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 δ¹³C variations preserved anywhere on Earth. New carbon isotopic data from Siberia extend the known pattern up through the first half of Early Cambrian time (the Late Tonnomian up through the middle of the Attabanian stage). These data reveal a fourth δ¹³C 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 Attabanian 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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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 we have received considerable attention in the stratigraphic search for a Precambrian/Cambrian boundary. First we refined a new carbon isotope results from the Zhurinsky Mys section on the Lena River in Siberia, which extend the previous work on strata of latest Precambrian (Vendian) and Tommotian age 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 iron-rich marine carbon isotopic pattern, which we formally designate as Siberian carbonic isotopic cycles I through IV. In addition to the excellent arcachonians and small shelly fossil records, the Tommotian and Atdabanian stages of the Siberian platform now have two independent, nonbiological correlation methods (carbon isotopes 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 magnetostatigraphic correlation to Siberia. These results support strongly these proposed correlations, and confirm that the polarity interpretation now in use between Siberia, Morocco, and Australia are correct for the Precambrian/Cambrian boundary interval. We use the Siberian reference carbon and magnetic pattern to test proposed correlations between Siberia and the Mienchun section in south China, which has recently also been the subject of carbon isotopic and magnetostatigraphic studies. An analysis of the data supports the contention that the lower Mienchun 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 is easy to suggest correlation with the lower Tommotian stages as suggested by other authors (for discussions, see Cowie, 1985; Brazier, 1989; Qian and Broome, 1989). Figure 2 shows the probable Early Cambrian locations for these three important reference sections upon which the paleogeographic reconstruction adapted from Kirschvink (1991).

GEOLICAL BACKGROUND AND RESULTS

Siberia: The Siberian Platform contains one of the world's best preserved sequences of Late Precambrian 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 Miasarozhchik, 1966), the stages around the boundary interval now include the late Precambrian Vendian and the Early Cambrian Tommotian, Atdabanian, and Botomian, type localities being clifted in cliffs along the Aldan and Lena Rivers (Rozanov, 1984). The Tommotian is characterized by the first appearance of widespread mineralized molluscan and aracnothyan faunas, and the Atdabanian by mineralized arthropods. Our new carbon isotopic data from the Zhurinsky Mys and Mienchun sections on the Lena River, from sparse material collected for magnetostatigraphic studies (Kirschvink and Rozanov, 1984). At Zhurinsky Mys, a nearly complete section through most of the Precambrian formation extends from the (archaean) D. regularis zone in the lower half of the Tommotian Stage and continues through to the Atdabanian/Botomian boundary. This sequence overlaps with the Mienchun 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). Calculated/dolomite ratios were determined by X-ray diffraction, by means of standard techniques. Differences in carbon isotope ratios between dolomite fractions and whole-rock samples (dolomite + calcite) are minimal, in most cases within analytical error (0.1%). Oxygen isotopic values, however, do show differences of up to 0.8‰ between these fractions. This similarity in carbon ratios supports the suggestion made earlier (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 Siberian platform samples show a range of values typical of marine carbonates and do not show the extremely δ18O-depleted values characteristic of fresh-water components or contamination from organic sources. It would, however, be interesting to know if the carbon inorganic 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 Dvoryt locality on the Aldan River (Magaritz et al., 1986) has shown the presence of three cycles in the δ13C values, each characterized by positive swings, as shown here in Figure 2 (D 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 δ13C cycle IV. This cycle occupies the first half of the Atdabanian Stage, and at present it is documented only from the Zhurinsky Mys locality. Not only is the carbon shift begins at approximately the Tommotian-Atdabanian boundary.
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The Siberian carbon isotopic record is likely complete for the Precambrian/Cambrian boundary interval. In comparison with previous work in the geologic literature, it is clear that the magnitude of the sharp drop in δ13C values at the base of the protracted Siberianian Stage (250 Ma) in the Siberian carbon cycle (Shi et al., 2019) is an event comparable to that at the Precambrian/Cambrian boundary. Cretaceous/Tertiary boundaries. Faunal changes in both the Permain/Triassic and Cretaceous/Tertiary boundaries were accompanied by rapid drops in the δ13C values (Hsu et al., 2012; 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 ecol-
ogical systems being disrupted by mass extinctions, climatic shifts in pro-
ductivity, or factors as yet unknown. In the process, however, the total amount of isotopically light carbon locked in the biomass will decrease, producing a shift in the δ13C values of the in-
organic marine carbon reservoir. The cause for this drop in Siberia is unknown. Significant work has been done on in-
ternational boundary stratotype sec-
tion and horizon, the Precambrian/Cam-
brian boundary (Brown et al., 1990) has narrowed their search to three ar-
eas: the Aldan River in Siberia, the Mesosiderites in South China, and the Burin Peninsula in Newfoundland (Cowie, 1985). As the International Stratigraphic Commission has empha-
sized that boundaries of the geological time scale should be based on the ma-
jor changes in the history of life on this planet (Hedburg, 1978; Cowie, 1986), it seems clear that the Precam-
bian/Cambrian boundary should be located in one of these sequences that a-
level that corresponds to the top of the cycle I. It should be clear, from the above analysis and from the data of Bizard et al. (1990), that the Meicunian section does not contain a top of the Siberian carbon cycle I; it contains a relatively gentle rise in δ13C values that probably correlates with the base of the Siberian carbon cycle IV. The section also contains a major strata above the Meicunian section, only about 5 m above the proposed boundary at the China B horizon. Both of these events are unique and are common for an international boundary stratotype section.

