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UHLIGI — COMPLEX BELEMNITES OF THE PUAROAN (LOWER - ? MIDDLE TITHONIAN) STAGE IN THE PORT WAIKATO REGION OF NEW ZEALAND

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Abstract

Belemnite guards range through 2700 feet of Puaroan strata in the Port Waikato region. All are *Belemnopsis* of the *uhligi*-complex. *Belemnopsis aucklandica aucklandica* (Hochstetter) in its most typical form may be restricted to the lower 700 feet of the sequence. Three species are described, together with what may be transitional forms. The morphology of juvenile guards is in marked contrast with that of mature specimens, and development of the adult guard is revealed by examination of internal sections. Some aspects of belemnite paleoecology are discussed. Belemnite biostratigraphy of the area is outlined and the more important fossil localities are described.

INTRODUCTION

The work outlined in this paper was undertaken in an attempt to define the belemnite stratigraphy and content of the Puaroan Stage in the Port Waikato region. Belemnite guards had been collected from a number of sites of Puaroan age by previous workers in the area (e.g. Hochstetter 1864, p. 29, Purser 1961, pp. 9-10) and Stevens (1965, p. 83) suggested that these were probably all *Belemnopsis aucklandica aucklandica* (Hochstetter). However, this is not known with certainty as most of Purser's specimens cannot now be located. A few guards collected by the writer some time ago from sites in Maraitai (Maretae) Valley showed marked variation in size and general appearance, suggesting the possible presence of more than one species of belemnite.

It has been shown by Stevens (1965, p. 26) that the Puaroan Stage at Kawhia Harbour contains a well defined succession of belemnites. The earliest species to occur is *Belemnopsis spathi* Stevens which appears at the top of the Ohauan Stage and persists into the lower Waiharakeke Conglomerate, which is of basal Puaroan age (for the geology of the Puaroan Stage at Kawhia Harbour see Fleming and Kear 1960, pp. 37-41). *Hibolithes arkelli* Stevens has been collected from the top 400 feet of the Waiharakeke Conglomerate, but has not been found in the lower 900 feet of the overlying Puti Siltstone, although it reappears to range through an interval of 900-1150 feet above the base, associated with *Hibolithes marwicki marwicki* Stevens. *H.m. marwicki* is replaced by *Hibolithes marwicki mangaoraensis* Stevens, which is in turn replaced by *Hibolithes* n. sp. *H.* n. sp. ranges up to a level 2500 feet above the base of the Puti Siltstone, and is the youngest belemnite to occur in the Kawhia Harbour sequence.

Although *Belemnopsis aucklandica aucklandica* is not known from Kawhia Harbour it is present, together with the lamellibranch *Buchia hochstetteri* Fleming, at the top of the Puti Siltstone in the area north and east of Kawhia (Player 1958, Stevens 1965, p. 82) and is probably separated from the upper limit of the Puti *Hibolithes* species by *ca.* 1200 feet of strata.

Hibolithes arkelli and *Belemnopsis aucklandica aucklandica* occur together in the Te Akau region (N 55) still further north (Stevens 1965, p. 82) but *Hibolithes arkelli* or the other members of the Puti *Hibolithes* group have not been recorded from the Port Waikato area.

On the basis of the presence of some 3000 feet of marine Puaroan strata at Port Waikato, and the succession of belemnite species in the Puaroan of the Kawhia Harbour sequence, it was expected that more than one belemnite species would be found within the Port Waikato Puaroan.

Geology

The geology of the Port Waikato area has been examined by Purser (1961) who found the structure of the Mesozoic rocks to be a major syncline flanked to the west by a smaller anticline (Fig. 8). These structures are interpreted as lying on the eastern limb of the northernmost extension of the Kawhia Regional Syncline (Fleming, in press). Puaroan sediments (including the non-marine Huriwai Formation) occur in and near the axis of the syncline, while the anticline to the west is wholly of Puaroan age, with the exception of a small area near the mouth of the Waikato River where sediments which may be of upper Ohauan age form the core of the structure.

Purser (1965, p. 9) has defined the Puaroan stage in the Port Waikato region as that part of the Jurassic sequence lying between the lowest occurrence of *Buchia hochstetteri* Fleming, and the lowest Huriwai plant flora. Using these criteria, some 3000 feet of Puaroan strata were measured by Purser, and subdivided into a lower zone (Zone A, 900 feet thick) characterised by *Buchia hochstetteri* Fleming (=*Buchia extensa* (Holdhaus) of Purser), and an upper zone (Zone B, 2100 feet thick) characterised by *Buchia plicata* (Zittel). The Zone B index fossil is apparently restricted to the lower 1500 feet of its zone.

More recent collecting in the area (J. A. Grant-Mackie pers. comm.) has shown that *Buchia hochstetteri* is present only in the upper half of its zone, and that a closely allied species currently known as *Buchia* aff. *misolica* (Krumbeck) occupies the lower part. When Purser drew his lower Puaroan boundary he did so at the base of what is now known to be the *Buchia* aff. *misolica* zone. For the purposes of this paper the base of the *Buchia* aff. *misolica* zone is taken to be the base of the Puaroan stage. With this exception, Purser's mapping of the Puaroan stage is accepted as the stratigraphic basis for this present study.

The lower 1350 feet of strata consist of well-bedded grey mudstone, with numerous lighter coloured beds of mudstone or siltstone (tuffaceous?) and occasional beds of concretions, some fossiliferous. Prominent marker beds seem to be absent. Above 1200 - 1300 feet from the base carbonised plant material becomes common, and at 1350 feet the lithology changes to poorly bedded massive sandstone which persists for some 750 feet. Siltstone with minor fine sandstone and conglomerate continues on upwards for another 900 feet, when the appearance of well-preserved plant fossils is taken as the lower boundary of the Huriwai Formation (Fig. 9).

Due to uniform lithology in the lower part of the stage it is not possible to correlate individual rock units in widely separated exposures, although it may be possible to do so in a few cases on the basis of fossils. As it was not possible to correlate beds accurately, fossil sites have been grouped, each group representing a stratigraphic interval of 100 or 200 feet, and the system follows that used by Purser (1961, Range-chart Jurassic Fauna and Flora), although in one or two

instances a closer grouping has been used. Some of the material used in this study was obtained from Purser's original fossil localities and in these instances his sheet fossil number (e.g. f 650, the collection number allocated to the particular locality in the New Zealand Fossil Record System) has been used. But in some cases, place names, or the spelling used by Purser, differ from those used in this paper, and where this occurs his usage is given in brackets. Also, as Purser used the grid system of the provisional 1:63360 topographical map series (sheet N 51, published 1943) new map references, in terms of the NZMS 1 national thousand-yard grid (sheet N 51, published 1964) have been allocated and are listed at the completion of the paper.

Sheet Fossil Numbers have been assigned to all new fossil localities collected by the writer.

Techniques

The methods used in the examination and description of the external features of belemnite guards are those used by Stevens (1965, pp. 38-47). The following criteria were found useful:

Measurement of maximum transverse diameter		dtM
Measurement of minimum transverse diameter		dtm
Measurement of maximum saggital diameter		dsM
Measurement of minimum saggital diameter		dsm
Index of transverse hastation	$= \frac{dtM \times 100}{dtm}$	Ht
Index of saggital hastation	$= \frac{dsM \times 100}{dsm}$	Hs
Index of flattening (at dtM)	$= \frac{dtM \times 100}{dsM}$	A

Total length of the guard from apex to intersection of the alveolar wall and side of the guard	=	L
Distance from apex of guard to dtM	=	v
Distance from dtM to dtm	=	u
Position of dtM (u divided by v)	=	u/v
Distance from apex to protoconch (Length of stem and apical regions)	=	l

Particulars of the ventral groove
Gross outline in ventral aspect (= outline)
Gross outline in lateral aspect (= profile)

Reference to Figure 1 will explain the descriptive terminology used in this paper.

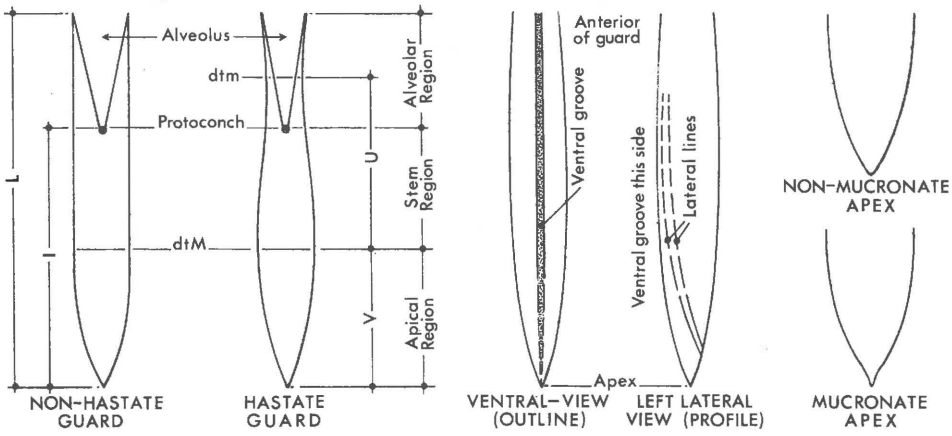

Figure 1. Terminology diagram to illustrate the morphology of Belemnite guards.

The accurate measurement of some guards was difficult due to the presence of a coating of hard lumpy matrix or to the guard being either damaged or incomplete. Various methods were used in an attempt to remove the matrix coating, but leaching briefly in dilute HCl, boiling in a mixture of H_2O_2 and water, and heating the guard followed by immersion in cold water were all relatively unsuccessful, although the latter process resulted in a sufficiently rapid temperature change within the guard to crack several specimens along the ventral groove.

The presence of obscuring matrix or damage to the alveolar region made it necessary to estimate the minimum transverse diameter in some cases, and for this reason it was occasionally difficult to decide if a specimen was slightly hastate, or completely lacking in hastation. The total length of a guard was seldom directly measurable and this was estimated by placing alongside the guard in the appropriate position a triangular piece of card cut at the previously determined alveolar angle, and estimating the point at which the sides of the guard would intersect the alveolus. This is similar to the method used by Stevens (1965, p. 44) to locate the position of the protoconch. In this paper the maximum diameter of the guard is compared with the total length, L, and not with l (distance from protoconch to apex) as used by Stevens.

A number of specimens were examined internally. Transverse and longitudinal sections were prepared by first embedding the guard in quick-setting dental plaster (variety E.P. 1 Stone) and then planing down the surface of the plaster block with a carpenter's wood rasp, until a plane 2 - 3 mm. above the desired section was reached. The specimen was then ground face downwards, using plenty of water, on successively finer grades of silicon carbide paper, commencing on grade 80 and finishing on 600. This last grade produced a semi-polished surface which was painted with clear plastic. Sections were prepared rapidly by this method, and revealed sufficient internal detail for this work.

In many localities belemnites are present only as moulds, the calcite of the guard having undergone partial or complete solution and removal. Where moulds are well preserved and in a fine-grained matrix, surface details of the guard will be retained on the walls of the mould and may be reproduced by suitable casting techniques.

The usual method employs a rubber moulding latex (Mr I. Keyes 1959, pp. 56 - 57, and pers. comm.), but the method is slow and not suitable for use in the field. Casts were prepared for this work using an acrylic material normally employed in the repair of the palate portion of artificial dentures. This preparation (Jet Acrylic, Lang Medical Co.) is prepared in two phases, a very fine freely-running powder and a mobile liquid, and when mixed the two undergo autopolymerisation to produce a tough solid. Briefly, the method is as follows:

The mould is first thoroughly cleaned with water, and a 20 ml nylon hypodermic syringe tipped with a 100 mm 12-gauge needle was found convenient for directing a concentrated jet of water right to the base of the mould. A small soft brush is useful in the final stages to remove any remaining debris. As well as cleaning the mould the water soaks into the walls and prevents penetration of the liquid phase of the acrylic, which is immiscible in water. After swabbing out any excess water with the brush, a few drops of acrylic liquid are run into the mould from a straight untipped eye dropper, and this is followed by enough powder, delivered from a plastic squeeze bottle equipped with a fine nozzle, to

soak up the liquid phase. This is repeated until the mould is filled. The exact proportion of powder to liquid is not critical and gentle stirring with a fine wire probe is useful to promote thorough mixing. Full polymerisation takes about 10 minutes, after which the completed cast may be removed with a hammer and chisel. The cast should not be left in the mould for an extended period as the acrylic material becomes more brittle as it ages. If the mould is not suitably orientated to allow the liquid phase to be run in, the two phases may be first mixed in a small mortar and the dampened powder tamped into the mould with a blunt wooden rod.

This method of casting will reveal quite fine details (e.g. lateral line patterns) provided the mould is well preserved, but it suffers from the major disadvantage that the mould is destroyed in the process. This is acceptable in many cases as it is frequently not possible to remove the mould in its matrix for processing in the laboratory.

PALEONTOLOGY

Nearly 300 specimens were collected, most of which fall naturally into one of two groups, although a few guards are more or less intermediate in form and cannot be assigned to either group.

The first group consists of slender guards which are often very hastate and show considerable variation in the form of the ventral groove, whereas guards of the second group are more robust, markedly larger, and usually slightly hastate. Despite marked contrasts in morphology, examination of the internal structure of specimens from both groups reveals that the first group consists of juveniles of the second.

All are *Belemnopsis* and most adults have been asigned to one of three species, although some guards cannot be so placed and are designated *Belemnopsis* sp. Juvenile guards cannot be separated on morphologic grounds and are apparently similar in two of the species. Juveniles were not found in association with the third species.

SYSTEMATIC DESCRIPTIONS

Family BELEMNITIDAE d'Orbigny 1845

Subfamily HASTITINAE

Genus *Belemnopsis* Bayle 1878

Belemnopsis aucklandica aucklandica (Hochstetter)

1863 *Belemnites aucklandicus* Hochstetter, Neuseeland: 129, Fig.

1864 *Belemnopsis aucklandicus* Hauer in Zittel,, Novara-Exped., Geol. Th. 1 (2): 29, pl. 8, Fig. 2a, b, c.

1959 *Belemnopsis aucklandica* (Hochstetter) Fleming, Lex. stratigr. int. 6 (4): 339 (Waikato Heads occurrence).

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

1961 *Belemnopsis* spp. Purser, N.Z. Geol. Surv. Bull. n.s. 69: 27 - 29.

1965 *Belemnopsis aucklandica aucklandica* (Hochstetter) Stevens, N.Z. Geol. Surv. Paleont. Bull. 36. 82 - 88; pl. 6 - 8.

Stratigraphic range

B.a. aucklandica is best developed in the lower 500 - 700 feet of the Puaroan stage in the Port Waikato sequence, but less typical specimens are present up to 1300 - 1500 feet above the base of the stage. *B.a. aucklandica* is associated with *Buchia* aff. *misolica* (Krumbeck) and *Buchia hochstetteri* Fleming in the lower part of its range, with *Belemnopsis* aff. *suavis* Stolley and *Buchia hochstetteri* in the middle part, and with *Belemnopsis* aff. *aucklandica* and *Buchia plicata* (Zittel) in the upper part of its range (Fig. 9). *Aulacosphinctoides brownei* (Marshall), the index fossil for the uppermost ammonite zone at Kawhia Harbour (Fleming and Kear 1960, p. 44) also occurs within the range of *B.a. aucklandica* at Port Waikato (Purser 1961, p. 29).

Description of Adult Guard (Figs. 2, 4)

B.a. aucklandica has been fully described by Stevens (1965, pp. 83 - 85) and the remarks which follow should be read in conjunction with his account of the species. Most specimens on which this work is based conform to Stevens' description but the ranges of measurements for the various dimensions of the guard are wider due probably to the greater number of specimens available.

