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Boundary between the Permian and Triassic rocks in the Moscow Syneclise reconstructed from the rock sequences exposed in the Kichmenga River basin

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Abstract. This paper presents the results of the paleomagnetic and magnetic minerals studies carried out along the sequence of the recently discovered oldest Nedubrovo (Early Triassic) rocks of the Moscow Syneclise, exposed in the lower course of the Kichmenga River, where they overlie the Late Permian (Vyatkan) claystone. The Triassic and Permian rock sequence is composed mostly of silty claystone, containing various fauna and flora remains, including those of terrestrial vertebrates. The argillaceous rocks contain the products of the chemical reworking and relics of some volcanogenic ash material. The Permian-Triassic transition is recorded in the magnetic properties of the rocks by a high (two- or three-order of magnitude) growth of their magnetic susceptibility and natural remanent magnetization. The most abnormal Permian-Triassic relationship is characteristic of the first layer having a thickness of about 6 m. The data available for the magnetic minerals suggest that characteristic of the Permian claystone is a magnetic goethite-hematite association, and that of the Triassic rocks is a maghemite-magnetite association. The latter is associated genetically with the processes of the low-temperature oxidation of the titanomagnetite. For this reason, the abundance of maghemite and magnetite in the argillaceous rocks of the region is supposed to have been caused by the addition of ash material to the sedimentation basin. The higher values of the magnetic properties of the Early Triassic rocks, compared to the Permian deposits, caused by the presence of maghemite and magnetite, are also characteristic of many other Lower Triassic continental rock sequences in the East of the Russian Platform, and also of the marine rock sequences of South China. In terms of their paleomagnetic properties, the deposits of the Nedubrovo Member show the stable negative polarity of the geomagnetic field.

Introduction

The Early Triassic rocks of the Moscow Syneclise are similar in many respects to the deposits that had accumulated there during the Tatarian Stage, especially in terms of its continuing molasse sedimentation and also in terms of its geomagnetic field. These rocks were always hard to be distinguished. Moreover, the tracing of a boundary between the Permian and Triassic rocks is complicated by the existence of unconformities, their volumes differing in different areas of the basin. Yet, these unconformities are reflected in the paleomagnetic data [*Burov and Boronin,* 1977]. The Triassic rocks may rest on the directly or inversely magnetized rocks of the Vyatka Stage and also on the rocks of the North Dvina Stage. Although directly magnetized rocks are usually found at the base of the Triassic rock sequence, in some areas they are replaced by inversely magnetized rocks, and one cannot always prove that a given magnetic zone of reversed polarity continues the Triassic rock sequence (R_0T), or was produced by the erosion of the direct-polarity zone (N_1T). The extent of the synchronous death of various groups of living organisms on the land and in the sea is still unknown. The Permian-Triassic boundary in the continental rocks is usually placed using the remains of terrestrial vertebrates,

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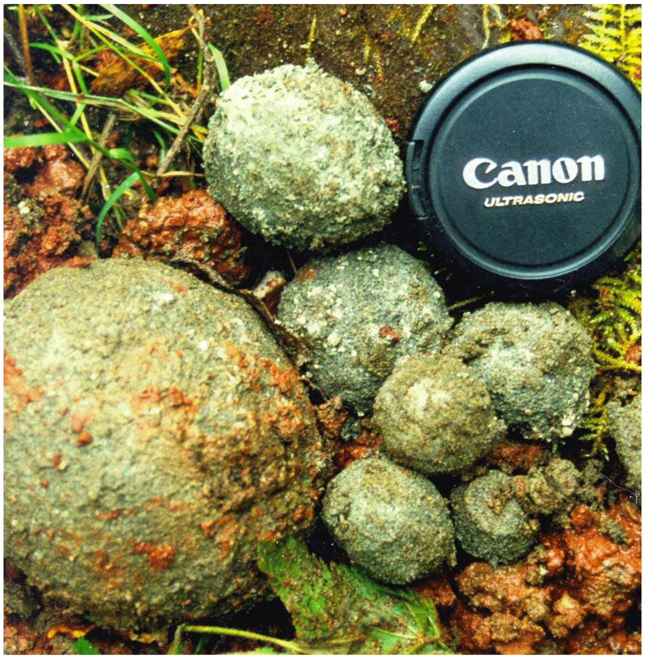

