Records of the Western Australian Museum Supplement No. 58: 123–131 (2000).

Early Devonian graptolites from Limekilns, New South Wales

R.B. Rickards[1] and A.J. Wright[2]

[1] Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, England
[2] School of Geosciences, University of Wollongong, Wollongong 2522, NSW
e-mail address: tony_wright@uow.edu.au

Abstract – Graptoloids from the Limekilns district of New South Wales, Australia, previously recorded as the Pragian *Monograptus yukonensis* by Packham (in Strusz *et al.* 1972), are reidentified and described as *Monograptus uniformis uniformis*, based upon original and new collections. This subspecies is a clear indicator of the earliest Devonian, Lochkov *Monograptus uniformis* Biozone and the occurrence is the first unequivocal record of the Biozone in Australia.

As other palaeontological data from the Limekilns area have indicated a Pragian age for the lower shaley part of the Limekilns Formation and its presumed correlative, the lower part of the Cunningham Formation, this new graptolite identification and the inferred correlation create alignment problems which are discussed but not resolved. The most obvious possible explanations of this situation are: (1) the Limekilns graptolite horizon does have a correlative level in the lower part of the Cunningham Formation which has not yet yielded diagnostic fossils; or (2) there are no equivalent strata in the Cunningham Formation, presumably due to non-deposition or erosion in the Hill End Trough sequence.

Dendrograptus sp. is noted from the Limekilns locality. A graptolite specimen previously record questionably as *M. uniformis*, from the Prídolí of Cheeseman's Creek, NSW, is reidentified and described as *M. prognatus*.

A review of all known records and claims of Devonian graptolites in Australia indicates that the valid Lochkov records are *M. u. uniformis* from Limekilns and *M. aequabilis* from Victoria. Valid Pragian records are *M. thomasi* from Victoria and Tasmania, and *M. aequabilis notoaequabilis* and *M. aequabilis* cf. *notoaequabilis* from Victoria.

INTRODUCTION

Early Devonian graptolites, initially referred to *Monograptus yukonensis* Jackson and Lenz 1963, were first recorded from strata then assigned to the Rosedale Shale in the Limekilns district of NSW, by Strusz *et al.* (1972) based on material collected and identified by Gordon Packham. This taxon is here reidentified, on the basis of the original collections and our new collections from the sole locality, as *Monograptus uniformis uniformis* Přibyl 1940.

This new identification indicates a significantly older age for the graptolitic bed than previously envisaged for the lower part of the Limekilns Formation (i.e., the former Rosedale Shale) on the basis of the earlier identification; therefore, we here describe this material and attempt to provide a cogent and coherent interpretation of the new data within the presently known stratigraphic context (Figure 1).

As stated in the abstract, the presence of *M. uniformis uniformis* indicates unambiguously assignment of this occurrence to the *uniformis* Biozone, of early Lochkovian (earliest Devonian) age. Our identification was made known by us in 1997 to Dr L. Sherwin of the Geological Survey of New South Wales and, with our permission, has been reported by Watkins *in* Pogson and Watkins (1998: 205). The statement that ".. the base of the Limekilns Formation ... is thought to be Lochkovian to early Pragian..." is clearly incompatible with the palaeontological data, as the graptolite occurrence can be no younger than early Lochkovian. The other statement (Pogson and Watkins 1998, also page 205) that the Limekilns Formation has an Early Devonian age of ".. late Lochkovian (base) to early Pragian (top) ..." is also not in accord with our data: *Monograptus uniformis* is an unambiguous indicator of the early Lochkov *uniformis* Biozone (Jaeger 1988, fig. 2).

