Sample	*1*	*2*	*3*	*4*
SiO_2	9.13	8.47	10.31	5.36
Mn	18.58	17.01	17.25	3.66
Fe	16.56	18.75	18.37	10.77
Al	0.069	0.079	0.075	0.067
Cu	0.052	0.042	0.067	0.047
Ni	0.42	0.31	0.32	0.12
Co	0.24	0.31	0.33	0.083
Cr	0.0063	0.0075	0.0073	0.0089
Zn	0.076	0.072	0.081	0.046
Pb	0.18	0.24	0.16	0.072
Mg	0.98	0.90	0.99	0.49
Ca	3.19	2.43	2.49	25.34
% *Ni* + *Cu* + *Co*	0.71	0.66	0.71	0.25

Table 1. Chemical analyses (%) of selected parts of polygenetic manganese nodule.

A comparison of Table 1 with Table 4 of Hinz & others (1978) shows that there is general agreement among the analyses of all nodules and crusts from KD13. The outer layer (Samples 1 & 2 in Table 1) and the upper third of the core (Sample 3) are also chemically very similar to one another. However, Sample 4, from the centre of the core, gives very different results. The high Ca value (25.34%) can be related to included carbonate-rich sedimentary material. An X-ray analysis of lighter coloured material from a fissure filling (see Fig. 1) showed that a major component, along with calcite, was apatite. This phosphatisation appears to be the cause of the relative strength of the fissure fillings.

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Clavohamulus primitus — A key North American conodont found in the Georgina Basin

E. C. Druce

The enigmatic conodont *Clavohamulus primitus* Miller is described from the Tremadocian part of the Ninmaroo Formation, Georgina Basin. This key subzone species for North American sequences in Oklahoma, Texas and Utah has been discovered in two samples, one from Western Queensland and the other from the Northern Territory. The discovery enables a firmer correlation of the Lower Tremadocian part of the Georgina sequence with sequences in North America.

The microstructure of *C. primitus* is discussed and illustrated.

Introduction

Tremadocian conodonts have been known from the Georgina Basin since Druce & Jones (1968) published a brief note which was followed (1971) by a monograph on material from the Burke River Structural Belt in which six conodont assemblage zones were erected. This information, together with additional knowledge of conodont distribution throughout the Tremadocian of the Basin, formed the basis for both the recognition of the Datsonian and Warendian stages (Jones, Shergold, & Druce, 1971) and the correlation of the rock sequences with those of North America and Europe.

In 1974 BMR began a detailed study of the Georgina Basin in order to improve the understanding of its geological history: studies include a detailed petrological study of the Ninmaroo Formation, a varied carbonate unit which straddles the Cambrian-Tremadocian boundary and extends at least to the Tremadocian-Arenigian boundary (Druce, Shergold, & Radke, in prep.). To get biostratigraphic control on the rock sequences measured and analysed by Radke, samples were collected at various intervals for micropalaeontological examination. Two of these samples have yielded a species of conodont, *Clavohamulus primitus* Miller, which previously had not been recorded from the Basin, but which is known from North America (Miller, 1969).

Location and geology

The species was recovered from two samples, GEO 228/2 and GEO 269/3 (Fig. 1). Sample GEO 228/2 is from Mount Ninmaroo (140°18′E, 22°37′S) in the Burke River Structural Belt, Queensland (BOULIA 1:250 000 Sheet area) 87.5 m above the base of the Ninmaroo Formation, corresponding approximately to sample BOU 2/43 or 44 of Druce & Jones (1971) (Fig. 2).

It is a peloidal skeletal grainstone with non-skeletal algae and trilobites. The grainstone forms the basal bed of the Jiggamore Member of the Ninmaroo Formation, immediately overlying the lowest member, the Unbunmaroo Member. The conodont sample yielded only *Clavohamulus primitus*.

Sample GEO 269/3 (137°49′E, 22°58′S) is from the Toko Syncline area, 5 km WSW of Burnt Well in the TOBERMORY 1:250 000 Sheet area, in the Northern Territory, 85 m above the base of the exposed sequence of the Ninmaroo Formation (Fig. 3).

