New paleomagnetic data for the Hauterivian–Aptian rocks of the Middle Volga region: Global correlation and dating of stratigraphic boundaries

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Abstract. The aim of this project was to study the paleomagnetic stratigraphy of the Hauterivian-Aptian deposits in the Middle Volga region, namely in the areas of the Saratov, Samara, and Uliyanovsk right-hand Volga areas. Original data were obtained for the first time for the magnetic polarity of the Hauterivian and Barremian rocks of the Russian Platform. The results obtained for the Aptian rocks agree very well with the results of the previous paleomagnetic studies which had been carried out in the Uliyanovsk region earlier [*Baraboshkin et al.,* 1999] and in the vicinities of Saratov City [*Grishanov,* 1984]. Based on the complex correlation of the bio- and magnetostratigraphic data for the rocks from the Middle Volga region, the North Caucasus, the North Mediterranean area, and South England, it is shown that the stage and substage boundaries of the Hauterivian, Barremian, and Aptian stages differ in terms of the absolute age from the similar boundaries in the Boreal Belt by a value of some 10^5–10^6 years, which is comparable with the duration of the Early Cretaceous ammonite zones. The diachronism of the Lower Aptian ammonite zones (Deshayesites volgensis – D. forbesi) and of the Middle Aptian Parahoplites melchioris zone in different regions. The results of this study called for a complex substantiation and tracing of the units of the General Stratigraphic Scale (GSS). The basic GSS unit must be a stage, rather than a zone, because where boundaries were traced over a large territory, the asynchronism of the boundaries between the zones is comparable with the duration of the zones, whereas in the case of a stage it is 1–2 orders of magnitude lower. Geomagnetic inversions or isotopic data can be used to test the isochronism of stratigraphic boundaries.

Introduction

The data used as a basis for writing this paper were collected in a 1998–2000 period of time jointly by the geologists of the Moscow and Saratov Universities in the middle course of the Volga River between Uliyanovsk and Saratov cities, where the Lower Cretaceous rocks of the Russian Platform are most complete. We studied 12 sections of the Hauterivian-Aptian deposits outcropping at the right bank of the Volga River: from Zakharievskii Mine to Polivna Village, in the areas of Kremenki Village, Sengilei Town, Russkaya Bektyashka Village (Uliyanovsk Region), Novokashpirskii Stl., Forfos Mt. (Syzran District of the Samara region), Chernyi Zaton Village, Fedorovskii Site rising 246 m high, Ershovskii Site (Khvalynskii area in the Saratov District, Dubki Stl., and Ust-Kudyum Village (Saratov District) (Figure 1). Samples for our paleomagnetic study were collected and field paleomagnetic measure-

ments were made along with the geological descriptions and biostratigraphic studies of the cross sections ("sample-in-sample"), which allowed us to exclude any potential errors in correlating the magnetic zones with the beds and paleontological finds. In addition, to plot a magneto-stratigraphic map for the Hauterivian-Aptian rocks of the Middle Volga region, we used the data available for the Aptian rocks of Mount Sokolov (Saratov City) [*Grishanov,* 1984], for the Aptian rocks of the Uliyanovsk City–Kremenki Village area [*Baraboshkin et al.,* 1999], and for the Hauterivian-Barremian rocks exposed by mapping holes 120 and 204 in the Saratov East-Volga region (Pugachev and Oza areas) (Figure 1). The comprehensive study of the core samples from these holes was carried out at the Laboratory of Paleomagnetism, Research Institute of Geology, Saratov Geological Survey, (headed by E. A. Molostovskii) in the framework of a contract for the work in which the authors of this paper had taken an active part. The data for the rocks penetrated by Holes 120 and 204 are used in this paper by the permission of the customers: the Saratov Hydrogeological Expedition and the Chief Department for Natural Resources in the Saratov Area.

The Hauterivian-Aptian deposits in the Middle Volga region are favorable objects for magnetostratigraphic studies [*Baraboshkin et al.,* 1999; *Grishanov,* 1984] and for the detailed (zonal) biostratigraphic mapping using ammonites and belemnites [*Baraboshkin,* 2001; *Baraboshkin and Mikhailova,* 2002; *Baraboshkin et al.,* 2003], which contributed to the reliable ground control of paleomagnetic units. The data obtained in this study are highly important for the detailed correlation of the stratigraphic scales available for the Hauterivian-Aptian rocks in the Boreal and Tethyan Cretaceous belts, because their direct correlation based on biostratigraphy, without using paleomagnetic data, is invalid for some intervals [*Baraboshkin,* 2001; *Baraboshkin and Mikhailova,* 2002; *Baraboshkin et al.,* 2001].

Stratigraphy

The rock sequences investigated in this study are represented by the alternation of variably silted clay beds, siltstones, and cross-bedded sands. The age of the rocks is substantiated by paleontologic finds which were used to trace a number of belemnite zones in the biostratigraphic map of the Barrhemian rocks in the Middle Volga region [*Baraboshkin,* 2002; *Baraboshkin and Mikhailova,* 2002; *Baraboshkin et al.,* 2003; *Mikhailova and Baraboshkin,* 2001].

The Aptian and Barremian/Aptian intervals were described earlier mostly in the Uliyanovsk Region [*Baraboshkin and Mikhailova,* 2002; *Baraboshkin et al.,* 1999], and the Barremian was described partially from the lower part of the rock sequence in the area of Syzran City [*Baraboshkin et al.,* 2001]. The more complete characteristics of the well documented rock sequences were offered by *Barabashkin* [2001] in his unpublished paper. Below follows the description of the entire Hauterivian-Aptian interval of rocks in the Middle Volga region, using the latest data and the same indices of the lithologic units for the entire Lower Cretaceous clayey-

sandy rock sequence. Member I varies highly in thickness, has been conventionally dated Late Valanginian, and is not discussed here. The Hauterivian-Aptian interval includes members II to XXIV (Figures 2 to 8, upward).

Member II consists of black gypsumized clay with scarce silt interlayers at the base. It includes several layers of carbonate and siderite concretions with large Speetoniceras fossils and also marcasite concretions. At the base there is a 0.1–0.3 m interlayer of dark gray sandy and silty clay, with a soft floor surface at the base. The top of this member is eroded. This member includes numerous Aulacoteuthis speetonensis and the following ammonite association: Speetoniceras versicolor, S. subinversum, Simbirskites coronatiformis. Speetoniceras versicolor var. astanta, S. povoljiense, S. Pavlowae, S. Pavlowae amota, S. leium, S. intermedium, S. inversum, Speetoniceras subinversum, S. subinversum virgata, S. inversumiforme, S. inversumiforme rarecostata, S. elegantum, Speetoniceras pressum, and numerous Astarte porrecta, sometimes in their living positions. The ammonite association includes several complexes corresponding to three subzones, namely: Speetoniceras versicolor (4.2 m) with Speetoniceras versicolor; Simbirskites coronatiformis (8 m) with Speetoniceras versicolor, S. subinversum, Simbirskites coronatiformis; and Speetoniceras inversum (5 m) with Speetoniceras inversum, S. versicolor, and S. subinversum. The total thickness of this member is 17.2 m.

Member III is composed of black, poorly gypsumized clay with several horizons of carbonate concretions, residing 1.5, 5, 8, 11, and 13 m above the base. The basal sequence (0.4–0.5 m) includes a characteristic interlayer of dark gray argillaceous siltstone. Its lower part contains numerous Astarte porrecta and scarce Heteropteria aucella (Trautsch.), which grow in size toward the top, single Aulacoteuthis speetonensis, and also (in the basal 0.4 m interval) Speetoniceras inversum, S. versicolor, S. subinversum, and Simbirskites Pavlowae of the Speetoniceras Pavlowae subzone.

The upper part of Member III includes three different assemblages of cephalopods. The lower 3.3 meters contain Milanowskia speetonensis, M. speetonensis angusta, M. concinna, Craspedodiscus phillipsi, C. gottschei Koen., C. barboti, Simbirskites elatus, S. decheni, S. kowaleveskii, and other cephalopods, which allow one to include these rocks in the Milanowskia speetonensis zone.

