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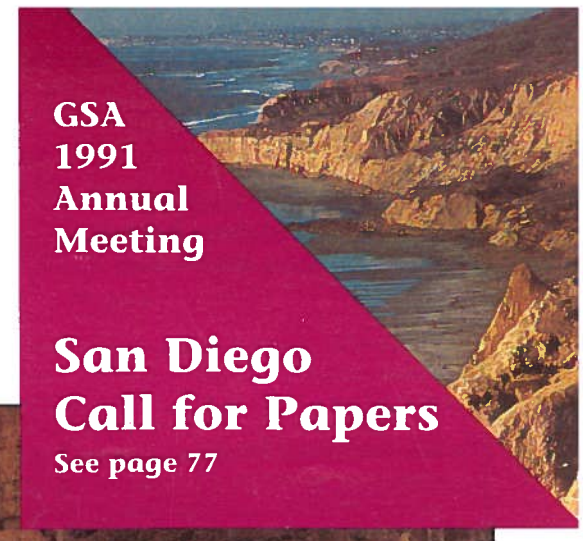

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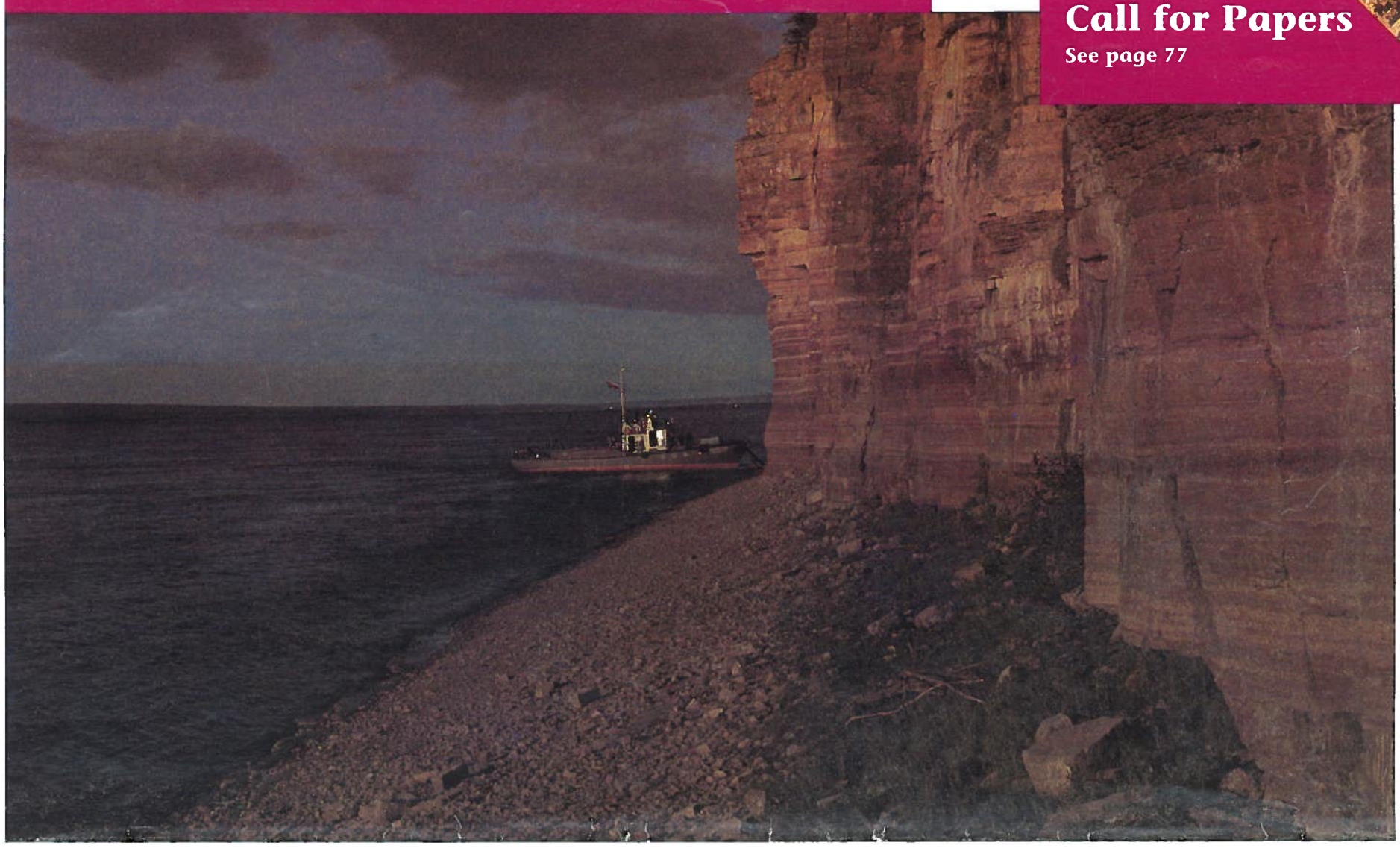

