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A third superchron during the Early Paleozoic

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Research on geomagnetic reversal chronology has established the existence of two superchrons, one during the Cretaceous and the other (Kiaman) during the Late Paleozoic. Over the past few years, we have performed several magnetostratigraphic studies on Early Paleozoic (Cambrian and Ordovician) sedimentary sequences from Siberia. Our results show high magnetic reversal frequencies during the Middle Cambrian. In contrast, several records show the occurrence of a ~20 Myr long reversed polarity interval in the Lower and Middle Ordovician, suggesting the presence of a third superchron. We propose to give the name of '†Moyero†' to this new superchron; this name is attributed to the Siberian section which first yielded a complete record of this reversed polarity interval.

Introduction

The construction of the Geological time scale requires the integration of a wide variety of different data types. In particular, magnetostratigraphy serves an indispensable tool to define high-resolution time constraints in stratigraphic sequences, and allows one to place biostratigraphy and/or chemostratigraphy in a global time frame. Magnetostratigraphic studies have largely confirmed and dated the polarity reversal record deduced from the marine magnetic anomalies, and have contributed to the establishment of the Late Mesozoic (Upper Jurassic) to Cenozoic magnetic polarity time scale (e.g. Channell et al., 1987; Gradstein et al., 1994; Cande and Kent, 1995). Prior to those periods, magnetostratigraphic data are less numerous and provide a fragmentary reversal record. Only the Upper Triassic was the subject of extensive combined biostratigraphic, magnetostratigraphic and cyclostratigraphic studies which help to construct a detailed time-calibrated magneto-biostratigraphic time scale (Kent et al., 1995; Krystyn and Gallet, 2002; Gallet et al., 2003). Magnetostratigraphic results are even more scarce for the Paleozoic, although we know that the Earth's magnetic field kept a constant reversed polarity during ~50 Myr between the Upper Carboniferous and the Upper Permian (for a synthesis see Opdyke and Channell, 1996). This interval constitutes the Kiaman superchron, and is at present the second example of superchron found during the Phanerozoic as we know that another (~35 Myr-long) superchron of normal polarity occurred during the Cretaceous. The detection of superchrons is clearly of broad interest both in stratigraphy and in the field of Earth's dynamics. The superchrons obviously limit the possibility for global (bio)stratigraphic correlation over long time intervals. In addition, their origin is still

hotly debated, as the superchrons were linked either to major events in the Earth's history, such as plumes or flushing events in the mantle (e.g., Courtillot and Besse, 1997; Gallet and Hulot, 1997; Brunet and Machel, 1998) or simply to spectacular consequences of non-linear processes of the geodynamo (Jacobs, 2001; Hulot and Gallet, 2003). Until recently, the possibility for other superchrons during the Phanerozoic, in particular during the Early Paleozoic, could not be seriously tested because of the scarcity of the available magnetostratigraphic results. In this paper, we summarize the data we obtained during the past few years from several Siberian sedimentary sections, bringing new constraints on the magnetic polarity pattern during the Cambrian and the Ordovician. These data strongly support the occurrence of a third superchron of reversed polarity during the Ordovician.

Brief overview of the studied sections and evidences for a primary magnetostratigraphic signal

The main sedimentary sections that we investigated (Moyero, Kulumbe, Khorbusuonka) are located in the northern part of the Siberian platform (Figure 1). They were all deposited in a shallow water environment, and principally consist of argillaceous reddish, greenish and greyish limestones and marlstones. Based on previous biostratigraphic investigations (e.g. Kanygin et al., 1987; Astahkin et al., 1991), these sections are considered as the most complete Cam-

