Continuing Work on the Precambrian-Cambrian Boundary

by J.W. Cowie

A proposal by the Precambrian-Cambrian Boundary Working Group to formally define the base of the Cambrian System in a section at Meishucun, Yunnan Province, China, has been deferred pending further studies on correlation. This article reviews investigations of the boundary interval since 1972 and outlines work in progress designed to resolve the remaining problems.

Introduction

Interest in the best placing of the boundary between Precambrian and Cambrian rocks goes back into the last century, but was much stimulated by new discoveries and improved techniques in the 1950s and 1960s. In 1972, the Working Group on the Precambrian-Cambrian Boundary was established by the International Commission on Stratigraphy (ICS). It is independent of the Subcommissions on Precambrian and Cambrian Stratigraphy but, like all intersystem working groups, is responsible directly to the ICS.

Up to 100 members from 20 countries have been involved in the Working Group, all recruited as individuals with relevant expertise, and at present there are 30 Voting Members. None of these is a delegate, and they are not therefore termed "titular," as their membership is not "held by virtue of a title." From 1974 to 1984 the Working Group also functioned as IGCP Project 29, now "on extended term."

Procedures and Results

From 1972 to 1984, a series of meetings was organized to examine and discuss Precambrian-Cambrian Boundary sections. Plenary sessions and workshops were held in Montreal (Canada, 1972), Paris (France, 1974), Moscow (U.S.S.R., 1975), Leningrad (U.S.S.R., 1976), Sydney (Australia, 1976), Beijing (China, 1978), Paris (1980), Golden (Colorado, U.S.A., 1981), Kunming (China, 1982), Bristol, (U.K., 1983) and Moscow (1984).

Field meetings were held on 15 occasions, involving both examinations of sections and discussions leading to subsequent research with local geologists (Fig. 1 and see Cover Photo). The following areas have been visited: East Siberia (1973 and 1981), Normandy and Brittany (1974), Ural Mts. (1975), Georgia (1975), Anti-Atlas Mts. of Morocco (1975 and 1976), Flinders Ranges in South Australia (1976), Iberian Peninsula of Spain and Portugal (1976), Central and South China (1978 and 1982), eastern Newfoundland (1979), Mackenzie Mts., Canada (1979), Nevada-California (1981), Wales and England (1983).

In plenary sessions at Paris (1974), Cambridge (1978) and Bristol (1983) a series of important decisions were reached; these are still relevant and in force. In Paris, the Working Group agreed that its primary task is the choice of a stratotype boundary point, with a secondary job to consider stratigraphic divisions above and below the boundary. Any succession selected for the boundary point must be marine,

and as continuous and monofacial as possible. The main method of guidance in selection should be biostratigraphy, but all possible methods of correlation should be enlisted. It was also agreed at this time that the "Ediacara" type fauna should be considered Precambrian, and the "olenellid-fallotaspid" trilobite faunas as Cambrian.

At the Cambridge meeting, the Working Group agreed to be guided primarily by the criterion that the Precambrian-Cambrian boundary should be approximately located in the chronostratigraphic scale near the evolutionary changes signalled in the rocks by the appearance of diverse fossils with hard parts. This decision was superseded in Bristol (1983) by one to place the boundary stratotype as close as practicable to the lowest known appearance of diverse shelly fossils with a good potential for correlation.

Figure 1: Members of the Working Group on the Precambrian-Cambrian Boundary disembarking on the shores of the Aldan River, east Siberia. In the middle distance are the river cliffs of Dvortsy, the type section for the Tommotian Stage in the Lower Cambrian strata of the U.S.S.R.

Figure 2: The Ulakhan-Sulugur section through the upper part of the Yudoma Formation (Vendian) and the lower part of the Pestrosvet Formation (Tommotian) on the Aldan River. Arrow points to Bed 8 of the Yudoma Formation, proposed earlier as a candidate for the Precambrian-Cambrian Boundary stratotype. (Photo by A. Yu. Rozanov).

The Cambridge meeting also emphasized that the boundary stratotype point is defined and placed in the rock, where it will be a reference point that should remain fixed, despite the possibility of fresh discoveries in the rocks stratigraphically below or above. It is worth noting that at this meeting, a minority view held that "in selecting a boundary stratotype point, one should ensure that there is a maximum potential for correlation, even if this implies a higher stratigraphic position so that there obtains a Precambrian shelly fauna."

