mentioned above) were studied during preparation of the description of *B. aucklandica* below.

Belemnopsis aucklandica is common throughout the Upper Puti Siltstone (Fig. 10) but is of little value in defining biostratigraphic divisions within the subunit (or within the Waikatoan Substage) as its morphology apparently does not vary in a systematic manner throughout its zone (see below). The most useful biostratigraphic markers are several species of *Buchia* that extend throughout the formation (Purser 1961; Rodgers & Grant-Mackie 1978).

The stratigraphically lowest is *Buchia* aff. *misolica*, which first appears at R13/f6987 in the Lower Puti Siltstone at Okahu Stream (Fig. 2, 10). It extends upwards into the Upper Puti Siltstone and occupies the axial beds of Kawaroa Anticline (Fig. 3). At Huriwai River (reference section of the Waikatoan Substage; Challinor 1977), it extends approximately from locality R13/f19 in the west to f7050 in the east (Fig. 3).

Buchia aff. *misolica* is succeeded by *Buchia hochstetteri*, which appears at locality R13/f30 on the eastern flank of Kawaroa Anticline (N. E. Hudson pers. comm. 1999) and is present at localities R13/f6644, 6645, and 6646 in the Maraetai valley. The *Buchia hochstetteri* zone is thin (see Kenny et al. 1977) and was not located on the western flank during this work but should be present near localities R13/f192 and f6636. Kenny et al. (1977) recorded it at R13/f7080.

Buchia hochstetteri is succeeded by *B. plicata* in the upper part of the Upper Puti Siltstone (R13/f6637, f6642, and f6647) and extends upwards into the overlying Coleman Conglomerate (Fig. 10). If, as seems likely, these *Buchia* species are part of an evolving lineage, some zonal overlap can be expected, with *B.* aff. *misolica* present in the lower part of the *hochstetteri* zone and the latter in the lower *plicata* zone. Some stratigraphic overlap is known between *hochstetteri* and *plicata* (J. A. Grant-Mackie pers. comm. 1999).

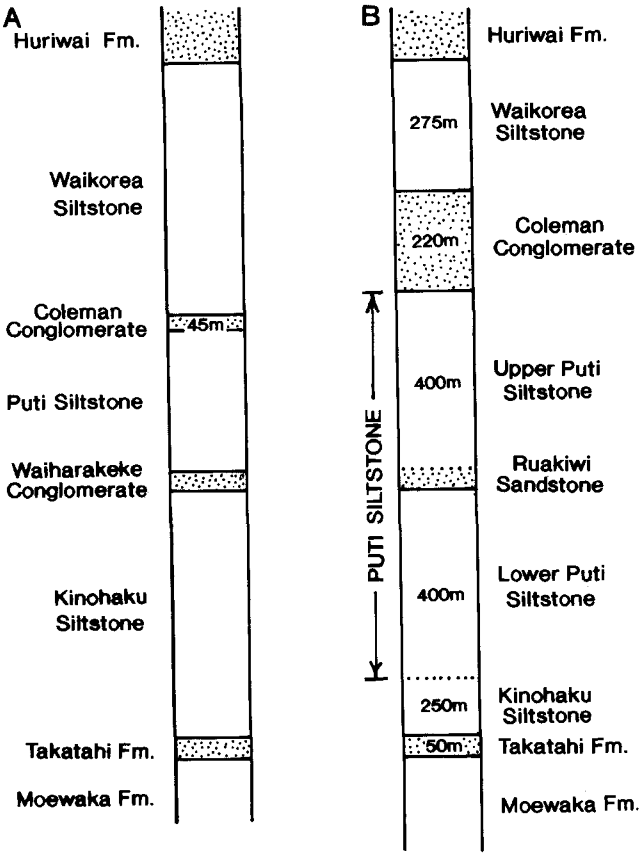


Fig. 11 Alternative correlations of the Late Ohauan–Puaroan sequence at Port Waikato: **A**, from Waterhouse (1978). **B**, correlations proposed in this paper. The provisional boundary between the Kinohaku Siltstone and overlying formation does not indicate a lithological change. It is based on paleontology and probably correlates with a horizon near the top of the Kinohaku Siltstone at Kawhia Harbour. The Waiharakeke Conglomerate occurs at and above this point at Kawhia but is not indicated by coarse sediments at Port Waikato.

Belemnopsis aucklandica, *Buchia hochstetteri*, and *B. plicata* are common to abundant fossils in the upper part of the Puti Siltstone in the Te Akau district (Kear 1966), supporting the correlations adopted here.

Few ammonites are known from the Upper Puti Siltstone at Port Waikato, paralleling the situation in the Lower Puti Siltstone. *Subplanites huriwaiensis* is known from R13/f6642 and f6650, and *Subdichotomoceras maraetaiensis* from f6640 and f6643 (Fig. 10). Both indicate a Late Tithonian age (Stevens 1997) and both are located low in the *Buchia plicata* zone.

Few fossils were found above the Upper Puti Siltstone during this work. *Buchia plicata* was noted at R13/f6975, and *Belemnopsis aucklandica* at R13/f6638 and f6714 (all Coleman Conglomerate). Both occur in the Coleman Conglomerate of the Te Akau district (Kear 1966). *Belemnopsis aucklandica* was collected from near the middle of the Waikorea Siltstone (R13/f6976) but no other fossils were found. Kear (1966) recorded rare *Buchia plicata* from the Waikorea Siltstone in the Te Akau district.

SUMMARY OF CORRELATIONS

Approximately 1500 m of Late Ohauan and Puaroan marine strata are present in the area studied between the Takatahi Formation and the base of the non-marine Huriwai Formation (Fig. 11). They are mostly mudstones and siltstones apart from a 50 m sandstone unit (Ruakiwi Sandstone) 650 m above base, a 220 m sandstone (Coleman Conglomerate) commencing 1100 m above base, and some sandstone in the overlying 275 m Waikorea Siltstone.

The 650 m of beds between the Takatahi Formation and the Ruakiwi Sandstone were previously correlated entirely with Kinohaku Siltstone, while the Ruakiwi Sandstone was correlated with Waiharakeke Conglomerate (Waterhouse 1978). Only the lower c. 250 m is here correlated with Kinohaku Siltstone, and the upper 400 m correlates with Puti Siltstone, the Lower Puti Siltstone of this paper. Some 400 m of siltstone above the Ruakiwi Sandstone, formerly regarded by Waterhouse (1978) as the entire Puti Siltstone, together with the Ruakiwi Sandstone member, forms the Upper Puti Siltstone of this paper.

These correlations are primarily paleontological, although stratigraphic position relative to known coarse-grained units is useful to some degree. There appear to be no coarse-grained correlatives of the Waiharakeke Conglomerate present but some of the fine-grained beds near the Kinohaku Siltstone/Puti Siltstone boundary are probably correlative.

The 220 m sandstone unit above the Upper Puti Siltstone is correlated with Coleman Conglomerate by lithology, stratigraphic position, and paleontology. The overlying 275 m of siltstone with some sandstone is correlated with Waikorea Siltstone by the same criteria. The Coleman Conglomerate is therefore considered to be stratigraphically higher within the area studied and thicker than indicated by Waterhouse (1978) (Fig. 11).

BELEMNITE ZONES OF THE LATE OHAUAN AND PUAROAN STAGES

The stratigraphic distribution of belemnites in the Late Ohauan and much of the Puaroan Stage is better known in relation to formation boundaries in the Kawhia region (Challinor 1999) than at Port Waikato. This is a result of more research in the former area and difficulty in recognising some formation boundaries in the latter. Stratigraphic ranges are now well enough known to recognise the following formal belemnite zones (Fig. 10).

***Belemnopsis trechmanni* Zone** This is thought to approximate the range-zone of the taxon. At Kawhia Harbour, the *B. trechmanni* Zone extends from the lower Takatahi Formation up to c. 150 m below the base of the Waiharakeke Conglomerate. The zone commences below the Takatahi Formation at Port Waikato but its top cannot be related to the Waiharakeke Conglomerate because the latter cannot be recognised in the area.

Meesook & Grant-Mackie (1966) defined the base of the Late Ohauan by the first appearance of *Belemnopsis trechmanni*.

***Hibolithes arkelli* Zone** The known range of *Hibolithes arkelli* commences just below the base of the Waiharakeke Conglomerate at Kawhia (Challinor 1999), and extends upwards for c. 900 m into beds that are thought to correlate with the middle of the Lower Puti Siltstone of this paper.

This probably approximates the range-zone of *H. arkelli*. The bases of the zones at Kawhia and Port Waikato are thought to correlate but the top of the zone at Kawhia is apparently younger than the observed top at Port Waikato.

The first appearance of *Hibolithes arkelli* indicates the base of the Puaroan Stage and of the Mangaoran Substage (Challinor 1999).

***Hibolithes marwicki* Zone** *Hibolithes marwicki* first appears in the middle of the lower part of the Puti Siltstone at Kawhia associated with *H. arkelli* and *H. mangaoraensis*. It extends upwards for c. 150 m but is relatively uncommon in the upper part of its range (Challinor 1999). Its known range constitutes the *Hibolithes marwicki* Zone.

H. marwicki extends through 60–70 m of strata at Port Waikato (Fig. 10), but the bases of the zones at Kawhia and Port Waikato apparently do not correlate (no association of *H. marwicki* and *H. arkelli* is known at Port Waikato), and it is not known if the tops of the zones correlate.

***Hibolithes mangaoraensis* Zone** *Hibolithes mangaoraensis* is associated with *H. arkelli* in a narrow set of beds at Puti Point, Kawhia Harbour, and with *H. marwicki* through c. 150 m of overlying sequence. *H. mangaoraensis* extends for at least 100 m above *H. marwicki* (Challinor 1999) but its total range is uncertain. Its known range constitutes the *Hibolithes mangaoraensis* Zone.

The *Hibolithes mangaoraensis* Zone has not been identified at Port Waikato, but fragmentary *Hibolithes* from locality R13/f6996 may indicate its presence.

***Belemnopsis aucklandica* Zone** The stratigraphic range of *B. aucklandica* at Port Waikato constitutes the *Belemnopsis aucklandica* Zone. Its known range extends from the base of the Upper Puti Siltstone up to approximately halfway through the Waikorea Siltstone.