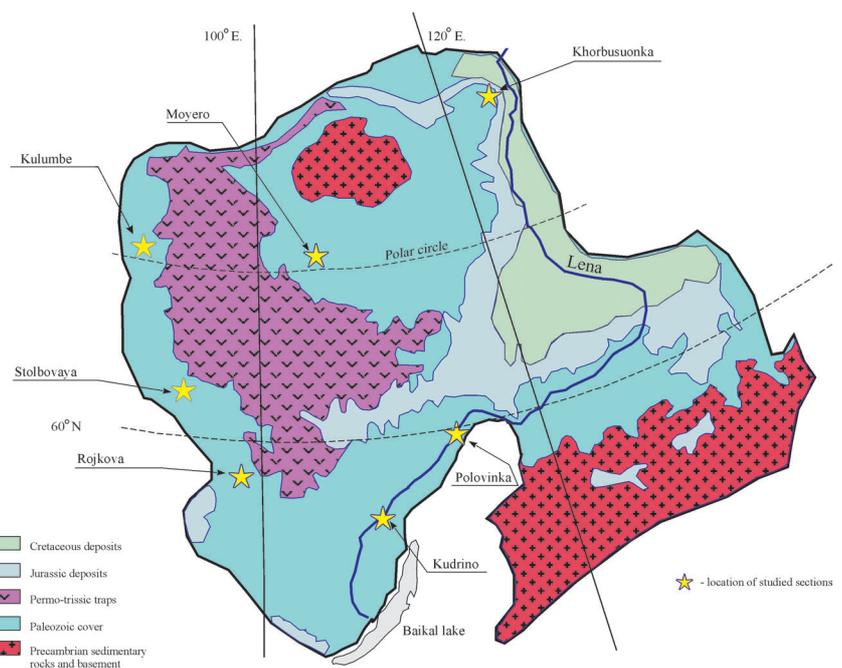


Figure 1 Simplified geological map of the Siberian platform and location of the main Middle Cambrian to Ordovician sedimentary sections that we investigated for magnetostratigraphy.

brian and Ordovician sedimentary successions from the Siberian platform. Although the endemic faunas (trilobites, brachiopods and ostracods) found there only yield a regional (Siberian) stage zonation, some rare fossils (e.g. conodonts) allow worldwide correlations with other distant sections. Hence, even if a precise correlation between the Siberian biozonation (Kanygin et al., 1987; Astashkin et al., 1991), the regional British series and the standard Geological time scale (Gradstein et al., 2004a,b) is not yet completely achieved, we assume that the remaining problems are not critical for the purpose of our study. In the next chapter, we will describe our magnetostratigraphic data according to the Siberian and British chronostratigraphic classifications as the related sedimentary sections were tied to these regional geological time frames by the Russian biostratigraphers. However, their correlation to the standard (global) geological time scale is also indicated in the different figures. More detailed descriptions of the studied sections can be found in Gallet and Pavlov (1996), Pavlov and Gallet (1998, 2001) and Gallet et al. (2003).

About two thousands paleomagnetic samples were thermally analysed. The studied rocks present very similar paleomagnetic behaviour, and for this reason, the primary or near primary origin of the isolated high temperature component relies on the same arguments from one section to another. Very simple paleomagnetic behaviour is generally observed even though pervasive remagnetization of Permo-Triassic age caused by Siberian trap intrusion occurred in many places. The magnetization is carried either by magnetite or hematite, and sometimes by both minerals. The magnetic polarity state of the studied samples clearly does not depend on the type of magnetic carriers, and similar paleomagnetic directions are obtained whether magnetite or hematite is the predominant magnetic mineral. Positive (but partial) fold tests are obtained between different sections at the geological stage level. This is the case between the Kulumbe and Khorbusuonka sections for the Middle Cambrian and between the Moyero and Kulumbe sections for the Upper Cambrian, Lower and Middle Ordovician (Figure 2). Moreover, some of our mean paleomagnetic directions defined at the geological stage level were confirmed by other studies (e.g., Torsvik et al., 1995a; Pisarevsky et al., 1997; Kazansky, 2002). Altogether, our data allow one to define a detailed apparent polar wander path for Siberia from the Middle Cambrian to the lowermost Silurian which is in its first order features in very good agreement with previous

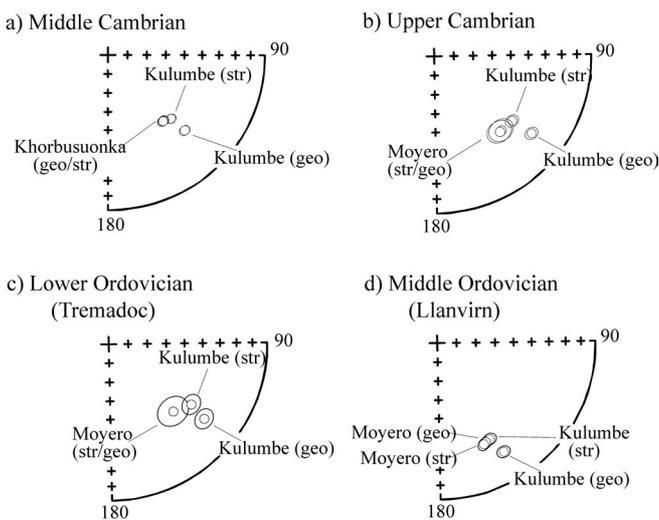


Figure 2 Positive (but partial) fold tests obtained at the geological stage level between the Middle Cambrian data from the Khorbusuonka and Kulumbe sections (Fig. 2a), and between the Upper Cambrian (Fig. 2b), Lower and Middle Ordovician (Fig. 2c,d) results from the Moyero and Kulumbe sections. Paleomagnetic poles and their 95% confidence limits were computed from the data described in Gallet and Pavlov (1996), Pavlov and Gallet (1998), (2001), Gallet et al. (2003).

