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PHANEROZOIC TIMESCALES

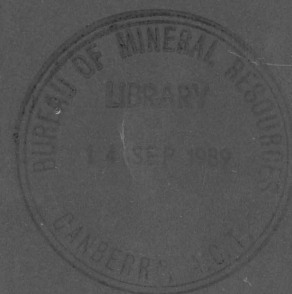
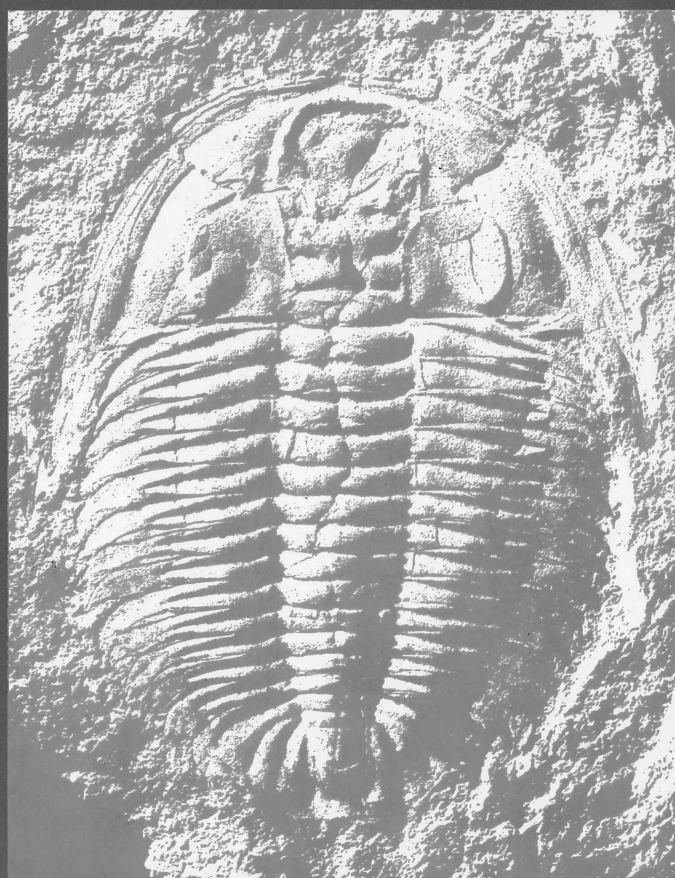
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AUSTRALIAN PHANEROZOIC TIMESCALES: DEVONIAN

G.C. YOUNG

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AUSTRALIAN PHANEROZOIC TIMESCALES

4. DEVONIAN

BIOSTRATIGRAPHIC CHART AND EXPLANATORY NOTES

by

G.C. YOUNG

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS



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

FOREWORD

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

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

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

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

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

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

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



P.J. Cook,

Chief, Division of Continental Geology

INTRODUCTION

This chart was first prepared as a contribution to the BMR/APIRA Palaeogeographic Maps Project, to provide biostratigraphic control for the Devonian correlation charts. The accompanying notes explain the basis for each of the 13 columns on the chart. Copies of an early version and explanatory notes were distributed for comment to various palaeontologists and biostratigraphers in early 1987. Suggestions and comments then received are incorporated in this preliminary edition, with an update of relevant literature to early 1989. The chart attempts to integrate (with emphasis on Australian data) currently available reliable isotopic ages for points on the Devonian time scale, with zonal schemes or preliminary biostratigraphic range data for various groups of Devonian fossils. For fossil groups lacking organised biostratigraphic data sets based on Australian occurrences, 'international' zonal schemes have been used where available.

It is evident that various fossil groups, widely applied in biostratigraphic studies of Devonian strata overseas, have been subjected to only a rudimentary level of investigation in Australian sequences. With more detailed systematic and biostratigraphic palaeontology considerable refinement of the biostratigraphic zonation can therefore be expected. Further revision of this chart will be undertaken as new biostratigraphic data become available, and will be necessary to take account of imminent new information on the Devonian system not available at the time of going to press. When published, the proceedings of the second International Symposium on the Devonian System (Calgary, 1987) will provide extensive new data on the Devonian of many regions, including Australia. In addition, it is expected that within the next year decisions will be reached on formal definitions for all Devonian stage boundaries, some of which are still under discussion by the Subcommission on Devonian Stratigraphy (SDS) of the International Commission on Stratigraphy. This will eradicate confusion that has resulted from different usage in different countries. Apart from these developments, ongoing research in systematic and biostratigraphic palaeontology of Devonian fossils, improved

isotopic dating techniques, and field studies in new areas clarifying relationships between isotopically and biostratigraphically dated strata, will necessitate both minor and major revisions of future versions of the chart.

COLUMN 1 - GEOCHRONOMETRIC SCALE

The calibrated scale on the left side of the chart is based on preferred dates for various boundaries as discussed below. For comparison the dates used by Harland *et al.* (1982) for the various boundaries are given on the right side of column 1. Generally more reliance has been placed on Australian isotopic dates, where the geological setting and detailed local biostratigraphy are better understood. The ages of the stage boundaries used here are as follows:-

Famennian/Tournaisian	354 Ma
Frasnian/Famennian	364 Ma
Givetian/Frasnian	370 Ma
Eifelian/Givetian	380 Ma
Emsian/Eifelian	387 Ma
Pragian/Emsian	397 Ma
Lochkovian/Pragian	402 Ma
Pridoli/Lochkovian	408 Ma

