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Superchron at the Mesoproterozoic–Neoproterozoic Transition

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The search for old superchrons represents an important direction in the study of geomagnetic field evolution. According to recent terminology, the superchron is a time interval (and corresponding state of the geomagnetic field), during which the process of reversal of the geomagnetic field polarity that is characteristic of any other period of geological history seems to become frozen and the field remains in one of two possible stationary states for many millions to tens of millions of years. It may confidently be postulated that the superchrons are the most remarkable and, probably, the most enigmatic events in the history of the geomagnetic field. Until recently, only two such superchrons had been reliably established: Cretaceous normal polarity and Carboniferous–Permian (Kiama Superchron) reversed polarity. Recent studies revealed a third Phanerozoic superchron in the Early–Middle Ordovician [1–3]. In this communication, we present evidence for a new geomagnetic superchron at the Mesoproterozoic–Neoproterozoic transition with outlining its boundaries and duration.

The statistical analysis of the duration of magnetic polarity intervals [4] demonstrates that superchrons are most likely characterized by their own distribution mode, which is different from that typical of all other magnetic polarity intervals. This inference may be considered as pointing to the relation of superchrons to some basic changes in the Earth's dynamo work. These changes might be induced by different factors: (1) layer D' evolution and formation of plumes; (2) mantle avalanches; (3) redistribution of "cryptocontinents" at the core surface; (4) transformation of the outer core shape; or (5) lateral variations in the heat flux across the core–mantle boundary regardless of the above-mentioned factors [5–10 and others]. Some researchers are pessimistic believing that superchrons reflect the complex nonlinear nature of the Earth's dynamo, which is completely independent from any external impact and, consequently, bears no information on changeable environments in the core and at the core–mantle boundary [11].

At the same time, the discovery of the third Phanerozoic superchron supports the earlier assumption [12] that there is a certain characteristic period existing in the frequency variation of geomagnetic field reversals and that this period is 150–200 Ma long. Our data [3] indicate that this inference is true, at least, of the Phanerozoic, i.e., the last 550 Ma. It is understandable that the characteristic period of superchron development favors the assumption that this process is controlled by some mechanism located in the Earth's interior. It is clear, however, that the existence of a characteristic period favorable for the superchron appearance itself needs additional evidence. Such data may be obtained only for the Precambrian by studying the frequency of Late Precambrian geomagnetic reversals. In order to understand the nature of superchrons and the mechanisms responsible for them as well as to prove the reality of these mechanisms, we should find out whether superchrons existed in the Late Precambrian and what their age is if there were any of them.

When studying the Late Mesoproterozoic Malgina Formation in the Uchur–Maya Riphean hypostratotype section of the southeastern Siberian Platform, we established that frequent variations in the magnetic field polarity at the beginning of the Malgina time (1043 ± 14 Ma) were followed by a relatively long period when it remained unchanged [13]. The existence of the interval with stable magnetic polarity was confirmed by a limited number of samples taken at several stratigraphic levels from four remote sections of the Malgina Formation. In total, not more than one-fourth of the Malgina Formation thickness was previously studied with respect to its magnetostratigraphy. In the course of this work, we carried out detailed magnetostratigraphic study of the entire Malgina Formation and