SYSTEMATIC PALAEONTOLOGY

Order Graptoloidea Lapworth 1875

Suborder Monograptina Lapworth 1880

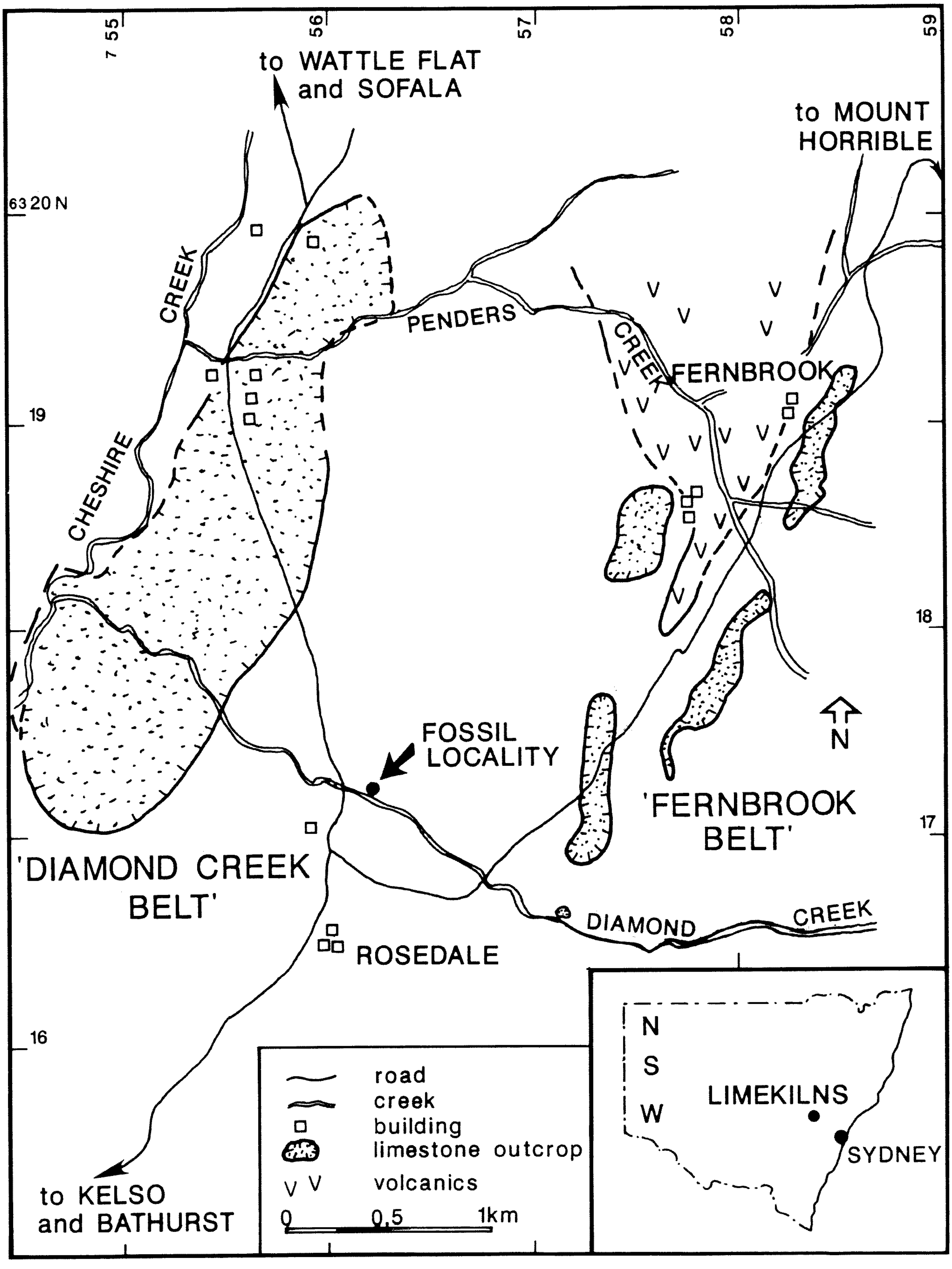


Figure 1 Map showing the graptolite locality map, and distribution of the so-called Jesse Limestone Member within the Limekilns Formation (modified after Wright and Haas 1990).

Family Monograptidae Lapworth 1873

Genus *Monograptus* Geinitz 1852

Monograptus uniformis uniformis Přibyl 1940
Figures 2E–Q

Monograptus (Pomatograptus) uncinatus var. *uniformis* n. var. Přibyl 1940: 71–72, pl. 1, fig. 1.

Monograptus uniformis: Jaeger 1959: 94–98, pl.1, fig. 3; pl. 3, figs 9–10; text-figs 4.15; text-fig. 16d–h.

Monograptus uniformis: Koren' 1968: 143–5, pl. 1, figs 1–4.

Monograptus uniformis uniformis: Obut 1968: 945–946, pl. 1, figs 1–3.

Monograptus yukonensis: Packham, in Strusz *et al.* 1972: 445.

Monograptus uniformis: Jaeger and Robardet 1973: 2130, fig. 2.

Monograptus uniformis uniformis: Bouček *et al.* 1976: 97–100, pl. 1, figs 1–6; text-figs 3a–d.

?*Monograptus uniformis uniformis*: Wang 1977: 613, pl. 226, figs 1–4.

?*Monograptus uniformis zhongguoensis*; Wang 1977: 613, pl. 226, figs 5–8.

M. uniformis: Koren' 1978: 118–119, pl. 1, figs 2–3; text-figs 3a–j.

Monograptus uniformis uniformis: Jackson *et al.* 1978: 22, pl. 4, fig. 3.

M. cf. *yukonensis*: Jaeger 1978: 506.

M. cf. *yukonensis*: Sherwin 1979: 162.

Monograptus uniformis uniformis: Porębska 1984: 149–151, text-figs 16.1–16.9.

Monograptus uniformis uniformis: Julivert *et al.* 1984: fig. 4a.

Monograptus yukonensis: Wright and Chatterton 1988: 94.

"?*Monograptus uniformis*": Jaeger 1988: 432 (map).

Monograptus uniformis uniformis: Jaeger 1988: 433, fig. 2A.

Monograptus yukonensis: Wright and Haas 1990: 139.

Monograptus uniformis: Chen and Quan 1992: 182, figs 3B, 4A–B, J.

Monograptus uniformis uniformis: Lenz *et al.* 1996: fig. 6A.

Monograptus uniformis: Zhang and Lenz 1998: 355; figs 3.13, 3.25–27, 4.7.

Material
Fifteen specimens (AMF92396–92410), well preserved in three dimensions, and other fragmentary specimens.

