

Late Permian magnetostratigraphy on the eastern Russian platform

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Abstract

The Late Permian is characterized palaeomagnetically by the transition from the long-lasting Permo-Carboniferous reversed polarity superchron (PCRS; also called: Kiaman reversed superchron) to the subsequent Permo-Triassic mixed polarity superchron, often called Illawarra mixed polarity superchron. Many discussions have been devoted to the exact time of the onset of the Illawarra reversals. Apparently contradictory data have been obtained from magnetostratigraphic sediment successions formed in different environments in many regions of the world. These sediments have been dated using classical geological or palaeontological correlation methods without the possibility of absolute age control because volcanogenic materials are missing. Application of the local or regional stratigraphic schemes leads to difficulties and apparent diachronous age estimates of the end of the PCRS. This paper shows that in agreement with earlier investigations, the continental red beds of the Upper Permian Tatarian stage on the eastern Russian platform record the Kiaman/Illawarra boundary. The Illawarra reversal sequence measured in a type section at the Volga river can be correlated well with the corresponding polarity pattern found in the Tethyan realm if one assumes a longer duration of the Tatarian than previously suggested.

Previous palaeomagnetic studies; objective of this study

Palaeomagnetic studies in Russia were carried out initially to compile a standard regional palaeomagnetic reversal sequence for the Palaeozoic (Khramov & Rodionov 1980, Khramov et al. 1974). In contrast to geomagnetic reversal time-scales, which are based on absolute age determinations, the Palaeozoic polarity column in Russia was only defined on a stage, series and system level using the stratigraphically most complete sections, and correlating between these sections. The Middle to Upper Palaeozoic part of the scale was compiled using rock samples from the Russian platform and its margin (Khramov 1963, Boronin 1979). The Kiaman reversed superchron covers the stratigraphic sequence from the Moscovian (Middle Carboniferous) to the Tatarian (Upper Permian). The lower boundary of the Illawarra mixed superchron is placed near the boundary between the Lower and Upper Tatar-

ian (Lozovsky & Yaroshenko 1994). Its upper boundary was thought to occur within the Lower Anisian (Triassic; Khramov & Rodionov 1980).

Two epochs of normal polarity and two of reversed polarity of the geomagnetic field have been recognized on the Russian platform in the Permian part of the Illawarra superchron (Khramov 1963). A mixed, normal and reversed polarity zone (NRP) which seems to indicate an interval of rapidly changing polarity just at the boundary of the Kiaman and Illawarra superchrons, has been found in many sections of the eastern Russian platform (Boronin et al. 1971). The stratigraphic position of this zone within the Tatarian stage, however, is not well defined everywhere and seems to occur in different stratigraphic horizons (Boronin 1979).

The correlation of the Russian Palaeozoic polarity sequence with world-wide palaeomagnetic data in general is limited because many formations lack a characteristic fauna that would allow for intercontinental stratigraphic comparison. The regional stage bound-

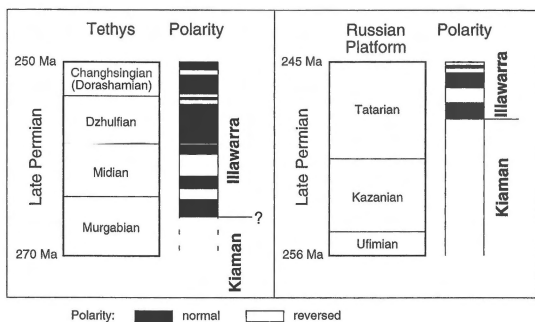


Figure 1. Late Permian stratigraphy and polarity distribution: Tethys (marine realm) according to Haag & Heller (1991) and Baud et al. (1996), Russian platform (continental series) according to Harland et al. (1990). Note the apparent age discrepancy of the termination of the Kiaman or Permo-Carboniferous reversed superchron (PCRS) between the two sequences.

aries also cannot be easily assigned absolute ages. In addition, continental as well as marine successions may suffer from unrecognized sedimentation breaks. The firm correlation of the boundary between the Kiaman and Illawarra superchrons (K/I) is still very difficult to achieve even if the Kiaman superchron has been documented in most continents. Peterson & Nairn (1971) defined the K/I boundary in Upper Guadalupian (Upper Permian) strata of North America. Other studies on Permian sections of central Europe (Menning 1995) place the K/I boundary in the upper part of the Rotliegendes formation whereas Haag & Heller (1991) and Baud et al. (1996) argue from evidence in marine limestones from Pakistan that this boundary should be placed near the base of the Upper Permian (Figure 1).