DEVONIAN-CARBONIFEROUS BOUNDARY

A date younger than 360 Ma better accommodates the Carboniferous data (Jones 1988), and is supported by evidence from eastern Victoria (Richards & Singleton 1981; Williams *et al.* 1982; Odin 1985b). Here, dated granites (360-366 Ma) intrude the Cerberean Volcanics (Frasnian; see below) and are unconformably overlain by the Mansfield Group, possibly Late Devonian in its lower beds, and containing a Carboniferous fish fauna in its middle part (Marsden 1976, p. 109; Odin & Gale 1982, p. 495). The fish fauna is currently being revised, and contains several endemic taxa (see Long & Campbell 1985; Long 1988a, 1989), but is most consistent with an Early Carboniferous age (J.A. Long pers. comm.). It should be noted that a Devonian placoderm fauna said to come from lower in the Mansfield Group (Long 1983a; Long & Campbell 1985, p. 87) is the South Blue Range fauna of Hills (1936), which lies beneath a major tectonic break in the Kevington Creek Beds, and is not part of the

Mansfield Group as depicted by Marsden (1976, fig. 5.11). Data from the Scottish Borderlands were used by Forster & Warrington (1985) to propose a 365 ± 5 Ma date, but on the same evidence McKerrow *et al.* (1985) suggest an age of 354 Ma, which is followed here. Odin (1985a, b) cites evidence from other areas consistent with the date of McKerrow *et al.* (1985). Gale (1985) has suggested slightly older alternatives (356, 358 Ma).

FRASNIAN-FAMENNIAN BOUNDARY

The lengths of the Late Devonian and its two stages are still poorly confined. Harland *et al.* (1982) gave the Frasnian and Famennian equal length of 7 Ma, but McKerrow *et al.* (1985) followed Ziegler (1978) in assigning 20 Ma to the Late Devonian, with the Famennian slightly longer (11 Ma) than the Frasnian. However there are no reliable isotopic data for the Frasnian-Famennian boundary. Odin (1985a) cautioned against using extrapolation to propose ages for stage boundaries. Sandberg *et al.* (1983) interpreted the Famennian as considerably longer than the Frasnian, on the assumption of approximately equal lengths of Late Devonian conodont zonal timespans. With the Frasnian-Famennian boundary placed at the base of the middle *Palmatolepis triangularis* conodont Zone (Ziegler & Klapper 1985), the Famennian comprises 20 conodont zones, and the Frasnian 8, but this difference is partly due to lack of subdivision of some Frasnian zones (the *Ancyrognathus triangularis* Zone may have a duration of up to 1 Ma; Sandberg *et al.* 1988, fig. 4). The biostratigraphic evidence suggests however that the Famennian was longer than the Frasnian (cf. Odin & Gale 1982, p. 494), and on the chart the Famennian is assigned an arbitrary length of 10 Ma, which allows a convenient 0.5 Ma per conodont zone for the Famennian, as estimated by Sandberg & Poole (1977). This has been suggested as an average duration, with individual zones ranging perhaps from as short as 0.3 to up to 0.7 Ma (Sandberg *et al.* 1988), although it is not possible to take account of such variations in a chart of this nature.

GIVETIAN-FRASNIAN BOUNDARY

McKerrow *et al.* (1985) proposed the same date (374 Ma) as Harland *et al.* (1982), within the 375 ± 5 Ma suggested by Gale (1985). In the recent literature this boundary is con-

sidered well constrained on the Australian evidence (Williams *et al.* 1982) from the Cerberian Volcanics of Victoria (a minimum 367 ± 2 Ma for the pre-late Frasnian), and the Mount Morgan Tonalite of Queensland (369 ± 5 Ma). The latter intrudes Givetian and is overlain by Frasnian strata, and Pickett (1972, p. 462) noted that some localities in the intruded Capella Creek Beds suggested Givetian, and others basal Frasnian ages. A reassessment of the conodont fauna in the overlying Dee Volcanics (Druce 1970, 1974) places it in the early Frasnian *Polygnathus asymmetricus* Zone (Mawson *et al.* 1985). This more closely confines the isotopic date to the Givetian-Frasnian boundary than has been assumed in the recent literature (cf. McKerrow *et al.* 1985; Gale 1985). Accordingly a younger age than 374 Ma is considered appropriate. The preferred date of 370 Ma gives a convenient average length of 0.75 Ma for Frasnian conodont zones, and a total duration for the Late Devonian (16 Ma) which lies between the values (14 and 20 Ma) used by other authors.

MIDDLE DEVONIAN

McKerrow *et al.* (1985) by extrapolation estimate the Middle Devonian at 17 Ma duration, with the Givetian (9 Ma) slightly longer than the Eifelian. This is longer than the Harland *et al.* (1982) Middle Devonian (13 Ma), but comparable with the 16 Ma estimate of Ziegler (1978). All agree that the Givetian is the longer stage. There are no isotopic data to constrain the Eifelian-Givetian boundary, but Richards & Singleton (1981, p. 405) report intrusions dated at 381 ± 7 Ma which are younger than deformed Emsian strata and the post-Emsian deformation, and older than the Late Devonian volcanics. This is consistent with the date selected here, as is Gale's (1985) 385 ± 8 Ma date for the Middle-Lower Devonian boundary. Accepting McKerrow *et al.*'s (1985) length of 17 Ma for the Middle Devonian allows retention of Harland *et al.*'s (1982) 380 and 387 Ma dates for the base of the Givetian and Eifelian respectively.

EARLY DEVONIAN

Duration of Early Devonian stages has been extrapolated from the Siluro-Devonian boundary date (see below), because isotopic data discussed in the recent literature cannot

be accurately correlated with the stage boundaries or faunal zonation. For example Devonian strata within the Mathinna beds of eastern Tasmania are dated within the *sulcatus* and lower *kindlei* conodont Zones (Pragian) on a diverse invertebrate assemblage including graptolites (*falcarius* Zone; Rickards & Banks 1979) and dacryoconarids (early late Pragian; Banks & Baillie 1989). However overlying volcanics limiting the age of deformation of the fossiliferous strata (Turner *et al.* 1986) are dated isotopically at 388 ± 1 Ma, which is probably at least four conodont zones younger (approximately *serotinus* Zone; late Emsian).