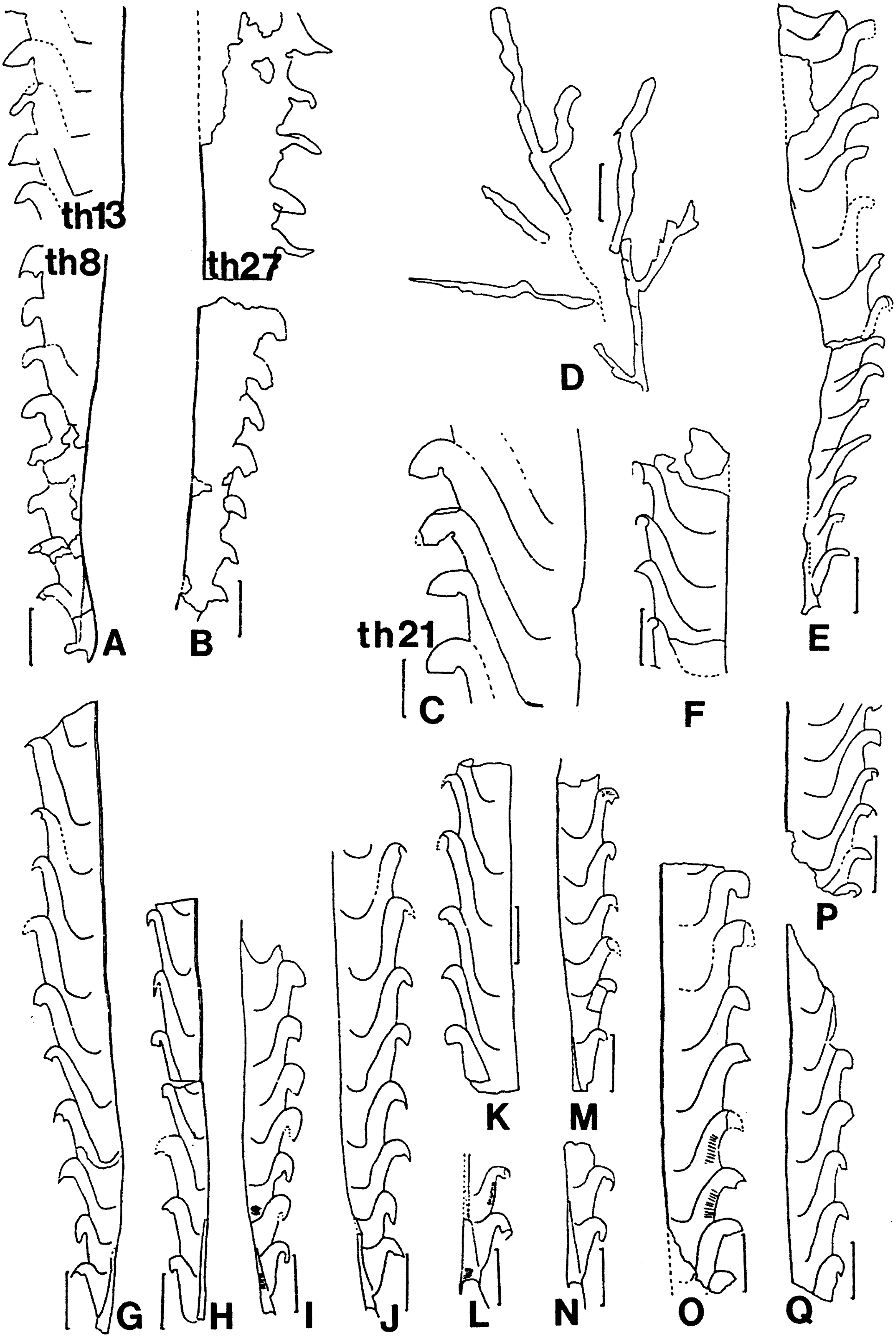
Locality Data
The graptolites were collected from grey to black shale about 150 m E of the small bridge where Diamond Creek crosses the Bathurst-Wattle Flat road (Figure 1), Limekilns district, NSW. It is a monotypic assemblage except for the occurrence of one dendroid specimen, *Dendrograptus* sp. (Figure 2D). Preservation is good, with periderm preserved in many specimens along with pyritic infill.

Diagnosis
Monograptus rhabdosomes with slight ventral curvature affecting 4–5 proximal thecae, reaching an overall dorso-ventral width of 1.75 mm at about 10–15 mm from the sicula Sicula 1.60–2.0 mm long, its apex at the level of the aperture of th2; almost straight or with straight ventral curvature; dorsal tongue; Σ = 1.12–1.25 mm. Proximal thecal spacing 10–12 in 10 mm; mesial spacing 9–11 in 10 mm. Thecal overlap 1/3–1/2 proximally and 2/3 mesially; thecal hoods uniform throughout colony occupying about 1/5 the width of the stipe and with a proximo-distal length of 0.40–0.60 mm; free ventral wall inclined at 5°–20°. Proximal thecae up to 2.0 mm long, mesial thecae up to 3.0 mm.

Description
The sicula is not well preserved in its apertural region: because the proximal extremity of the rhabdosome, in particular, is in full three dimensions, the sicular aperture is mostly obscured or broken. However, one specimen (Figure 2L) shows a pronounced dorsal process, and its presence cannot be ruled out on the other figured proximal ends. The sicular apex reaches to about the level of the aperture of th2, but not to the top of the hood of th2. It is difficult, however, to place the tip of the prosicula with accuracy.

The thecal hoods are conspicuous and occur on all thecae of the rhabdosome. The *apparent* involvement of the ventral apertural lip in some thecae is caused by the wide spread of the lateral part of the dorsal hood, and its overlap with the distal parts of the free ventral wall: contrast, for example, th9 of Figure 2G with Figure 2O. Thecal overlap is clearly seen by the obvious curved base to the interthecal septum. Thecal overlap gradually increases distally, but no really distal thecae are present in the collection: the maximum rhabdosome length in our material is around 15 mm.

Remarks
This material is better preserved than much previously described material of this taxon from different parts of the world. The dorso-ventral


th13
th8
th27
th21
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q

width of 1.75 mm at 10–15 mm length of rhabdosome is less than the figure given, for example, by Porębska (1984) in her detailed descriptions of material from the Polish Bardo Mountains (2.0–2.3 mm). This latter material is flattened, however, and flattening of the Limekilns specimens would certainly produce a dorso-ventral width in excess of 2.0 mm. Dimensions which remain unaffected by diagenetic flattening (thecal spacing, sicular length, Σ values, and thecal overlap) are very similar.