It is the purpose of this paper to reconsider the correlation problems and to discuss possible solutions based on data from a new Tatarian magnetostratigraphic type section at the Volga river.

General geological situation

Extensive sedimentary basins related to active graben systems were formed along the margins of the Russian platform already in the Early Cambrian (Nalivkin 1976). Very fast but discontinuous subsidence resulting in several major marine transgressions took place all over the Russian plate during the Middle and Late Palaeozoic. The Upper Permian rocks represent a sedimentation of mainly continental origin. Their facies reflect the changing subsidence rates. Lacustrine and lagoonal to shallow-marine sediments are characteris-

tic: sandstones, clays, marls, dolomites and limestones, with a typical paralic flora and fauna (Chepikov & Blom 1967).

The Upper Permian on the eastern part of the Russian platform along the Volga, Kama and Vyatka rivers contains the stratotype areas of the Ufimian, Kazanian and Tatarian stages (Figure 1). Marine, lagoonal and continental environments characterize the up to 200-m-thick Ufimian sediments whereas the Kazanian is represented here mainly by marine deposits of 100–200 m thickness. During the Tatarian, sedimentation returned to mainly lacustrine conditions. The sediment thickness varies considerably, but reaches several hundred metres (Ignatjev 1962, Forsh 1963). According to the time scale of Harland et al. (1990), the duration of the Late Permian amounts to 11 Myr. The Ufimian, Kazanian and Lower Tatarian strata are all reversely magnetized, thus representing the upper part of the Permo-Carboniferous reversed polarity superchron (PCRS = Kiaman) whereas the Upper Tatarian shows mixed polarity magnetizations (Figure 1).

The Tatarian stage on the eastern Russian platform consists of sandstones, clays and carbonate rocks containing a fresh-water fauna with bivalves and ostracodes (*Darwinula*). The correlation of these sediments is problematic. However, it has been possible to follow some stratigraphic units using biostratigraphic, rhythmostratigraphic and magnetostratigraphic data across the whole eastern part of the Russian platform from the river Sukhona in the north to the Volga and Vyatka rivers in the east (Ignatjev 1962, Boronin 1979).

Sampling sites

A flat-lying Upper Permian continental sequence of red beds which are considered to represent a rather continuous sediment pile, has been sampled at Monastirskoje on the banks of the Volga river (SW Tataria) for a magnetostratigraphic study. In the nearby section of Titjuschin where the sediments are exposed in a 100-m-wide complicated fold structure, additional samples have been collected for a fold test.

At Monastirskoje (54.80°N; 48.82°E), 300 oriented samples have been taken across 150 m of the section. The Tatarian here is represented mainly by a rhythmic alternation of loosely cemented aleuritic red clays and argillaceous siltstones. The fine lamination that characterizes the siltstones has been interpreted as evidence of yearly layering formed in a lacustrine environment

