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AUSTRALIAN PHANEROZOIC TIMESCALES

2. ORDOVICIAN

BIOSTRATIGRAPHIC CHART AND EXPLANATORY NOTES

compiled by

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COVER ILLUSTRATION: *Xystridura milesi* (Chapman, 1929) from the early Middle Cambrian, Beetle Creek Formation, Mount Isa district, Queensland.

FOREWORD

A time framework is essential to understanding the history of all aspects of the geosphere. It is a prerequisite to interpreting the development and structure of the sedimentary basins which host our major petroleum, coal, and sedimentary mineral deposits, and is important when seeking patterns in the distribution of these resources through time. It is also critical to our understanding of the interactive factors which have shaped the modern Australian environment, and in determining the patterns of global change.

For the Phanerozoic (the last 570 million years, the period of 'visible life'), the most efficient way of establishing such a time framework is by the study of fossils, which represent the most concrete evidence for the evolution of life.

The palaeontological study of Australian sedimentary basins began with the first fossil descriptions in the latter part of the eighteenth century, which during the nineteenth century were used to establish the age of major suites of sedimentary rocks. An early example of the systematic use of fossils as time markers for detailed correlation was the subdivision of Ordovician rocks in Victoria using graptolites at the beginning of this century. The development of Australian biostratigraphy over the last 50 years has seen the setting up of various biostratigraphic schemes using the fossil remains of a wide range of organisms - from the microscopic, such as pollen grains and spores of land plants, to the macro- and megascopic - the remains of larger invertebrates, fish, mammals, even of human artifacts.

Recent years have also seen a rapid growth in other methods of measuring geological time, using radioactive decay of mineral elements, or reversals in the Earth's magnetic field. But no method for measuring geological time can operate in isolation, and a comprehensive time framework needs to take into account information from a variety of sources.

This preliminary series makes available for immediate use a set of charts based on recent palaeontological data from the specialist scientific literature, as well as unpublished information from ongoing biostratigraphic research. The charts integrate zonal schemes using different groups of fossils with isotopic and other data (magnetic reversal, eustasy curves), and show the relationship of the Australian zones to standard international timescales and their numerical calibration, where this information is available. The aim was not to produce a separate 'Australian time scale' in competition with already established international scales, but rather to provide a set of up-to-date calibrated biostratigraphic charts for use in the Australian region. Inevitably the detail of treatment and reliability varies for different parts of the column and for different groups of fossils, and much work still needs to be done to develop a fully integrated chronological scale comparable to those available in the Northern Hemisphere.

Biostratigraphic charts were first prepared to provide a firm chronological base for the AMIRA (Australian Mineral Industries Research Association) sponsored *Palaeogeographic Atlas of Australia.* The charts and explanatory text produced in this series are part of the second phase of that project, the *Phanerozoic History of Australia,* which is funded in part by APIRA (Australian Petroleum Industry Research Association). The charts have been compiled by palaeontologists in BMR, but incorporate contributions by other specialists working in State Geological Surveys, Universities and the exploration industry, without which such a comprehensive compilation would not have been possible.

I am confident that the charts will prove to be an esential tool for the exploration industry in Australia.

P.J. Cook,

Associate Director, BMR

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INTRODUCTION (B.D. Webby)

Ordovician sediments are known from all states and mainland territories of Australia (Webby *et al.* 1981) where they were deposited in intracratonic basins and on the platforms and shelves of the margin (fig. 1) of the Australian Block. Correlation of these sediments is essential for a detailed and accurate interpretation of the depositional interrelationship of sediments in areas that are now geographically isolated. Because much progress has been made in the last 10 years on the accuracy of Ordovician biostratigraphy, there is a need to provide an update on the earlier synthesis of the Ordovician (Webby *et al.* 1981) and to provide a reference point for future stratigraphic and biostratigraphic studies.

HISTORICAL

The first Australian Ordovician fossils to be discovered were graptolites from Victoria, and these were found mainly by field geologists of the Geological Survey of Victoria. A.R.C. Selwyn (formerly Director of this Survey) is credited with making the first finds in auriferous slates in June 1856 (McCoy 1875), and there were many further discoveries in the next decade or so (Keble & Benson 1939). Darragh (1976) is incorrect in his assertion that Thureau was the first to report graptolites. Etheridge (1874) and McCoy (1874) provided the first illustrations and descriptions of some of these newly found graptolites. Tasmanian Ordovician fossils were also being reported from about 1860 onwards. For example, the stromatoporoid *Stromatocerium* was listed in Bigsby (1868), and the first trilobites were described by Etheridge (1883) under the names *Conocephalites stephensi* and *Dikelocephalus tasmanicus* (see review of the species in Jell & Stait, 1985a).

The rocks of these successions continued to be described in publications and represented on geological maps as having a 'Lower Silurian' age through most of the latter part of the nineteenth century, despite Lapworth's (1879) introduction of the Ordovician as a new System. As in Britain there was little initial reaction to Lapworth's proposal (Bassett 1979) of a new name but eventually it was accepted. T.S. Hall, the first Australian-born and trained palaeontologist of 'acknowledged distinction' (Vallance 1978) was the first to adopt the term Ordovician in the subtitle to the first of his series of papers on Victorian graptolites in 1897.

T.S. Hall was a major contributor to the early development of knowledge of Australian Ordovician geology and palaeontology, and not only documented the Victorian graptolite faunas, but established the first workable zonal scheme (Hall, 1895), which he later modified to 'series' subdivisions (Hall, 1899). As Dunn (1929) emphasised, one of the significant features of Hall's pioneer graptolite work was that in the goldfields of Victoria it provided a means of identifying the most productive horizons. Rocks of the four age-significant 'series' subdivisions had the following characteristics: the oldest Lancefield Series was not very auriferous, the succeeding Bendigo Series was the most auriferous, the overlying Castlemaine Series was only irregularly auriferous, and the youngest Darriwil Series was barren.

A distinguished line of Victorian graptolite workers followed T.S. Hall, and they published a series of very important papers on the Victorian Ordovician graptolite succession through the 1920's and 1930's. These contributions by Harris, Keble and Thomas established the foundations of the most comprehensive and detailed zonal subdivision of the Ordovician. By the end of the 1930's more than a hundred papers had been contributed on various aspects of Victorian and New South Wales graptolite research and relevant Ordovician geology by these and other workers (see reviews by Keble & Benson 1939; and Thomas 1960).

Elsewhere in Australia the record of descriptive work on Ordovician palaeontology is very patchy. Etheridge (1891; 1892; 1893; 1894) and Tate (1896) described some of the Ordovician shelly faunas (molluscs, brachiopods and trilobites) from the Amadeus Basin of central Australia. Then there is an important series of papers on nautiloids by Teichert (1939; 1947) and Teichert & Glenister (1952; 1953; 1954), on corals by Hill (1955; 1957), and on bryozoans by Ross (1961). However none of these works contributed greatly to an improved biostratigraphy.

Since the late 1960's the volume of output of descriptive palaeontological work has increased greatly, with many additional fossil

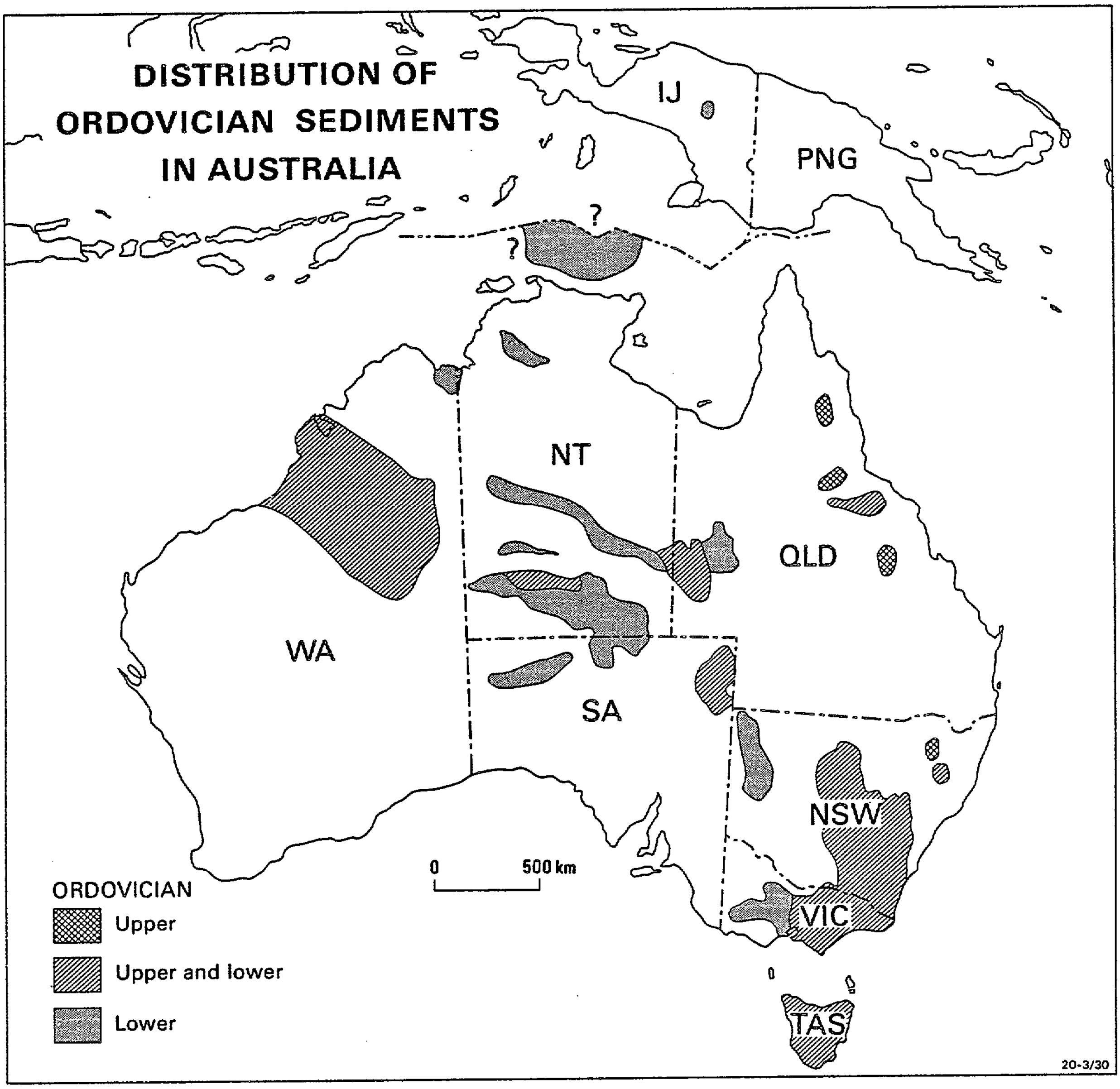

Figure 1. Distribution of Ordovician sediments on the Australian Block

groups being studied for the first time, and the emergence of more varied biostratigraphic schemes allowing a wider range of facies (not just the deeper, ocean basin biofacies) to be correlated. Contributions include the following:

Palynomorphs - Combaz & Peniguel (1972); Playford & Martin (1984); Playford & Wicander, 1988; Playford & Miller, 1988;

Algae (or Cyanobacteria) - Webby (1982);

Radiolarians - Webby & Blom (1986);

Stromatoporoids - Webby (1969; 1979); Webby & Morris (1976); Webby & Banks (1976);

Sponges - Webby & Rigby (1985); Rigby & Webby (1988);

Corals - Webby (1971; 1972; 1977; 1988), Hall (1975), McLean & Webby (1976), Webby & Semeniuk (1969; 1971); Webby & Kruse (1984);

Bivalves - Pojeta & Gilbert-Tomlinson (1977);

Rostroconchs - Pojeta *et al.* (1977);

Gastropods - Gilbert-Tomlinson (1973); Jell *et al.* (1984);

Nautiloids - Wade (1977a; 1977b); Stait (1980; 1982; 1983; 1984a; 1984b), Stait & Flower (1985), Stait & Laurie (1985) and Stait *et al.* (1985);

Brachiopods - Percival (1978; 1979a; 1979b); Laurie (1980; 1987);

Trilobites - Campbell & Durham (1970), Webby (1971; 1973; 1974), Legg (1976), Burrett *et al.* (1983), Henderson (1983), Jell (1985), Jell & Stait (1985a; 1985b), Fortey & Shergold (1984), Webby *et al.* (1970; 1988);

Echinoderms - Webby (1968), Jell *et al.* (1985);

Conodonts - Jones (1971); Druce & Jones, (1971), Jones *et al.* (1971), McTavish (1973), Palmieri (1978), Burrett (1979), Burrett *et al.* (1983), Nicoll (1980), B. Cooper (1981), Stewart & Fergusson (1988), Watson (1988);

Graptolites - R. Cooper (1973), Cooper & McLaurin (1974), Cooper & Ni (1986), Legg (1976), Henderson (1983), VandenBerg *et al.* (1984), Erdtmann & VandenBerg (1985);

Ostracods - Burrett *et al.* (1983), Schallreuter (1988), Schallreuter & Siveter (1988a; 1988b; 1988c);

Fishes - Ritchie & Gilbert-Tomlinson (1977);

Trace fossils - Webby (1983).

BIOSTRATIGRAPHIC SUBDIVISIONS

For many of these above-listed groups the documentation remains too limited as yet to adequately assess their potential for correlation. However some progress has been made in establishing biostratigraphic schemes using, in addition to the graptolites, the conodonts, trilobites, nautiloids, corals and stromatoporoids (see below).

The comprehensive Victorian Ordovician stage (formerly series) and zonal graptolite-based scheme established by T.S. Hall, Keble, Harris and Thomas (see Thomas 1935, 1960; Harris & Thomas 1938), subject of a major revision by VandenBerg (*in* Webby *et al.*, 1981) and updated in Cas & VandenBerg (1988), remains the main basis for correlation of basinal deposits, particularly in south-eastern Australia. Only at a comparatively few localities and horizons in Victoria and in the Australian Capital Territory have conodonts (of North Atlantic provincial type) been found in graptolite- bearing associations (Nicoll, 1980; Stewart, *in* Cas & VandenBerg, 1988; and herein) providing essential tie points between graptolite and North Atlantic-type conodont schemes.