M. u. uniformis is not dissimilar to *M. sudeticus* Porębska, but differs in its higher thecal spacing, greater dorso-ventral width and greater thecal overlap. In the *M. hercynicus* lineages, *M. u. uniformis* resembles only *M. praehercynicus* from which it differs in having a much lower value of Σ, a slightly shorter sicula, and in having the free ventral walls inclined outwards rather than being parallel to the rhabdosomal axis.

M. u. uniformis is not easily distinguished from the other two subspecies *M. u. angustidens* Přibyl 1940 and *M. u. parangustidens* Jackson and Lenz 1972, and many previous descriptions do not make the distinctions clear. *M. u. angustidens* is usually considered to be a more slender form (see, for example, Jaeger 1988), whereas Porębska (1984) considered the following changes to take place as *M. u. parangustidens* gave rise to *M. u. angustidens* and then to *M. u. uniformis* (all early in the *uniformis* Biozone):

1. *M. u. parangustidens* has a slight proximal dorsal curvature; *M . u. angustidens* is more or less straight; and *M. u. uniformis* more commonly has slight ventral curvature (as in the present authors' material);
2. An increase in rhabdosomal width (which we comment upon above);
3. An increase in the length of the distal thecae and their overlap (our material precludes us commenting upon this feature);
4. A decrease in the value of Σ (confirmed by our material).
5. An increase in the width of the sicular aperture (not well-preserved in our material).

Taken as a whole the differences are slight, but the Limekilns specimens fall fairly readily into *M. u. uniformis* rather than the other subspecies.

Jaeger (1988) was able to remark there were no undoubted records of Lochkov graptolites from Australia, recording only a doubtful *M. uniformis* from New South Wales. The record of graptolites of this age herein is therefore the first (see review section on Devonian graptoloids in Australia below).

DISCUSSION

Lithostratigraphy

The Limekilns area essentially provides a record of sedimentation within the marginal zone between the Hill End Trough to the west, and the Capertee High to the east. The Early Devonian sequence of the Limekilns area (Figure 1) was first described by Packham (1968), and the Early Devonian formations named by him and which are relevant to this paper are: the Crudine Group (lowest); the Merrions Tuff; the Rosedale Shale, the Jesse Limestone, the Limekiln Creek Shale (the last three comprising the Limekilns Group); and the Wynburn Tuff (highest). Wright and Haas (1990), Pogson and Wyborn (1994) and Pogson and Watkins (1998) concluded that three of these units (Rosedale, Jesse and Limekiln), which Packham (1968) correlated with the Cunningham Formation of the Hill End Trough sequence, should be merged and renamed the Limekilns Formation, largely because most of the limestone is clearly allochthonous within a largely monotonous mudrock sequence. The original stratigraphic terminology has been formally modified by Pogson and Watkins (1998) to: the Merrions Formation and the Limekilns Formation, the latter having a subordinate unit termed the Jesse Limestone Member. We are not convinced that these scattered limestone bodies should be accorded even member status, so we refer to this as the "Jesse Limestone Member".

The name Winburn Tuff was given by Packham (1969) to beds which, he considered, overlay the Limekilns Shale in this district, but was considered

◀ **Figure 2** A–C, *Monograptus prognatus* Koren' 1983, Wallace Shale, Cheesemans Creek area, NSW (see Sherwin 1971: 220). **A–B**, MMF 31621b, and counterpart MMF 31621a respectively. This specimen was recorded by Jaeger (1978) as "reminiscent of *Monograptus uniformis*" (see text herein under Review of Australian Devonian Graptolites). **A**, MMF 31621b. **B**, MMF 31621a: narrow view. **C**, MMF 31621b: most distal thecae of specimen in Fig. 2A; broad view showing thecal overlap [th8 etc. refers to particular thecae where preservation precludes illustration of the whole rhabdosome.] **D**, *Dendrograptus* sp., AMF 92410, Lochkov, *uniformis* Biozone, Limekilns Formation, Limekilns, NSW; this is the stratigraphically highest dendroid so far recorded from Australia. **E–Q**, *Monograptus uniformis uniformis* Přibyl 1940. Lochkov, *uniformis* Biozone, Limekilns Formation, Limekilns, NSW. **E**, AMF 92398a, the specimen originally referred to *M. yukonensis* in Strusz *et al.* (1972) on the basis of supposed dorsal curvature of the proximal end which is, in fact, broken; **F**, AMF 92407; **G**, AMF 92405; **H**, AMF 92406; **I**, AMF 92397; **J**, AMF 92405b; **K**, AMF 92402; **L**, AMF92403; **M**, AMF92400; **N**, AMF 92404; **O**, AMF 92396; **P**, AMF 92401. Scale bars 1 mm, all figures approximately x 10.

by Pogson and Wyborn (1994) and Pogson and Watkins (1998) a repetition of the Merrions Formation. As far as is known, the contact between the Merrions and Limekilns formations is conformable, but this will be discussed below.

The thickness of the Limekilns Formation was estimated by Pogson and Watkins (1998) at 260–510 m; the thickness of the Merrions Formation was stated by them to be in the order of 500–650 m. There is considerable doubt about the detailed structure within, and therefore the thickness of, the shale sequences in the Limekilns district due to lack of continuous exposure and the clear presence of small-scale structural complexities. The Limekilns Formation has been rather deformed as the Hill End Trough sequence was involved in at least two episodes of tectonism, in the Tabberabberan Orogeny (probably Eifelian-Givetian) and again in the Early Carboniferous Kanimblan Orogeny (Lu *et al.* 1996; Packham 1999). Notwithstanding this traumatic structural history, there is no sign that the graptolites are tectonically distorted, although there is some diagenetic compaction of the material.