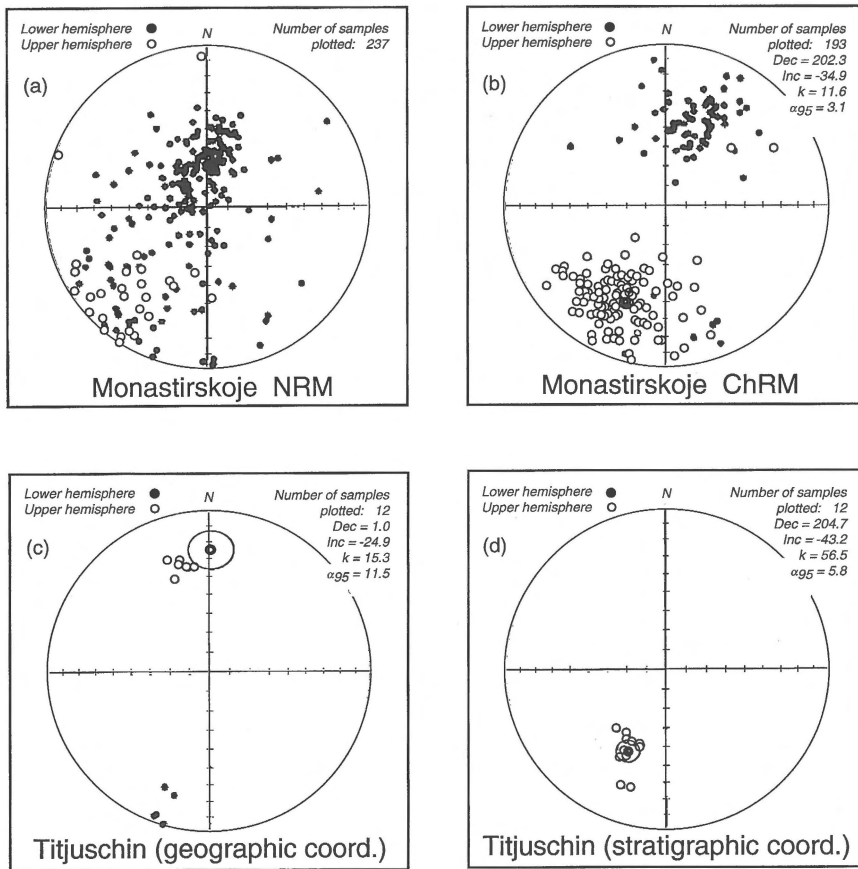


Figure 2. Stereographic projections of the NRM directions at Monastirskoje (a) before and (b) after thermal cleaning, and of the thermally cleaned NRM at Titjuschin (c) before and (d) after tectonic correction. Mean directions with 95%-circles of confidence and Fisher's (1953) statistical parameters calculated for one common polarity status of all samples.

(Nurgaliev et al. 1995). Thin whitish fresh-water limestone and dolomite beds are interbedded occasionally. Sometimes crossbedded sand banks with thicknesses between 2 and 6 m occur. The sand layers and small discordances between the silt and clay layers at different scales from millimetres to metres indicate that sedimentation was not always continuous. Depending on the lithology of the soft argillaceous clays and silts, and the hard limestones and dolomites, oriented cubic samples of 8 cm³ volume were cut with a knife, or cylindrical 1-inch cores were taken using a drilling machine. The sand banks could not be sampled because they are too weakly consolidated.

The stratigraphic succession crosses the boundary between the Lower and Upper Tatarian (Forsh 1963). Therefore the sediments are expected to record the transition from the Kiama reversed to the Illawarra mixed polarity chron. The NRP-zone mentioned above

should be present because the section at Monastirskoje is the most complete section of this part of the Tatarian; the section has been correlated bio- and rhythmostratigraphically with other sections in the Vyatka and Sukhona regions (Ignatjev 1962, Forsh 1963, Boronin 1979).

The fold complex at Titjuschin (54.53 °N; 48.35 °E) is formed by red clays interlayered with white limestones. The folding age is not well known. The outcrop may represent syndimentary slumping because the underlying Kazanian limestones and the overlying Triassic and Jurassic sediments are in horizontal unfolded position. Alternatively, hydrogeologic disturbance at a later date may have dissolved gypsum contained in the red-bed sequence causing fold structures along several faults in this region which are called 'Titjuschin folds' (Chepikov & Blom 1967). They have been assigned a pre-Neogene (Palaeogene) age because