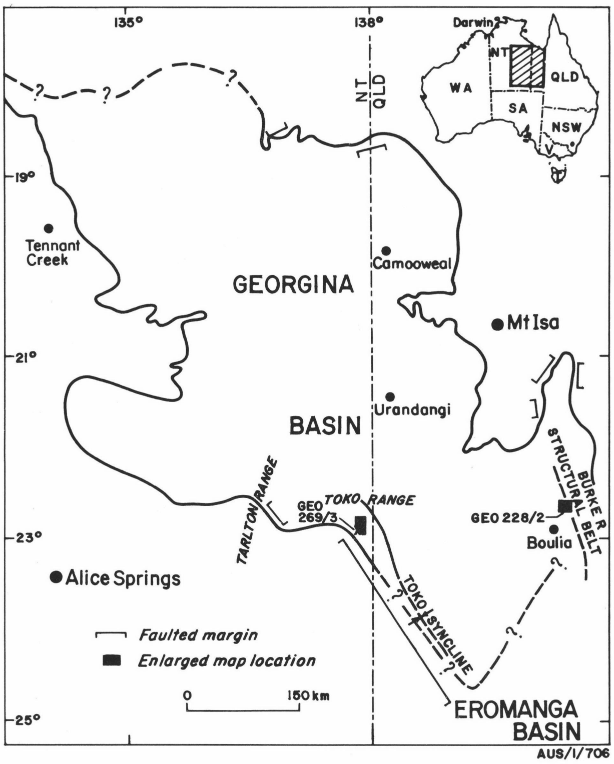


Figure 1. General locality map.

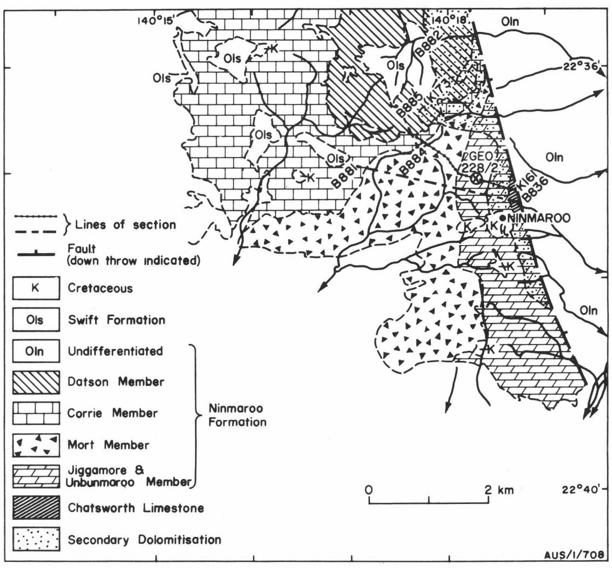


Figure 2. Detailed locality map, sample GEO 228/2.

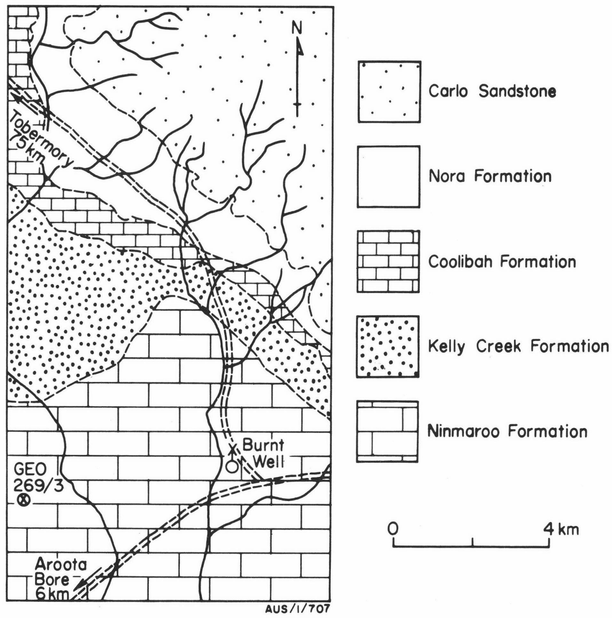


Figure 3. Detailed locality map, sample GEO 269/3.