Achchagy-Kyyry-Taas on the Lena River of Siberia. Tectonically undisturbed, the Early Cambrian limestone and dolomite of this section preserve excellent records of paleontological evolution as well as carbon isotopic variations and magnetic reversals. *Photo by Joseph Kirschvink*

# The Precambrian/Cambrian Boundary: Magnetostratigraphy and Carbon Isotopes Resolve Correlation Problems Between Siberia, Morocco, and South China

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## ABSTRACT

**Late Proterozoic and Early Cambrian age platform carbonates from the Siberian platform now have the most complete records of paleontological, magnetostratigraphic, and $\delta^{13}C$ variations preserved anywhere on Earth. New carbon isotopic data from Siberia extends the known pattern up through the first half of Early Cambrian time (the Late Tommotian up through the middle of the Atdabanian stage). These data reveal a fourth $\delta^{13}C$ cycle in the Siberian Precambrian/Cambrian boundary isotope curve, and in conjunction with the magnetostratigraphy provide two nonbiological techniques for testing proposed correlations. Similar patterns are present in both the carbon isotope and magnetic reversal stratigraphies in the upper Lie de Vin formation of Morocco, confirming recent biostratigraphic work. A unique match is also present in the comparison between Siberia and an important locality near Kunming in south China, and implies that at least half of the record of Atdabanian time is missing there. Hence, the Chinese section is not suitable as an international stratotype for the Precambrian/Cambrian boundary.**

## INTRODUCTION

In terms of its subsequent impact on the history of life on Earth, the Precambrian/Cambrian transition is comparable to the Paleozoic/Mesozoic and Mesozoic/Tertiary boundaries. Unlike the latter two, however, the fossil record of this boundary is one-sided, with few mineralized fauna on the Precambrian side to provide a record of the biological events that were transpiring. Because temporal correlation is a prerequisite for understanding any part of the geological record, the questions posed by the Precambrian/Cambrian boundary problem have been the focus of a special International Union of Geological Sciences (IUGS) working group devoted to improving stratigraphic correlation of this time interval to the point where the international geological community could agree on a stratotype section and horizon (e.g., Cowie, 1985). Primary emphasis has been placed on finding a biostratigraphic level suitable for global correlation of the boundary horizon. However, a consensus of the community has not yet been achieved. With the development of nonbiological correlation methods like stable isotope and geomagnetic polarity stratigraphy, it has become clear that biostratigraphy is not sufficient in many cases to resolve temporal correlation problems. Biostratigraphic correlations of Early Cambrian and Precambrian faunas, which are extremely complex because of high faunal provinciality in the

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**Precambrian** *continued from p. 69*


Early Cambrian and limited faunas in the Precambrian, are particularly suspect as "time-equivalent" horizons, making the application of alternative methods essential.

In this study we compare the magnetostratigraphic and carbon isotopic signatures of three slightly younger sections of Early Cambrian age that have received considerable attention in the stratigraphic search for a Precambrian/Cambrian boundary. First we report new carbon isotope results from the Zhurinsky Mys and Isit localities, on the Lena River of the Siberian platform, which extend the previous work on strata of latest Precambrian (Vendian) and Tommotian age up through the Tommotian/Atdabanian boundary and into mid-Atdabanian time (Magaritz et al., 1986; Magaritz, 1989). These results demonstrate that there are at least four major cycles in the inorganic marine carbon isotopic pattern, which we informally designate as Siberian carbon cycles I through IV. In addition to the excellent archaeocyathan and small shelly fossil records, the Tommotian and Atdabanian stages of the Siberian platform now have two independent, nonbiological correlation methods (carbon isotope and magnetostratigraphy) to help test intercontinental correlations.

We present new carbon isotopic results from the Tommotian and Atdabanian equivalent horizons in the Anti-Atlas Mountains of Morocco, in a test of recent biostratigraphic and magnetostratigraphic correlations to Siberia. These results support strongly these proposed correlations, and confirm that the polarity interpretations now in use between Siberia, Morocco, and Australia are correct for the Precambrian/Cambrian boundary interval. We use the Siberian reference carbon and magnetic patterns to test proposed correlations between Siberia and the Meishucun section in south China, which has recently also been the subject of carbon isotopic and magnetostratigraphic studies. Our analysis of the data supports the contention that the lower Meishucun section correlates to the approximate region of the Tommotian-Atdabanian interval on the Siberian platform, as proposed by Soviet paleontologists (Cowie, 1985), but we do not find it as easy to suggest correlations with pre-Tommotian strata, as suggested by other authors (for discussions, see Cowie, 1985; Brasier, 1989; Qian and Bengston, 1989). Figure 1 shows the probable Early Cambrian locations for these three important reference sections, plotted upon a paleogeographic reconstruction adapted from Kirschvink (1991).

