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Definition of a global boundary stratotype for the Darriwilian Stage of the Ordovician System

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*The International Commission on Stratigraphic Nomenclature and the IUGS Executive Committee have recently approved selection of a global stratotype section and point defining the base of the second stage of the Middle Ordovician Series. This stage is named the Darriwilian Stage after the Australian regional stage of the same name, with which it shares identical definition and scope. The base of the Darriwilian Stage is fixed at the base of the *Undulograptus austrodentatus* Biozone in a section through the Ningkuo Shale exposed at Huangnitang, Changshan County, Zhejiang Province, south-east China. This boundary is defined by the first appearance datum of the *U. austrodentatus* within a densely sampled succession of graptolite first occurrences that facilitate precise global correlation of this boundary. Conodont species are also present within this section and indicate that the base of the Darriwilian is likely to lie within the lower part of the *Microzarkodina parva* Biozone of the North Atlantic conodont zonal succession. Correlation of this boundary with well studied successions elsewhere indicates that it is coeval with a level in the mid Whiterockian in North America, and in the lower Fennian Stage of the upper Arenig of Wales. The base of the Darriwilian is about 467.5 ± 3 Ma.*

Introduction

Advances in our knowledge of the Earth's history, including development of an increasingly refined geological time scale, have led to the posing of questions in many areas of geological research that require yet further increases in the precision and reliability of this time scale. To address this need in the Ordovician, the IUGS/ICS Subcommittee on Ordovician Stratigraphy since 1989 has been engaged in an active program aimed at identifying those biological event horizons that exhibit the greatest potential for chronostratigraphic subdivision of the Ordovician System for world-wide use. In particular, this effort has focused on especially widely recognizable biozones within the pelagic graptolite and conodont faunas. The high degree of biogeographic differentiation which characterizes Ordovician biotas has made development of a precise, unified global standard a slow and difficult process. In most regions of the world,

provincially based, regional subdivisions are still actively used. The Ordovician System was first established in the British Isles and consequently the British series, although also based on local and often endemic biotas, have been widely employed as a *lingua franca* for international correlation within the Ordovician. Given these facts, adoption of the new global subdivisions and nomenclature will be a gradual process. Nevertheless, several important first steps have been accomplished, including the first, formally ratified proposal for a global Ordovician stage.

Early in 1996, by a 90% majority, the Titular members of the Ordovician Subcommittee voted in favor of a division of the system into three series named the Lower, Middle, and Upper Ordovician. This provides the basis for the next step; that is, to adopt a simple six-fold global stage level division in which each series is divided into two stages. Most of the stages and series have yet to be formally defined or named, but potential levels for their bases have been identified with particular conodont or graptolite biozones with potential for long range correlation. The general framework of these global stages and series of the Ordovician System has now emerged (Figure 1). It is within this context that the Darriwilian GSSP has been proposed.

The task of identifying suitable levels for series and system subdivision has been conducted by means of a series of intra-Ordovician working groups. Within the interval of the Middle Ordovician (Figure 1), the Ordovician Subcommittee working groups identified two biozonal levels that appeared to have potential for subdivision of the series: the base of the *Didymograptus artus* (= *D. bifidus* of Elles), and the *Undulograptus austrodentatus* biozones. The former level is coincident with the base of the British Llanvirn Series, and the second with the base of the Darriwilian Stage of Australia. The scope, rank, and correlation of the Llanvirn Series have been the subject of much discussion and disagreement (among recent papers see, for example, Fortey and others, 1990; Cooper and Lindholm, 1990; Maletz, 1992; Berry, 1995). Fortey and others (1995), in an effort to address the need for a better unit in this interval, recently revised the Llanvirn Series. Although they identified a possible stratotype section for the base of the Llanvirn in Wales (see Fortey and others, 1991, p. 13), no Welsh candidate sections for a global stratotype at this level have been submitted to the Subcommittee for Ordovician Stratigraphy for consideration. Members of the *Artus* Working Group discussed several additional sections from other regions of the world as a potential stratotype for a stadial boundary at the base of the *D. artus* Biozone, but none appear ideal and again none have been submitted formally to the Subcommittee for consideration.

The Ordovician succession in Australia has a long history of biostratigraphic study. The Darriwilian Stage was erected by Hall (1899), redefined by Harris (1916, 1935), Harris and Keble (1932), and most recently by VandenBerg and Cooper (1992, p. 53) for the interval between the base of the *Undulograptus austrodentatus* Biozone and the *Nemagraptus gracilis* Biozone. Since the 1930's, the

SYSTEM	GLOBAL SERIES	GLOBAL STAGES	KEY GRAPTOLITE/ CONODONT (C) BIOHORIZONS	TRADITIONAL REGIONAL SUBDIVISIONS (SOME UNITS LIKELY TO BE USED IN GLOBAL STAGE NOMENCLATURE)					
				BRITAIN	BALTOSCANDIA	NORTH AMERICA	AUSTRALASIA	CHINA	
ORDOVICIAN	UPPER	--- ? ---	← <i>P. acuminatus</i> (GSSP - Dob's Linn)	Ashgill	Harju	Cincinnatian	Bolindian	Chientang-kiangian	443 Ma
			← <i>D. complanatus</i> , or <i>A. ordovicicus</i> (c)	Caradoc				Viru ^{xxxxxxx} _{BB} ^{xxxx} _{MB}	
	MIDDLE	DARRIWILIAN	← <i>N. gracilis</i>	Llanvirn	Oeland	Whiterockian	Darriwilian		Zhejiangian
			← <i>U. austrodentatus</i> (GSSP - Huangnitang)	Arenig				Kunda	Yapeenian
	← <i>T. laevis</i> (c)	Tremadoc	Volkhov		Castlemainian				
	LOWER			← <i>T. approximatus</i>	Tremadoc	Latorp	Ibexian	Chewtonian	
		← <i>Iapetognathus</i> n.sp. 1 (c)		Tremadoc				Bendigonian	lchangian
							Lancefieldian		