Harland *et al.* (1982) assigned equal lengths of 7 Ma to the three Early Devonian stages, but palaeontological assessment of duration (Ziegler 1978) suggests that the Emsian and pre-Emsian were approximately of equal length. The selected durations (10, 5, 6 Ma) for the Emsian, Pragian, and Lochkovian approximate to the relative durations of Early-Middle Devonian stages assessed by Ziegler (1978).

For the Siluro-Devonian boundary Owen & Wyborn (1979, p. 40) suggested a 410 Ma date, based on intrusions (e.g. Jackson Granite; *op. cit.*, table 1) into strata (Mountain Creek Volcanics) underlying fossiliferous limestones of *dehiscens* to *serotinus* Zone age (Emsian). A maximum age of earliest Devonian is provided by the early Lochkovian conodont *Icriodus woschmidti* in the Elmside Formation of the Bowning Group (Link & Druce 1972), which is older than the Bowning event. The dated granites (Rb/Sr 400-406, on the Boggy Plain igneous suite, inferred on similar chemical characteristics to include the Mountain Creek Volcanics; see Wyborn, Turner & Chappell 1987) are younger than the Bowning event, and are therefore of Devonian, pre-Emsian age. This is consistent with the 420 ± 2 Ma Laidlaw Volcanics date for the base of the Ludlow (Wyborn *et al.* 1982), the 398 ± 7 Ma minimum age for the Siluro-Devonian boundary suggested by Jones *et al.* (1981), and the pre-Pragian 402 Ma date from the Gocup Granite (Richards *et al.* 1977). However it excludes the 401 Ma suggested boundary date of Jones *et al.* (1981) and the younger end of the range (395 to 410 Ma) for the boundary of Gale

(1985). Odin (1985a, p.96) quotes three other radiometric studies indicating a boundary clearly older than 400 Ma. Other evidence (e.g. the Katahdin Batholith in Maine intruding Oriskany (Pragian) rocks; McKerrow *et al.* 1985; Kirchgasser *et al.* 1985) might point to an older age for the boundary than the Harland *et al.* (1982) date of 408 Ma. The Harland *et al.* date is somewhat younger than the 412 Ma of McKerrow *et al.* (1985), but is consistent with the relevant isotopic data listed by Gale (1985, p. 86). It is retained here for convenience as a close approximation to the reliable date of Owen & Wyborn (1979).

COLUMN 2 -STAGES

Stage names used for the Devonian are those recently decided (Bassett 1985) by the Subcommission on Devonian Stratigraphy (SDS). The name 'Tournaisian' is restricted to the Carboniferous, although 'zones' *Tn1a* and *Tn1b* are shown as part of the late Famennian (see Jones 1985).

COLUMN 3 - CONODONTS

This zonation is the current international standard on which Devonian stage boundaries as decided by the SDS were defined by Ziegler & Klapper (1985) as follows:

base of Famennian - lower boundary of Middle *Palmatolepis triangularis* Zone

base of Frasnian - lower boundary of Lower *Polygnathus asymmetricus* Zone

base of Givetian - lower boundary of *Polygnathus ensensis* Zone

base of Emsian - lower boundary of *Polygnathus dehiscens* Zone

base of Pragian - lower boundary of *Eognathus sulcatus* Zone

base of Lochkovian - (approximate) lower boundary of *Icriodus woschmidti* Zone

The base of the Lochkovian corresponds to the Siluro-Devonian boundary, which is formally defined at the base of the *Monograptus uniformis* Zone (McLaren 1973; i.e. slightly below the first appearance of *I. woschmidti*). Lower boundaries for the Pragian, Emsian, and Givetian stages are still subject to discussion within the SDS, but those used here are currently most widely accepted. The Fras-

nian-Famennian boundary is problematic, the previous recommendation (Ziegler & Klapper 1985), as used here (lower boundary of the Middle *Palmatolepis triangularis* Zone), having been withdrawn, because of difficulty in identifying the base of this zone. Current discussion within the SDS concerns placement at the base of either the Lower or Upper *Palmatolepis triangularis* Zones. In view of this uncertainty the earlier suggestion for this boundary (Ziegler & Klapper 1985) has been retained for the present on the chart.

For the Famennian the *Palmatolepis*-based subdivision proposed by Ziegler & Sandberg (1984) is used. The subdivisions (*Fa1a-Tn1b*) for the Famennian - 'Strunian' part of the Belgian succession (Dinant Basin) are shown as picks down the left margin following the recent scheme of Conil *et al.* (1986). However this places the base of *Fa2d* at a higher level than previously suggested (see discussion in Jones 1985). The 'Strunian' as used by Conil *et al.* (1986) comprises *Fa2d*, *Tn1a*, and the lower part of *Tn1b*.

A discussion of recent research on the Devonian-Carboniferous boundary is given in Flajs *et al.* (1988). Recent work on Devonian conodont zonation of Australian sequences is presented by Mawson *et al.* (1985), and Mawson (1987), and conodont dated transgression-regression cycles in Australian sequences were recently discussed by Talent & Yolkin (1987).

COLUMN 4

CONODONTS

On the left equivalent Famennian conodont zones from the previous international zonal scheme of Ziegler (1962, 1971) are given, for comparison with the *Palmatolepis* zonation of column 3. On the right is the scheme using shallow-water icriodid species as summarised by Sandberg & Dreesen (1984).

GRAPTOLITES

The *Monograptus* zonation for the Early Devonian is modified from Garratt (1983). This was based on Victorian sequences, and may not be applicable elsewhere (L. Sherwin, pers. comm.). Jenkins (1982) has discussed the relationship between graptolite and con-

dont zones near the Siluro-Devonian boundary in the Yass area.