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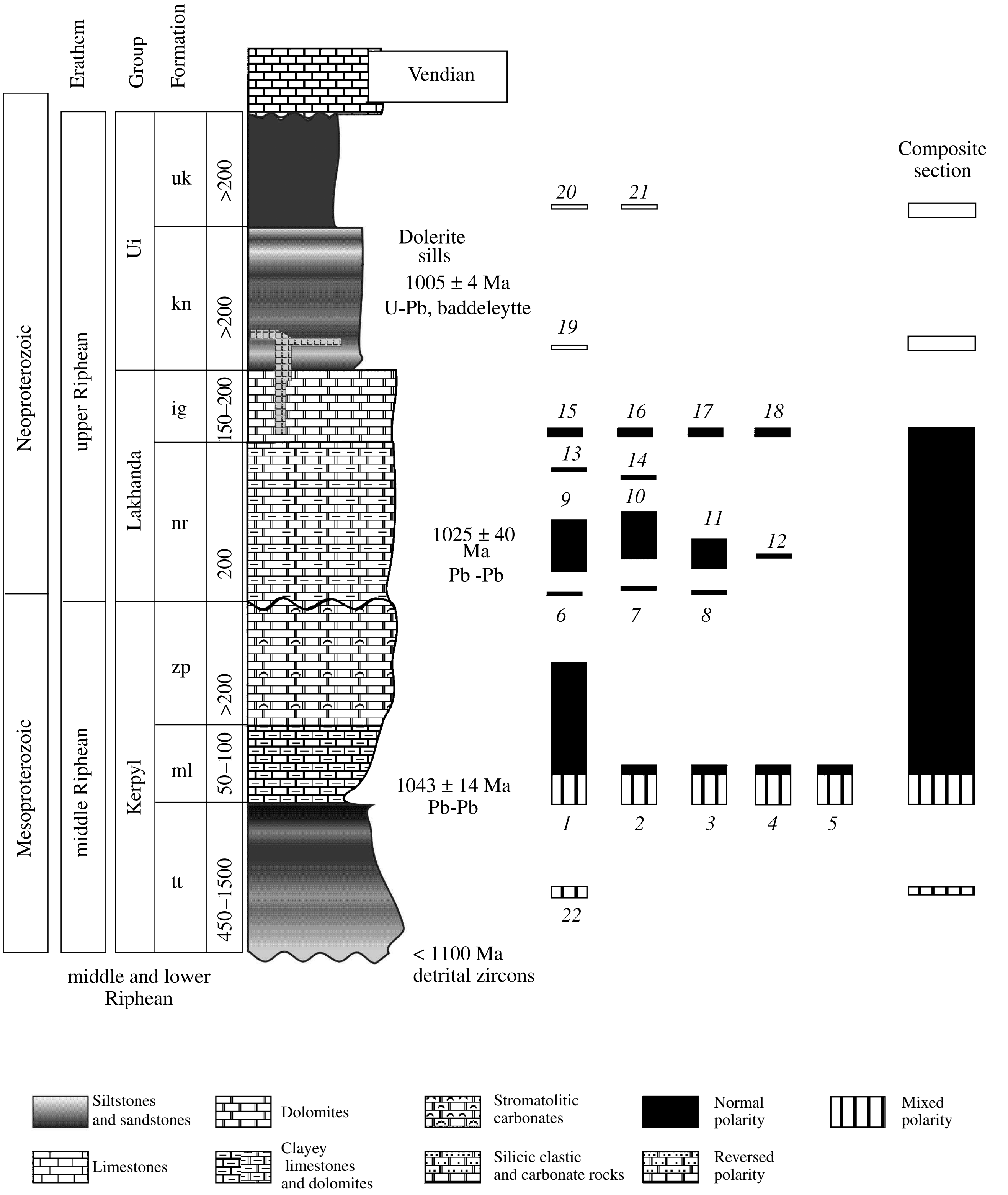

Fig. 1. The Upper Mesoproterozoic–Lower Neoproterozoic magnetostratigraphy of the Uchur–Maya Riphean hypostratotype section. Malgina Formation (mlg): (*1*) Talakh-Khaiya, (*2*) Seliya, (*3*) Emeleken, (*4*) Khaakhar, (*5*) Ingili [13]. Neryuen Formation (nr): (*6*) Neryuen, (*7*) Khandy-Makit, (*8*) Ingili, (*9*) Ytyrynda, (*10*) Nel'kan, (*11*) Ingili-3, (*12*) Tastakh, (*13*) Lakhanda, (*14*) Nel'kan-2 [14]. Ignikan Formation (ig): (*15*) Emeleken, (*16*) Ingili-4, (*17*) Krasnye Skaly, (*18*) Chuiskie Ozera [14]. Sills: (*19*) Suordonnakh. Ust'-Kirbin Formation (uk): (*20*) Kyry-Ytyga, (*21*) Kaval'kan [15]. Totta Formation (tt): (*22*) Mount Borya [15].