Russian data as compiled by Khramov et al. (1987) and Van der Voo (1993). We just mention that during the Earliest Paleozoic, Siberia was located in the southern hemisphere and oriented up side down relative to its present position. Siberia passed the equator near the end of the Middle Ordovician Epoch (Gallet and Pavlov, 1996).

Middle Cambrian to Upper Ordovician magnetostratigraphy

Middle Cambrian (Amgan and Mayan) magnetostratigraphic data were obtained from the Kulumbe and Khorbusuonka sections (Pavlov and Gallet, 2001; Gallet et al., 2003). The Kulumbe section contains the uppermost part of the Middle Cambrian (upper Mayan stage) and our paleomagnetic analyses revealed the occurrence of numerous magnetic polarity intervals (Figure 3). To complete these results through the entire Middle Cambrian, we next investigated the magnetostratigraphy of three sections along the Khorbusuonka river, encompassing the uppermost Lower Cambrian (Toyonian), the Amgan and the lower part of the Mayan stage. The composite Amgan and Mayan sequence shows a succession of at least 54 magnetic intervals (Figure 3). Together with the data from Kulumbe, this number could increase up to ~70–80 intervals depending on the cor-

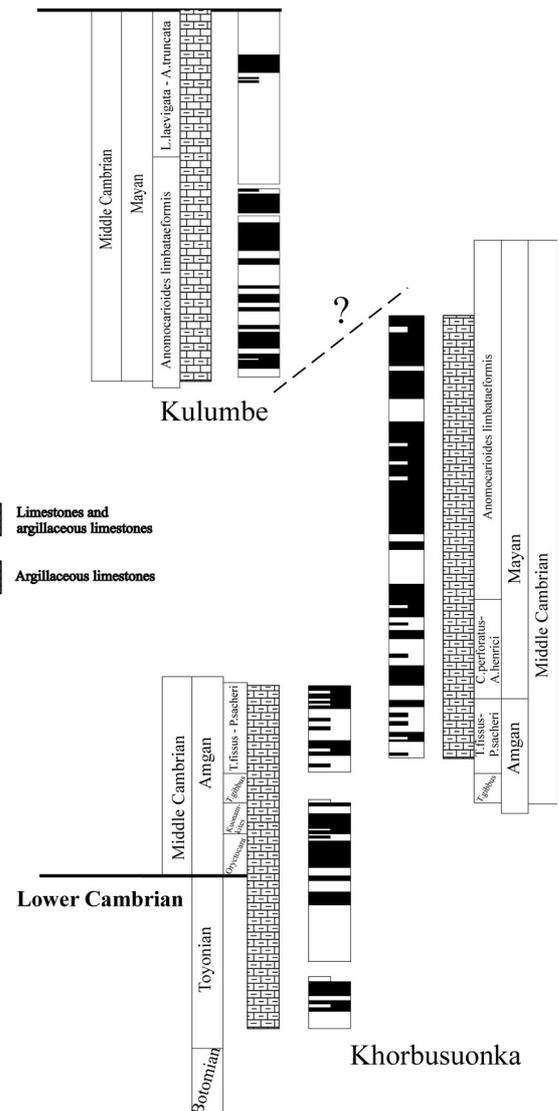


Figure 3 Magnetic polarity sequences obtained for the Middle Cambrian from the Kulumbe (Pavlov and Gallet, 2001) and Khorbusuonka (Gallet et al., 2003) sedimentary sections.