## GEOLOGICAL BACKGROUND AND RESULTS

### Siberia

The Siberian Platform contains one of the world's best preserved sequences of Late Proterozoic and Cambrian platform carbonates, which lie undeformed on the stable Archean basement of the Aldan Shield. Intensive studies of Early Cambrian faunas from the Siberian platform have allowed strata there to be subdivided into a series of zones and stages (e.g., Rozanov and Missarzhevsky, 1966); the stages around the boundary interval now include the late Precambrian Vendian and the Early Cambrian Tommotian, Atdabanian, and Botomian, type localities being located in cliff exposures along the Aldan and Lena Rivers (Rozanov, 1984). The Tommotian is characterized by the first appearance of widespread mineralized molluscan and archaeocyathan faunas, and the Atdabanian by mineralized arthropods. Our new carbon isotopic data are from the Zhurinsky Mys and Isit localities on the Lena River, from spare material collected for magnetostratigraphic studies (Kirschvink and Rozanov, 1984). At Zhurinsky Mys, a nearly complete section through most of the Pestrotsvet Formation extends from the (archaeocyathan) *D. regularis* zone in the lower half of the Tommotian Stage and continues through to the Atdabanian/ Botomian boundary. This sequence overlaps with the Isit section, as shown in Figure 2.

Our sampling focused on the Tommotian and lower Atdabanian part of both sections. Samples poor in organic material were prepared for carbon and oxygen isotopic analysis using methods discussed previously (Magaritz and Kafri, 1981). Calcite/dolomite ratios were determined by X-ray diffraction, by means of standard techniques. Differences in carbon isotope ratios between dolomitic fractions and whole-rock samples (dolomite + calcite) are minimal, in most cases within analytical error (0.10‰). Oxygen isotopic values, however, do show differences of up to 0.8‰ between these fractions. This similarity in carbon ratios supports the suggestion made in earlier studies (Magaritz, 1985; Magaritz et al. 1986, 1988) that, although the carbonate sequences undergo a stage of dolomitization that may alter the oxygen isotopic signatures, in the absence of organic material this process will not alter seriously the carbon record. Oxygen values from the unaltered calcitic samples show a range of values typical of marine carbonates and do not show the extremely $^{18}O$-depleted values characteristic of fresh-water components or contamination from organic material. Thus, we conclude that the carbon isotopic values measured in the carbonate rocks from this section reflect those that were present in the oceanic waters covering the Siberian platform at the time the carbonates were deposited.

Previous work from the Dvortsy locality on the Aldan River (Magaritz et al., 1986) has shown the presence of three cycles in the $\delta^{13}C$ values, each characterized by positive swings, as shown here in Figure 2 ($\delta^{13}C$ cycles I, II, and III). A surprising feature in the extension of these data, however, is the presence of yet another well-defined oscillation in the carbon record, here called the Siberian $\delta^{13}C$ cycle IV. This cycle occupies the first half of the Atdabanian Stage, and at present it is documented fully only from the Zhurinsky Mys locality. Note that the carbon shift begins at approximately the Tommotian-Atdabanian boundary,