Figure 1. Calcareous-arenaceous nodules from the bottom of the basal layer of the Nedubrovo member deposits in the Glebov Ravine.

the first appearance of *Lystrosaurus*, or the presence of palynological remains showing a typical Triassic appearance. In marine deposits this boundary is usually located by the first appearance of *Otoceras* ammonites. It has been suggested recently that this boundary should be placed somewhat higher, at the base of the *Hindeodus parvus* conodont zone. It should be noted that in addition to the marine fossils the *Otoceras* beds are usually characterized well by palynological complexes [*Balme,* 1979], this allowing their correlation with continental rock formations.

The Lower Vokhma horizon has been identified in the Triassic rocks using the stratotypes of the Vetluga River basin and, proceeding from its rhythmic structure, has been subdivided in detail into the Astashikha, Riabina, and Krasnaya Bakovka members. The differentiation of the Triassic rocks in this area was based on the fauna of terrestrial vertebrates, as well as on phyllopodia, chonkhostracia, ostracodes, flora, and some spore and pollen complexes.

It has been found recently [*Lozovskii et al.,* 2001a, 2001b] that the Astashikha fossil-bearing rocks overlie, in the Kichmenga River basin, another older, Triassic, Nedubrovo rhythmic rock member. Also traceable here is the contact between the Vokhma rocks and the underlying Vyatkan rocks of the Tatarian series of the Permian rock series. The Nedubrovo member differs from the enclosing rocks by the diversity and abundance of various terrestrial biota groups [*Lozovskii,* 2001a, 2001b].

Figure 2. The general view of the Nedubrovo outcrop.

Geological Characteristics of the Rock Sequence

Owing to the bright light color of its claystone and siltstone, the Nedubrovo member has a typical Vetluga appearance, differing drastically from the underlying claystones and sandstones of the Vyatkan Stage. V. R. Lozovskii found a skull fragment of a *Tupilakosaurus sp.* amphibia, a typical form of the Vokhma rocks, in the basal sandstone (up to 2 m thick) of the Nedubrovo member. The basal beds of this member are composed of brownish gray sand with a greenish tint, which shows indistinct oblique bedding and is cemented locally (in the form of interlayers) by a calcareous cement to the state of not strong sandstone. The bottom of these beds includes an interlayer, less than 20 cm thick, composed of ball-shaped, elongated round, and peculiar elongated sandstone concretions (Figure 1), Tatarian red clay gravels, and fragments of labyrinthodonts (*Tupilakosaurus sp.*) [*Shishkin et al.,* 2000]. These basal beds rest on the water-bearing calcareous clay of the Vyatkan Stage.

The basal beds exposed in this ravine are composed of thinly (to lenticular) intercalated greenish gray and gray,

Figure 3. The outcrop of thin-bedded argillaceous siltstone in the lower part of the Nedubrovo outcrop.

thin-plated claystone and siltstone beds, containing abundant charred plant remains. Similar to the overlying beds of the Nedubrovo member, the rocks of this layer are exposed in a picturesque exposure at the steep left bank of the Kichmenga River in the area of the Nedubrovo Village (Figure 2), where the following rock sequence was described [*Lozovskii et al.,* 2001a, 2001b] beginning from the water level:

1. Thin (to lenticular) intercalation of greenish gray and gray thin-plated claystone and siltstone beds with their bedding planes showing inclusions of charred plant remains (Figure 3). The bottoms of some interbeds show a violet-pink color, the tops including an interlayer of light gray marl nodules ranging from 3 cm to 5 cm in size. Occasional lenses and concretions of fine-grained argillaceous sandstone occur in the middle of this layer. Also found in this layer were numerous dispersed phytoleims, *Otynisporites* megaspores, pollen grains and spores, ostracodes, conchostracans, and insects. According to the data reported by V. R. Lozovskii, the argillaceous constituent of the rocks is represented mainly by smectite, the product of volcanic ash alteration. In terms of its origin, this layer represents the estuarine deposits that had accumulated under oxygen-free conditions with the markedly seasonal supply of the rock material. The thickness of this layer is 5–6 m.