In the continental platform successions of northern Australia there is a workable Lower Ordovician conodont stage and zonal scheme established by Druce & Jones (1971) and Jones *et al.*, (1971) - see also Webby *et al.*, (1981) and Druce *et al.*, (1982) - and it is further developed by Nicoll herein. These assemblages include elements of North Atlantic, North American Midcontinent and Chinese provincial aspect. Relationships between the Victorian conodont occurrences of Stewart, the conodont Zones and other occurrences of northern Australia, the North American Midcontinental Zones and the North Atlantic (Baltoscandian) Zones are shown in the accompanying correlation, and further discussed by Nicoll herein (p.14).

Other biostratigraphic subdivisions include the Upper Ordovician coral-stromatoporoid scheme outlined by Webby herein (p.18), the nautiloid assemblages described by Stait herein (p.17) and the trilobite and brachiopod occurrences discussed by Shergold & Laurie herein (p.16).

A full discussion of the subsystemic, series and stage subdivisions and classification of the Ordovician System in Australia and New Zealand was presented at the Fifth International Symposium on the Ordovician System in St. John's, Newfoundland in August 1988 (Webby *et al.*, in press). It includes outlines of the main biostratigraphic zonal schemes, major faunal events for correlation, and comments on the applicability of use of overseas series names in Australasia.

LIMITS OF THE ORDOVICIAN

In terms of defined limits of the System, the Cambrian-Ordovician boundary cannot be located in the Victorian graptolitic successions because it lies below the earliest records of planktic graptolites as currently used to recognise the earliest stage, the Lancefieldian (R. Cooper 1979). On the other hand in platformal carbonate sequences of the Georgina Basin, with accompanying conodont Zones of mainly North American Midcontinent aspect, it will be possible to place the boundary precisely within the Datsonian zonal succession (Jones *et al.*, 1971; Druce *et al.*, 1982), that is, when the Cambrian-Ordovician boundary is ratified internationally in a few years time (Norford 1988) using similar conodonts. Another apparently structurally uncomplicated Cambrian-Ordovician boundary section in western New

South Wales is developed in deeper, off-shelf, silty trilobite-bearing beds with a diverse latest Cambrian fauna of *Rhaptagnostus*, *Pseudoyuepingia*, *Proceratopyge*, *Hedinaspis* and *?Prosaukia* succeeded by an earliest Ordovician (basal Tremadoc) occurrence of index fossil *Hysterolenus*. A number of Cambrian-Ordovician boundary sections in south-east and northern China have similar faunal components (Webby *et al.*, 1988).

The Ordovician-Silurian boundary is not well exposed in Australia. Near Darraweit Guim, north of Melbourne (VandenBerg *et al.*, 1984) there may be a continuous succession of beds spanning the Ordovician-Silurian boundary but representatives of key graptolites of the *persculptus* Zone below and the *acuminatus* Zone above the boundary (Cocks 1985) are not found in a single structurally uncomplicated section of the area (VandenBerg *et al.*, 1984; VandenBerg & Webby 1988). The latest Ordovician stage, the Bolindian, has been revised upwards to include the *persculptus* Zone (Cas & VandenBerg, 1988). In the Forbes-Parkes area of central-western New South Wales (Sherwin 1970; 1973) there is a succession of beds which may also span the boundary but the critical part of the section is not exposed (VandenBerg & Webby, 1988). Also in Tasmania, there is a graptolitic horizon in the Westfield Sandstone suggesting either the *persculptus* Zone or a position low in the *acuminatus* Zone (Baillie *et al.* 1978; Banks 1988).

LOWER-UPPER ORDOVICIAN SUBSYSTEMIC BOUNDARY

Harris & Thomas (1938) introduced a tripartite subdivision of the Ordovician into Lower, Middle and Upper, and this was followed by most later workers. In this usage, Middle Ordovician applied only to the Darriwilian. VandenBerg (*in* Webby *et al.* 1981), and Cas & VandenBerg, (1988) have noted that in Victoria prior to Harris & Thomas' (1938) subdivision, no Middle Ordovician was used. They have recommended a reversion to the former two-fold subdivision into Lower and Upper, the boundary being placed at the base of the *Nemagraptus gracilis* Zone. This approach, that is, for a Lower-Upper Ordovician subsystemic boundary taken at the base of *N. gracilis*, coinciding with the base of the Gisbornian, is supported by Webby *et al.*, (1988). The main difficulty is how to correlate this boundary precisely into the shallow, carbonate platform sequences like those exposed in Tasmania. The Tasmanian succession is reasonably complete, but there are parts of the sequence with endemic faunas and, at some levels, supratidal to intertidal strata. Brachiopods and nautiloids are well represented but much information on the brachiopods remains unpublished, as does the data for the conodonts and the trilobites. Graptolites are useful at a few horizons but not close to the level of the proposed subsystemic boundary. External correlations of the Tasmanian sequences are mainly with the North American platform successions, and the North American Stage and Series names such as 'Chazyan' and 'Whiterockian' can be comparatively easily applied. Subdivisions of Lower, Middle and Upper are employed more-or-less as in North America with the Lower approximately equivalent to the Ibex Series (formerly Canadian), the Middle to the Whiterock plus the Mohawk Series (both sometimes referred to the 'Champlainian' and the Upper to the Cincinnati Series (Ross, 1984). The subdivisions of Lower, Middle and Upper Ordovician in Tasmania are therefore quite different from those of the formerly accepted Harris & Thomas (1938) tripartite subdivision.

Perhaps the most promising means of correlating the proposed Lower-Upper Subsystemic boundary into Tasmania is: (1) by establishing zonal ties in mixed graptolite, shelly, coralline and perhaps conodont biofacies, like those represented in the Ordovician of central New South Wales; and (2) by recognising links between the Tasmanian conodont succession and conodonts in sequences of mixed graptolite and conodont biofacies, such as those in North China.

A conodont *Tasmanognathus* Zone has been recognised in parts of North China (An *et al.*, 1985), and its general correlation is with the *Glyptograptus teretiusculus* to *N. gracilis* Zones. *Tasmanognathus* also occurs in Tasmania (Burrett 1979), but not closely associated with graptolites. It is now vitally important (1) to establish precise stratigraphic ranges of species of *Tasmanognathus*, and relationships with associated conodonts and other faunas in the respective Chinese and Tasmanian successions; and (2) to link these ranges in the best North

Chinese sections to occurrences of the zonal index *N. gracilis*. Once tie points are established it will be possible to correlate the Lower-Upper Ordovician subsystemic boundary (base of *N. gracilis* Zone) into Tasmania.

GEOCHRONOLOGY

Only a very limited amount of geochronologic data presently available in Australia has good stratigraphic control and is of much use in constructing an Ordovician time scale. Consequently most of the data used in constructing the various presentations of the time scale come from overseas. These include the proposals of Ross *et al.* (1978), Harland *et al.* (1982), Ross & Naeser (1984), McKerrow *et al.* (1985), Gale (1985), Kunk *et al.* (1982), Odin (1985), and Sloan (1987). Harland *et al.* (1982) established a base for the Ordovician at 503 Ma and top at 438 Ma, giving a duration of 65 Ma. McKerrow *et al.* (1985) expanded this to 513 Ma for the base and 435 Ma for the top (i.e., giving a 78 Ma duration). Odin (1985), on the other hand, interpreted the base at 495 Ma and top at 425 Ma (i.e., for a 70 Ma duration), while Sloan (1987) has given values which are almost identical to those of Harland *et al.*, (1982).

Of the stratigraphically well-controlled radiometric dates the whole rock rubidium/strontium date of 500.7±7.4 Ma obtained for a mudstone bed lying 8.5m below the proposed international Cambrian-Ordovician boundary stratotype at Dayangcha in North China (Chen *et al.*, 1988) is of particular interest. Secondly from the established 421 Ma pooled Rb-Sr and K-Ar age of the early Ludlow Laidlaw Volcanics of the Yass-Canberra region of south-eastern Australia (Wyborn *et al.*, 1982) it seems likely that an Ordovician-Silurian boundary would need to be at least 430 to 435 Ma old.

A Lower-Upper Ordovician subsystemic boundary at the base of *N. gracilis* (base of Gisbornian) is estimated to be about 460 Ma old (Gale 1985). This is supported by the recognition of a K/Ar age of 455±10 Ma for the Doubtful River Gabbro in the Snowy Mountains area of southern New South Wales, which is thought by Owen & Wyborn (1979) to be related to the Nine Mile Volcanics, and to intrude the upper Darriwilian-Lower Gisbornian Temperance Formation. The upper part of the Nine Mile Volcanics (Webby *et al.*, 1981) has an upper Gisbornian graptolite assemblage and a solitary rugose coral (therefore no older than coral-stromatoporoid Fauna I of Webby 1969; and herein). The Owen & Wyborn (1979) field evidence suggests the Doubtful River Gabbro intruded as a sill into the Temperance Formation when it was only partly lithified, and therefore immediately following its deposition in late Darriwilian-early Gisbornian time. The dates shown on the left margin of the chart broadly concur with these estimates.

REGIONAL SETTING

From the available palaeomagnetic data (Embleton, *in* Veevers *et al.*, 1984), the Australian part of Gondwana remained in low latitudes through the Ordovician, moving from the south side of the equator at the beginning of the Ordovician, then to the north side and back again to the south side by the end of the Period. There is ample evidence, for instance, from the recognition of Lower Ordovician evaporites in the Bonaparte Gulf and Amadeus Basins (Webby 1978), and the record of Upper Ordovician corals and stromatoporoids in Tasmania and central New South Wales (this latter a part of an offshore volcanic island-arc complex), that the region remained in the tropics throughout the Ordovician Period.

Biogeographic relationships of the Australian Ordovician faunas have been discussed recently by Webby (1987), in particular as they apply to the differing tectonoenvironmental settings of the Gondwana continental margin and the offshore 'suspect terranes'.

GRAPTOLITES (A.H.M. VandenBerg)

Ordovician graptolites are abundant in much of the turbidite and black shale facies of the Lachlan Fold Belt but are sparse in the shallow-water deposits and limestones. Early Ordovician graptolites have a rather limited distribution - being abundant only in the Bendigo-Ballarat structural belt and on Mornington Peninsula, both in central Victoria. They are exceedingly rare in the thick Lower Ordovician turbidite sequences of eastern Victoria (Tabberabbera, Omeo and Mallacoota structural belts, where the age is largely known from conodont faunas) and their continuation into New South Wales (Molong-South Coast Anticlinorial Zone). Late Ordovician graptolites have a much wider distribution. They are very abundant in the turbidite and black shale facies in central Victoria (Melbourne 'trough') and in the black shale facies in eastern Victoria (Buchan and Mallacoota structural belts). In southeastern New South Wales they occur almost exclusively to the east of the Wagga Anticlinorial Zone, for instance in the shallower-marine(?) andesite-derived sandstone and mudstones of the Parkes-Forbes-Orange region, and in the deep-marine black shale facies in the Goulburn, Cooma and Delegate regions.

Elsewhere in Australia, graptolites are very restricted in their occurrence. The Florentine Valley sequence in central Tasmania contains the Lancefieldian genera *Psigraptus* and *Clonograptus*, and *Didymograptus* and *Phyllograptus* at higher levels (Banks & Burrett, 1980; Rickards & Stait, 1984). A single specimen of *Loganograptus* is the only recorded Ordovician graptolite from the Mathinna beds in northeastern Tasmania. The Westfield Sandstone in southwestern Tasmania contains a few (unidentified) Late Ordovician diplograptaceans and *Glossograptus*, as well as basal Silurian graptolites (*Atavograptus*, '*Akidograptus*', '*Glyptograptus*' ex. gr. *persculptus*) (Baillie *et al.*, 1978).

A rather richer graptolite fauna (but still very sparse by Victorian standards) extending from the Lancefieldian (La2) into what is possibly the Chewtonian, occurs in a volcanic-sedimentary sequence in the Mount Windsor Subprovince of northeastern Queensland (Henderson, 1983).

The Canning Basin sequence in Western Australia contains reasonably diverse and often well-preserved graptolite faunas extending from the Lancefieldian to about the top of the Lower Ordovician. An interesting feature here is that the lower faunas (Bendigonian and Chewtonian) are entirely of the Pacific faunal province similar to those in Victoria, whereas the upper fauna from the Goldwyer Formation is largely of the Atlantic faunal province, but with several important Pacific elements (Legg, 1976). Although the detailed biostratigraphy is still to be worked out, this faunal association provides some grounds for correlation of the Llanvirnian *Didymograptus artus* Zone (= '*D. bifidus* Zone') of Wales, with probably a large portion of the Darriwilian of Victoria.

The Horn Valley Siltstone near King's Canyon in the Amadeus Basin (Northern Territory) contains a small fauna of graptolites including extensiform didymograptines, of Early Ordovician age (Bagas, 1988).

The Dullingari Group in the Warburton Basin contains very sparse, poorly preserved graptolites. The records are all unpublished, but have been cited in B. Cooper (1986). They consist of 'vague traces of graptolites... suggestive of a *Clonograptus*', from the Delhi Santos Pandieburra No. 1 well, identified by B. Daily, and 'biserial graptolites (Diplograptids)' and 'uniserial graptolites' from the Dulllingari No. 1 well, identified by Öpik and Jones. The inferred ages are Early Ordovician for the ?*Clonograptus*, and 'Middle' (i.e. Darriwilan?) to Late Ordovician for the others.

VICTORIAN GRAPTOLITE SEQUENCE

The Victorian sequence of graptolite zones (fig. 2) is the standard used in Australasia, and for the larger part is the most finely subdivided in the world. It is the result of a long and nearly continuous effort by graptolite workers, beginning with McCoy and Etheridge (1870's), and was given a solid biostratigraphic foundation by T.S. Hall (1895 to 1920). This first phase was followed by thorough taxonomic and biostratigraphic studies from the 1930's to the 1950's, with W.J. Harris as the principal author, working alone or together first with R.A. Keble and later with D.E. Thomas.