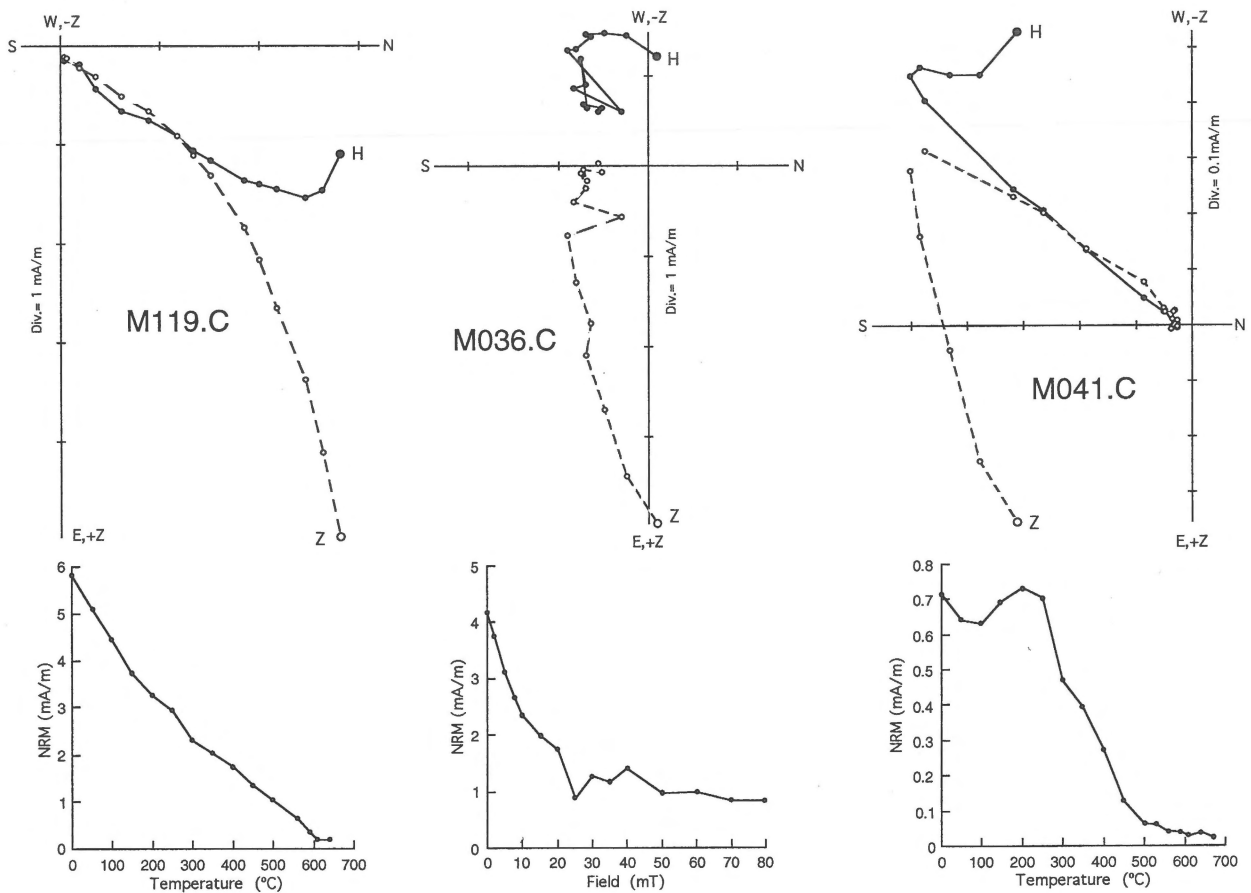


Figure 3. Orthogonal vector diagrams as introduced by Zijdeveld (1967) showing the NRM vector during demagnetization separated into a horizontal (H, closed symbols) and a vertical (Z, open symbols) component for three samples from Monastirskoje. Thermal demagnetization (samples M119.C, M041.C) removes a steeply inclined and northerly directed present-day field component whereas gently inclined normal and reversed directions are unblocked at higher temperatures, giving evidence of a primary Late Permian NRM component. AF cleaning (sample M036.C from a reversed polarity zone approximately 1 m distant from M041.C) removes some of the steep secondary component but does not allow to establish the presence of a Late Permian magnetization.

considerable tectonic activity occurred during this time (Milanovsky 1940). Six hand samples from which 30 subspecimens were obtained, were collected in the Titjuschin outcrop along both sides of a 10-m-wide fold with a subhorizontal approximately E-W striking fold axis.

Laboratory measurements and palaeomagnetic results

The natural remanent magnetization (NRM) has been measured with a three-axes cryogenic magnetometer (2G Enterprises). The red marls, red clays and red argillaceous siltstones are characterized by high NRM

intensities of the order of 10^{-3} to 10^{-2} A/m, whereas the NRM of the limestones and white dolomites averages 10^{-5} to 10^{-4} A/m.

Red-bed pilot samples from different stratigraphic levels in the Monastirskoje section were selected and subjected to progressive demagnetization using both thermal treatment or alternating magnetic fields (AF). Upon AF cleaning, the NRM intensity was reduced to 20 to 60% of the initial value at 80 mT, the maximum field applied. A present-day field component which is predominant before cleaning (Figure 2a), was removed, but a high-coercivity overprint could often not be erased (Figure 3, sample M036.C) and resulted in highly scattered data after AF demagnetization. This contrasts the behaviour of other contemporary red beds such as those