2. Brownish-red thin-bedded clay with marl concretions, up to 5 cm in size, and two interbeds of gray clay, 0.3 m and 0.1 m thick. The top of the layer includes, locally, lenticular interlayers (0.1–0.2 m thick) and nodules of greenish-gray and pinkish fine-grained sandstone and marl nodules (Figure 3). The thickness of this layer is 6–7 m.

These rocks are overlain, with traces of erosion, by greenish-gray alluvial polymictic sand interbedded by layers of poorly cemented sandstone and conglomerate which

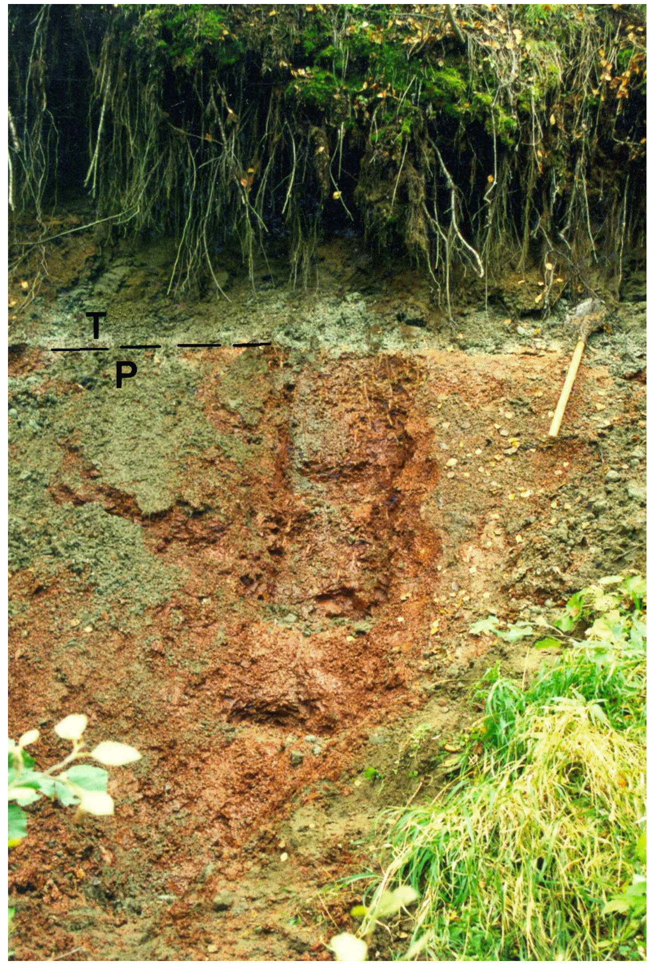

Figure 4. A Triassic-Permian contact in the Glebov Ravine.

represent the basal layers of the Astashikha member, with a visible thickness of about 2.5 m, in which a *Tupilakosaurus sp.* vertebra and unidentified remains of Triassic procholophones were found. The upper part of the slope is composed of Quaternary deluvial sandy loam and loam with gravels and pebbles

Magnetic Properties

Oriented monolithic samples were collected along the section of the Nedubrovo rocks at intervals of 0.5–0.8 m. The rocks of these samples were used to saw 50 cubic samples with a side of 24 mm to be used for paleomagnetic analyses. The numerous isolated outcrops at the slopes of a gully between the Glebovo and Vaganovo settlements repeat almost the whole of the Nedubrovo rock sequence consisting of reddish-brown (layer 2) and greenish-gray (layer 1) platy clay. Exposed in the lower part of the gully is a contact with the Permian rocks and about a four-meter sequence of the Vyatkan clay. The Permian rocks are represented by reddish-brown to brown, lumpy clay with abundant small lime nodules (Figure 4).