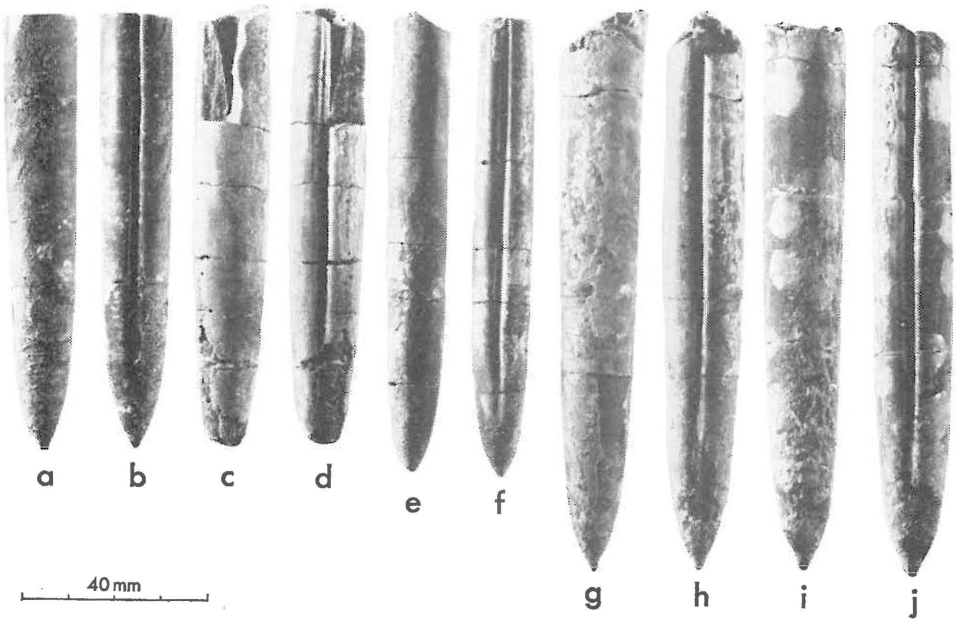

Figure 2. Belemnopsis aucklandica aucklandica
× 0.6 approx.

a, b, Te Karamu Stream N51/f 952	a, left lateral view	b, ventral view
c, d, western tributary Okahu Stream N51/f 958	c, left lateral view	d, ventral view
e, f, Maraitai Valley N51/f 962	e, left lateral view	f, ventral view
g, h, Waikawau Valley N51/f 963	g, left lateral view	h, ventral view
i, j, Maraitai Valley N51/f 961	i, left lateral view	j, ventral view

Guard elongate and robust. Length approximately 6 - 7 times the maximum diameter. Outline symmetrical and slightly hastate (Ht = 102 - 112). The maximum transverse diameter is anterior in position (u/v = 0.35 - 0.8). Posterior to dtM the sides converge gradually towards the apex but the rate of curvature increases over the last 15 - 20 mm of the apical region and the apex itself is mucronate, sometimes strongly so (Fig. 2h, j). Anterior to dtM the sides converge gradually

to a point 10 - 15 mm anterior to the protoconch and thereafter diverge again to accommodate the phragmocone.

The profile may be symmetrical or asymmetrical, and in the latter case the ventral surface of the apical region is more inflated than the dorsal surface and the apex is directed dorsally (Fig. 2g). The profile may be non-hastate (Fig. 2a, i) or slightly hastate (Fig. 2g). When present, saggital hastation is produced by the ventral surface converging slightly towards the mid-line of the guard, this convergence commencing just anterior to the protoconch (Fig. 2e). The dorsal surface remains parallel to the mid-line of the guard (Hs = 101 - 107).

The cross-section is depressed in the apical region, usually depressed in the stem region, but sometimes equidimensional or slightly compressed (A= 99 - 102). Anteriorly the cross-section is compressed.

Median ventral groove deep and broad and extending from alveolus almost to the apex. The groove is deepest in the stem region and it shallows posteriorly, gradually at first, but more rapidly near the apex. Anteriorly the groove narrows in the alveolar region (Fig. 2f).

Lateral lines appear to be a normal feature of the guard but are not usually prominent and may be visible only in the apical region. Due to the presence of obscuring matrix the anterior course of the lateral lines could not be traced in any of the specimens on which this description is based.

Table 1 sets out the dimensions of selected adult *B.a. aucklandica*, and they are illustrated in Figures 2 and 4.

Table 1. Dimensions (in mm) of *B.a. aucklandica* illustrated as Figures 2 and 4.

Figure 2	L	u	v	u/v	dtM	dtm	dsM	dsm	Ht	Hs	A
Spec. a, b	110		78*		14.97		14.80				101
Spec. c, d	110		70*		15.75		15.45				102
Spec. e, f	98	38	53	0.66	12.5	11.1	12.2	12.07	112	101	102
Spec. g, h	115	33	66	0.5	16.5	15.5	16.35	16.18	106	101	101
Spec. i, j	118	30	71	0.43	16.38	15.75	16.3		104	NH	100.5
Figure 4											
Spec. a, b	126	55	71	0.75	19.85	19.4	19.85		102	NH	100
Spec. c, d	77	41	36	1.14	11.53	10.2	10.8	10.27	113	105	107
Spec. e, f	102	47	55	0.85	15.23	15.15*	14.95	14.95*	100.5	NH	102
Spec. g, h	96	43	48	0.9	12.05	10.78	12.18	11.1	112	107	99

* approximate NH Non-hastate

Description of Juvenile Guard (Fig. 3)

Guard elongate and slender with a length of between 7 and 10 times the maximum diameter.

Outline symmetrical and hastate (Fig. 3b, f), sometimes markedly so (Ht = 105 - 133) but some specimens are only slightly hastate (Fig. 3d). Maximum transverse diameter posterior in position (u/v = 1 - 1.4). Posterior to dtM the sides of the guard converge toward the apex, sometimes smoothly, but often more rapidly over the last 5 mm or so, producing an increase in the rate of curvature near the apex. Apex mucronate (Fig. 3b) or non-mucronate (Fig. 3f). Anterior to dtM the sides converge, smoothly at first, but sometimes more rapidly near the protoconch, producing a marked decrease in transverse diameter in this region (Fig. 3f).

The profile is usually asymmetrical and hastate (Hs = 112 - 130). Anterior to dtM the dorsal surface converges gradually towards the midline of the guard whereas the ventral surface converges more rapidly, particularly near the protoconch, often producing a step in the ventral profile in this region (Fig. 3e). The profile of the apical region may be either symmetrical or asymmetrical, and asymmetry is produced by inflation of the ventral surface (Fig. 3a).

The cross-section at dtM varies from compressed to depressed (A = 96 - 105) and is compressed anteriorly.

The median ventral groove is frequently a prominent feature of the guard and extends from alveolus almost to the apex (Fig. 3d, h, j) although it varies widely in both width and depth. In many specimens the ventral groove is not prominent and is sometimes narrow and almost slitlike in the alveolar region (Fig. 3f) and quite shallow in the posterior stem and apical region. In some cases the groove persists into the apical region only as a broad shallow depression (Fig. 3f). When the groove becomes narrow towards the anterior, it does so only in the alveolar region where the walls of the alveolus approach the surface of the guard; posterior to this it broadens and shallows.

Lateral lines are present in most specimens and appear to be relatively more prominent than in the adult. They begin on the dorso-lateral surface close to the apex and at first their course is approximately parallel to the mid-line of the guard. About 5 - 10 mm posterior to dtM they swing towards the ventral surface and run diagonally downwards across the flanks of the guard, attaining a ventro-lateral position in the posterior stem region. Anterior to dtM they begin to diverge slightly and often shallow markedly, but may sometimes be traced into the alveolar region, usually as a shallow depression which approximately parallels the ventral surface of the guard.

The dimensions of selected juvenile *B.a. aucklandica* are listed in Table 2 and the guards are illustrated in Figure 3.

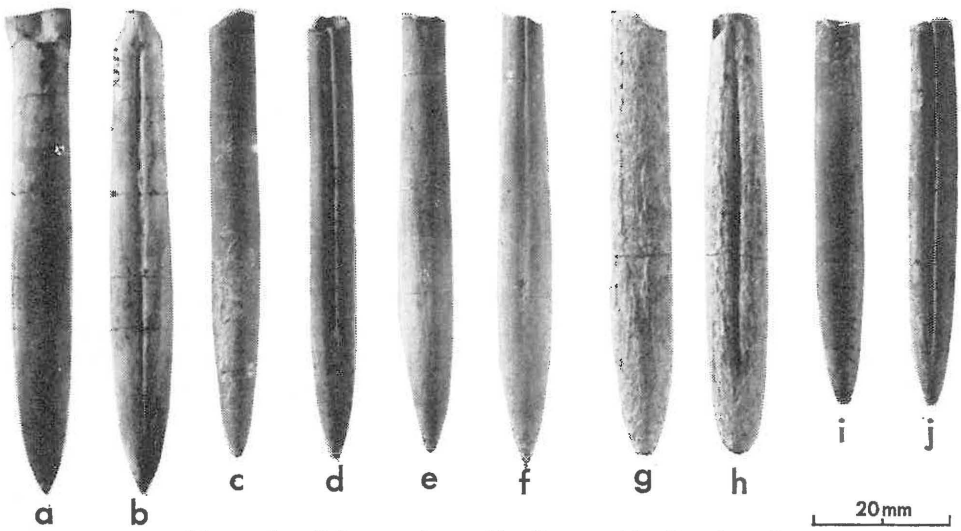

Figure 3. Belemnopsis aucklandica aucklandica juvenile
× 0.9 approx.

a, b, Maraitai Valley N51/f 639	a, left lateral view	b, ventral view
c, d, Maraitai Stream N51/f 962	c, left lateral view	d, ventral view
e, f, Huriwai Stream N51/f 967	e, left lateral view	f, ventral view
g, h, Huriwai Stream N51/f 969	g, left lateral view	h, ventral view
i, j, Maraitai Valley N51/f 642	i, left lateral view	j, ventral view

Table 2. Dimensions (in mm) of *B.a. aucklandica* juveniles illustrated as Figure 3.

Specimen	L	u	v	u/v	dtM	dtm	dsM	dsm	Ht	Hs	A
a, b	70	36	28	1.29	8.87	7.38	8.79	7.98	120	110	101
c, d	68	30	38	0.8	6.72	6.65	7.00	6.95	101	101	96
e, f	65	35	26	1.35	7.78	6.10	7.67	6.5	127	118	101
g, h	66	35	31	1.13	9.5	7.4	8.8	7.85	127	112	107
i, j	59	28	31	0.9	7.32	6.4	7.37	6.6	114	111	100

Internal Structure and Development

Longitudinal sections were prepared from four adult and four juvenile guards, and as Stevens (1965, p. 85) has suggested, the internal structure of the adult guard appears to be characterised by four major growth stages, although they may not all be readily visible. The protoconch is a convenient reference point in longitudinal sections, and the length of the growth stage from this point to the apex is readily measurable. This dimension of the guard is the index l (see above).

Table 3 sets out measurements of the growth stages of Figure 11a, b, in which all stages are visible, although in Figure 11b the first growth-stage is ill-defined and may not be visible in the illustration. These measurements are approximate but do serve to compare the relative proportions of adult and juvenile guard. The growth-stages are numbered from the interior outwards, and for growth-stages 2 and 4, the total length of the guard (L) is also compared with the diameter.

Table 3. Dimensions (in mm) of major growth stages in *B.a. aucklandica.*

Figure 11a

Growth Stage	l	ds	l/ds	L/ds	u/v	Hs
1	25	2.75	8			137
2	56	8.5	6.5	9	1	107
3	70	14	5			
4	73	15	5	7		

Figure 11b

Growth Stage	l	dt	l/dt	L/dt	u/v	Ht
1	29	3	9			120
2	48	7.5	6.5	9	1	115
3	60	13.5	5.5			
4	64	14	4.5	6		

It will be seen that there is a major increase in both length and diameter between growth-stages 1 and 2, thereafter the increase in length is retarded in comparison with that of diameter and the guard becomes more robust. Normally the first growth-stage is markedly hastate, and the second moderately so (*cf.* Fig. 11a) but with development of the third growth-stage that part of the guard anterior to the position of maximum diameter increases more rapidly in diameter than does the posterior part. Consequently the maximum diameter becomes anterior in position with the index u/v attaining a typical value of 0.5 - 0.8. Most of this differential growth occurs during development of the third growth-stage and the fourth growth-stage is merely an amplification of the preceding one.

In none of the sections prepared is the second growth-stage as highly hastate as some juveniles (*cf.* Fig. 3f) and these highly hastate juveniles may be at a stage of development somewhere between growth-stages 1 and 2.

The apical line is ventrally placed, markedly so in some mature specimens. The alveolar angle is *ca.* 20°.

Transverse sections were prepared from a number of adult guards and in general their structure supports the findings from longitudinal sections. The major growth-stages, particularly the third and fourth, are often ill-defined in longitudinal sections and are usually better shown by transverse sections. To reveal all four growth-stages, adult guards must be sectioned in a region which extends along the guard from just anterior to the protoconch for a distance of *ca.* 35 mm towards the apex (*i.e.* in the stem region). Sections anterior or posterior to this may not intersect the first growth-stage.

Sections were prepared from apical, stem and alveolar regions, and in some transverse sections, as in some longitudinal ones, all four growth-stages were not evident, although the guards were sectioned in an appropriate region.

Variation

There is considerable variation in *B.a. aucklandica* but critical assessment of the significance of this variation is difficult as many guards collected are not fully developed adults. There appears to be some variation in gross size between mature forms which further complicates matters. These differences are regarded as infraspecific variations unless otherwise indicated.

The overall shape of the guard varies from hastate in immature adults (Fig. 2e, f) to semi-hastate (Fig. 2g - j) or almost cylindrical (Fig. 2a) in fully developed adults, but a semi-hastate form similar to Figure 2g, h, is most common in the lower part of the sequence.

In many specimens the index of flattening (A) is close to 100, but this value ranges from 99 to 104. Some of this variation may be due to distortion of the guard resulting from stresses during burial, but the significance of this factor cannot be assessed.

The apical region of the guard is particularly prone to variation and may be acute (Fig. 3c, d) moderately obtuse (Fig. 2a, b) or quite blunt (Fig. 4c, d). This last specimen is unusual in that the dorsal surface of the apical region is inflated and the apex is directed downwards, and in some features this guard resembles *B.a. trechmanni* more than *B.a. aucklandica.* However, it lacks the prominent flattening which is developed in the anterior stem and alveolar regions of the guard in *B.a. trechmanni.* Furthermore, Figure 4c, d, is not a fully developed guard and too much emphasis should not be placed on a resemblance which may only be temporary. A few specimens of *B.a. aucklandica* are apparently non-mucronate.

Figure 4a, b, illustrates an unusually massive specimen, the maximum transverse and saggital diameters of which are almost 25% greater than those of any other guard from the writer's collections. In this guard the ratio of total length (L) to maximum diameter is approximately 6; if the method of Stevens (1965, p. 39) is used and the maximum diameter is compared with l (distance from apex to protoconch) the ratio becomes 4, and these ratios are outside the known dimensions of *B.a. aucklandica.* (In *B.a. aucklandica* the ratio of L to maximum diameter is about 7, and that of l to maximum diameter about 5.)