Figure 1 Chart illustrating stratigraphic relationships between global Ordovician Series, Stages, key faunal markers (two of which now have ratified GSSPs) and some regional subdivisions (after Webby, 1997). Volcanic ash event marker (the Big (=Kinnekulle) Bentonite, BB, and correlative Millbrig Bentonite, MB), as well as approximate radiometric dates (after Tucker & McKerrow 1995), also shown.

graptolite zonation upon which the Darriwilian is based has been widely used as a basis for international correlation, particularly in the Pacific Province, and is readily recognizable in graptolite facies around the globe. The Darriwilian Stage spans a stratigraphic interval which is similar to but slightly larger than that of the revised Llanvirn Series of Fortey and others (1995).

Issues raised by the need to choose one or the other of the *D. artus* or *U. austrodentatus* levels were discussed at length during workshops held at the Sixth International Symposium on the Ordovician System in Sydney, Australia, in 1991, and at a subcommission field meeting in Nanjing in 1993, and again at the Seventh International Symposium on the Ordovician System at Las Vegas, USA, in 1995, all minuted in issues of *Ordovician News*, nos. 9 (1992), 11 (1994), and 13 (1996). In 1992–93, in response to discussions at the Sydney meeting of the Subcommission, Chen Xu organized an international working group to investigate sections spanning the Yapeenian-Darriwilian interval in the Jiangshan-Changshan-Yushan area (JCY area) along the border between Zhejiang and Jiangxi provinces, China, and an open invitation was made for participants to join the working group (*Ordovician News*, no. 9, p. 20, 1992). The resulting JCY working group included specialists from China, the USA, France, Germany, and Australia. Based on this joint investigation, as well as the previous work of our Chinese colleagues, the base of the *Undulograptus austrodentatus* Biozone of the Huangnitang section in this area has been identified as a suitable GSSP for the Darriwilian (Chen and others 1995b; Chen and Bergström, 1995; Mitchell and Maletz 1995). This section was chosen as the GSSP because it represents the best available section through the interval including the base of the *U. austrodentatus* Biozone. Five other sections in the JCY region were included in the study, and several of these come near to rivaling the Huangnitang section in their exposure, fossil content, and continuity of succession. With this work in mind, B. D. Webby, Chair of the Ordovician Subcommission, sent an advisory questionnaire to Titular members of the Ordovician Subcommission in early 1995 (*Ordovician News*, no. 13, p. 30-31). The results of this survey provided further guidance for decision-making in favor of using the base of the *U. austrodentatus* Biozone.

The name Darriwilian (Hall, 1899), based on the Australian regional stage, was chosen by the JCY working group because of its priority for the interval extending upwards from the base of *U. austrodentatus* Biozone. Furthermore, it has been agreed by a vote of the Titular members of the Subcommission (82% in favor) in February 1996 that the overlying global stage (and series) will be defined by the base of the *Nemagraptus gracilis* Biozone. Thus, the conception of the global Darriwilian Stage interval, from its base to its top, conforms exactly with prior Australian regional usage.

In July of 1996 the Darriwilian GSSP proposal was overwhelmingly approved by the Titular members of the Ordovician Subcommission (17 votes in favor, 1 against, 2 abstentions, and 1 no response, for a 94% majority). Subsequently, the Darriwilian GSSP was also approved by the ICS, and finally, ratified by a unanimous vote of the IUGS Executive Committee at its January, 1997 meeting.

Recommended global stratotype section and point

The recommended GSSP is located along an unpaved road on the riverside near Huangnitang village, 3.5 km southwest of the Changshan County Town of Zhejiang Province (Figures 2, 3). The section is accessible by vehicle (in fair weather) from the town of Erduqiao, 500m east of Huangnitang. A state highway connects the Changshan County Town with Hangzhou and Shanghai. Conservation and protection of the section has been assured by the Changshan County Government and the Zhejiang Provincial Government together with the Nanjing Institute of Geology and Palaeontology, Academia Sinica.