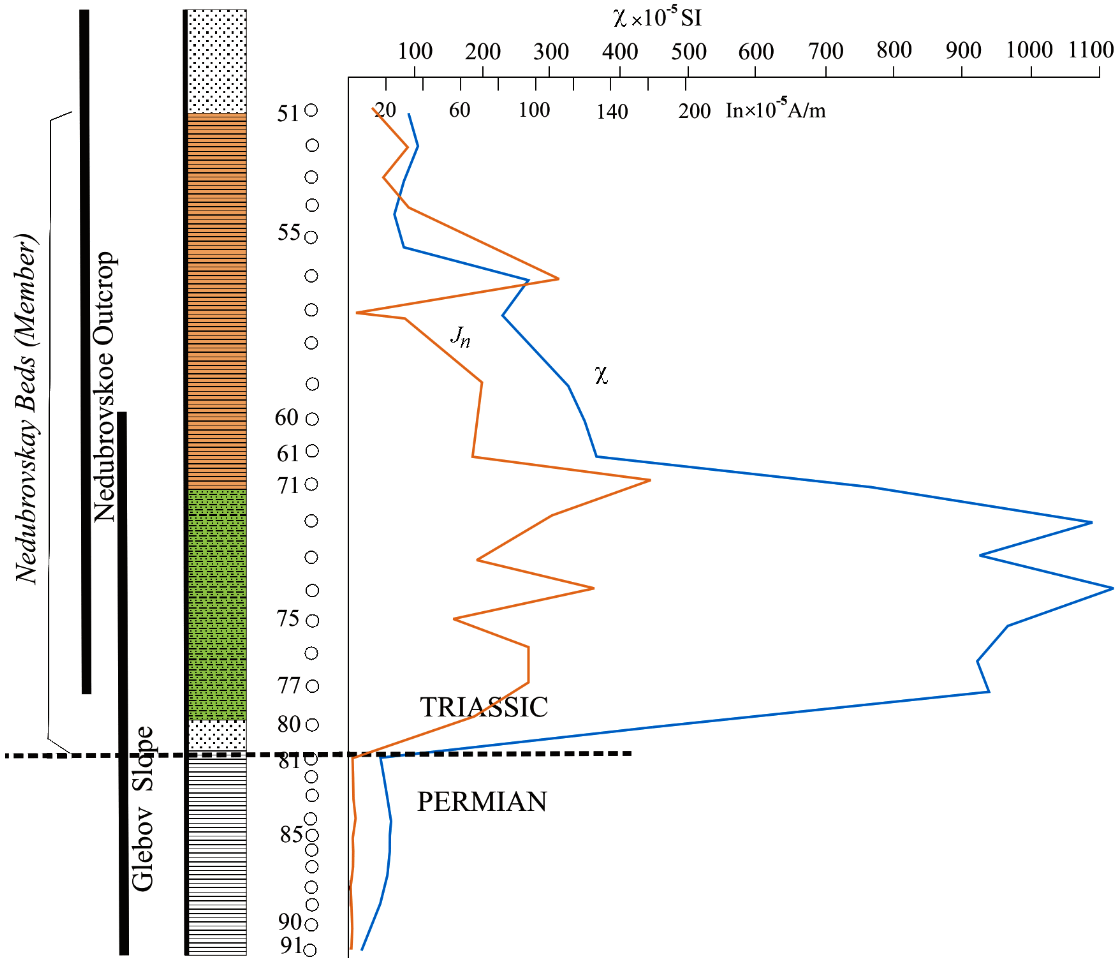

Figure 5. Variation of magnetic susceptibility (χ – blue line) and natural remanent magnetization (J_n – brown line) across the Nedubrovo rocks.

The clay acts as a water-resistant material and shows a high water content. Oriented monolithic rock samples were collected at distances of 0.5 m from nine depth levels from a layer of Triassic greenish platy siltstone. The oriented monolithic samples of the Permian claystone were collected from 10 depth levels spaced 0.2 m apart. Magnetic susceptibility was measured throughout the Nedubrovo rocks at distances of 0.5 m using a field-type KT-5 instrument (Figure 5).

Measured at the laboratory were remanent magnetization using a JR-4 spin-magnetometer, and magnetic susceptibility using a KLY-1 instrument. All rock samples had been subject to magnetic cleaning using a temperature of 250°C.

Many rock sequences of the Russian Platform show a specific feature consisting in the fact that the Permian-Triassic boundary coincides with a depth level marked by an abrupt change in the magnetic properties of the rocks [*Burov,* 2004].