The base of the *B. aucklandica* Zone marks the base of the Waikatoan Substage of the Puaroan Stage (Challinor 1977).

Belemnopsis aucklandica is not present at Kawhia Harbour, where beds of the appropriate age are missing. It is associated with *Buchia plicata* north of Kawhia Harbour (Player 1958) at least 700 m above *Hibolithes arkelli* (Stevens 1965). It is present in the Te Akau area associated with *Buchia hochstetteri* and *B. plicata* in the Puti Siltstone and Coleman Conglomerate (Kear 1966).

SYSTEMATICS

Redescription of *Belemnopsis aucklandica* (Hochstetter)

The first appearance of *Belemnopsis aucklandica* indicates the base of the Late Puaroan (Waikatoan) Substage. Earlier descriptions of the taxon are not sufficiently detailed, particularly of pre-adult material. If *B. aucklandica* is to realise its full potential as a marker fossil, as much detailed knowledge as possible of its morphology, including that of the pre-adult, is essential. This redescription is directed towards that outcome.

Two previous systematic studies of *B. aucklandica* have been published. Stevens (1965) studied c. 80 specimens and/or fragments, 75% of which were collected within the area covered by Fig. 3. About half the specimens studied are held in the Hochstetter Collection, Naturhistorisches Museum, Vienna, and have not been restudied here. Some material held at the University of Auckland has been re-examined but many of the specimens listed by Purser (1961) cannot be found, perhaps because they were field observations of uncollected specimens. Stevens recognised a single taxon.

Challinor (1970) examined c. 300 specimens and/or fragments, most from within the areas of Fig. 2 and 3, although a few were found on Te Karamu Stream south of Fig. 2, and some on Waikawau Stream south of Fig. 3. Most were identified as *Belemnopsis aucklandica*, although a few were segregated as *Belemnopsis* aff. *suavis* Stolley or *B.* aff. *aucklandica* (Hochstetter). The specimens studied in 1970 were re-examined in this study, together with large collections made by staff and students of the University of Auckland, mostly between 1970 and 1998.

Methods

Terminology used here is broadly that of Stevens (1965), although some terms have been partly superseded. "Rostrum", for example, replaces "guard", particularly in European works, as the functional connotations of the latter term are no longer considered valid. "Clavate" sometimes replaces "hastate", although phrases such as "anterior tapering" are often preferred. To be consistent with my previous papers, the older terms continue to be used here. Techniques and descriptive terms broadly follow Stevens (1965), but graphical and statistical descriptive methods developed in a series of papers (Challinor 1975, 1979a, b, 1999; Challinor & Skwarko 1982) allow a more comprehensive approach.

The main terms used are summarised in Fig. 12. Indices and symbols used in text, tables, and figures are explained below.

l = postalveolar length (mm). Distance from protoconch to apex.
$dMax$ = maximum diameter (mm). Depending on specimen morphology, $dMax$ may be anteriorly or posteriorly located, and may be a transverse or a sagittal measurement.
A = index of flattening or compression. Values >100 indicate a flattened (depressed) cross-section; <100 indicates compression.
AA = A in anterior region of guard, approximately where indicated in Fig. 12.
AP = A in posterior region.
H = hastation (mm). Difference between $dMax$ and diameter at protoconch.
Ht = transverse hastation (mm).
Hs = sagittal hastation (mm).
lvg/lg = index of ventral groove length. Ventral groove length posterior to protoconch divided by postalveolar guard length.
$l/dMax$ = index of guard robustness. Postalveolar length divided by maximum diameter.

In adult guards (see below), $dMax$ is located posterior to, at, or anterior to the protoconch. In hastate adults, anterior minimum diameter is usually located near the protoconch or somewhere along the alveolar region. It was not possible to adopt a consistent approach that took into account the different permutations and at the same time produced an adequate dataset. For this reason, no values of hastation are included in the statistics of adult *Belemnopsis aucklandica* (Table 2).

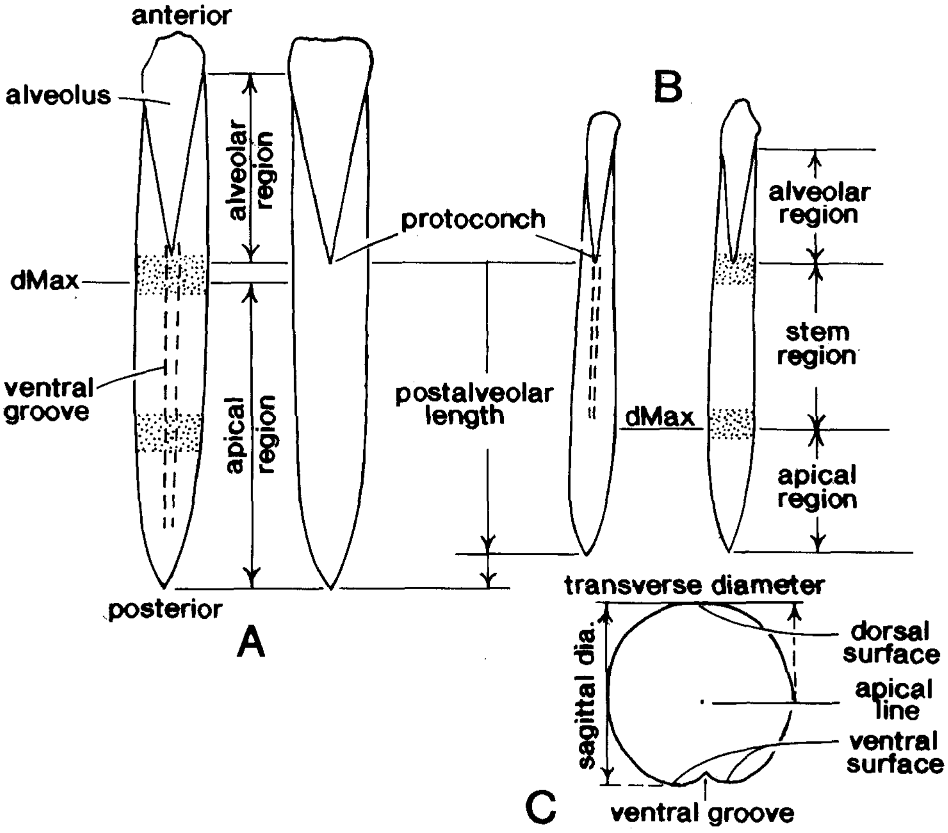


Fig. 12 Schematic outline (left) and profile (right) of adult (**A**) and pre-adult (**B**) *Belemnopsis aucklandica*, and cross-section (**C**), illustrating terminology. Shading indicates the approximate position of tabulated measurements.

In pre-adult guards, *dMax* is usually located well behind the protoconch. Hastation in pre-adult guards is defined as the difference between diameter at *dMax* and diameter at the protoconch. These are the values listed in Table 3. This approach has been adopted to remove the uncertainty produced by the frequent loss during collection of part of the slender fragile alveolar region in which true minimum diameter is usually located. Readers should be aware of the different concepts of hastation applied to adult and pre-adult guards.

Table 2 Statistics of adult *Belemnopsis aucklandica* from Port Waikato. Parameters are postalveolar length (*l*), maximum diameter (*dMax*), index of flattening of posterior guard (AP), index of flattening of anterior guard (AA), index of guard robustness (*l/dMax*), and index of ventral groove length (*lvg/lg*).

l (mm)	*n*	50
	$\bar{x}$	64.0
	σn-1	10.1
dMax (mm)	*n*	55
	$\bar{x}$	13.8
	σn-1	2.0
AP	*n*	73
	$\bar{x}$	100.8
	σn-1	2.3
AA	*n*	60
	$\bar{x}$	98.2
	σn-1	2.7
l/dMax	*n*	50
	$\bar{x}$	4.7
	σn-1	0.6
lvg/lg	*n*	45
	$\bar{x}$	0.78
	σn-1	0.06

A total of c. 300 complete or nearly complete specimens and c. 200 damaged or partial specimens were examined. Pre-adult specimens outnumber adults by c. 2:1. Not all complete specimens provide a full suite of measurements, and sample sizes on which the graphs and tables are based vary. Stratigraphic coverage is adequate in the Upper Puti Siltstone, poor in the Coleman Conglomerate, and very poor in the Waikorea Siltstone, from which only a single specimen is known (Fig. 10).

Order **BELEMNITIDA** Zittel, 1895
Suborder **BELEMNOPSEINA** Jeletzky, 1965
Family **BELEMNOPSEIDAE** Naef, 1922
Genus ***Belemnopsis*** Bayle, 1878

Belemnopsis aucklandica (Hochstetter)

Fig. 13–80; Table 2, 3.

Partial synonymy

1863 *Belemnites aucklandicus* (Blainville) Hochstetter, Neuseeland: 129, fig.

1867 *B. aucklandicus* Hochstetter, New Zealand: 275, fig.

1911 *B. canaliculatus aucklandicus* (Blainville) Hauer (partim); Boehm, Neues Jb. Min. Geol. Palaont. (1911) 1: 16.

1913 *B. c. aucklandicus* (Blainville) Hauer; Thomson, N. Z. Geol. Surv. Paleont Bull. 1: 34, 101, pl. 5, fig. 2 a,b.

1953 *Belemnopsis aucklandica* (Hochstetter) (partim); Marwick, N.Z. Geol. Surv. Paleont. Bull. 21: 29, 123, pl. 17, fig. 5, 6.

1961 *Belemnopsis aucklandica* (Hochstetter); Purser, N.Z. Geol Surv. Bull. n.s 69: 9, 10.

1965 *Belemnopsis aucklandica aucklandica* (Hochstetter); Stevens, N.Z. Geol. Surv. Pal. Bull. 36: 82–88, pl. 6, fig. 1–6, 10–15; pl. 7, fig. 1–7, 11–13; pl. 8, fig. 1–10.

1970 *Belemnopsis* aff. *suavis* Stolley; Challinor, Earth Science Journal 4(2), fig. 5c–h.

1970 *Belemnopsis* aff. *aucklandica* (Hochstetter); Challinor, Earth Science Journal 4(2), fig. 7a–l.