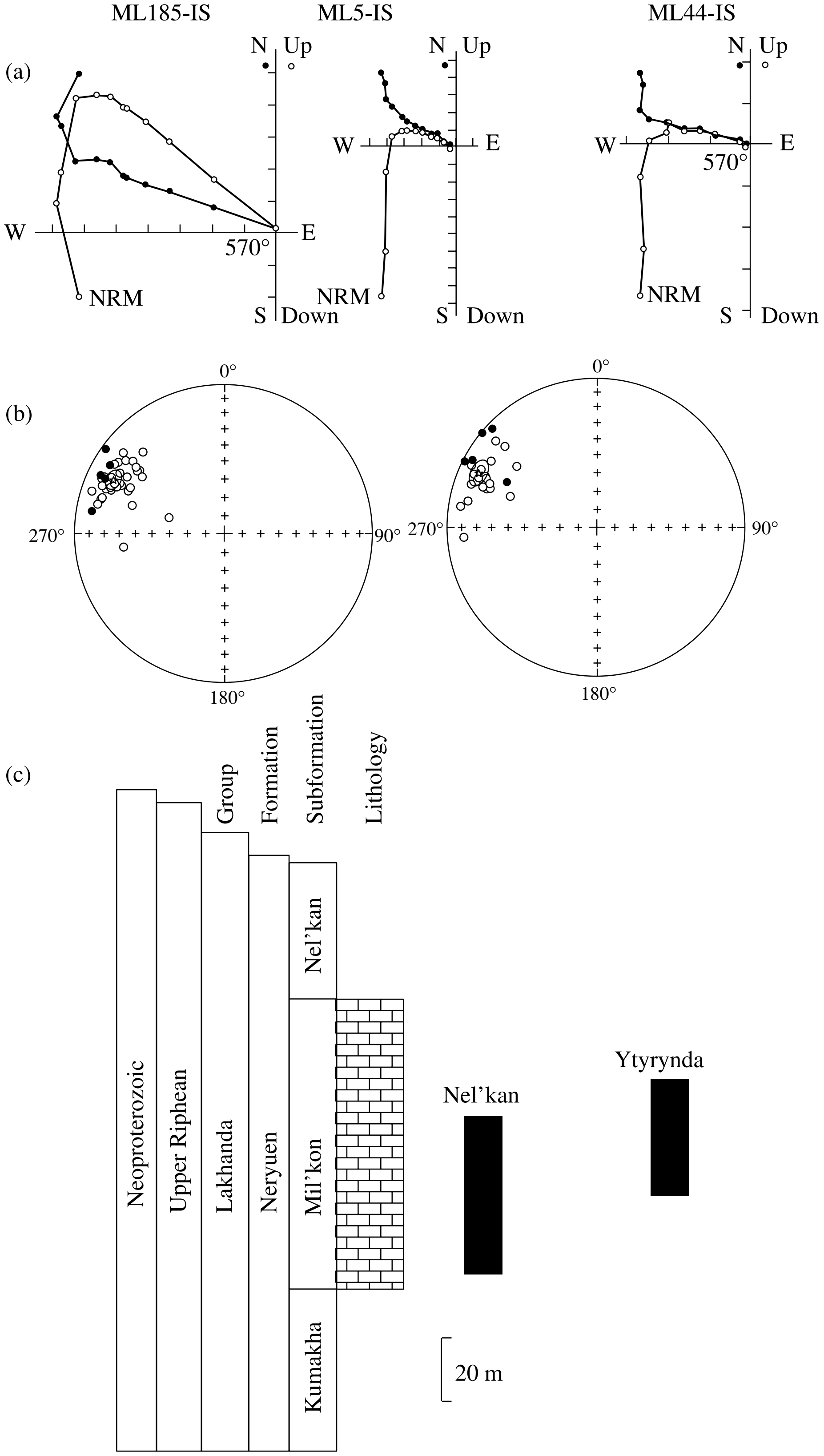

Fig. 2. The paleomagnetic record patterns in the Nel'kan and Ytyrynda outcrops of the Neryuen Formation. (a) Zijderveld diagrams. Solid circles designate projection of the vector on the horizontal plane, open circles are projections of the vector on the vertical plane; (b) stereograms illustrating the distribution of characteristic magnetization vectors in the Nel'kan (left) and Ytyrynda (right) outcrops; (c) polarity of characteristic magnetization in the Nel'kan and Ytyrynda outcrops.

a significant portion of the overlying Tsipanda Formation approximately 200 m thick in total. The Malgina Formation is largely composed of reddish, greenish, and pale limestones, and the Tsipanda Formation is represented by grayish and subordinate pinkish dolomites.

The magnetostratigraphic study was conducted in the Talakh-Khaiya section (Maya River middle reaches), which was selected due to its appropriate lithology and relatively easy accessibility. In total, over 600 samples were taken from this section with the sampling step ranging from 5 cm to 1 m in its lower and upper parts, respectively. Practically all the examined samples from the Malgina Formation demonstrate the presence of the old paleomagnetic signal, which attenuates rapidly in samples from the lower part of the Tsipanda Formation. Nevertheless, the number of samples with such a signal appeared to be sufficient for calculating for the first time the paleomagnetic pole for the Tsipanda time $\left(\Phi = -23.4°,\ \Lambda = 223.8°,\ \frac{dp}{dm} = \frac{6.5°}{11.3°},\ A95 = 8.6°, N = 14\right)$, which fills partly the gap in the succession of the Uchur–Maya Mesoproterozoic–Neoproterozoic poles between the Malgina and Lakhanda paleomagnetic poles. The characteristic magnetization of the Malgina Formation (and, probably, similar magnetization of the Tsipanda Formation) was formed during or immediately after sedimentation. This