Like the similar rocks of the Vyatkan member, the Permian rocks exposed in the Yug River drainage basin in the vicinities of the Medvezhii Vzvoz, Gavrino, Rogovik, and other villages show the low values of magnetic susceptibility ($\chi_{\mathrm{av}} = 57\times10^{-5}$ SI in the Glebov Gully) and of natural remanent magnetization ($J_{n\mathrm{av}} = 7.3\times10^{-5}$ Am m^{-1}). The transition to the Triassic rocks is accompanied by a high growth of magnetic susceptibility up to $\sim1000\times10^{-5}$ SI, (the average value being 623×10^{-5} SI), typical mainly of Layer 1 composed of greenish-gray, argillaceous siltstone and claystone residing at the base of the Nedubrovo Member (Figure 1).

Beginning from the base of the 2nd layer, magnetic susceptibility declines to 100–400$\times10^{-5}$ SI, the average value being 159×10^{-5} SI, that is, an order of magnitude higher than the value obtained for the Permian rocks, except for some depth levels where magnetic susceptibility was found to be close to the Permian values.

The magnetic properties of the rocks composing the Permian-Triassic molasse are controlled mainly by the authigenic or allothigenic admixture of magnetic minerals, such as, magnetite, hematite, goethite, maghemite, greigite, pyrrhotite, and the like. In the case of finely dispersed silty and clayey rocks, which are commonly used in paleomagnetic reconstructions, the main carriers of magnetic properties are the minerals of the hematite-goethite association (Figure 6a) [*Burov et al.,* 1986]. These rocks are distinguished by their relatively low χ values (mainly at

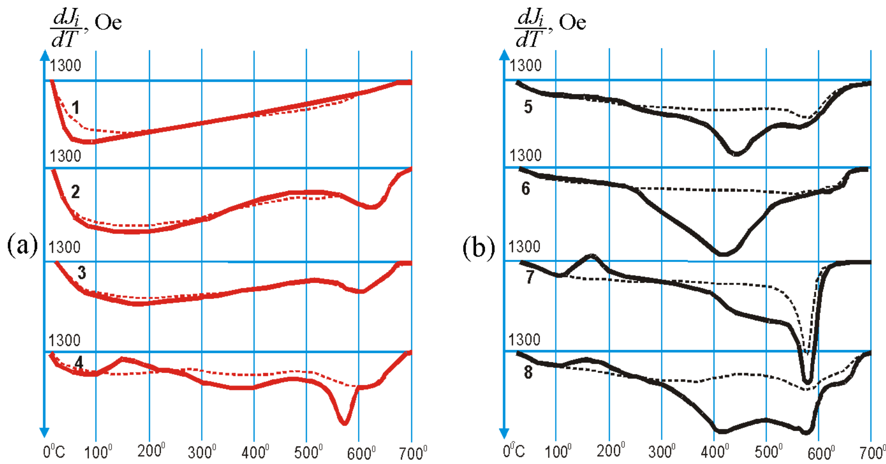

Figure 6. The typical thermomagnetic spectra of the goethite-hematite ferromagnetic rock association (silty clay of Samples 1 and 2), of the magnetite-maghemite-hematite association (sandstone of Samples 4, 7, and 8) and of the maghemite-hematite association (silty clay of Samples 5 and 6). The broken line shows the spectra of the second heating. (a) shows the Tatarian rocks at the Putyatino outcrop, (b) shows the outcrops of the Triassic (Indian) rock outcropping in the Shilikha area.

the expense of paramagnetic rock-forming minerals), low J_n values, the low content of the viscous component, and high coercivity.

Our study of magnetic minerals in the Triassic rocks suggest that even the finely dispersed rocks at the lower horizons of the Vetluga Series are enriched almost everywhere, irrespective of their facies, in magnetite, maghemite, and hematite, which control the high magnetization of the rocks (Figure 6b). A similar magnetic mineral association is widely developed and has been studied in detail [*Burov et al.,* 1986] in the products of low-temperature titanomagnetite oxidation. In our opinion, volcanic ash contributed to the formation of the petromagnetic characteristics of the Early Triassic rocks in the study area.