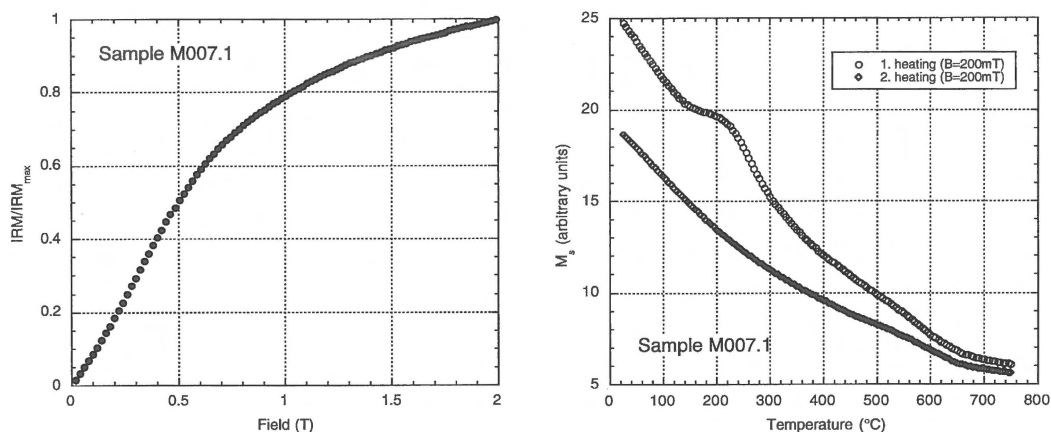


Figure 4. IRM acquisition (left) and saturation magnetization versus temperature $M_s(T)$ (right) of a red siltstone sample from Monastirskoje. High coercivity, Curie temperatures around 660 °C, and irreversibility of $M_s(T)$ upon heating, as indicated by the inflexion between 150 and 250 °C during the first heating cycle and the reduced intensity in the second heating curve, indicate the presence of haematite and probably also maghemite.

in the Esterel where Zijdeveld (1975) successfully AF-demagnetized present-day overprints which were, however, of smaller magnitude. According to isothermal-remanent-magnetization (IRM) acquisition experiments and measurements of saturation magnetization as a function of temperature, the magnetic properties of the Monastirskoje red beds are controlled by haematite and maghemite (Figure 4).

Other red-bed samples from Monastirskoje were demagnetized thermally up to 500 °C in 50 °C steps; from 500 to 680 °C the increments were reduced to 30 °C. Two components of magnetization were detected in most of the measured samples utilizing linear segments of the demagnetization curves (Figure 3). The magnetization component removed below 300 °C reflects the present-day field (inclination = 71 °). The components isolated between 350 and 680 °C show two magnetization polarities with northerly declinations and shallow positive inclinations, and with southerly declinations and shallow negative inclinations, respectively. According to the behaviour of the pilot specimens, the remaining red-clay and argillaceous-siltstone samples were heated in the temperature interval in which the characteristic component was isolated. Only about 20 among 210 of these samples behaved in an unstable fashion during heating inhibiting isolation of the characteristic component. The low-field susceptibility measured with a KLY-2 bridge after each step of the thermal procedure did not give evidence of mineralogical changes during the heating, at least until 600 °C.

Pilot samples from the white limestones and dolomites did not yield a stable NRM behaviour during demagnetization. The magnetization intensity of most of these samples was strongly reduced at 100 °C already, suggesting goethite to carry large NRM proportions. Unstable NRM directions were observed mostly at higher demagnetization temperatures. Therefore the remaining carbonate specimens were not analysed further.

From the red-bed samples collected at Titjuschin, 12 samples have been chosen from both sides of the fold and subjected to progressive thermal demagnetization. The samples are characterized by a stable NRM with two components of magnetization. The directions of the primary component were scattered before the tectonic correction, while the grouping improved significantly after the bedding correction (Figure 2c: $k = 15.3$ before unfolding, Figure 2d: $k = 56.5$ after unfolding). Therefore the fold test indicates that the characteristic magnetization pre-dates the folding and may be of very early origin if synsedimentary slumping occurred, or at least of pre-Palaeogene age if the site was deformed at that time (see Milanovsky 1940).

The normal polarity mean direction of all Monastirskoje samples with a characteristic remanence regardless of the actual polarity has a declination of 22.3 ° and an inclination of 34.9 ° (statistical parameters in Figure 2b). It is consistent with the unfolded direction at Titjuschin. The resulting formation palaeolatitude at 19.2 °N confirms the palaeogeographic situation of the eastern European platform described by Zakharov & Sokarev (1991). Thus the character-