Biostratigraphy

In rocks of the largely flyschoid Hill End Trough sequence, occurrences of fossils are so rare that any biostratigraphic information, such as that emanating from the graptolites under discussion here, is crucial to our biochronology of events in the Trough. Macrofossils reported from the Limekilns area are from the top of the Crudine Group, and from the Limekilns Formation; discussion of these data is a necessary part of our assessment of this problematical topic.

Crudine Group. A brachiopod fauna from (as far as can be determined) very high in the Crudine Group, was considered earliest Devonian by Garratt and Wright (1988), as they correlated the fauna with the *Boucotia australis* zone. The close resemblance of this *Reticulatrypa-Ogilviella* brachiopod fauna to the silicified brachiopod fauna described by Savage (1971) from the Garra Formation (formerly Savage's Mandagery Creek Formation) at Manildra, NSW and also known from the Yellowmans Creek Formation S of Mudgee (NSW), indicates it is least as old as the *eurekaensis* conodont zone, which probably correlates with the upper part of the *uniformis* graptolite zone. As no maximum age for this brachiopod fauna is established, this occurrence does not greatly constrain the age of the base of the Merrions Formation. Nevertheless, there may be little time available for the deposition of the Merrions Formation; this is quite possible as much of the Merrions consists of dacitic tuffs and lavas and could have been deposited very quickly.

Cunningham Formation. The lack of (good) macrofaunas has very largely precluded estimates of the age of fossils from the clastic trough facies of the Cunningham Formation, with one exception. Wright (1994) concluded, on the basis of poorly preserved brachiopods and other shelly fossils from a locality close above the base of the formation, that a Pragian age was most probable for the basal Cunningham. The Limekilns Formation, which has been assumed to be a correlative of the Cunningham Formation, has yielded a shelly fauna to which Wright and Haas (1990) ascribed a Pragian age and Talent and Mawson (1999) have documented a late Emsian (*serotinus* zone) conodont fauna from the "Jesse Limestone Member". Percival (1998) assigned late Pragian to middle Emsian ages to conodonts from various carbonate horizons in the Cunningham Formation. Wright and Haas (1990) also drew attention to the uncertain relationship between the supposed Pragian shales and the late Emsian "Jesse Limestone Member" of the Limekilns Formation. However, the problem is now compounded by the serious anomaly between the previously inferred broadly Pragian age for the Limekilns Formation and the early Lochkov age presently indicated by the reidentified graptolites.

"Rosedale Shale". Wright and Haas (1990) considered that fossils, particularly the tentaculitids, occurring with the trilobite *Paciphacops crawfordae* in the "Rosedale Shale", indicated a Pragian (late early Early Devonian) age, and that the occurrence of the late Pragian conodont *Polygnathus pireneae* (then known from beds low in the "Jesse Limestone") did not conflict with the Pragian age inferred for the Rosedale Shale. Subsequently, studies of conodonts from the Jesse Limestone (Talent and Mawson 1999) have demonstrated that the limestone should be correlated with the late Emsian *serotinus* zone, with older conodonts reworked into the Jesse Limestone. This stratigraphic succession is, therefore, problematical as there appears to be no more than 100 m of sequence separating the graptolite horizon from the Jesse Limestone, suggesting a hiatus or condensed sequence. So, full evaluation of the graptolite fauna is a high priority in the solution of biostratigraphic problems in the district. The relative stratigraphic positions of the *Paciphacops crawfordae* Wright and Haas horizon and the graptolite horizon cannot be determined as the trilobites were not found *in situ*.

No associated macrofauna occurs **with** the graptolites, but occasional pyritised (?) plants fragments occur. Rare brachiopods and clams occur in adjacent beds; the most common brachiopod species appears to be the same undescribed leptocoeliid that occurs in the Warratra Mudstone at Queens Pinch, Mudgee district (Wright and Haas 1990), for which a late Emsian age is indicated by the presence of *Polygnathus serotinus* (S. McCracken, quoted by Pemberton *et al.* 1994) in beds low in the overlying formation, the Sutchers Creek Formation.

In the original Limekilns collections made by

Elisabeth Crawford (1969) from an unknown locality, there are, in addition to the trilobite material described as *P. (Paciphacops) crawfordae* Wright and Haas, brachiopods including *Boucotia australis*(?) as well as tentaculitids and hyolithids; this material was certainly not collected from the graptolite locality discovered by Dr Gordon Packham.

The sequence of fine clastics is interrupted by thin (up to 200 mm thick) light-coloured sands which are prominently bioturbated; their upper surfaces are littered with shell fragments and, therefore, appear to have been hardgrounds developed during decreased amounts of clastic input.

Radiometric data

In any consideration of the geology of this area, SHRIMP age data for the Merrions Formation are crucial, as they demonstrate that the unit is Devonian. As this unit underlies the Limekilns Formation, there can thus be no doubt as to the Devonian age for the latter formation. Pogson and Wyborn (1994) reported an age of 411± 3.1 Ma from the formation base. Pogson and Watkins (1998: 194) listed six preliminary SHRIMP dates for the Merrions as follows: 411±3 Ma, 410 ± 4 Ma, 410 ± 5 Ma, 410 ± 4 Ma, 411 ± 2 Ma and 410 ± 4 Ma; more correct (Jagodzinski and Black, 1999), from the type section of the Merrions Formation, are: 404.8 ± 4.8 Ma (upper part of formation); and 408.3 ± 4.3 Ma, 409.6 ± 4.6 Ma and 410.7 ± 5 Ma (lower part of the formation).

As is well-known, there is no agreement concerning the radiometric age of the base of the Devonian. Recent estimates of 410 Ma have been given by Young (1996) and Rickards *et al.* (1998) and of 417 Ma by Tucker *et al.* (1998). Thus the age determination based on the graptolite fauna is in excellent agreement with the numerically lower of these radiometric ages, but not those of Tucker *et al.* (1998).

