TIMESCALES

CALIBRATION AND DEVELOPMENT

3

AGSO
AUSTRALIAN
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SILURIAN

Cainozoic
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Cretaceous
141
Jurassic
205
Triassic
251
Permian
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Carboniferous
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Devonian
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Silurian
434
Ordovician
490
Cambrian
545

RECORD 1995/32

NATIONAL GEOSCIENCE INFRASTRUCTURE AND RESEARCH PROGRAM
AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

AGSO RECORD 1995/32

TIMESCALES

3. SILURIAN

AUSTRALIAN PHANEROZOIC TIMESCALES
BIOSTRATIGRAPHIC CHARTS AND EXPLANATORY NOTES
SECOND SERIES

by

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FOREWORD

This second series of Timescales Calibration and Development Correlation Charts and Explanatory Notes revises that originally entitled Australian Phanerozoic Timescales which was published as Bureau of Mineral Resources Records 1989/31-40. That series was prepared to provide a firm chronological base for the AMIRA (Australian Mineral Industry Research Association) sponsored *Palaeogeographic Atlas of Australia* and APIRA (Australian Petroleum Industry Research Association) funded *Phanerozoic History of Australia.*

The Correlation Charts and Explanatory Notes for each system have formed the basis for the development of a composite Australian Geological Survey Organisation (AGSO) Phanerozoic Timescale Chart and a condensed single volume summary. The summary chart and single volume together provide ready access to the ages of most Phanerozoic chronostratigraphic subdivisions in Australia. The Correlation Charts and Explanatory Notes also provide the specialist biostratigrapher with the data to understand the basis for the ages estimated. It is anticipated that both charts and notes will be updated at regular intervals, as and when significant bodies of new information become available.

The revised charts have been compiled mostly by palaeontologists of the Timescales Calibration and Development Project from data published in the specialist literature, as well as unpublished information from on-going biostratigraphical research. As previously, the charts integrate zonal schemes using different groups of key fossils with isotopic and magnetostratigraphic data, and where possible related to sea level curves. Recent geochronological numbers generated by SHRIMP (Sensitive High-Mass Resolution Ion Microprobe) technology have been responsible for significant revision of the timescale applied to some systems, notably the Cambrian, Ordovician, Carboniferous and Permian. Similarly, the definition of the base of the Cambrian by the International Union of Geological Sciences, Commission on Stratigraphy, at a level approximately 545 my old has led to a shortening of the Phanerozoic timescale by some 25 my. Such changes are represented in the new cover design for the Timescales Calibration and Development charts that depicts the geochronological time scale currently used in AGSO.

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INTRODUCTION

The Silurian System was first referred to by Murchison (1835), with a very full account being provided subsequently (Murchison, 1839). He based this monumental work on his extensive studies in Wales and the Welsh Borderland, coining the name for his System from the Roman name for the Welsh tribe ruled by Caratacus: Silures. He understood his System to incorporate all strata between Sedgwick's Cambrian System and the Old Red Sandstone, but this led, as geological studies progressed, to a highly acrimonious disagreement with Sedgwick which was only resolved by the erection of the intervening Ordovician System by Lapworth -- although even that solution was greatly argued internationally (Bassett, 1991, p. 46) . The whole affair was reviewed briefly by Holland (1974), and in more detail by Bassett (1991). In view of this early history, it is perhaps not all that surprising that the System was only formally internationally recognised at the 1960 International Geological Congress in Copenhagen. Subsequent advance has been relatively rapid: the Silurian is the first System for which the System and all Series boundaries have been formally established under the auspices of the International Commission on Stratigraphy (see Holland, 1985, 1989).

The first reference to Silurian rocks in Australia was by Mitchell (1838), but their presence was only firmly established by Clarke (1848), who reported trilobites and brachiopods from Yass and Yarralumla (now part of Canberra). Recent general accounts of our knowledge of the Australian Silurian have been given by Talent *et al.* (1975) and Jell & Talent (1989); Pickett (1982) gave a detailed account for New South Wales, Day *et al.* (1983), VandenBerg (1988) and Banks & Baillie (1989) briefer accounts for Queensland, Victoria and Tasmania respectively. Strusz (1989) published a biostratigraphic synthesis which formed the basis of the palaeogeographic atlas of Walley *et al.* (1990).

This Record is a revision of Strusz (1989), integrating recent moves by the Subcommission on Silurian Stratigraphy to establish reliable international correlation, as well as some new or revised radiometric dates, and the few papers describing new or previously unpublished faunas (especially a significant one on graptolites by Rickards *et al.,* 1995). Where known, taxonomic revisions have also been taken into account. The results are presented as a main Timescale Chart, charts comparing several recent graptolite and conodont zonal schemes, and range charts for selected species of rugose corals, articulate brachiopods, and trilobites. Strusz (1989) should be consulted for a more extensive list of references than is found in this revised edition.

THE TIMESCALE CHART

Geochronology: Column 1

Column 1 of the Timescale Chart shows a linear geochronological scale for the Silurian Period. This shows little change from that published in 1989, which essentially followed McKerrow *et al.*(1985), because the relationship between the biochronological scale for the Silurian and available radiometric dates is still subject to significant argument and uncertainty (see below). Important advances since then are two developments in technique, and the availability of several dates, obtained using one or both of those techniques, from biochronologically well constrained localities.

The two closely related new methods, which would appear to make dates obtained by previous methods of somewhat secondary value, are (1) mass spectrometric isotope dilution (MSID - see Tucker *et al.*, 1990) and (2) the Sensitive High Resolution Ion Micro-Probe (SHRIMP - see Compston & Williams, 1992). Both use the U-Pb system as found in zircons carefully chosen to avoid errors from inheritance or leakage, differing in that one uses a small set of crystals for each age determination, the other analyses small areas on single crystals. The former has greater analytical precision, the latter has somewhat less precision but significantly less risk of error from inherited material. The relative merits have been presented by Compston & Williams (1992) and Tucker & McKerrow (1995). A significant observation is that there appears to be a systematic difference in the results from the two methods, with the SHRIMP dates being younger. Only one sample within the Silurian has been dated by both methods (Compston & Williams give details of several others), but it is critical for the age of the Ordovician/Silurian boundary. This is a bentonite in the lower Birkhill Shales at Dob's Linn, Scotland, within the upper Rhuddanian Zone of *Coronograptus cyphus*. The MSID date is 438.7 ± 2.1 Ma (Tucker *et al.*, 1990), the SHRIMP date 430 ± 3 Ma; the difference is statistically significant. Interestingly, another Silurian sample has been dated twice -- the Laidlaw Volcanics near Yass, NSW. Wyborn *et al.* (1982) obtained a highly reliable Rb/Sr age of 421.1 ± 1.3 Ma. Compston & Williams (1992) compare this with the biotite and sanidine K/Ar age (419.5 ± 1.9 and 408.9 ± 3.6 Ma respectively), and a SHRIMP U/Pb date of 419.6 ± 2.8 Ma. The Rb/Sr, biotite K/Ar and SHRIMP dates are not significantly different.

Which of the two zircon-based methods is the more reliable is still subject to considerable argument. In view of this, and the persistent paucity of data within or close to the Silurian, the geochronological scale has not been significantly altered from the 1989 version.

Ordovician/Silurian boundary: 434 Ma?

The dates which bracket this boundary are now a little closer to it than they were for the 1989 chart, but still too far apart for confidence. Tucker *et al.* (1990) reported an MSID date of 445.7 ± 2.4 Ma for a tuff in the Upper Hartfell Shales at Dob's Linn, Scotland, within the mid-Ashgill (Rawtheyan) Subzone of *Paraorthograptus pacificus*. The next youngest date is that for the lower Birkhill Shales noted above. The difference between the two mean dates is either 7 or 15.7 Ma, depending on which figure is used for the lower Birkhill Shales. Tucker & McKerrow (1995) argue from their results for a boundary date of 443 Ma, which is close to the date of 443.5 Ma calculated on different grounds by Fordham (1992). Odin (1994) has examined the various approaches to data combination used in dating boundaries such as this, and using recent data has decided on a rather imprecise boundary age of 435 +6/-4 Ma. In view of these persisting disagreements, I have chosen to leave the age as 434 Ma (originally determined following the careful arguments in McKerrow *et al.*, 1985).

Llandovery/Wenlock boundary: 425 Ma?

Tucker (1991) reported an MSID date of 430.1 ± 2.4 Ma for a bentonite in the Buttington Mudstone at Long Mountain, Wales. Cocks *et al.*(1992) consider biostratigraphic data for the formation (of Telychian age) to be poor, but Tucker & McKerrow (1995) report that the bentonite is within the *Monoclimacis crenulata* Zone, thus late Telychian. A SHRIMP date is not available. Tucker & McKerrow put the base of the Wenlock at 428 Ma (compare Fordham's 427.5 Ma), Odin (1994) at 430 Ma but with a large error (± 6 Ma). Until the matter of the age of the base of the Llandovery is more nearly resolved, I have decided to leave the base of the Wenlock unchanged at 425 Ma.

Wenlock/Ludlow boundary: 420 Ma

The age of the Laidlaw Volcanics appears to be well established at about 420 Ma (421.1 ± 1.3 Ma on Rb/Sr in biotite, 419.5 ± 1.9 Ma on K/Ar in biotite, 419.6 ± 2.8 Ma on U/Pb in zircon by SHRIMP). The agreement between the different methods and different laboratories may have a significant bearing on the current arguments noted above -- perhaps the problems arise when dealing with complex samples containing inherited zircon which is not always readily detected. The horizon lies between the Cliftonwood Limestone Member of the Yass Formation and the Euralie Limestone Member of the Silverdale Formation (terminology following

Owen & Wyborn, 1979), both of which contain a conodont fauna of long-ranging forms. Link & Druce (1972) referred this fauna to their *Neoprioniodus excavatus* Assemblage Zone, which (together with their succeeding *Spathognathodus* cf. *ranuliformis* Assemblage Zone) they correlated with Walliser's *Ozarkodina crassa* Zone, considered to be early Ludlow. Simpson (1995) has critically reviewed conodont zonations in Australia, and concluded that these earliest faunas at Yass can be no younger that the earliest Gorstian Zone of *Neodiversograptus nilssoni*, and could well be older - i.e. Homerian. It follows from this that the Laidlaw Volcanics are very likely to contain the Wenlock/Ludlow boundary, for which an age of 420 Ma (as argued by McKerrow *et al.*, 1985) remains appropriate. This contrasts with the age of 423 Ma used by Tucker & McKerrow (1995), who refer the Laidlaw Volcanics to the broader (and by implication rather younger) Gorstian *nilssoni* to *scanicus* zonal range. Fordham (1992) calculated an age of 423.5 Ma, Odin (1994) gives 425 ± 5 Ma.

Ludlow/Přídolí boundary: 414 Ma ?

The only useful date between that for the Laidlaw Volcanics and the Early Devonian is one for a bentonite at about the middle of the Upper Whitcliffe Formation at Ludlow, Shropshire. Tucker (1991) has obtained an MSID date of 420.2 ± 3.9 Ma. This level is above the highest graptolites in the Welsh Borderland, but the Ludlow Bone Bed overlying the Formation has been closely correlated with the base of the Přídolí, and so the date should be a close approximation to the age of the Series boundary. A big problem is the statistically indistinguishable date for the Wenlock/Ludlow boundary, noted above, which potentially compresses the whole of the Ludlow into 1 Ma or less. To compound the problem, Odin *et al.* (1986) have obtained three K/Ar dates on biotites in the bentonite sample (from the Elton Formation, of Gorstian age) used for fission-track dating by Ross *et al.* (1982). The latter had obtained a date of 419 ± 7 Ma (which agrees reasonably well with the Laidlaw Volcanics date for a slightly older horizon), while the K/Ar dates ranged from 420.5 ± 4.1 to 426.4 ± 4.2 Ma.

Again, there is a division in the recently published dates for the boundary: 419 Ma by Tucker & McKerrow (1995) and 418.5 Ma by Fordham (1992), 415 Ma by Odin (1994) and 414 Ma by Strusz (1989). Until the problem is resolved, the date used on the Chart is left unchanged at 414 Ma.

Silurian/Devonian boundary: 410 Ma ?

All previous dates for the Period boundary have been deduced by extrapolation from widely separated and not biochronologically well constrained levels (see discussion in Strusz, 1989). Tucker & McKerrow (1995) report additional data: an Ar/Ar date on amphiboles in andesites in the Glencoe Volcanics of Scotland of 421 ± 4 Ma; and a mean Rb/Sr date on biotites on lavas and associated intrusions in the Arbuthnot Group of Scotland of 411.9 ± 1.8 Ma (whose accuracy is bolstered by a Sm/Nd date on garnets in another associated intrusion of 411.9 ± 1.9 Ma). In both cases the biochronological control is by plants. The Glencoe Volcanics are ".. thought to be of Přídolí or early Pragian age ..", so that date is of little help, particularly as it is older than the base of the Přídolí according to Tucker & McKerrow, and older than the base of the Ludlow using the Laidlaw Volcanics date. The Arbuthnot Group has been shown to be early Pragian, thus about a third of the way through the Early Devonian. So control on the age of the Silurian/Devonian boundary remains poor.

Tucker & McKerrow put the age of the boundary at 417 Ma, rather older than others recently published: 408.5 Ma by Fordham (1992), who explicitly followed Harland *et al.* (1990), and 408 +5/-9 Ma by Odin (1994). In 1989 I used 408 Ma, following Harland *et al.* (1982) for want of anything distinctly better, but noted that Owen & Wyborn's (1979) suggested 410 Ma would leave the Přídolí in better proportion to the Ludlow. In the current Chart I have placed the boundary at 410 Ma.