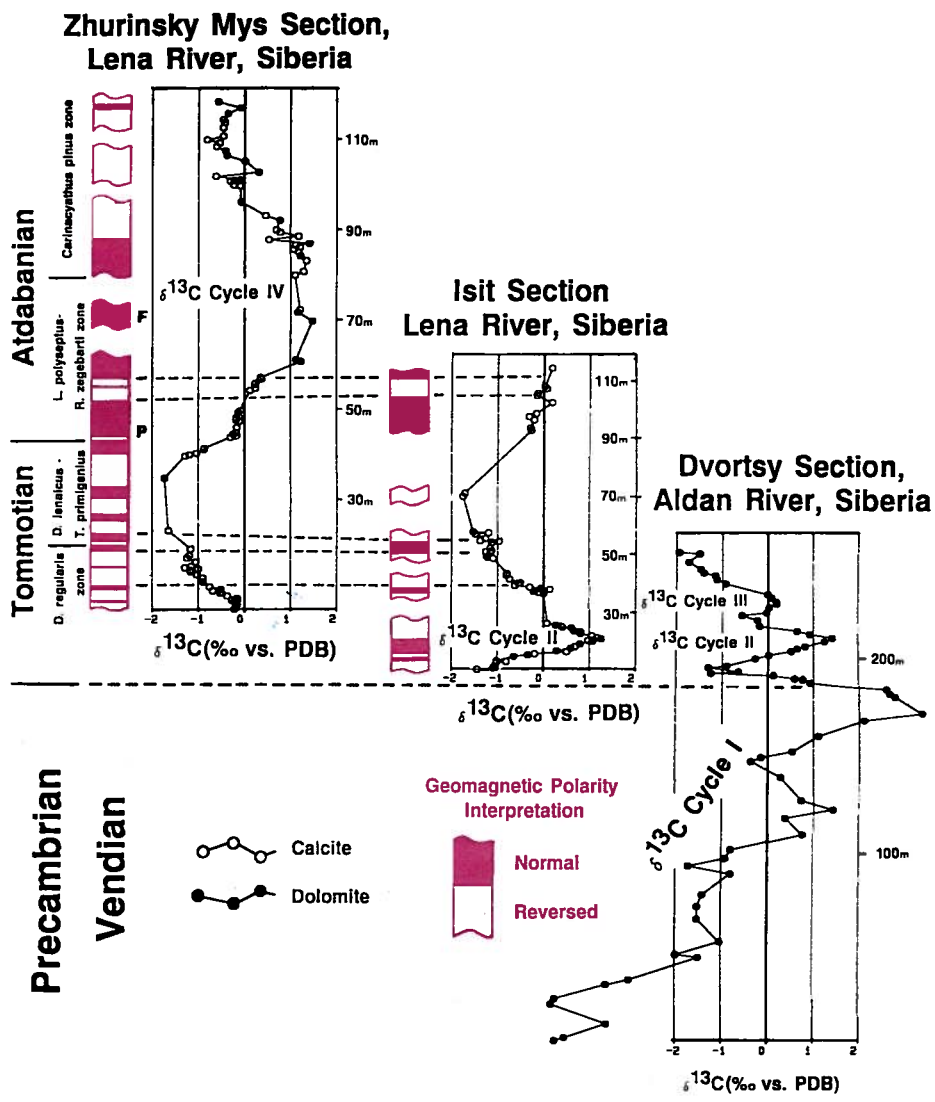


**Figure 2.** Paleomagnetic, paleontologic, and new carbon isotope stratigraphies from the Zhurinsky Mys and Isit sections on the Lena River, Siberia, compared with that from Dvortsy (Magaritz et al., 1986). The magnetic polarity patterns are from Kirschvink and Rozanov (1984); color and white indicate the revised interpretations for normal and reversed polarity, respectively, as discussed by Kirschvink (1991). In the Zhurinsky Mys section, P in the *L. polyseptum–R. zegebarti* zone indicates the first appearance of profallotaspid trilobites, and F marks the similar horizon for *Fallotaspid* trilobites. Solid symbols in Figures 2–4 show results from isotopic analyses of samples that were dolomitic (>50% as determined by X-ray diffraction), whereas open symbols are for whole-rock samples. Oxygen isotope data run for the same samples (data not shown) generally fall in the –7‰ to –5 ‰ range; none of the samples display the highly negative values usually associated with contamination from fresh-water or organic materials.

**Precambrian-Cambrian Boundary Carbon Isotope Sample Localities**

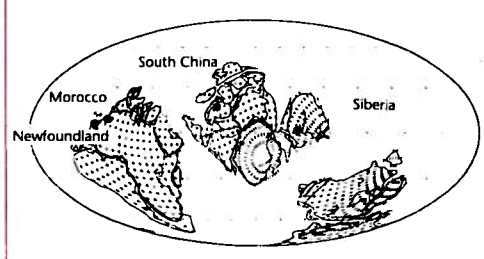


**Figure 1.** Paleogeographic reconstruction for the Precambrian/Cambrian boundary (adapted from Kirschvink, 1991), showing locations for the sections yielding carbon isotope and magnetic reversal patterns.

which is marked by the first influx of the earliest trilobites (*Profallotaspis*).

Magnetic polarity patterns for the Zhurinsky Mys and Isit sections from the data of Kirschvink and Rozanov (1984) are also shown in Figure 2 for comparison with the carbon isotope and paleontologic changes. It is now clear that the original interpretation of the geomagnetic polarity made by Kirschvink and Rozanov (1984) was probably reversed in comparison with results from Australia and North America (Kirschvink, 1991; Ripperdan, 1990). These reinterpreted magnetic data show that this new carbon cycle (IV) is characterized by an interval of predominantly normal geomagnetic polarity (with a few short reversed zones) sandwiched between two intervals of largely reversed polarity (with a few normal zones). This period of dominantly normal polarity is the only such interval yet found in the Siberian sections. Although the paleomagnetic results from the late Vendian exposures on the Aldan River are not as reliable as those from the Lena River, owing to a regional dolomitization problem, those few paleomagnetic samples that yield stable results are of reversed polarity, with the exception of a thin normal zone at the Yudoma/Pestrotsvet boundary. The combination of this distinctive magnetic signature, as well as the start of carbon cycle IV, gives the Tommotian/Atdabanian boundary two nonbiological tools with which to test proposed intercontinental correlations.