The most highly magnetic rocks in the Nedubrovo member are the rocks of the first claystone-siltstone layer. The volcanic-ash origin of the bulk of its argillaceous material is proved not only by the data available for its magnetic minerals (Figure 7), but also by the data proving the wide distribution of smectite in the argillaceous rocks, identified as the product of the argillaceous reworking of the volcanic rocks and ash relics [*Lozovskii et al.,* 2001a, 2001b].

The characteristic effect of the growth of magnetization at the temperature of 180°C and its substantial decline after the first heating to 600°C suggests the presence of maghemite in association with magnetite in the rocks.

Paleomagnetic Data

Even the first measurements of many oriented samples, collected from the Nedubrovo member, prior to their magnetic cleaning, suggested its belonging to a zone of reversed magnetic polarity. The two-hour holding of the samples between magnetic screens at temperature of 250°C resulted in the 2- to 5-fold NRM decline and in the almost complete "cleaning" of the ancient component. Figure 8 shows the resulting NRM trends after the temperature cleaning for individual rock samples.

The fact that almost all of the levels shown in the figure had several duplicates allowed us to estimate, though with a not high accuracy, the mean direction of the old NRM component (D = 229.2°, $J = -47.3°$, $K = 6$, and $\alpha_{95} = 15.9°$), the paleolatitude (28.5°N), and the position of the geomagnetic pole ($\theta = 44.4°$N and $\lambda = 157.2°$E).

The Permian rocks of the sequence were characterized merely by a few oriented rock samples, the NRM component of which, though being thermally stable, varied greatly along the section in terms of its direction, and did not correspond to both the direct and inverse polarity of the geomagnetic field.

The normally magnetized Astashikha deposits, ranked as the oldest Triassic rocks of the Moscow Syneclise, are underlain in this sequence by the reversely magnetized rocks of the Nedubrovo member. It should be noted that the nearest potential heat sources, namely, the basalt traps of the Adz'va River basin in the Pechera area bordering the Ural region begin the sequence of the Lower Triassic rocks and their primary magnetization has a reversed polarity either [*Balabanov,* 1988].

Conclusion

It can thus be concluded that the Nedubrovo rock sequence is unique in the study region because of its most complete Lower Triassic rocks of the Russian Platform. The high magnetization values obtained for the first layer are anomalous and not characteristic of normal sedimentary rocks. It is not inconceivable that this is just the level where not only