Series and Stages: Column 2

The Series and Stages of the Silurian System have been defined, after considerable international discussion, by the Subcommission on Silurian Stratigraphy. The definitions have been summarised by Holland (1985), and their history discussed by Holland in Holland & Bassett (1989). They comprise a Global Standard, and are used in Australia as elsewhere. The System is informally divided into Lower and Upper Silurian, the former comprising the Llandovery and Wenlock Series, the latter the Ludlow and Přídolí Series. This stands in contrast to the threefold subdivision (Llandovery, Wenlock and Ludlow = Lower, Middle and Upper Silurian) generally applied before the realisation that the Downton Series of the UK was Silurian, not Devonian, and correlated with levels in eastern Europe (Poland, Bohemia and Podolia) which had long been recognised as being pre-Gedinnian (i.e. pre-Devonian) in age.

Llandovery Series

The base of the Silurian System is defined by the base of the Llandovery Series and the coincident base of the **Rhuddanian** Stage. This is at the base of the *Parakidograptus acuminatus* biozone, 1.6 m above the base of the Birkhill Shale (upper Moffat Group) at Dob's Linn, Southern Uplands, Scotland. This is definitely above the widespread end-Ordovician brachiopod-dominated *Hirnantia* Fauna (which may not have been the case with the earlier-used base of the *Glyptograptus persculptus* Biozone), as discussed by Rong (1984) and Bassett (p. 233 in Holland & Bassett, 1989).

The middle Stage of the Llandovery is the **Aeronian**, defined as beginning at the base of the *Monograptus triangulatus* Biozone in the Trefawr Formation of the type Llandovery area, Dyfed, southern Wales.

The third Llandovery Stage is the **Telychian**, defined as beginning just above the last occurrence of the brachiopod *Eocoelia intermedia* and below the earliest recorded *E. curtisi* near the top of the Wormwood Formation in the Llandovery area. This correlates very closely with the base of the *Monograptus turriculatus* Biozone.

Wenlock Series

The Wenlock Series was revised and its two Stages defined by Bassett *et al.* (1975). The base of the Series, coincident with the base of the **Sheinwoodian** Stage, is defined as the base of the Buildwas Shale in Hughley Brook, near Much Wenlock, Shropshire, England. Graptolites a little above this level, and near the top of the underlying Llandoverian Purple Shales, indicate ".. that the base of the Buildwas Shale must lie at or close to the base of the [*Cyrtograptus*] *centrifugus* Biozone" (Bassett in Holland & Bassett, 1989, p. 61).

The upper Stage of the Wenlock Series is the **Homerian**, whose base is defined as the base of the *Cyrtograptus lundgreni* Biozone within the Apedale Member of the Coalbrookdale Formation in Whitwell Coppice, near Much Wenlock.

Ludlow Series

For the Ludlow Series, the third Series of the Silurian System, international agreement had been reached by 1981 (Martinsson *et al.*, 1981). The base coincides with the base of the **Gorstian** Stage, defined as the base of the Lower Elton Formation in a quarry in Pitch Coppice near Ludlow, Shropshire. Graptolites are rare at this level, but are indicative of the *Neodiversograptus nilssoni* Biozone, while species of the preceding *Monograptus ludensis* Biozone occur in the underlying Much Wenlock Limestone, so the Series base closely approximates the base of the *nilssoni* zone.

The base of the overlying **Ludfordian** Stage is defined as the base of the Lower Leintwardine Formation in Sunnyhill Quarry near Ludlow; this approximates to the base of the *Saetograptus leintwardinensis* Biozone.

Přídolí Series

The fourth Series of the Silurian System is the most recently recognised, being formally proposed (as a Stage) by Berdan *et al.* in 1969 and accepted as a Series at the 27th IGC in Moscow, 1984. The base of the Přídolí Series is defined as the base of the Požáry (formerly Přídolí) Formation and the base of the *Monograptus parultimus* Biozone in the Požáry Quarry near Řeporyje in the Daleje Valley near Prague (Holland, 1985, p. 103; Kříž in Holland & Bassett, 1989). There are no Stages for the Přídolí Series. Discussions on such subdivision have been held at numerous meetings of the Subcommission on Silurian Stratigraphy, but such proposals have been opposed by Czech geologists because of the lithological uniformity and lack of biostratigraphic subdivision of the Series in the Prague Basin. Jaeger *et al.* (1995) have put forward a "very preliminary" proposal for discussion, but commented that this was ".. to convince SSS members that it is really difficult to subdivide [the Přídolí] ..". Recognition of Stages within the Series is clearly very unlikely to occur in the near future.

Top of the Silurian System

The top of the Silurian is defined by the base of the Devonian System, which is at the base of the Lochkovian Stage, placed at the base of the Zone of *Monograptus uniformis* at Klonk, overlooking Suchomasty in the southwestern Prague Basin. In that section (and seemingly elsewhere in the region) the conodont Zone of *Icriodus woschmidti* starts very slightly earlier, but for normal purposes of correlation it may also be taken to define the base of the Devonian.

Graptolite Biostratigraphy: Column 3

As noted by Sherwin (p. 27 in Pickett, 1982), most of the graptolite zones that have been recognised in Europe have been recognised also in Australia (see below), although rarely in extended sequences. A small number of papers has since added to that level of recognition (Jell & Talent, 1989; Rickards & Banks, 1992; Rickards, Davidson & Banks, 1993; Rickards *et al.*, 1994, 1995), but they have introduced no changes. The Australian zonation in Column 3 of the Timescale Chart is therefore that of Strusz (1989), derived from Rickards (1976), Rickards *et al.* (1977), Jaeger (1977) and Holland (1985), modified after Pickett (1982) and Garratt (1983), with the taxonomy brought reasonably up to date.

In recent years the Subcommission on Silurian Stratigraphy has been working towards a zonation which permits global correlation, to be used in a project on Silurian palaeogeography. Two drafts have been produced, each after extensive consultation amongst graptolite workers (Koren & Cocks in Subcommission on Silurian Stratigraphy, 1993 & 1995; see also Nestor, 1994). Because these schemes are designed for international correlation, both have used combined zones where the individual component zones have yet to be widely recognised, and are essentially compromises. The overall situation is in a state of flux because of modern work on detailed zonation and taxonomy (e.g. Koren, 1994; Loydell, 1992, 1993a, 1993b; Loydell, Štorch & Melchin, 1993; Štorch, 1994). It remains to be seen whether all the zones which have been recognised in areas with long and relatively continuous sequences (such as Poland) will be widely recognised. Some are possibly of only regional extent, as faunal provinciality, which varies through the Silurian, can be significant.

The relative duration of the graptolite zones, especially the Llandoverian ones, is a contentious subject, because of the extreme paucity of good radiometric dates and consequent reliance on rates of sedimentation etc. (see *e.g.*

			CURRENT AUSTRALIAN GRAPTOLITE ZONES After Strusz, 1989, and Rickards et al., 1995	GENERALISED GRAPTOLITE ZONES Subcommission on Silurian Stratigraphy 1993 draft zonation	GENERALISED GRAPTOLITE ZONES Subcommission on Silurian Stratigraphy 1995 draft zonation
DEVONIAN		Lochkovian	*Monograptus uniformis*	*Monograptus uniformis*	*Monograptus uniformis*
LATE SILURIAN	PRIDOLI		*Monograptus transgrediens*	*Monograptus bouceki* - *Monograptus transgrediens*	*Monograptus bouceki* - *Monograptus transgrediens*
			Monograptus perneri		
			Monograptus bouceki		
			Monograptus lochkovensis	*Monograptus lochkovensis*	*Monograptus branikensis* - *Monograptus lochkovensis*
			Monograptus ultimus	*Monograptus parultimus* - *Monograptus ultimus*	*Monograptus parultimus* - *Monograptus ultimus*
			Monograptus parultimus		
	LUDLOW	Ludfordian	*Bohemograptus*	*Monograptus formosus*	*Monograptus formosus*
				Bohemograptus bohemicus - *Bohemograptus kozlowskii*	*Bohemograptus tenuis* - *Bohemograptus kozlowskii*
			Saetograptus leintwardinensis	*Saetograptus leintwardinensis*	*Saetograptus leintwardinensis*
		Gorstian	*Pristiograptus tumescens*	*Lobograptus scanicus*	*Lobograptus scanicus*
			Lobograptus scanicus		
			Neodiversograptus nilssoni	*Neodiversograptus nilssoni*	*Neodiversograptus nilssoni*
EARLY SILURIAN	WENLOCK	Homerian	*Monograptus ludensis*	*Monograptus ludensis*	*Monograptus ludensis*
			Gothograptus nassa	*Gothograptus nassa* - *Monograptus deubeli*	*Monograptus praedeubeli* - *M. deubeli*
					Monograptus parvus - *Gothograptus nassa*
			Cyrtograptus lundgreni/*Testog. testis*	*Cyrtograptus lundgreni*	*Cyrtograptus lundgreni*
		Sheinwoodian	*Cyrtograptus ellesae*	*Cyrtograptus rigidus* to *Cyrtograptus ellesae*	*Cyrtograptus rigidus* to *Cyrtograptus ellesae*
			Cyrtograptus linnarssoni		
			Cyrtograptus rigidus		
			Monograptus riccartonensis	*Monograptus riccartonensis*	*Monograptus riccartonensis* - *Monograptus belophorus*
			Cyrtograptus murchisoni	*Cyrtograptus centrifugus* - *Cyrtograptus murchisoni*	*Cyrtograptus centrifugus* - *Cyrtograptus murchisoni*
			Cyrtograptus centrifugus		
	LLANDOVERY	Telychian	*Monoclimacis crenulata*	*Monoclimacis crenulata*	*Cyrtograptus lapworthi* -- *C. insectus*
					Monograptus spiralis
			Oktavites? exiguus *Monoclimacis griestoniensis*	*Monoclimacis griestoniensis*	*Monoclimacis griestoniensis* - *Monoclimacis crenulata*
			"Monograptus" crispus	*Spirograptus turriculatus* - *"Monograptus" crispus*	*Spirograptus turriculatus* - *"Monograptus" crispus*
			Spirograptus turriculatus		*Spirograptus guerichi*
		Aeronian	*Stimulograptus sedgwickii*	*Stimulograptus sedgwickii*	*Stimulograptus sedgwickii*
			Monograptus convolutus	*Monograptus convolutus*	*Demirastrites convolutus*
			Coronograptus gregarius *Monog. argenteus*	*Coronograptus gregarius*	*Monograptus argenteus*
			Diplog. magnus		*Demirastrites triangulatus* - *Demirastrites pectinatus*
			Monog. triangulatus		
		Rhuddanian	*Coronograptus cyphus*	*Coronograptus cyphus*	*Coronograptus cyphus*
			Atavograptus atavus	*Coronograptus vesiculosus*	*Coronograptus vesiculosus*
			Parakidograptus acuminatus	*Parakidograptus acuminatus*	*Parakidograptus acuminatus*
			Glyptograptus persculptus	*Glyptograptus persculptus*	*Glyptograptus persculptus*

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Fig. 1

the discussion by Hughes, 1995). The durations shown on this edition of the chart are based on those suggested by Koren & Cocks in 1993, although the same authors have retreated from that suggestion in the 1995 draft, no doubt because of the associated problems and uncertainties. The Australian and 1995 Subcommission zonations are shown on the Timescale Chart, with the zone boundaries (and therefore durations) in the latter aligned with those in the former. All three are shown in Fig. 1, similarly aligned.

Llandovery to Ludlow Zones

Up to the Přídolí Series, the zones (but few of the subzones) defined in Rickards (1976) have been used in Australia, and are shown in Column 3 (with the taxonomy generally updated), with the following differences.

1) The *Coronograptus cyphus* Zone was divided into a lower *Lagarograptus acinaces* Zone and a higher *C. cyphus* Zone *sensu stricto* by Rickards *et al.* (1977); this was followed by Pickett (1982). Those subdivisions have not been recognised in Australia, and were not included in the draft schemes of the Subcommission on Silurian Stratigraphy; they are omitted.

2) In most Australian successions of appropriate age the old Zone of *Coronograptus gregarius* still cannot be subdivided, although this probably reflects insufficient work (the *Monograptus triangulatus*, *Diplograptus magnus* and *M. argenteus* Zones have been recorded in sequence only in the Cadia Coach Shale). The Australian scheme therefore uses both alternatives. The 1993 Subcommission draft followed the common Australian practice of recognising a *gregarius* Zone, but interestingly the 1995 draft divided this into two: a combined zone of *Demirastrites triangulatus* to *D. pectinatus,* followed by a Zone of *M. argenteus*.

3) The *Rastrites maximus* Subzone of the (lower Telychian) *Spirograptus turriculatus* Zone cannot be recognised, and is omitted. The three schemes show considerable diversity at this level.

4) Following Garratt (1983, p. 79), a single Zone of *Oktavites? exiguus*, corresponding reasonably closely to the less often distinguished Zones of *"Monograptus" crispus* and *Monoclimacis griestoniensis*, is retained. Those two zones are, however, also shown because they can be recognised in places. Again, the three zonal schemes show significant diversity of approach.

5) The Zone of *Cyrtograptus lundgreni* is the same as Garratt's Zone of *Testograptus testis*, which is also the name preferred by Rickards *et al.* (1995); both names are shown. *Cyrtograptus* has rarely been recorded in Australia -- perhaps, again, for want of enough work.

6) The *Neodiversograptus nilssoni* Zone is not subdivided in either the Australian or Subcommission schemes. The UK Zone of *Lobograptus progenitor*, which corresponds to its upper part, has not been recognised with certainty in Australia, although Garratt (1983a) reports a *nilssoni* Zone fauna from the Dargile Formation at Studley Park which includes *Monograptus roemeri*, a species restricted to the *N. progenitor* Zone in the UK. The UK situation is discussed by Rickards (1976, p. 171).