LOCALITIES AND MATERIAL: All collection localities are within the area of map sheet R13, NZMS 260, Port Waikato, 1:50 000. The prefix R13 is omitted from fossil locality numbers below (e.g., R13/f24 becomes f24). Totals include only complete or nearly complete specimens. Additional fragments are available from some localities and from unlisted localities.

UNIVERSITY OF AUCKLAND COLLECTIONS: f24, 1 specimen (AU6452); f35, 8 (AU11262, 12724, 14312); f99, 1, (AU11895); f105, 1 (AU4583); f143, 1 (AU10605); f192, 1 (AU11398); f291, 4 (AU14937); f300, 1 (AU4593); f6020, 13 (AU862); f6636, 23 (AU807, 7806, 9473, 10314); f6637, 1 (AU14352); f6639, 12 (AU838, 848); f6642, 3 (AU12724); f6647, 3 (AU301, 304); f6650, 14 (AU855, 6407, 8046, 14931); f6691, 4 (AU841); f6714, 1 (AU834); f6811, 1 (AU7647); f6861, 3 (AU874); f6977, 3 (AU4597); f7050, 79 (AU4422, 4578, 4582, 4587, 4608, 8460, 8461, 8462, 8916, 9710, 11263, 14353); f7080, 1 (AU7444). Collection AU862 (f6020) unlocalised, possibly from Coleman Conglomerate. AU834 (f6714), is from mid Coleman Conglomerate. All other collections are from the Upper Puti Siltstone.

A.B. CHALLINOR COLLECTIONS: f6639 (2 specimens); f6642 (7); f6648 (1); f6650 (7); f6952 (2); f6953 (1); f6956 (5); f6957 (1); f6958 (1); f6961 (8); f6962 (2); f6963 (10); f6969 (6); f6971 (18); f6972 (41); f6973 (1); f6974 (3); f6976 (1); f6980 (4). Locality f6976 is in the mid Waikorea Siltstone. All other localities are in the Upper Puti Siltstone.

HOLOTYPE: Stevens 1965, pl. 6, fig. 4–6. Held in Hochstetter Collection, Naturhistorisches Museum, Vienna. Accession number 1865. XXXVII.73.

TYPE LOCALITY: South Head, Waikato River.

AGE: Late Middle Tithonian to Late Tithonian.

STRATIGRAPHIC AND GEOGRAPHIC RANGE: *Belemnopsis aucklandica* is present in the upper part of the Puti Siltstone, and in the Coleman Conglomerate and Waikorea Siltstone, from just north of Kawhia Harbour northwards to Port Waikato.

Description of adult guard

Adult guards (Fig. 19–30, 31–49) are here defined as those that equal or exceed a diameter of 10 mm. This somewhat arbitrary limit has been adopted because most specimens of that diameter have attained a characteristically slightly or non-hastate adult shape. A few specimens <10 mm in diameter are, however, almost non-hastate, and some adults are moderately hastate.

Guard elongate and robust. Postalveolar length 47–84 mm ($\bar{x}$ 64 mm, Fig. 13) and 3.5–6× maximum diameter ($\bar{x}$ 4.7, Fig. 14). Maximum diameter observed c. 19 mm.

Outline symmetrical and slightly hastate to subconical. Maximum transverse diameter anteriorly placed; in c. 50% of specimens it is located posterior to the protoconch (up to 20 mm), in the remainder either close or anterior to it. When maximum diameter is posteriorly placed, the guard is hastate (difference between maximum and minimum diameter 0.1–1.8 mm, $\bar{x}$ 0.8 mm). An increasingly posterior position of maximum diameter correlates approximately with increasing hastation (Fig. 19, 25, 29).

Table 3 Statistics of pre-adult *Belemnopsis aucklandica* from Port Waikato. Parameters are postalveolar length (*l*), maximum diameter (*dMax*), index of flattening of posterior guard (AP), index of flattening of anterior guard (AA), transverse hastation (*Ht*), sagittal hastation (*Hs*), index of guard robustness (*l/dMax*), and index of ventral groove length (*lvg/lg*).

Locality no.		R13/f7050		R13/f6972	All other localities
Collection no.		AU11263	AU9710		
l (mm)	*n*	28	27	36	28
	$\bar{x}$	51.5	51.6	53.0	46.6
	σ*n*-1	5.2	6.6	6.8	7.8
dMax (mm)	*n*	25	26	36	55
	$\bar{x}$	8.0	7.5	7.9	7.8
	σ*n*-1	0.6	1.1	1.0	1.3
AP	*n*	26	22	35	56
	$\bar{x}$	101.2	100.6	100.9	99.4
	σ*n*-1	2.3	3.0	3.2	3.1
AA	*n*	26	22	34	46
	$\bar{x}$	95.6	95.4	96.1	95.7
	σ*n*-1	3.4	3.2	3.7	3.3
Ht (mm)	*n*	25	22	34	30
	$\bar{x}$	1.2	1.1	1.1	0.8
	σ*n*-1	0.7	0.6	0.6	0.5
Hs (mm)	*n*	23	22	32	29
	$\bar{x}$	0.9	0.8	0.8	0.6
	σ*n*-1	0.5	0.4	0.5	0.4
l/dMax	*n*	27	26	36	28
	$\bar{x}$	6.6	6.9	6.8	6.1
	σ*n*-1	0.5	0.5	1.0	1.3
lvg/lg	*n*	26	22	34	29
	$\bar{x}$	0.6	0.5	0.6	0.7
	σ*n*-1	0.1	0.1	0.1	0.1

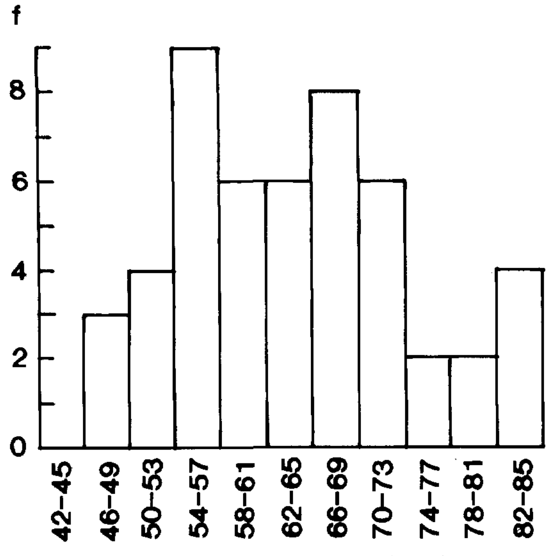


Fig. 13 Frequency distribution of postalveolar length in adult *Belemnopsis aucklandica*. $n = 50$, $\bar{X} = 64$ mm, σn–1 = 10.1 mm. All observations in Fig. 13–18, 50–54, are from Port Waikato specimens.

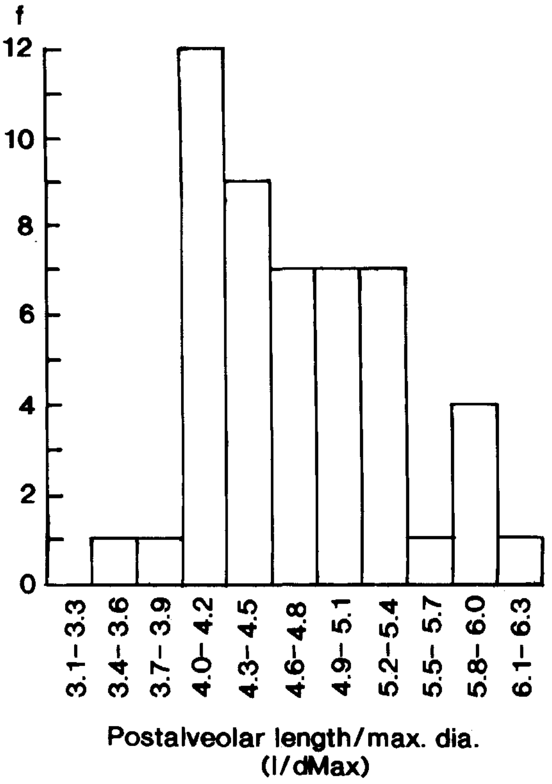


Fig. 14 Frequency distribution of indices of guard robustness (*l/dMax*) in adult *Belemnopsis aucklandica*. $n = 50$, $\bar{X} = 4.7$, σn–1 = 0.6.

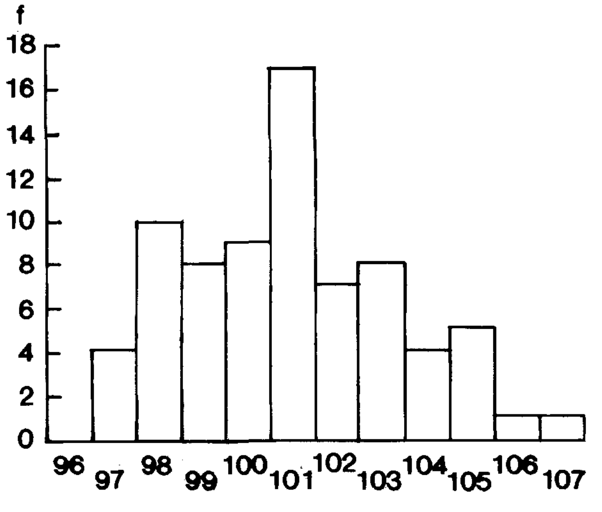


Fig. 15 Frequency distribution of indices of posterior flattening (AP) in adult *Belemnopsis aucklandica*. $n = 73$, $\bar{X} = 100.8$, σn–1 = 2.3.

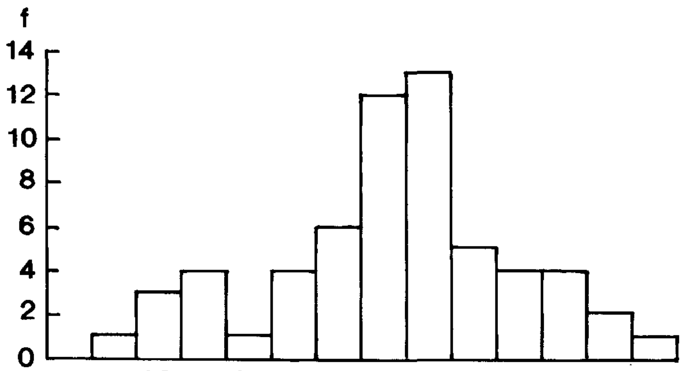


Fig. 16 Frequency distribution of indices of anterior flattening (AA) in adult *Belemnopsis aucklandica*. $n = 60$, $\bar{X} = 98.2$. σn–1 = 2.7.