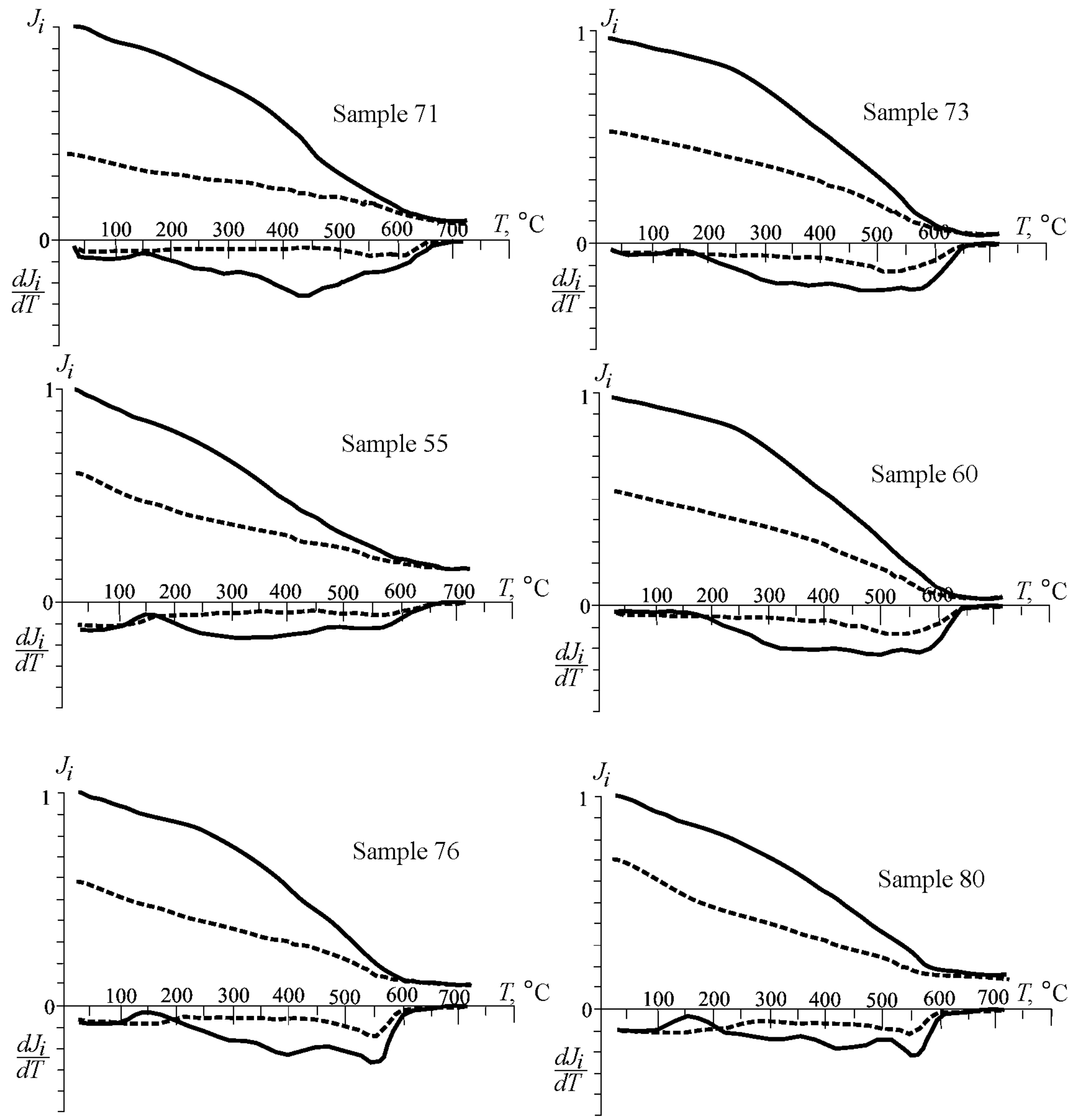

Figure 7. Thermomagnetic (integral and differential) relationships for individual Nedubrovo rock samples (the figures denote the sample numbers). Shown by the broken line are the results of repeated heating. The $J_\mathrm{i}(T)$ thermomagnetic analysis was made in the field of 130 mT.

ferromagnetic but also some other traces can be found for the onset of a new Mesozoic Era.

The almost ubiquitous participation of maghemite in the formation of the ferromagnetic habit of the almost all rocks of the Indian Stage, especially in its lower layers, irrespective of their facies, allows one to suggest that the genetic roots of this admixture had been associated with the air transportation and addition of the volcanic material. If our assumption of the airborne ferromagnetic ash material addition to the Triassic sediments is correct and that this material was voluminous enough, a similar effect can be expected in other sedimentary basins. Of particular interest are the stratons recorded at the Permian-Triassic boundary in South China. In contrast to those mentioned above, they consist of marine rocks. Their magnetic characteristics have been studied fairly well [*Heller et al.,* 1995]. The authors of this paper emphasized that the magnetization intensity of the Permian marine limestones in all rock sequences of South China is much lower than that of the Triassic ones. As follows from the results of their study, the Permian rocks of the Wulong and Shuijiang rock sequences show their average natural remanent magnetization to be as low as 0.353 mA m^{-1}, whereas this value was found to be as high as 4.85 mA m^{-1} for the Triassic rocks. These authors believe that the Triassic limestone contains single-domain magnetite and/or maghemite.