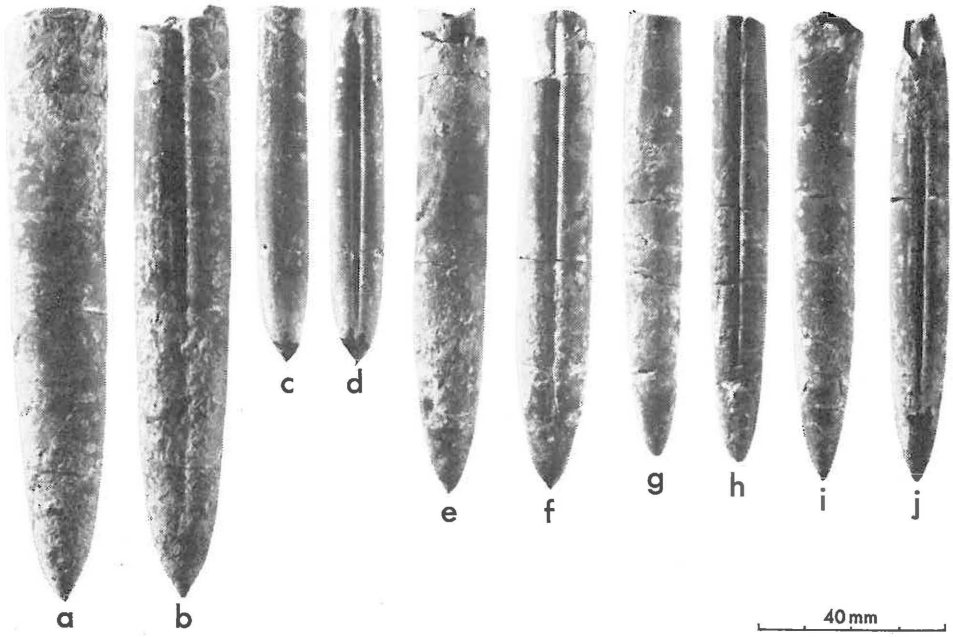

Figure 4. Belemnopsis aucklandica aucklandica (a - h)
Belemnopsis sp. (i - j)
× 0.6 approx.

a, b, Maraitai Valley N51/f 961	a, left lateral view	b, ventral view
c, d, Maraitai Valley N51/f 961	c, left lateral view	d, ventral view
e, f, Maraitai Valley N51/f 961	e, left lateral view	f, ventral view
g, h, Maraitai Valley N51/f 642	g, left lateral view	h, ventral view
i, j, Maraitai Valley N51/f 961	i, left lateral view	j, ventral view

Very slight transverse hastation is evident in this specimen, the flanks of the guard converging in the alveolar region, but saggital hastation is absent, and the dorsal and ventral surfaces diverge towards the anterior. The ventral groove is deep and broad and the apex is mucronate and approximately symmetrical. The internal structure is unusual in its proportions as far as can be ascertained from examination of the fractured cross-section of the guard. Measured at the break just posterior to dtM, the first growth-stage is 4 mm in diameter, the second is 11 mm, and the third is 18 mm in diameter. These measurements are approximate. Thus growth-stages 2 and 3 are relatively more massive than in typical *B.a. aucklandica,* and this may also be true of the first growth-stage which was probably not measured at its greatest diameter.

While this specimen has the general appearance of a very massive *B.a. aucklandica,* it is not completely typical of the species, particularly in the degree of hastation and in the shape of the apex. In the absence of other specimens of a similar size to which it can be compared, this guard is provisionally identified as *B.a. aucklandica.* However, the possibility that this specimen represents a second species, perhaps *Belemnopsis uhligi* Stevens, or a *B. uhligi - B.a. aucklandica* transitional form (Stevens 1965, pp. 86 - 87) must be considered.

Figure 4e, f, is another atypical specimen which is almost non-hastate (Ht = 100.5) and marked by a slightly depressed cross-section in the alveolar region. This last feature is possibly a result of sedimentary compaction. These

characteristics are again suggestive of a *B. uhligi* - *B. aucklandica* transitional form but this specimen is also provisionally identified as *B.a. aucklandica.*

Belemnopsis aff. *suavis* Stolley

cf. 1929 *Belemnopsis suavis,* Stolley, Pal. Timor 16 (29): 181.

(?) 1961 *Belemnopsis* sp. Purser, N.Z. Geol. Surv. Bull. n.s. 69, 27 - 29.

Stratigraphic range

Belemnopsis aff. *suavis* has been collected from only one locality (f 971) at a stratigraphic position 700 - 900 feet above the base of the Puaroan stage at Port Waikato. *B.* aff. *suavis* is associated with *Belemnopsis aucklandica aucklandica* and *Buchia hochstetteri* at this locality.

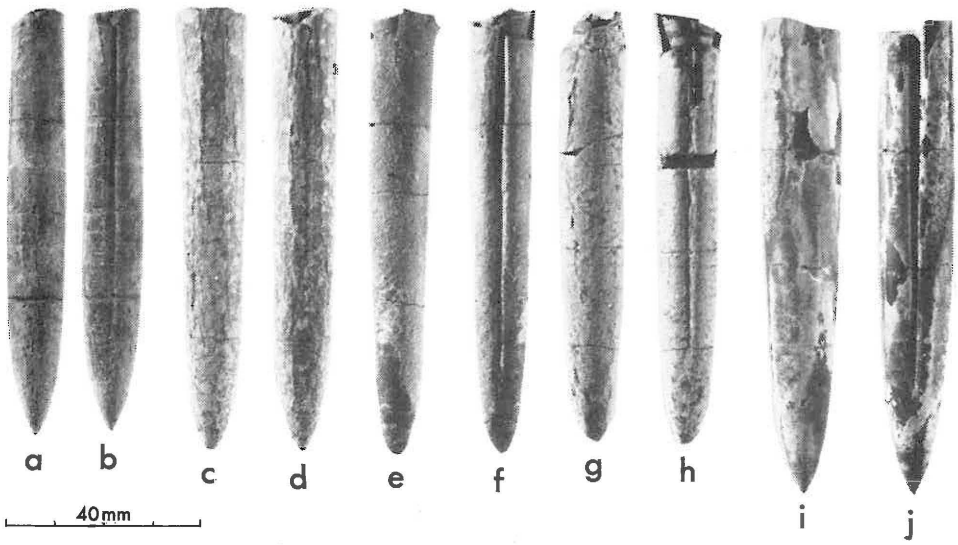

Figure 5. Belemnopsis aff. *suavis* (c - h)
Belemnopsis sp. (a - b, i - j)
× 0.6 approx.

a, b, Huriwai Stream N51/f 969	a, left lateral view	b, ventral view
c, d, Waikawau Valley N51/f 971	c, left lateral view	d, ventral view
e, f, Waikawau Valley N51/f 971	e, left lateral view	f, ventral view
g, h, Waikawau Valley N51/f 971	g, left lateral view	h, ventral view
i, j, Sunset Beach N51/f 973	i, left lateral view	j, ventral view

Description of Adult Guard (Fig. 5 c - h)

Guard elongate and slender. Length 7 - 8 times the transverse diameter (measured at the protoconch).

The outline of the guard is symmetrical and typically non-hastate, the sides of the guard diverging gradually towards the anterior (Fig. 5 d, f), although there may be very slight hastation in some instances (u/v = 0.8, Ht = 101). The sides of the guard curve rapidly near the apex; the apical angle is 50 - 60°, and is apparently more acute in less fully developed specimens. The apex is mucronate but not strongly so.

Profile asymmetrical and the apex is sub-central with the dorsal surface of the guard curving more strongly towards the apex than does the ventral surface (Fig. 5c, e). The profile is non-hastate, the dorsal and ventral surfaces diverging steadily towards the anterior (Fig. 5c, e, g).

The cross-section, if measured at a point midway between the apex and the protoconch, is usually slightly compressed, more rarely slightly depressed (A = 97 - 101), usually compressed at the position of the protoconch (A = 97 - 100) and compressed in the alveolar region (A = 95 - 99).

The median ventral groove is moderately prominent and extends from the alveolus into the apical region, apparently terminating *ca.* 15 mm from the apex. The groove is not wide but may be relatively deep (Fig. 5f). In Figure 5d, h, the ventral groove is obscured by matrix and these specimens give a misleading impression of this feature of the guard.

Faint lateral lines may be seen on one guard, but nearly all specimens are coated with matrix which partly obscures both the lateral lines and the ventral groove.

B. aff. *suavis* is illustrated in Figure 5 (specimens c to h) and the dimensions are listed in Table 4.

Table 4. Dimensions (in mm) of *B.* aff. *suavis* illustrated as Figure 5 (c - h).

Specimen	L	u	v	u/v	dtM	dtm	dsM	dsm	Ht	Hs	A
c, d	90				12.85		13.55		NH	NH	95
e, f	90				13.10		13.25		NH	NH	99
g, h	88	36*	52*	0.7*	12.33	12.07	12.73		102	NH	97

* approximate NH Non-hastate

Juvenile Guard

One juvenile guard was associated with *B.* aff. *suavis* at locality f 971, but was damaged. Most of the ventral surface had been eroded from this specimen and a longitudinal section (Fig. 12c) was prepared from it.

A large number of juvenile guards was collected from locality f 972 (Maraitai Belemnite Bed) within the 700 - 900 foot interval, and these immature specimens are similar in most respects to juvenile *B.a. aucklandica.* There may be a tendency for some juveniles from f 972 to be more hastate than is usual in juvenile *B.a. aucklandica* (Fig. 6b, d) and in some specimens the position of dtM may be nearer the apex (Fig. 6b, d). The ventral groove is weakly or moderately developed (Fig. 6b, j) and no deeply grooved specimens (*cf.* Fig. 3d, j) were noted. These differences may not be significant, particularly as similar weakly grooved specimens are found both higher and lower in the sequence and have been identified as juvenile *B.a. aucklandica.*

Some of these immature guards from locality f 972 *may* be juvenile *Belemnopsis* aff. *suavis,* but if this is so they are not readily distinguished from juvenile *B.a. aucklandica.*

Table 5 lists the dimensions of guards from f 972 which may be juvenile *B.* aff. *suavis* and these are illustrated as Figure 6.

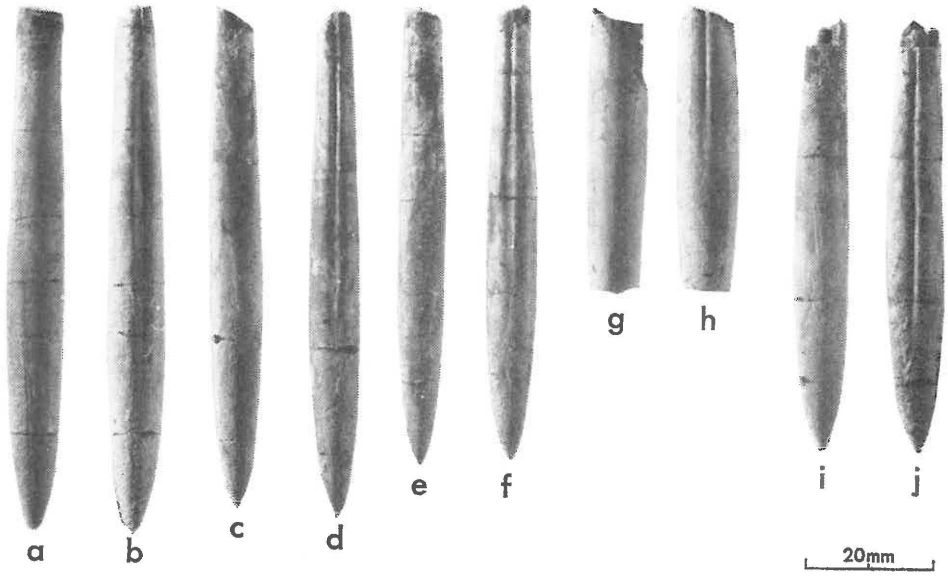

Figure 6. *Belemnopsis aucklandica aucklandica* juvenile and/or *Belemnopsis* aff. *suavis* juvenile from locality N51/f 972 Maraitai Belemnite Bed.
× 0.8 approx .
a, c, e, g, i, left lateral view b, d, f, h, j, ventral view

Table 5. Dimensions (in mm) of juvenile specimens from N51/f 972 illustrated as Figure 6.

Specimen	L	u	v	u/v	dtM	dtm	dsM	dsm	Ht	Hs	A
a, b	83	47	32	1.46	8.82	6.38	8.45	7.05	138	120	104
c, d	81	43	31	1.38	7.86	5.65	7.82	6.95	139	112.5	101
e, f	72	40	32	1.25	7.62	5.7	7.34	6.05	134	122	104
g, h					9.67		9.55				101
i, j	68	34	30	1.13	8.93	6.7	8.42	6.85	133	120	105

Internal Structure and Development

Longitudinal sections were prepared from three adult guards and an internal structure and sequence of development similar to that of *B.a. aucklandica* was revealed. There are again four major growth stages but in only one specimen (Fig. 11e) are they all readily visible.

The second growth-stage is prominent in all specimens and in two (Fig. 11f, g) is markedly hastate, more so than the corresponding feature revealed in longitudinal sections of *B.a. aucklandica* (*cf.* Fig. 11a, b). In the third guard (Fig. 11e) the second growth-stage is non-hastate but the first is highly so (Hs = *ca.* 170) and it is evident that the virtually non-hastate adult guard develops from a fully hastate juvenile.

All three specimens are marked by a relatively small increase in the length of the posterior part of the guard during development of the third and fourth growth-stages (*i.e.* in the increase in length of the guard from the apex of the second growth-stage to the apex of the outer growth-stage) and in two (Fig 11f, g) this is particularly marked. In both guards the third growth-stage is poorly defined and the fourth may be incomplete, but the increase in length is barely 3.5 mm. in Figure 11g and only 1 mm. in Figure 11f.

The apical line is ventrally placed.

The approximate measurements of the second growth-stages of these guards is given in Table 6 below.

Table 6. Dimensions (in mm) of the second growth-stage of *B.* aff. *suavis.*

	L	l	u/v	Ht or Hs
Figure 11f	66	52	1.35	121
Figure 11g	72	58	1.4	113

It will be seen that these dimensions are comparable with those of some of the more hastate guards from locality f 972 (Maraitai Belemnite Bed).

Variation

Some variation is apparent in the shape of the apex and perhaps also in the prominence of the ventral groove but insufficient specimens are available to evaluate this.

Remarks

The species is compared with *Belemnopsis suavis* Stolley, a late-appearing member of the *Belemnopsis* assemblage of Indonesia (Stevens 1965, pp. 205 - 206), but the ventral groove is apparently more prominent in the Port Waikato species.

Table 7. Comparison of some characteristics of *B.a. aucklandica* and *B.* aff. *suavis.*

	B.a. aucklandica	*B.* aff. *suavis*
General	elongate, moderately robust guard.	elongate, moderately slender guard
Hastation	hastate or semi-hastate	typically non-hastate and cylindrical, rarely slightly hastate
Ventral groove	deep and broad	relatively weak, but may be incised
Cross-sections	slightly depressed in apical and stem regions, compressed anteriorly	usually compressed throughout
Apex	ventrally inflated, blunt, sometimes strongly mucronate	non-inflated, apex sub-central, slightly mucronate

Belemnopsis aff. *aucklandica* (Fig. 7)

Stratigraphic Range

Belemnopsis aff. *aucklandica* is present in the upper part of the Puaroan sequence at Port Waikato and ranges from *ca.* 1300 to *ca.* 2700 feet above the base of the stage. *B.* aff. *aucklandica* is associated with *B.a. aucklandica, Buchia plicata* (Zittel) and *Pseudolimea* sp. at the base of its range (locality f 973) and with *Buchia plicata* in the middle part (localities f 974, f 975) but is apparently not accompanied by marine fossils in the upper 400 - 500 feet of its range.