When maximum diameter is located close to the protoconch, the flanks may converge very slightly in the alveolar region to produce weak hastation (Fig. 23), or the guard is approximately parallel sided (Fig. 21), or the anterior flanks diverge slightly to produce a weakly conical outline (Fig. 39). The sides converge posteriorly towards the apex from the widest point, gradually at first but more strongly and rapidly over the terminal 15–20 mm (Fig. 23, 37). The outline of the apical 25 mm is variable. The sides may converge rapidly close to the apex to produce a relatively blunt apex, often with a well-developed mucro (Fig. 41), or they may converge more slowly (Fig. 25). In a few specimens, the postalveolar guard is almost conical in outline (Fig. 40).

Profile slightly asymmetric, either the ventral surface (usually) or the dorsal surface (occasionally) is more inflated near the apex than its counterpart (Fig. 24, 30). Apex usually slightly dorsally placed. In most specimens, the dorsal and ventral surfaces remain approximately parallel in the anterior regions (Fig. 32), or they diverge slightly and the profile is weakly conical (Fig. 22, 36). The ventral surface in the remainder converges slightly towards the dorsal surface near

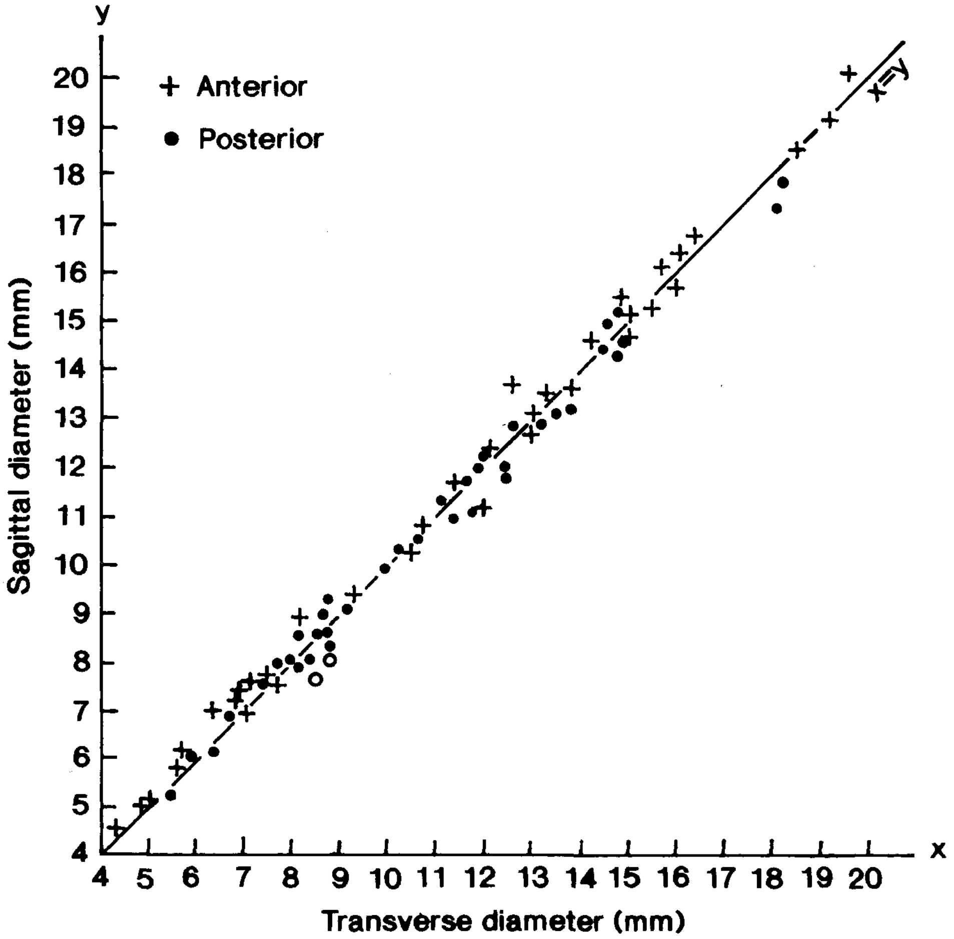


Fig. 17 Relationship between guard diameters in *Belemnopsis aucklandica*. Open circles data from *Belemnopsis* sp. (R13/f6636B); both observations from posterior region of same specimen; see text.

the protoconch (difference between maximum and minimum anterior diameters 0.2–0.7 mm, $\bar{x}$ 0.4 mm) and the profile is weakly hastate (Fig. 20, 26, 30).

Cross-sections slightly compressed to depressed in the posterior half of the guard (*A* = 97–107, $\bar{x}$ 101, Fig. 15). They are usually more compressed anteriorly (*A* = 92–104, $\bar{x}$ 98, Fig. 16), but a few specimens are slightly depressed in this region also. The cross-section becomes slightly more depressed as the guard matures (Fig. 17). Posteriorly, the cross-section is usually slightly oblate in shape and becomes slightly prolate near the protoconch. Weakly developed ventrolateral flattened areas may be present in the alveolar region.

Median ventral groove usually wide and deep and commences at the alveolar break. It extends down the guard for c. 60–90% of the protoconch to apex distance ($\bar{x}$ 80%) and usually terminates 10–15 mm from the apex (Fig. 23, 31). It is deepest and usually narrowest in the alveolar and anterior stem region, shallows and widens posteriorly, and is c. 2 mm deep and 4–5 mm wide in large specimens.

Lateral lines weakly developed and in most specimens only faint traces are visible. In a few they are more prominent and in these they first become visible just dorsal to the midline of the guard some 10–15 mm from the apex. They pass diagonally down across the flanks of the guard in its mid region and extend throughout the alveolar region. They are narrow and relatively deeply incised and close together near the apex, diverge from one another and at the same time become broader and shallower in the mid regions of the guard, and are broad, very shallow, and separated by 3–5 mm in the alveolar region. The dorsal line is situated near the midline of the guard throughout its length; the ventral line becomes ventrally placed in the anterior half of the guard. The wide and very shallow nature of the ventral lines anteriorly is responsible for the occasional ventrolateral flattened areas mentioned in the discussion of cross-sections above.

Internal features

Transverse sections reveal that the guard is composed of many closely spaced growth lamellae that vary in colour and prominence. Colour variation is probably due to alteration produced by the passage of pore fluids migrating through the guard. Three or four well-marked growth stages are often visible (Fig. 42, 47), although sections in the posterior half of the guard may not intersect them all.

A major growth stage some 7–9 mm in diameter, bounded by several growth lamellae darker or lighter than the remainder, is almost invariably present (Fig. 44, 46). It seems to mark an important stage of development, perhaps a growth pause and/or a change from a length to a width orientated growth pattern. Many of the pre-adult guards available are at this stage of development.

The apical line is ventrally placed (Fig. 18), strongly so in large specimens, particularly in the apical half of the guard. Dorsoventral alveolar angle c. 20°.

A splitting surface is usually visible, particularly in transverse sections that intersect the alveolus. It appears as

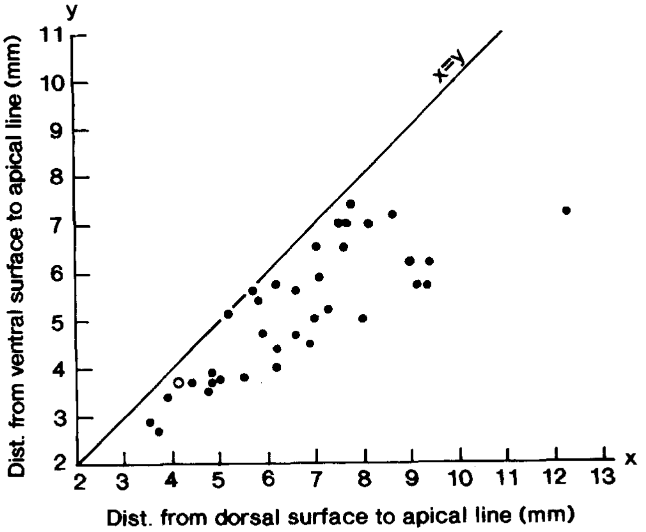


Fig. 18 Position of the apical line in *Belemnopsis aucklandica*. Open circle data from *Belemnopsis* sp. (R13/f6636B).

a narrow, often almost plane fissure extending from the base of the ventral groove to the alveolus (Fig. 42) and is often accompanied by a parallel zone of discolouration. It may be visible externally as a narrow fissure at the base of the ventral groove and may extend onto the postalveolar guard.

Dorsoventral or transverse long sections indicate the pre-adult guard is relatively slender and more hastate than the adult (Fig. 48, 49). A growth stage apparently corresponding to that 7–9 mm in diameter seen in transverse sections is sometimes particularly prominent (Fig. 48).

Systematic changes in morphology

No evolutionary changes were noted during phylogeny of the taxon by which particular parts of its time range could be identified. The mean postalveolar length of specimens in the lower part of its range (c. 70 mm) may be slightly greater than that from higher levels, but only six specimens are sufficiently complete for reliable measurement. This mean falls well within the range for the taxon as a whole (Fig. 13) and the observed increase may be due to sampling error. Apart from this, mean postalveolar length remains similar throughout. Cross-section, ventral groove, hastation, profile, and outline are also similar throughout its range, apart from random variation.

Less typical forms

A number of specimens were segregated from *B. aucklandica* by Challinor (1970). Those identified as *Belemnopsis* aff. *suavis* (Stolley, 1929) are no longer recognised as distinct from *B. aucklandica*. A combination of features suggested a picture rather different from that given by most *B. aucklandica*. These include retention of a long section of the alveolar region, a maximum diameter less than the mean value for adult *B. aucklandica* combined with early development of a weakly conical guard, and a deeper and narrower ventral groove than is usual in similar-sized specimens (Fig. 33, 34). These features can all be found in some typical specimens of *B. aucklandica*, and *B.* aff. *suavis* of Challinor (1970) is accordingly submerged in that taxon.