is confirmed by many data and considerations, positive conglomerate, fold, inversion, and other tests included [13]. This study revealed additional evidence in favor of the primary magnetization nature. For example, it was established that the examined rocks are characterized by a trend of average directions from the base of the formation toward its roof, which reflects most likely the motion of the Siberian plate during Malgina Formation accumulation.

The examined magnetostratigraphic section (Fig. 1, Outcrop 1) consists of two parts. The 24-m-thick interval with a record of 23 geomagnetic polarity reversal events is followed by a 60-m-thick interval characterized by uniform polarity. Unfortunately, most of the Tsipanda Formation is lacking the paleomagnetic record, which prevents us from tracing this interval upward through the section up to the boundary with the overlying Neoproterozoic Neryuen Formation (1025 ± 40 Ma). Nevertheless, the Neryuen Formation itself sampled in many outcrops is characterized by a distinct paleomagnetic signal (Fig. 2). Its magnetization demonstrates uniform polarity similar to that registered in the upper part of the Malgina Formation [14]. The overlying red-colored dolomites from the lower part of the Ignikan Formation are characterized by the same polarity. The different polarity is recorded only substantially higher [15] in the middle part of the Kandyk Formation (1005 ± 4 Ma) and in the Ust'-Kirbin Formation (Fig. 1).

These data provide serious evidence for the existence of a long uniform-polarity period (superchron) in the terminal Mesoproterozoic and initial Neoproterozoic. The onset of this superchron corresponds to the first third of the Malgina time (approximately 1040 Ma ago). Proceeding from available isotope ages and typical sedimentation rates, the duration of the superchron may be estimated to approximate 40 Ma.

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