At the 1983 Bristol meeting, candidates for the global stratotype section and point were discussed in some detail, and three were selected for further consideration: Ulakhan-Sulugur on the Aldan River in east Siberia, U.S.S.R.; on the Burin Peninsula, of eastern Newfoundland, Canada; and at Meishucun in Yunnan Province, southern China. The 32 members of the Working Group present (out of a total membership of 100) voted by 19 to 13 to put the Ulakhan-Sulugur stratotype section (see Rozanov, 1984) to a postal ballot of all the Voting Members of the Group. The result of this postal vote was a rejection of the Siberian candidate by 9 against, 7 in favour and 3 abstentions.

The reasons given for rejecting the Ulakhan-Sulugur candidate (Fig. 2) were that the section is too inaccessible, not suitable for isotopic dating, and that it is neither continuous nor monofacial. Moreover, the section has disconformities and facies changes close to the candidate boundary point horizon. Another difficulty arises in comparing the eastern Siberian Precambrian-Cambrian boundary outcrops with relevant successions in northern Siberia, which are probably more complete but inaccessible. Here doubts are raised that the succession at the candidate stratotype on the Aldan River is complete. Horizons of skeletalized faunal assemblages of earliest Cambrian age may be missing here due to the disconformities and facies changes.

By December 1983, there was still no satisfactory standard available for the Newfoundland candidate, so it was decided to put the Chinese section to a postal ballot. This resulted in a clear majority (nearly 80% of votes) for placing the stratotype section and point at Meishucun in south China (Fig. 3). This decision was submitted in June 1984 for discussion at the Moscow Geological Congress in August 1984, to be followed by a postal ballot of Voting Members of ICS, with the result submitted for ratification by the IUGS Executive in 1985.

The substance of the submission to ICS on the Precambrian-Cambrian boundary stratotype is given below, followed by a rider added at the ICS meeting in Moscow. The whole question is still being actively discussed.

The Meishucun Submission:

The June 1984 submission dealt with the intersystem boundary between the "Terminal Precambrian System" of the Precambrian "Supereon" and the Cambrian System. It proposed a stratotype section and point for the "Precambrian-Cambrian Boundary" at Kunyang Quarry, Meishucun, Jinning County, Yunnan Province, China. The position of the quarry is 24° 44' north latitude, 102° 34' east longitude, at a height of about 1500 m above sea-level. The region is located on the southwestern margin of the Yangtze platform, and the Meishucun section is on the southern limb of the approximately east-west trending Xiangjiaocong Anticline. The section through the late Precambrian Sinian

Figure 3: The Xiaowaitoushan segment of the Meishucun section, Jinning, Yunnan; figures on left give scale. The middle ground outcrop includes the candidate global stratotype section and point with Bayanshao, Xiaowaitoushan and Zhongyicun Members of the Yuhucun Formation (see Table 1).

Table 1: Precambrian-Cambrian stratigraphy and calibrated Rb-Sr isotopic dates, Meishucun China. The isotopic ages given for the Badaowan Member may be somewhat too old due to the presence of inherited detrital minerals. (Dates after Cowie and Johnson, in press).

System	Formation	Member	Representative Isotopic Ages (Ma) and Method		
CAMBRIAN	Shuijintuo		573±7	Rb-Sr	
			568±12	U-Pb	
			572±13	Rb-Sr	
			570±4	Rb-Sr	
			574±20	Rb-Sr	
	-----hiatus at least in places-----				
	Dengying	Tientzushan	602±15	Rb-Sr	
		Tientzushan	615±20	Rb-Sr	
		Baimatuo	614±18	Rb-Sr	
		Shibantan			
Hamojin					
SINIAN	Touchantuo		700±5	Rb-Sr	
			691±29	Rb-Sr	
			727±9	Rb-Sr	
	Nantuo (with tillites)				
		Datangpo	728±27	Rb-Sr	
		Gucheng			
		Lientuo	740±16	U-Pb	
	PRESINIAN	Huangling Granite		823±7	K-Ar
				806±4	Rb-Sr
			819±54	Rb-Sr	
			860±50 (2)	U-Pb	

Table 2: Late Precambrian-Early Cambrian stratigraphy, Yangtze area, Hubei Province, China. Isotopic ages from Cowie and Johnson (in press).

system into Lower and Middle Cambrian strata is continuous, marine, monofacial, rich in shelly fossils and trace fossils and with ease of access.

The Kunyang Quarry section is conserved as a national monument. It is approximately 75 km south of Kunming, the capital of Yunnan, about 1.5 hours travel away by public bus, automobile or taxi. Kunming and the surrounding tourist area constitute an important center in southern China, which is served by good air, rail and road communications. There are regular scheduled air services from Beijing, Hong Kong and elsewhere. A new large international standard hotel and other good accommodations are available in Kunming. Accessibility by wheeled transport is excellent throughout the year, and there is a congenial climate at this altitude and latitude.