REVIEW OF AUSTRALIAN DEVONIAN GRAPTOLITES

Jaeger (1978: 505) noted that material from Cheeseman's Creek near Orange, NSW was "reminiscent of *M. uniformis*". He subsequently (Jaeger 1988: 431) stated that "there are no indubitable finds of Lochkovian graptolites in Australia", and (Jaeger 1988, figure 1 [map]) showed the Cheeseman's Creek occurrence as questionable *M. uniformis;* he did not comment on the occurrence in his text.

Sherwin (1979) listed this Cheeseman's Creek form as *M.* aff. *thomasi* Jaeger 1966, a Pragian species. However, were this correct, then the grapolites which occur with "*M.* aff. *thomasi*" at Cheesemans Creek would be unlikely to be *M. transgrediens* Perner 1899 (see Jaeger 1978: 505; Sherwin 1979: 161–2) which is characteristically Přídolí. Through the kindness of Dr Sherwin, we have re-examined the 2 specimens from Cheeseman's Creek. The *thomasi*-like form is, in our opinion, unquestionably referable to *Monograptus prognatus* Koren' 1983, a Přídolí species (Figure 2A–C herein), and the other specimen is *M. transgrediens* Perner 1899. Therefore this locality must be considered Přídolí (Silurian) and not Devonian. Note that *M. prognatus* shows (preservational) narrow and broad views (see Iordan and Rickards 1971).

Rickards and Garratt (1990) recorded *M.* aff. *uniformis angustidens* Přibyl 1940 from high in the Humevale Formation of Victoria, but considered the form more likely to be late Přídolí than Lochkov. Jenkins (1982) also convincingly argued a late Přídolí age for his record of *M.* cf. *angustidens* from the Elmside Formation of Yass, New South Wales; although this form has been revised by Rickards and Wright (1999) who described it as *Monograptus hornyi* Jaeger 1986. A late Přídolí age was supported by Rickards and Wright.

Thus the only Lochkov graptoloids recorded with certainty from Australia are: *M. u. uniformis* Pribyl 1940 described in this paper; and *M. aequabilis* (Přibyl 1941) described by Jaeger (1966) from Victoria.

Jaeger (1966, 1978, 1988) also reviewed the Australian Pragian graptolites listing *M. thomasi* Jaeger 1966, *M. aequabilis notoaequabilis* Jaeger and Stein 1969 and *M. yukonensis* Jackson and Lenz 1963. Jaeger (1978: 506) first of all listed Packham's (*in* Strusz *et al.* 1972) identification as *M.* cf. *yukonensis*, but he later (corrected by Jaeger's hand in reprints) deleted the "cf" . However, in his lists (1978: 502, table 1) he recorded *M. y. yukonensis* only with an interrogative. This form we have reidentified in this paper as *M. u. uniformis* (see above).

Other Pragian graptolites recorded by Rickards and Banks (1979) and Banks and Rickards (1989) include: *M. aequabilis* cf. *notoaequabilis* Jaeger and Stein 1969 from the Mathinna Beds of Tasmania, by the first authors; and *M. thomasi* Jaeger 1966 from Flowery Gully in Tasmania by the latter authors. The first of these records was not mentioned by Jaeger (1988).

The only other Devonian graptolite in Australia, of which we are aware, is the *Dendrograptus* sp. recorded in this paper (Figure 2D). The genus ranges up into the Carboniferous.

ACKNOWLEDGEMENTS

We extend our thanks to colleagues who helped with preparation of this paper: Dr Gordon Packham for making available his original collections from Limekilns, and Dr Lawrence Sherwin for making available the *Monograptus prognatus* material in his collections from the Orange district of NSW. Professors Ruth Mawson and John Talent very kindly made available a copy of their manuscript which provided information on conodonts of the Limekilns district. Dr Elizabeth Jagodzinki and Dr Lance Black made their SHRIMP data on the Merrions Formation available to us and discussed these problems, and John Watkins assisted with enlarged geological maps. Very helpful reviews of our manuscript were provided by Tatjana Koren', Alf Lenz and Lawrence Sherwin.

This paper is a contribution to IGCP Project 421: *North Gondwanaland mid-Palaeozoic bioevent/ biogeography patterns in relation to crustal dynamics.*

REFERENCES

Banks, M.R. and Rickards, R.B. (1989). Early Devonian graptolites from Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* **123**: 111–117.

Boucek, B., Mihajlovic M. and Veselinovic, M. (1976). Graptolites of the Upper Silurian and Lower Devonian of Zronaèka Banja (Eastern Serbia). *Glas* CCXCVI *Académie Serbe des Sciences et des Arts, Classe des Sciences mathémathiques et naturelles* **39**: 79–114.

Chen, X. and Quan, Q.-Q. (1992). Earliest Devonian graptolites from Ximeng, southwestern Yunnan, China. *Alcheringa* **16**: 181–187.

Crawford, E.A. (1969). *The geology of the Limekilns district, New South Wales*. Unpublished BSc (Hons) thesis, University of Sydney.

Garratt, M.J. and Wright, A.J. (1988). Late Silurian and Early Devonian biostratigraphy of southeastern Australia, 647–662. *In* McMillan, N.J., Embry, A.F. and D.J. Glass (eds), *Devonian of the World. Memoir of the Canadian Petroleum Geologists Association* **14**, volume 3.

Geinitz, H.B. (1852). *Die Versteinerungen der Grauwecken-Formation (Die Graptolithen)*. Leipzig: Verlagwilkelm Engelmann, 58 pp.

Iordan, M. and Rickards, R.B. (1971). Not asupra graptolitilor din Platforma moesic. *Dri de seam ale sedintelor* **57**: 5–19.