B. aff. *aucklandica* is described on the basis of very limited material and the description which follows is derived in the main from one complete and well-preserved guard (Fig. 7a, b). Two casts prepared from natural moulds (Fig. 7g, h), one very badly leached and fragmentary specimen, two alveolar-stem fragments (Fig. 7c - f) and three stem-apical or apical fragments furnish some information.

Description of Adult Guard

Guard elongate. Length approximately 7 - 8 times the maximum diameter.

Outline symmetrical and hastate (Ht = 114). The maximum transverse diameter is about midway along the guard (Fig. 7b). Posterior to dtM the sides of the guard converge regularly towards the apex, with a slight increase in curvature over the last few mm (Fig. 7b). There is a zone of approximately equal diameter which extends along the guard for some distance (*ca.* 20 mm). Anterior to this the sides converge regularly.

The profile is hastate and almost symmetrical. The apical region is more regularly curved than that of *B.a. aucklandica* and is mucronate but not strongly so; the apex is directed forward. There may be very slight ventral inflation of the apical region (Fig. 7a). Anterior to dsM the dorsal surface remains approximately parallel to the mid-line of the guard, the ventral surface does so throughout most of the stem region but in the anterior stem and alveolar region it converges towards the dorsal surface (Fig. 7a, c) producing a moderate degree of hastation (Hs = 108).

The cross-section is depressed in the apical region, approximately equidimensional at dtM and compressed anteriorly.

Median ventral groove broad but not particularly deep (Fig. 7b), and extends from alveolus well into the apical region, apparently further posterior than in *B.a. aucklandica*. The groove may narrow in the anterior alveolar region.

Remarks

The specimen on which this description is largely based has some unusual features which may not be characteristic of the species as a whole, but the remaining fossil material is either incomplete or too badly preserved to ascertain this. In Figure 7b the position of maximum transverse diameter is part of a zone of approximately equal diameter which extends along the guard for *ca.* 15 - 20 mm. If the most anterior part of this zone is taken as the position of dtM, then the index u/v equals 0.9; if the posterior part of the zone is so defined then u/v equals 1.4. Two alveolar-stem fragments (Fig. 7c - f) from the same locality (f 973) give some indication of a similar zone of equal diameter but they are not sufficiently complete for this to be stated with certainty.

The cross-section of the guard is also unusual in that the positions of maximum transverse and saggital diameters are not coincident; that of dsM is anterior to that of dtM by *ca.* 20 mm. If the usual method of calculation is applied, the index of flattening (A) is 100, but if the index is calculated at dtM, A = 101, and the corresponding index at dsM is 98.5.

Lateral lines are apparent on the apical region of several specimens but are very evident in Figure 7a, and may be traced for nearly the full length of the guard. They begin on the dorso-lateral surface of the apical region and run diagonally across the flanks of the apical and stem regions as far anterior as the position of dtM, where they become ventro-lateral in position. Thereafter they parallel the ventral surface of the guard and continue as a broad shallow depression into the alveolar region.

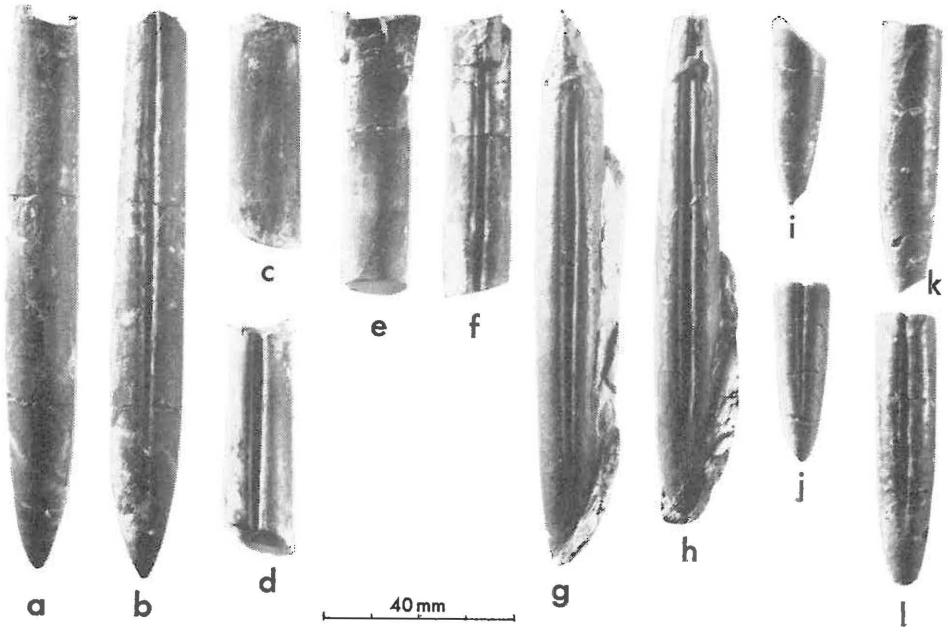

Figure 7. Belemnopsis aff. *aucklandica*

× 0.6 approx.

a, b, Sunset Beach N51/f 973	a, left lateral view	b, ventral view
c, d, Sunset Beach N51/f 973	c, left lateral view	d, ventral view
e, f, Sunset Beach N51/f 973	e, left lateral view	f, ventral view
g, near South Head N51/f 974		g, ventral view
h, near South Head N51/f 974		h, ventral view
i, j, South Head N51/f 975	i, left lateral view	j, ventral view
k, l, north of Okariha Point N51/f 976	k, left lateral view	l, ventral view

Juvenile Guard

No juvenile specimens were collected from within the stratigraphic range of *B.* aff. *aucklandica.*

Internal Structure

Longitudinal sections were not prepared, but the transverse surfaces of two specimens from the south-western end of Sunset Beach (f 973) were finely ground and painted with clear plastic.

The outer boundary of the second growth-stage is prominent in both instances and there are a number of less prominent growth lines interior and exterior to the second stage. These minor growth-stages are not individual growth lamellae, nor are they major growth-stages as more than four can be recognised. In a third specimen from South Head (f 975) these additional stages are not present, and the second and third growth-stages are the only ones defined. The apical line is ventrally placed.

B. aff. *aucklandica* is illustrated in Figure 7 and the dimensions of Figure 7a, b, are given in Table 8.

Table 8. Dimensions (in mm) of *B.* aff. *aucklandica* illustrated as Figure 7 a, b.

Specimen	L	u	v	u/v	dtM	dtm	dsM	dsm	Ht	Hs	A
a, b	120	58*	58*	1.0*	14.83	13.00	14.83	13.70	114	108	100

* See text description for these dimensions.

Table 9. Comparison of some characteristics of *B.a. aucklandica* and *B.* aff. *aucklandica.*

	B.a. aucklandica	*B.* aff. *aucklandica*
General	elongate, moderately robust guard	elongate, moderately slender guard
Hastation	hastate or semi-hastate	hastate
u/v	0.5 - 0.9	1 - 1.4
Apex	inflated ventrally, blunt, sometimes strongly mucronate	non-inflated and symmetrical, slightly mucronate
Lateral lines	relatively weakly developed	prominent
Ventral groove	broad and deep	broad, relatively shallow

Belemnopsis sp. Figure 4 i, j

Localities and Material

One complete and well-preserved guard from Maraitai Valley (f 961).

Brief Description

A slender, slightly hastate *Belemnopsis* with maximum transverse diameter anterior in position (u/v = 0.75). Outline symmetrical, profile asymmetrical with very slight inflation of the ventral surface of the apical region. Apex acute, directed forward. Ventral groove moderately developed, terminating *ca.* 15 mm from the apex. The specimen is marked by extreme compression of the cross-section (A = 94), some of which may be due to distortion. This guard may not be fully developed.

Belemnopsis sp. (Fig. 5a, b).

Localities and Material

One complete and well-preserved guard from Huriwai Stream (f 969).

Brief Description

A fully hastate *Belemnopsis* with the maximum transverse diameter posterior in position (u/v = 1.1). Outline symmetrical and hastate (Ht = 123), profile hastate (Hs = 110) with very slight inflation of the dorsal surface of the apical region. Apex acute, slightly mucronate. Ventral groove narrow and deep, extending from the alveolus into the apical region and terminating near the apex.

Remarks

This guard resembles a fully hastate juvenile *B.a. aucklandica* but is more massive (dtM = 12.4 mm) and the ventral groove is deeper, and narrower in the posterior part of the guard.

Belemnopsis sp. (Fig. 11d)

Localities and Material

One complete guard from Huriwai Stream (f 969).

Brief Description

A hastate *Belemnopsis* with the maximum transverse diameter posterior in position (u/v = 1.3). Outline symmetrical and hastate (Ht = 109); profile asymmetrical; dorsal surface of the apex slightly inflated. Apex moderately obtuse, non-mucronate. Ventral groove deep and broad, more prominent than in *B.* sp. (Fig. 5a, b).

Internal structure characterised by weakly defined growth-stages. Only what appears to be growth-stage 2 is defined and this very poorly, but there are vague growth-lines both internal and external to this. Alveolar angle *ca.* 25 - 30°. The alveolus is crushed and somewhat distorted.

Belemnopsis sp. (Fig. 5i, j).

Localities and Material

One well-preserved but incomplete guard from the south-western end of Sunset Beach (f 973). The alveolar region of the specimen is missing.

Brief Description

A semi-hastate *Belemnopsis* with maximum transverse diameter anterior in position (u/v estimated at 0.7). Posterior to dtM the sides converge gradually towards the apex but close to the apex they curve more strongly. General shape of the apical region similar to, but more elongate and slender than that of *B.a. aucklandica.* Apex mucronate and directed forward. Profile almost symmetrical, very slight inflation of the dorsal surface of the apex. Ventral groove prominent, extending well into the apical region.

Cross-section compressed. Maximum transverse and saggital diameters not coincident, dsM anterior to dtM by *ca.* 15 mm. Applying the usual method of calculation A = 98, at dtM A = 99, and at dsM A = 97.

Remarks

This *Belemnopsis* has some features in common with both *B.a. aucklandica* and *B.* aff. *aucklandica* but the cross-sectional shape sets it apart from these species.

The dimensions of *Belemnopsis* sp. (Fig. 4i, j, Fig. 5a, b, Fig. 5i, j, Fig. 11d) are listed in Table 10.

Table 10. Dimensions (in mm) of *Belemnopsis* sp.

Specimen	L	u	v	u/v	dtM	dtm	dsM	dsm	Ht	Hs	A
Figure 4 i, j	100*	45	52	0.86	12.15	11.35	12.95	12.7	107	102	94
Figure 5 a, b	90	45	40	1.1	12.4	10.1	11.81	10.7	123	110	105
Figure 11 d	73	40	30	1.3	12.15	11.15	11.9	11.4	109	104	102
Figure 5 i, j	110*	42*	60*	0.7*	15.75		16.17				97

* Approximate, see text descriptions.

BIOSTRATIGRAPHY

During collection of the fossil material for this paper, every attempt was made to secure an adequate sample from each stratigraphic interval but this was not always possible, and some intervals, particularly in the upper part of the sequence, are poorly represented.

Purser (1961, p. 9) used the lowest occurrence of *Buchia hochstetteri* Fleming (= *Buchia extensa* [Holdhaus] of Purser) to define the base of the Puaroan stage in the Port Waikato region, although he pointed out that 3200 feet of strata extend downwards from the lowest *Buchia hochstetteri* to the highest Ohauan fossils, and the exact age of these beds is therefore unknown.

In the pages which follow, the more important belemnite sites from each stratigraphic interval are discussed, particular points of interest are noted, and the occurrence of other fossils is recorded where relevant. Only locality names and Sheet Fossil numbers are quoted. Full locality descriptions, six-figure grid references, fossil lists and other data are given at the conclusion of the paper. Stratigraphic relationships are illustrated in Figure 9.

0 - 100 feet (above the base of the Puaroan Stage)

Basal Puaroan beds crop out in the valley of the southern tributary of the Okahu Stream, in the upper reaches of the Te Karamu (Upper Opuatia) Stream, and in the area immediately south of the Port Waikato Camping Ground. *B.a. aucklandica* is present in all three areas, with localities in the Te Karamu Valley yielding the best specimens. Almost complete guards were taken from f 952 (Fig. 2a, b) and f 953, and smaller fragments from several sites along the valley. The exposures are weathered and moulds are more frequent than calcareous specimens, but belemnite remains are not rare in these localities. The sites in the Te Karamu Valley must be close to Purser's f 631 - 3, but the *Buchia hochstetteri* (? aff. *misolica*) noted by him were not found.

Minor sites occur in the Okahu Valley (f 954, f 955), in the Port Waikato Camping Ground (f 956) and in the upper Oraeroa Stream Valley (f 957).

100 - 300 feet

Lack of exposure, and the weathered condition of such exposures as there are, has resulted in few specimens from this interval. Scattered moulds occur along the eastern side of the valley of the southern tributary to the Okahu stream, and one adult *B.a. aucklandica* (Fig. 2c, d) and some fragments of juveniles were collected from f 958. *Buchia* aff. *misolica* is common. Minor sites were found in the western Okahu Valley (near f 958), beside the upper Moewaka Stream (f 959) and adjacent to Klondyke (Lynch's) Road (f 960).

300 - 500 feet

This interval is particularly well exposed in the valley of the Maraitai (Maretae) Stream, southwards along the strike in the Huriwai Stream Valley, and also in the upper reaches of the Waikawau Stream.

Belemnite guards may be found in many exposures along Maraitai Stream and its tributaries, but two sites in the lower valley are particularly interesting. Beds which crop out beside the Port Waikato - Waikaretu Road (f 961) and immediately southwards in the western bank of Maraitai Stream (f 962) contain many well-preserved *B.a. aucklandica,* ranging in age from juveniles to fully developed adults. Abundant *Buchia hochstetteri* Fleming are also present.

Two specimens, CE 410 and CE 412 illustrated by Stevens (1965, Plate 8, Figs. 1 - 3, 4 - 6) appear to have been collected from f 961 by C. A. Fleming in 1930. The site description "GS5068. Kaawa Creek Rd. Roadside cutting 'greywacke' on west side of and about 20 feet above the north-south stream bed. N51/12 grid. ref. *ca.* 257927" (Stevens 1965, p. 192) is applicable although the grid reference differs. CE 412 is very similar to Figure 2e, f, of this paper, and

is at a similar stage of development, *i.e.* early growth-stage 4. CE 410 is almost identical to Figure 2i, j, collected from f 961 during this work and also with Figure 2g, h, and although both of these guards are slightly more massive than CE 410, all three are apparently fully developed adults. Both Figure 2g, h, and Figure 11c were collected from the upper Waikawau Stream (f 963).

These six guards are remarkably similar in appearance, and all conform very closely to Stevens' description of *B.a. aucklandica,* and his description, as far as it is based on New Zealand specimens, appears to be derived largely from guards from this stratigraphical level.

The very massive specimen provisionally identified as *B.a. aucklandica* (Fig. 4a, b) was collected from f 961.

It seems likely that the beds exposed in Maraitai Valley (f 961) correlate approximately with those in the upper Waikawau Valley (f 963) to judge from the belemnites, although the numerous *Buchia hochstetteri* present at f 961 were not found at f 963. Beds containing abundant *Buchia hochstetteri* are exposed in Waikawau Valley at a slightly higher horizon (f 964).