Specimens from the upper part of the range of *B. aucklandica* were segregated as *B.* aff. *aucklandica*. The material available was limited and the main differentiating criterion was relatively strong hastation (Fig. 25, 26). But moderate hastation is a feature of some adult *B. aucklandica* (e.g., the holotype; Stevens 1965, pl. 6, fig. 4–6) and is due to the retention of a normally paedomorphic feature into late development. It, and other minor features thought to define *B.* aff. *aucklandica*, are no longer considered significant, and the latter is here submerged in *B. aucklandica*.

A number of specimens were designated as *Belemnopsis* sp. They were provisionally segregated on minor features, all of which are now known to occur within *B. aucklandica*, and they are here included in that taxon.

Collections of pre-adult *B. aucklandica* from R13/f6972 and f7050 differ in some respects from pre-adult collections from other localities. This is discussed below.

Statistical data on *B. aucklandica* are set out in Table 2.

Pre-adult guard

The young guard (Fig. 55–80) is difficult to describe concisely because morphology alters during ontogeny. One important change is in the position of maximum diameter, which is located more toward the apex than in the adult and which migrates anteriorly with growth. This is only approximately correlated with increasing diameter, and in specimens of similar size the widest point may be located anteriorly as in the adult or relatively far towards the apex. This results in very different degrees of hastation.

The ventral groove varies in prominence, and this is at least partly correlated with hastation. In strongly hastate individuals, the groove frequently weakens at about midguard (i.e., near the region of maximum inflation) and often extends apically from this point as a wide and very shallow depression. Most weakly hastate specimens are more like the adult in general form, and in these the ventral groove is usually stronger and extends further towards the apex.

This description is based on c. 200 specimens, many of which have diameters of 6–9 mm and may best represent this particular stage of growth. As well, many are derived from two localities (R13/f6972, f7050); these collections may be different samples drawn from a single population and may not be fully typical of all pre-adult specimens (see below).

Description of pre-adult guard

Pre-adult guards are here defined as those with a maximum diameter of <10 mm (see above).

Guard elongate and usually fairly slender. Postalveolar length between 28 and 65 mm ($\bar{x}$ 51 mm, Fig. 50), and between 4 and 9 times maximum diameter ($\bar{x}$ 6.7, Fig. 51).

Outline symmetrical and hastate (Fig. 57, 77). Maximum transverse diameter approximately midway along the postalveolar guard (Fig. 55, 73). Flanks converge posteriorly, gradually at first, more rapidly near the apex (Fig. 61, 77). Posterior outline bilaterally symmetrical as in the adult but more regularly and smoothly curved. The apex may be mucronate. The flanks converge anteriorly, usually steadily, but are sometimes more rapidly constricted near the protoconch (Fig. 61, 80). Minimum transverse diameter is usually in the alveolar region several millimetres anterior to the protoconch. Difference between maximum transverse diameter and diameter at the protoconch is 1.2–2.9 mm ($\bar{x}$ c. 1 mm).

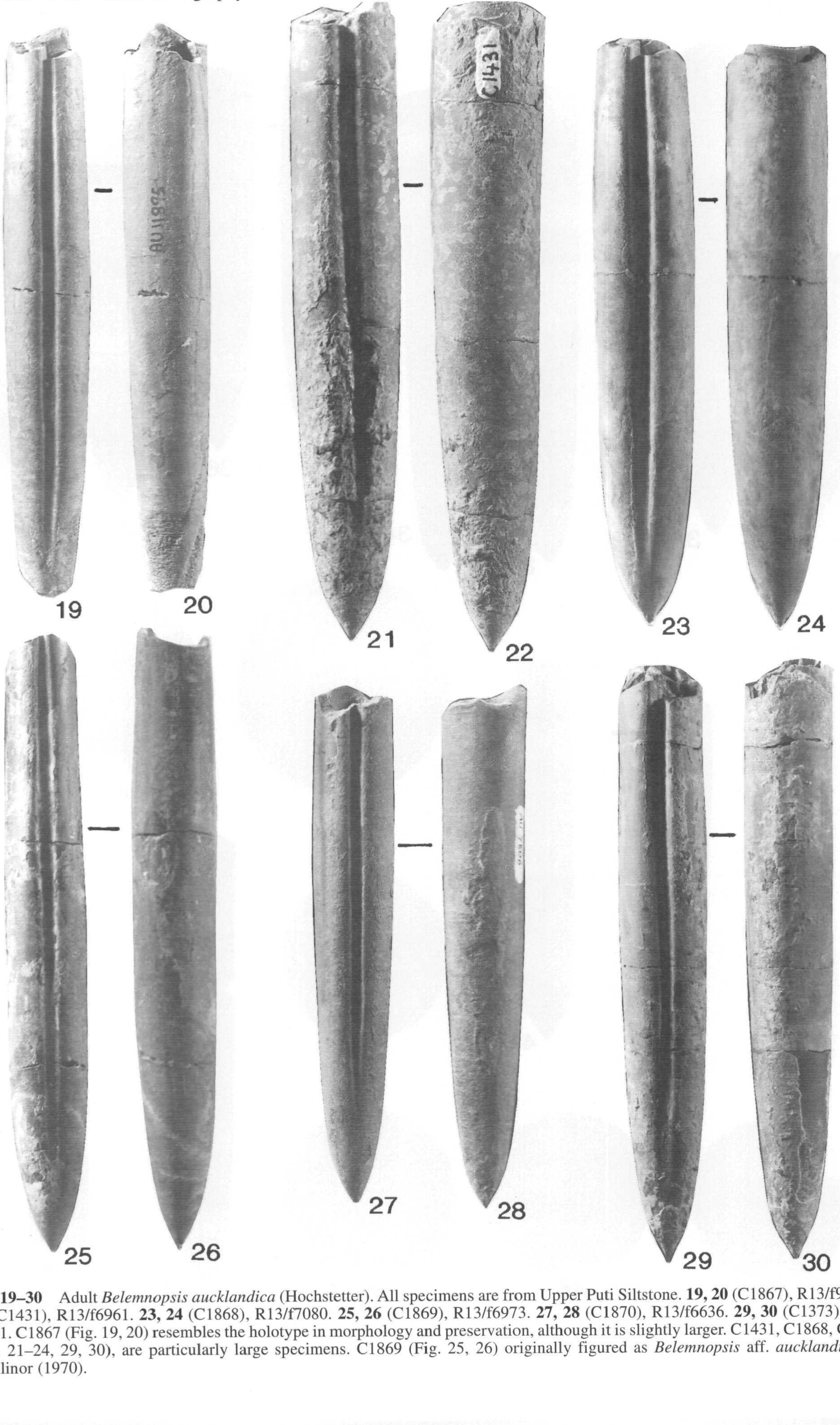
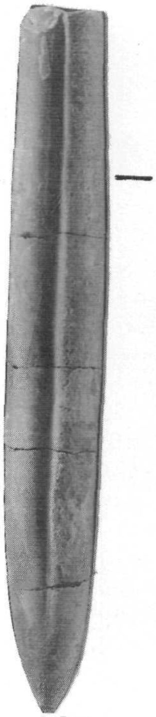


Fig. 19–30 Adult *Belemnopsis aucklandica* (Hochstetter). All specimens are from Upper Puti Siltstone. **19, 20** (C1867), R13/f99. **21, 22** (C1431), R13/f6961. **23, 24** (C1868), R13/f7080. **25, 26** (C1869), R13/f6973. **27, 28** (C1870), R13/f6636. **29, 30** (C1373), R13/f6961. C1867 (Fig. 19, 20) resembles the holotype in morphology and preservation, although it is slightly larger. C1431, C1868, C1373 (Fig. 21–24, 29, 30), are particularly large specimens. C1869 (Fig. 25, 26) originally figured as *Belemnopsis* aff. *aucklandica* by Challinor (1970).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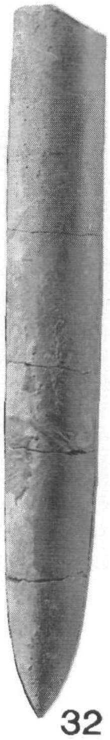
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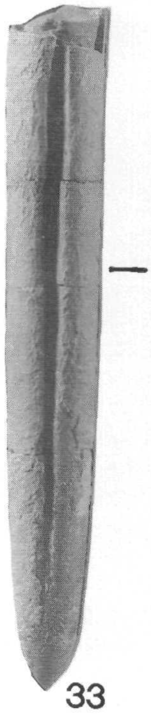
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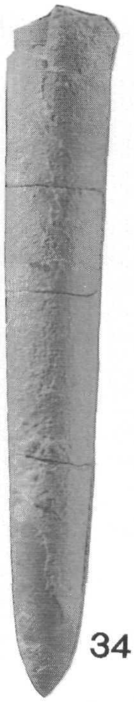
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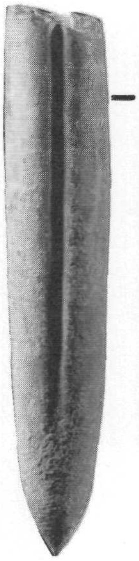
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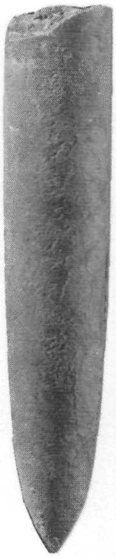
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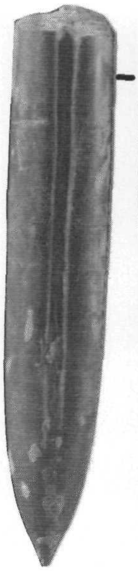
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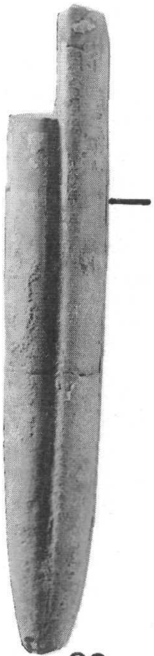
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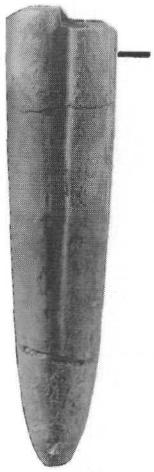
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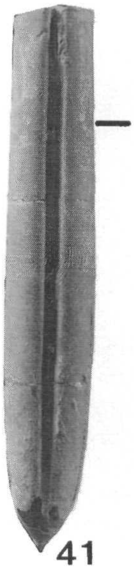
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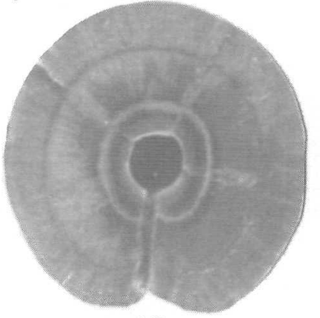
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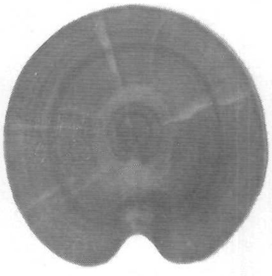
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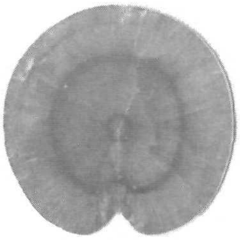
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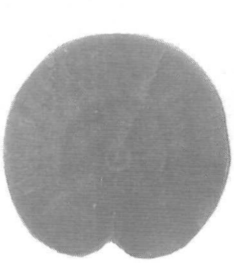
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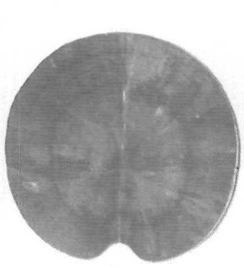
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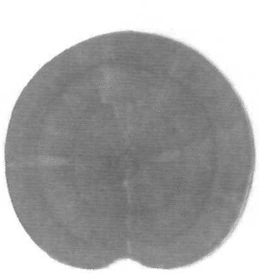
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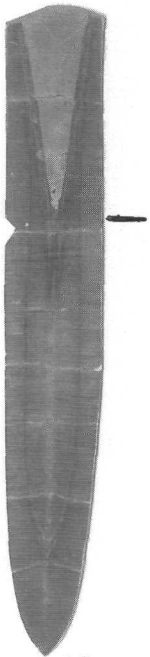
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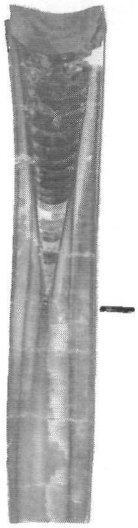
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Profile usually hastate and sometimes asymmetrical. In these specimens, the ventral surface may converge more rapidly towards the dorsal surface anteriorly (Fig. 58), the dorsal surface remaining approximately parallel to the guard midline. Difference between maximum sagittal diameter and sagittal diameter at protoconch 0–1.9 mm ($\bar{x}$ c. 0.7 mm).