Jackson, D.E. and Lenz, A.C. (1963). A new species of *Monograptus* from the Road River Formation, Yukon. *Palaeontology* **6**: 751–753.

Jackson, D.E. and Lenz, A.C. (1972). Monograptids from the Upper Silurian and Lower Devonian of the Yukon Territory, Canada. *Palaeontology* **15**: 579–597.

Jackson, D.E., Lenz, A.C. and Pedder, A.E.H. (1978). Late Silurian and Early Devonian graptolite, brachiopod and coral faunas from Northwestern and Arctic Canada. *Geological Association of Canada, Special Paper* **17**: 1–159.

Jaeger, H. (1959). Graptolithen und Stratigraphie des jüngsten Thüringer Silurs. *Abhandlungen der Deutschen Geologischen Akademie der Wissenschaften, Klasse Chemie, Geologie und Biologie* **2**: 1–197.

Jaeger, H. (1966). Two late *Monograptus* species from Victoria, Australia, and their significance for dating the *Baragwanathia* flora. *Proceedings of the Royal Society of Victoria* **79**: 393–413.

Jaeger, H. (1978). Late graptoloid faunas and the problem of graptoloid extinction. *Acta Palaeontologica Polonica* **23**: 497–521.

Jaeger, H. (1986). In Kříž, J., Jaeger, H., Paris, F. and Schönlaub, H.P. Přidolí – the fourth subdivision of the Silurian. *Jahrbuch der Geologisches Bundesanstalt* **129**: 291–360.

Jaeger, H. (1988). Devonian Graptoloidea, 431–438. In McMillan, N.J., Embry, A.F. and D.J. Glass (eds), *Devonian of the World. Memoir of the Canadian Petroleum Geologists Association* **14**, volume 3.

Jaeger, H. and Robardet, M. (1973). Découverte de *Monograptus uniformis* Přibyl, Graptolite gedinnien dans les "schistes et quartzites siluro-dévoniens" du Cotentin (Normandie, France). *Comptes Rendus de l'Académie des Sciences* **277**: 2129–2132.

Jaeger, H. and Stein, V. (1969). *In* Jaeger, H., Stein, V. and R. Wolfart. Fauna (Graptolithen, Brachiopoden) der unterdevonischen Swarzschiefer Nord-Thailands. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen* **133**: 171–190.

Jagodzinski, E.A. and Black, L.P. (1999). U-Pb dating of silicic lavas, sills and syneruptive resedimented volcaniclastic deposits of the Lower Devonian Crudine Group, Hill End Trough, New South Wales. *Australian Journal of Earth Sciences* **46**: 749–764.

Jenkins, C. J. (1982). Late Pridolian Graptolites from the Elmside Formation near Yass, New South Wales, *Proceedings of the Linnaean Society of New South Wales* **106**: 167–172.

Julivert, M., Duran, H., Rickards, R.B. and Chapman, A.J. (1985). Siluro-Devonian graptolite stratigraphy of the Catalonian Coastal Ranges. *Acta Geològica Hispànica* **20**: 199–207.

Koren', T.N. (1968). A find of graptolites in Borschov Horizon of Podolia. *Akademia Nauk SSSR, Izdatelstva "Nauka", Moskva 1968* **9**: 143–145. (in Russian).

Koren', T.N. (1978). Early Devonian graptolites of South Fergana, Central Asia. *Časopis pro Mineralogii a Geologii* **23**: 113–127.

Koren', T.N. (1983). New Late Silurian monograptids from Kazakhstan. *Palaeontology* **26**: 407–434.

Lapworth, C. (1873). On an improved classification of the Rhabdopora. *Geological Magazine* **10**: 500–4, 555–60.

Lapworth, C. (1875). *In* Hopkinson, J. and Lapworth C. Descriptions of graptolites of the Arenig and Llandeilo rocks of St. Davids. *Quarterly Journal of the Geological Society of London* **31**: 631–672.

Lapworth, C. (1880). On the geological distribution of the Rhabdophora. *Annals and Magazine of Natural History* **5**: 45–62, 273–285, 359–369; **6**: 16–29, 185–207.

Lenz, A.C. and Jackson, D.E. (1971). Latest Silurian (Přidolian) and Early Devonian *Monograptus* of northwestern Canada. *Geological Survey of Canada, Bulletin* **192**: 1–25.

Lenz, A.C., Robardet, M., Gutiérrez, J.C. and Piçarra, J.M. (1996). Devonian graptolites from southwestern Europe: a review with new data. *Geological Journal* **31**: 349–358.

Lu, J., Seccombe, P.K., Foster, D. and Andrew, A.S.

(1996). Timing of mineralization and source of fluids in a slate belt auriferous vein system, Hill End goldfield, NSW, Australia: Evidence from $^{40}Ar/^{39}Ar$ dating and O- and H-isotopes. *Lithos* **38**: 147–168.

Mawson, R., Talent, J.A., Engelbretsen, M.R. and Brock, G.A. (1990). Mid-Palaeozoic conodont data as fundamental chronological underpinning for analysis of allochthoneity of terranes in eastern Australia. *Geological Society of Australia Abstracts* **25**: 50.

Obut, A.M. (1968). Gratolity pogranichnykh sloev silura-devona v SSSR. *Doklady Akademia Nauk SSSR* **182**: 945–948.

Packham, G.H. (1968). The geology and sedimentary tectonics of the Hill End-Euchareena district, New South Wales. *Proceedings of the Linnean Society of New South Wales* **93**: 111–163.

Packham, G.H. (1999). Radiometric evidence for Middle Devonian inversion of the Hill End Trough, northeast Lachlan Fold Belt. *Australian Journal of Earth Sciences* **46**: 23–33.