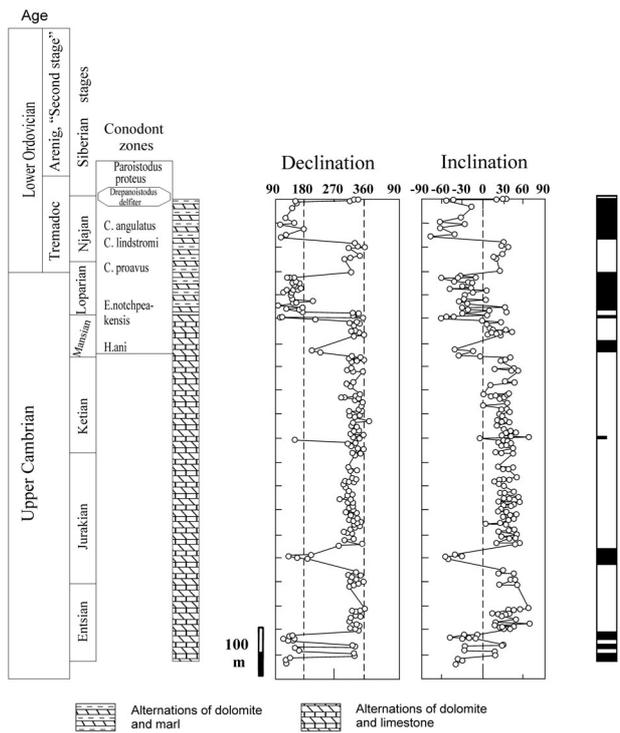
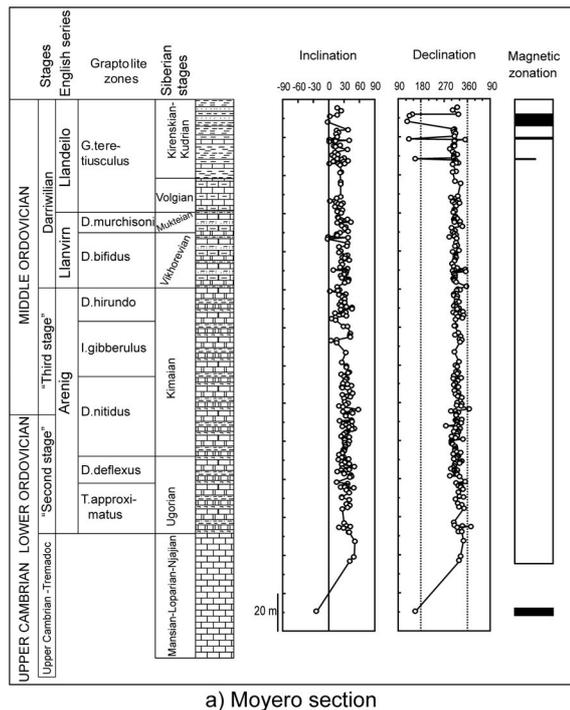


Figure 4 Upper Cambrian and Lower Ordovician (Tremadoc) magnetostratigraphic data obtained from the Kulumbe section (Pavlov and Gallet, 1998). We also show the conodont zonation based on the correlation between the Kulumbe and Batyrbay sections (Rozova, 1986; Dubinina, 2000).

relation between the two sections. This number is probably a minimum estimate as many magnetic intervals in both sections have a small stratigraphic thickness, less than 1 meter, and are defined by only one sample. Upper Cambrian and Lower Ordovician (Tremadoc) magnetostratigraphic data were also obtained from the Kulumbe section (Pavlov and Gallet, 1998). These results show a much more reduced number of magnetic reversals than previously



a) Moyero section

Figure 5 Magnetostratigraphic data obtained for the Lower (Arenig) and Middle (Llanvirn) Ordovician from the Moyero (Gallet and Pavlov, 1996) and Kulumbe (Pavlov and Gallet, 1998) sections.

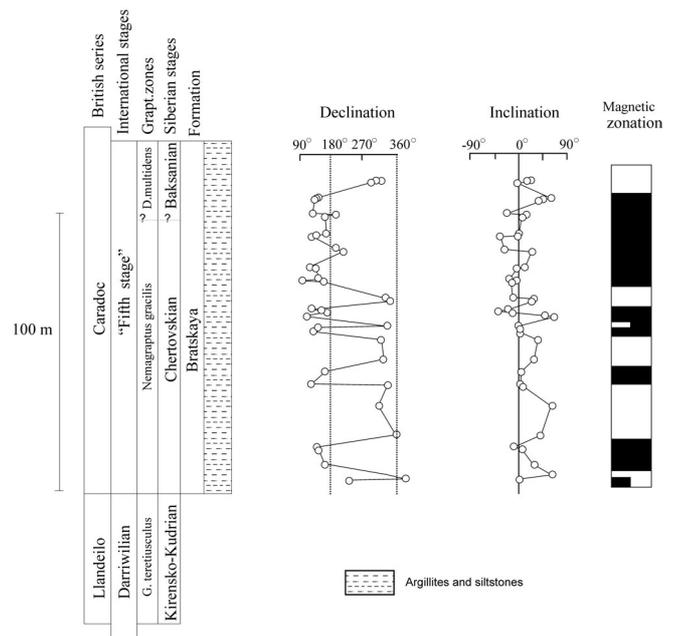
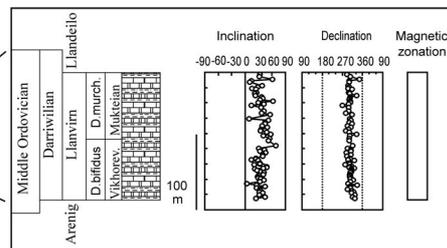


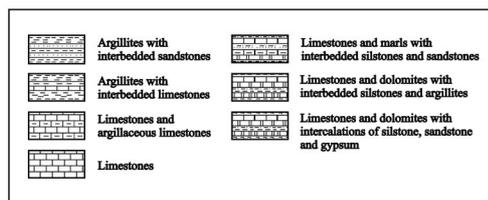
Figure 6 Caradoc (Upper Ordovician) magnetostratigraphic data obtained from the Rojkova section (Angara, river, Southern Siberia; Pavlov and Gallet, in preparation).

for the Middle Cambrian. The sequence contains only 17 magnetic intervals although the section is very expanded (Figure 4).