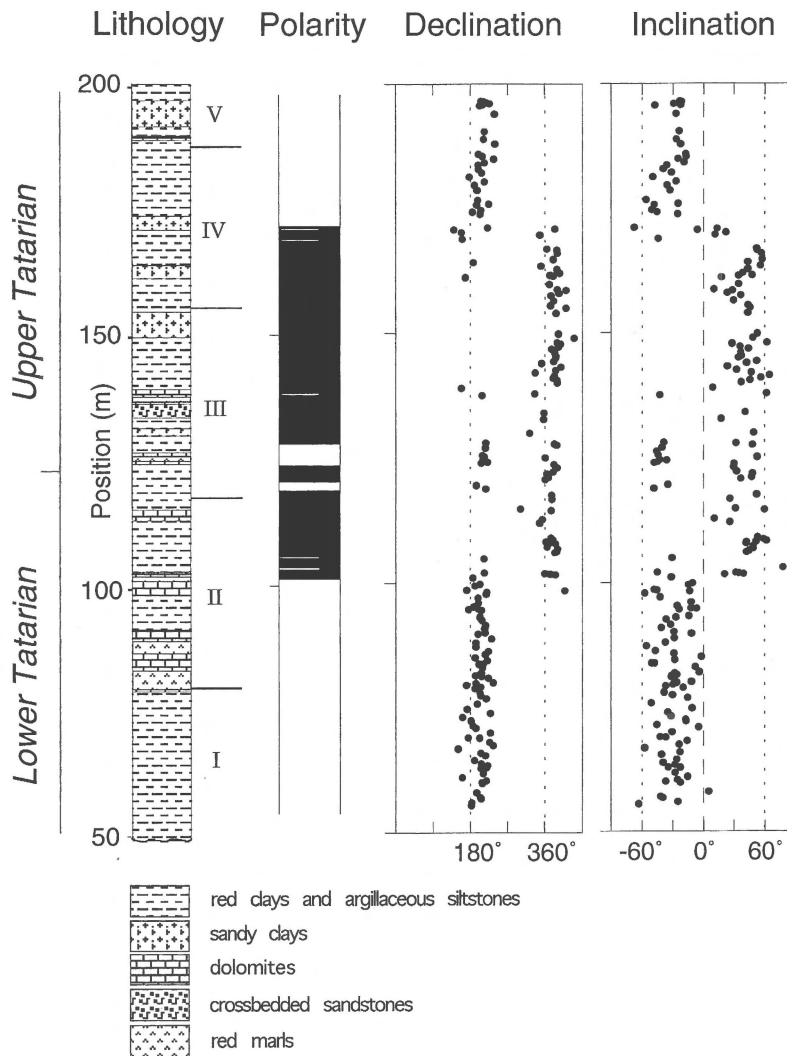


Figure 5. The section at Monastirskoje: Stratigraphy, lithology, including Tatarian substages I-V according to Forsh (1963), and polarity column obtained from the distribution of the declination and inclination components of the primary NRM.

istic remanent magnetization is considered a primary magnetization of early diagenetic origin.

Magnetostratigraphy

The normal and reversed primary magnetization directions define a clear magnetic zonation of the sediment sequence in the Monastirskoje outcrop (Figure 5). The samples collected in the lower and higher parts of the section carry a reversed polarity magnetization while the samples in the middle part carry mostly a normal

polarity magnetization, except in some places where thinner zones of reversed polarity, sometimes represented by single samples only, are present. Therefore, similar to the observations by the Russian investigators (Khramov 1963, Boronin et al. 1971), which were based only on low-temperature thermal demagnetization up to 300 °C or prolonged zero-field storage demagnetization, two zones of negative and one of positive main polarity, interrupted by some shorter events, can be distinguished. The first reversal occurs below the boundary between the Lower and Upper Tatarian, again in agreement with the earlier Russian work. No obvious correlation with lithology has been recognized

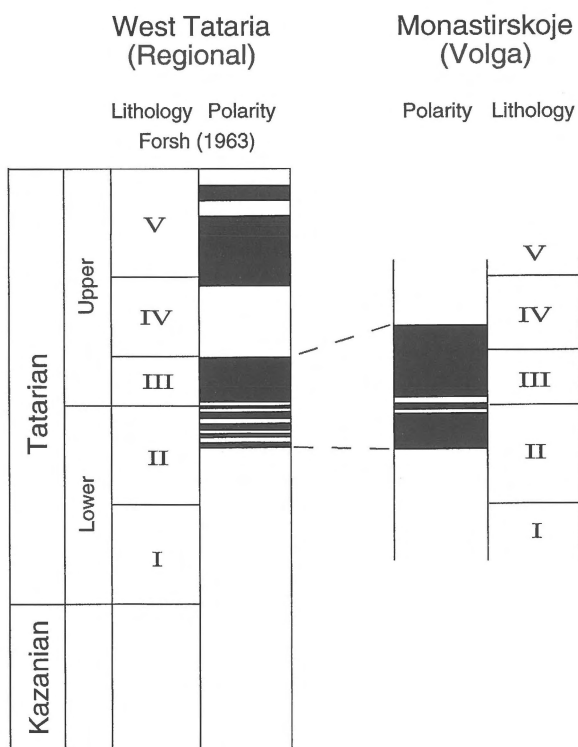


Figure 6. Correlation of the magnetostratigraphic section studied at Monastirskoje with the composite lithology and polarity development in west Tataria (Forsh 1963). The Tatarian lithological stages I–V, which have been described also at Monastirskoje, were used to scale the section at the Volga river to the regional scale.

lending further support to an early origin of the characteristic remanent magnetization.