The section exposed at Huangnitang provides the thickest and most fossiliferous succession across the base of the *Undulograptus austrodentatus* Biozone of any that we have examined (Figure 4). The Huangnitang section comprises mainly the Ningkuo Formation, which at this locality spans the interval from Bendigonian continu-

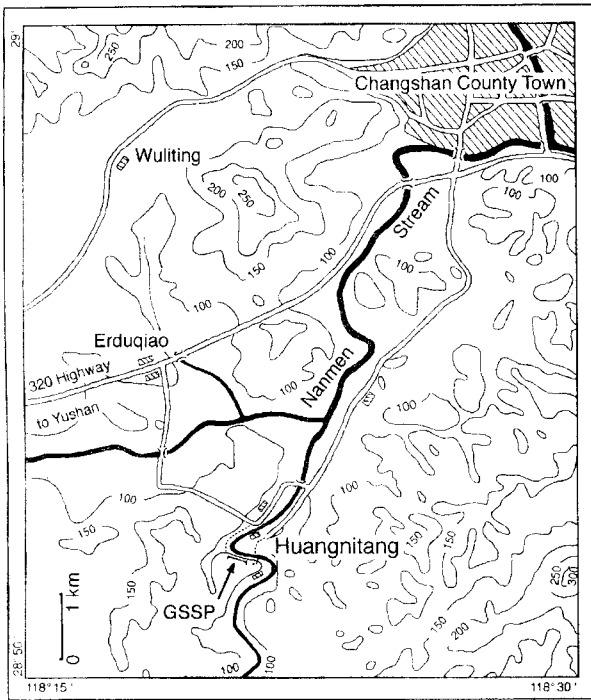


Figure 2 Map showing location of the Huangnitang-GSSP section relative to the nearby Changshan County Town.

ously to Darriwilian. The Ningkuo Formation yields abundant graptolites from the shales and conodonts from interbedded limestones. Ranges of main graptolite and conodont species in the Huangnitang section are shown in Figure 5.

The Ningkuo Formation is dominantly a well-sorted, fine-grained, thinly and evenly laminated black shale (Figure 4). The base of *U. austrodentatus* Biozone in the Huangnitang section, as well as the supplementary sections in the JCY area, lies within a black shale sequence that is entirely consistent in its sediment character and reflects apparently uniform depositional conditions throughout the Yapeinian and early Darriwilian. Tabular beds of dark gray limestone interleave with the shale. Thin sections reveal that in many

beds, the limestone constituents are well-sorted, fine-grained micritic intraclasts, superficial ooliths, and skeletal fragments set in calcite spar matrix. Analysis by graphic correlation based on faunal data from Huangnitang and the five supplementary sections studied in the JCY area indicates that the Huangnitang section has a consistently high sedimentation rate and no detectable stratigraphic breaks. Graptolites are common to abundant in the upper Ningkuo Formation. Above Bed AEP 178 many graptolites are pyritized and preserved in three dimensions, and from AEP 179 to about AEP 199 the rocks are essentially continuously fossiliferous.

The base of the *U. austrodentatus* Biozone in the Huangnitang section is selected as the base of Darriwilian Stage, and is defined as the level of the first appearance datum (FAD) of the name bearer: *Undulograptus austrodentatus* (Figure 6). This level is coincident with the base of Bed AEP 184 of the Huangnitang section, which is 22m below the top of the Ningkuo Formation (Figures 4, 5). Graphic correlation among the six sections examined in the JCY area indicates that this appearance in the Huangnitang section corresponds to the oldest known first appearance of the species (Zhang, 1995). Thus, it is probable that the base of the *U. austrodentatus* Biozone in this section represents the time of evolutionary origin of this key species.

The base of the Darriwilian is formally defined as the base of the *U. austrodentatus* Biozone, however, it is important to note that identification of this boundary is a distinct process from its definition. The base of the Darriwilian should not be identified on the basis of the first appearance of *U. austrodentatus* alone, apart from its faunal context, but only on the basis of the species' first appearance within a well controlled succession of other first-appearances. A second highly distinctive species, *Arienigraptus zhejiangensis* (= *Pseudisograptus angel* Jenkins), first occurs in bed AEP 182, 0.5 m below the FAD of *U. austrodentatus*. In the other JCY sections, the *A. zhejiangensis* FAD occupies a similar position at or just below the *U. austrodentatus* FAD. Within the precision of stratigraphic correlations in the region, the *Arienigraptus zhejiangensis* FAD is synchronous with the base of the *U. austrodentatus* Biozone. Thus, the appearance of *A. zhejiangensis* serves as important collateral evidence of the location of the base of the Darriwilian. For this reason, we employ this species as the name-bearer of the lower subzone of the *U. austrodentatus* Biozone (see below).