The third phase, which began in the 1970's and continues today, consists of follow-up studies concentrating on some particular problems, mainly of a taxonomic nature: in the Lancefieldian (R. Cooper & Stewart, 1979; Erdtmann & VandenBerg, 1985), in the Castlemainian and Yapeenian (R. Cooper, 1973; R. Cooper & McLaurin, 1974; McLaurin, 1976; R. Cooper & Ni, 1986), and at the Ordovician-Silurian boundary (VandenBerg *et al.*, 1984).

A revision of the entire Upper Ordovician biostratigraphic subdivision by VandenBerg is still in progress and is published only in summary form (VandenBerg, *in* Webby *et al.*, 1981; VandenBerg & Stewart, 1983; Cas & VandenBerg, 1988).

Systemic Subdivision

Cas & VandenBerg (1988) reverted to a two-part subdivision of the Ordovician into Lower and Upper, with the boundary placed at the base of the *Nemagraptus gracilis* Zone. This follows the two-part subdivision introduced by T.S. Hall and used up to the introduction of the Middle Ordovician in 1938 by Harris and Thomas. This new scheme was introduced to solve a purely local problem: it was intended to replace the Darriwilian, which differed so much from the 'old' Darriwilian of T.S. Hall that its continued use, it was felt by Harris & Thomas, was likely to lead to much confusion. Harris & Thomas themselves did not adhere to their own advice and in later publications used Darriwilian and Middle Ordovician as alternatives for the same interval.

However the Middle Ordovician, as used in Victoria, covers an interval which is quite different from anywhere else - indeed, there is no international agreement on the limits of the Middle Ordovician (Jaanusson, 1960). In view of this fact, the term is not used here and the Darriwilian is regarded as the uppermost stage of the Lower Ordovician. This does not entirely remove problems with different usages for the Lower, Middle and Upper Ordovician in different parts of the world (especially North America), but the boundary of the Lower and Upper Ordovician as used here, at the base of the *Nemagraptus gracilis* Zone, is likely to be a strong candidate for an internationally agreed subsystem boundary.

Victorian 'Stages' and Graptolite Zones

The terms series and stages are commonly used for the major Ordovician chronostratigraphic units in Victoria. This is however a misuse of the terms: the units are purely convenient groupings of graptolite zones and are divorced from the rocks which contain them. Definitions of the 'stage' boundaries are thus identical to the definitions of the zone boundaries at the stage limits.

Why this should be so is not easy to tell. When T.S. Hall (1899) introduced the first set of series, he gave them geographic names and almost certainly meant them to be used as series; the lack of precisely defined boundaries at that time was merely due to lack of good field information, which he no doubt intended to fill in later. The abstraction to pure biostratigraphic units seems to have happened gradually, and for several different reasons. One important probable reason is the fact that the entire graptolitic Lower Ordovician is a monotonous turbidite succession, with no distinctive lithology that can be traced for any distance. Another may have been the discovery that most of the 'series' occupied a fairly thin interval of rock, so that a more or less complete set of 'series' could be found in each district.

Whatever the process, it is clear that it had been completed by the time that Harris & Keble (1932) introduced the first revision of the zonal scheme. In their definition of the Lancefieldian, they stated: 'For the present we designate as L5 a bed not yet found in Australia, but which from analogy with the northern hemisphere may be expected to occur - a zone which would be characterised by *Dictyonema sociale* or a vicarious form'. The fact that this zone has not been located in Victoria is not relevant here - it is the philosophy behind their statement that clearly reveals the separation of the fossils from the rocks.

One consequence is that the 'stages' have no type sections. The lower three zones of the Lancefieldian have *strata typica*, but no other zone does. Harris & Keble (1932) did propose 'typical localities' for each zone, but these are of little practical use because firstly there was no supporting geographic or biostratigraphic documentation, and secondly no attempt was made to choose adjacent localities for adjacent zones - indeed, the opposite was the case.

At present, detailed sampling of stratigraphic sections has been carried out for the lower three zones of the Lancefieldian (La1, La1.5, La2), the Yapeenian, the lower Eastonian including the Gisbornian-Eastonian boundary; the Eastonian-Bolindian boundary, and the upper Bolindian. Detailed lithostratigraphic mapping of the Bendigo Goldfield has shown that the subdivision of the upper Lancefieldian to Yapeenian interval is quite workable although it may need some revision, especially in the Bendigonian zones. The Darriwilian and Gisbornian subdivisions are the least well known.

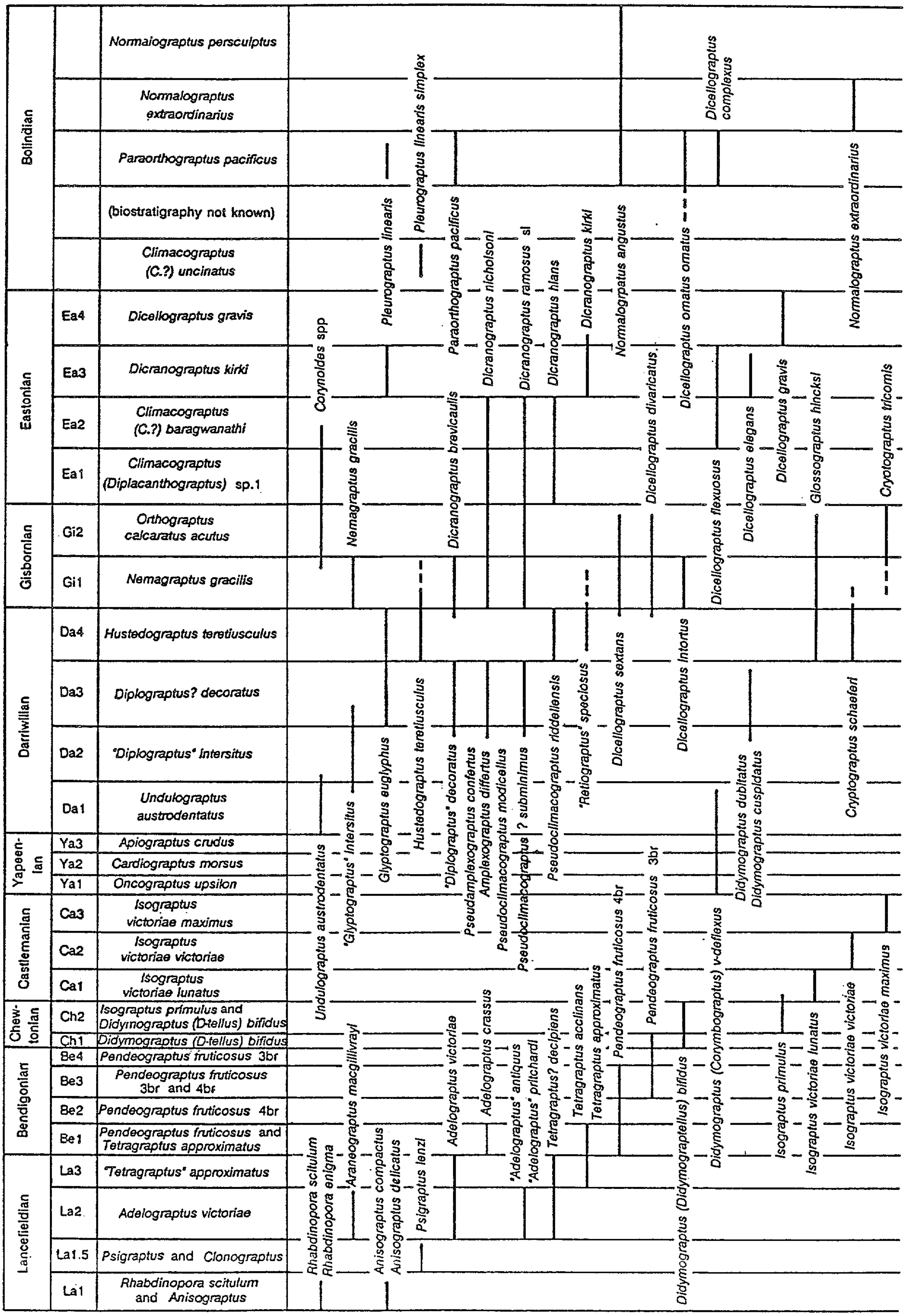

Figure 2. Stratigraphic Ranges of selected Ordovician graptolite species

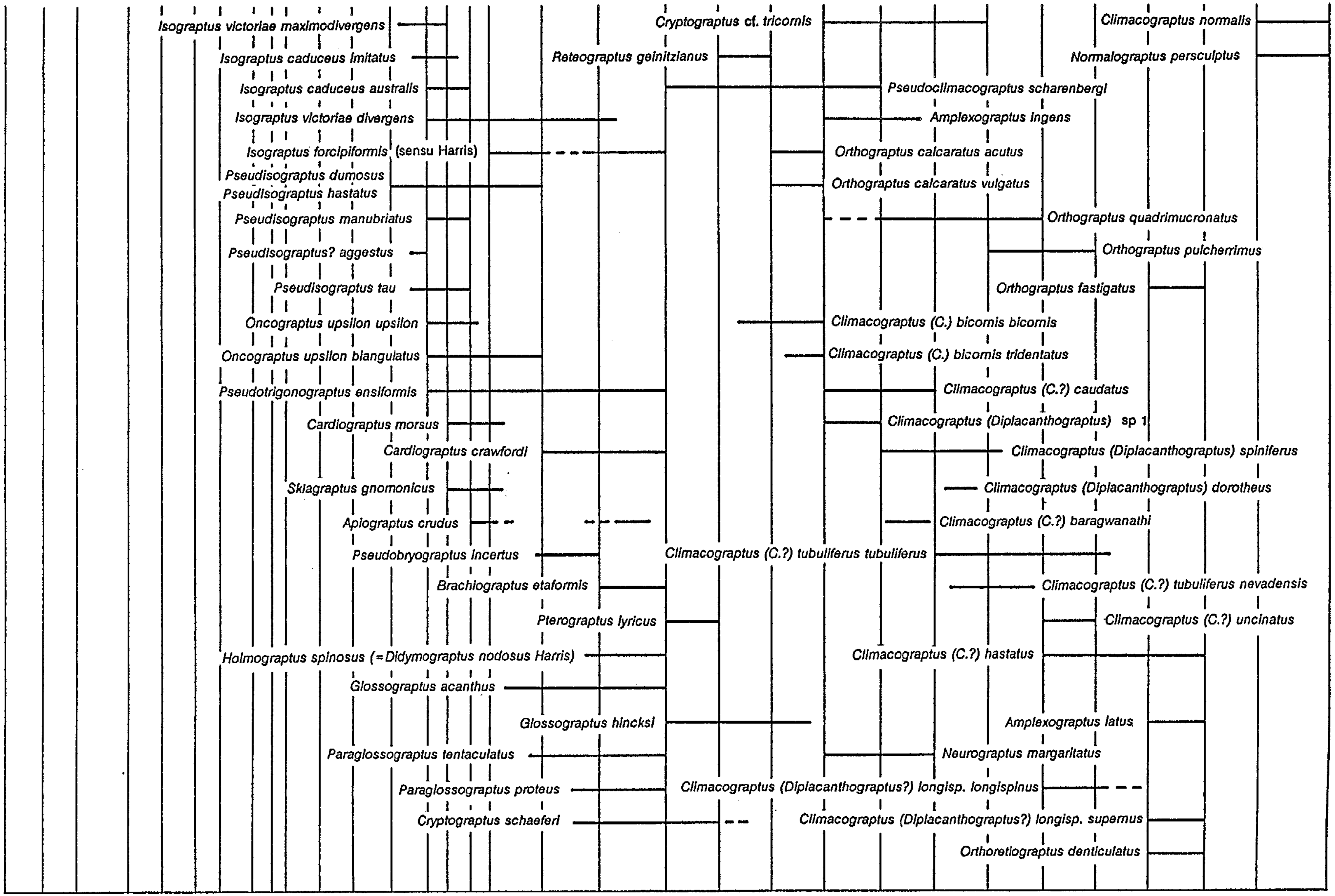

Figure 2. (continued from facing page)

Lancefieldian (La1-3): Faunas of this stage are dominated by anisograptids. The stage encompasses by far the longest time interval of any of the Victorian stages judging from the faunal changes and sedimentary thicknesses.

The lower two zones of the Lancefieldian contain only anisograptids. The La1 Zone of *Rhabdinopora scitulum* and *Anisograptus*, originally known as the Zone of *Dictyonema campanulatum*, *D. scitulum* and *Staurograptus diffissus* (Harris & Keble, 1932), was revised by R. Cooper & Stewart (1979). It is restricted to a band about 140 mm thick in the Stauro Gully Shale at Lancefield.

The La 1.5 Zone of *Psigraptus* was introduced by R. Cooper & Stewart (1979) for a newly discovered fauna at Lancefield, lying between the type localities of La1 and La2. The fauna is known from a single locality in the Bryo Gully Shale (Erdtmann & VandenBerg, 1985) and consists of *Psigraptus lenzi* Jackson, *Clonograptus* spp. and *Adelograptus* sp.

The La2 Zone of *Adelograptus victoriae* is distributed through a considerable stratigraphic thickness. It has a diverse fauna, consisting of *Adelograptus victoriae* (T.S. Hall), *A.* sp., *'Adelograptus' antiquus* (T.S. Hall), *Clonograptus* (3 species), *Araneograptus macgillivrayi* (T.S. Hall), together with the earliest dichograptids, *Temnograptus magnificus* Pritchard and perhaps *'Tetragraptus' decipiens* (T.S. Hall) (Figure 2).

In the La3 Zone of *Tetragraptus approximatus*, dichograptids have come to dominate the fauna. The zonal assemblage consists of *T. approximatus* Nicholson and *T. acclinans* Keble, and several species of *Didymograptus*, together with many La2 forms, including *Adelograptus victoriae*.

Bendigonian (Be1-4): This stage encompasses almost the full stratigraphic range of *Pendeograptus fruticosus*. The zonal boundaries of Be2, Be3 and Be4 are based on the different ranges of two common morphs of *P. fruticosus* (Hall). The fauna is dominated by dichograptids which occur in great abundance and variety. Sigmagraptids make their first appearance in the Bendigonian, with anisograptids forming a minor element.