Sample 269/3 is a stromatolite boundstone, and the bed is composed of small 15 cm diameter domes, with interstitial skeletal detritus including trilobites, nautiloids and conodonts. The sample has yielded abundant conodonts, which include:

Clavohamulus primitus
Cordylodus proavus Müller
Cordylodus cf. *C. proavus* sensu Druce & Jones
Oneotodus gracilis (Furnish)
Oneotodus nakamurai Nogami
Proconodontus notchpeakensis Miller

This fauna is indicative of the *Cordylodus proavus* Assemblage Zone, the zone recognised in the Mount Ninmaroo sequence from which the other *Clavohamulus primitus* specimens came.

In the Burke River Structural Belt the Ninmaroo Formation conformably overlies the Chatsworth Formation, a sequence of calcareous siltstones and grainstones whereas in the Tobermory area it disconformably overlies the Arrinthrunga Formation, an algal dolomite unit.

Correlation

Clavohamulus primitus has previously been described from Utah, USA (Miller, 1969) where it was originally reported from Member 6 of the Notch Peak Limestone in the House Range. Recently Miller (pers. comm.) has found it in the Llano Uplift area of Texas and in the Wichita Mountains, Oklahoma. Its first appearance marks the base of the *Acodus housensis-Clavohamulus primitus* Subzone within the *Cordylodus proavus-Cyrtoniodus oklahomensis* Zone of Miller (pers. comm.). Stitt (1977) has divided the North American Trilobite Zone of *Missisquoia* into two; the incoming of the upper subzone (*Missisquoia typicalis*) fauna coincides with the first occurrence of *Clavohamulus primitus* (Miller *fide* Stitt, 1977). Druce (1978) has already correlated the incoming of *Cordylodus proavus* with the base of the *Corbinia apopsis* Zone in North America, and this was considered to be equivalent to the Cambrian-Tremadocian boundary. Recently, however, Landing & Taylor (1977) have shown that *C. proavus* occurs with trilobites of the *Acerocare* Zone, the uppermost Cambrian zone of the Acado-Baltic Faunal Province. When the stages were erected for the Australian shelf carbonate sequences the conodont fauna from the lower part of the Tremadocian in North America was less well known and the correlation with the trilobite zones recognised in Oklahoma was tentative (Jones & others, 1971). The presently known distribution of conodonts in North America and Australia suggests that the Oklahoma zones were originally placed slightly too high with respect to the Australian sequence: for example the *Symphysurina* Zone was considered to be equivalent to the early Warendian although beginning in the latest part of the Datsonian (Jones & others, 1971) whereas it probably overlaps the late Datsonian and early Warendian (Fig. 4). Both the *Missisquoia* and *Saukia* Zones are also