We investigated the reversal pattern through the Arenig and the Llanvirn from two sections sampled along the Moyero and Kulumbe rivers (Figure 1). Data obtained from Moyero indicate that both series are characterized by a reversed magnetic polarity with no evidence for any reversal (Figure 5a; Gallet and Pavlov, 1996). A reversed polarity interval is also observed from the Llanvirn part of the Kulumbe section (Figure 5b; Pavlov and Gallet, 1998) and very recent data acquired from the Rojkova section sampled along the Angara river in Southern Siberia further show a single reversed magnetic polarity through the ~150 m of Arenig and Llanvirn strata (Pavlov and Gallet, in preparation). In contrast, the occurrence of several geomagnetic polarity reversals in the Llandeilo, at the end of the Middle Ordovician, is attested by different and concordant data sets. A few, rather short, normal polarity intervals are detected in Moyero during the middle part of the Llandeilo. Other magnetostratigraphic results obtained from several sections sampled in Siberia (Stolbovaya, Kudrian, Polovinka) and in the East European platform (Alexeevka) demonstrate the presence of geomagnetic reversals during the Middle and the Upper Llandeilo (Pavlov et al., 1999; Rodionov et al., 2001; Gallet and Pavlov, 2003). Finally, new data from the Rojkova section now help to constrain the magnetic polarity pattern during the Caradoc (beginning of the Upper Ordovician†; Pavlov and Gallet, in preparation). There, we obtain ~10 rever-