The problem of the high content of the volcanic material in the Triassic sedimentary rocks is of great interest not only in terms of new opportunities in the potential discretization and correlation of the events. The effect of the inferred high

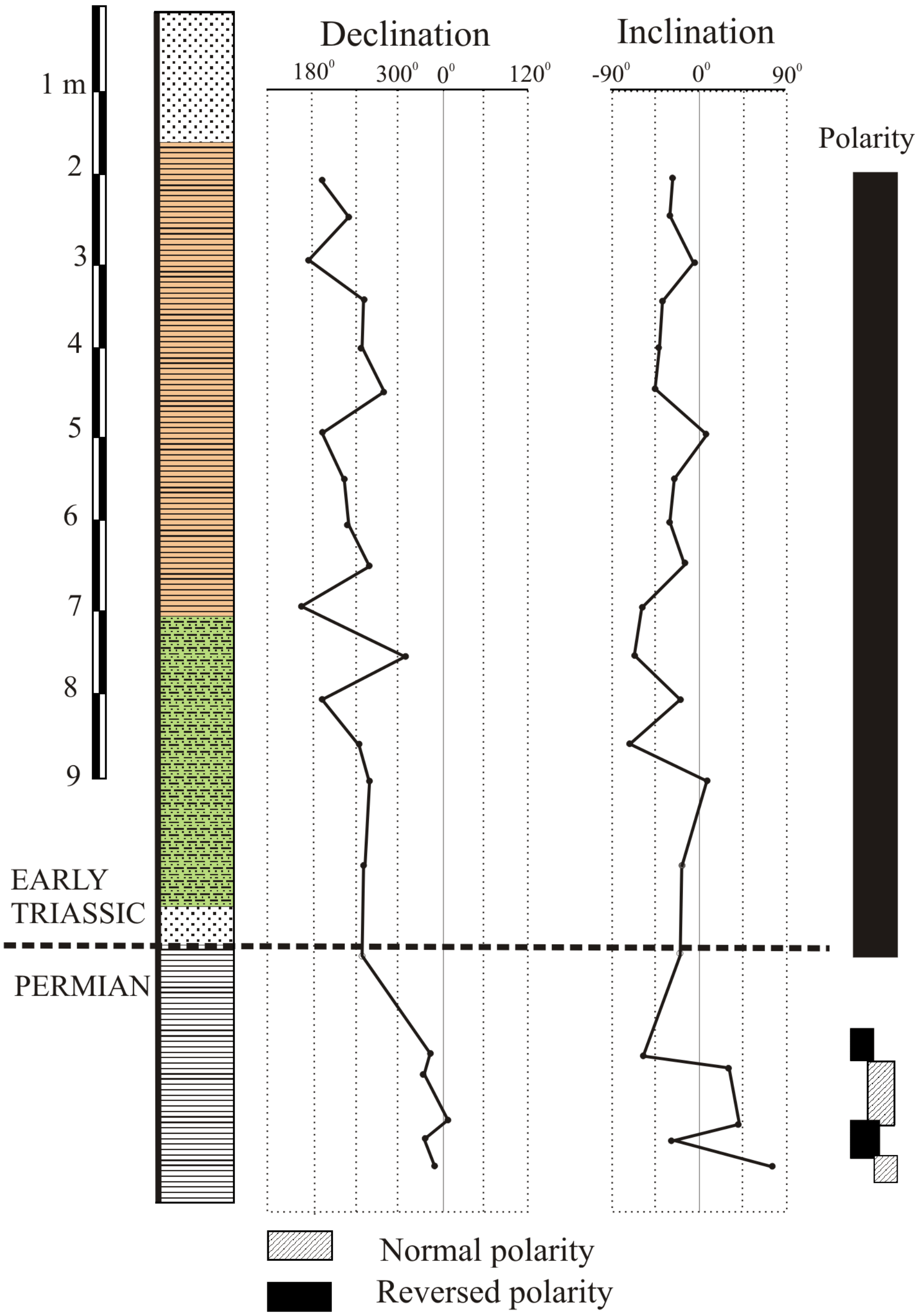

Figure 8. The paleomagnetic section across the Nedubrovo member.

reactivation of volcanic activity in the Early Triassic time suggests the higher global dusting of the atmosphere, as well as changes in its gas content, in solar luminance, in the temperature, and in some other side effects of the environmental transformations. It is possible that the magnitudes of these events at the beginning of the Triassic epoch turned out to be sufficient to disturb and change the climate of the planet and its biota at the transition from the Paleozoic to the Mesozoic Era.

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