As the remaining candidates, ca-
bon and oxygen isotopic data for the Newfoundland sequence are not yet avail-
able. However, the boundary in-
terval in this sequence, identified on the basis of trace fossils, is located on the Avalon Island Formation, which is characterized by deep-water claystone, not shallow-water carbonate rock. Among these is the occasional carbon-
ate nodules within the sequence, they clearly frmed during diagenesis, and the organic component of these nodule might be influenced by δ13C-depleted or-
ganic matter derived from the sur-
rounding claystone. In fact, the distribution of both the carbon and oxygen isotopes should resolve this question, and per-
haps provide a better correlation with the reference δ13C curves from the Siberian platform. Unfortu-

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Figure 4. Comparison of the carbon and magnetostratigraphic results from the lower Meicunian section in south China with the reference patterns from the Siberian platform. The Bayan～Yany, Xiaoqinkou, Zhangpi＃, and Daha are members of the Yucheng Formation, and the Badawo is the basal member of the Qiangnanbian Formation.
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data from the Island Chapla Forma-
tion, as the pale-colored rocks were re-
magnetized during Paleozoic formation
(Kirschvink, 1979).

Of all the areas currently under consider-
ation for the Precambrian/ Cambrian boundary stratotype, the sections on the Siberian platform are clearly the best preserved, but they are less
definite than either the Chinese or Newfoundland sections, and the
carbonate zonation, which provides work rely for local, regional, and
intercontinental correlation. In partic-
ular, the Siberian section is quite
pragmatic and shows that the sequences are
free of major stratigraphic breaks for an
interval of about 0.3 ca. (30-30 m.)
around the boundary horizon. How-
ever, in comparing the two major sec-
tions on the Ailak River, Ulakan-
Sulugur and Dvovty, it appears that the
Dvovty locality has a better record of the
B/C boundary (top of cycle I) than does Ulakan-
Sulugur. Thus, some of the auth-
or's petrology has been considered
seriously for the stratotype section.

We take this opportunity to sug-
gest another possible candidate for the
Precambrian/Cambrian boundary that is
not actively being considered by the
IUGS working group, but perhaps should be. Recent work by Dr. John A.
(Shallow-water carbonates in the
Antil-Atlas Mountains of Morocco has located previ-
ously undetected carbonate hori-
Zitomat/Atandian and Venadian/Tom-
motomot boundaries (this paper; Latham and

The section near the village of Torat has
deposition rates five times greater than
those on the Siberian platform, this
section contains at least trace fos-
liths (Latham and Riding, 1990) and per-
haps represents one of the two base of the
Precambrian (B. Daly, 1976, personal communication). Both
carbonate and organic stratigraphic
features have been obtained from the
section (Tucker, 1986; Ripperdan, 1990; this paper). Finally, the Moroc-
consequence contains occasional vol-
canic tuff horizons, at least one of
which has yielded typical magnatic zircons that have been dated by
means of U/Th techniques, thereby
yielding the oldest recorded U/Pb age es-
timate for the Tomatomat/Atandian boundary (124 Ma, Compston et al.,
1995).

If this possibility is accepted, we have
something for everyone, and thus
should be studied as intensively as have
all other suggested candidates for the
boundary stratotype.

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