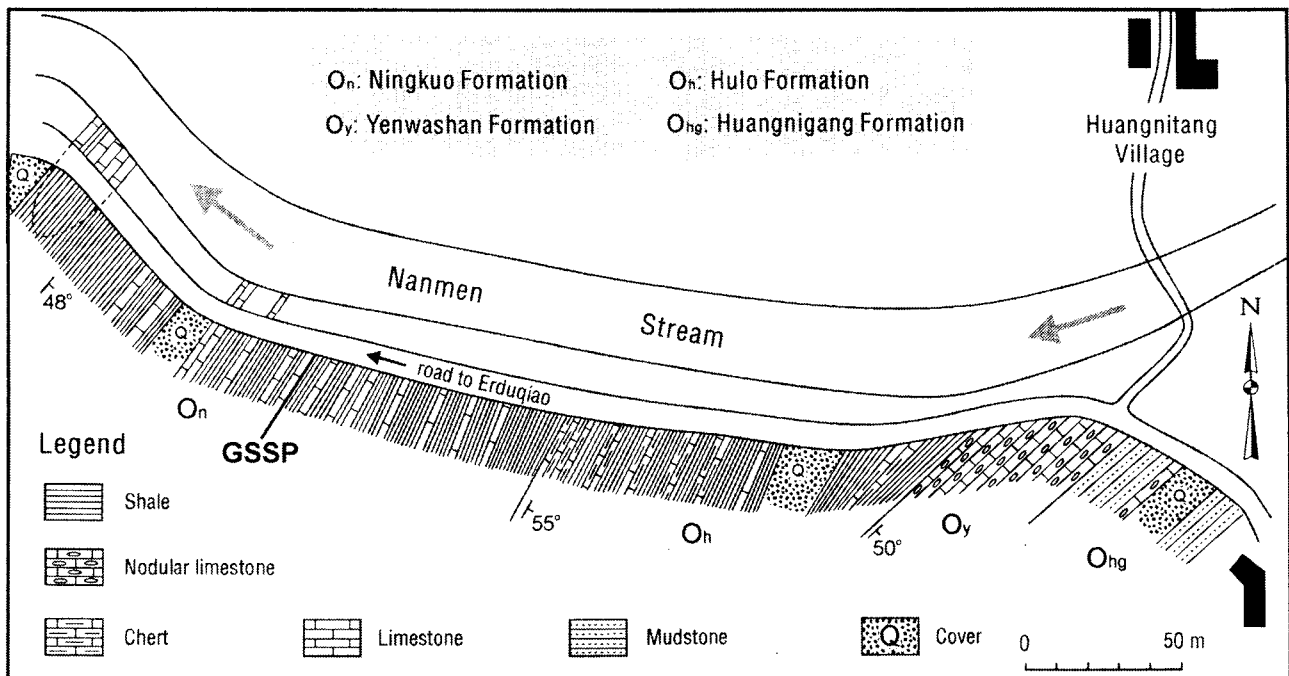


Figure 3 Geological sketch map of the Huangnitang section, Changshan, China. Rocks dip moderately to the east-south-east, and young in that direction.

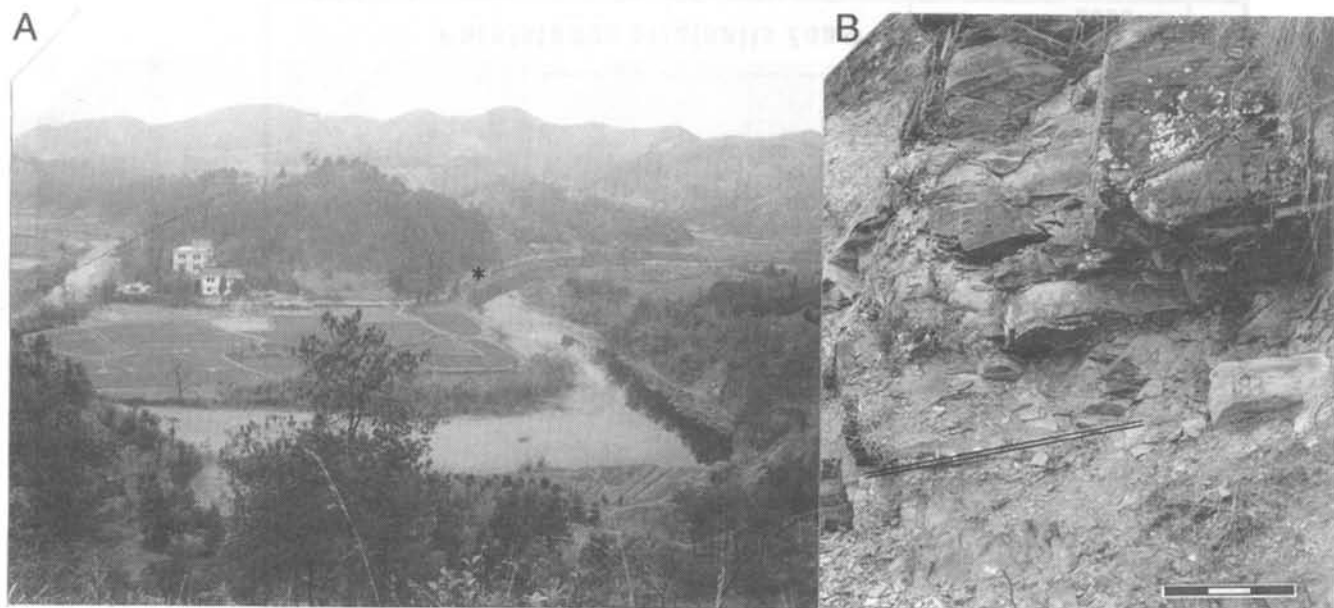


Figure 4 A. View of the Huangnitang section (looking west), and the surrounding country side. GSSP is near star along south bank of the Nanmen Stream. B. Close-up of section showing beds in the boundary interval. Base of the *U. austrodentatus* Biozone and Darriwilian Stage lies at base of bed AEP 184 (indicated by double line), just above limestone bed AEP 183. Scale marked in decimeters.