Chewtonian (Ch1-2): The base of the Chewtonian is defined by the first appearance of *Didymograptus* (*Didymograptellus*) *bifidus* (Hall), and the appearance of *Isograptus victoriae* Harris marks the base of the overlying stage. *Didymograptus protobifidus* Elles, name giver to Zone Ch1 in previous publications, has recently been shown to be a junior synonym of *D. bifidus* (Hall) - see Williams & Stevens (1988). The zone name has accordingly been changed. The classic subdivision is based on the presence (in Zone Ch1) or absence (in Ch2) of *P. fruticosus* (Harris, 1916, 1933; Harris & Keble, 1932), but Cas & VandenBerg (1988) changed this for practical reasons, with the base of Ch2 being redefined by the appearance of *Isograptus primulus* Harris. This definition was suggested by Harris (1935) and, although not used by later workers, was placed on a firmer taxonomic and biostratigraphic footing by R. Cooper (1973). Chewtonian faunas consist mainly of dichograptids and sigmagraptids.

Castlemainian (Ca1-3): The base of the Castlemainian is defined the first appearance of *Isograptus victoriae lunatus* Harris, and the first appearance of *Oncograptus* marks the base of the overlying Yapeenian Stage. The Castlemainian is dominated by isograptids, and the subdivision into three zones uses the increase in size of *Isograptus victoriae*. The remainder of the fauna consists of dichograptids and sigmagraptids, with *Clonograptus* as the sole remaining anisograptid. *Pseudisograptus*, which may be the first glossograptid, appears in Ca3. A zonal subdivision was first introduced in an informal fashion by Harris (1933, 1935) and more formally by Thomas (1960). The zonation was considerably refined by R. Cooper (1973), on the basis of statistical population studies of *I. victoriae*.

Yapeenian (Ya1-3): The Yapeenian is defined as the interval between the first appearance of *Oncograptus* at the base, and first appearance of *Undulograptus austrodentatus* at the base of the overlying stage. Its fauna is dominated by various isograptid genera (*Isograptus*, *Oncograptus*, *Cardiograptus*, *Skiagraptus*), and glossograptids (*Pseudisograptus*, *Apiograptus*) with the remainder made up of dichograptids and a few sigmagraptids. The enigmatic genus *Pseudotrigonograptus* is also common.

Two zones are generally recognised in the Yapeenian: the Ya1 Zone of *Oncograptus* and Ya2 Zone of *Cardiograptus*. McLaurin (1976) proposed a third, the Ya3 Zone of *Apiograptus*, but its applicability beyond central Victoria has yet to be proven. *Apiograptus* may not be common enough to be used as a zonal index fossil.

Darriwilian (Da1-4): The base of the stage is defined by the first appearance of *Undulograptus austrodentatus* (Harris & Keble), and the base of the overlying Gisbornian Stage is marked by the first appearance of *Nemagraptus gracilis* (J. Hall). This latter definition is slightly different from that of VandenBerg (*in* Webby *et al.*,1981), which involved the appearance of *Dicellograptus* and *Dicranograptus*, but is more precise and easily identified. It also circumvents some difficulties in the Darriwilian which have arisen recently, including the level at which *Dicellograptus* first appears.

The Darriwilian marks the first appearance of the Diplograptacea. It has been the custom in the past to classify these species on the basis of characters which are no longer considered to be of phylogenetic importance. A new, more phylogenetically based scheme was introduced recently by Mitchell (1987) and is mostly followed here, but most of the Darriwilian Diplograptacea are too poorly preserved to determine their true generic status - in these cases, the original generic name will be used in quotation marks.

The Darriwilian is formally subdivided into four graptolite zones: the Da1 Zone of *Undulograptus austrodentatus*, Da2 Zone of *'Diplograptus' intersitus* Harris & Thomas, Da3 Zone of *Diplograptus? decoratus* (Harris & Thomas), and Da4 Zone of *Hustedograptus teretiusculus* (*sensu* Jaanusson). The lower of these three zones are well documented from a continuous succession (Harris, 1935), but the nature of Da4 and its relationship with Da3 are less clear.

Few isograptids persist into the Darriwilian, whereas glossograptids are an important element, represented by *Glossograptus, Paraglossograptus, Kalpinograptus ('Isograptus') ovatus* (T.S. Hall), and *Cryptograptus*. The stage also contains Victoria's only sinograptid, *Holmograptus spinosus* (Ruedemann) [*Didymograptus nodosus* of Harris].

Upper Ordovician: The subdivision of the Upper Ordovician differs in several important respects from that of the Lower Ordovician. No serious attempt at subdivision was made prior to the 1930's, by which time the British scheme had become widely used as a standard. As a result, the Victorian subdivision did not develop in an empirical fashion as had occurred with the Lower Ordovician, but was modelled on the British scheme of Elles & Wood (1914). Moreover, little attempt was made to map individual fossiliferous outcrops in order to establish faunal successions, but collected material was instead correlated directly with the British Zones.

Gisbornian (Gi1-2): The Gisbornian is defined as the interval between the first appearance of *Nemagraptus gracilis* (Hall) at the base, and the first appearance of *Climacograptus* (*Diplacanthograptus*) n.sp. A marking the base of the overlying Eastonian. The definition of the base is different to that used by VandenBerg (*in* Webby *et al.*, 1981), partly because the earlier definition is based on poor documentation, and also because the appearance of *N. gracilis* is an important correlation marker on a global scale, whereas the appearances of *Dicellograptus* and *Dicranograptus* are not (Finney & Bergström, 1987).

Problems with the subdivision of the Gisbornian used by Thomas (1960, modified from Thomas, 1935) were discussed by VandenBerg (*in* Webby *et al.*, 1981), who modified Thomas' zones into a lower Zone of *Nemagraptus gracilis*, and an upper zone without *Nemagraptus* but also without any zonal index species. Cas & VandenBerg (1988) used the group of *Orthograptus calcaratus* Lapworth, especially *O. calcaratus acutus* Elles & Wood (often mistaken for *Diplograptus? multidens* Ellis & Wood by Thomas), in identifying upper Gisbornian, and introduced the *O. calcaratus acutus* Zone for this interval. The *Climacograptus bicornis* group (*C.* (*C.*) *bicornis bicornis* and *C.* (*C.*) *bicornis tridentatus*) is very useful to identify Gisbornian rocks, being entirely restricted to the Gisbornian. However, there are numerous records of *Climacograptus bicornis* from younger rocks in south-eastern Australia, involving misidentification of other spinose forms, in most cases probably *C.* (*Diplacanthograptus*) *spiniferus* (Ruedemann).

Diplograptacea form the main component of Gisbornian faunas - they include dicranograptids, orthograptids, and diplograptids, and are accompanied by *Glossograptus*, *Corynoides*, *Cryptograptus*, *Reteograptus*, and a single surviving dichograptid, a robust species of *Didymograptus*.

Eastonian (Ea1-4): The first definitive subdivision of the Eastonian, by Thomas (1960), used two zones: a lower Zone of *Climacograptus baragwanathi*, and an upper Zone of *Dicranograptus hians*. VandenBerg (*in* Webby *et al.*, 1981) considered this to be unsatisfactory because *D. hians* T.S. Hall completely overlaps the stratigraphic range of *Climacograptus* (*C.*) *baragwanathi* T.S. Hall. He proposed a new subdivision, into four zones: Ea1 Zone of *Climacograptus spiniferus* n. subsp. (= *C.* (*Diplacanthograptus*) n.sp. A), Ea2 Zone of *Climacograptus* (*C.*) *baragwanathi* T.S. Hall, Ea3 Zone of *Dicranograptus kirki* Ruedemann and Ea4 Zone of *Dicellograptus gravis* Keble & Harris.

The base of the Eastonian has been sampled in some detail, and involves the appearance of the index *Climacograptus* (*D.*) n.sp. A, shortly after the disappearance of *C.* (*C.*) *bicornis* (VandenBerg, 1986). Several other distinctive early Eastonian species appear at about the same level: *Neurograptus margaritatus*, *Dicranograptus hians*, *Climacograptus* (*C.*) *caudatus*, *Orthograptus quadrimucronatus*, *Amplexograptus tardus* (T.S. Hall), and *Pseudoclimacograptus? affinis* (T.S. Hall). *Amplexograptus ingens* (T.S. Hall) makes its entry somewhat higher. The long-ranging *Pseudoclimacograptus scharenbergi scharenbergi* disappears within Ea1.

In Ea2, *Climacograptus* (*C.*) *baragwanathi* is quite uncommon, so that the base of the zone is better defined by the appearance of *Climacograptus* (*Diplacanthograptus*) *spiniferus*, which is very common. However *C.* (*D.*) *spiniferus* has a considerable stratigraphic range, surviving into Zone Ea4. There are a number of distinctive early Eastonian species, and some longer-ranging forms, which disappear at about the top of Ea2. These include *Corynoides* spp., *Dicranograptus hians*, *D. nicholsoni*, *D. ramosus spinifer*, *Neurograptus margaritatus*, *Climacograptus* (*C.*) *caudatus* and *Amplexograptus ingens*.

Zone Ea3 is distinguished by its index species, *D. kirki* Ruedemann (=*D. tealei* Harris & Thomas), a descendent of *D. hians* with twisted and usually coiled stipes. The zone also contains occasional specimens of *Pleurograptus linearis* (Carruthers), formerly the zone fossil for the early Bolindian. Also abundant in this zone are *Orthograptus quadrimucronatus*. *Leptograptus eastonensis* and *Climacograptus* (*C.*) *tubuliferus*, all of which persist into the early Bolindian. The zone is considered to correlate with the British *P. linearis* Zone.

The index for Ea4 is *Dicellograptus gravis* Keble & Harris originally poorly described but considered to be a senior synonym of *Dicellograptus alector* Carter. This species provides an important correlation link with the British zonation scheme, for it occurs with *Dicellograptus complanatus* Lapworth in a *complanatus* Zone assemblage at Myoch Bay, Scotland; in the past, the British *complanatus* Zone was correlated with a rather higher level in the Bolindian.

Diplograptids are the main components of Eastonian faunas (Fig. 2). They are accompanied by orthograptids, dicranograptids, *Cryptograptus*, and in the lower part by *Corynoides*.

Bolindian: The zonal numbering scheme (Bo1, Bo, Bo(u)) introduced by VandenBerg (1981) was intended to be provisional, awaiting further work on the interval immediately above Bo1. No further progress has been made on this interval. In view of the added late Bolindian zones, this provisional system is now too cumbersome to persist with. Rather than introduce another provisional numbering scheme, I elected to delete the numbering scheme and use the graptolite zone name for subdivision until such time as the entire interval has been studied.

The base of the Bolindian is defined by the appearance of *Climacograptus? uncinatus* Keble & Harris, as was proposed by VandenBerg (*in* Webby *et al.*, 1981). The top however is redefined (Cas & VandenBerg, 1988) to coincide with the Ordovician-Silurian boundary, which is defined as the base of the *Akidograptus acuminatus* Zone (VandenBerg, *in* Rickards *et al.*, 1984).

The original subdivision, into a lower Zone of *Pleurograptus linearis* and an upper Zone of *Dicellograptus* cf. *complanatus* (Thomas, 1935; Harris & Thomas, 1938; and Thomas 1960) was again clearly modelled on the British scheme. VandenBerg (*in* Webby *et al.*, 1981) considered both zones to be problematical, the first because of the rarity and long stratigraphic range (Ea3 to near top Bolindian) of P. *linearis*, the second because of uncertainty about the identity of Victorian specimens assigned to *D.* cf. *complanatus*. He therefore proposed a new subdivision: Bol Zone of *Climacograptus uncinatus*, Bo(m) - biostratigraphy unknown, and Bo(u) Zone of *Dicellograptus ornatus* and *Climacograptus latus*. Cas & VandenBerg (1988) made two changes to this scheme: renaming the Bo(u) Zone *Paraorthograptus pacificus*, for the sake of brevity, and the addition of two new zones, a lower Zone of '*Glyptograptus*' (now *Normalograptus*) *extraordinarius*, and an uppermost Bolindian Zone of *Glyptograptus*? (now *Normalograptus*) *persculptus*. The stratigraphy and fauna of these zones was documented by VandenBerg, *et al.* (1984).

Bolindian faunas are again dominated by diplograptids, with much less abundant dicranograptids (*Dicellograptus* and uncommon *Leptograptus* and *Pleurograptus*). Monograptids first appear in the highest Bolindian, represented by *Normalograptus* spp.

Correlation with the 'Standard' British subdivision

Correlation of the Victorian graptolite scheme with the 'standard' British subdivision has been difficult in the past, due to endemism of many British graptolites, including many of the zonal index species. In the Upper Ordovician there has been an additional problem of correlating the Scottish graptolite zones with the Welsh stages based on shelly fossils. This latter problem has been largely solved with the detailed correlation of the Scottish and Welsh sequences given in Whittington *et al.* (1984). The correlation presented here is based on that account.

Tremadoc: The very characteristic Tremadoc *Rhabdinopora* ('*Dictyonema*') *flabelliforme sensu lato* and associated trilobites, do not occur in the Victorian sequence (or, for that matter, anywhere in the Pacific faunal province). The Tremadoc Series is broadly correlated with a substantial portion of the Lancefieldian (La1-La2) on the basis of anisograptids (*Clonograptus* and *Adelograptus*), but more precise correlation, even of the limits of the Tremadoc Series, is not possible.

Arenig: The Arenig Series has traditionally been the most difficult interval to correlate with Victoria and other regions in the Pacific faunal province. The few species that are common to both are too long-ranging to be of much use. It has been traditional to place the base of the Arenig Series within the Bendigonian - in Victorian terms, the series thus occupies a considerable interval, including most, if not all of the Bendigonian, and the entire Chewtonian, Castlemainian and Yapeenian. The occurrence of '*Glyptograptus*' *austrodentatus anglicus* in highest (but not precisely zoned) Arenig strata in Britain (Bulman, 1963) suggests that the top of the Arenig lies within the Darriwilian, possibly within Da1 or Da2. Williams & Stevens (1988) recently reviewed the correlation of the Arenig with other sequences, and indicated that the upper Arenig *D. hirundo* Zone may be as high as Da2.