7) The *Bohemograptus* Zone is that of Rickards *et al.*, 1977, fig. 31 -- which follows Teller (1969) and Holland & Palmer (1974), and is an acme ("proliferation") zone, not a total-range zone. Rickards *et al.* (1977, fig.1) give a range for the genus from lower *nilssoni* to *fecundus* Zone, while *Bohemograptus bohemicus* (commonly reported in Australia) appears as early as the *N. nilssoni* Zone in the UK and Europe. Only the topmost European Zone in this interval, of *Bohemograptus kozlowskii*, has been separately recognised, and then only in isolation at one Tasmanian locality (Rickards, Davidson & Banks, 1993), so it is not shown on the Chart. Garratt & Wright (1988) have suggested that careful study of the Australian bohemograptids may be rewarding.

Přídolí Zones

For the Přídolí Series, the zonation is as in Rickards *et al.* (1977), modified following the specific synonymies put forward by Jaeger (1977):

1. *Monograptus bugensis* = *M. ultimus.*
2. *M. chelmiensis, M. samsonowiczi, M. admirabilis* and *M. perbrevis* all = *M. transgrediens.*

Jaeger treated *M. angustidens* as a subspecies of *M. transgrediens*, but Holland (1985) shows it as a subspecies of *M. uniformis* -- in the System boundary stratotype at Klonk, *angustidens* appears at the same level as *uniformis*. Following Holland (1985) and subsequent authors is the insertion of a Zone of *M. parultimus* at the base of the Přídolí.

Occurrence of zones in Australia

Below are listed the graptolite zones currently recognised in Australia, and the formations in which they have been recorded. The information is taken from Baillie, Banks & Rickards (1978), Carr *et al.* (1980), Pickett (1982), Garratt (1983), Jenkins *et al.* (1986), Jell *et al.* (1988), Jell & Talent (1989), Rickards & Banks (1992), Rickards, Davidson & Banks (1993), and Rickards *et al.* (1994, 1995).

Parakidograptus acuminatus: Arndell Sandstone (Tas.), Deep Creek Siltstone (Vic.).

Atavograptus atavus, Coronograptus cyphus: unrecognised.

Coronograptus gregarius: Deep Creek Siltstone (Vic.), lower Greengrove and upper Millambri Formations (NSW). Also reported but never described from the *Illaenus* Band, basal Wapentake Formation, Victoria; the specimens are lost, and the trilobite fauna is more indicative of the Wenlock (Holloway, pers. comm. 23rd Nov., 1995).

Monograptus triangulatus: basal Cadia Coach Shale (NSW).

Diplograptus magnus: Avon Lea Mudstone Member, Cadia Coach Shale (NSW).

M. argenteus: topmost Cadia Coach Shale (NSW).

M. convolutus: possibly topmost Cadia Coach Shale (NSW).

Stimulograptus sedgwicki: unrecognised.

Spirograptus turriculatus: basal Springfield Formation (Vic.), upper Cotton Siltstone (NSW), Poley Cow Formation (Qld).

Oktavites? exiguus: widespread in Victoria and New South Wales, including the State Circle Shale and the Jerrara Beds; reported from the Quinton Formation in Queensland.

"Monograptus" crispus: Glendalough Formation (NSW).

Monoclimacis griestoniensis: upper Glendalough Formation (NSW), upper Poley Cow Formation (Qld).

Monoclimacis crenulata: upper Glendalough Formation (NSW).

Cyrtograptus centrifugus: Ashleigh Member of the Glendalough Formation (NSW).

C. murchisoni: unrecognised.

Monograptus riccartonensis: basal Panuara Formation (NSW).

C. lundgreni/Testograptus testis: upper Anderson Creek Formation (Vic.), Kurrajong Park, Panuara and basal Ulah Formations (NSW).

Gothograptus nassa: Mullum Mullum Member, upper Anderson Creek Formation (Vic.).

Monograptus ludensis: Ulah and Panuara Formations (NSW).

Neodiversograptus nilssoni: Dargile and upper Anderson Creek Formations (Vic.).

Lobograptus progenitor: Dargile Formation at Studley Park (Vic.).

Lobograptus scanicus: Dargile Formation (Vic.).

*Bohemograptus*Zone: upper Black Bog, Barnby Hills and Mackeys Creek Shales, and basal Bungonia Limestone (NSW); possibly Dargile, Melbourne, and Yea Formations (Vic.).

Bohemograptus kozlowskii: Mathinna Beds (NE Tas.).

Monograptus parultimus: Eldon Group (W. Tas.).

			CURRENT AUSTRALIAN GRAPTOLITE ZONES After Strusz, 1989, and Rickards et al., 1995		GENERALISED GRAPHITE ZONES Subcommission on Silurian Stratigraphy 1995 draft zonation	AUSTRALIAN CONODONT ZONES After Simpson, 1995	AUSTRALIAN CONODONT ZONES After Strusz, 1989	GENERALISED CONODONT ZONES Subcommission on Silurian Stratigraphy	
								1993 draft zonation	1995 draft zonation
DEVONIAN		Lochkovian	*Monograptus uniformis*		*Monograptus uniformis*	*Icriodus woschmidti*	*Icriodus woschmidti*	*Icriodus woschmidti woschmidti*	
LATE SILURIAN	PRIDOLI		*Monograptus transgrediens*		*Monograptus bouceki - Monograptus transgrediens*	[unzoned]	*Ozarkodina remscheidensis eosteinhornensis*	*Ozarkodina remscheidensis eosteinhornensis*	*Ozarkodina eosteinhornensis - Oulodus elegans detorta*
			Monograptus perneri						*Ozarkodina remscheidensis*
			Monograptus bouceki						
			Monograptus lochkovensis		*Monograptus branikensis - Monograptus lochkovensis*				
			Monograptus ultimus		*Monograptus parultimus - Monograptus ultimus*				
			Monograptus parultimus						
		Ludfordian	*Bohemograptus*		*Monograptus formosus*	*Ozarkodina crispa*	*Ozarkodina crispa* Subzone	*Ozarkodina crispa*	*Ozarkodina crispa*
					Bohemograptus tenuis - Bohemograptus kozlowskii	[unzoned]	*Ozarkodina snajdri*	*Ozarkodina snajdri*	*Ozarkodina snajdri*
			Saetograptus leintwardinensis		*Saetograptus leintwardinensis*	*Polygnathoides siluricus*	*Polygnathoides siluricus*	*Polygnathopides siluricus*	*Polygnathopides siluricus*
		Gorstian	*Pristiograptus tumescens*		*Lobograptus scanicus*	*Ancoradella ploeckensis*	*Ancoradella ploeckensis*	*Ancoradella ploeckensis*	*Ancoradella ploeckensis*
			Lobograptus scanicus						[unzoned]
			Neodiversograptus nilssoni		*Neodiversograptus nilssoni*	[unzoned]	*Ozarkodina crassa*	*Ozarkodina bohemica bohemica*	*Kockelella stauros*
EARLY SILURIA	WENLOCK	Homerian	*Monograptus ludensis*		*Monograptus ludensis*		*Ozarkodina sagitta sagitta*		*Ozarkodina bohemica*
			Gothograptus nassa		*Monograptus praedeubeli -- M. deubeli*				
					Monograptus parvus - Gothograptus nassa				*Ozarkodina sagitta sagitta*
			Cyrtograptus lundgreni/Testog. testis		*Cyrtograptus lundgreni*				
		Sheinwoodian	*Cyrtograptus ellesae*		*Cyrtograptus rigidus to Cyrtograptus perneri*	*Kockelella amsdeni*	*Kockelella amsdeni*		[unzoned]
			Cyrtograptus linnarssoni			*Kockelella ranuliformis*	*Kockelella ranuliformis*	*Ozarkodina sagitta sagitta*	*Ozarkodina sagitta rhenana - Kockelella patula*
			Cyrtograptus rigidus						
			Monograptus riccartonensis		*Monograptus riccartonensis - Monograptus belophorus*		*Pterospathodus amorphognathoides* + *Pterospathodus latus*	*Ozarkodina sagitta rhenana*	*Kockelella ranuliformis*
			Cyrtograptus murchisoni		*Cyrtograptus centrifugus - Cyrtograptus murchisoni*	*Pterospathodus amorphognathoides*			*Pterospathodus amorphognathoides*
			Cyrtograptus centrifugus					*Pterospathodus amorphognathoides*	
	LLANDOVERY	Telychian	*Monoclimacis crenulata*		*Cyrtograptus lapworthi - C. insectus*				
					Monograptus spiralis			*Pterospathodus celloni*	
			Oktavites? exiguus	*Monoclimacis griestoniensis*	*Monoclimacis griestoniensis - Monoclimacis crenulata*	*Pterospathodus celloni*	*Pterospathodus celloni*		*Pterospathodus celloni*
				"Monograptus" crispus	*Spirograptus turriculatus - "Monograptus" crispus*	*Distomodus staurognathoides*	*Astropentagnathus irregularis* + *Pterospathodus pennatus*	*Distomodus staurognathoides*	*Pterospathodus? tenuis - Distomodus staurognathoides*
			Spirograptus turriculatus		*Spirograptus guerichi*		*Aulacognathus antiquus* + *Distomodus staurognathoides*		
		Aeronian	*Stimulograptus sedgwickii*		*Stimulograptus sedgwickii*		hiatus - unzoned		
			Monograptus convolutus		*Demirastrites convolutus*	[unzoned]			
			Coronograptus gregarius	*Monog. argenteus*	*Monograptus argenteus*				
				Diplog. magnus	*Demirastrites triangulatus - Demirastrites pectinatus*	*Distomodus pseudopesavis*	*Distomodus pseudopesavis* + *Ozarkodina masurenensis*	*Distomodus kentuckyensis*	
				Monog. triangulatus					*Distomodus kentuckyensis*
		Rhuddanian	*Coronograptus cyphus*		*Coronograptus cyphus*	*Distomodus combinatus*	*Distomodus combinatus* + *Distomodus tridens*		
			Atavograptus atavus		*Coronograptus vesiculosus*				
			Parakidograptus acuminatus		*Parakidograptus acuminatus*	[unzoned]	hiatus - unzoned		*Oulodus? nathani*
			Glyptograptus persculptus		*Glyptograptus persculptus*				

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Fig. 2

M. ultimus: lower to middle Rosebank and basal Wallace Shales (NSW).
M. lochkovensis: unrecognised.
M. bouceki: lower Cowridge Siltstone, upper Wallace Shale (NSW).
M. transgrediens: lower Elmside Formation (NSW).

Conodont Biostratigraphy: Column 4

The use of conodonts in zonation of the Silurian System is still in a state of considerable flux. Regional schemes originating from studies in central Europe and North America have been fairly widely applied, but correlation between them has proved difficult. In Australia, only two studies until now have yielded zonations which could be compared with at least parts of these schemes: Link & Druce (1971), and Bischoff (1986). In Strusz (1989) a conodont zonal scheme was compiled which relied on the latter for the Llandovery and Sheinwoodian. For the Homerian onwards, the zonation was combined from Link & Druce (1972), Ziegler *et al.* (1974), Schönlaub (1980), Cooper (1980), Pickett (1982) and Aldridge in Higgins & Austin (1985), all building on the work of Walliser (1964, 1971). It was thus, for the later Silurian, essentially a recognition in Australia, generally not in sequence but as isolated occurrences, of zones established elsewhere. Subsequently, the Subcommission on Silurian Stratigraphy (1993, 1995) has put forward and then revised a set of generalised zones which the authors consider to be a reasonable compromise between the various regional schemes, suitable for international correlation. For Australia, Simpson (1995) has undertaken a detailed literature analysis from which has emerged a regional scheme which reflects wherever possible those in use in Europe and North America.

In view of these developments, the Timescale Chart now shows Simpson's scheme and the 1995 version of the Subcommission scale. In both, the zonal boundaries have been aligned as closely as possible with the graptolite zones, but this alignment is still generally imprecise. In Figure 2, these two scales are also compared with Strusz's 1989 scheme, and the Subcommission's 1993 draft.

Occurrences in Australia were originally compiled from Talent *et al.* (1975), Pickett (1982) and references therein, Jenkins *et al.* (1986), Bischoff (1986) and Jell & Talent (1989). To these may be added Simpson (1995) and data quoted therein, and recent papers by Simpson *et al.* (1993), Nicoll *et al.* (1994), Nicoll (1995), Simpson & Talent (1995) and Sloan *et al.* (1995).

The Ordovician/Silurian boundary cannot yet be recognised using conodonts, in Australia or elsewhere. Internationally, the Zone of *Oulodus? nathani* is now thought to cross the boundary (see the discussion by Barnes, p. 105, in Holland & Bassett, 1989). There are no data at this level in Australia -- as Simpson (1995, p. 329) noted, "Known sequences which probably cross this boundary are conspicuously lacking in carbonates". Simpson has accepted most of Bischoff's Lower Silurian zones, but with some modification. One of the grounds for redefinition applies to Bischoff's dual-name Assemblage Zones: the lower boundary of each is recognised by the entry of a single taxon, the upper boundary by the appearance of the zonal index species for the next zone; the zone **as thus defined** is therefore an interval zone, not an assemblage zone, and dual nomenclature is superfluous.

I find the use of two names clumsy and unnecessary, so support Simpson's use of a single zonal-name taxon, but I disagree that the zones defined by Bischoff are all simple interval zones. Thus, for example, the earliest of Bischoff's zones (*Distomodus combinatus* + *D. tridens*) is defined in two ways: the lower boundary is marked by the appearance of *D. combinatus,* while the zone itself is characterised by the co-occurrence of the two eponymous species and the less abundant *Ozarkodina australiensis* (together with occasional *Oulodus angullongensis* and *Oulodus* sp. A) but the absence of taxa characteristic of the succeeding zone. This, surely, is an Assemblage Zone. The comments of Rickards (1996), and remarks by Koren recorded therein, are, I believe, apposite.