The graptolite record

The presence of several short-ranging species and the pattern of graptolite species succession through the interval of the Darriwilian boundary are critical to reliable recognition of the base of the Darriwilian as well as to its precise international chronostratigraphic correlation. Several of the critical species are illustrated in Figure 6. The graptolite fauna present in the 3 m interval just below the base of the Darriwilian at Huangnitang is a typical Yapeenian assemblage that includes *Pseudisograptus manubriatus harrisi*, *P. manubriatus koi*, *Exigraptus uniformis*, and *E. clavus* (which is closely allied to *Apiograptus crudus*). The composite standard constructed for the JCY region (Zhang, 1995) indicates that strata in this interval in the JCY area also contain *Oncograptus magnus*, *Arienigraptus dumosus*, *Isograptus victoriae maximodivergens*, and *I. victoriae divergens* (see also Xiao and Chen, 1990). We refer the interval from AEP 180 to 183 to the *Exigraptus clavus* Biozone, the base of which is covered in this section. Shales of the mid to uppermost *E. clavus* Biozone (AEP 181 at Huangnitang) contain the first appearance of *Cardiograptus obesus* followed in bed AEP 182 by *C. amplus*, *Undulograptus sinodontatus*, and *Arienigraptus zhejiangensis* (Figure 5).

Based on the Huangnitang stratotype section, as well as other supplementary sections in the JCY area, we recognize two subzones, the *Arienigraptus zhejiangensis* (lower) and *Undulograptus sinicus* (upper) subzones, within the *U. austrodentatus* Biozone (Chen and others, 1995b; Mitchell and Maletz, 1995). The base of the *A. zhejiangensis* Subzone, like that of the zone itself, is defined by the first appearance of *U. austrodentatus*. The fauna of the *A. zhejiangensis* Subzone is very diverse and includes a rapid succession of first appearances of species of *Undulograptus*, *Cardiograptus*, and *Exigraptus* (Figure 5), including *Undulograptus formosus*, and *U. primus*. The base of the *Undulograptus sinicus* Subzone, is marked by the first appearance of *U. sinicus*. This level is very nearly coincident with the first appearance of *Cryptograptus antennarius* and *Paraglossograptus tentaculatus*, as well. The base of the upper subzone defines the top of the lower subzone. The last appearance of several of characteristically Yapeenian species that continue into the

lower *U. austrodentatus* Biozone occurs near the base of the *U. sinicus* Subzone. These species include *Pseudisograptus manubriatus*, *Isograptus victoriae divergens*, and *Oncograptus upsilon*. Overlap of these species with *U. sinicus* provides a very precise control of the base of the subzone.

The *Undulograptus austrodentatus* Biozone is overlain in the JCY region by the *Acrograptus ellesae* Biozone (Xiao and Chen, 1990). Preliminary data (Zhang Yuan-dong, unpublished) indicate that species of *Tylograptus*, *Sinograptus* and other graptolites characteristic of *A. ellesae* Biozone appear in the uppermost 5.2 m of the Ningkuo Formation and continue into the lower part of the Hulo Formation at the Huangnitang section (Figure 5).

Accurate identification of the index species *Undulograptus austrodentatus* and *Arienigraptus zhejiangensis* (see Figure 6) is essential to recognition of the base of this biozone. In the past, considerable controversy has surrounded the issue of whether or not the appearance of "biserial graptolites" was actually synchronous around the globe (e.g., Skevington, 1963; Berry, 1968; Cooper and Lindholm, 1990; Fortey and others, 1990; Maletz, 1992). Much of the confusion arose as a consequence of application of the term "biserial" to a wide variety of species (including glossograptids) and confusion about the identification of particular species such as *Didymograptus bifidus* and *U. austrodentatus*. This problem has been solved by recent systematic work based on especially well preserved material (e.g., Cooper and Fortey, 1982; Fortey and Cooper, 1986; Mitchell, 1992, 1994; Mitchell and Maletz, 1995), although contrary interpretations continue to have advocates (e.g., Berry, 1995). Chen and others (1995a) have redescribed *Undulograptus austrodentatus* (Harris & Keble) and *Arienigraptus zhejiangensis* Yu and Fang in detail.

The conodont record

Conodonts from limestone interbeds within the Huangnitang section (commencing with sample AEP 167) are referable to the *Paroistodus originalis* Biozone (Wang and Bergström, 1995). Although the fauna is of low diversity, elements are numerous and well preserved (Figure 4). They are typical of the low diversity North Atlantic