The intermediate rock sequence (4.2 m) contains Craspedodiscus discofalcatus, C. barboti, C. gottschei, C. phillipsi, Milanowskia progredica, M. polivnensis, Simbirskites pseudobarboti, S. umbonatiformis, S. decheni, and one specimen of Pictetia sp. This fauna assemblage corresponds to the Simbirskites pseudobarboti subzone of the Craspedodiscus discofalcatus zone.

Finally, the upper 3.5 m of the rocks contain Simbirskites umbonatits, S. pavlovi, S. yorkshirensis, Milanowskia progredica, M. sp., Craspedodiscus barboti, C. discofalcatus, C. discofalcatus aspera, C. discofalcatus dubia, C. borealis, and C. intergerinus and belong to the Simbirskites umbonatus subzone of the Craspedodiscus discofalcatus zone.

The total thickness of the above interval is 15.6 m.

IV. A member of black fine-detrital clay, silty at the base,

containing scarce horizons of limestone concretions. The rocks contain scarce Acroteuthis pseudopanderi, Craspedodiscus barboti, C. discofalcatus, C. discofalcatus aspera, C. discofalcatus dubia, C. borealis, and C. intergerinus, which suggest this interval to belong to the Craspedodiscus discofalcatus subzone of the zone having the same name.

The thickness of the above interval is 6 m.

The total thickness of the Upper Hauterivian rocks is 38.8 meters. In the direction toward Syzran City (Novokashpirskii Settl.), Member I and the lower part of Member II pinch out, the total thickness of members III–IV diminishing to 15–25 m.

V. A two-member rock sequence in the area of Uliyanovsk City includes a 2.5-meter argillaceous siltstone interlayer, the base of which marks a boundary between the Hauterivian and Barrhemian rocks, this boundary being unexposed in the Syzran rock sequences. The upper part of the member is composed of black clay, with single interlayers of dark gray siltstone, with soft ground (SG) surfaces located usually at their bases. Vertical Scolithos pipes extend downward from them. There are occasional horizons of calcareous concretions up to 2 m across. The top of this rock sequences shows traces of slight erosion. The thickness of these rocks in the Uliyanovsk area is about 10 m.

VI. A member of rhythmically interlayered black to dark gray clays (0.5–3 m), with a variable silt content, and light gray and greenish siltstones and fine-grained sand (0.1–0.75 m). The bottoms of the siltstone interlayers, usually starting the sedimentation rhythms, show SG surfaces. There are occasional weathered pyrite concretions and rare horizons of ellipsoidal and round limestone concretions up to 1 m in diameter (in the Uliyanovsk sections). All rocks are highly bioturbated with merely occasional thin tempestite interlayers with a crossbedded texture. The rhythms vary in thickness, becoming thinner up the section, with the growing sand content of the member.

The top of this member can be easily identified at all sites and is traceable following the SG surfaces in the base of a characteristic glauconite bed, 0.5 m thick. (Earlier, this boundary was conventionally assumed to be a Hauterivian-Barrhemian boundary [*Baraboshkin et al.,* 2001].

The thickness of this member in the Uliyanovsk sections is 22–24 m.

The V and VI members are almost indistinguishable in the sections near Syzran, where they are represented by a fairly monotonous sequence of dark-gray clay with thin (5–10 cm) interlayers of gray siltstone containing scarce small half-dissolved belemnites. The thickness of these rocks is about 53–54 m in the Kashpir area.

In the Uliyanovsk sections, the bottom of this rock sequence was found to contain the remains of Heteropteria cf. aucella (Trautsch.), single species of Praeoxyteuthis jasikofiana and P. hibolitiformis (Stoll.), and Cymbula? sp. indet., the top containing some single species of Mclearnia imperialis (Keyserling). The sections near Kashpir were found to contain juvenile Praeoxyteuthis sp. which had been identified earlier erroneously as Hibolites sp. and H. cf. jaculoides Swinn. [*Baraboshkin et al.,* 2001], Praeoxyteuthis sp. (?ex gr. jasicofiana (Lah.)), and P. sp.

indet. (?ex gr. hibolitiformis (Stoll.)).

VII. A member of rhythmic alternation of the slightly bioturbated interlayers of greenish small- and fine-grained glauconite-quartz sand (0.15–0.9 m, lower rhythm element), at the base of which there are softground surfaces and the surfaces of black poorly silty micaceous clay (0.65–4 m, the upper element of the rhythms). The thicknesses of the rhythms decrease notably toward the top of the member. The Scolithos burrows extend from the softground surfaces to depths of 30–40 cm and contain elevated amounts of glauconite. The sand layers of the rhythms contain comparatively rare slightly opened belemnite rostra of Praeoxyteuthis sp., P. sp. juv., P. hibolitiformis (Stoll.), P. cf. jasikofiana (Lah.), and rare Mclearnia imperialis (Keyserling) in the lower part and P. jasikofiana (Lah.), P. cf. jasikofiana (Lah.), and P. aff. jasikofiana (Lah.) at the top. The basement includes a 0.4–0.5-meter bed of quartz-glauconite sand.

The thickness of this member is 11–12 m in the Ulianovsk sequence and about 5 m in the Forfos sequence.

VIII. A member of black and brownish homogeneous bioturbited mica clay with rare siderite concretions and remnants of small Aconeceras sp. ammonites. The base of this sequence includes a soft ground surface; encountered above this surface were the scarce rostra of Praeoxyteuthis jasikofiana (Lah.), P. aff. pugio (Stoll.), P. sp, and P. sp. juv. The clay was found tp contain single rostra of Praeoxyteuthis pugio (Stoll.) and P. cf. pugio (Stoll.), Leda cf. nuda (Keys.). Closer to the top this member grows more sandy at the expense of deep (up to 1.5 m) Scolithos and Ophiomorpha burrows, exposed at the softground surface in the top of this member and filled by sand material.

The thickness of these rocks at the Forfos site is 14.6–14.7 m. The top of this member and the overlying rocks are not exposed in the Uliyanovsk sections, and the exposed thickness is >8 m.

IX. A member of brownish-gray thin-bedded clay, consisting of thinly alternating light silt and varying-color clay. There are occasional sublayered bioturbation units. A lower 0.1–0.2 m layer at the base consists of brown sand with a troughlike and diagonal oblique bedding, containing numerous Praeoxyteuthis pugio (Stoll.) rostra. The basis of the lower clay interval (0.9–1 m) is sandy and includes the remains of unidentifiable bivalves. The middle part of this member contains sporadic accumulations of Inoceramus (Neocomiceramus) species and scarce Cyprina? sp. indet. The visible thickness in the Forfos section is 5.5–6 m.

The middle clay interval is exposed in the Fedorovskii Site section, where it consists of light gray and gray striated clay, locally enriched in silt, with a shell detritus, Chondrites tracks, Oxytoma sp. and Nucula sp. bivalves, and single Praeoxyteuthis sp. rostra.

The upper 2–5 m of the clay are represented in the Fedorovskii Site and Chernyi Zaton sections by thinly interlayered greenish-gray micaceous siltstone (0.02–0.15 m) and black, highly micaceous bioturburbated clay. The thickest siltstone layers show oblique bedding which vanishes occasionally at the expense of bioturbation. The lower part includes numerous pyrite nodules (1–2 cm), small gastropods, thick-walled bivalves, Corbula (?) sp., small belemnites

Praeoxyteuthis pugio (Stoll.), P. sp., P. sp. juv., and nest-like accumulations (10–15 cm) of Ditrupa notabile (Eichw.).

The visible thickness of the rocks is 5 m in the Chernyi Zaton section, and 17.1 m in the Fedorovskii Site section. The total thickness of this member is 20–25 m.

In the Uliyanovsk area these and a part of the overlying rocks are not exposed, therefore their description is given here on the basis of the Saratov Povolzhie rock sequences.