Llanvirn: The Llanvirn Series is characterised largely by the occurrence of 'tuning-fork' didymograptids (chiefly *D. artus*) which are unknown from the Pacific faunal province. Other Llanvirn species, such as *Glossograptus acanthus* and *G. ciliatus* are relatively long-ranging in the Darriwilian.

Llandeilo: Whittington *et al.* (1984) place the base of the Llandeilo Series within the *Glyptograptus teretiusculus* Biozone in Britain. Correlation with a level high in the Darriwilian is suggested - however, the upper Darriwilian '*Glyptograptus* (*Hustedograptus*) *teretiusculus* Zone' is very poorly documented. Any attempt at correlation must await further study of its fauna.

Caradoc: The base of the Caradoc has yet to be defined in its type region - according to Whittington *et al.* (1984), it lies either within or below the *Nemagraptus gracilis* Zone. On this basis, it correlates with a level within the upper Darriwilian and lower Gisbornian.

Ashgill: The problems of correlating the Caradoc-Ashgill boundary within the classic Scottish graptolite zones has been discussed at some length by Whittington *et al.* (1984). Most important for correlation with the Victorian scheme is the occurrence of *Dicellograptus gravis* in a *D. complanatus* Zone assemblage consisting of *Dicellograptus com-*

planatus, *D. minor*, *Orthograptus quadrimucronatus*, *O. pulcherrimus*, *O.* ex gr. *amplexicaulis*, and *Climacograptus tubuliferus* (identifications by A.H.M.V.) in the Upper Whitehouse Group at Myoch Bay near Girvan Scotland, from a level which Whittington *et al.* (1984) regard as Pusgillian. This assemblage is typical of Ea4 age (with the exception of *D. complanatus*, which is absent from Australia). Whittington *et al.* suggest that the base of the Ashgill lies within the *Pleurograptus linearis* Zone; in Victorian terms, this correlates with a level within the Ea3 Zone of *Dicranograptus kirki*.

CONODONTS (Robert S. Nicoll)

The earliest report of conodonts in Australia is that of Crespin in 1943 on a small fauna from the Ordovician Larapinta Group, probably the Horn Valley Siltstone, of the Amadeus Basin, Central Australia. This was followed by the mention of conodonts in the Ordovician Prices Creek Group (Emanuel Formation) of the Canning Basin by Guppy & Öpik (1950) and the later recognition of subsurface Ordovician sediments in the Canning Basin through the identification of conodonts by Glenister & Glenister (1958).

The next phase of conodont studies in Australia was also devoted to the Ordovician with reports by Jones (1961) and later by Druce & Jones (1968, 1971), and Jones (1971) on faunas from the Georgina, Daly River and Bonaparte Basins. The establishment by Druce & Jones (1971) of a series of six assemblage zones in the lowermost Ordovician of the Burke River Structural Belt (Georgina Basin) and a seventh zone added by Jones (1971) in the Bonaparte Basin still represents the only Australian Ordovician conodont biostratigraphic scheme supported by published data. The zonal scheme of McTavish & Legg (1976) for the Canning Basin has never had the supporting subsurface distribution data published.

Ordovician conodont faunas have now been described in publication from all Australian states and mainland territories (Figure 3, Appendix 1). The bulk of the papers describe small faunas from single localities or a few samples, but are important for the age control they provide in otherwise poorly dated sequences. Reflecting the relative abundance of Lower, compared with Upper, Ordovician rocks, most of the described faunas have been of Early Ordovician age.

Conodont workers (Bergström, 1973; Sweet & Bergström, 1974) have recognised two major conodont biofacies. One, the North American Midcontinent Province (NAMCP) fauna, is found predominantly in shallow and warmer waters of the cratonic basins and shelf margins, especially those located in equatorial areas. The second, the North Atlantic Province (NATP) fauna, is found in sediments associated with the deeper or cooler waters of the shelf margins and higher latitudes. More recently Sweet & Bergström (1984) have recognised that in terms of the world-wide distribution the province names were not entirely appropriate and have used the informal terms warm- and cold- water pelagic faunas. Miller (1984) used the terms warm and cold faunal realm (WFR & CFR) and these terms will be used here.

In Australia conodont faunas from the cratonic basins (Canning, Bonaparte, Amadeus and Georgina Basins) are all indicative of the WFR, as are most of the conodont faunas found in Tasmania, western New South Wales and Queensland (Fig. 3). Conodont faunas from Victoria and eastern New South Wales are more often associated with the CFR. Following Sweet & Bergström (1974) the genera *Oulodus*, *Plectodina*, *Phragmodus* and *Belodina* are indicative of the warm-water faunal realm and the genera *Eoplacognathus*, *Pygodus*, *Prioniodus* and *Periodon* are indicative of the cold-water faunal realm. The presence of these genera have been used to assign Australian faunas to one of the two faunal realms.

Bergström (1971) has indicated that some Australian conodont faunas did not closely correspond to either the NAMCP (WFR) or NATP (CFR), and might represent a distinctive Australian province. There is no strong evidence yet that such a province does exist. However there may be some indications that an Australasian or Gondwanan province may have existed in the early Ordovician. For example, the genus *Serratognathus* is now found in China, Korea and Australia (Canning and Arafura Basins). Many other forms are found in common at the species level in the three countries. Until detailed studies of more of the Australian faunas have been published the extent and nature of such a province would be difficult to define.

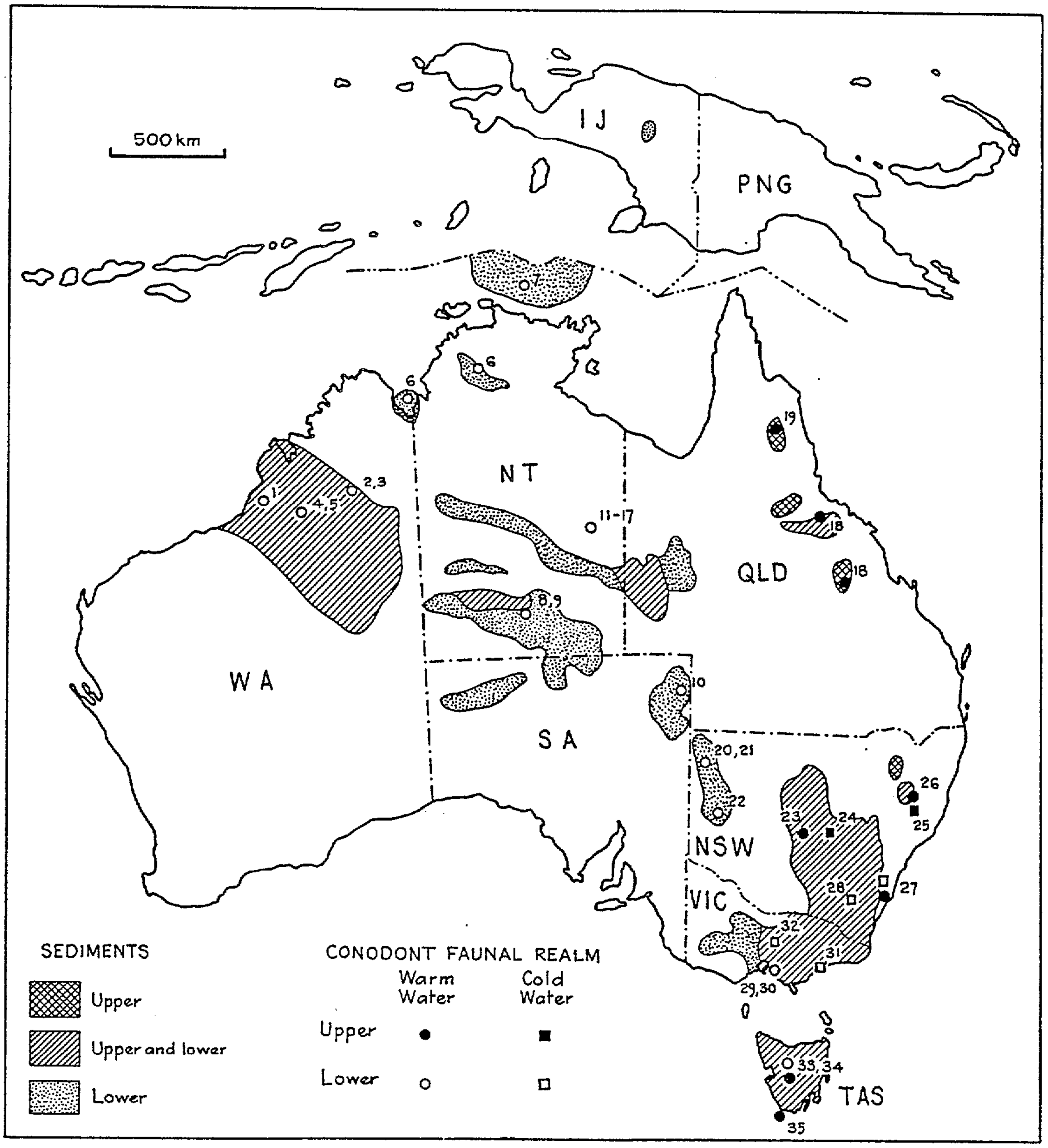

Figure 3. Location of studies of Ordovician conodont faunas in Australia and an indication of the faunal realm represented. Numbers refer to the list in Appendix 1.

Preliminary analysis of conodont faunas in the Amadeus, Canning and Georgina Basins does indicate that there is a gradation from shallow water near shore faunas to deeper water offshore faunas. In the Pacoota Sandstone of the Amadeus Basin the clastic sequence is dominated by coniform elements, especially *Drepanodus*, but in the laterally equivalent deeper water carbonate-shale lithofacies of the Emanuel Formation, of the Canning Basin the fauna is dominated by ramiform species.

TRILOBITES (John R. Laurie & J. H. Shergold)

Trilobites are relatively common throughout most of the Ordovician sequences of Australia, with the notable exception of the graptolitic facies in Victoria and south-eastern New South Wales.

Trilobites were first described from the Australian Ordovician in Tasmania (Etheridge, 1883, 1904) and central Australia (Etheridge, 1893; Tate, 1896). It was much later that further work was done on isolated faunules from Tasmania (Kobayashi, 1940a, b). Three more decades elapsed before any more work was published on Ordovician trilobites from New South Wales (Campbell & Durham, 1970; Webby, 1971; 1973; 1974; Webby, Moors & McLean, 1970; Webby, Wang & Mills, 1988), Queensland and the Northern Territory (Tomlinson *in* Hill, Playford & Woods, 1969; Shergold, 1975; Henderson, 1983; Fortey & Shergold, 1984; Shergold, in press; Laurie, in prep.), Western Australia (Legg, 1976; 1978), Tasmania (Stait & Laurie, 1980; Burrett, Stait & Laurie, 1983, Jell & Stait, 1985a, b) and Victoria (Jell, 1985) (see Appendix 2).

No comprehensive biostratigraphic scheme for Ordovician trilobite faunas has been erected in this country, however, local assemblage successions and zonations have been used by several workers. Webby (1974) recognised four stratigraphically distinct Upper Ordovician trilobite faunules from central New South Wales. Legg (1978) erected a sequence of combined trilobite-graptolite faunas for part of the Lower Ordovician of the Canning Basin. Stait & Laurie (1980) used trilobites (later described by Jell & Stait, 1985) and brachiopods to define a sequence of seven assemblages for the Lower Ordovician Florentine Valley Formation in south-central Tasmania. Their scheme was later incorporated in the preliminary biostratigraphic subdivision of the Tasmania Ordovician by Banks & Burrett (1980). More recently, successions of trilobite assemblages have been recognised in the Lower Ordovician sequences of the Amadeus (Shergold, in press; Laurie, in prep.) and Georgina Basins (Fortey & Shergold, 1984).

BRACHIOPODS (John R. Laurie)

Brachiopods are widespread in the Ordovician shallow water sequences of central and northern Tasmania and in the deeper water successions of southernmost Tasmania and central New South Wales. They also form a ubiquitous but only occasionally dominant portion of the faunas of the central and northern Australia basinal sequences. Apart from some shell debris contained in turbidites, and occasional phosphatic brachiopods in siliceous siltstones, they are absent from the thick turbidite and black shale sequences of Victoria and southeast New South Wales.

First noted and described in papers dealing predominanently with trilobite faunas (e.g., Etheridge, 1893; 1904; Kobayashi, 1940) it is only more recently that they have been the major topic of publications in their own right (Brown, 1948; Percival, 1978; 1979a; 1979b; Laurie, 1980; 1987a; 1987b).

Apart from a short paper dealing with trilobite and brachiopod biostratigraphy of a single formation in central Tasmania (Stait & Laurie, 1980) no brachiopod biostratigraphic scheme has been published although Laurie (in prep.; unpublished Ph.D. thesis) has proposed a zonal scheme for the shallow water predominantly carbonate succession of Tasmania. Percival (1978; 1979a; 1979b unpublished Ph.D. thesis) has related the brachiopod faunas from the central New South Wales sequence to the coral-stromatoporoid biostratigraphic sequence of Webby (1969; 1972; 1975).

Publications where brachiopods are described or listed are to be found in appendix 3.

MOLLUSCS (J.H. Shergold)

Relatively few Ordovician molluscan faunas have been described from Australia. Nautiloids, rostroconchs and pelecypods have received the bulk of the attention, and some data of biostratigraphic significance is plotted on the chart. Little is known about the detailed stratigraphic distribution of the monoplacophorans, polyplacophorans and gastropods which are recorded, but rarely described, in many Australian publications. (Tate, 1896; Hill *et al.*, 1969; Gilbert-Tomlinson, 1973; Runnegar *et al.*, 1979; Jell *et al.*, 1984)

NAUTILOID FAUNAS (Bryan Stait)

Although nautiloids are known from most of the Ordovician platform and slope sequences in Australia, definition of a formal biostratigraphic zonation is currently impossible. The main problem is the rarity of specimens which does not allow ranges for individual species, and in most cases genera, to be established. This lack of detailed information means that the nautiloids do not provide the contribution to Ordovician biostratigraphy that their rapid evolution in the Lower Ordovician would otherwise allow.

Ordovician nautiloid faunas have been described from Tasmania, central New South Wales, western New South Wales, Georgina Basin, Amadeus Basin and Canning Basin. Extremely rare specimens have also been described from the deep-water sequences of Victoria. Unfortunately the collecting localities are often not accurately known and cannot be reliably slotted into subsequent biostratigraphic frameworks.