**Morocco**

In the Anti-Atlas Mountains of Morocco, a thickness of nearly 3 km of platform carbonates and siliciclastic sediments is deposited on basement of Pan-African (late Precambrian) age. On the basis of new algal and trace fossil discoveries, Latham and Riding (1990) placed the approximate level of the Tommotian/Atdabanian boundary in the upper quarter of the Lie de Vin formation at the Tiout locality studied by numerous other authors (e.g., Debrenne and Debrenne, 1978; Sdzuy, 1978), a position that is in agreement with paleontological studies in the overlying Igoudine Formation (formerly called the Calcaire Superieur [Debrenne et al., 1989]). Figure 3 shows our new stable isotope results from this part of the sequence, based on samples collected for the magnetostratigraphic work reported by Ripperdan (1990) as well as on others supplied by S. Awramik. These show a pattern in the carbon isotopes similar to that reported previously from this section by Tucker (1986), with an increase in $\delta^{13}C$ values ranging from –4.0‰ to +2.6‰ in the upper sequence of the Lie de Vin and base of the Igoudine Formation, at approximately the Tommotian/Atdabanian boundary level suggested by Latham and Riding (1990). Thus, this probably correlates with the Siberian carbon cycle IV discussed above, and is consistent with the magnetostratigraphic comparison. This correlation also implies that the first trilobites found in Morocco (e.g., Sdzuy, 1978) can be correlated with the *Pagetiellus anabarus* trilobite zone of the Siberian platform.

**South China (Meishucun)**

One of the most controversial problems that has arisen in the quest for a Precambrian/Cambrian boundary stratotype is the correlation between the section at Meishucun, near Kunming in the Yunnan Province of south China, and the standard sequences on the Siberian platform. The Chinese strata were deposited in a shallow embayment on the Yangtze platform, and they consist of a series of fine- to coarse-grained dolomites, massive phosphorites, and variable siliciclastic rocks (Luo et al., 1984; Li, 1986; Brasier et al., 1990). Although the sequence is richly fossiliferous, it is plagued with problems of faunal endemism and suspected diastems. Detailed descriptions of the section, including paleontological results and interpretations, are given in Xu et al. (1989). A brief stratigraphic column of this sequence is shown in the left-hand column of Figure 4.

At an early stage of the stratigraphic work, the Precambrian/Cambrian boundary was placed at a dramatic lithologic change at the base of the Qiangzhusian Formation, from phosphatic carbonate to clay and siltstone (Xu et al., 1989). This boundary, now referred to as China C, is characterized by an apparent iridium anomaly and a very large carbon isotope shift toward negative values (Hsü et al., 1985). The first trilobite in China occurs higher in the stratigraphic column (at the

**Precambrian** *continued on p. 87*

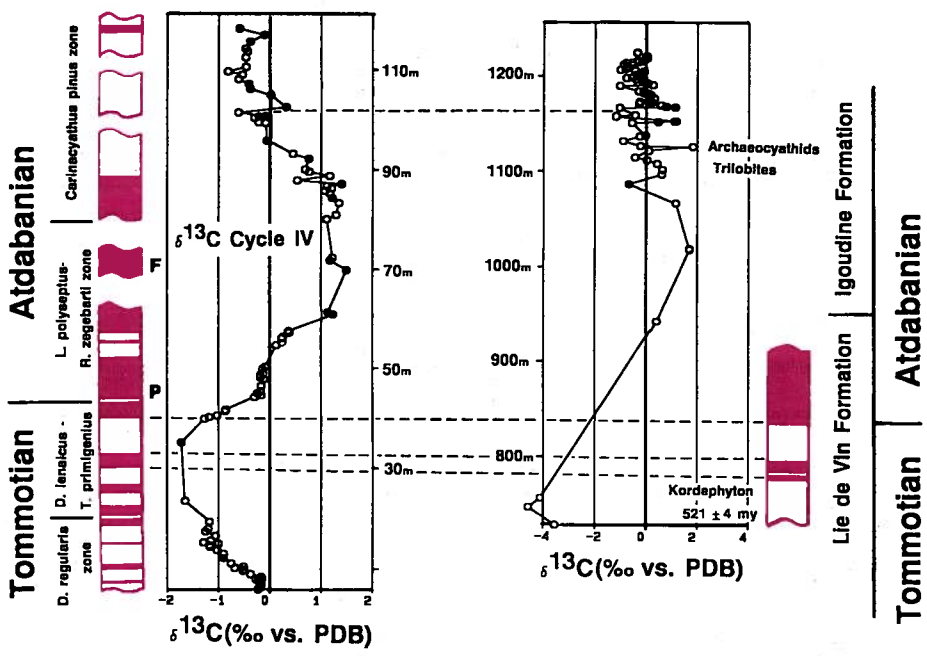


**Figure 3.** Carbon isotopic results from the upper half of the Lie de Vin formation of Morocco, compared with the magnetic polarity pattern from this sequence from Ripperdan (1990) and the standard carbon and magnetic pattern from Siberia of Figure 2. Stratigraphic positions are in metres relative to the base of the Lie de Vin formation as measured by Monninger (1979). The 522 ±4 Ma date shown on the Moroccan section is the U/Pb ion microprobe on zircon result from Compston et al. (1990).