The stratotype section from upper Precambrian Sinian system strata to trilobitic Lower Cambrian is almost continuously exposed at Tuanshanding, Xiaowaitoushan and Badaowan, within a few hundred metres of the small town of Meishucun. Excavations now being undertaken will make the outcrop completely continuous. The recommended stratotype point (the "golden spike") is placed at the base of Unit (Bed) 7 in the section near Xiaowaitoushan (Fig. 3), which is also the junction of Fossil Zones I and II.

The generalized late Precambrian to Early Cambrian succession is shown in Table I. For the sake of brevity only Units 6-8 of the Yuhucun Formation are described here (Xing and Luo, 1984).

Unit 8: 1.1 m thick, grey, thin and moderately thick-bedded, quartzose silty phosphatic and manganiferous dolomite, intercalated with striped cherts, yielding hyolithids, hyolithelminthids, tubetichitids, conodontomorphs, monoplacophorans, gastropods and brachiopods.

Unit 7: 0.3 m thick, grey, thin-bedded, oolitic or pseudo-oolitic dolomitic phosphorite, containing hyolithids, hyolithelminthids, tubetichitids, conodontomorphs, monoplacophorans, gastropods, brachiopods and trace fossils.

Unit 6: 5 m thick, blue-grey, moderately thick-bedded, pseudo-oolitic or oolitic, siliceous and dolomitic phosphorite intercalated with a thin layer (0.2 m) of phosphatic, intrasammitic lutaceous shale yielding hyolithids, hyolithelminthids, monoplacophorans and acritarchs.

As regards criteria for correlating the boundary level, Chinese specialists claim that the continuous (as supported by seismic stratigraphy), monofacial, marine deposits rich in skeletalized animal body fossils and trace fossils of the Meishucun section have the best potential for correlations among the boundary sections known in other parts of the world. Indeed good correlations have already been achieved, based not only on biostratigraphic criteria but also on modern studies of other factors: isotopic ages, magnetostratigraphy, biotic characteristics of small shelly fossils, and trace fossils.

Series . . .	Upper Sinian		Lower Cambrian			
Stage . . .	Dengyingxia	Meishucun			Qiongzhusi	
Shelly fossils		A.-C.		P.-S.	S.-E.	P. E.
Trace fossils		S.	C.	D.	P.	
China (Yunnan)	Yuhucun Formation			Qiongzhusi Formation		
Mongolia	Tsaganolom Formation		Bayangol Formation		Salanygol Formation	
Siberian Platform	Yudom Formation		Pestrovskaya Formation (Tommotian)		Tumuldur Formation (Atdabanian)	
E. European Platform						
Morocco						
U.K.	Charnian			Hartshill Formation	Stockingford Formation	
U.S.A.	Reed Dolomite	Deep Spring Formation			Campito Formation	
Newfoundland		Grand Bank Formation	Miquelon view Formation	Random Formation	Brigus Formation	
Mackenzie	Map Unit 10 b	Map Unit 11	Map Units 12, 8, 13		Sekwi Formation	
Australia	Pound Quartzite	Urutanna Formation	Parachilina Formation		Ajax Limestone	

Figure 4: Intercontinental correlation of Precambrian-Cambrian boundary sections. Fossil zones are explained in the text (after Xing and Luo, 1984).

Isotopic ages-dates are given in Table 1 for the stratotype section (Xue, 1984; Zhang et al., 1984; Cowie, in press). Table 2 presents more comprehensive data from the Yangtze River area in Hubei Province, which is closely correlated on biostratigraphic grounds with Meishucun and which gives added information for earliest Cambrian times and the Sinian Period. The isotopic age for the recommended Precambrian-Cambrian boundary stratotype point in the Meishucun section is estimated therefore at 600 ± 10 Ma.

With regard to magnetostratigraphy, material from 48 sampling sites has provided 69 measurements on a spin magnetometer with thermal demagnetization also conducted on a modern instrument. These results show a dominance over the whole section of normal magnetizations but with reversals at five positions.

Biotic characteristics of small shelly fossils give three assemblages that bracket the boundary point (see Table 1 and Fig. 4; Song, 1984; Jiang, 1984; Xing et al., 1984; Xing and Luo, 1984):

Zone I (oldest): Anabarites-Circotheca (A-C) assemblage; Units 1-6 with genera Circotheca, Turcutheca, Conotheca, Spinulitheca, Barbitositheca, Anabarites and others.*

Zone II: Paragloborilus-Siphonoguchites (P-S) assemblage; Units 7 and 8 with genera Ovalitheca, Torelloella, Paragloborilus, Lophotheca, Siphonoguchites, Zhiyinites, Latouchella, Yangtzespira, Bemella, Ilsanella, Tannuella, Sunnaginina and others.