The zones accepted by Simpson (1995) are:

Distomodus combinatus
Redefined as ".. the interval characterised by the occurrence of *D. combinatus* prior to the appearance of *D. pseudopesavis*". This redefinition of Bischoff's Zone of *Distomodus combinatus* plus *D. tridens* by Simpson follows on two grounds, the first being the general one noted above, the other being that Bischoff's eponymous species may be synonymous (Simpson & Talent, 1995). The scope of the zone remains unchanged: the known earliest occurrence is separated from an unconformity by a barren interval, and the zone can be equated to the *Atavograptus atavus* Zone plus the lower part of the *Coronograptus cyphus* Zone (on the Subcommission scale, *C. vesiculosus* plus lower *C. cyphus*). The zone occurs in the lower Bagdad Formation, and Simpson & Talent (1995) report *D. combinatus* in the McCartys limestone lens, Cowombat Formation, northeastern Victoria.

Distomodus pseudopesavis
Redefined by Simpson (1995) as ".. the interval characterised by the occurrence of *D. pseudopesavis*". As defined by Bischoff, the lower boundary is defined by the first appearance of that species and *Ozarkodina masurenensis* (the earlier assemblage persists for a short interval). Bischoff also considered as significant for the zone the occurrence of *O. panuarensis* and *Pterospathodus cadiaensis*, and (in its lower part) of *Distomodus calcar*. The zone occurs in the upper Bagdad Formation, and its upwards extent is uncertain, there being a gap before the next conodont zone, the Panuara Hiatus. Bischoff suggested the upper limit could perhaps be defined by the disappearance of *Ozarkodina masurenensis*, and aligned the zone with the upper *Coronograptus cyphus* and *Monograptus triangulatus* Zones.

Distomodus staurognathoides
The base of the Zone of *Aulacognathus antiquus* + *Distomodus staurognathoides* morphotype α was defined by Bischoff (1986) by the first occurrence of *D. staurognathoides* morphotype α, the top by the appearance of *Astropentagnathus irregularis*. As there is a gap between this and the previous zone, and the apparently oldest occurrence of the zone is in megaclasts, the precise correlation of the lower zonal boundary is uncertain. *A. antiquus* occurs only in this lowest part of the zone, while important components of the zonal fauna are *Aulacognathus angulatus, A. bifurcatus* and *Ozarkodina waugoolaensis*; *Oulodus planus planus* is sporadically dominant. Simpson (1995) has noted various problems with Bischoff's interpretation of the zone, and considers it should be equated with the internationally recognised zone of *D. staurognathoides* ("e.g. Aldridge & Schönlaub, 1989"). Following that comparison, and allowing for the likely extent of the Panuara Hiatus, I have here aligned the Australian zone approximately with the upper *Monograptus convolutus* to lower *"Monograptus" crispus* Zones.

Pterospathodus celloni
This zone, originally recognised by Walliser at Cellon in the Carnic Alps, was redefined by Bischoff following reassessment of conodont ranges in the Cellon section, and observations in New South Wales. There, he redefined it as the interval between the entry of *Pterospathodus celloni* and of *P. latus* (which marks the base of his succeeding Assemblage Zone of *Pterospathodus amorphognathoides* + *P. latus*). Bischoff also introduced between this zone and his Zone of *Aulacognathus antiquus* + *Distomodus staurognathoides* morphotype α another assemblage zone, that of *Astropentagnathus irregularis* plus *Pterospathodus pennatus*. Simpson (1995) has criticised the taxonomic basis for Bischoff's changes, and concluded that most or all of this last-mentioned assemblage zone can be ".. correlated with the *celloni* Zone as originally defined by Walliser (1964)". There are consequent uncertainties regarding the base of the zone in New South Wales, but for the time being it is placed within the *"Monograptus" crispus* Zone (which is the position shown by the 1995 Subcommission scale). In New South Wales the upper

boundary is not in sequence with the succeeding zone, and cannot readily be related to the graptolite zonation, so its correlation is uncertain. Consensus seems to be approximate alignment with the base of the Zone of *Monoclimacis crenulata* (or *Monograptus spiralis*). The zone as defined by Simpson occurs in the Cobblers Creek, Liscombe Pools and lower Quarry Creek Limestones, and the Glendalough and lower Boree Creek Formations of New South Wales, the Chillagoe and lower Quinton Formations in northern Queensland, and parts of the Cowombat Formation in northeastern Victoria.

Pterospathodus amorphognathoides
As with the preceding zone, Simpson (1995) has found that Bischoff's replacement of Walliser's zone with a Zone of *P. amorphognathoides + P. latus* cannot be supported, and has reverted to the earlier usage of a zone whose lower boundary is defined by the entry of *P. amorphognathoides*. The upper boundary is defined as the lower boundary of the Zone of *Kockelella ranuliformis*. The correlation of the zone is uncertain; the base approximates to the base of the Zone of *Monoclimacis crenulata* (or *Monograptus spiralis*), the top lies within the Zone of *Cyrtograptus murchisoni*. In New South Wales the zone is known from the Quarry Creek Limestone, limestone lens A in the Boree Creek Formation, and the limestone at 'Cooinbil' in the Peppercorn Formation. It occurs in the Chillagoe and lower Quinton Formations in Queensland, and the Cowombat Formation in Victoria. Problems associated with the correlation of the Quarry Creek Limestone, discussed by Strusz (1989) have largely been resolved following restudy of the graptolites (Rickards *et al.*, 1995), but the correlation of the distinct sequences in Quarry, Boree and Cheeseman's Creeks still needs to be re-examined.

Above the *P. amorphognathoides* Zone, Bischoff adapted the Oklahoma zonation of Barrick & Klapper (1976).

Kockelella ranuliformis
This zone was defined by Barrick & Klapper (1976) to be the interval between the entries of *Pseudooneotodus bicornis* and *Kockelella amsdeni*. In the absence of *P. bicornis* Bischoff redefined the base, for New South Wales at least, as being at the entry of *Ozarkodina sinuosus*, and the disappearance of *Apsidognathus tuberculatus tuberculatus*, *A. tuberculatus lobatus*, *Aulacognathus borenorensis*, *Carniodus carnulus*, *Oulodus planus borenorensis*, *Pyrsognathus latus* and *P. obliquus*. The zone is known from the upper Boree Creek Formation and lower Borenore Limestone in New South Wales. Both boundaries are in a continuous limestone sequence, and lack close graptolite control. The zone is approximately aligned with the Zones of *Monograptus riccartonensis* and *Cyrtograptus riccartonensis*. In northeastern Victoria the zone has been reported from the lower Claire Creek Limestone Member, Cowombat Formation, and in Queensland from the Chillagoe Formation.

Kockelella amsdeni
This is as defined by Barrick & Klapper (1976), the base being defined by the entry of *K. amsdeni*, the top by the entry of *K. stauros*. The latter is not known from the Orange district, so in New South Wales the upper limit of the zone is indefinite. Again, it cannot be closely correlated with the graptolite zonation, but approximates to the Zones of *Cyrtograptus linnarssoni* and *C. ellesae* (1995 Subcommission scale: middle and upper parts of the combined zone of *C. rigidus - C. perneri*). The zone is known from the upper Borenore Limestone.

Simpson (1995) found himself unable to recognise any zones corresponding to the Homerian or earliest Gorstian. This is largely for want of appropriate species in any of the studied successions. In the lower part of the Yass sequence Link & Druce (1972) recognised two assemblages, of *Neoprioniodus excavatus* and *Spathognathodus* sp. cf. *ranuliformis*, both of which they tentatively correlated with the Cellon Pass Zone of *Ozarkodina crassa*. Simpson has summarised the problems both with this correlation and with the last-mentioned zone, and suggests that the lower levels of the

Yass sequence (up to the lower Bowspring Limestone Member) could include strata of Wenlock age. In Australia, this unzoned interval probably extends from about the base of the Zone of *Testograptus testis* to fairly high in the zone of *Neodiversograptus nilssoni*. In the 1995 Subcommission scale (as shown here in Fig. 1, right-hand column) an unzoned interval occurs below the Zone of *Cyrtograptus lundgreni* (= Zone of *Testograptus testis*). This separates an older combined Zone of *Ozarkodina sagitta rhenana - Kockelella patula* from a Homerian Zone of *Ozarkodina sagitta sagitta*. Owen & Wyborn (1979) recorded *O. sagitta* from the lower Cooleman Limestone, but without re-examination it is not possible to see where this fits in the current scheme.

Ancoradella ploeckensis

With a base defined by the first appearance of *Ancoradella ploeckensis*, this is the same as the *Kockelella variabilis - A. ploeckensis* Assemblage Zone of Link & Druce; as Simpson has pointed out, the dual nomenclature is unnecessary. It approximates to the Zones of *Lobo-graptus scanicus* and *Pristiograptus tumescens* (the single Zone of *Lobograptus scanicus* in the 1995 Subcommission scale). The zone occurs in the upper Silverdale Formation (Bowspring Limestone Member to Hume Limestone Member) at Yass, the Claire Creek Limestone Member of the Cowombat Formation in northeastern Victoria, and the lower to middle Jack Formation of northern Queensland.

Polygnathoides siluricus

Defined by the first appearance of *Polygnathoides siluricus*, this is the *Belodella triangularis - P. siluricus* Assemblage Zone of Link & Druce, who recorded it from the middle to upper Hume Limestone Member at Yass. The upper limit is indefinite in the Yass sequence, dominated by clastic sediments above the Hume Member. The zone also occurs in the Jack Formation of northern Queensland, and probably elsewhere (see Simpson, 1995).

Few conodonts have been recorded from levels above the *siluricus* Zone in Australia, which Simpson leaves essentially unzoned. Link & Druce tentatively correlated the conodont fauna of the Yarwood Siltstone Member with the Zone of *Ozarkodina snajdri*, but only long-ranging taxa are present. At the highest levels in the Australian Silurian there are various reports of *Ozarkodina remscheidensis* and *O. eosteinhornensis*, but none has been reexamined in the light of current taxonomic and bio-stratigraphic concepts (see Simpson, 1995, for a discussion of the possible relationships). Simpson recognises only one zone within this interval, that of *Ozarkodina crispa*.

Ozarkodina crispa

Defined by the first appearance of the eponymous species, this zone underlies the Zone of *Monograptus parultimus* which defines the base of the Přídolí. The 1995 Subcommission scale aligns it with the Zone of *Monograptus formosus*. Cooper (1977) recorded *O. crispa* from the upper Yarrangobilly Limestone, and it has also been reliably reported from the Derriwong Beds in New South Wales. The zone also occurs high in the Cowombat Formation of northeastern Victoria (Simpson *et al.*, 1993). Other reported occurrences (Narragal Limestone, Kildrummie Formation) probably involve misidentification (Simpson, 1995).

Icriodus woschmidti woschmidti

Proposed by Walliser (1964) as a basal Devonian zone. The subspecies is not known in the boundary stratotype at Klonk, but at Cellon and elsewhere in central Europe it occurs slightly below the entry of *Monograptus uniformis*, which defines the base of the Devonian. The species has been recorded from the limestones in the upper Elmside Formation at Yass, the Camelford Limestone near Wellington, NSW, and the Jack and Chillagoe Formations in northern Queensland. In all cases the units concerned would appear to encompass the Silurian/Devonian boundary.

Chitinozoan Biostratigraphy: Column 5

Little work has been done on Palaeozoic chitinozoans in Australia, none for the Silurian. However, a recent attempt has been made to compile a globally applicable biozonation for the group. Preliminary versions were published by the Subcommission on Silurian Stratigraphy (1993, 1995), and formal definitions for a revised version have been provided by Verniers *et al.* (1995). This revised version is shown in Column 5 of the Timescale Chart, with the boundaries aligned to the graptolite zonations shown in Column 3. In summary, the zones proposed (specifically as interval zones, whose tops are defined by the bases of succeeding zones) are:

Spinachitina fragilis
The base is defined by the first occurrence of *S. fragilis* in the basal Rhuddanian of Estonia. Known from about the base of the *Parakidograptus acuminatus* Zone in the Prague Basin.

Belonechitina postrobusta
The base is defined by the first occurrence of *B. postrobusta* within the local equivalent of the *Coronograptus vesiculosus* Zone in Estonia.

Conochitina electa
The base is defined by the first appearance of *C. electa* in the lower *Coronograptus cyphus* Zone in Estonia.

Spinachitina maennili
The base is defined by the first occurrence of *S. maennili* in the uppermost *Coronograptus cyphus* Zone in Estonia.

Conochitina alargada
The base is defined by the first occurrence of *C. alargada* in the Aeronian of Léon, Spain (the correlation by graptolites requires reevaluation).

Eisenackitina dolioliformis
The base is defined by the first occurrence of *E. dolioliformis* in the upper Aeronian of Estonia (close correlation with the graptolite zonation is lacking).

Angochitina longicollis
The base is defined by the first occurrence of *A. longicollis* in the middle or upper Telychian of Gotland. The index species occurs in the *Monograptus spiralis* Zone in the Prague Basin.

Margachitina margaritana
The base is defined by the first occurrence of *M. margaritana* at the base of the Sheinwoodian in the stratotype section, Hughley Brook, Shropshire, England (there are no chitinozoa in the underlying strata), and slightly below the Llandovery/Wenlock boundary in Gotland and the eastern Baltic.

Cingulochitina cingulata
The base is provisionally defined by the first occurrence of *C. cingulata* in the upper Sheinwoodian of Estonia. A reported earlier occurrence of the index species in the *Monograptus riccartonensis* Zone in Shropshire requires taxonomic reevaluation.

Conochitina pachycephala
The base is defined by the first occurrence of *C. pachycephala* in the Sheinwoodian of Estonia (close correlation with the graptolite zonation is lacking).

Sphaerochitina lycoperdoides
The base is defined by the first occurrence of *S. lycoperdoides*in the *Monograptus deubeli* Zone, Gotland. On Gotland it is a total-range zone, and there is a significant interval for which chitinozoan zones cannot yet be defined both on Gotland and in other sections.

Angochitina elongata
The base is defined by the first occurrence of *A. elongata* in the Gorstian of Shropshire, England (close correlation with the graptolite zonation is lacking).

Eisenackitina philipi
The base is defined by the first occurrence of *E. philipi* in the Ludfordian stratotype section in the Whitcliffe area, Ludlow, England (close

correlation with the graptolite zonation is lacking).