There are many minor sites in this interval. Those in Maraitai Valley (f 639 and f 965); in the upper Waikawau Stream (f 966); adjacent to the Port Waikato - Waikaretu Road (f 648); in the Huriwai Stream Valley (f 967 and f 657); and near Sunset Beach (f 636); are some of the more important. Purser (1956, pp. 28 - 29) lists undetermined *Belemnopsis* from a number of other sites and these are almost certainly all *Belemnopsis aucklandica aucklandica.*

Although Stevens' description of *B.a. aucklandica* may have been based largely on specimens from the 300 - 500 foot interval, similar guards are present down to the base of the Puaroan Stage. While Figure 2a, b, from the basal 100 feet of the sequence is not wholly typical of *B.a. aucklandica,* it does not differ sufficiently to warrant exclusion from the species. This specimen is rather more cylindrical than normal but much of this is due to the absence of the major part of alveolar region, and decrease in transverse diameter of this part of the guard produces the normal hastation characteristics of *B.a. aucklandica.* Figure 2c, d (100 - 300 feet), although damaged, can be seen to have most features in common with guards from the overlying interval (note particularly the similar position of dtM).

500 - 700 feet

Few specimens were obtained from this interval. Scattered juvenile moulds are present in the upper tributaries of the Moewaka Stream (f 968) and leached adult guards in weathered exposures in the middle reaches of the Waikawau Stream (f 651?). Both are poorly preserved, and little information can be gained from them other than that the adult guards have a prominent boundary between the second and third growth stages.

Belemnite guards are contained in the top beds of about 100 feet of strata exposed in the northern bank of the Huriwai Stream (f 969). Most are juvenile *B.a. aucklandica,* but two more fully developed guards (Fig. 5a, b, Fig. 11d) have not been identified specifically, and are designated *Belemnopsis* sp.

Two early adult specimens were found in the upper Waikawau Stream (f 970) and appear to be essentially similar to *B.a. aucklandica* from the underlying interval.

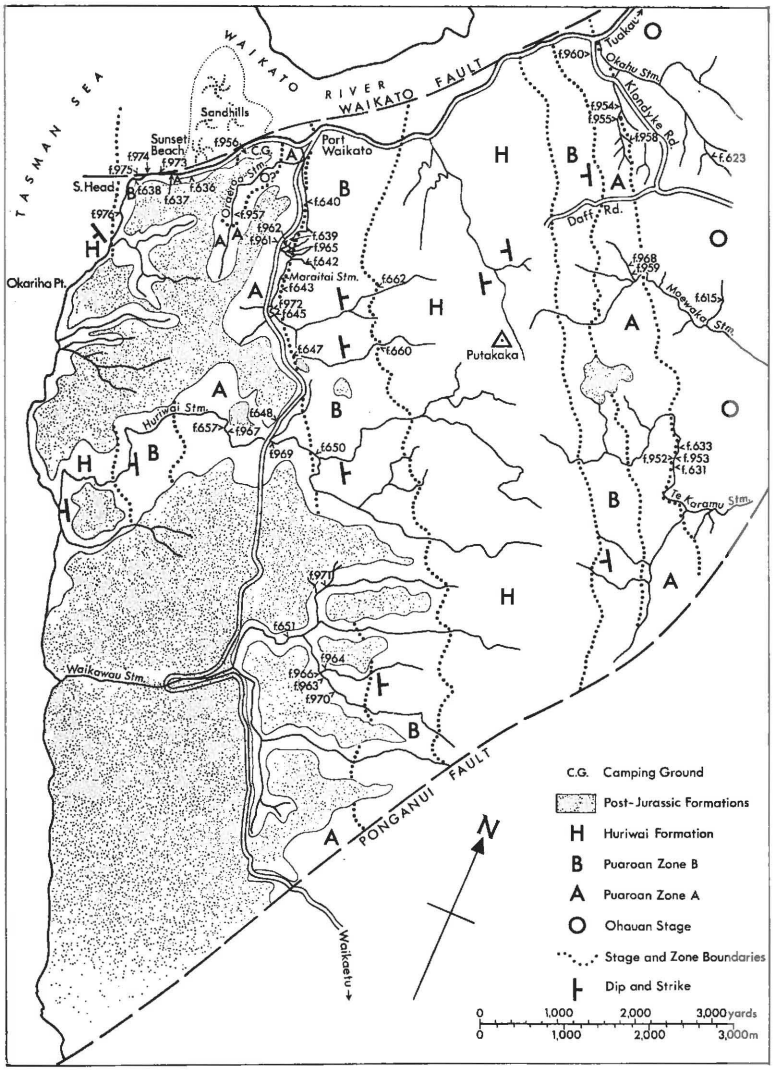

Figure 8. Locality and Geological Map of the Puaroan Stage at Port Waikato. (Based on Purser, 1961, modified.)

700 - 900 feet

While specimens from below 700 feet from the base of the Puaroan sequence conform closely to Stevens' *B.a. aucklandica,* some guards from above this level begin to diverge in certain characteristics, and although these changes are slight, and not present in all specimens, they precede alterations in form which develop higher in the sequence. Specimens of the characteristic shape of Figure 2g, h, or CE 410 (Stevens 1965, Plate 8, Figs. 1 - 3) were not found within or above this interval.

Of the sites in the 700 - 900 foot interval, that in the northernmost tributary of the Waikawau Stream (f 971) is one of the most interesting. About 50 feet of Puaroan beds are exposed in the eastern bank of the stream and these contain an interesting belemnite fauna together with common *Buchia hochstetteri* Fleming.

This locality is the only one from which *B.* aff. *suavis* has been identified with certainty, and its non-appearance at similar stratigraphic positions in Maraitai Valley, Huriwai Stream, and the southern tributaries of Waikawau Stream, suggests that the species may be only a temporary development, perhaps confined to a relatively narrow set of beds. *B.a. aucklandica* is also present at f 971.

A high proportion of guards from f 971 have retained the initial chambers of the phragmocone, and in the case of some specimens (Fig. 12a) up to 40 chambers are still *in situ*. Loose phragmocones, some of which appear to be almost complete (Fig. 12b, e) are common. The guards from this locality consist almost exclusively of the remains of adult animals, with the exception of one juvenile guard from which Figure 12c was prepared. None is comparable in size with fully developed *B.a. aucklandica.*

Another site in the lower Maraitai Stream (f 972) is also unusual. This locality, in the steep bank between the Port Waikato - Waikaretu Road and the Maraitai Stream, must be close to Purser's f 645, although the *Buchia hochstetteri* collected by him were not found. Here a bed of grey mudstone of undetermined thickness, but greater than 2 feet, contains abundant juveniles (Fig. 6) most of which are well preserved. About 50 specimens were taken, but many more could have been collected if required. An unusual feature of this locality is that no specimens at a stage of development much later than growth-stage 2 were noted, and only one guard was found which was significantly less developed.

The concentration of guards in this bed recalls the abundance of specimens in both the Captain King's Shellbed of the lower Heterian at Kawhia Harbour (Fleming and Kear 1960, p. 25, Stevens 1965, p. 75, Challinor 1968, pp. 111 - 112) and the Kinohaku Belemnite Bed of the upper Ohauan at Kawhia Harbour (Fleming and Kear 1960, p. 34, Stevens 1965, p. 89), but there are marked contrasts in some respects. The guards at locality f 972 lie parallel to the bedding planes, as do most of those in the Captain King's Shellbed. But whereas those from Maraitai Valley seem to be all at, or near the same stage of development, a much greater range of development is shown by those from Captain King's Shellbed (Challinor, 1968, pp. 112 - 113). The wide variety of other fossils in the Captain King's Shellbed contrasts with the absence of other forms from the Maraitai Valley site.

Specimens from the Kinohaku Belemnite Bed show some diversity in their degree of development, but the range is comparable with that of guards from the Maraitai Valley bed. However, the chaotic appearance of the guards in parts of the Kinohaku bed, with masses of specimens crowded together, and many inclined at a high angle to the bedding planes, suggests some abnormal method of deposition.

Locality f 972 in Maraitai Valley is here designated the Maraitai Belemnite Bed. The top and base of the bed, which is exposed at this locality as a dip slope, are not visible, and its full thickness could not be determined.

900 - 1100 feet

With the exception of one juvenile guard and a few fragments collected from sites in Maraitai Valley (close to Purser's f 640, f 643 and f 647), few fossils were found within the 900 - 1100 foot interval.

1100 - 1300 feet

Purser's localities f 642, in the valley of a small tributary to Maraitai Stream, and f 650, in the upper Huriwai Stream, are the most notable in this interval.

At the Maraitai Valley locality (f 642) three beds containing numerous belemnite guards crop out in the southern bank of the stream adjacent to a small waterfall. These beds are separated by three to four feet of sediment and appear to be surfaces on which much organic material has accumulated. Both adult and juvenile guards are numerous, and are frequently actually in contact. All specimens are in poor condition, badly corraded, often incomplete and frequently leached. Common *Buchia plicata* (Zittel) and scattered gastropods occur in the same beds. Both belemnite remains and bivalves occur both above and below the horizons of abundant fossils, but in greatly reduced numbers.

The poor condition of the fossil material suggests that the guards have been subjected to much movement on the sea floor before burial. These horizons may represent intervals of either reduced deposition, or as seems more likely, times of increased current activity which prevented the accumulation of sediment and caused the surface damage noted in the fossils, prior to their eventual burial. The *Buchia* may represent the *in situ* fauna whereas the belemnites are possibly a transported fauna. The alternative explanation, that the horizons indicate times of great abundance of belemnites, is argued against by the increased numbers of *Buchia plicata* in the beds. It is unlikely that two molluscs with such contrasting ways of life would have reached peak abundance at the same times.

A similar configuration of belemnite-bearing horizons is present at Purser's f 650 in the upper Huriwai Stream. A considerable thickness of beds is exposed at this site, the belemnite beds dipping eastwards across the face of the exposure and approaching the surface of the stream at the eastern end of the site. Three horizons, similar to those in Maraitai Valley, are present at this locality, and have a similar concentration of badly preserved guards, but the specimens in the top bed are less numerous than those of the top bed at f 642, and there are more fossils in the intervening sediment. *Buchia plicata* is also present. A less well-defined fourth bed is also present at f 650 but the equivalent horizon is not exposed at f 642.

These beds at f 650 may be the lateral extension of those in Maraitai Valley although some difference in the thickness of sediment between the beds in the two localities is evident. This could be accounted for by differential deposition and/or compaction. Alternatively, this stratigraphic level may be characterised by numerous beds notable for their belemnite content, but no further beds of a similar nature were found in the 100 feet or so of strata exposed at the Huriwai Valley site.

No fully developed guards were noted at either of the localities. Figure 4g, h, is a comparatively well-preserved guard from Maraitai Valley (f 642) but most specimens are quite badly damaged. One small phragmocone was found at the Huriwai Stream site.

No trace of these beds was found on the seaward limb of the anticline at Sunset Beach and the occurrence of belemnites at this locality appears to be restricted to scattered moulds. Purser noted *Belemnopsis aucklandica* from f 637 but he may have referred to moulds.

The original specimens of *Belemnopsis aucklandica,* including the holotype, were collected from this stretch of coastline by Hochstetter in 1859. The exact location of his site is doubtful but is somewhere in the cliffs which back the south-western end of Sunset Beach (grid ref. 235.938 to 234.935) near the coastal expression of the Waikato Fault (Fig. 8).

The sites in Maraitai Valley (f 642) and Huriwai Valley (f 650) are the stratigraphically highest inland localities from which specimens were collected, although rare moulds occur in Huriwai Valley just eastwards of f 650. Guards become increasingly rare as one ascends the sequence from this point, and all specimens which were collected from higher stratigraphic positions came from the continuously exposed coastal section between Sunset Beach and a beach north of Okariha Point (grid ref. 234.935 - 229.933 - 220.927).

In general, specimens collected from between 900 and 1300 feet are poorly preserved and to judge from their appearance, are not fully developed guards. Certainly none is comparable in size to Figure 2g, i, and other specimens from the 300 - 500 foot interval in Maraitai Valley.

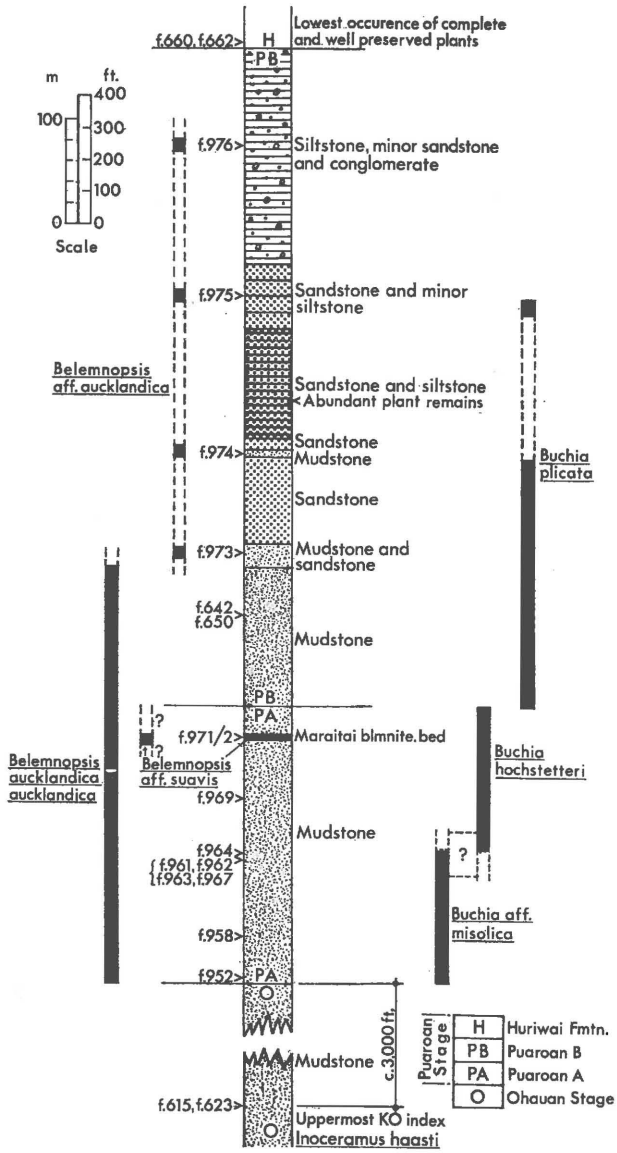

Figure 9. Statigraphic Column of the Puaroan Stage at Port Waikato with known ranges of Belemnites and *Buchia*.

1300 - 1500 feet

An isolated block of strata at the south-western end of Sunset Beach (f 973) contains a sparse fauna which includes *Buchia plicata, Pseudolimea* sp., and scattered *Belemnopsis*. This block of strata, consisting of *ca.* 150 feet of beds, is immediately south of two down-thrown blocks of Tertiary calcareous sandstone, and is separated from them by Purser's Waikato Fault. The Jurassic beds are bounded at their western extremity by the sea, and at their eastern and southern margins by beach sands. The lower 100 feet is mudstone with occasional sandstone beds; the top 50 feet is massive sandstone with beds showing evidence of intraformational slumping. These beds strike towards strata at the south-western end of the beach which evidence similar slumping (Purser, 1961, p. 22).

Belemnites appear to be absent from the sandstone beds, but scattered specimens were found throughout the underlying mudstone. Most are well preserved but incomplete, but one complete and one almost complete guard were collected (Fig. 5i, j, Fig. 7a, b).