X. A member of the lenticular alternation of crossbedded siltstone (0.2–0.3 m), micaceous siltstone with an admixture of fine-grained glauconite, and black micaceous clay (0.03–0.05 m). The rocks contain a great number of diagenetic concretions; siderite lenses are produced in place of clay interbeds, and calcareous siltstone concretions, in place of siltstone. ?Aulacoteuthis sp. juv. remains have been found. The total thickness of the member is 6.8 m

XI. Two-member clay sequence:

XI(a). The base of this member is composed of black, highly silty, micaceous, bio-turbidity clay with small siderite and pyrite nodules and scarce belemnites (Aulacoteuthis cf. descendens Stoll., Aulacoteuthis sp., and Astarte sp. bivalves in their living positions. In some places the top of the rocks is cemented by siderite, was the surface of a solid floor, and shows traces of high erosion. The thickness of the rocks is 2.6 m.

XI(b). Clays similar to those of submember VIa. The bottom includes a 0.2-meter layer of bright green quartz-glauconite sand with rare redeposited rostra of Aulacoteuthis cf. descendens Stoll. and A. sp., and with not redeposited Oxyteuthis sp. (brunsvicensis? juv.), O. sp., and O. sp. juv. The thickness of these rocks is 7.4 m.

The total thickness of this rock sequence is 9.9–10 m.

The exposed thickness of this rock sequence in the area of Novouliyanovsk City (Kremenki Village) is about 6 m. The rocks are brown-gray clay with rare silt interbeds showing a softground or erosion surface. The lower part of this interval includes large (max 1×5–6 m) brown silty limestone concretions. The silt interlayers and clays include occasional and poorly preserved fossils of Oxyteuthis sp. indet., O. sp. juv., and ?O. cf. brunsvicensis Stoll.

XII. A member of greenish-gray micaceous, gently cross-bedded to parallel-bedded siltstone, fine-grained sandstone (<0.3 m), and dark-gray bioturbation clay. The lower part of the sequence (1 m) is dominated by clay and has a dark-gray color. The clay is silty, lenticular-bedded, and bioturbated to ichnolayered. The rocks include extensive lenses of cross-bedded siltstone, varying in thickness. The fossils of Oxyteuthis cf. germanica Stoll. were found there. The uppermost part of this member is gradually enriched in clay and is terminated by an interbed of low-clay siltstone (0.5 m). The bottoms of sand interlayers contain the scattered valves of Cucullaea golowkinskii (Sinz.), Nucula sp., Eucyclus? sp. gastropods, Oxyteuthis lahuseni (Pavl.) belemnites, O. sp., and scarce shark teeth. The top of this interval includes a siderite interlayer, 0.1 m thick. The total thickness of this member in the Saratov region is 5.2 to 6 m.

In the Uliyanovsk region, this member becomes less sandy and resembles the underlying rock sequence. It is composed of brown-gray clay alternating with siltstone interbeds with a softground surface always present at the base. The

rocks are bioturbited, with silts always showing oblique bedding and containing small calcareous and pyrite concretions. This member contains occasional gypsumized Oxyteuthis lahuseni (Pavl.), O. barremicus Glas., and O. sp. Its thickness is 3.5 m.

XIII. A member dominated by clay. At the base (1.5 m) the clay is compact, micaceous, almost devoid of silt, and has a dark gray color. Upward, the clay is enriched in silt and includes interbeds (<1 m) where yellow-gray gently oblique-bedded siltstone beds (0.05–0.1 m) alternate with dark-gray clay beds (0.01–0.02 m). The overlying material is clay with a variable silt content, highly bioturbated with occasional ochreous silt interbeds. This member incudes occasional scattered layers of siderite and limestone nodules and rare bivalves: Arctica? sp., Cymbula? sp., and C. nuda (Keys.). Apart from these, the Uliyanovsk rock sequences (Kremenki) contain Oxyteuthis lahuseni (Pavl.) in the lower 1.5–1.7 m intervals.

The visible thickness of the rocks is 9.4–9.5 m, the total thickness of this member being 20–25 m.

The Barremian-Aptian boundary, traced along the basement of the M0 magnetic anomaly [*Baraboshkin et al.,* 1999; *Guzhikov et al.,* 2001], rests inside this member (Figures 3, 6, 7). The total thickness of the Barremian rocks is 70–75 m in the Uliyanovsk sections, and about 125 m in the Khvalynian ones.

XIV. A member of dark-gray bioturbated silty clay and siltstone with occasional layers of siderite concretions. Softground surfaces are usually present at the bases of the sand interlayers.

This member is as thick as 27 m under a 246-meter peak. Closer to Saratov City its thickness decreases to 18–20 m with the rocks growing more sandy: in the Sokolov Mount it consists mainly of brown and dark-gray fine- and medium-grained sands and sandstones, cross-bedded and bioturbated, with siltstone and less common clay interbeds. Their sandstone, limestone, and limonite concretions were found to contain Deshayesites tenuicostatus (von Koenen, 1902), D. ex gr. tenuicostatus (von Koenen, 1902). D. bodei (von Koenen, 1902), and D. aff. bodei (von Koenen, 1902), D. sp. [*Baraboshkin and Mikhailova,* 2002], and also numerous small bivalves and gastropods.

In the Uliyanovsk area this member has a much lower thickness (7–8 m), its top being eroded. Here, it is represented by the rhythmic alternation of green-brown soft glauconite-quartz sandstone (0.2–0.5 m), dark gray claystone (0.2–3 m), gray banded bioturbation clay (1.5–2 m), and silty clay with siderite concretions, with soft ground surfaces at the bases of all sand layers. This member consists of three rhythms. The rocks include Deshayesites cf. tenuicostatus (von Koenen, 1902), bivalves: Cymbula nuda (Keys.) and Neocomiceramus volgensis (Glas.), and numerous serpulids Ditrupa notabile (Eichw.).

XV. A two-member unit.

XVa. A submember of dark-gray and black slightly silty clay with individual thin interbeds of siltstone, colored bright yellow because of its jarosite. The lower part of the visible sequence includes several levels of black argillaceous limestone concretions, as large as 0.3–0.4×0.1 m. The most characteristic level is 4 m below the top and contains scarce

Deshayesites volgensis Sason fossils. The roof shows indications of slight erosion. The thickness in the Khvalynian rocks is about 9.5–10 m, this member is missing in Uliyanovsk apparently because of erosion.

XVb. A submember of light- and dark-brown thin-laminated (1–5 mm) bituminous shale with pyrite nodules at the base. The bedding planes often show abundant ammonites, aptychi, and fish scales. Some individual surfaces are almost wholly lined with ammonite embryonic shells. At a level 3–5 m higher above the bottom there are two layers of carbonate concretions with Deshayesites volgensis Sason and Sinzovia trautscholdi (Sinz.) fossil remains. The layered diagenetic carbonate concretions, known as the "Aptian Plate", with a thickness of some 40–60 cm, is locally absent. The shale top is gradational.

The base of the Uliyanovsk rock sequences shows one or two erosion surfaces and contains wood fragments, shell detritus, and small phosphate concretions. The ammonites from these rocks have been identified as Deshayesites gracilis Casey, D. volgensis Sason., D. forbesi Casey, D. consobrinoides (Sinz.), D. saxbyi Casey, D. aff. vectensis Spath, D. sp., Paradeshayesites imitator (Glas.), Obsoleticeras levigatum (Bogdan.), and Sinzovia trautscholdi (Sinz.), Volgoceratoides schilovkensis I. Mich. et Bar., Koeneniceras tenuiplicatum (v. Koen.), K. rareplicatum I. Mich. et Bar., and also Cymbula sp. and Phacoides borealis Glas bivalves.

The thickness of this member in the Khvalynian rocks is 10.6 m and decreases to 3.8–4 m toward Uliyanovsk. It also decreases to 4–5 m in Saratov City (a quarry of a brickyard at the Guselka River), where the rocks grow more silty and are highly bioturbated.

The overlying part of the sequence is subdivided in more detail and is richer in fossils in the Uliyanovsk Volga region, but its correlation with the rocks of the Saratov Volga region is more conventional in many respects, yet is based on the correlation of biostratigraphic, paleomagnetic, and petromagnetic data.

XVI. Dark-gray clay with the disseminated shell detritus and ammonites: Deshayesites multicostatus Swinn., D. consobrinoides (Sinz.), D. sp., Paradeshayesites ssengillyensis (Sason.), P. callidiscus (Casey), P. topleyi (Spath), P. similis (Bogd.), P. imitator (Glas.), Ancyloceras matheronianum d'Orb., Lithancylus aff. grandis (J. de C. Sow.), L. glebi I. Mich. et Bar., L. grandis (J. de C. Sow.), L. igori I. Mich. et Bar., L. russiensis I. Mich. et Bar., L. tirolensiformis I. Mich. et Bar. The thickness of these rocks in the Uliyanovsk area is 3–3.2 m.