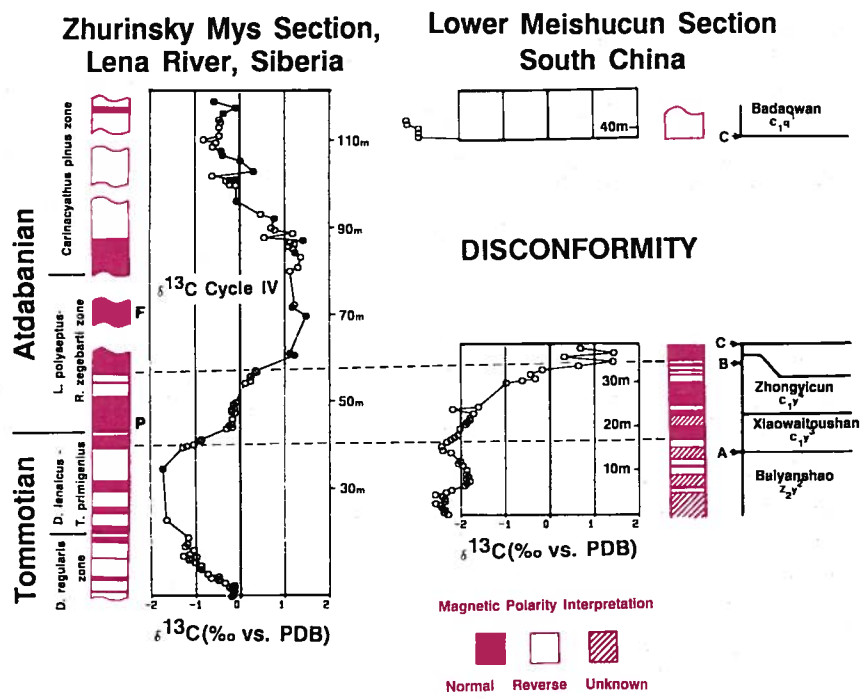


**Figure 4.** Comparison of the carbon and magnetostratigraphic results from the lower Meishucun section in south China with the reference patterns from the Siberian platform. The Baiyanshao, Xiaowaitoushan, Zhongyicun, and Dahai are members of the Yuhucun Formation, and the Badaowan is the basal member of the Qiangzhusian Formation.

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base of the Yuanshan Member), referred to as the China D level (Zhang, 1984). Two other levels, termed China A and China B, have been suggested on the basis of the first occurrence of shelly fauna and of a faunal diversification event, respectively. The China B horizon is favored for the boundary point, should this section be selected for the international stratotype (Cowie, 1985).

Carbon and oxygen isotope data for this sequence have been published by Brasier et al. (1990), and the carbon results are replotted here in slightly modified form in Figure 4. We have eliminated from our pattern results from ten samples that are characterized by highly negative $\delta^{18}O$ and $\delta^{13}C$ values, as these probably indicate the presence of a diagenetically altered carbon isotope record and hence do not reflect the isotopic signature of the surface ocean waters at the time they formed. Nine of these samples correspond to the phosphorites in the Zhongyicun Member, and the other is at the China C horizon at the base of the Badaowan Member. It is important to note that three independent studies on material taken from the China C horizon have all found $\delta^{13}C$ values of around –6‰ (Hsü et al., 1985; Xu et al., 1989; Brasier et al., 1990) accompanied by a drop in $^{18}O$ content ($\delta^{18}O$ = –12.5‰). Thus, it is clear that Hsü et al.'s (1985) model of the "Strangelove ocean" was based on a sample of carbonate that did not retain its original carbon or oxygen isotope compositions.

After removing these samples, we are left with the carbon pattern shown in Figure 4. At the base of the sequence in the Baiyanshao Member, the $\delta^{13}C$ values are around –2‰. These are followed by a gradual $^{13}C$ enrichment of 4‰ up to the China C level. At this point, however, the carbon values take an abrupt negative jump of more than 4‰; no intermediate directions are preserved. Above this, the Badaowan Member carbonate $\delta^{13}C$ values drop gradually from –3.5 to –6‰ (data not shown in Fig. 4). Similar patterns without the highly depleted $\delta^{13}C$ zone are also reported from the Maidiping section (Brasier et al., 1990).

We interpret the China C horizon as a major disconformity within the section for several reasons. First, field evidence indicates a depositional break, marked by a ferromanganese- and phosphorite-encrusted disconformity (Voronin et al., 1982; Brasier et al., 1990). Second, detailed studies of carbon isotope stratigraphy in other boundary intervals have shown repeatedly that abrupt jumps in the carbon record are commonly associated with nondeposition or erosional events, since the isotopic composition of carbon in the ocean requires a few tens of thousands of years or more to respond to massive perturbations (Baud et al., 1989; Magaritz et al., 1988; Magaritz and Holser, 1990). Third, the trace-metal anomalies at this horizon (interpreted previously as impact debris) can also be generated by weathering during an erosional or nondepositional event, particularly if other ferromanganese metals are concentrated. Finally, as discussed below, sediments on opposite sides of this boundary have opposite magnetic polarities. If a stratigraphic break is longer than the average duration of a magnetozone, there is an equal chance of finding a reversal at the horizon.