This locality marks the first appearance of *B.* aff. *aucklandica,* and perhaps also the last occurrence of *B.a. aucklandica,* one damaged specimen of which was found in the same beds. The holotype of *B.a. aucklandica* collected from the underlying stratigraphic interval (1100 - 1300 feet) is therefore close to the upper limit of its species. The holotype (Stevens 1965, p. 85, Plate 6, Figs. 4, 5, 6) is apparently not a mature guard and the form it would have assumed when fully developed is not known, but no specimens comparable with the mature forms of *B.a. aucklandica* (Fig. 2g, h, of this paper, CE 410 of Stevens 1965, Plate 8, Figs. 1, 2, 3) were found within 400 feet of this point in the sequence. The *Belemnopsis* illustrated as Figure 5i, j, was collected at locality f 973.

With the incoming of the first sandstone beds at *ca.* 1350 feet, belemnite remains become rare. This may be partly due to the difficulty in locating fossils on the rough and weathered surfaces of the coarser beds, but the absence of guards from most of the minor siltstone and mudstone beds which occur throughout the sandstone section suggests that this apparent rarity is real.

1500 - 1700 feet

No trace of belemnites or other fossils was found in the massive sandstone beds which comprise most of the 1500 - 1700 foot interval.

1700 - 1900 feet

Finer sediments are exposed in a small bay (f 974) just east of the beach at South Head. Rare *Belemnopsis* and *Buchia plicata* are present in the shore platform. Only three belemnite occurrences were noted, spanning about 20 feet of mudstone beds at the eastern end of the bay. Two of them were moulds from which the casts illustrated as Figure 7g, h, were prepared, while the third is a badly leached guard from which little information may be gained.

Both casts indicate that the positions of maximum diameter are close to the midpoints of the guards ($u/v = 0.9\text{-}1$) and the cross-sections appear to be roughly equidimensional posteriorly and compressed anteriorly. Measurement of the casts is not possible as matrix obscures the apical regions of both. They are identified as *B.* aff. *aucklandica.*

1900 - 2100 feet

From 1900 to 2300 feet the sediments consist of fine sandstones and siltstones, with prominent banded sandstones marking the eastern part of the bay at South Head. The presence of the compressed and carbonised remains of what must have been masses of vegetation on the bedding planes of some of these beds, suggests that this part of the sequence is a very shallow water facies, perhaps estuarine. No marine fossils were noted in the 1900 - 2100 foot interval.

2100 - 2300 feet

Fine sandstone beds in the shore platform near the base of the cliffs, towards the western end of South Head beach (f 975) contain occasional *Buchia plicata*. One of these beds yielded a small apical fragment of *Belemnopsis* (Fig. 7i, j). This site may be close to Purser's f 638 but is probably not identical, as he describes the lithology of f 638 as "shales" (Purser 1961, p. 28).

Little information regarding the overall shape of the guard may be gained from the fragment, but the apex has no features which suggest that it is in any way different from specimens from the nearest fossiliferous intervals. On stratigraphic grounds this fragment is identified as *B.* aff. *aucklandica*.

The remaining 600 feet of the sequence, above the massive sandstone which forms South Head promontory, consists of siltstone with minor sandstone and conglomerate. Rare igneous and scattered greywacke pebbles, some of which are typical discoid river shingles, occur throughout, the greywacke pebbles becoming more numerous towards the top. No marine fossils were noted in the lower 300 - 400 feet, but carbonised wood and plant fragments are scattered throughout.

2700 - 2900 feet

A single incomplete guard was collected from this interval (Fig. 7k, l). The collection site, f 976 in the northern headland of the beach north of Okariha Point, is approximately 300 feet below the base of the Huriwai Formation. A small stack forms the southernmost part of the point, and is almost separated from the remainder of the headland by a narrow cleft. The top of the stack is sandstone, the lower parts siltstone, and the specimen was found in the base of the stack on the landward side. Belemnite guards are usually found lying parallel to the beds in which they occur, as would be expected from their shape, but this specimen was unusual in that it was orientated with its long axis making an angle of about 70° with the bedding planes.

Assuming a length to maximum diameter ratio of 7, this guard was originally about 90 mm in length. Only the posterior 55 mm was collected, the anterior stem and alveolar regions having previously been eroded from the bed. One flank is abraded anteriorly, and the apical 2 - 4 mm was lost during removal.

The position of maximum diameter is situated 20 mm from the anterior of the fragment. If the original position of minimum transverse diameter is assumed to have been 10 mm from the anterior, then the index u/v for the complete guard equals 1, and it is therefore likely that dtM was situated about midway along the guard.

Locality f 976 represents the highest known occurrence of *B.* aff. *aucklandica*, and is also the youngest site in New Zealand from which a Jurassic belemnite has been collected. Although the remaining 300 feet of the marine part of the sequence is well exposed in the shore platform, a heavy growth of algae partially covers most of the beds. While a prolonged search would no doubt reveal further

specimens, there is every indication that belemnite remains are rare in the top 1000 feet.

Microfloras from the Puaroan B beds are of Lower Tithonian age, while those from the Huriwai Formation indicate a Middle or Upper Tithonian age (Norris 1968, p. 340). Therefore belemnites from the upper part of the sequence (e.g. localities f 975 and f 976) must be regarded as of Lower Tithonian age, although there may be a possibility that they are very early Middle Tithonian.

GENERAL DISCUSSION

The uhligi-complex

From the paleontological descriptions given above it will have been noted that certain minor characteristics are common within limits to all species. The various species-groups have been segregated on the basis of prominent characteristics such as the position of dtM, the degree of hastation or lack of it, and to some extent on the shape of the cross-section. Some specimens exhibit characteristics which suggest that they are intermediate or transitional forms, and it may be equally valid to regard the whole group as a single highly variable species.

However, the three species described are partly separated stratigraphically, and the objects of stratigraphy are better served by regarding the group as consisting of at least these three species, together with interspecific variants.

In his definitive study of the belemnites of New Zealand, Dr G. R. Stevens discussed the *uhligi*-complex, a term he used to describe a group of broadly similar *Belemnopsis* from the Upper Jurassic of Indonesia. He stated: "Typically, an assemblage of belemnites of the *uhligi*-complex consists of *Belemnopsis* with robust, non-hastate or semi-hastate guards with well-developed ventral grooves, which can be separated into groups that previous authors have designated as species, together with numerous transitional forms. Little work has been done on the relationships of the species contained in the *uhligi*-complex." (Stevens 1965, p. 205).

He found the group to be of Kimmeridgian-Tithonian age and considered *B.a. trechmanni* (Ohauan) and *B.a. aucklandica* (Puaroan) to be New Zealand representatives of the complex. In Indonesia the *uhligi*-complex is temporarily replaced in lower Tithonian times by *Hibolithes,* and in New Zealand, *B.a. trechmanni* and *B.a. aucklandica* are separated in lower Tithonian (Puaroan) times by the *Hibolithes* group of the Puti Siltstone.

The *Belemnopsis* assemblage of the Port Waikato Puaroan sequence has the characteristics of the *uhligi*-complex, and as far as may be judged from the individual species contained within it (*B.a. aucklandica, B.* aff. *aucklandica* and *B.* aff. *suavis*) the Port Waikato assemblage is equivalent to the top part of the *uhligi*-complex of Indonesia (*i.e.* that part of the complex above the *Hibolithes* zone in the Lower Fatjet Shale [and Demu M 31] of the Misol stratigraphic column, see Stevens 1965, p. 139, Table 13, *and* discussion pp. 138 - 141). The suggestion that the Port Waikato *Belemnopsis* assemblage represents the top part of the *uhligi*-complex is also supported by the non-appearance of a *Hibolithes* zone in that region.

There are three possible explanations for the presence of *B.a. aucklandica* in beds mapped as basal Puaroan in the Port Waikato region.

(i) the stratigraphic range of *B.a. aucklandica* at Port Waikato is greater

than previously thought and extends downwards at least to the base of the Puaroan,

(ii) the base of the Puaroan stage at Port Waikato is incorrectly placed, and should be lower in the sequence,

(iii) the base of the Puaroan stage at Port Waikato is correct but the lower part of the stage is missing.

At present it is not possible to state which of these explanations is the correct one. The collection of known lower Puaroan markers such as members of the Puti *Hibolithes* group, from either above or below the base of the stage as it is mapped at present, would simplify the problem. Similarly the discovery of fossils in the 3200 feet of strata which underlie the base of the Puaroan stage, and which appear to lack either Ohauan or Puaroan markers (Purser 1961, p. 9) would supply a more accurate age determination for this part of the sequence.

Variation in Internal Structure

In the remarks which follow, the various species described above are considered as a single group (*i.e.* as *uhligi*-complex), as insufficient sections were prepared from any one species to give a reliable indication of the range of variation.

Stevens (1965, p. 55) states that "the belemnite guard is composed of concentric calcareous growth lamellae, each reproducing in detail the external form of the guard (e.g. grooves). These growth lamellae are not regular throughout the cross-section of the guard; at intervals they become closely spaced, and organic matter is concentrated along this zone to produce a prominent layer". These prominent growth lines form the main internal growth-stages of the guard.

In discussing the internal structure the procedure adopted here is to number the stages from the interior outwards, and it is assumed that each major stage represents one year in the life of the belemnite (Stevens 1965, pp. 55 - 56, Clayton and Stevens, 1965, p. 6).

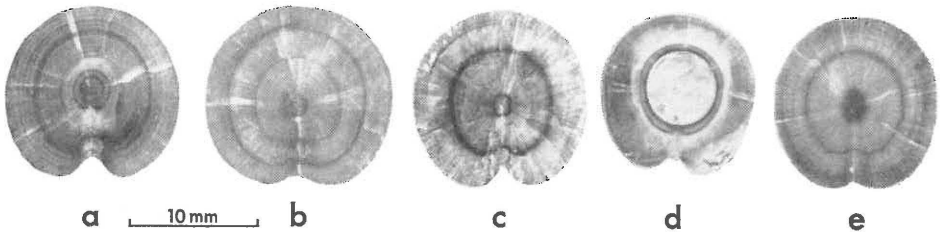

Figure 10. Transverse Sections of *Belemnopsis*.
(In most instances these sections were prepared from fragmentary guards which have not been determined specifically.)
× 1.7 approx.
a, Te Karamu Stream N51/f 952 — b, Maraitai Stream N51/f 961
c, Maraitai Stream N51/f 961 — d, Waikawau Stream N51/f 971
e, Huriwai Stream N51/f 650
a, d, alveolar sections — b, apical section. — c, e, stem sections.

From comments on internal structure which were outlined under the headings of the various species, it will have been noted that individual specimens exhibit considerable variation, some guards apparently lacking the full complement of growth-stages. There are two types of variation evident. In the first, all four

growth-stages are present but their prominence varies from a condition in which all four are well defined (Fig. 10b), to one in which the major growth-stages can only be separated with difficulty from numerous minor ones (Fig. 10a, e). But the second growth-stage appears to be nearly always more prominent than the remainder. In the second type of variation some stages, usually the first, are missing.

The first type of variation is attributed to environmental conditions, and Dr G. R. Stevens (pers. comm.) has suggested, on the basis of O^{16}/O^{18} analyses of belemnite guards, that guards with well defined growth-stages may have lived inshore where seasonal temperature fluctuations are at a maximum, whereas those with poorly defined stages may have lived off-shore where seasonal fluctuations were minimal.

There is some indication that guards with well defined growth-stages may be more common at certain stratigraphic positions in the Puaroan of Port Waikato. CE 410, the radiograph of which indicates well defined growth-stages (Stevens 1965, p. 70, Fig. 22f) was collected from a site in Maraitai Valley (probably f 961, see above) at a position 300 - 500 feet above the base of the Puaroan stage. Most of the writer's specimens with four prominent growth-stages (Fig. 10b, Fig. 11a) came from sites in Maraitai Valley, again from near the 300 - 500 foot interval.

This perhaps indicates that relatively shallow water conditions may have prevailed at the time of deposition of the Puaroan rocks now outcropping along the Maraitai Valley, and the abundance of associated benthic fossils (*Buchia hochstetteri* Fleming, *Inoceramus* aff. *everesti* Oppel, *Pseudolimea* sp.) supports this suggestion. Conversely, guards from basal Puaroan strata are characterised by numerous minor growth-stages and only the second growth-stage is noticeably more prominent (Fig. 10a) and this may indicate somewhat deeper water conditions. The rarity of bottom dwelling forms in these beds when compared with beds in the 300 - 500 foot interval is supporting evidence. It may not be wise to carry this line of reasoning too far, as belemnites were presumably highly mobile animals, and need not necessarily have lived their lives in the region of the beds in which their remains occur.

In the first draft of this paper the writer was inclined to view the second type of variation as indicating two contrasting types of development in the belemnite guard, one of which was characterised by the presence of four major growth-stages, and the other marked by the absence of the first and sometimes of later growth-stages. But this could not be reconciled with evidence that both types of structure were present in different individuals of the same species, as this implied two methods of development. This is well shown by Figure 11a, c. These two specimens of *B.a. aucklandica* were collected from the same stratigraphical level and therefore are closely equivalent in time, but the apparent contrast in internal structure is marked.

Dr G. R. Stevens (pers. comm.) has suggested that this type of variation may be the result of the state of preservation of the guard. Oxygen isotope analysis has revealed the presence in the central parts of many guards of an anomalous high temperature zone (Clayton and Stevens 1965, p. 6, Figs. 2a, 2b) which is attributed to exchange and deposition of secondary calcite by solutions passing along the apical line. Such recrystallization may blur or erase early-formed growth lines. Dr Stevens (pers. comm.) states "Recrystallization can often be quite subtle — its presence can frequently only be proved by O^{16}/O^{18} analysis — but any degree of isotopic exchange can blur the growth lines and present quite

a misleading picture".

What may be visual evidence of recrystallization can be detected in the central parts of some of the guards collected from Port Waikato. The region surrounding the apical line may be lighter or darker in colour (Fig. 10a, e), and in some transverse sections a zone of lighter coloured material extends from the central regions towards the ventral groove. This zone is frequently evident in the alveolar region and may be associated with a crack in the guard which connects ventral groove and alveolus (Fig. 10a). In other specimens the whole second growth-stage, including that part of the guard which would normally constitute the first growth-stage, may be conspicuously lighter in colour than the remainder (Fig. 11c, f), or the first growth-stage may be represented only by a lighter coloured zone (Fig. 11g, h).

The two factors outlined above, acting either singly or in conjunction, seem adequate to explain the variation in internal structure noted during this work.

Correlation of Adult and Juvenile Guards

Some remarks on the relationship of juvenile to adult have already been made under the headings of the various species, but most of the following points are applicable to the *uhligi*-complex as a whole.

The adult guard develops from a juvenile which is hastate, sometimes highly so in the early stages, and the major change in external form (*i.e.* that from fully hastate to semi- or non-hastate) takes place after completion of the second growth-stage. This is evidenced by the many fully hastate juvenile guards found at about this stage of development, and internal sections also reveal this (Fig. 11b, g). In some instances attainment of a slightly hastate or non-hastate form occurs earlier (Fig. 11c, e) and occasionally juvenile guards are found which are apparently no more developed than the second growth-stage and yet are virtually non-hastate (Fig. 3c, d).

Many features which characterise juvenile guards are revealed in the second growth-stages of longitudinal sections. The overall shape of some juveniles compares well with the second growth-stage in some sections (compare Fig. 6a with Fig. 11g, and Fig. 3d with Fig. 11c), the index u/v is similar (compare Fig. 11g with Fig. 6a), and the rapid decrease in transverse diameter near the alveolar region is common to both (compare Fig. 6j with Fig. 11b). The mucron is sometimes lacking in both juveniles and early growth-stages (compare Fig. 11c with Fig. 3f) and this is therefore a true feature of the guard and not an accident of preservation. Variation in the relative prominence of the mucron may also be seen in the same longitudinal section at different stages of development. Transverse sections prepared anterior to the protoconch in adults will sometimes reveal the narrow ventral groove shown by some juvenile guards (Fig. 10d).