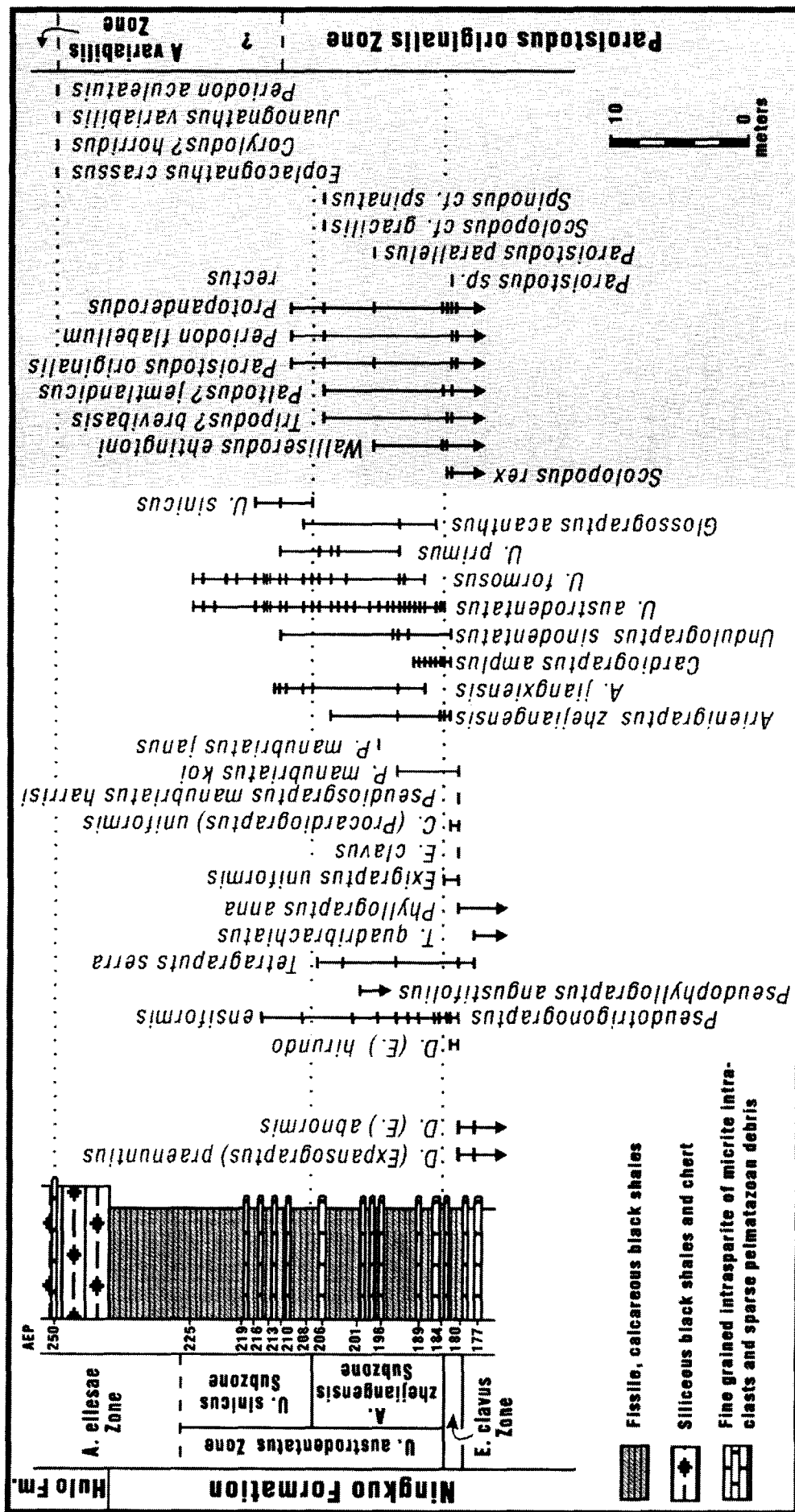


Figure 5. Stratigraphic succession across the Darrwillian boundary interval., Huangnitang GSSP, showing lithological units, biozones, and the vertical ranges of graptolite (left) and conodont (shaded, at right) species (based on data from Chen and Bergström, 1955). Detailed graptolite range data for the Acrograptus ellesae Biozone not yet available.

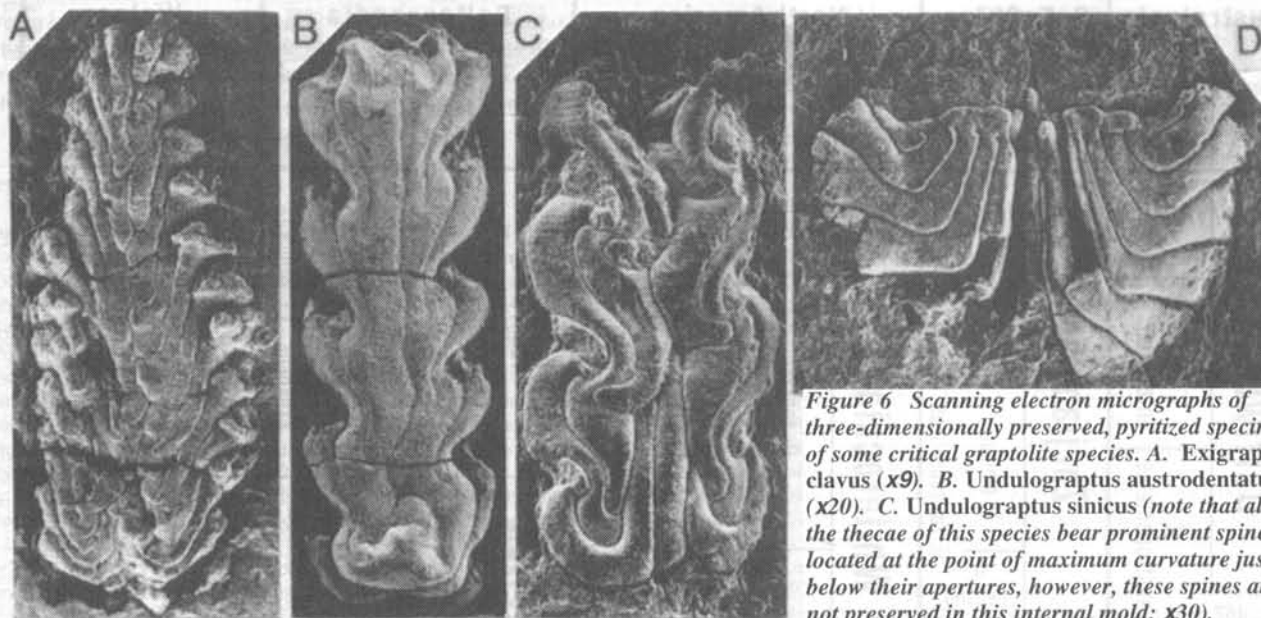


Figure 6 Scanning electron micrographs of three-dimensionally preserved, pyritized specimens of some critical graptolite species. A. *Exigraptus clavus* (x9). B. *Undulograptus austrodentatus* (x20). C. *Undulograptus sinicus* (note that all of the thecae of this species bear prominent spines located at the point of maximum curvature just below their apertures, however, these spines are not preserved in this internal mold; x30). D. *Arienigraptus zhejiangensis* (x20).