Eisenackitina barrandei
The base is defined by the first occurrence of *E. barrandei* in the upper Ludfordian of the Ludlow/Přídolí stratotype section at Požáry, Prague Basin, where the zone is a total-range zone. The underlying *E. philipi* Zone has not been found in the Prague Basin, but in the Upper Whitcliffe Formation of Shropshire there is a gap between the two, and this interval is at present unzoned.

Fungochitina kosovensis
The base is defined by the first occurrence of *F. kosovensis* just above the base of the Přídolí in the stratotype section at Požáry, Prague Basin.

Margachitina elegans
The base is defined by the first occurrence of *M. elegans* in the Přídolí of Algeria (close correlation with the graptolite zonation is lacking).

Anthochitina superba
The base is defined by the first occurrence of *A. superba* in the Přídolí of Algeria (close correlation with the graptolite zonation is lacking). The top is the base of the *Eisenackitina bohemica* Zone, just above the base of the Devonian in the stratotype section at Klonk, Prague Basin.

Vertebrate Biostratigraphy: Column 6

As noted by Turner (in Long, 1993), Silurian microvertebrates have been reported sporadically from Australia since 1982, but ".. systematic searching of Silurian limestones .. has only been underway for about a decade .." Since Turner's review, only one taxonomic paper has been published (Burrow & Simpson, 1995), on a new acanthodian from a Gorstian interval in the Jack Formation of northern Queensland. However, an international zonal scheme is emerging (see Blieck & Janvier, 1991). A tentative scheme based on the East Baltic succession and published by the Sub-commission on Silurian Stratigraphy (1993, 1995) has been revised and published by Märss *et al.* (1995), and it is that scheme which is shown in Column 6 of the Timescale Chart, appropriately aligned with Columns 2 and 3. This scheme, like that for Chitinozoa, is one of interval zones with each base defined by the entry of the defining species, and each top by the base of the succeeding zone. The scheme uses mainly thelodont taxa, but osteichthyans are used where thelodonts are as yet unclear. Tie-points noted by Märss *et al.* with the biochronological scale or the Subcommission's 1995 draft graptolite - conodont zonal schemes are:

Loganellia avonia
The base coincides with the base of the Sheinwoodian.

L. grossi
The base is high in the zone of *Ozarkodina sagitta rhenana - Kockelella patula*.

Paralogania martinssoni
The base is at or close to the base of the *Ozarkodina bohemica* and *Monograptus parvus - Gothograptus nassa* Zones (mid-Homerian).

P. ornata
The base is slightly below that of the *Ancoradella ploeckensis* Zone on Gotland, and the zone corresponds to the upper *Lobograptus scanicus* Zone.

P. elegans
The base is at or close to the base of the *A. ploeckensis* Zone.

Andreolepis hedei
The base is approximately coincident with that of the *Polygnathoides siluricus* Zone.

Thelodus sculptilis
The base is within the *Ozarkodina snajdri* Zone.

Nostolepis gracilis & *Poracanthodes punctatus*
These zones both lie within the conodont zone of *Ozarkodina remscheidensis*.

Kataporodus lithuanicus - K. timanicus
This zone (each species characterises a different facies) corresponds to the conodont zone of *Ozarkodina eosteinhornensis - Oulodus elegans detorta.* The top corresponds to the base of the basal Devonian zones of *Monograptus uniformis* and *Turinia pagei.*

Coral Assemblages: Column 7

In Strusz (1989) a series of four coral assemblages was recognised. These were based on range data for a combination of tabulatan and rugosan species, drawing on published data, and a summary in Pickett (1982) of an unpublished thesis by J.G. Byrnes. They were an extension of work begun by Vandyke & Byrnes (1976), who proposed one of the assemblages as the "Dripstone Fauna". These assemblages do not constitute a formal coral biozonation because there is insufficient continuity in the Australian coral-bearing sequences, ages are often still imprecise to highly uncertain, and there is far too little information on facies relationships of the relatively few described faunas. It does appear that all too many of the commoner species, both tabulatan and rugosan, appear to be long-ranging, so that coral-based correlation of small isolated faunas, which they are likely to dominate, is difficult. It is nevertheless interesting to note that the rugosan faunas of North Queensland, whose publication by Munson is imminent, appear to fit reasonably well into the scheme. This is being discussed elsewhere by Strusz & Munson.

There has been no advance in the knowledge of the tabulates, and the reader is referred to the range chart in Strusz (1989) for that group. In Fig. 3 are shown the ranges of selected rugosan taxa (the two Orders Cystiphyllida and Stauriida shown separately), incorporating data provided by Munson for North Queensland, and scaled according to the current Australian graptolite biozonation as shown in the main Timescale Chart.

Bridge Creek Assemblage

This is based on the rugosan and tabulate faunas of the Bridge Creek Limestone and underlying Wire Gully Limestone Members of the Bagdad Formation, southwest of Orange, these being of Rhuddanian to possibly early Aeronian age (Bischoff, 1986). The exact age limits of the assemblage are unknown, although the top is probably late in the Aeronian. There are major stratigraphic hiatuses above and below the Bagdad Formation. The Bridge Creek Limestone rugosans have been described or revised by McLean (1974b, 1974c, 1977, 1985), while the halysitids were described by Etheridge (1904). The fauna of the lower unit has not been described, but McLean's (1977) data suggest rugosans are rare, tabulatans not abundant.

In thin-bedded clean limestones of the Bridge Creek Member *C. (Cystiphyllum) khantikaense* is the characteristic rugosan and halysitids are common, while in the muddy facies the common rugosans are the smaller *Grewingkia parva, G. neumani* and *Calostylis panuarensis* (the tabulatans are also smaller), accompanied by the longer-ranging *C. (C.) siluriense cylindricum* and *Dentilasma honorabilis. Amplexoides gephyra*occurs in both facies - perhaps therefore a potential 'index species' for the fauna. According to Byrnes in Pickett (1982), the characteristic tabulate is *Pseudoplasmopora follis*, while *Palaeofavosites* (a holdover from the Ordovician, as is *Grewingkia* -- see McLean & Webby, 1976) is common, and *Desmidopora* makes its appearance. The Assemblage's halysitids too are a development of Ordovician faunas, with the continued presence of the *Catenipora* group and *Quepora*, and the expansion of the *Halysites catenularius* group. *H. nitidus* and *H. priscus* are characteristic, and *Schedohalysites orthopteroides* (far more widespread in the succeeding assemblage) makes its appearance. No coral faunas of this age have been recorded in northern Queensland.

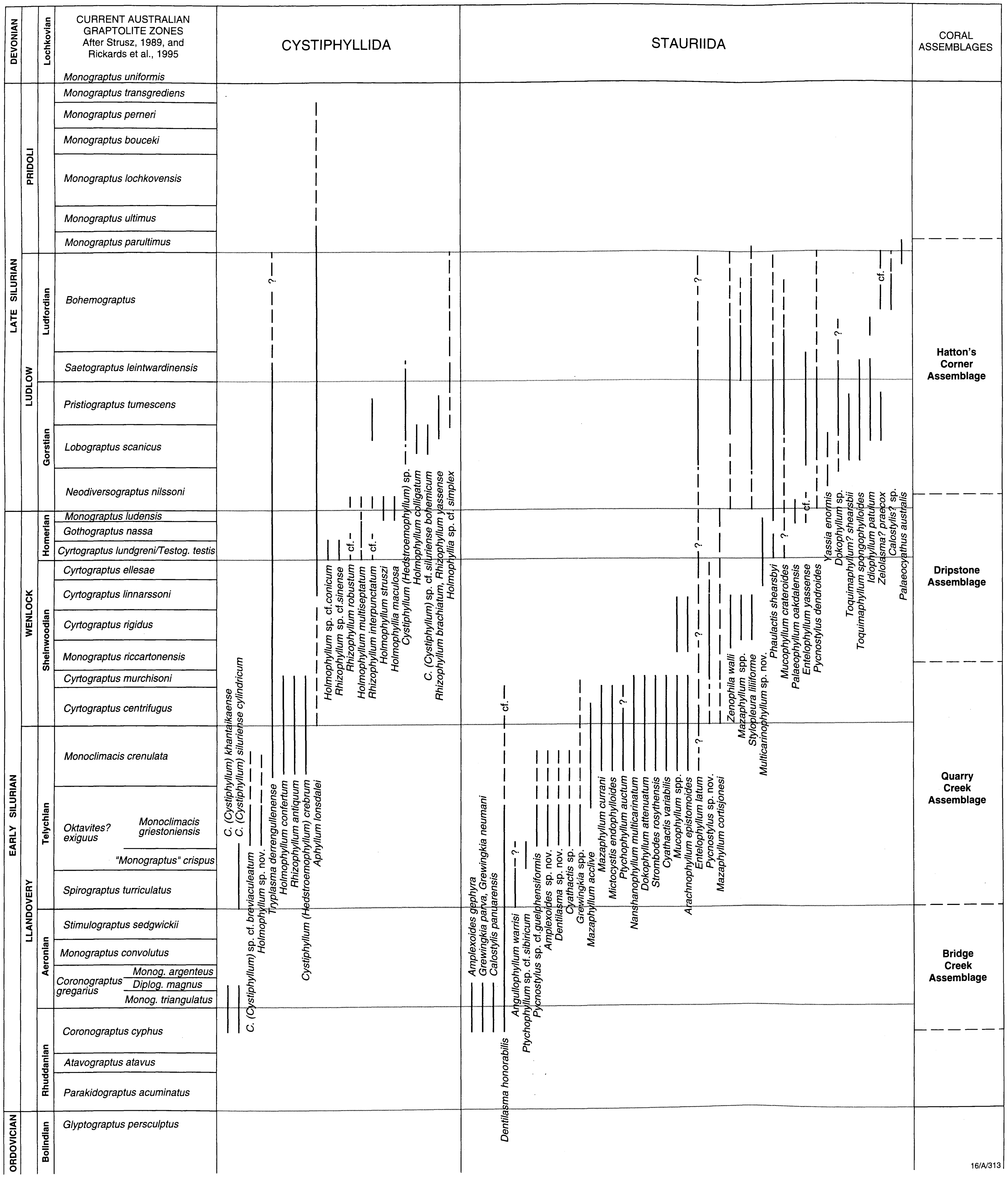
DEVONIAN
Lochkovian
CURRENT AUSTRALIAN GRAPTOLITE ZONES After Strusz, 1989, and Rickards et al., 1995
CYSTIPHYLLIDA
STAURIIDA
CORAL ASSEMBLAGES
Monograptus uniformis
LATE SILURIAN
PRIDOLI
Monograptus transgrediens
Monograptus perneri
Monograptus bouceki
Monograptus lochkovensis
Monograptus ultimus
Monograptus parultimus
LUDLOW
Ludfordian
Bohemograptus
Saetograptus leintwardinensis
Gorstian
Pristiograptus tumescens
Lobograptus scanicus
Neodiversograptus nilssoni
EARLY SILURIAN
WENLOCK
Homerian
Monograptus ludensis
Gothograptus nassa
Cyrtograptus lundgreni/Testog. testis
Sheinwoodian
Cyrtograptus ellesae
Cyrtograptus linnarssoni
Cyrtograptus rigidus
Monograptus riccartonensis
Cyrtograptus murchisoni
Cyrtograptus centrifugus
LLANDOVERY
Telychian
Monoclimacis crenulata
Oktavites? exiguus
Monoclimacis griestoniensis
"Monograptus" crispus
Spirograptus turriculatus
Aeronian
Stimulograptus sedgwickii
Monograptus convolutus
Coronograptus gregarius
Monog. argenteus
Diplog. magnus
Monog. triangulatus
Rhuddanian
Coronograptus cyphus
Atavograptus atavus
Parakidograptus acuminatus
ORDOVICIAN
Bolindian
Glyptograptus persculptus
C. (Cystiphyllum) sp. cf. braviaculeatum
C. (Cystiphyllum) khantaikaense
C. (Cystiphyllum) siluriense cylindricum
Holmophyllum sp. nov.
Tryplasma derrengullenense
Holmophyllum contertum
Rhizophyllum antiquum
Cystiphyllum (Hedstroemophyllum) crebrum
Aphyllum lonsdalei
Holmophyllum sp. cf. conicum
Rhizophyllum sp. cf. sinense
Rhizophyllum robustum
Holmophyllum multiseptatum
Rhizophyllum interpunctatum
Holmophyllum struszi
Holmophyllia maculosa
Cystiphyllum (Hedstroemophyllum) sp.
Holmophyllum colligatum
C. (Cystiphyllum) sp. cf. siluriense bohemicum
Rhizophyllum brachiatum, Rhizophyllum yassense
Holmophyllia sp. cf. simplex
Amplexoides gephyra
Grewingkia parva, Grewingkia neumani
Calostylis panuarensis
Dentilasma honorabilis
Angullophyllum warrisi
Ptychophyllum sp. cf. sibiricum
Pycnostylus sp. cf. guelphensiformis
Amplexoides sp. nov.
Dentilasma sp. nov.
Cyathactis sp.
Grewingkia spp.
Mazaphyllum acclive
Mazaphyllum currani
Mictocystis endophylloides
Ptychophyllum auctum
Nanshanophyllum multicarinatum
Dokophyllum attenuatum
Strombodes rosythensis
Cyathactis variabilis
Mucophyllum spp.
Arachnophyllum epistomoides
Entelophyllum latum
Pycnostylus sp. nov.
Mazaphyllum cortisjonesi
Zenophila walli
Mazaphyllum spp.
Stylopleura lilliforme
Multicarinophyllum sp. nov.
Phaulactis shearsbyi
Mucophyllum crateroides
Palaeophyllum oakdalensis
Entelophyllum yassense
Pycnostylus dendroides
Yassia enormis
Dokophyllum sp.
Toquimaphyllum? shearsbii
Toquimaphyllum spongophylloides
Idiophyllum patulum
Zelolasma? praecox
Calostylis? sp.
Palaeocyathus australis
cf.
?
Hatton's Corner Assemblage
Dripstone Assemblage
Quarry Creek Assemblage
Bridge Creek Assemblage

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Fig.3

Quarry Creek Assemblage

This more widespread and considerably more diverse Assemblage is based on the corals of the Quarry Creek Limestone and equivalent levels of the Rosyth Limestone, and the higher-energy sediments of the Cobbler's Creek Limestone and the Burly Jack Sandstone Member of the Glendalough Formation; (McLean, 1974a, 1974b, 1975b, 1977), all near Orange. The assemblage is now considered to be of Telychian to early Sheinwoodian age (Zones of *Spirograptus turriculatus* to *Cyrto-graptus murchisoni*).