In the case of *B.a. aucklandica,* it has not been possible to demonstrate the presence of highly hastate juvenile growth-stages within the adult guard. This may be a result of the chance selection of guards in which the second growth-stage is not particularly hastate and the overall shape of this stage is quite variable as mentioned above. As pointed out earlier, highly hastate juveniles may not be fully developed second growth-stage guards, and therefore could be expected to be relatively more hastate. One item of negative evidence also indicates that the highly hastate weakly grooved juveniles from the lower part of the Puaroan stage are *B.a. aucklandica,* for if they are not so assigned there are apparently

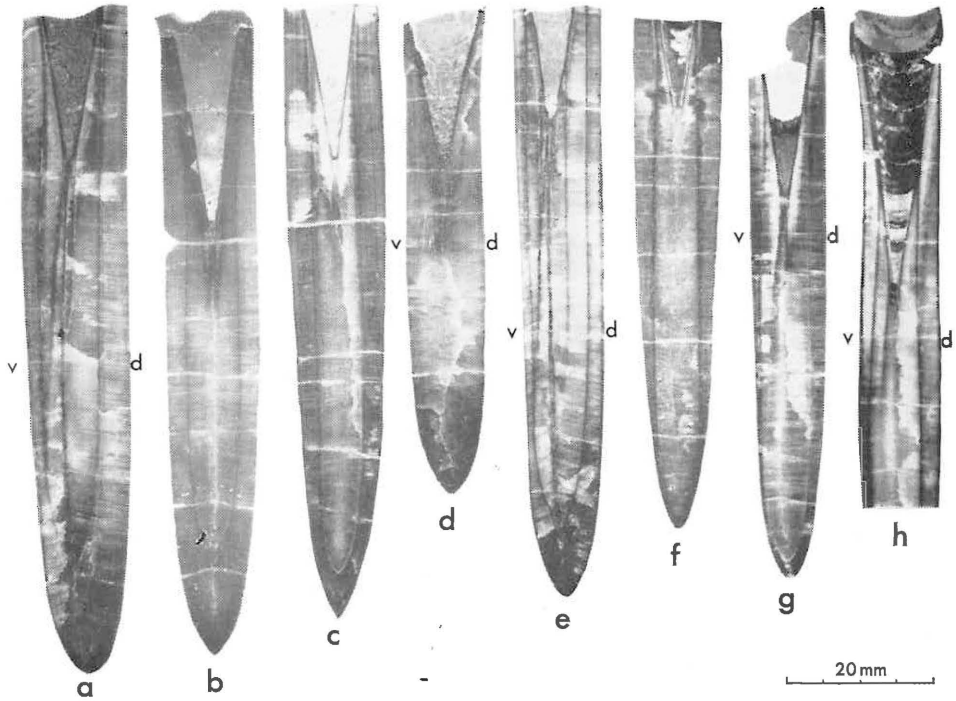

Figure 11. Longitudinal Sections of *Belemnopsis*
Belemnopsis aucklandica aucklandica (a, b, c)
Belemnopsis aff. *suavis* (e, f, g)
Belemnopsis sp. (d, h)
× 0.9 approx.

a, b, Maraitai Valley N51/f 961 c, Waikawau Stream N51/f 963
d, Huriwai Stream N51/f 969 e, f, g, h, Waikawau Stream N51/f 971
a, d, e, g, h, longitudinal saggital sections. v, venter. d, dorsum.
b, c, f, longitudinal transverse sections.

no adults in the lower 700 feet of the sequence to which they *can* be related.

A corollary arises from the relationship of juvenile to adult *B.a. aucklandica.* In an earlier paper (Challinor 1968, p. 124) the writer suggested that certain small guards present in the top 700 feet of the Kinohaku Siltstone at Kawhia Harbour were not *Belemnopsis aucklandica trechmanni* Stevens. Many of these guards bear a similar relationship to adult *B.a. trechmanni* as the juvenile guards of this paper do to adult *B.a. aucklandica,* and therefore the writer's suggestion is probably incorrect. Many of these small guards are likely to be early growth-stages of *B.a. trechmanni* as was originally suggested by Stevens (1965, p. 89). The apparent absence of typical adult *B.a. trechmanni* in the top part of the Kinohaku Siltstone is still unexplained.

Structure of Phragmocone and Protoconch

As well as revealing the mode of development of the guard, longitudinal sections show the structure of the protoconch and initial chambers of the phragmocone where these are preserved. Normally the alveolus is empty, but it is not uncommon for the first few chambers of the phragmocone to be preserved, although it is rare to find a substantial number remaining. Figure 11h is unusual in that

over 40 chambers remain *in situ*. The alveolar region of this specimen is reproduced at a scale of 1.7 × (Fig. 12a) and the protoconch and first few chambers have been sketched at a scale of 11 × (Fig. 12d).

In Figure 12a the initial 36 chambers of the phragmocone are intact, apart from a slight dislocation of the septa in one or two cases, and a further four are present in a crushed condition. The first 40 chambers are filled with calcite which varies in colour from pearly white to dark brown, and are surmounted by a further two filled with mudstone matrix. The light coloured lines (x - x) crossing the specimen are cement used in assembling the guard before the section was prepared.

The protoconch (Fig. 12d) is ventrally placed and roughly spherical in shape, with the initial chamber of the phragmocone occupying about ⅓ of its circumference. The siphuncle enters the first chamber sub-centrally and converges towards the ventral wall of the phragmocone during its passage through the first three chambers, thereafter remaining parallel to the ventral wall. The dark area immediately posterior to the protoconch is a cavity in the specimen.

Several loose phragmocones were collected from locality f 971 and the two largest are illustrated (Fig. 12b, e). From the relationship of these large phragmocones to the chambers remaining *in situ* in Figure 12a it appears that the complete phragmocone would contain at least 60 chambers.

Figure 12c is a sketch of the protoconch and initial chambers of a specimen from locality f 971, this time sectioned transversely from the ventral surface. The dark area, with radiating dark lines which cross the section at right angles to the phragmocone, is a cavity. Posterior to the protoconch there is a vague shadowy structure, very poorly defined, which may be the primordial guard described by Hanai (*vide* Stevens 1965, p. 55) as "a series of thick cone-like plates". This description, if applied to Figure 12c, would be more accurately expressed as a *cone-like series* of thick plates. Vague suggestions of a similar structure are present in two other sections (Fig. 11b, c) but are even more poorly defined than in the specimen from which Figure 12c was drawn.

Some Aspects of Belemnite Paleoecology

Some general patterns in New Zealand Upper Jurassic belemnite assemblages are beginning to emerge as a result of recent collections. Stevens (1965, p. 56) has suggested that New Zealand belemnites frequently occur as assemblages of individuals all at a similar stage of growth, *i.e.* all adult or all juvenile guards, with little admixture of the two. While this is certainly true in some instances (e.g. the Kinohaku Belemnite Bed in the Upper Ohauan at Kawhia Harbour, see Fleming and Kear 1960, p. 34, and sites f 971 and f 972 of this paper) more detailed collecting has revealed the presence of both juveniles and adults in a number of assemblages previously thought to consist almost exclusively of individuals of one age group.

The collections on which this paper is based reveal an association of adult and juvenile guards throughout much of the Puaroan stage at Port Waikato, although occasionally only juvenile material is present (f 972) while at other sites juveniles are rare (f 971). Very early growth-stages (*i.e.* those markedly earlier than growth-stage 1 - 2) comprise only about 2% of the guards collected; those near the second growth-stage account for 70%, and adult or near-adult guards make up about 28% of the total.

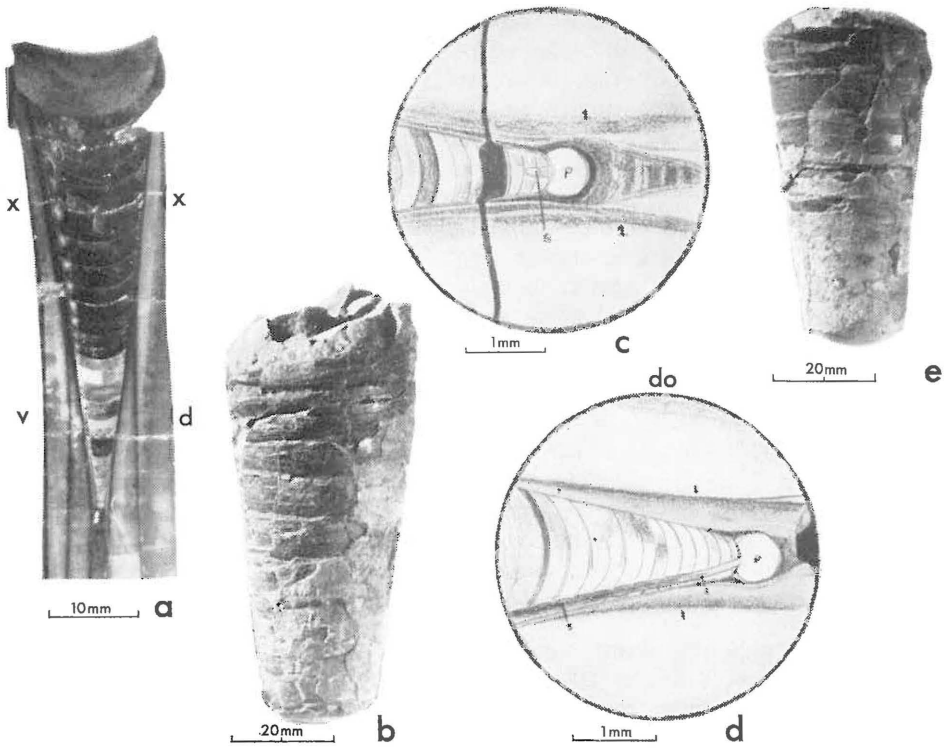

Figure 12. Detail of Protoconch and Phragmocone.

a, alveolar region of Fig. 11h, × 1.5 approx. v, venter. d, dorsum. x - x cement.
Note.—The bar scale on this figure is incorrect.

Locality N51/f 971 Waikawau Stream.
b, large phragmocone fragment × 0.7 approx. (? complete, ? dorsal view).
Locality N51/f 971 Waikawau Stream.
c, longitudinal section × 11 approx. (ground from ventral surface).
s, siphuncle. p, protoconch. 1.1, left lateral side of specimen.
l, outer boundary growth-stage 1.
Locality N51/f 971 Waikawau Stream.
d, region near protoconch × 11 approx. Fig. 12a, Fig. 11h.
s, siphuncle. p, protoconch. do, dorsal surface of specimen.
l, outer boundary growth-stage 1.
Locality N51/f 971 Waikawau Stream.
e, large phragmocone fragment × 0.7 approx. (? complete, ? dorsal view)
Locality N51/f 971 Waikawau Stream.

Systematic collecting at Kawhia Harbour has shown the presence of both adult and juvenile material in the Ohineruru Formation, the Kiwi Sandstone (Challinor 1968, pp. 114 - 115), the lower Kinohaku Siltstone (Stevens 1965, Plates 9, 10, 11), and to judge from gross size both adults and juveniles are present in the Captain King's Shellbed, Waikutakuta Siltstone, and the Kowhai Point Siltstone (Challinor 1968, pp. 112, 114, 121).

Collecting at present being carried out in the upper 2000 feet of the Ohauan stage at Port Waikato has revealed only scattered belemnites, but guards ranging in age from very young specimens (pre-growth-stage 1 ?) to apparently fully-developed adults have been collected.

Therefore it seems that assemblages consisting predominantly of guards of one age group may not be as prevalent as formerly thought, although the top

700 feet of the Kinohaku Siltstone seems to contain only juvenile *B.a. trechmanni* Stevens and possibly other juveniles (Challinor 1968, p. 124; *cf.* this paper) and the Puti Siltstone at Puti Point, Kawhia Harbour, from which collections have been made for many years, appears to contain few juvenile *Hibolithes*. Based on the apparent segregation of age groups in belemnite fossil assemblages, Stevens (1965, p. 56), suggested that concentrations of adult guards may result from the death of large numbers of animals after spawning, and that juvenile assemblages may be the consequence of the death for one reason or another, of swarms of immature animals within a restricted area. He has postulated a belemnite life-cycle similar to that of present-day squids with segregation of adult and juvenile animals during life.

Observations made while collecting for this and other works do not wholly support these contentions. The association of juveniles and adults in many fossil assemblages has already been noted, and this is particularly evident in the Puaroan stage at Port Waikato where many sites have yielded a selection of guards at widely differing stages of development (f 952, f 958, f 961, f 642). However, guards at a stage of development markedly earlier than growth-stages 1 - 2 are comparatively rare, and this is the case in most belemnite assemblages, although the belemnite fauna of the Captain King's Shellbed at Kawhia Harbour is a notable exception (Stevens 1965, p. 56, Challinor 1968, pp. 111 - 113).

It will be seen that many assemblages which were formerly thought to be segregated (*i.e.* contain either all adult or all juvenile guards) are in fact normal assemblages in the sense that guards at all stages of development are present. The relative rarity of specimens near the first stage of growth may be partly a result of their insignificance, and they are not usually seen during collecting unless very favourably placed, or unless attention is directed to them by the proximity of larger specimens. But Stevens' suggestion (1965, p. 56) that very young belemnites may have inhabited shallow inshore waters whereas more mature animals preferred deeper off-shore waters may equally well be correct, and belemnite assemblages may be segregated to this extent.

Quite frequently in the course of collecting, two guards will be found embedded in matrix with their surfaces in contact, and less frequently a cluster of several specimens will occur. Sometimes these groups consist of guards all at a similar stage of growth (Challinor 1968, p. 115). This is the more common type of cluster, and has been observed in the Waikutakuta Siltstone, Kiwi Sandstone, and Ohineruru Formation at Kawhia Harbour, and in the Puaroan stage at Port Waikato. But sometimes a group will contain members at widely different stages of growth and this has been noted in the Kiwi Sandstone (an association of adult, second growth-stage guards, and pre-growth-stage 2 guards of *Belemnopsis* sp. y) and in the upper part of the Ohauan stage at Port Waikato (pre-growth-stage 1, and growth-stage 2 - 3 *Belemnopsis* sp.). This last occurrence is of particular interest as guards are comparatively rare in this part of the sequence.

While it is possible to explain contact clusters of adults as the result of mass deaths after spawning (Stevens 1965, p. 56, *cf.* squids) the close association of adults and juveniles cannot be accounted for in this manner. The theory advanced here is that these clusters result from predation, the predator swallowing the belemnites and later voiding the accumulated hard parts. The relative rarity of material near growth-stage 1 *could* be explained by the predator retaining or rejecting in fragmented form the small slender first growth-stage guards (*cf.* Challinor 1968, p. 115).

If the clusters consisting of both adults and juveniles are the result of predation, then it is logical to attribute clusters consisting only of adult guards to the same cause, and there is no reason why many of the numerous occurrences of single guards should not also result from this. It is suggested here that rich belemnite assemblages such as those in the Waikutakuta Siltstone and in the lower part of the Port Waikato Puaroan stage (and in the Puti Siltstone if juveniles are found to be present) are due at least in part to the action of predators during times in which belemnites were particularly abundant. Possibly the peaks of concentration which occur in certain beds (*cf.* Waikutakuta Siltstone, Challinor 1968, p. 116) result from the death of spawning swarms but the greater part of such assemblages seems explainable in the above terms.