b) Kulumbe section



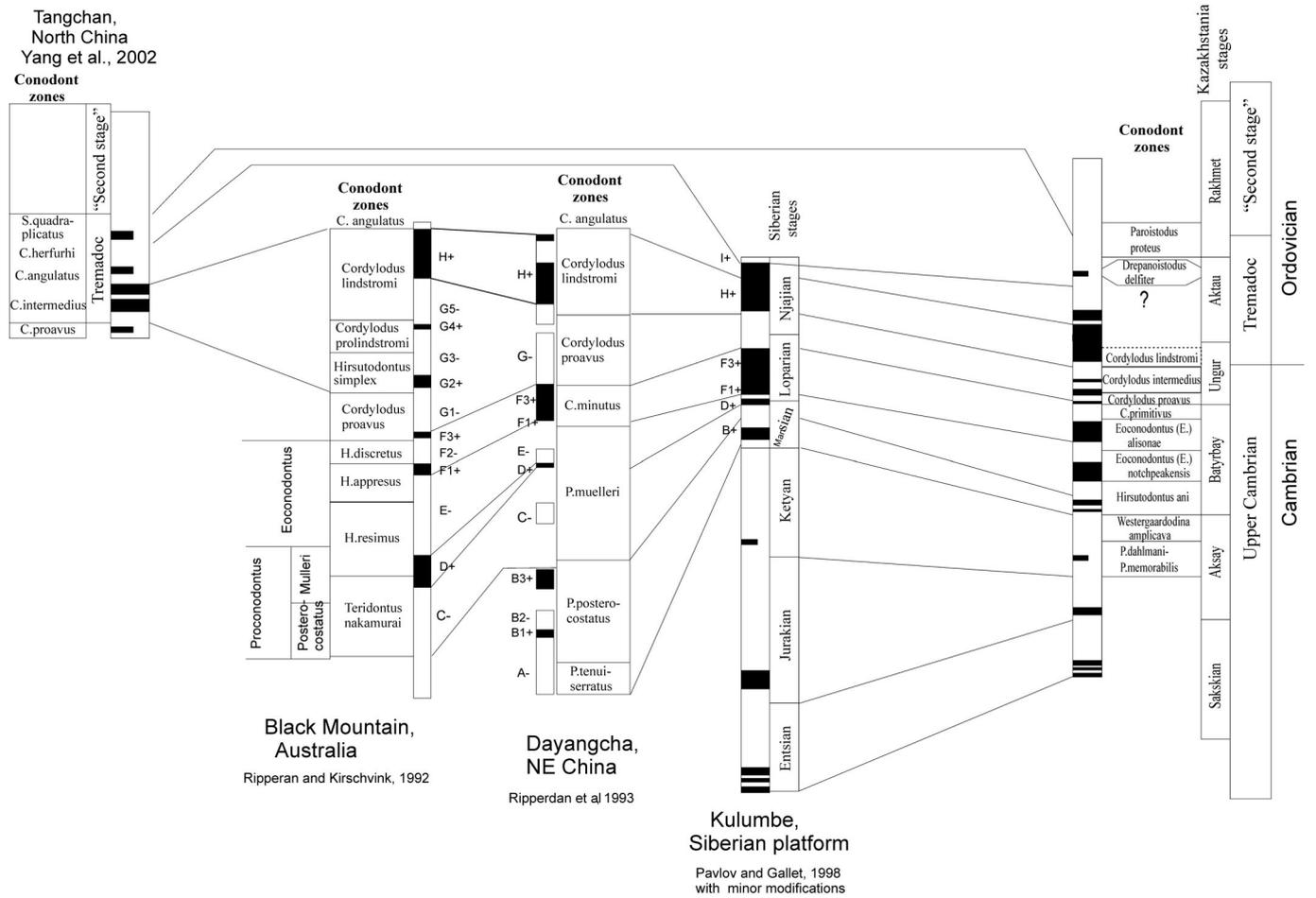


Figure 7 Comparison between different Upper Cambrian-Tremadocian magnetostratigraphic data obtained from Siberia (Pavlov and Gallet, 1998), China (Ripperdan et al., 1993; Yang et al., 2002) and Australia (Ripperdan and Kirschvink, 1992). Correlation lines between the sequences are indicated according to the biostratigraphic results available from the Batyrbay section (Rozova, 1986; Dubinina, 2000). These correlations allow one to propose a preliminary composite magnetic polarity time scale containing the Cambrian/ordovician boundary.

sals within the Caradoc part of Bratskaya Formation (Figure 6; Knjazev, 1978; Kanygin et al., 1984).

Discussion

Our magnetostratigraphic results from Siberia indicate that the Middle Cambrian was a period of very high magnetic reversal frequency, no less than ~6 to 8 reversals per Myr assuming a duration of ~10 Myr for this epoch (e.g. Meert, 1999; Gallet et al., 2003 and references therein). Although magnetostratigraphic results were obtained from different Lower Ordovician sections from Siberia, China (Ripperdan et al., 1993; Yang et al., 2002) and Australia (Ripperdan and Kirschvink, 1992), the construction of a Tremadocian magnetic polarity time scale still remains a difficult exercise. For drawing correlation lines between the different sections, we use the time constraints provided by the numerous biostratigraphic data based on conodonts and trilobites available from the Batyrbay section in southern Kazakhstan (Rozova, 1986; Dubinina, 2000). In particular, the latter section, which until recently was considered by many biostratigraphers as a good candidate for the International Cambrian/Ordovician boundary stratotype, offered the possibility to correlate the Siberian biozones to the standard geological time scale. A composite magnetic polarity sequence encompassing the Upper Cambrian and the Tremadocian is presented in Figure 7. The Cambrian/Ordovician boundary is placed at the first appearance of conodont *I. fluctivagus*, near the base of the *C. lindstromi* conodont zone

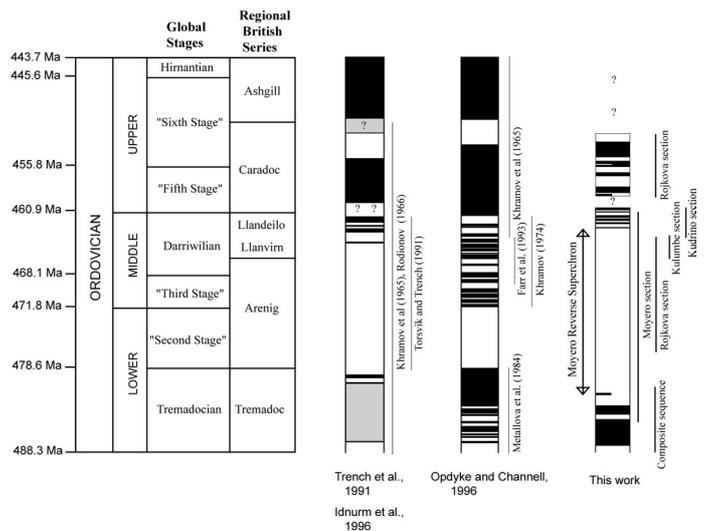


Figure 8 Composite Ordovician magnetic polarity times scales successively proposed by Trench et al. (1991) (see also Trench, 1994 and Idnurm et al., 1996), Opdyke and Channell (1996) and in this work. To the right of each sequence are indicated the data sets used by the different authors. Note that the discrepancy observed for the Tremadocian sequence between Opdyke and Channell (1996) and this study may be due to a different biostratigraphic definition for the Cambrian/ordovician boundary.