Cross-section variable posteriorly (*A* = 93–107, $\bar{x}$ 100, Fig. 52), slightly oblate, circular, or slightly prolate. It is usually compressed anteriorly and prolate (*A* = 87–103, $\bar{x}$ 96, Fig. 53), and the ventrolateral flanks may be flattened.

Median ventral groove variably developed. In strongly hastate specimens it may be moderately narrow and moderately deep in the alveolar and anterior stem regions. Sometimes it becomes quite shallow at midguard, in the region of maximum inflation (Fig. 61, 73), and almost imperceptible in the posterior half of the guard (Fig. 63, 73). In less hastate specimens it is more prominent posteriorly; where the guard is almost parallel-sided, it may be prominent for much of guard length (Fig. 65, 69). It is usually c. 0.5 mm deep and c. 1.5 mm wide near and within the alveolar region, and usually shallower and wider posteriorly. It extends down the postalveolar guard for 40–80% of guard length ($\bar{x}$ 60%). Variation in ventral groove development, hastation, and of combinations between them, are illustrated in Fig. 55–80.

Traces of lateral lines are visible on most specimens and are prominent in some. In position and configuration they resemble those of the adult but are usually more prominent.

The apical line is ventrally placed (Fig. 18), the dorsoventral alveolar angle is similar to that of the adult, and in transverse sections within 20–30 mm of the protoconch, a prominent growth stage 1–4 mm in diameter is often present. Long sections show vague colour changes which presumably represent earlier growth stages, but except for that 2–4 mm in diameter mentioned above, they are not prominent. A splitting surface is present.

One taxon or several?

From time to time field identifications from the Port Waikato region suggest that other belemnite taxa (usually identified as *Hibolithes*) are present in the Upper Puti Siltstone. Therefore, it is necessary to justify the argument that all the pre-adult guards described here (except Fig. 81–82) are immature *B. aucklandica.*

◄ **Fig. 31–49** Adult *Belemnopsis aucklandica* (Hochstetter). All specimens are from Upper Puti Siltstone. **31, 32** (C1871), R13/f6962. **33, 34** (C1872), R13/f6971. **35, 36** (C1873), R13/f6636. **37, 38** (C1874), R13/f6980. **39** (C1875), R13/f7050. **40** (C1876), R13/f6637. **41** (C1877), R13/f6961. **42** (C1878), R13/f6980. **43** (C1879), R13/f6642. **44** (C1880), R13/f6639. **45** (C1881), R13/f6639. **46** (C1882), R13/f6639. **47** (C1883), R13/f6642. Fig. 42–47 are representative transverse sections. C1878, C1879 (Fig. 42, 43) section in alveolar region near protoconch. C1880, C1881 (Fig. 44, 45), near midguard. C1882, C1883 (Fig. 46, 47), towards apex. C1878 (Fig. 42) weathered specimen accentuating growth stages and splitting surface. Growth stages moderately well defined in C1879, C1880 (Fig. 43, 44), C1882, C1883 (Fig. 46, 47); poorly defined in C1881 (Fig. 45). Splitting surface visible in C1880, C1882, C1883 (Fig. 44, 46, 47). C1872 (Fig. 33, 34) originally figured as *Belemnopsis* aff. *suavis* by Challinor (1970). **48** (C1883A), R13/f6961, transverse long section illustrating slender transversely hastate pre-adult growth stage. **49** (C1884), R13/f6971, sagittal long section illustrating greater sagittal hastation in pre-adult growth stage.

Many of the growth changes documented here are known to occur during the ontogeny of other taxa. Forward movement of maximum diameters occurs in other *Belemnopsis* and in *Duvalia* (Challinor 1991), in *Hibolithes* (Challinor 1999), and probably occurs in most taxa where maximum diameter is anteriorly placed in the adult. A general increase in robustness and decrease in hastation is common (references above), and a small increase in the amount of cross-section flattening with growth occurs widely (Challinor 1979a, 1991, 1996). A relatively more strongly developed ventral groove in adults occurs in some *Hibolithes* (Challinor 1999).

More specific evidence for identity is the presence of appropriately shaped pre-adult guards within adults (Fig. 48, 49). No very hastate early growth stages similar to Fig. 63 were found in sectioned specimens, but this is not unexpected because such strong hastation occurs relatively rarely. Other evidence includes a posterior outline and profile in the pre-adult similar to, but less accentuated than, that of the adult, similarly configured lateral lines (as far as can be seen), and similarities in ventral profile in and near the alveolar region.

Changes in the relationship of maximum diameter to postalveolar length during ontogeny are illustrated in Fig. 54. The data points are not a random sample but have been selected to illustrate some aspects of the material studied. All suitable specimens <6 mm maximum diameter, and most adults in the collections studied, are included.

Data from pre-adult guards occupy the lower left and lower centre of the graph, and of those specimens data from R13/f6972 and f7050 (indicated by crosses) dominate the right and left extremities of that field. This suggests that both the largest and smallest specimens in this group occur most often at those localities.

This is a function of the large numbers of specimens from R13/f6972 and f7050 (c. 150) compared with smaller numbers from all other localities (c. 50, indicated by small filled circles). In particular, specimens <6 mm maximum diameter are relatively uncommon, but the proportion of small slender guards from R13/f6972 and f7050 is approximately correct when overall numbers are considered. The dominance of data from f6972 and f7050 in the centre and right of the pre-adult field also reflects the nature of those collections, interpreted as different samples from a large population of animals mostly at a late pre-adult stage of growth (see below).

Postalveolar length and diameter do not increase in the same proportions. A trend line fitted by eye to data points from pre-adult specimens (Fig. 54, A) indicates that maximum diameter increases relatively more rapidly than does length, although not markedly so. A similar trend line fitted to adult data points (Fig. 54, B) indicates that diametral growth is much more rapid late in ontogeny. This growth pattern has been documented in some *Hibolithes* (Challinor 1975), and probably characterises most moderately robust and robust belemnite taxa.

The other symbols in Fig. 54 (large filled and empty circles, squares, and triangles) indicate length/diameter ratios of sectioned adult guards and of their contained pre-adult growth stages, plotted in their corresponding fields. They suggest that very slender pre-adult guards (Fig. 59) develop into similarly proportioned adults (Fig. 25). The dispersion

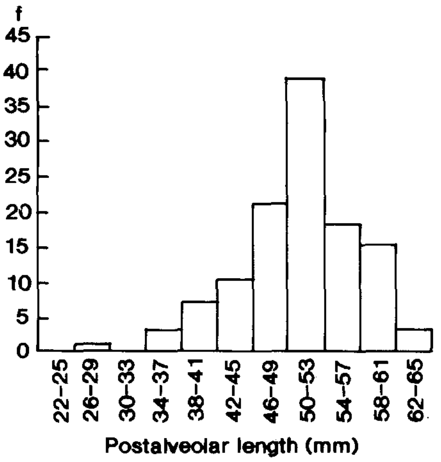


Fig. 50 Frequency distribution of postalveolar length (*l*) in pre-adult *Belemnopsis aucklandica*. $n = 118$, $\bar{x} = 50.6$ mm, $\sigma n{-}1 = 7.0$ mm.