Therefore, segregation during life, together with factors operative during collection, may be the explanation for the low proportion of very young guards encountered while collecting material for this paper. Swarming of growth-stage 2 belemnites may have occurred at certain times, and as Stevens (1965, p. 56) has suggested, this could explain such fossil occurences as the Kinohaku Belemnite Bed, and also the Maraitai Belemnite Bed (f 972) of this paper. But it may be unwise to place too much significance on evidence from such infrequent occurrences, particularly when they are of limited physical extent.

The prominence of the second growth-stage revealed in sections, and the high proportion of specimens collected at this stage of growth, suggests that this may have been a critical time in the development of the animal, and one which was marked by a higher death rate than normal.

One further point is worth noting in connection with the clustering of specimens mentioned above. When a single guard is being extracted it is always advisable to excavate a little more matrix than necessary to remove the specimen in question as this will sometimes reveal further guards in the immediate vicinity. This may be particularly rewarding when specimens are scattered or rare.

CONCLUSIONS

The main findings of this work may be summarised as follows : —

Belemnite guards are common throughout the lower 1500 feet of the Puaroan sequence at Port Waikato; above this point they are comparatively rare although they extend upwards for a further 1200 feet to within 300 feet of the base of the Huriwai Formation. All are *Belemnopsis* and a zone of *Hibolithes* such as is developed at Kawhia Harbour is not evident. If a *Hibolithes* zone is present in the Port Waikato region it is either insignificant or occurs below the base of the Puaroan stage as it is mapped at present.

Three reasonably well defined species are present. *B.a. aucklandica* is best developed in the lower 500 - 700 feet of the sequence but extends up to *ca.* 1500 feet from the base of the stage. *B.* aff. *suavis* is apparently confined to the 700 - 900 foot interval, and *B.* aff. *aucklandica* ranges from *ca.* 1300 feet to *ca.* 2700 feet above the base of the stage. Some specimens do not conform to the above-mentioned species, and some appear to be interspecific or transitional forms.

A sequence of development in which the juvenile guard is fully hastate and the adult less or non-hastate appears to be common to all species as far as can be judged from the limited number of internal sections prepared. Certain other minor characteristics are also shared. All specimens collected are typical members of Stevens' *uhligi*-complex and the assemblage in the Port Waikato Puaroan stage is equated with the upper part of the *uhligi*-complex of Indonesia.

If the identification in this paper of *B.a. aucklandica* from basal Puaroan beds is correct, then either the species has a greater range in time than previously thought, or the base of the Puaroan Stage at Port Waikato is incorrectly placed or marked by an unconformity. Further collecting in the region in areas mapped as Upper Ohauan may resolve the problem.

Contrasts in internal structure are due to differing environmental conditions during the life of the animal, or result from alteration and recrystallization of the guard subsequent to death.

Juvenile guards are present in many belemnite assemblages previously thought to consist largely of adult specimens and this suggests that adult and juvenile animals were not completely segregated during life. The association of juvenile, adolescent and adult guards in contact clusters is thought to have resulted from the action of predators, and predation may have played a large part in producing rich belemnite deposits such as those in the Waikutakuta Siltstone at Kawhia Harbour and in the lower part of the Puaroan stage at Port Waikato.

FOSSIL LOCALITIES

Fossil localities mentioned in this paper are described below. Locality numbers (e.g. N51/f 650) are those of the New Zealand Fossil Record for sheet N51 (N.Z.M.S. 1 published 1964); in the text and illustrations the prefix N51 is omitted.

Localities originally discovered by Purser are numbered from 615 to 662, and where these were recollected, revised locality descriptions and grid references are given. Localities marked * were not relocated and all details are from Purser 1961.

With the exception of belemnites only stratigraphically important fossils are listed.

N51/f 615 Moewaka Stream. Grid ref. 323962. Mudstone and shale.
* *Inoceramus haasti* Hochstetter
Buchia n.sp.

N51/f 623 Okahu Stream. Grid ref. 313973. Mudstone.
* *Inoceramus haasti*
Malayomaorica malayomaorica (Krumbeck)

N51/f 631 Upper Te Karamu Stream. Grid ref. 326928. Grey mudstone and shale.
* *Belemnopsis* sp.
Buchia hochstetteri Fleming

N51/f 633 Upper Te Karamu Stream. Grid ref. 325932. Grey mudstone and shale.
* *Belemnopsis* sp.
Buchia hochstetteri

N51/f 636 Sunset Beach. Grid ref. 236940. Concretionary grey mudstone with tuffaceous bands in quarry at roadside adjacent to shop and surf club building.
Belemnopsis aucklandica aucklandica (Hochstetter)
Belemnopsis aucklandica aucklandica juvenile
Buchia hochstetteri

N51/f 637 Sunset Beach. Grid ref. 233940. Shales and mudstone.
* *Belemnopsis aucklandica*
Buchia plicata (Zittel)

N51/f 638 South Head. Grid ref. 231938. Shales.
* *Buchia plicata*

N51/f 639 Maraitai Valley. Grid ref. 255934. Concretionary grey mudstone with tuffaceous bands in a high cliff an the eastern side of Port Waikato - Waikaretu Road and above Maraitai Stream.
Belemnopsis aucklandica aucklandica

Belemnopsis aucklandica aucklandica juvenile
Buchia hochstetteri

N51/f 640 Maraitai Stream. Grid ref. 256940. Brown mudstone.
* *Belemnopsis aucklandica*
Buchia plicata

N51/f 642 Maraitai Valley. Grid ref. 258930. Grey-brown weathered mudstone 75 yards up westward-flowing tributary to Maraitai Stream. Belemnite beds in the south bank 15 feet above stream and adjacent to a 3-foot waterfall. Other fossils in stream bed and banks above and below.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile
Inoceramus aff. *everesti* Oppel
Buchia plicata

N51/f 643 Maraitai Stream. Grid ref. 257930. Grey mudstone in south-west bank.
* *Belemnopsis aucklandica*
Buchia plicata
Aulacosphinctoides brownei (Marshall)

N51/f 645 Maraitai Stream. Grid ref. 258928. Grey mudstone south-west bank.
* *Buchia hochstetteri*
Belemnopsis sp.

N51/f 647 Maraitai Stream. Grid ref. 264924. Grey mudstone west bank.
* *Buchia plicata*
Belemnopsis sp.
Uhligites hectori Spath

N51/f 648 Huriwai Valley. Grid ref. 265907. Hard grey mudstone above Huriwai Stream and Port Waikato - Waikaretu Road and below Tertiary outcrops.
Belemnopsis aucklandica aucklandica juvenile
Buchia hochstetteri

N51/f 650 Upper Huriwai Valley. Grid ref. 272907. Concretionary grey-brown mudstone in cliff in the north bank of Huriwai Stream just westwards of confluence with north-flowing tributary.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile
Inoceramus aff. *everesti*
Buchia plicata
Aulacosphinctoides brownei

N51/f 651 Waikawau Stream. Grid ref. 280882. Brown mudstone.
* *Buchia hochstetteri*
Belemnopsis sp.

N51/f 657 Huriwai Stream. Grid ref. 256911. Grey mudstone north bank.
* *Buchia hochstetteri*
Belemnopsis sp.

N51/f 660 Putataka Trig. Grid ref. 278932. Brown mudstone.
* *Cladophlebis australis* (Morris)
Cladophlebis reversa (Fiestmantel)
Taeniopteris arctica Heer

N51/f 662 Upper Maraitai Stream. Grid ref. 273941. Brown mudstone.
* *Cladophlebis australis*
Taeniopteris arctica

N51/f 952 Te Karamu Stream. Grid ref. 324928. Weathered brown mudstone south-western bank of prominent meander, *ca.* 30 feet of beds exposed.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile moulds

N51/f 953 Te Karamu Stream, eastern bank. Grid ref. 326925. Grey mudstone beneath track, and not visible from track.
Belemnopsis aucklandica aucklandica

N51/f 954 Okahu Stream. Grid ref. 297973. Grey-brown weathered mudstone with prominent 2 in. - 4 in. beds, just westward of confluence of tributaries.
Belemnopsis sp.

N51/f 955 Okahu Stream. Grid ref. 298972. Grey mudstone bed in stream just south of confluence of tributaries.
Belemnopsis ex. gr. *aucklandica*

N51/f 956 Port Waikato Camping Ground. Grid ref. 247945. Weathered grey-brown mudstone at the western boundary of camping ground in slip high above road.
Belemnopsis aucklandica aucklandica mould
Belemnopsis aucklandica aucklandica juvenile

N51/f 957 Oraeroa Stream. Grid ref. 246938. Concretionary grey mudstone in eastern bank adjacent waterfall.
Belemnopsis ex. gr. *aucklandica*

N51/f 958 Okahu Valley. Grid ref. 301964. Weathered grey-brown mudstone in slip high on eastern side of valley of southernmost tributary of Okahu Stream.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile
Buchia aff. *misolica* (Krumbeck)

N51/f 959 Upper Moewaka Stream. Grid ref. 309951. Very soft, badly weathered, brownish-black mudstone at confluence of several tributaries, and at intervals for 50 yards upstream of northernmost branch of system.
Belemnopsis aucklandica aucklandica

N51/f 960 Klondyke Road. Grid ref. 290978. Weathered grey-brown mudstone in road cutting above Okahu Stream *ca.* 100 yards west of farm house and sheds.
Belemnopsis ex. gr. *aucklandica*
Buchia aff. *misolica*

N51/f 961 (? N51/f 12) Maraitai Valley. Grid ref. 255934. Hard grey mudstone in road cutting north-western side of Port Waikato - Waikaretu Road 20 - 30 feet above Maraitai Stream and 70 yards west of high cliff (f 639).
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile
Belemnopsis sp.
Buchia hochstetteri

N51/f 962 Maraitai Valley. Grid ref. 255934. Hard grey mudstone in bank of Maraitai Stream at western limit of meander. Southwards across Port Waikato - Waikaretu Road from f 961.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile

N51/f 963 (?N51/f 656) Waikawau Valley. Grid ref. 286876. Northern tributary system of Waikawau Stream. Grey mudstone in northern bank of southernmost tributary above a small cataract and adjacent to blocks of Tertiary sandstone.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile

N51/f 964 Waikawau Valley. Grid ref. 286878. Northern tributary system of Waikawau Stream. Grey-brown mudstone in north bank and near the mouth of westward-flowing tributary (just north of f 963).
Buchia hochstetteri

N51/f 965 Maraitai Valley. Grid ref. 256933. Small grey-brown mudstone outcrops high on southern side of spur which has f 639 on its northern side.
Belemnopsis aucklandica aucklandica juvenile

N51/f 966 Waikawau Valley. Grid ref. 285876. Northernmost tributary system of Waikawau Stream. Fifteen-yard outcrop of hard grey mudstone in western bank of stream just south of confluence of tributaries.
Belemnopsis aucklandica aucklandica juvenile

N51/f 967 Huriwai Stream. Grid ref. 256907. Grey mudstone in north bank just westward of small tributary.
Belemnopsis aucklandica aucklandica
Belemnopsis aucklandica aucklandica juvenile

N51/f 968 Moewaka Stream. Grid ref. 305953. Badly weathered brownish-black mudstone western bank.
Belemnopsis ex. gr. *aucklandica* moulds

N51/f 969 Huriwai Stream. Grid ref. 267908. Grey mudstone cliff in northern bank, just eastwards of confluence with south-flowing tributary. Belemnites in upper part of *ca.* 100 feet of beds.
Belemnopsis aucklandica aucklandica juvenile
Belemnopsis sp.

N51/f 970 Waikawau Valley. Grid ref. 289875. Northern tributary system of Waikawau Stream. Grey-brown mudstone in eastern bank at the mouth of a short, steep, northward-flowing tributary.
Belemnopsis aucklandica aucklandica

N51/f 971 Waikawau Valley. Grid ref. 282886. Northern tributary system of Waikawau Stream. Grey mudstone in bed and eastern bank of northernmost tributary adjacent to large fallen blocks of Tertiary sandstone.
Belemnopsis aucklandica aucklandica
Belemnopsis aff. *suavis* Stolley
Belemnopsis sp.
Isolated phragmocones
Buchia hochstetteri Fleming

N51/f 972 Maraitai Valley. Grid ref. 257924. *Maraitai Belemnite Bed.* Steep bank immediately below Port Waikato - Waikaretu Road and above Maraitai Stream.
Belemnopsis aucklandica aucklandica juvenile
and/or *Belemnopsis* aff. *suavis* juvenile

N51/f 973 Sunset Beach. Grid ref. 234937. An isolated block of strata on beach immediately south of two downthrown blocks of Tertiary sandstone.
Belemnopsis aucklandica aucklandica
Belemnopsis aff. *aucklandica*
Belemnopsis sp.
Buchia plicata

N51/f 974 Coastline east of South Head . Grid ref. 231934. A small bay immediately eastwards of the beach at South Head. Grey mudstone beds at top of shore platform, base of beach at the eastern end of the bay. Siltstone, sandstone above, siltstone, sandstone below.
Belemnopsis aff. *aucklandica*
Buchia plicata

N51/f 975 South Head. Grid ref. 229933. Western end of beach. Fine grey sandstone beds at top of beach, base of cliff, amongst fallen boulders.
Belemnopsis ex. gr. *aucklandica*
Buchia plicata

N51/f 976 Coastline South of South Head. Grid ref. 229927. Small stack of siltstone capped with sandstone, at northern end of the beach north of Okariha Point.
Belemnopsis aff. *aucklandica*

Note : When the term "*affinis*" (aff.) is used in this paper in reference to belemnite guards, it indicates that the fossil material is well enough preserved for identification, and slightly different from the named species.

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REPOSITORY OF MATERIAL

The fossil material on which this paper is based is at present located at 141 Russell Road, Huntly, and is available for examination.

REFERENCES

Challinor, A. B., 1968: Notes on the Belemnite Content of the Heterian and Ohauan Stages at Kawhia Harbour, N.Z. *Earth Sci. Jnl.* 2 (2), pp. 109-125.

Clayton, R. N.; Stevens, G. R., 1968: Paleotemperatures of New Zealand Belemnites. *Proc. 1965 Spoleto Conf. on Paleotemperatures and Isotopic Oceanography.* (Natl. Council of Research, Italy).

Fleming, C. A.; Kear, D., 1960: The Jurassic Sequence at Kawhia Harbour. *N.Z. Geol. Survey Bull.* n.s. 67 pp. 50.

Fleming, C. A., 1970: The Mesozoic of New Zealand: Chapters in the history of the circum-Pacific mobile belt. *Q. Jnl. Geol. Soc. Lond.*, pp. 125.

Hochstetter, F. von, 1864: *Geology of New Zealand,* translated and edited by C. A. Fleming, 1959. N.Z. Govt. Printing Office, pp. 320.

Keyes, I. W., 1959: Paleontological Casting and Moulding Techniques. *N.Z. Jnl. Geol. Geophys.*, 2 (1) pp. 56-65.

Norris, G., 1968: Plant Microfossils from the Hawks Crag Breccia, Southwest Nelson, N.Z. *N.Z. Jnl. Geol. Geophys,* 11 (2), pp. 312-344.

Player, R. A., 1958: The Geology of North Kawhia. Unpublished *Univ. of New Zealand* Thesis. Lodged in Univ. of Auckland Library.

Purser, B. H., 1961: Geology of the Port Waikato Region. *N.Z. Geol. Surv. Bull.* n.s. 69, pp. 36.

Stevens, G. R., 1965: The Jurassic and Cretaceous Belemnites of New Zealand and a Review of the Jurassic and Cretaceous Belemnites of the Indo-Pacific region. *N.Z. Geol. Surv. Pal. Bull.*, 36, pp. 231.