Arachnophyllum epistomoides is characteristic of most occurrences (it persists to the upper *Monograptus riccartonensis* Zone in the lower Mirrabooka Formation), supplemented by *Angullophyllum warrisi* and persisting *C. (Cystiphyllum) siluriense cylindricum* at lower levels, and by species of *Ptychophyllum*. The Assemblage sees the appearance of *Cystiphyllum (Hedstroemophyllum), Holmophyllum, Rhizophyllum* and *Mazaphyllum* amongst many others. Of the tabulates, *Angopora hisingeri, Kitakamaia mirabilis, Liscombea insolens* and *Thecia* are known only from this level, in which also occur the earliest *Cladopora seriatopora, Coenites pinaxoides, Multisolenia* and possibly *Propora*. The halysitids, ubiquitous in the Quarry Creek Limestone, show a major radiation, with the entry of several long-ranging species-groups. The earlier-appearing *Halysites catenularius* and *Schedohalysites orthopteroides* are prominent, the several forms confined to the assemblage are not.

The Quarry Creek Assemblage is also known from the rather limited fauna in a limestone lens in the Peppercorn Formation at 'Cooinbil' southwest of Canberra (Hill, 1954), in the Zone of *Pterospathodus amorphognathoides*, and from a fault block in the Woolomin Beds of the New England area (Hall, 1978), where the distinctive rugosan is *Mazaphyllum acclive*. Taxa typical of the Assemblage have been listed by Sherwin (1971) from limestone lens A at the base of the Boree Creek Formation (near Orange), also in the *Pt. amorphognathoides* Zone. The list includes *Mucophyllum*; if correct, this would be the earliest occurrence of that genus.

The rugosans occurring near the base of the Quinton Formation (Graveyard Creek Group) in North Queensland are being described by Munson. Conodonts indicate a late Telychian age. The earlier Bridge Creek Assemblage is reflected in the occurrence of *Dentilasma honorabilis* (uncommon there), species of *Grewingkia*, and a new *Amplexoides*, but indicative of the Quarry Creek Assemblage are *Holmophyllum*, a new arachnophyllid genus, *Cyathactis*, and the entry of *Rhizophyllum*. The occurrence of *Pycnostylus* and *Aphyllum* foreshadows the Dripstone and Hattons Corner Assemblages.

Dripstone Assemblage

The Dripstone Fauna was proposed by Vandyke & Byrnes (1976) for the faunas of the Homerian - earliest Gorstian Wylinga and Catombal Park Formations (Dripstone Group) near Wellington, NSW (and their equivalents elsewhere in the State). The faunas of those formations have been described by Strusz (1961) and McLean (1975a).

There is no sharp change in the rugosan element from the preceding assemblages, but an expansion in the variety of tryplasmatids and goniophyllids, and the entry of *Zenophila, Stylopleura* and *Holmophyllia* (a taxon considered distinct by McLean but synonymous with *Holmophyllum* by Hill, 1981). *Phaulactis shearsbyi* and *Aphyllum lonsdalei* probably also enter at this level. While the general tabulate fauna is clearly increasingly varied the multisoleniids are at their end, and the halysitids are less diverse (the fairly widespread *Acanthohalysites australis* probably first appears in this assemblage). Characteristic tabulates are *Drymopora* and *Favosipora*.

Representatives of this Assemblage have been listed (but not described) from the lower

Mirrabooka Formation (limestone lens D) near Orange (Sherwin, 1971; Pickett, 1982, p. 147), part of the nearby Borenore Limestone (Pickett, 1982, p. 20), and a limestone lens near Uriarra Crossing near Canberra now known to be within the Walker Volcanics (Strusz in Pickett, 1982, p. 133). The age of the assemblage thus extends from the mid-Sheinwoodian (probably high in the zone of *Monograptus riccartonensis*) to the earliest Gorstian; the age of upper boundary is somewhat uncertain, as the conodont faunas of the Catombal Park Formation and overlying Narragal Limestone have yet to be properly described and assessed (see Simpson, 1995, p. 337).

The Jack Formation (Graveyard Creek Group) in the Broken River Province contains three successive coral faunas (Hill *et al.*, 1969, figured some tentatively identified corals from the formation). The oldest appears to represent the Dripstone Assemblage. As farther south, the rugosans, which include such forms as *C.* (*Cystiphyllum*), *Aphyllum* and *Pycnostylus*, show no sharp change from the Quarry Creek Assemblage. Near the top of this lower Jack Formation fauna appear possible forerunners of the Hattons Corner Assemblage: *Multicarinophyllum* and *?Entelophyllum latum* (the latter may occur earlier as well); conodonts at this coral-rich level give a general Homerian age.

Hatton's Corner Assemblage

The corals of the Yass sequence, most of which occur in what is now the Silverdale Formation (Hatton's Corner Group of Link & Druce, 1972 -- for the confused nomenclatural history of this sequence see Owen & Wyborn, 1979), were well described by Hill (1940) and in various papers by O.A. Jones. The rugosans have been revised by McLean (1976). These corals form the basis of the Hatton's Corner Assemblage, of Ludlow and possibly Přídolí age - the upper limit is indefinite, as there are few described Přídolí species.

The commonest rugosans are usually the earlier-appearing *Phaulactis shearsbyi* and *Aphyllum lonsdalei*, but species appearing at this level include *Toquimaphyllum spongophylloides*, *T. shearsbii*, *Idiophyllum patulum*, the distinctive *Yassia enormis*, *Zelolasma? praecox* and probably *Entelophyllum latum*. There are several species of the earlier-appearing *Rhizophyllum*. As noted by Pickett (1982, p. 23), the favositids are increasingly dominated by large-celled squamulate species such as *Squameofavosites richardsi*; the only other distinctive tabulatan is the laminar *Placocoenites*. Overall the non-halysitid fauna shows little change from the Dripstone Assemblage apart from the disappearance of the multisoleniids. The halysitids continued to decline; they are frequently -- almost characteristically -- absent. In sequences where halysitids are still present diversity is low, one species usually is dominant, and all belong to the long-ranging groups which started in the Llandovery.

In the Yass Syncline the Hattons Corner Assemblage appears in the Cliftonwood Limestone, diversifies through the Silverwood Formation, and also occurs in the mid-late Gorstian Yarwood Siltstone Member (Black Bog Shale). Only the small solitary *Palaeocyathus australis* occurs above that level at Yass, but elsewhere other species representative of the Assemblage persist probably to the end of the Ludlow and possibly into the Přídolí. Following the work of Link & Druce (1972) the earliest age is early Gorstian, but Simpson (1995) has suggested it may even be late Homerian; the matter remains to be settled.

Apart from Yass, the Assemblage is known in the Quidong Limestone near Delegate, southern N.S.W. (Pickett, 1982, p. 117), the Glenbower Formation south of Yass, the Yarralumla Formation in Canberra, the upper Yarrangobilly Limestone southwest of Canberra (Hill, 1954), uncertain but not low levels in the nearby Cooleman Limestone, the Narragal Limestone and lenses in the succeeding Barnby Hills Shale southeast of Wellington (Strusz, 1961, McLean, 1975a, Pickett, 1982, p. 151), and the middle? to upper Mirrabooka Formation west of Orange

(Sherwin, 1971). The upper Molong and Borenore Limestones are of appropriate age, but little is known of their coral content. The Rainbow Hill Member at Yass and the coralline limestones of the Barnby Hills Shale near Wellington may be of early Přídolí age.

Two small faunas in lenticular limestones in northeastern Victoria almost certainly represent this Assemblage (see VandenBerg, 1988): Talent *et al.* (1975) recorded *Stylopleura liliiforme* (as *Mucophyllum*), *Propora conferta* and *Favosites allani* from the Gibbo River Siltstone (Ludlow?), while Talent (1959) listed *S. liliiforme, Aphyllum lonsdalei* (as *Fletcheria dendroidea*) and *Mucophyllum crateroides* from the late Gorstian to Ludfordian Cowombat Siltstone.

The middle of the three Jack Formation faunas clearly belongs with the Hattons Corner Assemblage, with such taxa as *Tryplasma derrengullenense, Stylopleura liliiforme, Entelophyllum latum* and *E. yassense* plus the entry of a new kyphophyllid, *Dokophyllum* and *Ptychophyllum. Multicarinophyllum* persists from the lower fauna, and the occurrence of *Cystiphyllum* (*Hedstroemophyllum*) recalls the earlier Quarry Creek Assemblage. Conodonts suggest a late Gorstian age for this fauna. The upper fauna, on conodonts correlated with the Ludfordian at Yass, is a reduced continuation of the middle fauna, including the new kyphophyllid, *T. derrengullenense, S. liliiforme* and *E. latum*. There are no fresh taxa.

Relative Sea Level: Column 8

Until fairly recently, little has been published on relative sea levels through the Silurian. However, it is now possible to add to the chart a reasonable curve showing changes on a global scale. The one shown in Column 8 of the Timescale Chart is by Johnson *et al.*, 1991, redrawn to accord with the relative lengths of stages and graptolite zones shown in Columns 2 and 3. The curve shows a general trend of deepening during the Rhuddanian and Aeronian, relatively deep water during most of the remaining Early Silurian, then rapid shallowing at the beginning of the Homerian, that shallowing more or less continuing (although less abruptly) until the end of the Silurian. Superimposed on this overall pattern is a sequence of high and low stands which the authors have recognised globally. In Australia the main points on this global curve that they have recognised are:

High stand about the Rhuddanian/Aeronian boundary, corresponding to the graptolitic Avon Lea Mudstone (Angullong, south of Orange, NSW; see Jenkins *et al.*, 1986).

Low stand within the *Coronograptus cyphus* Zone, corresponding to the upper part of the Cadia Group (Jenkins *et al.*).

High stand within the *Spirograptus turriculatus* Zone, represented by the Cobbler's Creek Limestone near Orange.

Low stand within the *"Monograptus" crispus* Zone, represented by the sandstones above the Cobbler's Creek Limestone.

High stand within the *Monoclimacis crenulata* Zone, represented by the Ashleigh Member, Glendalough Formation (Jenkins *et al.*).

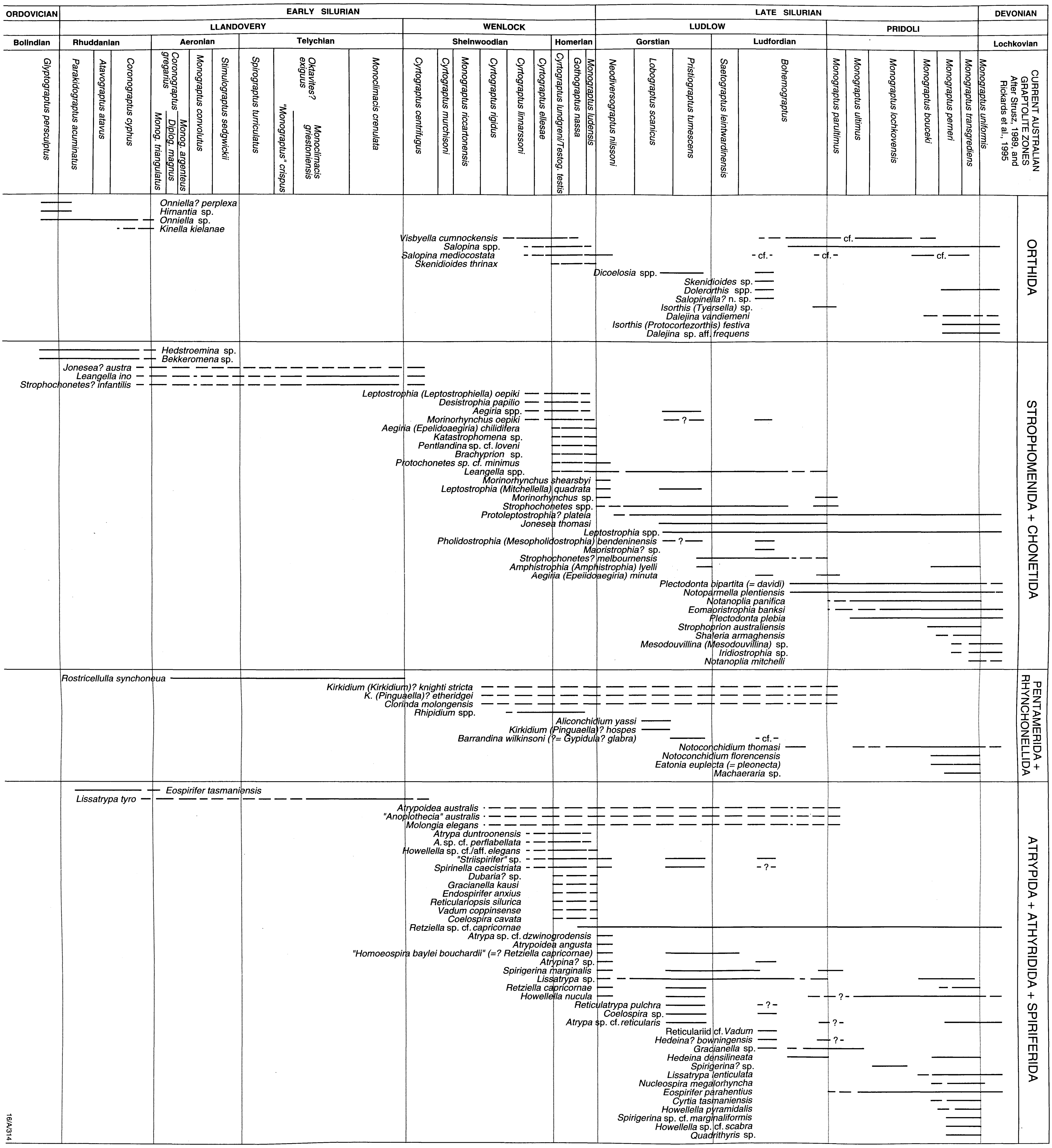
Low stand in the early *Cyrtograptus murchisoni* Zone, represented by the Willow Glen Formation at Cudgegong, with gypsum-bearing oolitic beds (Jones *et al.*, 1987).