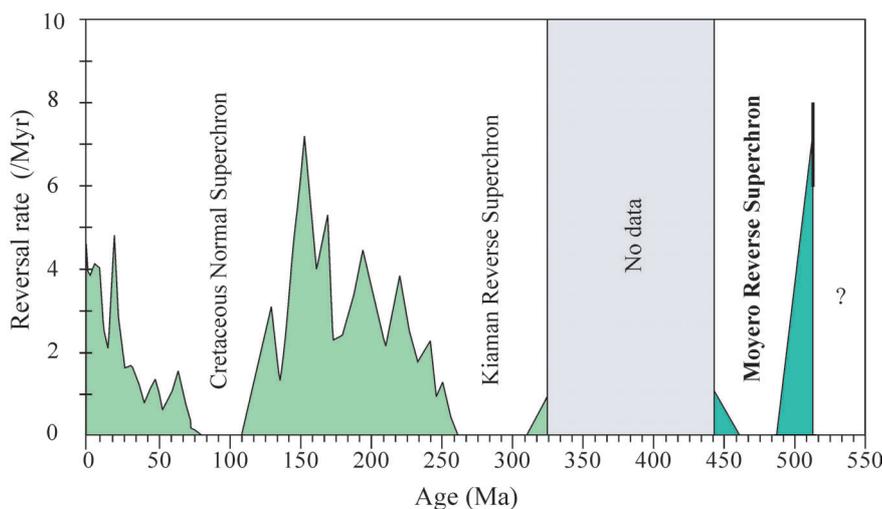


Figure 9 Synthesis of the changes in magnetic reversal frequency during the Phanerozoic deduced from marine magnetic anomalies and magnetostratigraphic data (revised from Gallet et al., 1992). The reversal rates are estimated considering time windows given by the duration of the different geological stages. Note the absence of frequency estimates between the Uppermost Ordovician and the Devonian.

according to Cooper et al. (2001). Although preliminary, our composite sequence shows a low to moderate number of magnetic intervals, which suggests that the magnetic reversal frequency was moderate during this time interval. A few existing magnetostratigraphic studies can test our results for the Arenig and Llanvirn, which correspond to the time interval containing the “Second Stage”, the “Third Stage” and the Darriwilian in the International Stratigraphic Chart (Gradstein et al., 2004a,b). All but one (Farr et al. 1993) confirm the occurrence of a single reversed polarity interval during the Arenig (Torsvik and Trench, 1991; Trench et al., 1991; Torsvik et al., 1995b; Yang et al., 2002), while several short normal polarity intervals (up to three) have been suggested during the Llanvirn. It is actually possible that short magnetic intervals were missed in our records because of the magnetization lock-in process of hematite which is the predominant magnetic carrier in the Arenig to Llanvirn strata. However, Torsvik et al. (1995b) noted a strong asymmetry between the normal and the reversed polarity directions obtained from the Swedish Gullhöggen Quarry, which they attributed either to non-dipole field or remagnetization effects. This makes these intervals still uncertain. The occurrence of magnetic polarity reversals is much better attested for the Llandeilo (during the Upper Darriwilian) and the Caradoc (corresponding to the “Fifth Stage” and the lower part of the “Sixth Stage”). Unfortunately, a magnetic reversal frequency cannot be yet derived from the Caradoc results as both the biostratigraphic data and the conditions of sediment exposures do not permit the precise location of the Llandeilo-Caradoc and Caradoc-Ashgill series boundaries in Rojkova. However, the number of observed polarity intervals is relatively moderate which might indicate a moderate reversal rate during the lower part of the Upper Ordovician.

The most prominent feature derived from our magnetostratigraphic results for the Ordovician, summarized in Figure 8 together with previous composite sequences proposed by Trench et al. (1991) (see also Trench, 1994; Idnurm et al., 1996) and Opdyke and Channell (1996), is the occurrence of a long reversed polarity interval, beginning during the Tremadocian, encompassing the entire “Second” and “Third” Stages (roughly equivalent to the Arenig) and ending in the upper part of the Darriwilian (probably in the Middle Llandeilo). Considering the most recent International Stratigraphic chart (Gradstein et al., 2004a,b), this reversed interval would have a duration of ~20 Myr and would thus correspond to a superchron. We propose to give the name of “Moyero” to this superchron (or MRS - Moyero reverse Superchron-), as the Moyero section first yielded a complete record of this reversed polarity interval (Gallet and Pavlov,

1996). The duration of the superchron would remain rather similar, perhaps a little bit longer (~25 Myr), if previously proposed Early Paleozoic geological time scales are considered (e.g., Harland et al., 1990; Odin and Odin, 1990; Odin, 1994; Tucker and McKerrow, 1995; Gradstein and Ogg, 1996).