In the direction toward Khvalynsk City the thickness of this member increases to 26–27 m, and the composition of its rocks becomes more diverse. The dark-gray and silty clay (7.7–8 m) lying at its base are followed upward by alternating fine- and medium-grained sand and clay (6–6.3 m) with clay and silty clay (12.5–13 m) lying at the top. Southward, toward Saratov, the thickness of this member diminishes to 23–24 m, and the rocks become more homogeneous (clay and silt). Southward, in the direction to Saratov, the thickness of this member diminishes to 23–24 m, and its composition becomes more homogeneous (clay and silt).

XVII. Dark-gray, bioturbated silty clay with rare lenticular glauconite-quartz sandy interlayers containing numerous valves: Arctica anglica (Woods), Cymbula gardneri (J. Nikit.), Modiolus sp., Thetironia sp., Panopea neocomiensis (Leym.), Corbula sp., Neocomiceramus volgensis (Glas.), N. borealis (Glas.). This member includes two horizons of carbonate concretions and minute disseminated phosphorite particles. The clay and concretions contain Deshayesites aff. rarecostatus Bogd., Kvant., and Schar., D. sp., Paradeshayesites ssengillyensis (Sason.), Cheloniceras ex gr. cornuelianum (d'Orb.), and Nautiloidea: Cymatoceras aff. bifurcatum (Oost.), C. karakaschi Shim., and C. cf. karakaschi Shim. Heteromorphic ammonites have been found at two levels. The lower level contains Proaustraliceras tuberculatum (Sinz.), P. rossicum (Glas.), P. laticeps (Sinz.), P. sp., Pseudoaustralicaras pavlowi (Vass.), and Toxoceratoides sp. The rocks at the upper level contain Audouliceras renauxianum (d'Orb.), Toxoceratoides royerianus (d'Orb.), T. ex gr. royerianus (d'Orb.), and T. sp. The thickness of these rocks in the Uliyanovsk sections is 4 m.

Southward this member grows thicker: 9 m at the Ershovka Site and 13.5 m at Saratov and Doktorovka sites, its composition changes to a sandy one. The sand shows bioturbation, being crossbedded and well-sorted up to pure quartz sand with thin clay layers in the top, and contains large concretions with Deshayesites spp. and Paradeshayesites spp.

XVIII. The rhythmic alternation of gray clayey silts (0.2 m) and glauconite and dark-gray clay (0.2–0.3 m) with shell detritus and fragments of Cymbula nuda (Keys.) and Neocomiceramus borealis (Glas.). The base of the member includes large flat siderite nodules with large ammonites Tropaeum (Tropaeum) bowerbanki (J. de C. Sow.), as large as 80 cm across, and accumulations of Neocomiceramus cf. borealis (Glas.). Softground surfaces are developed at the top of the member. They are as thick as 1.6–1.8 m in the areas near Uliyanovsk.

A similar sequence of rocks with a comparable fauna assemblage is observed in this member in the Saratov area, where its thickness is supposed to be 14–15 m. Its mere difference is the appearance of crossbedded sand lenses and interlayers.

Above follow Middle Aptian deposits.

XIX. Dark-gray bioturbated clay with shell detritus and a few horizons of carbonate and marcasite nodules. A siltstone interlayer is present at the base, and an erosion surface, at the top. The following ammonites have been found: Tonohamites sp., Aconeceras nisum (d'Orb.), Nuculana lineata (Sow.), N. sp., Cymbula gardneri (J. Nikit.), Modiolus cf. subsimplex (d'Orb.), M. reversus (J. Sow.), Neocomiceramus cf. borealis (Glas.), Arctica sedgwicki sedgwicki (Walker), Venilicardia (V.) protensa (Woods), V. (V.) sp., Panopea neocomiensis (Leym.), and Dentalium? sp. The thickness of this member is 7 m.

XX. Gray and light-gray silty clay, bioturbited and detrital, with layers of marcasite nodules. The base of this member contains Pinna fossils in their living positions and also Cymbula sp. The rocks are 5.5–5.6 m thick.

XXI. This member is similar to member XIX. It has

a softground surface at the base and top, accentuated at the base by glauconite accumulations. The rocks contain Arctica sedgwicki sedgwicki (Walker), Liostrea sp., Nuculana scapha, Nucula seeley, Lucina? sp., and Proveniella? sp. The thickness of this member is 5.5 m.

XXII. Interbedding of bioturbation gray siltstones, silty clays, and dark-gray clays. There are a few layers of siderite nodules and softground surfaces in the middle and top of the member. Occasional Arctica ex gr. sedgwicki (Walker) valves are found. The thickness of this unit is 4.8 m.

Members XIX–XXII are not present in the Khvalyn and Saratov rock sequences. Their depth interval is occupied there by the alternation of dark-gray bioturbation clay, silty clay interbedded by obliquely bedded sand layers, and brownish sandstones. The total thickness of this interval is not less than 18 m.

XXIII. A member of the rhythmic cross-bedded alternation of greenish gray glauconite-quartz sand (0.05–0.4 m), gray siltstone, grading to sandy clay (0.2–1.5 m), and dark clay interbeds (2.5 m). The rocks are bioturbated and contain sulfide concretions. Softground surfaces are present at the base of each rhythm, the lower part of the member being more sandy. The base of each member includes a large interval of reverse polarity, a potential analog of an ISEA chron suggesting its stratigraphic correspondence to some part of the Parahoplites melchioris zone [Baraboshkin et al., 1999]. This member has a thickness of 8–10 m in the Uliyanovsk area.

An analog of this member in the Saratov area is the Ust-Kurdyum sequence which also includes a large reversed polarity interval, an ISEA analog (Figure 8). This member has a three-member structure, absolutely different from the rock sequences of the Uliyanovsk area.

XXIIIa. Dark-gray micaceous silty clay? also showing high bioturbidity. Its top and base include horizons of ellipsoidal dark-gray calcareous siltstone concretions (0.2–0.3×0.1 m). The thickness of this unit is >5 m.

XXIIIb. Alternation of dark gray micaceous clay (0.14–0.4 m) and thin (0.01–0.04 m) interbeds of gray micaceous silt. This member includes a few horizons of ellipsoidal dark-gray micaceous calcareous siltstone concretions. An erosion surface is present in an interval 2.4 m higher above this member base, which is overlain by a horizon with very small (0.01–0.03 m), well rounded pebbles of black phosphorite, some of which are bored by stone borers. The thickness of this unit is 7.4 m.

XXIIIc. A member of dark-gray bioturbed micaceous silty clay with a few horizons of ellipsoidal and irregular-shaped nodules of dark gray calcareous siltstone. The upper roughly one-meter interval of the member is highly sandy. The thickness of this unit is 9.4 m.

The Aptian rock sequence is terminated by member XXIV which was studied in a pipeline trench near Uliyanovsk City and in the Russkaya Bestyashka open pit. This member is composed mainly of gray and brownish bioturbation clay with plant and wood remains. The clay is superseded by silty clay and siltstone containing brown siderite concretions both at the base and top of this member. Also present here are 1-cm sand layers showing a minor erosion. The thickness of this member is about 13–14 m; its top is eroded and overlain

by an Albian phosphorite conglomerate. No analogs of this member have been found in the vicinity of Saratov City.

The base of the Russkaya Bektyashka rock sequence, which is generally believed to be unfavorable in terms of paleomagnetic stability, was nevertheless found to include intervals of inverse or anomalous polarity (Figure 3), which may belong to a reverse polarity magnetic zone, an ISEA analog.

As far back as 1959 and 1973, A. E. Glazunova reported the presence of the late Aptian substage (Hypacanthoplites jacobi zone) near the Dolgii Buerak settlement. The reexamination of this ammonite revealed that it belonged to the Middle Aptian Parahoplites genus [Baraboshkin et al., 1999]. It follows that there are no proved late Aptian deposits in the Middle Volga region. The exact stratigraphic positions of the upper rocks of the XXIII member and of the whole of the XXIV member need be verified.