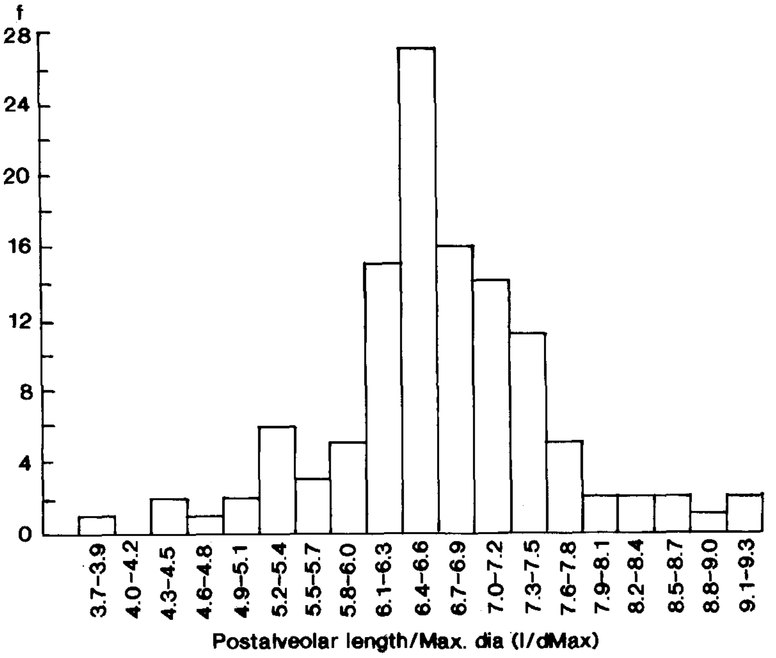


Fig. 51 Frequency distribution of indices of guard robustness (*l/dMax*) in pre-adult *Belemnopsis aucklandica*. $n = 117$, $\bar{x} = 6.7$, $\sigma n{-}1 = 9.1$.

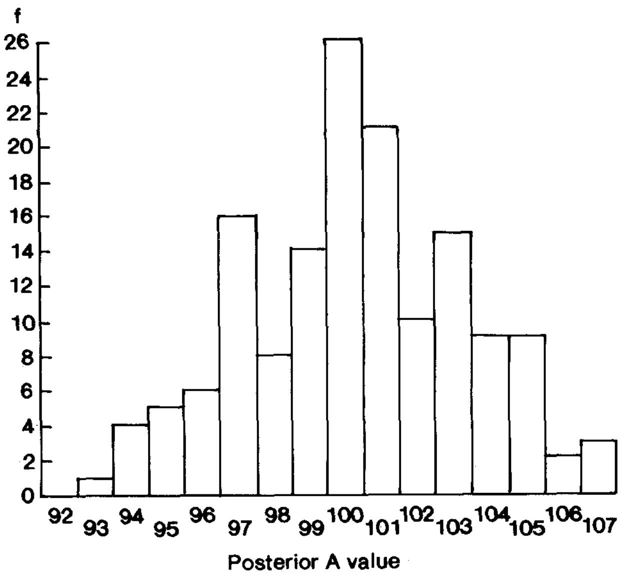


Fig. 52 Frequency distribution of indices of posterior flattening (AP) in pre-adult *Belemnopsis aucklandica*. $n = 141$, $\bar{x} = 100.3$, $\sigma n{-}1 = 3.0$.

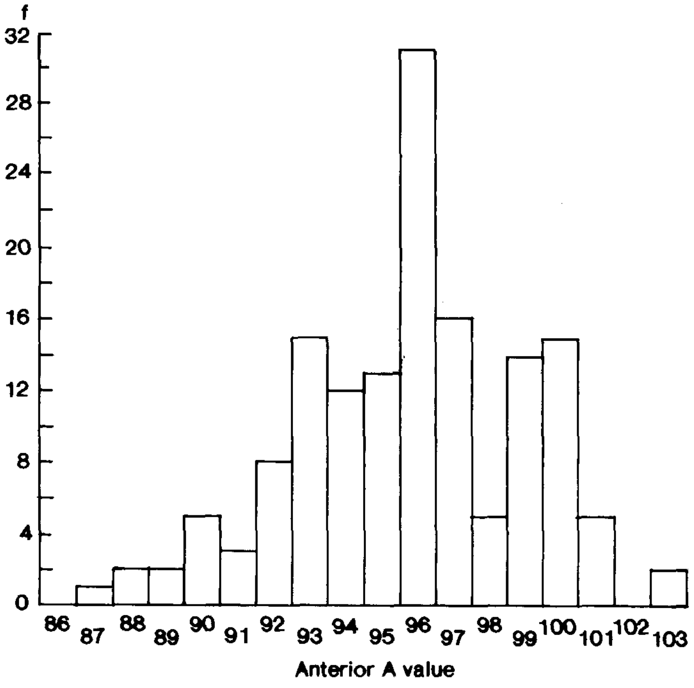


Fig. 53 Frequency distribution of indices of anterior flattening (AA) in pre-adult *Belemnopsis aucklandica*. $n = 149$, $\bar{x} = 95.8$, $\sigma n{-}1 = 3.2$.

of length:diameter ratios is less in adult than in pre-adults (Fig. 14, 51), as expected when growth is complete or nearly so in the members of one group but only partly complete in the other.

The data-point groupings in Fig. 54 could also be interpreted as indicating sexual dimorphism, with one sex retaining a slender pre-adult form and the other developing a larger more robust guard. A number of previous researchers have discussed possible dimorphism in belemnites. Doyle (1985) recognised it in *Youngibelus* (Belemnitina; Belemnitidae). Makowski (1963) outlined conditions for the recognition of dimorphism in ammonites, and similar criteria could be applied to belemnites.

Two of these conditions (comparable sex ratios to modern forms; no intermediate forms in the adult stage), are not met by the material studied here. Numerical ratios are 2:1 in

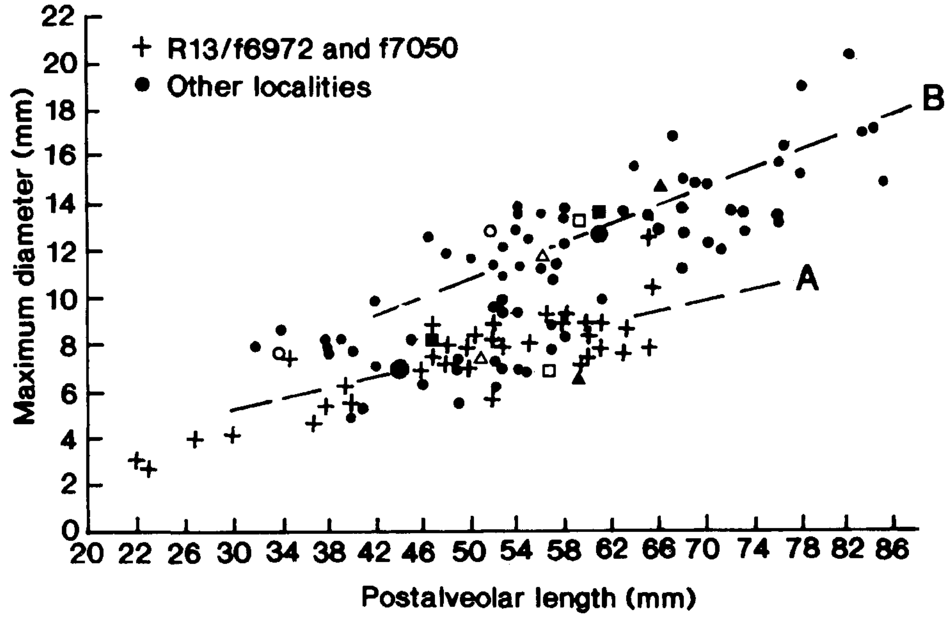


Fig. 54 Relationship between postalveolar length and maximum diameter in pre-adult *Belemnopsis aucklandica* (centred on line A) and adult *Belemnopsis aucklandica* (centred on line B). Crosses indicate observations from specimens from localities R13/f6972 and f7050 (thought to contain the same pre-adult population, see text), and small filled circles indicate observations from other localities. Other symbols (large filled and empty circles, filled and empty triangles and squares), indicate data from sectioned adult specimens and from their contained growth stages, each plotted in its respective field (see text).

favour of pre-adults for all collections studied here, and almost 50:1 for localities R13/f6972 and f7050 (cf. c. 1:1 in *Youngibelus* and similar in modern coleoids; Doyle 1985). Small adults (e.g., Fig. 41) are not much larger than some pre-adults (Fig. 65). The data available do not allow an unambiguous interpretation, and, although the dimorphism present could possibly be sexual, a conservative and more direct approach is adopted here and it is attributed to ontogenetic changes.

The occasional specimens identified as *Hibolithes* are likely to be strongly hastate, weakly grooved specimens (e.g., Fig. 63, 73). Both strong hastation and a weak ventral groove are parts of morphological continua, and both grade via intermediate forms into slightly hastate and more strongly grooved conditions. It is not acceptable to segregate these extreme specimens, when in other features (e.g., cross-section, gross size) they resemble other pre-adult guards as well as internal growth stages of *B. aucklandica*. In addition, if they are regarded a discrete taxa (presumably pre-adult), there are no known adult forms to which they can be related.

Unusual collections

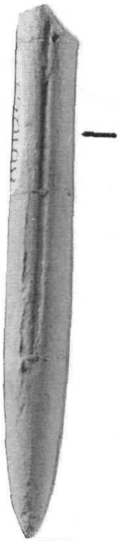
With one exception (Fig. 81–82), all pre-adults studied are here identified as *B. aucklandica*, but there are unusual aspects to some collections. With few exceptions the many specimens from localities R13/f6972 and f7050 are remarkably uniform in appearance and measurable features, and differ in some characteristics, particularly mean postalveolar length and mean length:diameter ratio, to those from other localities. Statistics from the larger collections from f6972 and f7050 and pooled statistics from the other localities are listed in Table 3.

Data similarities in the R13/f6972 and f7050 collections are best interpreted as indicating that a single population was sampled and that collections represent mortality in an assemblage of animals nearly all at a similar late pre-adult growth stage. Stevens (1965) discussed mass mortality in present-day squids, and similar processes may have operated in the past to produce accumulations of belemnite guards. But the specimens at R13/f7050 are distributed through a stratigraphic interval of at least 1 m (J. A. Grant-Mackie pers. comm. 1999), and at first sight this does not support a single-population hypothesis.

Concentrations of belemnite guards are not uncommon in the geologic record. Doyle & Macdonald (1993) suggest five different processes of accumulation. A combination of their types 2 and 5 processes (i.e., mass mortality followed by resedimentation), could result in the type of accumulation present at Port Waikato. This would involve death of a large swarm of late pre-adult belemnites, deposition of their remains on a single bedding plane, and subsequent slumping or turbidity current transport.