Wu et al. (1989) reported a detailed magnetostratigraphic study of the Meishucun section. Although only about 10% of the samples exhibit stable behavior upon demagnetization, both normal and reversely magnetized samples were present. Unfortunately, Wu et al. were not able to determine which direction corresponded to either normal or reversed polarity, as there is not now a complete apparent polar wander path for the Yangtze platform. However, Ripperdan (1990) and Kirschvink (1991) noted that all of the latest Proterozoic and Cambrian paleomagnetic data for south China fit on the Australian apparent polar wander track, in the correct sequence, if the Yangtze platform is fit adjacent to the northwestern margin of Australia, thus resolving this polarity ambiguity. Furthermore, the relative magnetic polarity interpretations for the Early Cambrian of Siberia, Morocco, and south China are all dependent upon the Australian apparent polar wander path; hence, any error would force the polarity interpretation of all four continents to switch, and thus would not influence any of our arguments concerning their stratigraphic correlation. However, because there is excellent agreement between the magnetostratigraphy of the North American Cambrian/Ordovician boundary interval (in western Newfoundland) and that of Australia (Ripperdan, 1990), an error in polarity interpretation of the Australian path is unlikely. The Meishucun magnetostratigraphic pattern is thus largely of reversed polarity in the Baiyanshao Member, switching to dominantly normal polarity in the lower part of the Xiaowaitoushan Member, as shown in Figure 4.

Figure 4 also shows our best match between the reference magnetic and isotopic patterns from the Siberian platform and those from the Yangtze platform. This correlates the positive shift in the Meishucun $\delta^{13}C$ values with the bottom half of Siberian carbon cycle IV, as shown. This correlation also makes a reasonable match with the magnetic polarity pattern, correlating the reversed to normal shift near the Tommotian/Atdabanian boundary in Siberia with the similar change in the lower part of the Xiaowaitoushan Member. Thus, as shown in Figure 4, the China A horizon correlates with the middle of the Siberian *D. lenaicus* archeocyathan zone, and the China B and C horizons (below the China C disconformity) correlate into the middle part of the *R. zegebarti–L. polyseptus zone.*

Other correlations are perhaps feasible but are not as easy to support using both the carbon isotope and magnetic data. Nothing in the $\delta^{13}C$ pattern from the Vendian-aged Yudoma Formation in Siberia (carbon cycle I) matches well with the Meishucun data, and although the data are scanty, most of carbon cycle I appears to be of reversed polarity. One possibility might be to correlate the Meishucun section with the base of the Siberian carbon cycle II in the lower half of the Tommotian Stage, but the magnetic polarity pattern there is largely reversed, with a few short normal zones, conflicting with that from Meishucun. Hence, if one rejects the correlation of the Meishucun with the Tommotian/Atdabanian interval outlined in Figure 4, we would be forced to conclude that it does not overlap in time with anything in the $\delta^{13}C$ record from the Siberian platform.

Following the lead of Luo et al. (1984), several authors have used correlation diagrams between Meishucun and Siberia which imply that Meishucunian faunal zones I and II are pre-Tommotian, in disagreement with the analysis presented above. Most of these faunal comparisons are based on the first occurrences of fossils with incompletely known stratigraphic ranges, however, and most of the correlations are not at the species levels, but rather at higher taxonomic "group" levels, such as the *Chuaria* group, trilobite first appearances, the Vendotaeniid flora, and the *Protohertzina anabarica* group (Brasier et al., 1990). None of these first-occurrence events has been shown to be synchronous on a global scale. In conjunction with the putative presence of Atdabanian faunal elements in the vicinity of the China B marker (Cowie, 1985), the correlation shown here in Figure 4 seems to be the simplest interpretation of all available data.

Strata above the disconformity at the China C horizon are not as easy to correlate with the present Siberian $\delta^{13}C$ pattern, as they go continuously from values of about –2.5‰ to –6‰ (Brasier et al., 1990) and nothing like this is present in the Siberian pattern. Hence, the China C disconformity must remove the strata correlative with everything from the middle of the *L. polyseptus–R. zegebarti* archaeocyathid zone through at least the end of the *Carinacyathus pinus* zone of the Atdabanian Stage. We are at present extending the Siberian carbon pattern to younger rocks in an attempt to test this hypothesis.