Province faunas usually obtained in off-shore settings, and contain none of the shallow water endemics found in rocks of the Yangtze Platform. Based on these faunas as well as occurrences of conodonts and graptolites together in the Dawan Formation of the Yichang region, Yangtze Platform (about 700 km WNN of the JCY region; see Wang and Bergström, 1995), and in the Vinini Formation of central Nevada (Finney and Ethington, 1992; Mitchell, 1992), the base of the *U. austrodentatus* Biozone lies just above the base of the *Microzarkodina parva* Biozone in the North Atlantic conodont zonation and within the upper part of the *Histiodella altifrons* Biozone in the North American midcontinent conodont zonation.

Conodonts from bed AEP 250 in the Huangnitang section include *Eoplacognathus crassus*. In terms of graptolite zones, this bed lies within the *Acrograptus ellesae* Biozone. The AEP 250 conodont fauna indicates that these strata belong to the lower, but not lowermost, part of the *Amorphognathus variabilis* Biozone of the North Atlantic conodont zonation, consistent with an *M. parva* Biozone age suggested for the base of the *U. austrodentatus* Biozone.

Chitinozoan and acritarch records

Correlation between the Lower Ordovician low latitude faunas of the Pacific Province and the dominantly cool to cold water faunas of Gondwana has been a persistently difficult problem. Correlation via the trilobite faunas in Wales represents one possibility, albeit largely untested at present. Recent attempts to obtain chitinozoans from the *U. austrodentatus* boundary interval suggest another potential solution. Paris and Chen (1995, 1996) report discovery of chitinozoans from Huangnitang and three other sections in the JCY area. Taxa present include species of the genera *Conochitina*, *Cyathochitina*, *Rhabdochitina*, *Tanuchitina*, *Laufeldochitina*, *Belonechitina*, *Desmochitina* and *Sagenachitina*. Specimens of the first three genera are the most common in their collections. Several of these genera are known from Gondwanan locales and *Sagenochitina* in particular is a characteristic element of upper Arenig (Whitlandian) to lower Llanvirn strata in northern Gondwana (e.g., France, Portugal, Algeria, and Libya; see Paris, 1990).

Servais and others (1995), in a thorough revision of the distinctive acritarch *Dicrodiacrodium ancoriforme*, report that its first appearance lies within the latest Yapeenian *U. sinodontatus* Biozone in the Dawan Formation, China. Although not yet known from the

JCY area, *D. ancoriforme* has been previously reported widely from the Llanvirn and younger strata in Europe and northern Africa. This species is also present in late Arenig rocks within the Sárka Formation in Bohemia together with a *D. bulla* Biozone chitinozoan fauna (Vavrdová, 1993).

Clearly, additional work is required on these fossils and their distribution. Further research into their occurrence in the JCY and Yangtze Platform regions is underway currently. However, the available data are sufficient to indicate that chitinozoans and acritarchs may offer the opportunity to make an accurate correlation of the base of the Darriwilian with late Arenig successions of the peri-Gondwanan realm, where *U. austrodentatus* and its associates are absent.

Prospects for paleomagnetic reversal stratigraphy and radiometric age determinations

No paleomagnetic work has yet been carried out in the Middle Ordovician sections of the JCY area. However, in view of the fact that the Conodont Color Alteration Index (CAI) is only 3–4, indicating heating of the rocks to a maximum of about 100°C–300°C (Wang and Bergström, 1995), there is clearly potential for successful establishment of magnetic reversal stratigraphy across the base of the Darriwilian. The only rocks in the Ningkuo Formation in the study region that are potentially useful for radiometric age determinations are two thin K-bentonite beds in the *Azygograptus suecicus* Biozone described by Huff and Bergström (1995) in a section at Hengtang. No radiometric age data are yet available from these beds, but in a companion paper to the present contribution, Huff and others (1997) report a U-Pb age of 464±2 Ma from a K-bentonite located within the lower Darriwilian *U. austrodentatus* Biozone in the Precordilleran Terrane of Argentina.

Australasia		S. E. China		North America				Baltoscandia			Wales			
Stages	Victorian graptolite zones	Series	Graptolite zones	Series	Texas graptolite zones	Mid-continent conodont zones	shelly zones	Stages	Graptolite zones	Conodont zones	Trilobite zones	Series	Graptolite zones	Trilobite zones
Cast Yap	I. v. maximo-divergens	Yushanian	I. caduceus imitatus	Whiterockian	Isograptus	P. tentaculatus	L M N O	Volkhovian	D. (E.) hirundo	M. parva	P. originalis	Arenig	I. gibberulus	S. abyfrons
	Oncogr.		Exigraptus clavus											
467.5±3	Cardiogr.	Zhejiangian	A. zhejiang.	Whiterockian	Isograptus	P. tentaculatus	L M N O	Kundan	D. (D.) artus	A. variabilis	A. "raniceps"	Llanvirn	D. (D.) artus	D. levigena
	U. austrodentatus		U. sinicus											
Diplogr.?	decoratus	Zhejiangian	A. ellesae	Whiterockian	Isograptus	P. tentaculatus	L M N O	Kundan	D. (D.) artus	A. variabilis	A. "raniceps"	Llanvirn	D. (D.) artus	D. levigena
	U. intersitus		U. sinicus											