The Ninmaroo Formation, Georgina Basin, contains an Upper Cambrian fauna very similar to that of North China. This fauna contains the typical genera *Protactinoceras*, *Acaroceras* and *Plectronoceras*. Higher in the Ninmaroo Formation the oldest Ordovician nautiloids yet recorded from Australia occur, including *Ellesmeroceras*, *Muriceras*, *Quebecoceras*, *Ectenolites* and *Clarkoceras*. The Canning Basin faunas begin in the Middle Canadian, Emanuel Formation, with *Kyminoceras*, *Eothinoceras* and *Anthoceras*. The Upper Canadian faunas are possibly the most widespread in the Australian Ordovician. In Tasmania this is the oldest assemblage containing *Manchuroceras*, *Piloceras*, *Yehioceras*, *Alloctoceras* and *Pycnoceras*. A fauna of similar age in the Georgina Basin not only contains endocerids such as *Manchuroceras*, but also has the oldest known actinocerid faunas, including *Actinoceras*, *Georgina* and *Armenoceras*. Equivalent faunas of the Canning Basin include *Hardmanoceras*, *Aethinoceras*, *Thylacoceras* and *Notocycloceras*. The oldest identifiable nautiloids from the Amadeus Basin are Upper Canadian to Whiterockian faunas of the Horn Valley Formation. Some genera, such as *Ventrolobendoceras* and *Anthoceras*, also occur in the Canning Basin faunas while others, such as *Madiganella* and *Bathmoceras*, are not known elsewhere in Australia. *Anthoceras* is widespread in the Upper Canadian with *A decorum* occurring in the Canning Basin and Amadeus Basin, and *A. arrowsmithense* known from western New South Wales and possibly the Georgina Basin.

The next, Whiterockian, fauna represents the great expansion of the actinocerids in Australia. In Tasmania it is characterised by the *Wutinoceras-Adamscoceras* assemblage of the Karmberg Limestone and equivalents. Coeval faunas of the Georgina Basin contain *Georgina*, *Armenoceras*, *Wutinoceras* and *Williamoceras*. In the Amadeus Basin the Stairway Sandstone contains *Armenoceras* and *Georgina*, Faunas of this age have not been described from the Canning Basin although rocks of appropriate age and lithology exist. Further study should locate cephalopods in these sequences. Above this level no nautiloid faunas are known from the northern Australian basins (Georgina, Canning and Amadeus Basins).

Throughout the remainder of the Ordovician, the only faunas known are those from the platformal sequences of Tasmania and the Island-arc of central New South Wales. Although these faunas are contemperaneous they contain only one genus in common - the nearly cosmopolitan *Gorbyoceras*. In Tasmania nautiloid sequences above the Whiterockian are dominated by the Gouldoceratidae and have been divided into four assemblages. These assemblages are not formal biostratigraphic units and are only intended as convenient groupings of broadly coexisting faunas useful when describing the Tasmanian sequences. These assemblages, in ascending order, are: *Discoceras - Gorbyoceras* assemblage; *Tasmanoceras - Hectoceras - Gouldoceras* assemblage; *Gordonoceras* assemblage; and *Westfieldoceras* assemblage.

These assemblages are difficult to correlate outside Tasmania due to the preponderance of endemic, as well as long ranging and widespread genera. However reasonable correlations can be made using the coexisting conodont faunas.

The central New South Wales faunas contain endemic and cosmopolitan genera, possibly reflecting the small area and isolation of these island-arc carbonate platforms. The value of these faunas for biostratigraphy is extremely limited.

ROSTROCONCHS (J.H. Shergold)

It is now known that the 'pecular bivalves' illustrated by Etheridge in 1883 (p. 158, Pl. 2, figs 15a,b) from the Caroline Creek Sandstone (northwestern Tasmania), now referred to *Tolmachovia corbetti* by Pojeta & Gilbert-Tomlinson (1977, p.32), was the first rostroconch mollusc to be described in

Australia. A second, described as *Conocardium* sp. indet. by Tate (1896, p. 110, Pl. 2, Fig. 13) from what is probably the Stokes Siltstone of the Amadeus Basin, is a rostroconch belonging to the Superfamily Conocardiacea (Pojeta & Gilbert-Tomlinson, 1977). Eighty years later, Pojeta & Runnegar (1976, p. 62, Pl. 14, Figs. 9-19) described *Tolmachovia? jelli* from the top of the Ninmaroo Formation in the Georgina Basin. This is now refered to the genus *Pauropegma* by Pojeta *et al.* (1977) (see chart) who monographed the Cambrian and Ordovician rostroconchs of the Amadeus and Georgina Basins. Ordovician species named in this publication (Appendix 5) are plotted stratigraphically on the chart. Occurrences in the Ninmaroo Formation of the Georgina Basin were correlated to the early Ordovician conodont biostratigraphy by Druce *et al.* (1982, range chart, fig. 4), and these are shown here. Occurrences in the Amadeus Basin are less readily assessed in the absence of conodont control. They are plotted against the trilobite stratigraphy established by Shergold (in press) and Laurie (in prep.).

PELECYPODS (J.H. Shergold)

Ordovician pelecypod molluscs were first described from Tasmania by Johnston (1888), and subsequently from the Amadeus Basin by Etheridge (1894) and Tate (1896). Hill *et el.* (1969) illustrated pelecypods, mostly under open nomenclature, from the Toko Range, Georgina Basin. Subsequently, all known Australian Ordovician pelecypods were systematically described for the first time by Pojeta & Gilbert-Tomlinson (1977). The ranges established by these authors lack a detailed chronological control and are listed essentially by formations. Mostly, they are from the Pacoota Sandstone, Stairway Sandstone and Stokes Siltstone of the Amadeus Basin and correlative Nora Formation and Carlo Sandstone of the Georgina Basin. Other material, described from the Gordon Limestone of Tasmania by Pojeta & Gilbert-Tomlinson (1977), is not included on the chart because of the difficulty in locating it biostratigraphically (Appendix 4).

CORALS, STROMATOPOROIDS & SPONGES (B. D. Webby)

Ordovician corals and stromatoporoids are mainly distributed through the shallow-water carbonate successions of the Tasmanian Shelf (at the margin of Gondwana) and offshore settings of the Molong High and Parkes Platform (volcanic 'island-arc' remnants) of central New South Wales. There are also more localised occurrences in the Tamworth Terrane of north-eastern New South Wales, and from the flanks of the Anakie High and the Broken River Embayment of central and northern Queensland (Webby 1985; 1987; Webby *et al.*, 1981; Strusz *et al.*, 1988).

Little was known about Australian Ordovician sponges until recently. Most of the early discoveries were of discrete siliceous spicules. For example, there were species of *Protospongia* and other doubtfully assigned forms from Lower Ordovician 'deeper water' sequences of Victoria (Hall, 1888; 1889) and *Hyalostelia australis* Etheridge 1916 from the Stairway Sandstone of the Amadeus Basin, central Australia (Pickett 1983; Shergold 1986). However, the first calcareous sponges were recognised more recently as occurring in the Upper Ordovician 'shallow-water' successions of the Molong High and Parkes Platform, and these comprise the sphinctozoans *Cliefdenella* Webby 1969, first described as a stromatoporoid, and the genera *Angullongia* and *Belubulaia* (Webby & Rigby 1985). More remarkable are the beautifully preserved siliceous sponges described by Rigby & Webby (1988) from 'deeper water', allochthonous limestone blocks in the basinal, graptolitic Malongulli Formation of central New South Wales. They include most varied associations of demosponges(35 species), hexactinellids (8 species), and silicified? sphinctozoans (2 species). Apart from the sphinctozoans, they are thought to have lived in a deeper slope habitat on the flanks of the offshore island shelf (Molong High).

Only the corals and stromatoporoids have been employed in biostratigraphical work, mainly for local use in correlating limestones of the Parkes Platform and Molong High in central New South Wales (Webby 1969; 1975; Webby *et al.*, 1981; Strusz *et al.*, 1988). The four biostratigraphically distinct faunas (I-IV) range through the Upper Ordovician (upper Gisbornian-middle Bolindian). Only occurrences of *Stromatocerium* and *Foerstephyllum* from the lower part of the Billabong Creek Limestone of the Parkes Platform (Pickett 1985) apparently came from an earlier (?middle Gisbornian) horizon. Pickett has reported the North Atlantic conodont index *Pygodus anserinus* from the underlying beds (i.e., from beds of early Gisbornian *Nemagraptus gracilis* Zone age). The Fauna I assemblage is of late Gisbornian-early Eastonian age, and is typified by abundant labechiid stromatoporoids (notably *Cystistroma*. *Labechiella* and *Stratodictyon*), a varied tabulate component including many species of *Tetradium* and appearance of the rugosan *Hillophyllum*. It is best represented in the Fossil Hill Limestone of the Cliefden Caves area, eastern side of the Molong High.

Fauna II is of middle Eastonian age and is characterised by the first appearances of clathrodictyid stromatoporoids (*Clathrodictyon* and *Ecclimadictyon*), the sphinctozoan *Cliefdenella*, and rugosan *Palaeophyllum* and a most varied and abundant assemblage of heliolitine corals. It is well developed in the upper part of the Belabula Limestone and in the Vandon Limestone at Cliefden Caves, and in the Quondong Limestone at Bowan Park (to the eastern and western sides of the Molong High, respectively).

Fauna III may be subdivided into IIIa and IIIb depending on certain specific faunal elements (Webby *et al.*, 1981, p.9), but may alternatively be viewed as an undifferentiated assemblage of broadly late Eastonian-earliest Bolindian age. It is typified by first appearances of streptelasmatinid rugosans, *Favistina*, halysitines and favositids. It is best represented in the upper parts of carbonate sequences of the western (Bowan Park) side of the Molong High and also occurs in shallow-water limestone blocks of the breccia deposits in the graptolitic Malongulli Formation of the eastern (Cliefden Caves) side of the Molong High.

The latest assemblage, Fauna IV, is of about middle Bolindian age, and has a restricted distribution at the top of the Malachi's Hill Beds in the Bowan Park area. It is characterised by its rich rugosan element (*Bowanophyllum*, *Rhabdelasma* and *Cyathophylloides*) and tabulates (abundant favositids, the first agetolitids, *Catenipora* and *Adaverina*).

Taxonomic descriptions and discussion of the biogeographic significance of the Ordovician corals, stromatoporoids and sponges in the offshore island shelf and slope associations of central New South Wales are included in the following papers:

Stromatoporoids: Etheridge 1895; Webby 1969; 1971a; Webby & Morris 1976; Pickett 1970; Lin & Webby 1989.

Corals: Etheridge 1909; Hill 1957; McLean & Webby 1976; Webby 1971b; 1972; 1977; 1988; Webby & Kruse 1984; Webby & Semeniuk 1969; 1971; Lin & Webby 1989.

Sponges: Webby 1969; 1986; Webby & Morris 1976; Webby & Rigby 1985; Rigby & Webby 1988.

General biogeography: Webby 1985; 1987.

In Tasmania elements of a pre-*Tasmanognathus* (?late Darriwilian or North American Chazyan) age assemblage of stromatoporoids (*Labechia* aff. *prima*, *Stratodictyon vetus* and *Stromatocerium bigsbyi*) occur in the Cashions Creek Limestone of the Florentine Valley and the Standard Hill Formation of the Mole Creek area (Webby 1979; Banks & Burrett 1980; Burrett & Goede 1987), a part of the Tasmanian OT10 assemblage of Banks & Burrett (1980), and immediately prior to the first appearances of corals. However the precise stratigraphic relationship between the Florentine Valley and Mole Creek sections is unclear because Burrett & Goede (1987, Table I) have shown the Standard Hill Formation at Mole Creek correlating with the Karmberg Limestone of the Florentine Valley, that is, to a level beneath the Cashions Creek Limestone. Pickett's (1985) association of *Stromatocerium* and *Foerstephyllum* from the Billabong Creek Limestone of central New South Wales is probably younger than the Tasmanian OT10 assemblage because it includes coral *Foerstephyllum* which first appears with conodont *Tasmanognathus* and other corals like *Lichenaria* and *Tetradium* (numerous species) in the Lower Limestone Member of the Benjamin Limestone, that is, through the interval of assemblages OT12-14 (Burrett 1979; Banks & Burrett 1980; Corbett & Banks, 1973). The *Thamnobeatricea-Tetradium- Lichenaria-Foerstephyllum* assemblages of the Lower Limestone Member of the Benjamin Limestone and equivalents in Tasmania broadly correlate with the Fauna I associations of central New South Wales.

The lower part of the Upper Limestone Member of the Benjamin Limestone exhibits an association of *Palaeophyllum*, *Bajgolia*, *Eofletcheria* and various heliolitines which characterise the OT16 assemblages, and this equates with the New South Wales Fauna II association. Towards the top of the Upper Limestone Member, a rich and varied assemblage (OT19) occurs. It includes a large *Aulacera* and the first clathrodictyids, *Favistina*, favositids and halysitines. This correlates with the central New South Wales Fauna III assemblages of late Eastonian-earliest Bolindian age.

Taxonomic descriptions of the Tasmanian coral and stromatoporoid faunas are so far limited to the contributions of Hill (1942; 1955), Webby & Banks (1976), and Webby (1979).

The isolated Tamworth Terrane remnants in north-eastern New South Wales have similar Fauna III-type coral assemblages (Hall 1975; Webby in press). They include a varied fauna comprising *Favistina*, *Palaeophyllum*, *Cyathophylloides*, *Crenulites*, *Calopoecia*, haylsitines, heliolitines and favositids. The Fork Lagoons Beds of the Emerald area, on the south-east flanks of the Anakie High in central Queensland (Anderson & Palmieri, 1977) have an undescribed coral fauna which may be of similar age.

Occurrences of *Agetolites*, *Catenipora* and *Plasmoporella* have been recorded from the Carriers Well Limestone of the Broken River Embayment in northern Queensland (Hill *et al.*, 1969), and may, on the basis of the presence of agetolitids, represent a younger? middle Bolindian (Fauna IV) age.