Paleomagnetism and Petromagnetism

Field and Laboratory Studies

Samples for our paleomagnetic studies were collected at 379 stratigraphic levels in 12 cross-sections. The sampling interval varied from 0.5 to 1 m. The rock lump collected from each level was sawed into 3–4 cubes with edges measuring 20 mm. At least two cubes from each lump were used in our paleomagnetic measurements. In addition, most of the geologic sections were used to measure magnetic susceptibility (k) in the field with an interval 3–5 times more frequent than the paleomagnetic sampling: at least 5 k measurements were made at each stratigraphic level.

Paleomagnetic measurements were made at the Laboratory of Paleomagnetism at the Geological Research Institute of the Saratov Geological Survey. The laboratory work included the measurements of k and natural remanent magnetization (EOH, J_n), magnetic cleaning using temperature, plotting the curves of normal magnetization, the subsequent measurements of remanent saturation magnetization (J_{rs}) and the determinations of the saturation fields (H_s) and remanent coercitive force (H_{cr}), as well as thermomagnetic and differential thermomagnetic analyses (TMA and DTMA).

Remanent magnetization was measured using a JR-4 spin magnetometer, magnetic susceptibility, using IMV-2 instruments (in the laboratory) and KT-5 instruments (in the field). TMA and DTMA measurements were made using magnetic balances in the Laboratory of Paleomagnetism at the Research Institute of the Saratov Geological Survey and in the "Borok" Geophysical Observatory of the United Institute of the Earth's Physics, Russian Academy of Sciences.

Temperature cleanings were made using a stove, designed by V. P. Aparin, with five-layer permalloy screens, capable of attenuating the outer magnetic field to a few nanoteslas. Heating was performed successively in the temperature range of 100 to 350°–500°C with a step of 50°C during 1–2 hours. In order to account for the potential magnetization

of the rocks from an uncompensated magnetic field, not less than 2 cubes with an opposite orientation along the two constituents of the J_n vector, taken from each rock lump, were placed into the stove.

Diagnostics of Ferromagnetic Minerals

Almost all samples that had been collected from the sections under study were subjected to magnetic saturation. The results of this artificial magnetization (Figure 9 (1)) showed that all samples included a rock phase with $H_s =$ 1500–2500 mT and $H_{cr} = 500–700$ mT. The H_s an H_{cr} values of this kind are typical of fine-dispersed or partially oxidized magnetite.

The TMA and DTMA results obtained for the samples collected from different lithological varieties of the rocks suggest the presence of magnetic minerals close to magnetite, which are indicated by an abrupt magnetization decline in the region of $530°–560°$C (Figure 9 (2)).

The rock sequence in the area of the Polivna Village (Uliyanovsk Region) was found to include, at the base of the Craspedodiscus discofalcatus zone, a rock interval, 5 m thick, enriched in magnetic iron sulfides of the pyrrhotite, greigite, and melnikovite types. The presence of these minerals is indicated reliably in the DTMA curves by the high growth and the subsequent decline of magnetization in the $300–350°$C range (temperature of the phase transition of magnetic sulfides to magnetite) (Figure 9 (2)), and is clearly indicated in the rock sequence by the abnormally high k values (up to 140×10^{-5} SI units) (Figure 2). A similar interval was found in Hole 120 (Pugachev area, Saratov region). In other areas magnetic sulfides were found at some single levels distributed sporadically over the rock sequences.

Some individual samples showed the presence of a magnetically rigid phase (H_s of 4700 mT and higher and H_{cr} of up to 1500 mT), associated with iron hydroxides and possibly with hematite.

To sum up, with very rare exceptions, the main magnetization carriers are magnetic minerals, close to magnetite.

Petromagnetic Characteristics

In this respect the Hauterivian rocks show the lowest magnetization ($k = 5–20\times10^{-5}$ SI units and $J_n = 0.5–1.5$ mA/m) (Figures 2 and 4). The only exception is a narrow rise (about 5 m thick) of the abnormally high magnetic susceptibility (up to 122×10^{-5} SI units) and EOH as high as 62 mA/m) caused by magnetic sulfide. This highly magnetic interval is located inside member III and is restricted to the base of the Craspedodiscus discofalcatus zone of the Upper Hauterivian rocks (Figure 2).

The Barremian deposits show two intervals of elevated magnetization against the background of similar k and J_n values ($k=5–25\times10^{-5}$ SI units, $J_n=0.5–2$ mA/m). The lower interval, traced in the Chernyi Zaton and Fedorovskii Site, corresponds to member X (base of the Lower Barremian Aulacoteuthis descendens zone), where k is as high as $40–60\times10^{-5}$ SI units with J_n ranging between 9 and 11 mA/m (Figure 6). The upper, thinner and less intensive, interval (with k measuring $25–35\times10^{-5}$ SI units and J_n as high as 3–8 mA/m) was recorded in the base of member XII (Oxyteuthis germanica and O. lahuseni zone of Late Barremian) (Figure 6).

The Aptian rocks generally show moderate natural magnetization ($k = 10–30\times10^{-5}$ SI units and $J_n = 0.5–2.5$ mA/m) and do not show any significant variations over the section (Figures 3, 6, 7, and 8).

Component Analysis and Paleomagnetic Stability of Rocks

In paleomagnetic terms the Lower Cretaceous rock sequence investigated in this study consists of two parts: members VII–XXIII (Barremian-Aptian), showing high paleomagnetic stability, whereas most of the samples collected from members II–VI (Hauterivian-Early Barremian) and from member XXIV (Upper Aptian) show low paleomagnetic stability.

Members VII–XXIII

The typical Zeiderveld diagrams shown in Figure 9 (3) for the samples differing both in lithology and polarity show the presence of two J_n components: a low- and a high-temperature one, which have the forms of rectilinear segments. The low-temperature component seems to be of viscous origin, because its direction is close to that of the vector of the modern geomagnetic field. As a rule, it is destroyed completely at temperatures of $150°–250°$C. The high-temperature component is preserved up to $350°–500°$C (Figure 9 (3)). All diagrams showed that after the destruction of the low-temperature component, the vector changes its direction upward the center of the coordinates, this suggesting the absence of any other J_n components (see 3 in Figure 9).

The stereoprojections of the high-temperature components produce two sets (Figure 10), the average directions of which are close to the antiparallel ones (see the Table 1). The directions that are grouped in the first quadrant of the lower hemisphere and in the third quadrant of the upper were interpreted in this study as corresponding to the normal (N) and reverse (R) polarities, respectively.

Our hypothesis of the monocomponent groups of the paleomagnetic directions, obtained after a series of cleanings, was tested in terms of its correspondence to the Fisher distribution using a method offered by *Bazhenov and Ryabushkin* [1978]. This procedure was used for each section separately. In all cases we got positive results, that is, the J_n data sets analyzed obeyed the Fisher distribution with the significance level $p = 0.05$.

The results of our testing, combined with the analysis of the Zyiderveld diagrams, show that there are no grounds to rank the resulting EOH distributions as multicomponent ones, and, hence, our statistical estimates (see the Table 1), calculated for them, are correct.

During the statistical analysis of our paleomagnetic data samples, we discarded the anomalous directions, that were observed, in some cases, at the boundaries of the magnetic zones (for example, in the Chernyi Zaton area, see Figure 6), which seem to have been produced by transition zones or by digressions.

Members II–VI, XXIV

The high-quality Ziyderweld diagrams were obtained only at some single levels. In most cases this is associated with the extremely low magnetization of the samples, because of which the EOH value was comparable with or lower than the threshold sensitivity of the JR-4 instrument as early as after the heating to $200°$–$300°$C. In some samples the effect of the viscous component could not be eliminated totally up to $450°$C. Along with the low natural magnetization (and, hence, very low contents of magnetite), paleomagnetic instability was caused by the secondary alterations of the rocks caused by the oxidation of the magnetite particles and by the formation of iron hydroxide. The latter is recorded in the curves of magnetic saturation by the insignificant growth of J_{rs} up to the 4700 mT fields, and seem to be the carriers of a rigid viscous component.