## DISCUSSION

The Siberian carbon isotopic record is at present the most continuous and complete for the Precambrian/Cambrian boundary interval. In comparison with others in the geological time scale, it is clear that the magnitude of the sharp drop in $\delta^{13}C$ values at the base of the Tommotian Stage (the top of Siberian carbon cycle I shown here in Fig. 2) is an event comparable to that at either the Permian/Triassic or the Cretaceous/Tertiary boundaries. Faunal changes in both the Permian/Triassic and the Cretaceous/Tertiary boundaries were accompanied by rapid drops in the $\delta^{13}C$ values (Hsü et al., 1982; Magaritz et al., 1988; Baud et al., 1989; Magaritz and Holser, 1990). Magaritz (1989) has argued that this type of shift in the carbon isotopes probably arises from a massive change in the biosphere, produced perhaps by entrenched ecological systems being disrupted by mass extinctions, climatic shifts in productivity, or factors as yet unknown. In the process, however, the total amount of isotopically light carbon locked in the biomass will decrease, producing a sharp drop in the $\delta^{13}C$ values of the inorganic marine carbon reservoir. The cause for this drop in Siberia is unknown.

In terms of the selection of an international boundary stratotype section and horizon, the Precambrian/Cambrian boundary working group has narrowed their search to three areas: the Aldan River in Siberia, the Meishucun section in south China, and the Burin Peninsula in Newfoundland (Cowie, 1985). As the International Stratigraphic Commission has emphasized that boundaries of the geological time scale should be based on the major changes in the history of life on this planet (Hedburg, 1978; Cowie, 1986), it seems clear that the Precambrian/Cambrian boundary should be located in one of these sequences at a level that corresponds to the top of carbon cycle I. It should be clear, from the above analysis and from the data of Brasier et al. (1990), that the Meishucun section does not contain the top of Siberian carbon cycle I: it contains a relatively gentle *rise* in $\delta^{13}C$ values that probably correlates with the base of Siberian carbon cycle IV. The section also contains a major stratigraphic break at the China C horizon, only about 5 m above the proposed boundary at the China B horizon. Both of these are unacceptable attributes for an international boundary stratotype section.

Of the remaining candidates, carbon and oxygen isotopic data for the Newfoundland sequence are not yet available. However, the boundary interval in this sequence, identified on the basis of trace fossils, is located in the Chapel Island Formation, which is characterized by deep-water claystone, not shallow-water carbonate rock. Although there are occasional carbonate nodules within the sequence, they clearly formed during diagenesis, and their isotopic compositions may therefore be influenced by $^{13}C$-depleted organic matter derived from the surrounding claystone. Detailed studies of both the carbon and oxygen isotopes should resolve this question, and perhaps provide a better basis for correlation with the reference $\delta^{13}C$ curves from the Siberian platform. Unfortunately, there appears to be little hope for obtaining magnetostratigraphic

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data from the Chapel Island Formation, as the pale-colored rocks were remagnetized during Paleozoic deformation (Kirschvink, 1979).

Of all the areas currently under consideration for the Precambrian/Cambrian boundary stratotype, the sections on the Siberian platform are clearly the best. Tectonically, they are less deformed than either the Chinese or Newfoundland sections, and the carbon and magnetic stratigraphies work reliably for local, regional, and intercontinental correlation. In particular, the $\delta^{13}C$ pattern is quite distinctive and shows that the sequences are free of major stratigraphic breaks for an interval of at least 300 m (ca. 30 m.y.) around the boundary horizon. However, in comparing the two major sections on the Aldan River, Ulakhan-Sulugur and Dvortsy, it appears that the Dvortsy locality has a better record of the $\delta^{13}C$ drop at the critical horizon (top of cycle I) than does Ulakhan-Sulugur. Thus, some of the authors of this paper feel that Dvortsy, rather than the official Soviet candidate, Ulakhan-Sulugur, should be considered seriously for the stratotype section.

We take this opportunity to suggest another possible candidate for the Precambrian/Cambrian stratotype which is not actively being considered by the IUGS working group, but perhaps should be. Recent work on the thick sequence of shallow-water carbonates in the Anti-Atlas Mountains of Morocco has located precisely positions for both the Tommotian/Atdabanian and Vendian/Tommotian boundaries (this paper; Latham and Riding, 1990; Ripperdan, 1990). The section near the village of Tiout has deposition rates five times greater than those on the Siberian platform, this section contains at least trace fossils (Latham and Riding, 1990) and perhaps small shelly fossils near the base of the Lie de Vin formation (B. Daily, 1976, personal communication). Both carbon isotope and magnetic stratigraphies have been obtained from the sequence (Tucker, 1986; Ripperdan, 1990; this paper). Finally, the Moroccan sequence contains occasional volcanic tuff horizons, at least one of which has yielded typical magmatic zircons that have been dated by means of U/Pb techniques, thereby yielding the first stratigraphically bound age estimate for the Tommotian/Atdabanian boundary (521 ±4 Ma, Compston et al., 1990). The sequence seems to have something for everyone, and thus should be studied as intensively as have the other candidate sections for the boundary stratotype.

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