COLUMN 5 - AMMONOIDS

The standard ammonoid zonation for the latter half of the Devonian (*Maenioceras* Stufen and above) is tied in with the conodont scheme following Klapper & Ziegler (1979, fig. 8), House *et al.* (1985), and the discussions in Ziegler & Klapper (1985) and Klapper *et al.* (1987). For the Australian Devonian Glenister (1958) described the Frasnian ammonoids, and Petersen (1975) the Famennian ammonoids from the Canning Basin. Four of the five classic German 'Stufen' for the Upper Devonian are developed in the Canning Basin, and conodont zone equivalents have been recognised for the *Wocklumeria*-Stufe, which is not represented by ammonoid material (Petersen 1975).

The older *Anarcestes* and *Anetoceras* Stufe approximate to the Eifelian and Emsian respectively (House 1979), but neither is known from Australia, and a detailed zonation in relation to conodonts is not yet worked out. *Cabrieroceras* (*Anarcestes*-Stufe) is known from Australia (J.A. Talent, pers. comm.). The type localities for Australian species *Talentoceras talenti* Erben and *Teichertoceras teichert* Chlupac & Turek from the Buchan Caves Limestone fall within the *dehiscens* and *perbonus* Zones respectively (Mawson *et al.* 1985). *Talentoceras* is very close to *Anetoceras* (House 1987), which is consistent with the Emsian range of the latter in Europe.

COLUMN 6 - BRACHIOPODS

Zones of Veevers (1959) for the Middle-Late Devonian of the Canning Basin are shown as interpreted by Roberts *et al.* (1972). The top of the *Stringocephalus* zone is placed above the base of the *disparilis* conodont Zone (Mawson *et al.* 1985), which leaves a gap beneath the *saltica* brachiopod zone. The youngest Early Devonian zone (*Spinella-Buchanathyris*) is equivalent to assemblage IV of Strusz (1972), and correlates with the *dehiscens* conodont Zone (A.J. Wright, pers. comm.). Beneath this on the left are shown the *Boucotia* zones of Garratt (1983). These

are based on Victorian sequences, and are not readily applied to the shallow water assemblages of western New South Wales (L. Sherwin, pers. comm.). An informal zonation based on assemblages (Sherwin 1980) has proved useful in this area, but much taxonomic work is required before a formal zonal scheme can be proposed. Sherwin (*in Glen et al.* 1985, figs. 10, 11) outlined an informal scheme of five assemblage zones for the Cobar Supergroup of western New South Wales which is included on the right side of column 6, with *Spinella* characterising his youngest faunal assemblage. Most of the taxa in these assemblages are either undescribed, or in need of revision. For a recent monographic treatment of Australian Devonian brachiopods see Lenz & Johnson (1985a, b).

COLUMN 7

BRACHIOPODS

The five Famennian productid zones of McKellar (1970) from the Star Basin in Queensland are given, as modified by the conodont work of Pickett (1981), who demonstrated that the boundary between McKellar's *profunda* and *minuta* zones lay within the Lower *marginifera* conodont Zone. The five brachiopod zones are therefore placed at a lower level than interpreted by McKellar (1970). The relationship of these zones to the Tournaisian *tenuistriata* Zone is discussed by Roberts (1975).

CORALS

Strusz (1972) and Pickett (1972) discussed the coral-conodont faunal scheme of Philip & Pedder (1967) for the Early-Middle Devonian, and the eleven zones A-K as used then are given here, with minor revision (*Carlinastrea halysitoides* replaces the '*Spongophyllum*' zone; see Pedder 1985). No stratigraphic scheme was provided in the work of Hill & Jell (1970) on corals of Middle-Late Devonian age from the Canning Basin.

COLUMN 8

OSTRACODS

Most useful biostratigraphically (e.g. Gooday & Becker 1979) are the pelagic entomozoan ostracods, but although these have been

recorded from Australia (Jones 1968, 1974), they are very poorly known. Included on the chart are the local zones of Jones (1968, 1989) based on benthic ostracods from the Late Devonian of the Bonaparte Basin. The Famennian zones are now known (Playford 1982; Jones 1985) to cover only the latest Famennian (?*Fa2c* - *Tn1a*). They correspond approximately to assemblage A of Jones (in Veevers & Wells 1961), recorded from the 'Fairfield Group' (now Gumhole Formation) in the Canning Basin. The '*hanaicus*' zone occurs in the Westwood Member (late Frasnian) of the Cockatoo Formation (Jones 1968).

DACRYOCONARIDS

The scheme of Lutke (1979), which relates 12 named dacryoconarid zones to the standard conodont zonation, is summarised for the Early and Middle Devonian in column 8, with extra zones for the Lochkovian-Pragian interval added from Chlupac et al. (1985). More detailed dacryoconarid zonations are available (18 named zones are used by Alberti 1984) but precise correlation for some of these with conodont zones is not available. In Australia, Sherrard (1967) recorded *Nowakia* aff. *acuaria* from the Garra Formation (*pesavus-dehiscens* Zones; Strusz 1972), and lower Taemas Formation (*dehiscens-serotinus* Zones; Mawson et al. 1985) in New South Wales, and *N. acuaria* is widely distributed in the Lower Devonian of the Melbourne Trough (Garratt 1983). These occurrences are consistent with Lutke's scheme. Stratigraphically significant dacryoconarids in the Taravale Formation in Victoria are noted by Mawson et al. (1985) but details of zonation are not yet available. Abundant dacryoconarids indicative of an early late Pragian age, including *Viriatellina* sp., *Metastyliolina* sp. and *Nowakia matlockiensis*, occur in the Mathinna beds of Tasmania (Banks & Baillie 1989, p. 236).