TASMANIAN 'OT' ZONES

(Bryan Stait)

Banks and Burrett (1980) subdivided the Tasmanian Ordovician sequences into 20 zones, labelled OT1 to OT20. This zonation was an extension of the nine informal zones established by Stait and Laurie (1980) for the Lower Ordovician clastics of the Florentine Valley Formation. Although the OT zones are established using co-occurring faunas they are not rigorously defined using the total ranges of the constituent species. Therefore, they are only of very limited use in describing the Tasmanian biostratigraphy in general and can have no formal biostratigraphic significance. Once the ranges of the faunas of Tasmania are well established and documented there will be a good case for the establishment of a zonation like the OT zones which may even prove useful standard for the shallow-water shelly facies of Australia.

PALYNOMORPHS (Geoffrey Playford)

Published occurrences of Australian Ordovician palynofloras, specificially of acritarchs and chitinozoans, are restricted to unweathered and essentially unmetamorphosed marine sedimentary rocks obtained through exploratory drilling in the cratonic Canning and Georgina Basins. Consequently, the biostratigraphic potential of palynomorphs in the Australian Ordovician has yet to be adequately explored, and may well remain so due to the scarcity of suitably palyniferous strata.

Moderately diverse and fairly well preserved acritarch assemblages were described by Combaz & Peniguel (1972) and Playford & Martin (1984) from portions of the Canning Basin's Lower Ordovician sequence, especially the Goldwyer and Nita Formations (probably late Arenig-Llanvirn). In the first-mentioned work, chitinozoans were also reported. Playford & Wicander (1988) detailed a profuse acritarch flora from the early-mid Arenig Coolibah Formation of the Georgina Basin. As noted by Playford and his coauthors, these Early Ordovician acritarch assemblages appear to be largely endemic. Chitinozoans described by Playford & Miller (1988) from the Coolibah and basal Nora Formations in the Georgina Basin bear some similarities, in terms of their general morphological simplicity, with forms recorded from Arenig deposits in Spitsbergen and Quebec.

BIOSTRATIGRAPHIC CHART

(Robert S. Nicoll)

The chart summarizes our current understanding of the biostratigraphic relationships of the various major faunal groups used in the bio-zonation of Ordovician sediments in Australia. We have chosen the base of the *Hirsutodontus simplex* Zone (Nicoll, in press; Miller, 1988) as the base of the Ordovician in this edition of the chart. We acknowledge that there is some pressure to utilise the base of the *Cordylodus proavus*

Zone to define the systemic boundary, and that a case can also be made for the younger *Cordylodus lindstromi* Zone. The intermediate *Hirsutodontus simplex* Zone is used here however until a final decision is made on the boundary level by the IUGS-ISC Working Group on the Cambrian-Ordovician Boundary (Norford, 1988).

Not all of the information on the chart has been fully documented in publication, but most of the unpublished data are available in reports or manuscripts in press. For some of the groups an appendix gives expanded information about the range and distribution of individual taxa.

The time scale on the left margin of the chart is included as a best available estimate of geochronologic relationships of the faunas detailed. Reliable radiometric dates in the Ordovician are scarce worldwide and almost nonexistant in Australia.

The column on the graptolite zonation of the Canadian Cordillera is based on Larson & Jackson (1966), Lenz & Chen (1985), Lenz & Jackson (1986) and Lenz (1988). The graptolite zonation of northeastern North America is based on Riva (1974), Rickards & Riva (1981) and Williams & Stevens (1988).

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APPENDIX 1. AUSTRALIAN ORDOVICIAN CONODONTS

The following is a list of all of the studies of the Ordovician in Australia that have had either their primary focus on conodonts, or which have used conodonts as a major biostratigraphic tool. For each entry the number refers to a location of the study plotted on figure 3. The basin and stratigraphic units studied, along with their approximate age and nature of the fauna, whether it represents the warm (WFR) or cold (CFR) faunal realm, are indicated.

1.	Glenister, B.F. & Glenister, A.T., 1958 Canning Basin, biostratigraphy	Arenig	WFR
2.	McTavish, R.A., 1961 (unpub) Canning Basin, Prices Creek Group	Arenig	WFR
3.	McTavish, R.A., 1973 Canning Basin, Emanuel Formation	Arenig	WFR
4.	McTavish, R.A. & Legg, D.P., 1974 Canning Basin, biostratigraphy	Arenig-Llanvirn	WFR
5.	Watson, S.T., 1988 Canning Basin, Goldwyer & Nita Fms.	Llanvirn	WFR
6.	Jones, P.J., 1971 Bonaparte Basin, Clark Sst. (C), Pander Greensand Daly River Basin, Jinduckin Fm. (C), Oolloo Lst.	Tremadoc-Arenig Tremadoc-Arenig	?WFR ?WFR
7.	Bischoff, G.C.O. & Nicoll, R.S., in prep. Arafura Basin, unnamed unit	Arenig	WFR
8.	Crespin, I., 1943 Amadeus Basin, ?Horn Valley Siltstone	Arenig	WFR
9.	Cooper, B.J., 1981 Amadeus Basin, Horn Valley Siltstone	Arenig	WFR
10.	Cooper, B.J., 1986 Warburton Basin, 'Innamincka Red-Beds'	Arenig	?
11.	Jones, P.J., 1961 Georgina Basin, note		
12.	Druce, E.C. & Jones, P.J., 1968 Georgina Basin, biostratigraphic note		
13.	Druce, E.C. & Jones, P.J., 1971 Georgina Basin, Chatsworth Lst. (C), Gola Beds (C) Ninmaroo Fm.	Tremadoc	WFR
14.	Druce, E.C., 1978 Georgina Basin, *Clavohamulus*	Tremadoc	WFR
15.	Druce, E.C., Shergold, J.H. & Radke, B.M., 1982 Georgina Basin, biostratigraphy	Cambrian-Tremadoc	WFR
16.	Nieper, C.M., 1969 Georgina Basin, taxonomy		
17.	Nieper, C.M., 1970 Georgina Basin, Nora Fm.	Arenig-Llanvirn	WFR

18.	Palmieri, V., 1978		
	Anakie High, Fork Lagoons Beds	Ashgill	WFR
	Broken River Embayment, Carriers Well Ls.	Ashgill	WFR
19.	Nicoll, R.S., 1988		
	north Qld., Mulgrave Fm.	Ashgill	WFR
20.	Warris, B.J., 1967		
	northwestern N.S.W., Tabita Fm.	Arenig	WFR
21.	Kennedy, D.J., 1975		
	northwestern N.S.W., Tabita Fm.	Arenig	WFR
22.	Kruse, P. & Webby, B.D., 1986		
	western N.S.W., unpubl. data, Dolo Hills	?Cambrian-Tremadoc	?
23.	Packham, G.H., 1967		
	central N.S.W., Billabong Creek Lst.	Caradoc	WFR
24.	Pickett, J., 1978		
	central N.S.W., Sofala Volcanics	Llandeilo-Caradoc	WFR
25.	Cawood, P.A., 1976		
	northern N.S.W., Drik-Drik Fm.	Llanvirn-Caradoc	CFR
26.	Philip, G.M., 1966		
	northern N.S.W., Trelawney Beds	Caradoc	WFR
27.	Whalan, G.A., 1986		
	east-central N.S.W., 'Jocks Creek' Formation	Llanvirn	CFR
	Bubalahla Formation	Caradoc-Ashgill	WFR
28.	Nicoll, R.S., 1980		
	A.C.T., Pittman Fm.	Llanvirn-Llandeilo	CFR
29.	Kennedy, D.J., 1971		
	Victoria, Digger Island Lst.	Tremadoc	?
30.	Jell, P.A., 1985		
	Victoria, Digger Island Lst.	Tremadoc	?
31.	Stewart, I.R. & Fergusson, C.L., 1988		
	eastern Victoria, Hotham Group	Tremadoc-Llandeilo	CFR
32.	Stewart, I.R. in Cas & VandenBerg, 1988		
	Victoria, biostratigraphy	Tremadoc-Llandeilo	CFR
33.	Banks M.R., & Burrett, C.F., 1980		
	Tasmania, biostratigraphy	Tremadoc-Ashgill	WFR
34.	Burrett, C.F., 1978		
	central Tasmania, biostratigraphy (unpubl)	Llanvirn-Ashgill	WFR
35.	Burrett, C.F. & others, 1981, 1983		
	southern Tasmania, palaeogeography	Llanvirn-Caradoc	WFR

WFR = warm faunal realm (North American Midcontinent Fauna)
CFR = cold faunal realm (North Atlantic Fauna)
C = Cambrian

APPENDIX 2. TRILOBITES

The biostratigraphic chart indicates the range of 12 trilobite faunas. Below are faunal lists for each of the stratigraphic units or intervals indicated on the chart.

1. Faunas of the Ninmaroo Formation, Georgina Basin, Western Queensland (Shergold, 1975).

Onychopyge assula Shergold, 1975
Leiostegium floodi Shergold, 1975
Asaphellus sp.
Warendia bidecorata Gilbert-Tomlinson, *in* Hill *et al.*, 1969

2. Kayrunnera fauna, western New South Wales (Webby, Wang & Mills, 1988)

Hysterolenus furcatus Webby, Wang & Mills, 1988

3. Digger Island fauna, Waratah Bay, Victoria (Jell, 1985)

Australoharpes singletoni Jell, 1985
A. expansus Jell, 1985
Barachyhipposiderus logimus Jell, 1985
Landyia elizabethae Jell, 1985
Leiostegium douglasi, Harrington, 1937
Micragnostus hoeki (Kobayagshi, 1939)
Natmus victus Jell, 1985
N. tuberus Jell, 1985
Neoagnostus eckardti Jell, 1985
Onychopyge parkerae Jell, 1985
Parahystricurus sp. cf. P. fraudator Ross, 1951
Pilekia sp.
Protopliomerops lindneri Jell, 1985
Pseudokainella diggerensis Jell, 1985
Shumardia erquensis Kobayashi, 1937
Tesselacauda ? sp.
Victorispina holmesorum Jell, 1985

4. Florentine Valley faunas, Tasmania, OT 2-4, 5-7 (Banks & Burrett, 1980, 1989; Stait & Laurie, 1980; Jell & Stait, 1985a)

Asaphellus sp. cf. *A. trinodosus* Chang, 1949
Asaphopsoides florentinensis (Etheridge, 1905)
Chosenia adamsensis Jell & Stait, 1985
Dikelocephalina asiatica Kobayashi, 1934
Hystricurus lewisii (Kobayashi, 1940)
H. penchiensis Lu, 1976
H. sp. cf. *H zrbustus* Ross, 1951
Megistaspis (Ekeraspis) euclides (Walcott, 1925)
Pilekia sp. nov.
Pilekiidae gen. et sp. nov.
Protopliomerops hamaxitus Jell & Stait, 1985
P. sp. cf. *P. punctatus* Kobayashi, 1934
Scotoharpes lauriei Jell & Stait, 1985
Tanybregma tasmaniensis Jell & Stait, 1985

5. Canning Basin faunas (1-6), Legg (1976, 1978)

	FAUNA
(i) Carranya Beds, NE Canning Basin	
Dikelocephalina sp.	1
(ii) Emanuel Formation	
?*Asaphellus pricensis* Legg, 1976	2/3a
Bumastus sp	3b
Canningella hardmani Legg, 1976	3b

Carolinites bulbosa Kobayashi, 1940	3a/b,d
Encrinurella reedi Legg, 1976	3b
Fitzroyaspis guppyi Legg, 1976	3a/b
Geragnostu sp.	3a/b
Gogoella wadei Legg, 1976	3b
?Hapalopleurid gen. et. sp. undet.	3a,c
Hystricurus sp.	2/3a
Kayseraspis brakesbuschi (Kayser, 1898)	2
?*Kayseraspis* sp.	2
Nambeetella fitzroyensis Legg, 1976	3a,c
Ogygiocaris teicherti Legg, 1976	3a
Plesiomegalaspis emanuelensis Legg, 1976	3a
Pliomeroides blatchfordi Legg, 1976	2/3a
?*Presbynileus* sp.	3a
Priceaspis oepiki Legg. 1976	3a
Protoencrinurella maitlandi Legg, 1976	3a
Rossaspis sp.	2

(iii) Nambeet Formation

Apatokephalus sp.	2
?*Asaphellus pricensis* Legg, 1976	2/3a
Carolinites bulbosa Kobayashi, 1940	3a,b,d
Geragnostus sp.	3a/b
Hapalopleura sp.	3a
?Hapalopleurid gen. et sp. indet	3a,c
Hystricurus sp.	2/3a
Kayseraspis brakesbuschi (Kayser, 1898)	2
?*Kayseraspis* sp.	2
Ogygiocaris teicherti Legg, 1976	3a
Opipeuter emanuelensis Legg, 1976	3a/b
?*Pliomerops* sp.	3a
cf. *Priceaspis* sp.	3a
Protoencrinurella maitlandi Legg, 1976	3a
Rossaspis sp.	2
?*Tungtzuella* sp.	2

(iv) Willara Formation

Carolinites bulbosa Kobayashi, 1940	3a/b,d
Geragnostus sp.	3a/b
Hapalopleurid gen. et sp. indet.	3a,c
Ogygiocaris teicherti Legg, 1976	3a
Plesiomegalaspis emanueleusis Legg, 1976	3a

(v) Wilson Cliffs Formation

Carolinites bulbosus Kobayaski, 1940	3a/b,d

(vi) Goldwyer Formation

?*Basilicus* sp. cf. *B. mckeei* Ross, 1970	6
Carolinites ekphymosa Fortey, 1975	4
Endymionia canning Legg, 1976	4/5
Illaenus sp.	6
Lonchodomas blackstonensis Legg, 1976	4/5/6
Lycophron sp.	4/5
cf. *Megalaspides* sp.	5
?*Neseuretus* sp.	6
Nileus sp.	5
Prosopiscus edgarensis Legg, 1976	6
Pseudoptyocephalus spinosus Legg, 1976	4/5
Ptychopyge canningensis Legg, 1976	4/5/6
Shumardia matchensis Legg, 1976	5
Telephina matchensis Legg, 1976	5
Triarthrus goldwyerensis Legg, 1976	4

6. Pacoota Sandstone faunas, Amadeus Basin, (Shergold, in press).

(i) Assemblage-Zone 2 (late Warendian)
Apatokephalus sp. cf. *A. hyotan* Kobayashi, 1953
Asaphellus sp. cf. *A. trinodosus* Chang, 1949
Asaphellus? sp. indet. 1
Hystricurus sp. cf. *H eurycephalus* Kobayashi, 1934
Kayseraspis? *belli* Shergold sp. nov.
Koraipsis sp. cf. *K. taiziheensis* Kuo & Duan, 1982
Pacootella collativa Shergold gen. et sp. nov.
Psilocephalina sp. cf. *P. lubrica* Hsu, 1948
Shumardia sp. indet.