However, our comparison of the stereographic distributions of the EOH vectors before and after the temperature cleanings shows that after a series of heatings the trend toward the formation of paleomagnetic vectors in the northern and southern projection bearings was obvious (Figure 10). Therefore, in spite of the obvious "contamination" of their old components these data can be used for magnetostratigraphic purposes.

The results of the paleomagnetic measurements were discarded where magnetic cleaning failed to destroy even partially the viscous component or some laboratory biasing was discovered. For this reason, the determinations for 28 lump samples were discarded in members II to VI and XXIV for 59 lump samples, this accounting for 23% of the total sample collection.

The Nature of the Paleomagnetic Zones

In order to substantiate the primary origin of the EOH components used to single out the magnetic zones we used the following geological and geophysical criteria and tests providing information for the age of the magnetization.

1. Since the inversion of the magnetic field is a planetary phenomenon, the coincidences of the paleomagnetic boundaries with the contacts produced by local and regional factors are unlikely. On the contrary, the fact that the polarity is indifferent to lithological and mineralogical characteristics is an important indication of a relationship between the J_n sign and the regime of the ancient field. The indifference of the magnetic zones both to the lithological units and to the petromagnetic variations reflecting the properties of the magnetic fraction is obvious (Figures 2–8).

2. The substantiation of the orientation (postorientation) nature of magnetization is identical to the substantiation of the primary character of the latter. Our analysis of the paleo- and petromagnetic data revealed a number of regularities, characteristic of the detrital EOH type and, oppositely, not typical of the chemical J_n :

– the rocks show low Q factor values: hundredth and tenth fractions of one;

– the paleomagnetic interlayer concentrations are relatively low: 10 to 30 (see the Table 1 and Figure 10);

– a significant relationship is observed between the interlayer concentrations and the grain size of the rocks. The dissemination of the J_n directions in the silty and sandy rocks is 1.57 times greater than in pure clay (see Table 1 and Figure 10 (9). This relationship is significant at the level of $p = 0.05$. The significance of a ratio between the paleomagnetic clusters ($k_{\max}/k_{\min}$) was verified using an F criterion $\{2(n_1 - 1),\ 2(n_2 - 1), p\}$, where n_1 and n_2 denote the number of rock samples in the data samples [*Shipunov,* 1993].

3. A $180°$ difference between the mean directions of the paleomagnetic vectors corresponding to the direct and reversed polarity is an indicator in favor of the primary magnetization. D_{av} and I_{av} in the studied data samples are close to the opposite ones, yet, they lack some $10°$–$20°$ to be truly antiparallel, this being caused by a difference in declination (see Table 1 and Figure 10). It appears that this is caused by the incomplete destruction of the low-temperature EOH component, which is especially significant in the case of the R-vectors.

4. The proximity of a virtual geomagnetic pole to the locations of the other virtual geomagnetic poles (VGP) located earlier for this lithospheric block is considered to be another important criterion for the substantiation of its primary type [*Van der Voo,* 1993]. For the calculation of our poles we used the N-directions traced in the VII–XXII (Barremian-Aptian) rock sequences of the Khvalyn and Syzran areas. As has been shown above, the deposits of these members are stable in the paleomagnetic respect, and their cross-sections are close enough (Figure 1) to get a combined data sample. The poles determined in the R-directions using a reversal approach have been discarded because they had an obviously understated latitude. This was done because the incomplete obliteration of the low-temperature EOH component (valid for our collection, because the average N-and R-vectors are not strictly antiparallel) resulted in the significant distortion of the direction of the high-temperature R component, because it was almost opposite to the remagnetization direction. At the same time the not completely destroyed part of the low-temperature component poorly affects the vector of the high-temperature N-component, because their directions are fairly close.

The virtual geomagnetic pole (VGP) located using the Barrhemian deposits of the Chernyi Zaton area coincides almost exactly with the pole obtained by *Bazhenov and Shipunov* [1985] using the Lower Aptian rocks in the Sengiley area (Table 1 and Figure 11). The insignificant scatter of the paleomagnetic poles, located in some other areas (Table 1 and Figure 11), can be associated with intensive landslide activity widespread in the Uliyanovsk, Samara, and Saratov regions at the right banks of the Volga R., where the Hauterivian-Aptian rocks are exposed. Unfortunately, it

is impossible, in most cases, to fix changes in the bedding (which can be as large as ten degrees). It is possible that the 7°–15° differences of the Barremian-Aptian virtual geomagnetic poles in the Middle Volga region, including the data reported by *Bazhenov and Shipunov* [1985], from the average poles dated 110–129 Ma for the North Eurasian Platform [*Molostovskii and Khramov,* 1997] (see the Table 1 and Figure 11), can be attributed to the intensive landslide processes.

For the reasons mentioned above the calculated virtual magnetic poles can hardly deserve to be added to the data base for paleomagnetic poles, yet, they can be useful in terms of magnetic stratigraphy. The similarity of the virtual geomagnetic poles derived from the Barhemian-Aptian rocks to the standard North Eurasian poles of this age (some differences can easily be explained by sliding activity in the Volga region) and the coincidence of the pole determinations for the Barrhemian-Aptian in the Chernyi Zaton and Sengiley areas [*Bazhenov and Shipunov,* 1985] agree with the view of the primary magnetization.

5. An important argument in favor of the old nature of the magnetization is the "the criterion of external similitude", that is, the identity of the paleomagnetic structure of the deposits of the same age in remote areas. The more the compared rock sequences differ in lithofacies and in lithostructures to which they belong, the more valuable is the outer similarity, as the proof of the J_n primary origin. The beds of the same age in the Hauterivian-Aptian rock sequences of the Middle Volga region show an almost identical magnetic zoning pattern (see Figures 12 and 13). On the whole the paleomagnetic pattern of the composite Hauterivian-Aptian rock sequence is in perfect agreement with the data available for the behavior of the Early Cretaceous geomagnetic field (Figure 14). However, the detailed magnetostratigraphic correlation between the Barremian-Aptian rocks of the Russian Platform and those from other regions (at the level of substages and zones) calls for a special discussion which is presented in the section that follows.

Each of the above tests, taken separately, does not provide a proof for the primary character of J_n, merely confirming this proposition indirectly. However, the whole package of independent observations, which agree with the ancient character of the magnetization, is a ponderable argument in favor of the fact that the sequence of the magnetic zones imprinted in the Saratov rock sequences is a good reflection of the Hauterivian-Aptian geomagnetic field.

Paleomagnetic Characteristics

The composite magnetostratigraphic section of the Hauterivian-Aptian rocks in the Volga region consists of eight magnetic zones: four of normal polarity (N) and four of reversed polarity (R) (Figure 12).

The first zone of normal polarity N_1h (about 5 m) corresponds to the lower rocks of the Speetoniceras versicolor zone (versicolor subzone and possibly the base of the coronatiformis subzone) of the upper Hauterivian rocks (lower part of member II). Its fragments have been recorded in the section of the Zakharievskii Mine section (Site 2350)

(Figure 2). It appears that this magnetic zone (versicolor subzone) includes the *r*-interval recorded in the same section (Figure 2).

The next reverse polarity R(h) zone (about 15 m) embraces the top of the S. versicolor zone (coronatiformis, inversum, Pavlowae subzone) and possibly the lower rocks of the Milanowskia speetonensis zone of the upper Hauterivian (the larger part of member II and the lower part of member III). This magnetic zone was also recorded in fragments in the area of the Zakharievskii Mine (Sites 2350 and 2352) (Figure 2).

The $N_1(h)$ and R(h) zones cannot be mapped reliably using these data alone, because member II is least favorable in paleomagnetic respect. However, the similar two-zone magnetic polarity structure of the S. versicolor zone has been proved reliably in Well 204 (Saratov Zavolzhie), where the exact stratigraphic position of this interval was determined exactly using the finds of Speetoniceras cf. coronatiforme (M. Pavlowa) (Figure 13).