High stand in the early *Lobograptus scanicus* Zone, represented by the Barrandella Shale Member of the Silverdale Formation at Yass (Jenkins *et al.*).

Low stand in the *Saetograptus leintwardinensis* Zone, represented by the succeeding Hume Limestone Member at Yass.

High stand during the Late Ludfordian, represented by the generally sparsely fossiliferous shales above the Silverdale Formation at Yass.

Low stand towards the Silurian-Devonian boundary, represented by the limestones of the upper Elmside Formation at Yass.


ORDOVICIAN
EARLY SILURIAN
LATE SILURIAN
DEVONIAN
LLANDOVERY
WENLOCK
LUDLOW
PRIDOLI
Bolindian
Rhuddanian
Aeronian
Telychian
Sheinwoodian
Homerian
Gorstian
Ludfordian
Lochkovian
Glyptograptus persculptus
Parakidograptus acuminatus
Atavograptus atavus
Coronograptus cyphus
Coronograptus gregarius
Monog. triangulatus
Diplog. magnus
Monog. argenteus
Monograptus convolutus
Stimulograptus sedgwickii
Spirograptus turriculatus
Oktavites? exiguus
"Monograptus" crispus
Monoclimacis griestoniensis
Monoclimacis crenulata
Cyrtograptus centrifugus
Cyrtograptus murchisoni
Monograptus riccartonensis
Cyrtograptus rigidus
Cyrtograptus linnarssoni
Cyrtograptus ellesae
Cyrtograptus lundgreni/Testog. testis
Gothograptus nassa
Monograptus ludensis
Neodiversograptus nilssoni
Lobograptus scanicus
Pristiograptus tumescens
Saetograptus leintwardinensis
Bohemograptus
Monograptus parultimus
Monograptus ultimus
Monograptus lochkovensis
Monograptus bouceki
Monograptus perneri
Monograptus transgrediens
Monograptus uniformis
CURRENT AUSTRALIAN GRAPTOLITE ZONES After Strusz, 1989, and Rickards et al., 1995
ORTHIDA
Onniella? perplexa
Hirnantia sp.
Onniella sp.
Kinella kielanae
Visbyella cumnockensis
cf.
Salopina spp.
Salopina mediocostata
cf.
cf.
cf.
Skenidioides thrinax
Dicoelosia spp.
Skenidioides sp.
Dolerorthis spp.
Salopinella? n. sp.
Isorthis (Tyersella) sp.
Dalejina vandiemeni
Isorthis (Protocortezorthis) festiva
Dalejina sp. aff. frequens
STROPHOMENIDA + CHONETIDA
Hedstroemina sp.
Bekkeromena sp.
Jonesea? austra
Leangella ino
Strophochonetes? infantilis
Leptostrophia (Leptostrophiella) oepiki
Desistrophia papilio
Aegiria spp.
Morinorhynchus oepiki
?
Aegiria (Epelidoaegiria) chilidifera
Katastrophomena sp.
Pentlandina sp. cf. loveni
Brachyprion sp.
Protochonetes sp. cf. minimus
Leangella spp.
Morinorhynchus shearsbyi
Leptostrophia (Mitchellella) quadrata
Morinorhynchus sp.
Strophochonetes spp.
Protoleptostrophia? plateia
Jonesea thomasi
Leptostrophia spp.
Pholidostrophia (Mesopholidostrophia) bendeninensis
?
Mapristrophia? sp.
Strophochonetes? melbournensis
Amphistrophia (Amphistrophia) lyelli
Aegiria (Epelidoaegiria) minuta
Plectodonta bipartita (= davidi)
Notoparmella plentiensis
Notanoplia panifica
Eomaoristrophia banksi
Plectodonta plebia
Strophoprion australiensis
Shaleria armaghensis
Mesodouvillina (Mesodouvillina) sp.
Iridiostrophia sp.
Notanoplia mitchelli
PENTAMERIDA + RHYNCHONELLIDA
Rostricellulla synchoneua
Kirkidium (Kirkidium)? knighti stricta
K. (Pinguaella)? etheridgei
Clorinda molongensis
Rhipidium spp.
Aliconchidium yassi
Kirkidium (Pinguaella)? hospes
Barrandina wilkinsoni (?= Gypidula? glabra)
cf.
Notoconchidium thomasi
Notoconchidium florencensis
Eatonia euplecta (= pleonecta)
Machaeraria sp.
ATRYPIDA + ATHYRIDIDA + SPIRIFERIDA
Eospirifer tasmaniensis
Lissatrypa tyro
Atrypoidea australis
"Anoplothecia" australis
Molongia elegans
Atrypa duntroonensis
A. sp. cf. perflabellata
Howellella sp. cf./aff. elegans
"Striispirifer" sp.
Spirinella caecistriata
?
Dubaria? sp.
Gracianella kausi
Endospirifer anxius
Reticulariopsis silurica
Vadum coppinsense
Coelospira cavata
Retziella sp. cf. capricornae
Atrypa sp. cf. dzwinogrodensis
Atrypoidea angusta
"Homoeospira baylei bouchardii" (=? Retziella capricornae)
Atrypina? sp.
Spirigerina marginalis
Lissatrypa sp.
Retziella capricornae
Howellella nucula
?
Reticulatrypa pulchra
?
Coelospira sp.
Atrypa sp. cf. reticularis
?
Reticulariid cf. Vadum
Hedeina? bowningensis
?
Gracianella sp.
Hedeina densilineata
Spirigerina? sp.
Lissatrypa lenticulata
Nucleospira megalorhyncha
Eospirifer parahentius
Cyrtia tasmaniensis
Howellella pyramidalis
Spirigerina sp. cf. marginaliformis
Howellella sp. cf. scabra
Quadrithyris sp.

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GROUPS NOT SHOWN ON TIMESCALE CHART

Brachiopods

The use of brachiopods in Australian biostratigraphy has advanced little since the first Timescale Record (Strusz, 1989) was published. Only two papers describing new faunas have appeared: one for the poorly preserved and stratigraphically coarsely controlled faunas of western New South Wales (Sherwin, 1995), the other dealing with faunas of Ordovician and earliest Silurian age in Tasmania (Laurie, 1991). Otherwise, there have been some taxonomic revisions affecting generic position or name, but little else.

It remains the case that the only succession with a sufficient stratigraphic range to offer the possibility of zonation is that of the Melbourne Trough. Unfortunately the Silurian part of this sequence is monotonous lithologically but relatively complex tectonically, so that control on known brachiopod occurrences is often poor. Garratt (1983) proposed two late Silurian brachiopod zones, further discussed by Garratt & Wright (1989) but strongly criticised by Jell & Talent (1989). As much of the taxonomy supporting Garratt's stratigraphic work remains unpublished, this zonation cannot be properly put in context or assessed for reliability, and is not shown on the Timescale Chart.

Garratt's older zone is that of *Aegiria thomasi* (now *Jonesea thomasi*), whose base is defined by the first occurrence of *J. thomasi* in unit 2 of the Dargile Formation at Whittlesea, Heathcote and Kinglake. The age of the Zone is considered to be essentially Gorstian.

The younger of Garratt's two Silurian zones is that of *Notoparmiella plentiensis*, whose base is defined by the appearance "in abundance" of the eponymous and other species some distance above the base of the Humevale Formation in the Whittlesea area. It is an acme-zone, not an interval zone, as *N. plentiensis* is known sporadically and in small numbers at lower stratigraphic levels. The Zone is considered to be essentially of Ludfordian and Přídolí age.

In Fig. 4 the ranges of selected brachiopod taxa have been plotted against the current Australian graptolite zonation, using the currently available ages for the strata involved (mostly based on a combination of graptolites and conodonts). One significant change from the more extended 1989 version of this range chart concerns the *Illaenus* Band at the base of the Wapentake Formation. The age of this unit was based on graptolites, but the fauna was never published, and the specimens cannot now be found. Holloway (pers. comm.) considers the early Aeronian age unlikely because the trilobite fauna includes *Ananaspis*, which nowhere else is older than Wenlock. I have represented the age of the Band as uncertain, either the original (Zone of *Coronograptus gregarius*), or very latest Telychian to early Sheinwoodian. Two of the relevant brachiopod species shown in Fig. 4 are known from Telychian strata elsewhere in the Melbourne Trough (based on ranges plotted by Garrett, 1983), which lends some support to a late Telychian age for the *Illaenus* Band.

Fig. 4 is divided into columns each representing one or several Articulate brachiopod Orders, to make searching for particular taxa somewhat faster. Taxonomic changes which should be noted are:

Aegiria austra is now *Jonesea? austra* (Cocks & Rong, 1989).

A. thomasi is now *J. thomasi* (ibid.)

Sowerbyella? plebia is now *Plectodonta (Plectodonta) plebia* (ibid.).

Camarotoechia synchoneua is considered to be a *Rostricellulla* (Baillie, p. 228 in Banks & Baillie, 1989).

Molongia elegans capricornae is now *Retziella capricornae*, and other un-named *Molongia* are also considered to be either *R. capricornae* or at least *Retziella* (Rong *et al.*, 1994). *M. elegans* is restricted to the type locality.

The apparent steps in ranges are as yet largely an artefact of publication. Several papers by Strusz