COLUMNS 9,10 - VERTEBRATES

The oldest Devonian fish remains in Australia dated by conodonts are scales of the acanthodian *Nostolepis* in the Coopers Creek Formation, which contains conodonts of the early Pragian *sulcatus* Zone (Philip 1965; Klapper & Ziegler 1979). The Tumblong microfauna described by Pickett, Turner &

Myers (1985) contains similar *Nostolepis* scales, associated with the thelodont *Turinia* and shark scales (*Ohiolepis*). *Ohiolepis* is well known in the Taemas-Buchan fauna, suggesting a slightly younger age than the Coopers Creek fauna for the Tumblong fauna. The Silverband fauna from the Gramians (Turner 1986) is of possibly equivalent age or older, based on the presence of *T. fuscina*, a primitive species of *Turinia*. Isotopic dates for associated intrusive rocks indicate a youngest possible age for the Gramians Group of 400 ± 3 Ma (Warren *et al.* 1986). More widespread is *Turinia australiensis*, reported by Turner (1984, and pers. comm.) from the Yarra Yarra Creek Group, Talingaboolba Formation, Mineral Hill Volcanics, Belvedere Formation, Condobolin Formation, Trundle Group and Garra Formation in New South Wales, the Graveyard Creek Formation and Martins Well Limestone in the Broken River area of Queensland, and the Point Hibbs Limestone in Tasmania. The Martins Well Limestone is late Lochkovian-early Pragian (*pesavus-sulcatus* Zones; Mawson *et al.* 1985), as is the Garra Formation (Strusz 1972), and the Graveyard Creek Formation is slightly older (Wyatt & Jell 1980). Other occurrences dated by conodonts or invertebrate macrofossils are the Lochkovian Mineral Hill Volcanics, Talingaboolba Formation, Condobolin Formation, and Trundle Group (Sherwin 1980), and the Point Hibbs Limestone (*sulcatus* Zone). Thus there is good evidence that most of these occurrences are Emsian or older, in contrast to the *T. australiensis* from the Mulga Downs Group and Cravens Peak Beds (Turner *et al.* 1981), which must be younger (see below). This apparent discrepancy may be due to the fact that the latter occurrences are in very near-shore to non-marine facies.

The Taemas-Buchan assemblage is an abundant and diverse fauna of Emsian age (*dehiscens* to *serotinus* Zones). *Cheiracanthoides*, *Ohiolepis*, *Ohioaspis*, *Ligulalepis*, '*Skamolepis*', buchanoosteid and acanthothoracid scales etc. occur in the microfauna. The macrofauna contains abundant and diverse placoderms (arthrodires exemplified by *Buchanoosteus*, various acanthothoracids, petalichthyids and ptyctodontids), lungfishes, acanthodians, onychodontids, and porolepiforms (see Young 1981, 1985b;

Long 1984a, 1986). The distinctive palaeoniscoid *Ligulalepis* is also known from the Condobolin Formation, is associated with *Skamolepis* in the Jesse Limestone (Turner 1982a), and has been provisionally identified in the Early Devonian of Western Australia (Turner *et al.* 1981).

A maximum age for the *Wuttagoonaspis* fauna of the Mulga Downs Group in western New South Wales (Ritchie 1973) is provided by the underlying marine Cobar Supergroup. Pickett (1980) identified conodont faunas ranging from *woschmidtii* to *dehiscens* or *perbonus* Zones, but more recent studies have not corroborated the presence of *Polygnathus*, so the younger date may not be reliable (J. Pickett, pers. comm.), and the Cobar Supergroup is probably older than any *Polygnathus* zone. At its oldest, therefore, the *Wuttagoonaspis* fauna is possibly contemporaneous with the upper Taemas-Buchan fauna, and may extend into the Middle Devonian. This fauna was apparently widespread in Australia, and is now recorded from western New South Wales, and the Canning (Gross 1971), Georgina (Turner *et al.* 1981; Young 1984), Amadeus (Young 1985b, 1988b; Young *et al.* 1987) and Officer Basins (Long *et al.* 1988).

Other Eifelian faunas are poorly represented and/or poorly known. The Hatchery Creek fauna was assigned a late Eifelian age by Young & Gorter (1981), but may be younger (see below). Eifelian fishes in the Broken River sequence include large brachythoracid arthrodires, asterolepid antiarchs etc. Microfaunas contain turiniid thelodonts and cheiracanthid and machaeracanthid acanthodians (Turner 1982a, 1986, and pers. comm.). An isolated placoderm or dipnoan plate from the subsurface (Bury Limestone member of the Log Creek Formation) in the Adavale Basin resembles material in both the Taemas-Buchan and Broken River faunas. Recovery of vertebrate microfossils from this sequence has not yet been attempted. Givetian faunas also occur in marine limestones of the Broken River sequence, and the Hatchery Creek is a non-marine fauna in which bothriolepid antiarchs (*Monarolepis*) and turiniid thelodonts are associated with asterolepids, phlyctaeniid arthrodires etc. This association is unique, and a Middle

Devonian age is probable, representing overlap in stratigraphic range of freshwater turiniids with the earliest bothriolepid antiarchs. Another, probably younger (?Givetian-Frasnian), turiniid occurrence is *Australolepis* in the marine Gneudna Formation, Western Australia (Turner & Dring 1981), where it is associated with the lungfish *Chirodipterus australis* (Smith & Campbell 1987).