Zone III: Sinosachites-Eonovitatus (S-E) assemblage; Units 9 to 13 with genera Eonovitatus, Allatheca, Neogloborilus, Palaeacmaea, Ilsanella, Tannuolina, Sinosachites, Sachites, Lapworthella, Coleoloides, Rhabdochites, Chancelloria and others.

Zone IV and V (youngest): Parabadiella (P) and Eoredlichia (E) trilobite assemblages respectively.

*Xing and Luo, 1984, and Xing et al., 1984, proposed to set the boundary at the base of the Zone I assemblage. The decision to vote on the base of Zone II was based on several complex factors (see e.g. Luo et al., 1984, p127-129). -Ed.

Trace fossils occur in large numbers and are uniquely useful at Meishucun because of their association in the same pieces of rock with small shelly fossils that are an internationally correlatable feature, according to current work on the Precambrian-Cambrian Boundary strata. This feature is not at present known elsewhere. Ichnogenera include Didymaulichnus, Rusophycus, Cruziana, Plagiogmus and Gordia, and correlations with Newfoundland, France and farther afield can consequently be suggested. A series of trace fossil zones have been set up at Meishucun (see Fig 4):

youngest: P - Plagiogmus arcuatus
D - Didymaulichnus miettensis
C - Cavaulichnus viatorus
oldest: S - Sellaulichnus meishucunensis

In summary, due to the abundant small shelly fossils, trace fossils, algae, microphytolites, worms and acritarchs and the utilization of isotopic ages and magnetostratigraphy, the Meishucun Precambrian-Cambrian boundary is claimed to be correlatable extensively with known regions elsewhere (and will be to others yet undiscovered) characterized by carbonate and clastic-rock facies. It, therefore, possesses all the main requirements necessary for a global stratotype section and point for the Precambrian-Cambrian Boundary.

Arguments Against Meishucun

Nevertheless, there are also objections to the Chinese section. It is composed of dolomites and phosphorites, which are known everywhere as deposits that have many breaks, and certain horizons with faunas can be missing. Some assemblages in these kinds of deposits can also be of mixed origin, leading to difficulty in correlation. Faunas from the Meishucun section commonly are badly preserved. This leads to faulty determinations and sometimes to the creation of a large number of taxa that show only the character of preservation and not the true taxonomic identity, thus giving an illusion of correlation.

The age of Zone II at Meishucun is not established, and palaeobiological and magnetostratigraphical correlations suggest that it may not be at the desired earliest level. It may be younger than the Tommotian Stage and equivalent in age to the immediately overlying Atdabanian Stage, both in the Early Cambrian of Siberia.

Conservation of the Meishucun section depends on the cooperation and exploitation policy of the phosphate mining authorities. Moreover, the radioisotope dating is suspect and grossly inaccurate. Finally, the global distribution of trace fossils near the Precambrian-Cambrian boundary is still poorly known and zonation by trace fossils is not a viable method of biostratigraphy.

The Moscow Rider

For these and other reasons, the Working Group Chairman/Project 29 Leader following discussions in Moscow added a "rider" to the June 1984 submission for presentation to the full Commission meeting in Moscow in August 1984. He stated that although the Chinese candidate is "on the table and will stay there unless removed by postal ballot of the Voting Members of the Working Group or a Commission decision, . . . there is still an urgent need for more accurate and detailed correlation with other areas." A full description

is needed of the small shelly fossils, and putative trilobites, in the earliest Cambrian in Siberia, China and elsewhere, and for further correlation involving magnetostratigraphy.

The Working Group Chairman throughout the Moscow meetings maintained that he was "mandated to make a Submission of the Chinese candidate to the Commission because of postal ballots," in which the Voting Members of the Group agreed to the Meishucun section by 15 to 4. This decision was endorsed by 10 votes for to 3 against by the Voting Members of the Cambrian Subcommittee, and unanimously by the Precambrian Subcommittee.

The Chairman also stated that it seemed "reasonable to accept from the Commission any postal ballot vote, if it transpires, of postponement" so as to enable further studies to be made before resubmission. "Postponement would probably be wiser than acceptance at this stage, but it is not my prerogative or within my mandate to formally suggest this in view of the 80% majority view of the Voting Members of the Working Group expressed in a formal postal ballot."