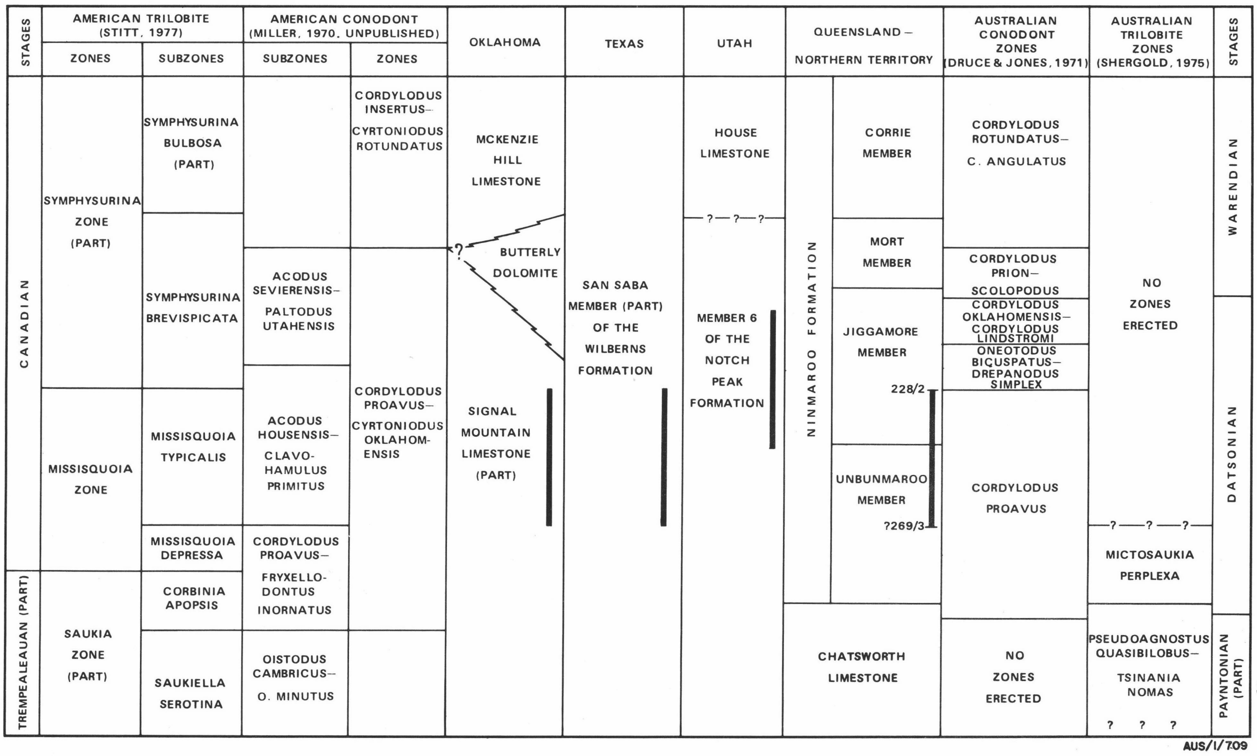


Figure 4. Ranges of *Clavohamulus primitus* in North America (after Miller, pers. comm.) and Australia, and a possible correlation of stages and zones.

considered to correlate with slightly older parts of the Australian shelly sequence, although the *Saukia* Zone still overlaps the earliest Datsonian which is thus equivalent to the latest Trempealeauian.

Shergold (1975, p. 27) notes that the *Mictosaukia perplexa* Trilobite Zone precedes the first occurrence of *Cordylodus proavus,* but that the relevant intervals are sparsely fossiliferous. It is probable that the *C. proavus* Zone overlaps rather than succeeds the *M. perplexa* Zone.

Systematic palaeontology

Clavohamulus primitus Miller, 1969
(Fig. 5A-Y)

1969 *Clavohamulus primitus* Miller, *J. Paleont.,* 43, 423, pl. 64, figs. 7-12.

Material. 12 specimens; CPC 18419-18421 from sample GEO 228/2, and CPC 18422-18426 from sample GEO 269/3 figured.

Range and occurrence. The specimens are from the Unbunmaroo Member and the basal bed of the overlying Jiggamore Member within the Ninmaroo Formation: locations are given above.

Description. Small rotund cones shaped like a boxing glove: curved towards the posterior and compressed antero-posteriorly. The surface, apart from a collar around the aboral margin and the lower part of the posterior face, is covered with ornament. This varies from rounded nodes (Fig. 5J) to short spines (5D) but always gives a pustulose appearance. The ornament is arranged in diagonal rows which wrap around the crown of the unit, the nodes becoming slightly more elongate and posteriorly inclined towards the posterior-oral margin. The diagonal pattern is sometimes disrupted by the incipient development of a hexagonal pattern (Fig. 5J). The basal cavity is variable: it is well developed in specimens from Mount Ninmaroo whereas in Burnt Well specimens the cavity is not as open. The aboral opening is generally circular, although in some specimens it is elongate laterally (Fig. 5S).