Our magnetostratigraphic results are in very good agreement with the conclusion reached by Johnson et al. (1995) and Algeo (1996), although these authors considered a very different approach. They indeed used very large compilations of paleomagnetic data and recognized the existence of a strong reversed polarity bias, possibly a superchron, during the first half of the Ordovician. The Kiaman superchron was detected by McElhinny (1971) and Irving and Pullaiah (1976) also from similar first-order estimates and from a more limited paleomagnetic database. Algeo (1996) further suggested the possibility of a sharp transition between a period of strong reversed polarity bias, called Burskan, between the Middle Cambrian and the Middle Ordovician and a period of strong normal polarity bias (so-called Neapan) between the Upper Ordovician and the Upper Silurian. If we exclude the period which contains the Moyero superchron, our magnetostratigraphic data do not confirm this hypothesis.

Combining all our data, we propose a drastic decrease in magnetic reversal frequency between the Middle Cambrian and the end of the Tremadocian, at the beginning of the superchron (Figure 9). This behaviour would be similar to the one prevailing during the Lower Cretaceous, before the Cretaceous Long Normal superchron. The magnetic reversal frequency during the Middle Cambrian may be comparable to the reversal frequency observed during the Middle Jurassic (Gallet et al., 1992; Opdyke and Channell, 1996). After the Moyero superchron, in particular during the “Fifth Stage” (~first half of the Caradoc), the magnetic reversal process would resume at a moderate frequency rate. There is presently no magnetostratigraphic data with adequate time resolution to further constrain the magnetic reversal behavior during the uppermost Ordovician (the “Sixth Stage” and the Hirnantian), the Silurian and the Devonian.

Our magnetostratigraphic studies from Siberian sections constitute a first step towards the construction of an Early Paleozoic geomagnetic polarity time scale. A general picture of the magnetic reversal behavior seems already to emerge, principally marked by the occurrence of a new superchron. Additional studies are clearly needed, in biostratigraphy for better constraining the correlation between the Siberian and the standard biozonation (and thus to refine the geological age of the Moyero superchron), and in magnetostratigraphy for deciphering the origin (geomagnetic or remagnetization) of the short normal polarity intervals found in some sections during the Llanvirn.

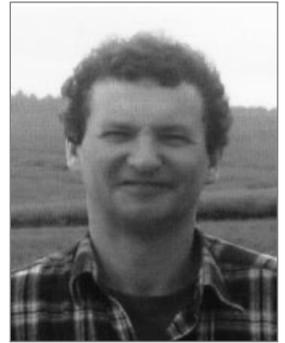
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Hutchison 'Young Scientist' Fund

William Watt Hutchison, "Hutch" to his many friends around the world, was a Scots-born Canadian geologist who served Canada and the IUGS in myriad dynamic and creative ways. Most notably, he served as the IUGS Secretary General (1976–1980) at a pivotal time in its history, and as IUGS President (1984–1987). The same boundless energy, enthusiasm, skill in communications, and ability to foster teamwork that characterized his work with the IUGS also carried him to preeminent scientific administrative positions in the Canadian Government, where he served as Director General of the Geological Survey of Canada and as Assistant Deputy Minister of Earth Sciences. His distinguished career was terminated in 1987 by his untimely death at the age of 52, following a painful struggle with cancer.

One of Hutch's last wishes was to establish under IUGS auspices a memorial foundation intended to promote the professional growth of deserving, meritorious young scientists from around the world by supporting their participation in important IUGS-sponsored conferences. The first 3 beneficiaries of the **Hutchison "Young Scientist" Foundation** attended the 28th International Geological Congress (IGC) in Washington, D.C., in 1989.

Initially, earned interest on the funds available to the Hutchison Foundation were insufficient to sustain comparable grants every four years without seriously eroding the principal. For that reason, the IUGS made no grants from the Foundation for the 30th IGC (1996), preferring instead to strengthen the fund by allowing it to earn interest for a longer period of time and by appealing for donations from the international geologic community. Grants from the Foundation again supported deserving young scientists beginning with the 31st IGC (2000), and should continue for future Congresses. The IUGS would like to expand the resources of the Foundation to make it possible also to offer support to deserving young scientists to attend other important IUGS-sponsored scientific meetings. The **Hutchison "Young Scientist" Foundation** is a worthy cause that honors a fine, caring man and a distinguished, public-spirited scientist and administrator. The foundation also celebrates and promotes those things that gave Hutch the most professional satisfaction: geology, international scientific collaboration, and stimulating young minds.

The IUGS welcomes contributions to the **Hutchison "Young Scientist" Foundation**. Please send donations to:

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