(ii) Assemblage-Zone 3 (early Arenig)
Asaphellus? sp. undet. 2.

7. Mount Windsor faunas, NE Queensland sector of Tasman Orogenic Zone, Rollston Range Formation, (Henderson, 1983),.

(i) Assemblage B (Lancefieldian 3)
Acanthopleurella meridionalis Henderson, 1983

(ii) Assemblage C (Bendigonian - Chewtonian)
Carolinites bulbosa Kobayashi, 1940
Hypermecaspis mimitis Henderson, 1983
Opipeuter *insignis* Henderson, 1983

8. Claravale fauna, Fergusson River area, Northern Territory (Õpik, 1968; Jones, 1971)
(*Oneotodus gracilis*/*Drepanodus sexplicatus* A.Z.)

Asaphellus sp.
Dactylocephalus sp.
Richardsonellid indet
Ptychopariina indet.

9. Caroline Creek Sandstone fauna, Tasmania (Etheridge 1883, 1919; Kobayashi, 1940; Jell & Stait, 1985b).

Carolinites tasmaniensis (Etheridge, 1919)
Etheridgaspis carolinensis (Etheridge, 1919)
?*Parabasilicus lewisi* (Kobayashi, 1940)
?*Protoencrinurella subquadrata* (Kobayashi, 1940)
Tasmanocephalus stephensi (Etheridge, 1883)

10. Horn Valley Faunas, Amadeus Basin, Central Australia (Etheridge, 1893, 1894; Tate, 1896; Laurie in press).

(i) Assemblage HV1
"*Basiliella*" *illarensis* (Etheridge, 1893)
Carolinites tasmaniensis (Etheridge, 1919)
  (= *C. genacinaca* Ross, 1951)
Encrinurella sp.
Lycophron howchini (Etheridge, 1894)
n. gen. aff. *Ogygitoides* n. sp.
Prosopiscus sp.

(ii) Assemblage HV 2
?*Birmanites* n. sp.
Carolinites tasmaniensis (Etheridge, 1919)
  (= *C. genacinaca* Ross, 1951)
?*Fitroyaspis* n. sp. aff. *F. irritans* Fortey in Fortey & Shergold, 1984
Lycophron n. sp.
"*Parabasilicus*" n. sp.

11. Nora Formation faunas, Southern Georgina Basin, central Australia (Fortey & Shergold, 1984).

Annamitella strigifrons Fortey in Fortey & Shergold, 1984
A. brachyops Fortey in Fortey & Shergold, 1984
Asaphid gen. et sp. indet.
Carolinites tasmaniensis (Etheridge, 1919)
(= *C. genacinaca* Ross, 1951)
Carolinites sp. cf. *C. ekphymosa* Fortey, 1975
Fitzroyaspis irritans Fortey in Fortey & Shergold, 1984
Gogoella brevis Fortey in Fortey & Shergold, 1984
Hungioides acutinasa Fortey in Fortey & Shergold, 1984
Lycophron sp. A
Nambeetella embolion Fortey in Fortey & Shergold, 1984
Norasaphus (*Norasaphus*) *skalis* Fortey in Fortey & Shergold, 1984
N. (*N.*) *monroeae* Fortey in Fortey & Shergold, 1984
N. (*N.*) *vesiculosus* Fortey in Fortey & Shergold, 1984
Phoracephala sp. aff. *P. genalata* Lu, 1975
Presbynileus sp. cf. *P. utahensis* (Hintze, 1952)
Prosopiscus praecox Fortey in Fortey & Shergold, 1984
Prosopiscus sp. A.

12. Central-Western New South Wales faunas, various formations (Campbell & Durham, 1970; Webby, Moors & McLean, 1970; Webby, 1971, 1973, 1974). Gisbornian-Early Bolindian).

(i) *Pliomerina prima* faunule (L. Cliefden Caves Limestone and correlatives)
?*Encrinuraspis* sp. B
Heptabronteus (=*Eokosovopeltis*) *atavus* Webby, 1974
Pliomerina prima Webby, 1971
Pseudobasilicus? *fortis* Webby, 1973
Remopleurides acer Webby, 1973

(ii) *Pliomerina austrina* faunule (U. Cliefden Caves Limestone and correlatives)
Amphilichas encyrtos Webby, 1974
A. nasutus Webby, 1974
?*Encrinuraspis* sp. A
Harpid gen. et sp. indet.
Pliomerina austrina Webby, 1971
Pseudobasilicus? sp. A
Remopleurides saenuros Webby, 1973
Sphaerocoryphe exserta Webby, 1974

(iii) *Malongullia oepiki* faunule (Malongulli Formation and correlatives)
(*Dicranograptus hians* Zone)
Encrinuraspis optimus Webby, Moors, McLean, 1970
Heptabronteus (=*Eokosovopeltis*) *major* Webby, 1974
Illaenus (*Parillaenus*)? sp. A
Malongullia oepiki Webby, Moors & McLean, 1970
Parkesolithus dictyotos Webby, 1974
Parkesolithus gradyi Campbell & Durham, 1970
Remopleurides exallos Webby, 1973
Toernquistia arguta Webby, 1974

(iv) "*Illaenus*" *incertus* faunule (U. Bowan Park Group and correlatives)
Asaphid undet.
Encrinurid indet.
Illaenus (*Parillaenus*)? *incertus* Webby, 1973
Proetid indet.
Remopleurides sp.
Trinucleid indet.

(v) Oakdale Formation, Mumbil area (Gisbornian - early Eastonian) (Webby, 1974)
Geragnostus sp.
Shumardia sp.

(vi) Cheesemans Creek Formation, Cheeseman's Creek (Sherwin, 1971; Webby, 1974)
Triarthrus sp.

APPENDIX 3. AUSTRALIAN ORDOVICIAN BRACHIOPODS

The following is a list, state by state, of all papers dealing with Australian Ordovician brachiopod faunas, their approximate age and the geographic location of the study.

TASMANIA

Etheridge, 1904; Kobayashi, 1940; Brown, 1948; Corbett & Banks, 1974; Laurie, 1980; Stait & Laurie, 1980. Lancefieldian 1.5-Castlemainian, southern Tasmania.

Burrett, Laurie & Stait, 1981; Burrett, Stait, Sharples & Laurie, 1984. ?Kirkfield, southern Tasmania.

Laurie, 1981; 1982. Lancefieldian 1.5-Early Llandovery, Tasmania.

NEW SOUTH WALES

Semeniuk, 1970; 1972; Percival, 1976; Webby and Percival, 1983. Gisbornian-Eastonian, central New South Wales.

Percival, 1978; 1979; 1979. late Eastonian-early Bolindian, central New South Wales.

Percival, 1980. Early Caradoc-Early Ashgill, central New South Wales.

Fletcher, 1964; Warris, 1967. Early Ordovician, northwestern New South Wales.

NORTHERN TERRITORY

Etheridge, 1891; 1893; Tate, 1896; Shergold, 1986. Llanvirn-Middle Arenig, Amadeus Basin.

WESTERN AUSTRALIA

Prendergast, 1935; Guppy & Öpik, 1950; Laurie, 1987a. Middle Arenig, Canning Basin.

VICTORIA

Laurie, 1987b. Early Tremadoc, Waratah Bay, Victoria.

APPENDIX 4. BIVALVE MOLLUSCS

The following lists indicate the stratigraphic source for the ranges of bivalve molluscs shown on the biostratigraphic chart.

1. Pacoota Sandstone, Amadeus Basin, N.T. Assemblage-Zone 2 (Shergold et al., in press).

Colpantyx woolleyi Pojeta & Gilbert-Tomlinson, 1977
Cyrtodontula hadzeli Pojeta & Gilbert-Tomlinson, 1977
Deceptryx sp. A
Pharcidoconcha raupi Pojeta & Gilbert-Tomlinson, 1977
Xestoconcha kraciukae Pojeta & Gilbert-Tomlinson, 1977

2. Stairway Sandstone, Amadeus Basin, N.T.

Alococoncha crassatellaeformis (Tate, 1896)
Ambonychiid sp. B.
Ctenodonta youngi Pojeta & Gilbert-Tomlinson, 1977
Cyrtodonta carberryi Pojeta & Gilbert-Tomlinson, 1977
C. hazeli Pojeta & Givert-Tomlinson, 1977
C. staffordae Pojeta & Gibert-Tomlinson, 1977
C. wattii (Tate, 1896)
Cyrtondontula hadzeli Pojeta & Gilbert-Tomlinson, 1977
Eritropsis opiformis (Tate, 1896)
Eritropsis sp. A.
Inaequidens campbelli Pojeta & Gilbert-Tomlinson, 1977
Johnmartinia cordata Pojeta & Gilbert-Tomlinson, 1977
J. orbicularis (Tate, 1896)
Modiolopsis? sp. A
Nuculites wattii (Tate, 1896)
Palaeoneilo smithi Pojeta & Gilbert-Tomlinson, 1977
Pteronychia haupti Pojeta & Gilbert-Tomlinson, 1977
Sthenodonta eastii (Tate, 1896)
S. etheridgei (Tate, 1896)
Sphenosolen draperi Pojeta & Gilbert-Tomlinson, 1977

3. Stokes Siltstone, Amadeus Basin, N.T.

Lophoconcha corrugata (Tate, 1896)
Palaeoneilo smithi Pojeta & Gilbert-Tomlinson, 1977
Sthenodonta eastii (Tate, 1896)
S. etheridgei (Tate, 1896)
S. jelli Pojeta & Gilbert-Tomlinson, 1977
Sthenodonta? sp. A

4. Nora Formation, Georgina Basin, Queensland-N.T. (=Stairway/Stokes transition)

Copidens browni Pojeta & Gilbert-Tomlinson, 1977
Leiconychia doylei Pojeta & Gilbert-Tomlinson, 1977
Noradonta shergoldi Pojeta & Gilbert-Tomlinson, 1977
Palaeoneilo smithi Pojeta & Gilbert-Tomlinson, 1977
Sthenodonta eastii (Tate, 1896)
S. passmoreae Pojeta & Gilbert-Tomlinson, 1977

5. Carlo Sandstone, Georgina Basin, Queensland-N.T. (= Lower Stokes Siltstone)

Ambonychia? sp. A
Glyptonychia wilsoni Pojeta & Gilbert-Tomlinson, 1977
Pteronychia cf. *haupti* Pojeta & Gilbert-Tomlinson, 1977
Runnegaria cuneata Pojeta & Gilbert-Tomlinson, 1977

6. Gordon Limestone, Tasmania

Ambonychia? sp. A
Ctenodonta jonesii (Johnston, 1888)
C. macalesteri Pojeta & Gilbert-Tomlinson, 1977
Cyrtodontula sohli Pojeta & Gilbert-Tomlinson, 1977
Deceptrix banksi Pojeta & Gilbert-Tomlinson, 1977
Fidera maryae Pojeta & Gilbert-Tomlinson, 1977
Inaequideus davisi Pojeta & Gilbert-Tomlinson, 1977
Zeehania jacksoni Pojeta & Gilbert-Tomlinson, 1977

APPENDIX 5. ROSTROCONCH MOLLUSCS

The following lists indicate the stratigraphic source of the ranges of rostroconch molluscs shown on the biostratigraphic chart.

1. Ninmaroo Formation (Georgina Basin)

Apoptopegma dickinsi Pojeta, Gilbert-Tomlinson, & Shergold, 1977
Apoptopegma sp. A
Apoptopegma? sp. B
Bransonia chapronierei Pojeta, Gilbert-Tomlinson & Shergold, 1977
Eopteria struszi Pojeta, Gilbert-Tomlinson & Shergold, 1977
Euchasma caseyi Pojeta, Gilbert-Tomlinson & Shergold, 1977
Pauropegma jelli (Pojeta & Runnegar, 1976)
Ptychopegma burgeri Pojeta, Gilbert-Tomlinson & Shergold, 1977
Ribeiria sp. A
Technophorus planei Pojeta, Gilbert-Tomlinson & Shergold, 1977
Wanwania drucei Pojeta, Gilbert-Tomlinson & Shergold, 1977

2. Swift Formation (Georgina Basin)

Pauropegma jelli (Pojeta & Runnegar, 1976)

3. Tomahawk Beds (Georgina Basin)

Ribeiria runnegari Pojeta, Gilbert-Tomlinson & Shergold, 1977
Technophorus kempae Pojeta, Gilbert-Tomlinson & Shergold, 1977
Tolmachovia belfordi Pojeta, Gilbert-Tomlinson & Shergold, 1977

4. Coolibah Formation (Georgina Basin)

Euchasma skwarkoi Pojeta, Gilbert-Tomlinson & Shergold, 1977
Euchasma sp. A
Eopteria Sp. A.

5. Pacoota Sandstone (Amadeus Basin)

Pinnocaris sp. C.
Technophorus nicolli Pojeta, Gilbert-Tomlinson & Shergold, 1977
T. walteri Pojeta, Gilbert-Tomlinson & Shergold, 1977

6. Stairway Sandstone (Amadeus Basin)

Pinnocaris sp. A
Ribeiria csiro Pojeta, Gilbert-Tomlinson & Shergold, 1977

7. Stokes Siltstone (Amadeus Basin)

Conocarioid sp. A

8. Gordon Limestone (Tasmania)

Bransonia townleyi Pojeta & Gilbert-Tomlinson, 1977

9. Caroline Creek Siltstone (Tasmania)

Tolmachovia corbetti Pojeta & Gilbert-Tomlinson, 1977