The Monastirskoje polarity sequence which is stratigraphically restricted to the middle part of the Tatarian, can be put into a larger stratigraphic frame by comparison with the west-Tatarian polarity column developed by Khramov (1963) on the basis of the lithological regional subdivision of the Tatarian by Forsh (1963). The first normal polarity zone in Monastirskoje at profile position 101.30 m (Figures 5, 6) indeed marks the PCRS termination and the onset of the Illawarra reversals where the consistently reversed magnetizations of the Kazanian and of three quarters of the Lower Tatarian end in the Tatarian lithological substage II (Forsh 1963). Both polarity columns of Figure 6 broadly coincide, even though subtle differences are recognized. The frequent reversals reported earlier and plotted on the regional scale have not been observed at Monastirskoje. Here a largely normal polarity zone occurs. The positions of the boundaries of the normal and reversed polarity zones with respect to the litholog-

ical substages III and IV in the regional profile differ slightly from those in the Monastirskoje profile. This suggests that either the lithological stage boundaries are diachronous within the Volga-Vyatka basin or, less likely, that the rigorous thermal demagnetization techniques which were applied, produced different results in some parts of the Monastirskoje profile.

Discussion

The revised polarity pattern on the eastern Russian platform can be compared with other Late Permian polarity sequences (Figure 7). The most suitable records come from palaeontologically well-dated sections of marine carbonates in Pakistan (Haag & Heller 1991) and in Transcaucasia (Kotlyar et al. 1984, Zakharov & Sokarev 1991). The Transcaucasian data are especially important for the magnetic polarity definition at the Permian/Triassic boundary because the uppermost Permian stage, the Dorashamian (covered by seven samples according to Zakharov & Sokarev 1991), as well as the boundary with the Triassic Induan are preserved. Unfortunately, the sections of Kotlyar et al. (1984) which are represented by 200 to 300 m of stratigraphic thickness corresponding to about 20 Myr of geological time, have been documented scarcely with less than 30 palaeomagnetic samples. A further restriction is the fact that the K/I boundary has not been observed below the well-documented Illawarra reversals although the Upper Permian Murgabian stage which is located just above the boundary between the Lower and Upper Permian has been sampled at least in the upper parts of the marine sediment series in both Pakistan and Transcaucasia. Thus only a minimum age of the K/I boundary, which must be placed in the Murgabian or stratigraphically even lower, can be estimated.

This is supported by the result from an earlier study in south China (Heller et al. 1995). The polarity pattern of the Upper Permian in south China can be correlated with that in Pakistan. When correlating the oldest normal polarity in Pakistan with the normal polarity of the Maokou formation in south China (Wulong section) the minimum age for the K/I boundary has to be placed at the end of the Early Permian or earlier. Consequently the K/I boundary on the Russian platform, which is found below the boundary between the Lower and Upper Tatarian, must be situated deep in the early stages of the Late Permian (Figures 7, 8).

The comparison of the Tatarian magnetostratigraphy with the combined marine polarity pattern giv-