It is important to recognise that possible processes are known which could have produced the Port Waikato accumulate, although this is not a claim that those outlined are responsible in this instance. Sedimentary structures at R13/f7050 offer no support. As far as can be seen, the siltstones are undisturbed and indistinguishable from enclosing sediment, but the exposure is small and relations are not fully observable. Locality R13/f6972 was originally a large exposure but is now substantially revegetated and otherwise obscured. Collections were made over a number of years and their exact location within the exposure is not known. Part of the outcrop contains thin tuffaceous beds that are not redeposited, but the distribution of specimens in relation to the tuff beds is not known. An alternative explanation for the observed distributions could be bioturbation in soft sediment.

A full investigation of possible accumulation processes is beyond the scope of this paper, but statistical data from R13/f6972 and f7050 favour a single-population hypothesis. It is difficult to explain the near-identity of statistical data and overall appearance in other ways. The bed correlation indicated in Fig. 3 is based on these data. Differing data from the pooled localities are probably due to sampling from many horizons, populations, and varying growth stages as opposed to a restricted horizon, population, and growth stage. The pooled data may better represent pre-adult specimens than data from R13/f6972 and f7050.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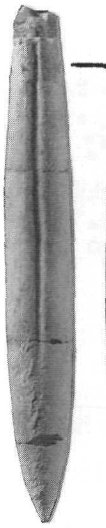
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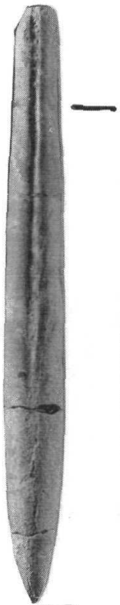
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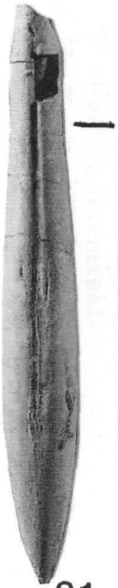
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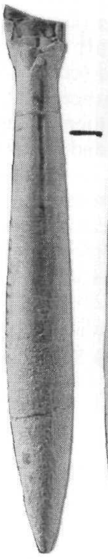
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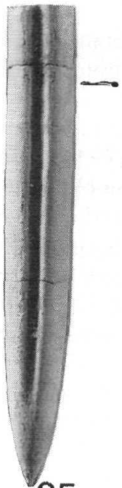
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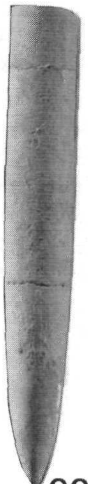
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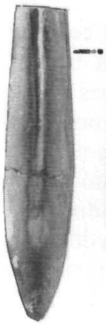
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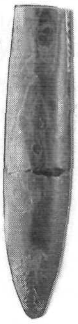
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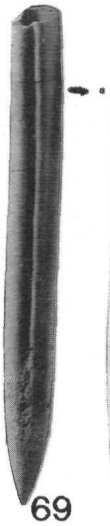
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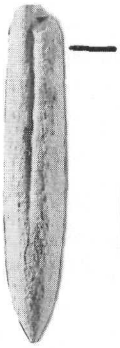
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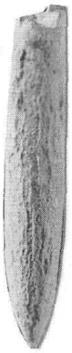
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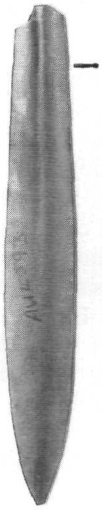
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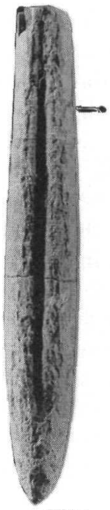
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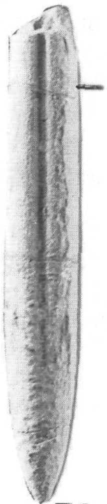
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Occasional adults also occur at R13/f6972 and f7050. A complete adult (Fig. 39, and co-ordinates 65, 12.7 in Fig. 54) is included in collection AU8461, and an almost complete near-adult (co-ordinates 65, 10.4) in AU8640. An alveolar fragment 12.1 mm in diameter was found at R13/f6972. They may be from the same horizons as the pre-adult specimens or from different horizons at the same localities.

Species or subspecies?

Belemnopsis aucklandica aucklandica and *B. a. trechmanni* were previously classified as subspecies (Stevens 1965) on the evidence of many shared features (similar ventral groove, cross-section, inflated ventral surface, blunt mucronate apex). But these are similarities, not evidence, that *aucklandica* has evolved from *trechmanni*. There is certainly an overall resemblance between adults of both, but similar *Belemnopsis* are known from other parts of the Indo-Pacific region. *B. a. aucklandica*, *B. a. trechmanni*, and other subspecies of *B. aucklandica* were at one time thought to be present in eastern Indonesia (Kruizinga 1920; Stevens 1965; Challinor & Skwarko 1982), but this is now considered to be an example of close homeomorphy (Challinor 1991). In addition, the Indonesian taxa (*Belemnopsis galoi* and transitional forms; Challinor 1991) are now thought to be of Kimmeridgian age (Francis & Westermann 1993), whereas *B. trechmanni* and *B. aucklandica* occur in Middle and Late Tithonian beds in New Zealand (ages from Stevens 1997).

B. aucklandica was considered to be derived from *B. trechmanni* by partial loss of hastation (Stevens 1965), and the two differ appreciably in cross-section (cf. data in this paper with that in Challinor 1996). It is not enough to claim that these conditions in *trechmanni* have been modified to produce *aucklandica*. What is needed is evidence of progressive modification. The initiation of changes during the time range of *trechmanni* (e.g., partial loss of hastation, a decrease in cross-section flattening) have not been demonstrated, nor have they been shown to continue in *aucklandica*.

The similarities discussed are not considered to be sufficient to warrant subspecific status and there is some direct evidence that argues against it. Both Stevens (1965) and Challinor (1996) stated that the ventral groove in *trechmanni* was prominent at all stages of growth, although Challinor (1996) found that it was relatively weak in some very young guards which are possible members of the taxon. There is no evidence that the ventral groove in late pre-adult *trechmanni* is as weakly developed as that of many *aucklandica*, and the strong hastation seen in some late pre-adult *aucklandica* has not been observed in *trechmanni*. These indicate a growth pattern in *aucklandica* that differs from that of *trechmanni*.

◄ **Fig. 55–80** Pre-adult *Belemnopsis aucklandica* (Hochstetter). All specimens are from the Upper Puti Siltstone. **55, 56** (C1885), R13/f7050. **57, 58** (C1886), R13/f6972. **59, 60** (C1887), R13/f6972. **61, 62** (C1888), R13/f7050. **63, 64** (C1889), R13/f7050. **65, 66** (C1890), R13/f6650. **67, 68** (C1891), R13/f6972. **69, 70** (C1892), R13/f6962. **71, 72** (C1893), R13/f6811. **73** (C1894), R13/f300. **74** (C1895), R13/f6963. **75** (C1896), R13/f6636. **76** (C1897), R13/f7050. **77** (C1898), R13/f6969. **78** (C1899), R13/f6971. **79** (C1900), R13/f6971. **80** (C1901), R13/f7050. Specimens illustrating a range of size and morphology are figured. C1886, C1888, C1889, C1894 (Fig. 57–58, 61–62, 63–64, 73) are strongly hastate. C1890, C1892, C1900 (Fig. 65–66, 69–70, 79) are weakly hastate. C1889, C1894, C1900 (Fig. 63–64, 73, 79) have narrow shallow anterior ventral grooves with a weak posterior extension. C1887, C1888, C1901 (Fig. 59–60, 61–62, 80) have wider, deeper anterior ventral grooves with a stronger posterior extension. C1890, C1892, C1898, C1899 (Fig. 65–66, 69–70, 77, 78) have wide, deep, and long ventral grooves. C1891, C1893 (Fig. 67–68, 71–72) are particularly short specimens. C1887, C1888 (Fig. 59–60, 61–62) are long specimens.

Fig. 81, 82 *Belemnopsis* sp., Upper Puti Siltstone. (C1902), R13/f6636B.

Based on the lack of direct evidence supporting subspecific relationship, and on the ontogenetic evidence against it, such a relationship is not accepted here. The two are regarded as warranting full specific status. *B. a. trechmanni* becomes *B. trechmanni* Stevens and *B. a. aucklandica* reverts to *B. aucklandica* (Hochstetter).

***Belemnopsis* sp.**

(Fig. 81, 82, and some data in Fig. 17, 18).

LOCALITY AND MATERIAL: A partial guard from R13/f6636B (AU807).

AGE: Waikatoan (Late Tithonian).

Description

A single fragment, 49 mm long and 9 mm maximum diameter, consisting of the apical and part of the stem region of a probably pre-adult guard. Outline elongate, symmetrical, apical region tapering slowly, more rapidly near apex. Profile similar, ventral surface slightly inflated near apex. Cross-sections strongly depressed (A = 113 c. 25 mm from apex, 110 at anterior break; Fig 17). Ventral groove 3.2 mm wide, 0.8 mm deep at anterior break, narrows and shallows posteriorly, terminating very close to apex. Lateral lines moderately prominent. Apical line ventrally placed (Fig. 18). A prominent growth stage c. 3 mm in diameter and a second less prominent one towards guard exterior are visible at the anterior break.

Discussion

The specimen is associated with adult *B. aucklandica* at f6636 but its cross-section is much more depressed than that of adults or pre-adults of that taxon. It differs also in outline and ventral groove characters, particularly from pre-adult *B. aucklandica*. It is provisionally segregated from that taxon.

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I thank Roger Briggs (University of Waikato) and Jack Grant-Mackie (University of Auckland) for constructive criticism of the first manuscript. Referees Peter Doyle and Hamish Campbell provided suggestions and advice that greatly improved the final presentation. The Department of Geology, University of Auckland, made specimens available for study; Jack Grant-Mackie supplied new data on the distribution of *Buchia* spp.; Frank Bailey drew the diagrams; and Elaine Norton and Clare Harris typed the manuscript.

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