Remarks

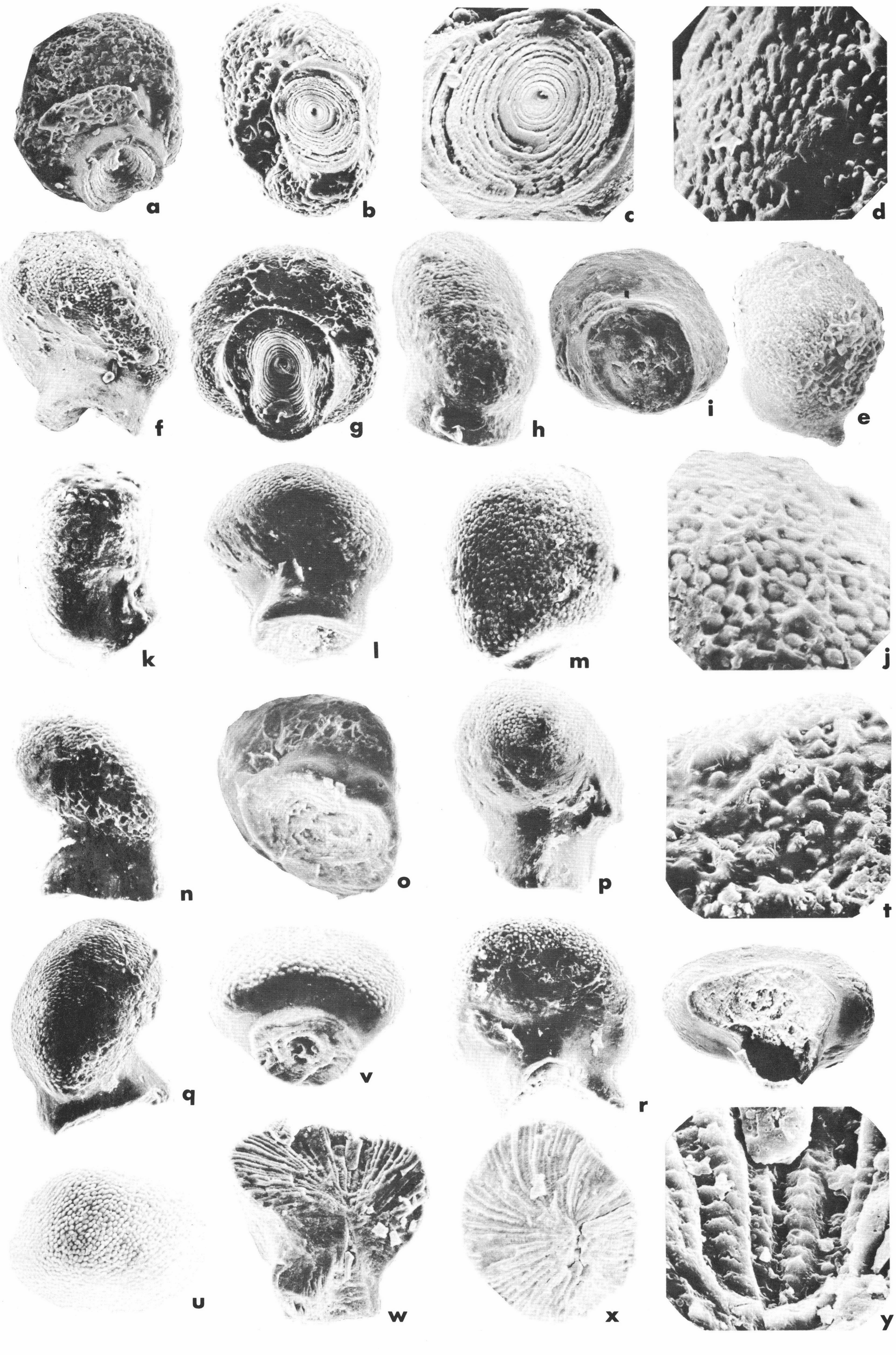
There is some difference between the specimens from the Northern Territory and those from Queensland, particularly in the basal cavity which is much more open in the Queensland specimens, displaying the intersection of the circular growth laminae with the conical surface of the cavity. This difference in the basal cavity means that the Queensland specimens may be closer to the genus *Hirsutodontus* than the Northern Territory specimens. Miller (1969, p. 422) redefines *Clavohamulus* and notes that the basal cavity is 'greatly reduced or nearly absent, in which case the basal side is merely flattened and marked by faint concentric ridges; a basal cone is absent'. Although the basal cavity appears to be greatly reduced in the Northern Territory specimens, the cross-section (Fig. 5W) shows that it is reasonably developed.