For Late Devonian non-marine fish faunas the bothriolepid antiarch *Bothriolepis* is common and widely distributed (e.g. Long 1983a; Long & Turner 1984; Long & Werdelin 1986). Its earliest well-dated Australian occurrence is in the basal Frasnian Gogo Formation of the Canning Basin (Young 1974), but an older first appearance is possible, as in China (Eifelian). On the chart a first appearance in the Givetian *varcus* Zone is assumed, as is demonstrated in Euramerica (Young 1988a). In southeastern Australia the downward range of associated placoderms *Pambulaspis*, *Austrophyllolepis*, and *Placolepis*, and the acanthodian *Culmacanthus* (Long 1983b, 1984b; Ritchie 1984; Young 1983, 1989) is not known, but they are unlikely to extend far beneath the Givetian-Frasnian boundary. As well as *Bothriolepis*, the diverse fish fauna from the Gogo Formation (Long 1988b) contains various genera (*Holonema*, *Griphognathus*, *Holodipterus*, *Chirodipterus*, *Moythomasia*) which overseas are generally indicative of a Givetian-Frasnian age (e.g. Gardiner & Miles 1975). Abundant marine microfaunas are also known from the early Late Devonian, but except for the Gneudna assemblage (see above), faunal content is not yet documented.

In the Famennian a *Bothriolepis*-*Phyllolepis*-*Remigolepis*-*Groenlandaspis* association is typical in non-marine rocks of eastern Australia (e.g. Hervey Group, Merrimbula Group in central and southeastern New South Wales, Trapyard Hill fauna in eastern Victoria), and also occurs in central Australia (upper Dulcie Sandstone in the Georgina Basin; Young 1988b). A sinolepid antiarch assemblage (including *Bothriolepis* and *Remigolepis*) may represent the youngest Famennian nonmarine assemblage, as it does in China (Pan 1981; Pan & Dineley 1988). Antiarchs in the Canning Basin extend into

the latest Famennian (Yellow Drum Sandstone; Young 1987), but neither *Phyllolepis* nor *Groenlandaspis* has yet been recorded from the west. Famennian microfaunas from marine rocks in the Canning include osteichthyans and elasmobranchs (J.A. Long, pers. comm.). In Queensland the elasmobranchs *Harpagodus*, *Protacrodus*, and *Phoebodus* are recorded by Turner (1982b), the last two referred on conodonts to the *marginifera* Zone (Pickett 1981).

COLUMNS 11,12 - PALYNOMORPHS

Column 12 summarises two recently published zonal schemes for the Old Red Sandstone Continent (Richardson & McGregor 1986), and the Ardenne-Rhenish region of Europe (Streel *et al.* 1987). Both works provide detailed integration with the standard conodont zonation for the marine Devonian. An informal Australian scheme is given in column 11, which is based for the Early-Middle Devonian on the work of de Jersey (1966) and unpublished reports by Price (1980) and Price *et al.* (1985) on the subsurface sequence in the Adavale Basin. This work has been recently discussed in a study of palynomorphs from the Gneudna Formation in Western Australia by Balme (1988). The unpublished work is not supported by systematic studies and remains to be tested in other areas. *Geminospora lemurata* in the Etonvale Formation suggests an age equivalent to the *varcus* Zone or younger (see below), and comparison with detailed recent work on plant microfossils from the Gneudna Formation supports de Jersey's (1966) conclusion that the highest levels are Middle rather than Late Devonian in age (Balme 1988). Beneath this assemblage Price *et al.* (1985, table 6) list five informal zones as tentatively shown in the lower part of the column. The PD2 and lower PD3 zones are assigned to the Early Devonian. Macrofossil evidence from the Log Creek Formation indicates a possible Emsian but more probably Eifelian age (Pickett 1972).

The highest palynostratigraphic unit of Price (1980), in the uppermost part of the Etonvale Formation, probably corresponds to the *optimus-triangulatus* Zone of Richardson & Mc-

Gregor (1986), if systematic studies confirm the provisional identifications (Balme 1988, p. 160). This indicates a late Givetian age. This zone contains *Geminospora lemurata*, a taxon reviewed by Playford (1983), who suggested a total range from the *varcus* Zone (middle Givetian) or younger, through the Frasnian and possibly into the early Famennian. Balme (1988, fig. 8) has suggested a different range, from Eifelian to middle Frasnian, with a doubtful younger extension into the basal Famennian. McGregor (1979, fig. 8) estimated a much greater (Emsian-Famennian) range for the possibly synonymous *G. svalbardiae*. *Geminospora* sp. is listed by Anan-Yorke (1975) from the Frasnian Bellbird Creek Formation of the Merrimbula Group, and *G. lemurata* is abundant in the Brewer Conglomerate palynoflora of the Amadeus Basin (Playford *et al.* 1976), but is absent from the Gogo Formation in the Canning Basin (Grey 1975; Balme 1988). The Brewer palynoflora also contains six species (*Grandispora clandestina*, *Hystricosporites porrectus* etc.) in common with the late Famennian Fairfield Formation palynoflora of the Canning Basin (Playford 1976). Using Playford's (1983) assessment of the range of *G. lemurata*, the Brewer assemblage would be placed in the early Famennian, but alternatively the clear late Famennian element might indicate that *G. lemurata* is reworked in this assemblage (Balme 1988).

Late Devonian acritarchs were listed from southeastern Australia (Merrimbula Group) by Anan-Yorke (1975), and described from the Fairfield Group and Gneudna Formation in the west by Playford (1976, 1981) and Playford & Dring (1981). From the Frasnian Bellbird Creek Formation Anan-Yorke (1975) listed seven genera (*Evittia*, *Maranhites*, *Navifusa*, *Stellinium*, *Tunisphaeridium*, *Veryhachium*, *Cymatiosphaera*) and one species (*Multiplicisphaeridium ramusculosum*) which also occur in the Gneudna Formation (Playford & Dring 1981). Downie (1979) lists *Maranhites* as age-diagnostic for the Late Devonian. Playford & Dring (1981, p. 74) considered the association of *Chomotriletes vedugensis*, *Daillydium pentaster*, *Unellium piriforme*, *U. winslowae*, and *Cymatiosphaera perimembrana* as the best evidence of a Frasnian age for the Gneudna Formation. For the

younger (Famennian) Worange Point Formation of the Merrimbula Group only two genera (*Cymatiosphaera*, *Stellinium*) are common to the Fairfield Group assemblage.