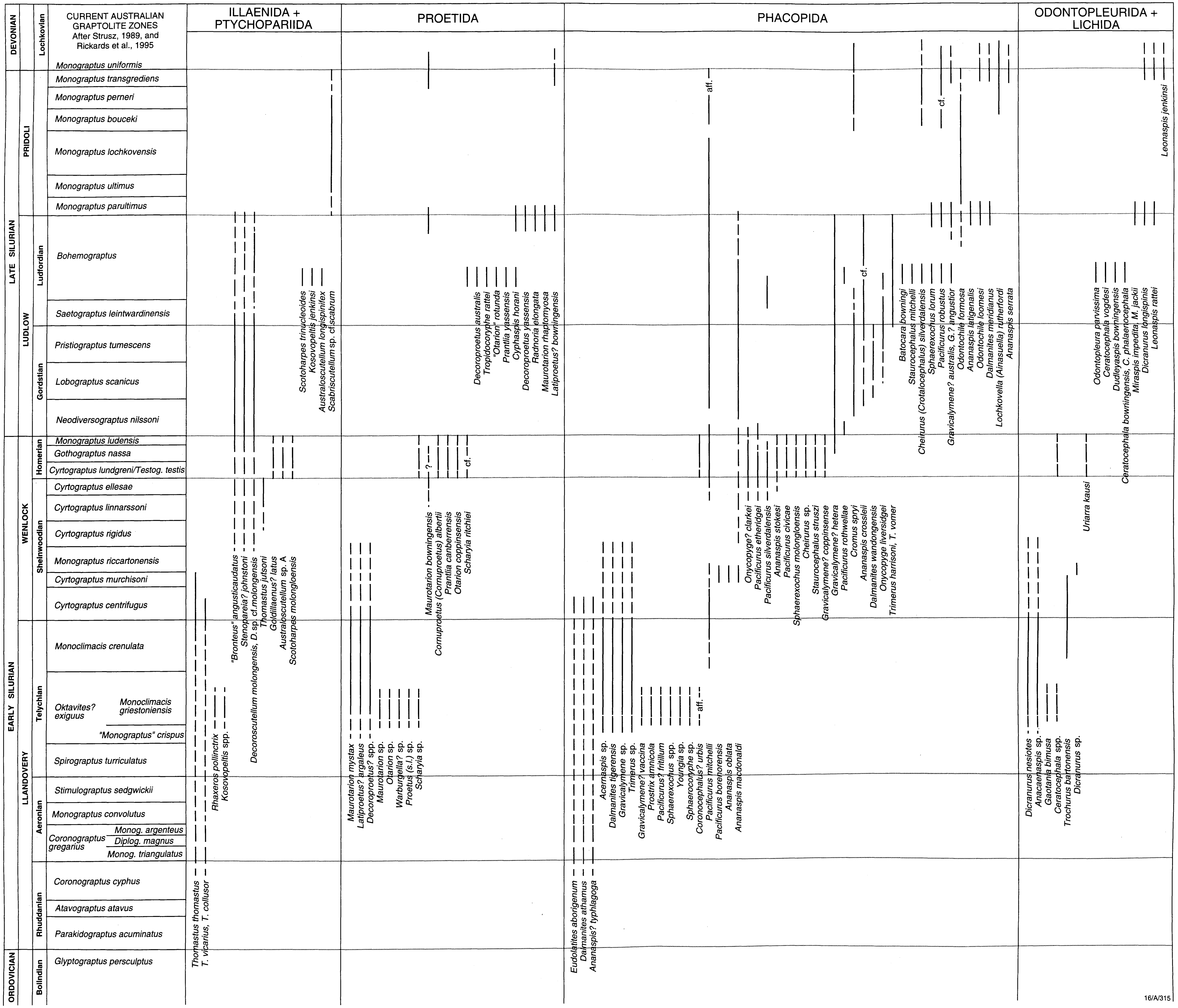
DEVONIAN
Lochkovian
LATE SILURIAN
PRIDOLI
LUDLOW
Ludfordian
Gordstian
EARLY SILURIAN
WENLOCK
Homerian
Sheinwoodian
LLANDOVERY
Telychian
Aeronian
Rhuddanian
ORDOVICIAN
Bolindian
CURRENT AUSTRALIAN GRAPTOLITE ZONES After Strusz, 1989, and Rickards et al., 1995
Monograptus uniformis
Monograptus transgrediens
Monograptus perneri
Monograptus bouceki
Monograptus lochkovensis
Monograptus ultimus
Monograptus parultimus
Bohemograptus
Saetograptus leintwardinensis
Pristiograptus tumescens
Lobograptus scanicus
Neodiversograptus nilssoni
Monograptus ludensis
Gothograptus nassa
Cyrtograptus lundgreni/Testog. testis
Cyrtograptus ellesae
Cyrtograptus linnarssoni
Cyrtograptus rigidus
Monograptus riccartonensis
Cyrtograptus murchisoni
Cyrtograptus centrifugus
Monoclimacis crenulata
Oktavites? exiguus
Monoclimacis griestoniensis
"Monograptus" crispus
Spirograptus turriculatus
Stimulograptus sedgwickii
Monograptus convolutus
Coronograptus gregarius
Monog. argenteus
Diplog. magnus
Monog. triangulatus
Coronograptus cyphus
Atavograptus atavus
Parakidograptus acuminatus
Glyptograptus persculptus
ILLAENIDA + PTYCHOPARIIDA
PROETIDA
PHACOPIDA
ODONTOPLEURIDA + LICHIDA
Thomastus thomastus
T. vicarius, T. collusor
Rhaxeros pollinctrix
Kosovopeltis spp.
"Bronteus" angusticaudatus
Stenopareia? johnstoni
Decoroscutellum molongensis, D. sp. cf. molongensis
Thomastus jutsoni
Goldillaenus? latus
Australoscutellum sp. A
Scotoharpes molongloensis
Scotoharpes trinucleoides
Kosovopeltis jenkinsi
Australoscutellum longispinifex
Scabriscutellum sp. cf. scabrum
Maurotarion mystax
Latiproetus? argaleus
Decoroproetus? spp.
Maurotarion sp.
Otarion sp.
Warburgella? sp.
Proetus (s.l.) sp.
Scharyia sp.
Maurotarion bowningensis
Cornuproetus (Cornuproetus) albertii
Prantlia canberrensis
Otarion coppinsensis
Scharyia ritchiei
?
cf.
Decoroproetus australis
Tropidocoryphe rattei
"Otarion" rotunda
Prantlia yassensis
Cyphaspis horani
Decoroproetus yassensis
Radnoria elongata
Maurotarion rhaptomyosa
Latiproetus? bowningensis
Eudolatites aborigenum
Dalmanites athamus
Ananaspis? typhlagoga
Acernaspis sp.
Dalmanites tigerensis
Gravicalymene sp.
Trimerus sp.
Gravicalymene? vaccina
Prostrix amnicola
Pacificurus? fritillum
Sphaerexochus spp.
Youngia sp.
Sphaerocoryphe sp.
Coronocephalus? urbis
Pacificurus mitchelli
Pacificurus boreronensis
Ananaspis oblata
Ananaspis macdonaldi
aff.
Onycopyge? clarkei
Pacificurus etheridgei
Pacificurus silverdalensis
Ananaspis stokesi
Pacificurus civicae
Sphaerexochus molongloensis
Cheirurus sp.
Staurocephalus struszi
Gravicalymene? coppinsense
Gravicalymene? hetera
Pacificurus rothwellae
Cromus spryi
Ananaspis crossleii
Dalmanites wandongensis
Onycopyge liversidgei
Trimerus harrisoni, T. vomer
Batocara bowningi
Staurocephalus mitchelli
Cheirurus (Crotalocephalus) silverdalensis
Sphaerexochus lorum
Pacificurus robustus
Gravicalymene? australis, G.? angustior
Odontochile formosa
Ananaspis latigenalis
Odontochile loomesi
Dalmanites meridianus
Lochkovella (Ainasuella) rutherfordi
Ananaspis serrata
Dicranurus nesiotes
Anacaenaspis sp.
Gaotania bimusa
Ceratocephala spp.
Trochurus bartonensis
Dicranurus sp.
Uriarra kausi
Ceratocephala bowningensis, C. phalaenocephala
Odontopleura parvissima
Ceratocephala vogdesi
Dudleyaspis bowningensis
Miraspis impedita, M. jackii
Dicranurus longispinis
Leonaspis rattei
Leonaspis jenkinsi

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Fig. 5

on the late Wenlock faunas of Canberra, and the papers by Etheridge and Mitchell (now long overdue for taxonomic revision) on the Ludlow to earliest Přídolí faunas of the Yass sequence dominate the lists.

Trilobites

As with Silurian brachiopods, so with Silurian trilobites the advances since Strusz (1989) have not been enough to contemplate even a coarse biozonation. Two papers (Holloway & Sandford, 1993; Holloway, 1994) have described new Llandovery faunas from Tasmania and North Queensland, and two other papers have revised some species and added new taxa to previously-described faunas in the Yass - Canberra area (Sun, 1990; Adrain & Chatterton, 1994). Other than these, and the effects of some age reassessments (noted in the sections on coral and brachiopod biostratigraphy), the detailed discussion in Strusz (1989) remains generally valid.

Fig. 5 displays the ranges of selected trilobite species -- the comments made concerning ranges in Fig. 4 apply here as well. In this figure also, the species have been grouped by Order, with some little-represented Orders themselves combined. Significant taxonomic changes from the species shown by Strusz (1989), or to species erected since then, are:

Harpidella rhaptomyosa Sun is placed in *Maurotarion*, after Holloway, 1994.

Otarion (Conoparia) horani has reverted to *Cyphaspis*, following Adrain & Chatterton, 1994, and Holloway, 1994.

H. (Harpidella) bowningensis is placed in *Maurotarion*, after Holloway, 1994.

Proetus bowningensis is placed in *Latiproetus*, after Owens, 1973, and Sun, 1990.

Otarion sp. aff. *horani* is now *Otarion coppinsensis* Adrain & Chatterton, 1994.

Ceratocephala jacki was placed in *Miraspis* by Ramsköld, 1991, and Holloway & Sandford, 1993.

Ceratocephala impedita is now *Miraspis*, after Holloway, 1994.

All species referred to *Sthenarocalymene* are now referred tentatively to *Gravicalymene*, after Holloway, 1994.

All species previously listed under *Encrinurus (Pacificurus)* are now listed as *Pacificurus*. I disagree with Holloway (1994) that *Pacificurus* cannot be separated from, and is thus a junior synonym of, *Batocara*. I refer his *Batocara fritillum* tentatively to *Pacificurus*.

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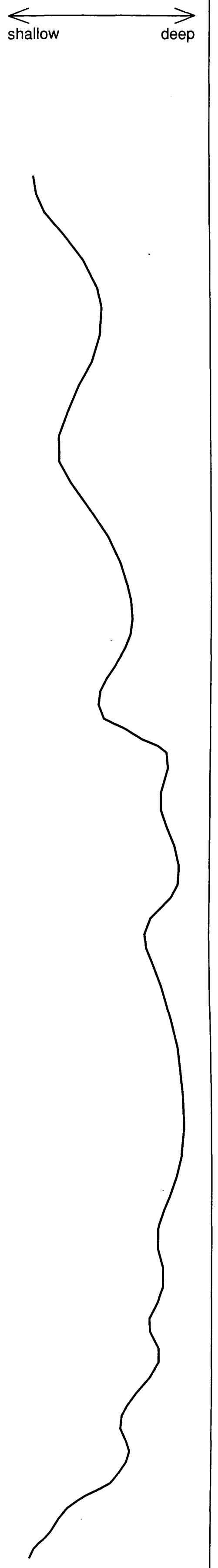
1	2			3		4		5	6	7
				CURRENT AUSTRALIAN GRAPTOLITE ZONES After Strusz, 1989, and Rickards et al., 1995	GENERALISED GRAPTOLITE ZONES Subcommission on Silurian Stratigraphy 1995 draft zonation	AUSTRALIAN CONODONT ZONES After Simpson, 1995	GENERALISED CONODONT ZONES Subcommission on Silurian Stratigraphy 1995 draft zonation	GLOBAL CHITINOZOAN ZONES Verniers, Nestor, Paris, Dufka, Sutherland & Van Grootel, 1995	GENERALISED VERTEBRATE ZONES Märss, Fredholm, Talimaa, Turner, Jeppson & Nowlan, 1995	CORAL ASSEMBLAGES Strusz, 1989
	DEVONIAN		**Lochkovian**	*Monograptus uniformis*	*Monograptus uniformis*	*Icriodus woschmidti*		*Eisenackitina bohemica*	*Turinia pagei*	
410	**LATE SILURIAN**	**PRIDOLI**		*Monograptus transgrediens*			*Ozasrkodina eosteinhornensis - Oulodus elegans detorta*		*Kataporodus timanicus - K. lithuanicus*	
				Monograptus perneri	*Monograptus bouceki - Monograptus transgrediens*			*Anthochitina superba*	*Poracanthodes punctatus*	
				Monograptus bouceki						
				Monograptus lochkovensis	*Monograptus branikensis - Monograptus lochkovensis*	[unzoned]	*Ozarkodina remscheidensis*	*Margachitina elegans*	*Nostolepis gracilis*	
				Monograptus ultimus	*Monograptus parultimus - Monograptus ultimus*			*Fungochitina kosovensis*		
				Monograptus parultimus					*Thelodus sculptilis*	
415		**LUDLOW**	**Ludfordian**	*Bohemograptus*	*Monograptus formosus* *Bohemograptus tenuis - Bohemograptus kozlowskii*	*Ozarkodina crispa* [unzoned]	*Ozarkodina crispa* *Ozarkodina snajdri*	*Eisenackitina barrandei* (unzoned) *Eisenackitina philipi*	*Andreolepis hedei*	
				Saetograptus leintwardinensis	*Saetograptus leintwardinensis*	*Polygnathoides siluricus*	*Polygnathoides siluricus*			**Hatton's Corner Assemblage**
			Gorstian	*Pristiograptus tumescens*	*Lobograptus scanicus*	*Ancoradella ploeckensis*	*Ancoradella ploeckensis*	*Angochitina elongata*	*Paralogania elegans* *Paralogania ornata*	
				Lobograptus scanicus			[unzoned]	(unzoned)		
				Neodiversograptus nilssoni	*Neodiversograptus nilssoni*		*Kockelella stauros*		*Paralogania martinssoni*	
420		**WENLOCK**	**Homerian**	*Monograptus ludensis*	*Monograptus ludensis*			*Sphaerochitina lycoperdoides*		
				Gothograptus nassa	*Monograptus praedeubeli -- M. deubeli* *Monograptus parvus - Gothograptus nassa*	[unzoned]	*Ozarkodina bohemica*			
				Cyrtograptus lundgreni/Testog. testis	*Cyrtograptus lundgreni*		*Ozarkodina sagitta sagitta*	*Conochitina pachycephala*		
			Sheinwoodian	*Cyrtograptus ellesae*			[unzoned]			
				Cyrtograptus linnarssoni	*Cyrtograptus rigidus to Cyrtograptus perneri*	*Kockelella amsdeni*		*Cingulochitina cingulata*	*Loganellia grossi*	**Dripstone Assemblage**
				Cyrtograptus rigidus			*Ozarkodina sagitta rhenana - Kockelella patula*			
				Monograptus riccartonensis	*Monograptus riccartonensis - Monograptus belophorus*	*Kockelella ranuliformis*	*Kockelella ranuliformis*			
				Cyrtograptus murchisoni				*Margachitina margaritana*	*Loganellia avonia*	
				Cyrtograptus centrifugus	*Cyrtograptus centrifugus - Cyrtograptus murchisoni*	*Pterospathodus amorphognathoides*	*Pterospathodus amorphognathoides*			
425	**EARLY SILURIAN**	**LLANDOVERY**	**Telychian**	*Monoclimacis crenulata*	*Cyrtograptus lapworthi - C. insectus* *Monograptus spiralis*			*Angochitina longicollis*		
				Oktavites? exiguus / *Monoclimacis griestoniensis*	*Monoclimacis griestoniensis - Monoclimacis crenulata*	*Pterospathodus celloni*	*Pterospathodus celloni*			**Quarry Creek Assemblage**
				"Monograptus" crispus	*Spirograptus turriculatus - Monograptus crispus*				*Loganellia scotica - L. sibirica*	
				Spirograptus turriculatus	*Spirograptus guerichi*	*Distomodus staurognathoides*		*Eisenackitina dolioliformis*		
			Aeronian	*Stimulograptus sedgwickii*	*Stimulograptus sedgwickii*		*Pterospathodus? tenuis - Distomodus staurognathoides*			
430				*Monograptus convolutus*	*Demirastrites convolutus*	[unzoned]		*Conochitina alargada*		
				Coronograptus gregarius: *Monog. argenteus*	*Monograptus argenteus*					
				Coronograptus gregarius: *Diplog. magnus*	*Demirastrites triangulatus - Demirastrites pectinatus*			*Spinachitina maennili*		**Bridge Creek Assemblage**
				Coronograptus gregarius: *Monog. triangulatus*		*Distomodus pseudopesavis*				
			Rhuddanian	*Coronograptus cyphus*	*Coronograptus cyphus*			*Conochitina electa* *Belonechitina postrobusta*	*Valyalepis crista*	
				Atavograptus atavus	*Coronograptus vesiculosus*	*Distomodus combinatus*	*Distomodus kentuckyensis*			
				Parakidograptus acuminatus	*Parakidograptus acuminatus*	[unzoned]		*Spinachitina fragilis*		
				Glyptograptus persculptus	*Glyptograptus persculptus*		*Oulodus? nathani*			

8

RELATIVE SEA LEVEL
redrawn from Jonhson, Kaljo & Rong, 1982



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Silurian Timescale Chart