The overlying zone of direct polarity $N_2(h)$ ($\sim$15 m) corresponds to the Milanovskia speetonensis zone and to the lower beds of the Craspedodiscus discofalcatus zone (pseudobatboti and umbonatus subzones of late Hauterivian age (member III). This magnetic zone has been proved in the rock sequences of the Zakharievskii Mine area (Site 2352) and Polivna Village (Site 2356) (Figure 2). Its fragment is believed to be present in the lower part of the rock sequence in the Novokashpirskii Village (Site 2369) (Figure 4). An analog of the $N_2(h)$ zone has been recorded in Hole 120 (Saratov Zavolzhie) (Figure 13). In spite of the fact that the paleontological data available cannot date the 6–36 meter depth interval more exactly than Hauterivian-Barremian, it was placed reliably at the base of the C. discofalcatus zone on the basis of the correlation based on the petromagnetic indication, namely, on the surge of the abnormally high k values caused by the presence of magnetic sulfides. This petromagnetically unique interval [*Guzhikov,* 2000] is identical to those found in Hole 120 (Figure 13) and in the cross-section of the Polivna Village (Site 2356), where it was proved by paleontological data. An analog of this petromagnetic benchmark has also been found in the Upper Hauterivian rocks of the Penza region [*Grishanov et al.,* 2003].

The rock sequence described above is followed by a zone of inverse polarity R(h-br) which embraces the upper rocks of the Late Hauterivian Craspedodiscus discofalcatus zone (discofalcatus subzone) and a significant part of the Lower Barremian Praeoxyteuthis hibolitiformis zone (members IV–VI, except for the top of the latter). Its thickness is almost equivalent to the total thickness of the IV–VI members (about 60 m). This magnetic zone is substantiated by the data from the Zakharievskii Mine – Polivna Village sections (Figure 2) and from the Novokashpirskii Stl. (Figure 4), where negative polarity has been found, though with significant lapses, in members IV–VI. The top of the R(h-br) zone has been found in the section of the Dubki Stl. (Saratov Region) (Figure 8). An R(h-br) analog is a thick (>20 m) magnetic zone of an inverse sign recorded in Well 120 (Figure 13).

Above follows a thick zone of direct polarity N(br). It

embraces almost the whole of the Barremian rock sequence (top of member VI, members VII–XII, and base of member XIII), except for the base of the Lower Barremian P. hibolitiformis zone. The total thickness of this magnetic zone is 75 m. The dominant normal polarity of members VII–XII was proved reliably in the Polivna Village sections (Site 2355) (Figure 2), in the Kremenki Village (Figure 3), in the Forfos Mt. (Figure 5), and at the sites of Fedorovskii Stvor and Chernyi Zaton (Figure 6). In the Forfos section the top of member VI (12 m) showed a direct polarity (Figure 5). N-polarity was found at the base of member XIII in the Chernyi Zaton rock sequence (Figure 6). Thus, the lower N(br) boundary is located in the top of member VI, and the upper, at the base of member XIII. The lower Barremian deposits (Praeoxyteuthis jasikofiana and P. pugio) from Well 204 (Saratov Levoberezhie) also have direct polarity (Figure 13). Their dating was based of the finds of Aconeceras sp., typical of the P. jasicofiana zone to the base of the P. pugio zone in the Middle Volga area.

The N(br) zone includes at least 6 narrow r-intervals which are marked either by reverse polarity or by anomalous directions. Of particular stratigraphic interest is one of these intervals recorded in the top of member VI, which has been traced from Uliyanovsk to Saratov in three sections: in Polivna Village (Site 2355) (Figure 2), in Forfos Mt. (Figure 5), and in Dubki Stl. (Figure 8). Another r-interval, about 2 m thick, occurs in the silt-sand sequence of the latter, about 0.8 m below this anomalous interval. It cannot be excluded that both of then can be constituents of the same thin zone of reverse polarity, corresponding to the top of the P. hibolitiformis zone. The intervals of negative sign located in the rock sequences of the Kremenki Village (Oxyteuthis brunsvicensis zone, submember XIb?) (Figure 2) and of the Fedorovskii Site (O. germanica? zone at the base of Member XII) (Figure 6) may be analogs of one another. The remaining three r-intervals, restricted to the P. pugio zone (the base and middle of unit VIII and the top of unit XI, respectively) were located at some single stratigraphic levels (the two lower ones in the Forfos Mt. and the upper one near the Fedorovskii Site) and have not been confirmed in any other sections.

The next zone of negative polarity $R_1(a)$ in the composite paleomagnetic column is restricted to the top of the Oxyteuthis lahuseni zone, inside of which a Barremian-Aptian boundary was traced along the base of the M0 chron [Baraboshkin et al., 1999; Guzhikov et al., 2001] and along the base of the Deshayesites tenuicostatus zone (lower part of member XIII). This magnetic zone was traced in five of the studied sections: Sengiley, Kremenki (Figure 2), Fedorovskii Site, Chernyi Zaton Village (Figure 6), and elevation 246 m (Figure 7). The data obtained from the two former sites confirmed the earlier data on the existence of a negative polarity magnetic zone there [Baraboshkin et al., 1999; Eremin and Guzhikov, 1991]. Moreover, some analogs of this magnetic zone were located in the Aptian rock sequences in the Sokolova Mount (Saratov City) [Grishanov, 1984]. The thickness of the $R_1(a)$ zone was found to be about 8 m in the Kremenki Village, Sengiley Town, and Sokolov Mt. As to the other sites only the visible thickness of this zone, not more than 8 m, has been proved.

Above follows a large magnetic zone of normal polarity N(a), corresponding to the Lower Aptian substage, except for the base of the D. tenuicostatus zone, and to the basal rocks of the Middle Aptian substage, namely, to the base of the Middle Aptian rocks, namely, to the Epicheloniceras tschernyschewi and Aconeceras nisum zones + the base of the Parahoplites melchioris? zone in the Saratov and Uliyanovsk Volga region, respectively, (the upper beds of member XIII and the XIV to XXII members). The obviously predominant normal polarity in these units was discovered during the study of rocks in the Sengiley Hill area (Figure 2), at the Ershovskii Site, and in the area of Height 246 m (Figure 7). The data obtained at the former site confirmed the data reported earlier by Eremin and Guzhikov [1991]. These data agree perfectly well with the data available for the Kremenki–Uliyanovsk section [Baraboshkin et al., 1999] and for the Sokolov Mt. [Grishanov, 1984]. The total thickness of the N(a) zone attains its maximum value (130 m) in the Khvalyn area, and declines to 50 m in the Uliyanovsk area.

Four narrow r-intervals were recorded in the upper part of the N(a) zone: three of them, in the lower Aptian interval of the rocks in the Ershov section (Figure 7), two contacting intervals, inside the Deshayesites deshayesi zone (top of member XVI and bottom of member XVII), and one interval in the Tropaeum bowerbanki zone (middle of member XVIII). Another r-interval was discovered in the Middle Aptian rocks (base of the P. melchioris? zone in the base of member XXII in the Uliyanovsk rock sequence [Baraboshkin et al., 1999].

The magnetostratigraphic section of the Hauterivian-Aptian rocks in the Middle Volga region is terminated by a negative polarity zone $R_2(a)$ distinguishing the top of the Middle Aptian rocks (members XXIII–XXIV). The reverse magnetization of the XXIII deposits was confirmed in the Ust-Kurdyum (Figure 8) and Uliyanovsk rocks [Barabashkin et al., 1999]. The fragmentary data available for the Russkaya Bektyashka rocks suggest that negative polarity is also characteristic of member XXIV. The maximum visible thickness of the $R_2(a)$ zone is as large as 15 m in the Ust-Kurdyum rock sequence.

The magnetic zones vary in stratigraphic volume and should be ranked, in terms of the Stratigraphic Code [1992], as the N(br) and N(a) orthozones, and the N_1h, R(h), N_2(h), R(h-br), $R_1(a)$, and $R_2(a)$[1] zones, as subzones. The intervals of reversed polarity, located in the N-magnetic zones, should be classified as microzones. This criterion is satisfied so far by only one interval in the upper part of the Early Barremian P. hibolitiformis zone (top of member VI). For this reason it was included into the composite magnetostratigraphic column.

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[1]The stratigraphic volume of an orthozone is comparable with that of a stage or a substage, and that of a subzone, with the zone of the General Stratigraphic Scale [Stratigraphic Code, 1992].