Pemberton. J.W., Colquhoun, G.P., Wright, A.J., Booth, A.N., Campbell, J.C., Cook, A.G. and Millsteed, B.D. (1994). Stratigraphy and depositional environments of the northern Capertee High. *Proceedings of the Linnean Society of New South Wales* **114**: 105–134.

Percival, I.G. (1998). Early Devonian (Pragian-Emsian) faunas from the Cunningham Formation. *Geological Survey of New South Wales, Unpublished Palaeontological Report* **98/02**: 1–5.

Perner, J. (1899). Études sur les Graptolites de Bohême, IIIb. *Paleontographica Bohemica*, Prague.

Pogson, D.J. and Watkins, J.R. (1998). Bathurst 1:250 000 Geological Sheet S1/55–8. Explanatory Notes. Geological Survey of New South Wales, Sydney. 430 pp.

Pogson, D. and Wyborn, D. (convenors) (1994). Excursion Guide for Bathurst 1:250,000 Geological Sheet. *New South Wales Geological Survey Report*, GS **1994/139**. 137 pp.

Porębska, E. (1984). Latest Silurian and Early Devonian graptolites from Zdanow section, Bardo Mountains (Sudetes). *Annales Societatis Geologorum Polonias* **52**: 89–209.

Přibyl, A. (1940). Die Graptolithenfauna des mittleren Ludlows von Böhmen (oberes e ß). *Věstník Státniho Geologického Ústavu* **16**: 63–73.

Přibyl, A. (1941). Über einige neue Graptolithen Arten aus dem böhmischen Obersilur. *Věstnik Casopis Spolecnost Nauk* **51**: 1–9.

Rickards, R.B. and Banks, M.R. (1979). An early Devonian monograptid from the Mathinna Beds, Tasmania. *Alcheringa* **3**: 307–311.

Rickards, R.B. and Garratt, M.J. (1990). Přidolí graptolites from the Humevale formation at Ghin Ghin and Cheviot, Victoria, Australia. *Proceedings of the Yorkshire Geological Society* **48**: 41–46.

Rickards, R.B. and Wright, A.J. (1999). Systematics, biostratigraphy and evolution of the late Ludlow and Prídolí (Late Silurian) graptolites of the Yass District, New South Wales. *Records of the Australian Museum* **51**: 187–214.

Rickards, R.B., Wright, A.J. and Pemberton, J.W. (1998). Graptolite evidence for the ages of the Sofala Volcanics and the Willow Glen Formation, northern Capertee High, NSW. *Alcheringa* **22**: 223–230.

Savage, N.M. (1971). Brachiopods from the Lower Devonian Mandagery Park Formation, New South Wales. *Palaeontology* **14**: 387–422.

Sherwin, L., (1971). Stratigraphy of the Cheesemans Creek district, New South Wales. *Geological Survey of New South Wales* **13**: 199–237.

Sherwin, L. (1979). Late Ordovician to Early Devonian Graptolite sequences in Australia. *Acta Palaeontologica Polonica* **24**: 155–163.

Springer, K.B. and Murphy, M.A. (1995). Punctuated stasis and collateral evolution in the Devonian lineage of *Monograptus hercynicus*. *Lethaea* **27**: 119–128.

Strusz, D.L., Banks, M.R., Bischoff, G., Cooper, B.J., Cooper, R.A., Flood, P.G., Gill, E.D., Jell, J.S., Pickett, J.W., Savage, N.M., Sherwin, D.L., Talent, J.A., Webby, B.D. and Wright, A.J. (1972). Correlation of the Lower Devonian rocks of Australasia. *Journal of the Geological Society of Australia* **18**: 427–455.

Talent, J.A. and Mawson, R. (1999). North-eastern Molong Arch and adjacent Hill End Trough, eastern Australia: mid-Palaeozoic conodont data and implications. *Abhandlungen der Geologischen Bundesanstalt* **54**: 49–105.

Tucker, R.D., Bradley, D.C., Ver Straeten, C.A., Harris, A.G., Ebert, J.R. and McCutcheon, S.R. (1998). New U-Pb ages and the duration and division of Devonian time. *Earth and Planetary Science Letters* **158**: 175–186.

Young, G.C. (1996). Devonian, 96–109. *In* Young G.C. and Laurie, J.R. (eds), 1–279, *An Australian Phanerozoic Timescale*. Oxford University Press, Melbourne.

Wang, X.-f. (1977a). The discovery of the latest Silurian and earliest Devonian monograptids from Qinzhou, Guangxi and its significance. *Acta Geologica Sinica* **2**; 190–205. (not seen).

Wang, X.-f. (1977b). Graptolites. *In* Hubei and others (eds), 610–613, *Atlas of the Ancient Life of central and southern China, 2, Late Palaeozoic Era*, Geological Science Research Institute, Geological Publishing House, Beijing.

Wright, A.J. (1994). Shelly fossils from the Cunningham Formation. Unpublished Report prepared for the Geological Survey of NSW: 1–4.

Wright, A.J. and Chatterton, B.D.E. (1988). Early Devonian trilobites from the Jesse Limestone, New South Wales, Australia. *Journal of Paleontology* **62**: 93–103.

Wright, A.J. and Haas, W. (1990). A new Early Devonian spinose phacopid trilobite from Limekilns, New South Wales: morphology, affinities, taphonomy and palaeoenvironment. *Records of the Australian Museum* **42**: 137–147.

Zhang, Y.-d. and Lenz, A.C. (1998). Early Devonian graptolites from Southwest Yunnan, China. *Journal of Paleontology* **72**: 353–360.

Manuscript received March 1999; accepted October 1999.