The *Retispora lepidophyta* assemblage in the Canning Basin is associated (Playford 1976, p. 8) with the *Icriodus platys* conodont assemblage of Nicoll & Druce (1979). *I. platys* is a junior synonym of *I. raymondi*, which disappears at the top of the Middle *expansa* Zone (Sandberg & Dreesen 1984). Playford (1982, p. 155) cites opinion that the first appearance of *R. lepidophyta* postdates the middle *styriacus* Zone (equivalent to the base of the *expansa* Zone). On this evidence the '*I. platys*' association in the Canning Basin must be near the base of the range of *R. lepidophyta*, and the base of this assemblage zone is placed at the base of the Middle *expansa* Zone. This is somewhat older than the level given in Conil *et al.* (1986; within the Upper *expansa* Zone), but compares well with that of Paproth & Streel (1979; just above the base of the Lower *costatus* Zone).

COLUMN 13 - MACROPLANTS

The Wilson Creek Shale in the Melbourne Trough contains the type locality of *Baragwanathia longifolia*, lycophyte and key member of the *Baragwanathia* Flora. This shale has been correlated with the Humevale Formation which also contains elements of the Flora in the Yea and Lilydale districts. Garratt (1983) placed this in the *Boucotia loyolensis* Assemblage Zone (early Pragian, *sulcatus* Zone). Best preserved material occurs in the Turtons Creek inlier (Liptrap Formation), correlated by Vandenberg (1975) with the Norton Gully Sandstone which also contains the assemblage in the upper Yarra area. Further details on the *Baragwanathia* Flora are included in Gould (1975), Hueber (1983), and Tims & Chambers (1984). Early Devonian vascular plants including *Baragwanathia* and *Hostimella* are also reported from Tasmania (Banks & Bailie 1989).

In the Middle Devonian the lycopods *Protepidodendron lineare*, *P. yalwalense*, and ?*Lepidodendron clarkei* are recorded from possible Givetian sediments in southeastern New South Wales. Chaloner &

Sheerin (1979) give *Protolepidodendron* an Emsian-Givetian range. *Pr. scharianum* is recorded with *Astralocaulis* in the Frasnian Dotswood Formation of Queensland (Gould 1975). Chaloner & Sheerin (1979) consider *Astralocaulis* to have a Givetian-Frasnian range. Other Frasnian records from Australia are ?*Cordaites* and ?*Archaeosigillaria* listed from the Twofold Bay Formation by Fergusson *et al.* (1979), the latter having a Givetian-Tournaisian range according to Chaloner & Sheerin (1979).

The most widespread Late Devonian lycopod in Australia is *Leptophloeum australe*, which is however recorded from rocks of possible Emsian age (Gould 1975) beneath the Sulcor Limestone (mainly Eifelian; Mawson *et al.* 1985) in the Yarrimie Formation of the New England fold belt. In view of the typical Late Devonian occurrence elsewhere (e.g. Chaloner & Sheerin 1979), field relationships of this occurrence require checking. *L. australe* is also recorded from probable Early Carboniferous rocks in the Canning Basin (Veevers *et al.* 1967), and associated with Tournaisian brachiopods in New South Wales (Jones *et al.* 1973). A more diverse Late Devonian flora from eastern Victoria, summarised in Marsden (1988), also includes *L. australe* in probable Frasnian and Famennian assemblages. Other genera in the Avon River Group include ?*Asterocalamites*, *Archaeopteris*, *Sphenopteris*, and *Rhacopteris*. *Phyllothea* occurs in the Moroka Glen Formation, *Taeniocrada* in the Wellington Rhyolite, and *Cordaites*, *Sphenopteris*, and *Archaeopteris* in the Mount Kent Conglomerate and Snowy Plains Formation. Associated fishes (Long 1983a) indicate that these occurrences are probably Frasnian, except for the Snowy Plains Formation (Famennian). The Genoa River Beds (Famennian) also contain *Leptophloeum*, *Cordaites*, *Archaeopteris*, *Sphenopteris*, and *Barinophyton*?, the last-mentioned having a wide (Emsian-Famennian) range according to Chaloner & Sheerin (1979).

OTHER GROUPS

Various other macro- and microfossil groups have proved biostratigraphically useful overseas, but have not yet been studied in sufficient detail for their utility in Australian

Devonian sequences to be assessed. Devonian protozoans (Radiolaria and Foraminifera) were discussed by Toomey & Mamet (1979). Radiolarians have potential bio-stratigraphic value for Upper Devonian strata, and Holdsworth & Jones (1980) put forward a preliminary zonation. Late Devonian (Frasnian) Radiolaria from the Gogo Formation of the Canning Basin were described by Nazarov *et al.* (1982) and Nazarov & Ormiston (1983), and they have recently been used to date siliceous rocks from the New England Fold Belt (Ishiga *et al.* 1988; Aitchison 1989). Calcareous Foraminifera underwent their first major radiation in the late Middle Devonian, and with agglutinated forms have bio-stratigraphic potential for the Upper Devonian, although much taxonomic work is required to sort out both groups (Toomey & Mamet 1979). Conkin & Conkin (1968) described Upper Devonian Foraminifera from Western Australia. Teichert *et al.* (1979) summarised the biostratigraphic distribution of some 209 nautiloid genera thought to be restricted to the Devonian. Over half of these are recorded from only one stratigraphic stage or finer stratigraphic subdivision, indicating significant biostratigraphic potential. Trilobites have proved valuable in world-wide correlation of Lower and Middle Devonian strata (Alberti 1979). Recent systematic studies on Australian Devonian trilobites include Chatterton *et al.* (1979), Holloway & Neil (1982), and Chatterton & Wright (1986). Amongst other arthropods only eurypterids, conchostracans and phyllocarids are sufficiently abundant to yield biostratigraphic data (Rolfe & Edwards 1979). Briggs & Rolfe (1983) described phyllocarids from Western Australia. The biostratigraphic utility of these and other groups in Australian sequences will depend on detailed systematics being carried out to provide a basis for determining the ranges of described taxa.