The Current Situation

As reported formally by M.G. Bassett elsewhere in this issue, both the ICS and the IUGS Executive have now voted to postpone the decision on the boundary in the light of the rider added to the 1984 Moscow Submission. The Working Group is now trying with all speed to improve correlations, and further actions should be taken in the near future. Chinese specialists are working on all aspects of the Meishucun candidate, in the Yangtze region of Szechuan, and in other parts of China such as Guizhou Province and Sinkiang. Recent work in China by K. Hsü indicates a catastrophic event in the Early Cambrian with an iridium anomaly, probably caused by a large meteorite impact, and related to a suppression of carbon-isotopic fractionation by biologic activity.

In India, research continues on the Precambrian-Cambrian transition sequences of Northwest Himalaya, in parts of the Kashmir and Spiti-Transkar basins and in the Krol belt of the Lesser Himalaya (Kumar, 1984). Here the focus is on Precambrian acritarchs and blue-green algae, and on trace fossils and small shelly fossils at levels in putative Precambrian and Cambrian strata. Resemblances to Siberia and China are notable.

Iran has well-preserved small shelly fossils at two horizons in the early Cambrian strata of the Elburz Mountains. These are being studied by Iranian experts in cooperation with German and Swedish palaeobiologists. The Precambrian-Cambrian boundary beds in eastern Newfoundland (Fletcher and Bengtson, 1983) are being studied by a number of researchers from Canada, U.S.A., U.K. and Sweden, with renewed emphasis on trace fossils as prime guides, but also on small shelly fossils. A field meeting to study these Precambrian-Cambrian boundary outcrops is being planned for August 1987.

The diagnostic character of the earliest Cambrian faunal assemblage of fossils with hard parts, which distinguish it from any late Precambrian assemblage fauna or individual fossils (soft-bodied or skeletalized, partly or completely) and from later faunas of the Cambrian has not yet been satisfactorily delineated and established. This diagnosis is essential for long-range correlation, such as between the Tommotian Stage of Siberia and the Meishucun Stage of China, or intercontinentally between Asia, Africa, Europe, America, Australia and Antarctica.

Working Group members and others are, however, now preparing for an intensive work session on the taxonomy and biostratigraphy of the earliest skeletal fossils, in cooperation with the Subcommittee on Cambrian Stratigraphy. This will take place in May 1986 in Uppsala, Sweden, when specialists will study each others' collections of fossils of late Precambrian and Early Cambrian age and attempt to resolve together some of the current problems of taxonomy and biostratigraphy at this stratigraphical level.

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References

- Bengtson, S. and Fletcher, T.P., 1983. The oldest sequence of skeletal fossils in the Lower Cambrian of southeastern Newfoundland. *Canadian Journal of Earth Sciences*, v. 20, p. 525-536.
- Cowie, J.W. and Johnson, M.R.W., in press. Late Precambrian and Cambrian Geological time scale. In: *Chronology of the Geological Record*. N.J. Snelling (ed.), Blackwell, Oxford.
- Jiang Zhiwen, 1984. Global distribution of the earliest shelly metazoans. *Geological Magazine*, v. 121, p. 185-188.
- Kumar, G. et al., 1984. IGCP Project 29. Demarcation of Precambrian-Cambrian boundaries: Status of work in India. Indian National Working Group for IGCP, Delhi, 29p. + plates.
- Luo Huilin et al., 1984. Sinian-Cambrian Boundary strata section at Meishucun, Jinning, Yunnan, China. Peoples Publishing House, Yunnan, 154 p. plus plates.
- Rozanov, A. Yu, 1984. The Precambrian-Cambrian boundary in Siberia. *Episodes*, v. 7, no. 1, p. 20-24.
- Song Xueliang, 1984. *Obruchevella* from the early Cambrian Meishucun Stage of the Meishucun section, Jinning, Yunnan, China. *Geological Magazine*, v. 121, p. 179-183.
- Xing Yusheng, Ding Qixiu, Luo Huilin, He Tinggui and Wang Yangeng, 1984. The Sinian-Cambrian boundary of China and its related problems. *Geological Magazine*, v. 121, p. 155-170.
- Xing Yusheng and Luo Huilin, 1984. Precambrian-Cambrian boundary candidate, Meishucun, Jinning, Yunnan, China. *Geological Magazine*, v. 121, p. 143-154.
- Xue Xiaofeng, 1984. Research on the isotopic age of the Sinian-Cambrian boundary at the Meishucun section in Jinning County, Yunnan Province, China. *Geological Magazine*, v. 121, p. 171-173.
- Zhang Zichao, Ma Guogan and Lee Huaqin, 1984. The chronometric age of the Sinian-Cambrian boundary in the Yangtze Platform, China. *Geological Magazine*, v. 121, p. 175-178.

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