All the Queensland specimens show the development of secondary apatite on the cusp, masking the ornament to some extent.

Microstructure

One specimen (CPC 18426) fractured during photography with the specimen separating along a horizontal fracture into an upper crown part and a lower basal part. This latter part then fractured vertically to give a cross section of the basal cavity area.

C. primitus is a cancellate conodont (in the sense that Barnes, Sass, & Monroe, 1973:12 use the term) with virtually all the cusp composed of white matter characteristically containing small holes (Fig. 5W). The white matter is arranged as rods radiating and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gently spiralling from the apex of the basal cavity and terminating in nodes on the outer surface. These rods are stacked so that each is superimposed in the hollow of two adjoining rods, thus giving the diagonal rows of nodes on the surface. Each rod appears to be separate from its neighbour and in Fig. 5Y the inter-rod areas appear as deep valleys.

The base of *C. primitus* is built up of concentric lamellae from the basal cavity (Fig. 5A-C, E, W). The lamellae are cone shaped around the basal cavity but in the crown part they are inflated into a global shape. Production of white matter at the expense of the original lamellae has tended to obscure the lamellae, but the intersection of the lamellae and inter-lamellar spaces with the rods and inter-rod spaces gives a knotted appearance to the rods: they are fatter in the lamellar area than in the interlamellar area (Fig. 5X, Y).

In Figure 5X the upper right quadrant of the photograph shows a broken transverse surface of the basal part of the unit. This lacks the rods of the crown part, but shows radial striations and lack of obvious lamellar structure, suggesting that it is white matter which is not rod-like, analogous to the material to the left of the upper part of the cavity in Fig. 5W.

Summary

The discovery of the stratigraphically restricted conodont *Clavohamulus primitus* in Australia, together with *Cordylodus proavus*, enables a more precise correlation to be made with North America.

Study of the structure of *C. primitus* shows that it is composed of a large number of radiating denticles, fused over their whole length apart from the tips which appear as nodes. These fused denticles form rods which have a knotted appearance due to the intersection of the growth lamellae.

Acknowledgements

Critical comments were made by Dr P. J. Jones and the figures were drawn by K. Barrett.

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Figure 5. *Clavohamulus primitus* **CPC 18419: a. aboro-posterior view showing secondary growth of apatite (mag. 180X); b. aboral view (mag. 220X); c. close-up view of basal cavity (mag. 500X); sample GEO 228/2. CPC 18420: d. elongate nodose ornament on crown (mag. 800X); e. latero-oral view showing nodose ornament (mag. 200X; sample GEO 228/2. CPC 18421: f. latero-posterior views showing lack of ornament on basal collar and postero-aboral face (mag. 160X); g. aboral view showing keyhole shaped cavity (mag. 180X); sample GEO 228/2. CPC 18422: h. lateral view showing wrap-around of ornament (mag. 220X); i. aboral view showing shallow cavity (mag. 220X); j. close up of ornament showing incipient development of hexagonal pattern (mag. 800X); specimen GEO 269/3. CPC 18423: k. lateral view showing flattened nodose ornament, (mag. 200X); l. aboro-posterior view showing shallow cavity and lack of ornament on lower part of crown (mag. 180X); m. anterior view showing nodose ornament (mag. 200X); sample GEO 269/3. CPC 18424: n. lateral view (mag. 180X); o. aboral view showing shallow cavity with lamellae (mag. 220X); p. posterior view (mag. 180X); sample GEO 269/3. CPC 18425: q. lateral view (mag. 180X); r. posterior view (mag. 180X); s. aboral view showing flaring of shallow basal cavity (mag. 200X); t. close up of ornament (mag. 1000X); sample GEO 269/3. CPC 18426: u. oral view showing diagonal arrangement of nodes (mag. 220X); v. aboral-lateral view (mag. 200X); w. lateral view of vertical cross section of basal part and horizontal cross section of crown (mag. 200X); x. aboral view of cross section of crown showing radiating rods with 'knots' (mag. 240X); y. close up of rods and 'knots' (mag. 1500X); sample GEO 269/3.**