Figure 7 Correlation chart showing chronostratigraphic relations between the base of the recently ratified global Darriwilian Stage of the Middle Ordovician Series and several well-known regional series and stages based on data and interpretations cited in Mitchell and Chen (1995) and Mitchell and Maletz (1995), with radiometric ages interpolated based on data from Tucker et al. (1995) and Huff et al. (1997), and relative stage durations from Cooper (1992).

Correlation of the base of the Darriwilian Stage

The distinctive fauna of the *U. austrodentatus* Biozone has been reported from Australia, New Zealand, North America, Europe, South America, China, Mongolia, and Kazakhstan permitting confident correlation with these regions (Figure 7). *A. zhejiangensis* Subzone faunas occur in the Marathon region, Texas, and similar faunas are also present elsewhere along the western North American Cordillera (Mitchell and Chen Xu 1995). An *U. sinicus* Subzone fauna has been recorded from Quebec and Newfoundland (Mitchell and Maletz 1995). Correlations with faunas from North America indicate that the base of the *U. sinicus* Subzone is nearly coincident with the base of the widely recognized *Paraglossograptus tentaculatus* Biozone. Similar relationships are present in the Argentine Precordillera (Ortega and others 1993; Albanesi and others, 1995; Edsel Brussa and C.E. Mitchell, unpublished data).

The oldest diplograptacean known from Wales is *Undulograptus cumbrensis* from the *Bergamia rushtoni* Biozone (Figure 7). Its FAD is certainly within the *U. sinicus* Subzone (Mitchell and Maletz, 1995). The base of the *U. austrodentatus* Biozone, therefore, should lie below the oldest occurrence of diplograptaceans yet discovered in Wales, within the lower part of the Fennian Stage. The interval of the lower *U. austrodentatus* Biozone is represented in North Wales (as at Nant y Gadwen) and in the Skiddaw Group of the Lake District, based on the presence there of *A. zhejiangensis* (reported as *P. angel*) in the upper *Isograptus caduceus gibberulus* Biozone (Fortey and others, 1990). The *U. sinicus* Subzone is present in younger rocks of the Lake District, where it is equivalent to the *Didymograptus hirundo* Biozone as used by Jackson (1962) and

in North Wales near Caernarfon and Bangor (Fortey and others, 1990).

In Sweden, *A. zhejiangensis* occurs in the middle part of the *D. hirundo* Biozone together with *Pseudisograptus manubriatus janus* and *Pseudophyllograptus cor.* *U. sinicus* and *U. cumbrensis* occur in the upper *D. hirundo* biozone (Mitchell and Maletz, 1995). The base of the Llanvirn most likely coincides with a level slightly above the base of the *A. ? ellesae* Biozone of southeast China, which is closely comparable to the *Undulograptus intersitus* Biozone (Darriwilian 2) in Australia and New Zealand. Conodont evidence from the JCY area indicates that the base of the *A. ? ellesae* Biozone corresponds to a level near the base of the *Amorphognathus variabilis* Biozone, which is in agreement with the conodont age of the rocks in the Arenig-Llanvirn boundary interval in the Baltic region.

As mentioned previously, conodont evidence from the JCY area indicates that the base of *U. austrodentatus* Biozone is in strata that probably correspond to either the upper part of the Baltoscandian *Paroistodus originalis* Biozone or lower part of the *Microzarkodina parva* Biozone. Comparison with the Yangtze Platform conodont succession favors the latter interpretation (Bergström and Wang, 1995). The conodont zonal assignment of rocks from both Sweden and Nevada that, based on their graptolite faunas, are correlatives of the lower *U. austrodentatus* Biozone also fall within the *M. parva* Biozone. Strata of the *A. ellesae* Biozone in the JCY area (e.g., AEP 250) as well as rocks from just above the *U. austrodentatus* Biozone in Quebec and Sweden belong to the *A. variabilis* Biozone (Bergström and Wang, 1995; Mitchell and Maletz, 1995). The *A. variabilis* Biozone fauna at Huangnitang includes the distinctive (albeit newly recognized) conodont, *Eoplacognathus crassus* Chen and Zhang, which is also present in this same interval in the Yangtze platform region, as well as at localities in Sweden, Estonia, and Poland (see Zhang, 1997). *E. crassus* appears to be a short rang-

ing species restricted to the lower, but not lowermost, part of the *A. variabilis* Biozone (i.e., the upper part of the *A. variabilis-Microzarkodina flabellum* Subzone). Based on these conodont-graptolite relations we are confident that the age of the base of the *U. austrodentatus* Biozone is consistent across both the Pacific and Atlantic provinces.

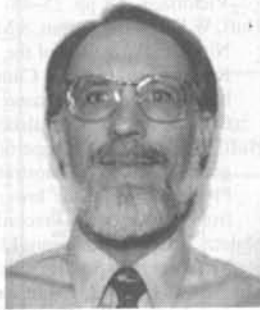
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