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DEVONIAN BIOSTRATIGRAPHIC CHART (1989 EDITION)

GEOCHRONOMETRIC SCALE		EPOCH		3. CONODONTS	4. CONODONTS	5. AMMONOIDS	6. BRACHIOPODS	7. BRACHIOPODS	8. OSTRACODS	9. MICROVERTEBRATES	10. MACROVERTEBRATES	11. PALYNOMORPHS	12. EUROPEAN PALYNOMORPH ZONES	13. MACROPLANTS	TOURNAISIAN
THIS CHART		STAGE		Ziegler & Sandberg (1984) Ziegler & Klopfer (1985) Sandberg et al. (1988)	Ziegler (1962, 1971), Sandberg & Ziegler (1985)	after House (1979)	Roberts et al. (1972) Garratt (1983) Sharwin (1985)	McKellar (1970) CORALS	Jones (1968, 1989) DACRYOCONARIDS			de Jersey (1966) Price (1980) Price et al. (1985)	Richardson & McGregor (1986) Steele et al. (1987)		
354	360	LATE DEVONIAN	FAMENNIAN	Tn1b <i>sulcata</i>	<i>Prolognathodus</i>	<i>Gattendorfia</i>		<i>Tulumbella tenuistriata</i>	<i>atypha</i>			PC1 <i>Grandispora spiculifera</i>	<i>lepidophyta</i>		VI
				Tn1a <i>praesulcata</i>	<i>Bispathodus costatus</i>	<i>Wocklumeria</i> VI		<i>Semiproductus etheridgei</i>	<i>ordensis</i>			PDB <i>Retispora lepidophyta</i>	<i>pusillites</i>		LV
				Fa2c <i>expansa</i>	<i>Polygnathus shyracus</i>	<i>Clymenia</i> V		<i>Sentosia plicata</i>	<i>tryphera</i>				<i>flexuosa</i>		Var.
				Fa2b <i>postera</i>	<i>Scaphignathodus vellifer</i>	<i>Platyclymenia</i> IIIβ	<i>proteus</i>	<i>transversa</i>	<i>altifrons</i>			? Brewer palynoflora	<i>varabilis</i>		Var.
				Fa2a <i>trachytera</i>		<i>IIIα</i>		<i>minuta</i>					<i>gracilis</i>		Mic.
				Fa2a <i>marginifera</i>		<i>IIIα</i>	<i>scopimus</i>						<i>gracilis</i>		Fam.
				Fa1b <i>rhomboidea</i>		<i>IIβ</i>		<i>profunda</i>					<i>gracilis</i>		GH
				Fa1b <i>crepida</i>		<i>IIα</i>							<i>gracilis</i>		(V)
				Fa1a <i>Pa triangularis</i>		post 18							<i>gracilis</i>		E
													<i>gracilis</i>		DB
360		LATE DEVONIAN	FRASNIAN	<i>linguiformis</i>	<i>Zones</i>	<i>Crickites holzapfeli</i> 18			<i>'hanaicus'</i>				<i>buliferus-jekobskii</i>		DB
				<i>gigas</i>			<i>apena</i>						<i>buliferus-media</i>		DB
				<i>A. triangularis</i>		<i>14</i>							<i>buliferus-media</i>		DB
				<i>asymmetricus</i>		<i>1β</i>	<i>torrida</i>						<i>buliferus-media</i>		DB
						<i>feisti</i>	<i>Stringocephalus</i>						<i>buliferus-media</i>		DB
				<i>disparilis</i>		<i>pernai</i>							<i>buliferus-media</i>		DB
				<i>hermanni-cristatus</i>		<i>arenicum</i>							<i>buliferus-media</i>		DB
				<i>varcus</i>		<i>1α</i>							<i>buliferus-media</i>		DB
				<i>ensensis</i>		<i>lunulicosta</i>							<i>buliferus-media</i>		DB
				<i>kockelianus</i>		<i>Maenioceras</i>							<i>buliferus-media</i>		DB
370		MIDDLE DEVONIAN	GIVETIAN	<i>australis</i>									<i>buliferus-media</i>		DB
				<i>costatus</i>									<i>buliferus-media</i>		DB
				<i>partitus</i>									<i>buliferus-media</i>		DB
				<i>patulus</i>									<i>buliferus-media</i>		DB
				<i>serotinus</i>		<i>Aneloceras</i>							<i>buliferus-media</i>		DB
				<i>inversus-laticostatus</i>									<i>buliferus-media</i>		DB
				<i>perbonus-gronbergi</i>		<i>Teichericeras</i>							<i>buliferus-media</i>		DB
				<i>dehiscens</i>		<i>Talenticerias</i>							<i>buliferus-media</i>		DB
				<i>pyreneae</i>		<i>Spinella - Buchanathyris</i>							<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
380		MIDDLE DEVONIAN	EIFELIAN	<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
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				<i>kindlei</i>									<i>buliferus-media</i>		DB
390		EARLY DEVONIAN	EMSIAN	<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
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				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
400		EARLY DEVONIAN	PRAGIAN	<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
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				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
405		EARLY DEVONIAN	LOCHKOVIAN	<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
408		EARLY DEVONIAN	PRIDOLI	<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
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				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB
				<i>kindlei</i>									<i>buliferus-media</i>		DB

BMR Record 1989/34

Compiled by P.J. Jones & G.C. Young, BMR. Drawn by P.J. Brown, BMR



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