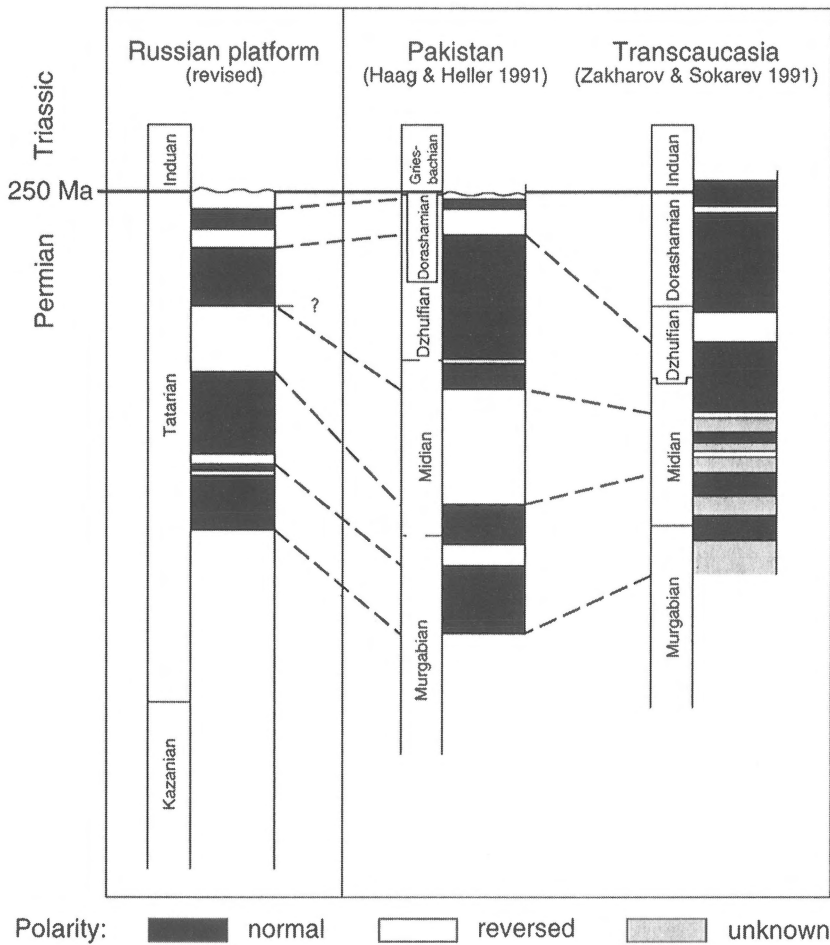


Figure 7. Correlation of the magnetostratigraphic scale of the Russian platform as re-defined in this study with the magnetostratigraphic scales observed in Pakistan (Haag & Heller 1991) and Transcaucasia (Zakharov & Sokarev 1991).

en in Figure 8 (Haag & Heller 1991, Baud et al. 1996) has important implications for the stratigraphic interpretation of the Upper Permian sediments on the Russian platform. The partly terrestrial and partly shallow-marine Ufimian and Kazanian sediments represent only a very short time interval in the Upper Permian because they are reversely magnetized throughout, and hence are interpreted to belong to the Kiaman superchron (or PCRS). Thus the Ufimian and Kazanian stages may represent only some 1 or 2 Myr, much less than suggested by the timescale of Harland et al. (1990). On the other hand, the polarity pattern of the terrestrial Tatarian sediments which unfortunately lack adequate faunas or volcanogenic material useful for relative or absolute age dating, seems to correlate well with that obtained in the Upper Permian marine stages from the Lower and Middle Murgabian to the

lower boundary of the Dorashamian (equivalent to the Changshingian).

The Russian-platform data are inconsistent with the recent results from a continental red-bed section in north China by Embleton et al. (1996) where the PCRS termination was placed in the Ufimian. Both, the Ufimian and the Kazanian are reversely magnetized throughout at their type localities (Khranov et al. 1974). As mentioned in the beginning, however, the discrepancy may be explained by correlation and age assignment problems in continental sequences.

Conclusion

The Tatarian most probably spans more than the approximately 10 Myr assigned to it by Harland et al.

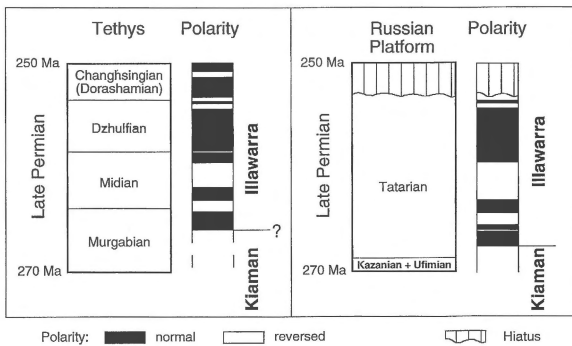


Figure 8. Age assignment of the Late Permian stratigraphic stages on the eastern Russian platform as a consequence of their comparison with the Tethyan stratigraphy and polarity distribution according to Haag & Heller (1991) and Baud et al. (1996).

(1990). It represents about 15 Myr, but the exact duration is difficult to derive. A sedimentation break occurring near the Permian/Triassic boundary is indicated by widespread conglomerates in the top of the Tatarian and by the missing equivalent of the Dorashamian polarity pattern (which in its top part is also cut by erosion). The Lower Tatarian must be of very short duration compared to the Upper Tatarian and must have a high sedimentation rate in Monastirskoje. It is completely missing on the other hand in the northern part of the Russian platform (Astafurov & Medvedeva 1991). The regularity and continuity of deposition of these continental red beds are in question since conglomerates are found in many places on the Russian platform within the Tatarian sequence. Metre to millimetre discordances such as discordant sandstone layers and microscale erosion features have been observed at Monastirskoje. Therefore it is questionable how much time of the postulated 15 Myr is really represented by the Tatarian red sediments. The good correlation with the main polarity pattern found in the Tethyan realm, however, indicates that the many obvious hiatuses did not last too long to prevent the successful record of the main polarity behaviour of the geomagnetic field during the Late Permian.

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