Discussion of Results

Identification of Magnetic Zones with the Chrons of the Magnetochronological Scale

The paleomagnetic structure of the Barremian-Aptian interval is rather simple in all known versions of magnetic polarity scales [*Ogg,* 1999; *Supplement...,* 2000] and, hence, the magnetic zones of the composite Barremian-Aptian rock sequence of the Russian Platform can be identified easily with the known chrons (Figure 14).

The $R_1(a)$ subzone can be correlated easily with the known M0 chron, the $R_2(a)$ subzone being an analog of the ISEA chron (Figures 14 and 15). The identification of the subzones, found in the Aptian Rocks of the Middle Volga region, with the known chrons is based on the absence of any other large anomalies near the Barremian-Aptian contact and in the upper Aptian rocks (Figure 14). For this reason these chrons can be easily recognized even in the paleontologically barren rocks. The visible thickness of $R_2(a)$, an analog of ISEA is greater than the thickness of $R_1(a)$, an M0 analog, whereas the latter lasted longer [*Ogg,* 1999; *Supplement...,* 2000]. This seems to have been associated with the different sedimentation rate: the $R_2(a)$ subzone is restricted mainly to the silty rocks whose sedimentation rate had been higher than that of the clayey deposits corresponding to the $R_1(a)$ subzone.

The N(br) (Barremian) orthozone can be correlated only with the M1 chron or with the superposition of the M1 + M2 chrons. It is not unlikely that in the latter case the R-microzone in the basal N(br) rocks (the top of the P. hibolitiformis zone of the early Barremian age, member VI) corresponds to a negative polarity segment at the base of the M1 chron (Figures 14 and 16).

The R(h-br) orthozone can be an analog only of the large chron of negative polarity M3, which resides in the lower part of the Barremian stage (Figures 14 and 16).

The identification of the Hauterivian subzones with the magnetic chrons is more ambiguous because of the complex paleomagnetic zoning of the Hauterivian rocks (Figure 14). Yet, using the entire stratigraphic thickness of the late Hauterivian rocks in the Volga region and the absence of any indications of long breaks in the sedimentation (except for the basal interval), it can be assumed that none of the known chrons, preceding M3, must have been wholly reduced in the composite paleomagnetic stratigraphy of the rock sequence. In these terms the $N_2(h)$ subzone corresponds to the M4 chron, the R(h) subzone, to the M5 chron, and the $N_1(h)$ subzone, to the M6 chron or to the M6 + M7 chron sum. In the latter case it is possible that the *r*-interval inside the $N_1(h)$ subzone corresponds with the inverse polarity in the top of the M7 chron (Figures 14 and 16). The paleontological control in the form of the schematic comparison of the zonal standards for the Hauterivian rocks of the Tethian and Boreal belts [*Barabashkin,* 2001], which was facilitated by the reliable correlation of the magnetic-pole data with the zonal divisions of the Late Hauterivian rocks of the Volga area (this paper) and of the Mediterranean region [*Channell et al.,* 1995] (Figure 16), confirms the correctness of this version of paleomagnetic correlation.

Interregional Correlation

Proceeding from the paleomagnetic correlation of the Early-Middle Aptian sediments of the Russian Platform, England, the North Caucasus, and the Mediterranean region (Figure 15), we can estimate the asynchronism of the bottom of the Lower Aptian Deshayesites volgensis zone in the distant rock sequences. In the magnetic stratigraphic map of the Lower Cretaceous rocks of the North Caucasus region the boundary between the Deshayesites weissiformis and Deshayesites volgensis zones is restricted to the $R_1(a)$ subzone (M0 analog), whereas in the Middle Volga region the base of the Deshayesites volgensis zone and of its West European analog, namely, the Deshayesites forbesi zone, is located much higher above M0, namely, in the region of direct polarity. The time difference is about 10^5–10^6 years (Figure 15), which is comparable with the duration of the ammonite zone. A similar situation can be found in the rocks of Southern England, though in the case of the latter the problem remains concerning the dating of the underlying Wealden Group rocks [*Kerth and Hailwood,* 1988].

A similar pattern of the gliding of the zonal boundaries seems to be observed in the Middle Aptian rocks (Figure 15). If the correlation of the ISEA chron with the Epicheloniceras subnodosocostatum zone [*Erba et al.,* 1996] is correct, then the conclusion of the earlier origin of the Parahoplites melchioris representatives in the area of the North Caucasus, compared to the Mediterranean region. In this case the asynchronism of the Parahoplites melchioris base in different regions can be as great as 10^5–10^6 years.

The comparison of the correlation lines reflecting the asynchronism of the zonal boundaries with the well known curve of the world ocean level oscillations [*Haq et al.,* 1988] (Figure 15) shows their significant similitude. This allows one to infer that the ammonites that originated in the North Caucasus paleobasin had propagated much farther during the eustatic sea-level changes. This control of ammonite migrations as a function of changes in the paleogeographic conditions was proved earlier [*Barabashkin,* 2001, 2002; *Barabashkin et al.,* 2003].

It is remarkable that the biostratigraphic boundaries grow younger in the latitudinal direction from the south to the north.

As to the Barremian deposits, the determinations of the magnetic poles have been strictly correlated with the belemnite sequence [*Baraboshkin,* 2001; *Baraboshkin et al.,* 2001]. The M1–M3 chrons were correlated with the Mediterranean zonal Barremian scale based on ammonites [*Channell et al.,* 1995]. The boundary between the lower and upper substages, drawn along the boundary between the Aulacoteuthis descendens and Oxyteuthis brunsvecensis zones, falls into the direct polarity, similar to the rock sequences of Northern Europe [*Mutterlose,* 1983, 1998], that is, is located within the M1 chron of the magnetochronological scale. In the Mediterranean region the substage boundary is characterized by negative polarity and resides in the top of the M3 chron. It follows that the boundaries between the Lower and

Upper Barremian rocks in the Tethian region and in the Russian Platform, based on different fauna groups, differ in time for more than a million years (Figure 16).

The boundary between the Hauterivian and Barremian rocks in the Mediterranean region is restricted in the paleomagnetic scale to the top of the M4 normal polarity chron, whereas in the Middle Volga region it has been established at the base of the R(h-br) negative polarity orthozone, an analog of the M3 chron (Figure 16). Therefore the placing of the Hauterivian-Barremian stage boundary into the Tethis and Boreal belt results in some asynchronism, although its magnitude is not more than 10^5 years.

The correlation of the Hauterivian zones of the Volga region with the magnetic chrons, correlated with the zone standard for the West Mediterranean region (Figure 16), does not contradict the correlation of the Tethyan and Boreal Upper Hauterivian standards [*Baraboshkin,* 2001]. The bases of the Balearites balearis, Pseudothurmannia angulicostata zones in the Mediterranean region and of the Milanovskia speetonensis, Craspedodiscus discofalcatus zones in the Russian Platform can be almost synchronous. In this case the Tethian Plesiospitidiscus ligatus zone and the top of the Subsaynella sayni zone must correspond to the boreal Speetoniceras versicolor zone, the analogs of the lower part of the Subsaynella sayni zone being obviously absent in the rock sequences of the Russian Platform.

Diachronism of the boundaries and the generation of the general stratigraphic scale

The data derived in this study for the diachronous boundaries of the biostratigraphic zones, as well as, of the substage and stage boundaries delineated in various paleobiogeographic belts, regions, and provinces, provide grounds for discussing the point of which unit must be the basic unit of the General Stratigraphic Scale (GSS).

We believe that the lithostratigraphic units of the General Stratigraphic Scale (GSS) should be chosen proceeding from the following principles:

1. The GSS structuring should, undoubtedly be based on the principle of the natural periodization of the geologic history.

2. The GSS units must have a planetary distribution and must be identified confidently in various regions.

3. The boundaries between the GSS units, supported by paleontological data, should be correlated with the important events of the planetary rank (geomagnetic inversions, tectonic cycles, anoxic events, etc.), bearing in mind that biotic events are sensible indicators of various geological events.

4. In prospect, each GSS unit must have an exact geochronological date.

5. The boundaries between all GSS units must be synchronous enough, that is, time differences, caused by the asynchronism of the boundaries in remote regions during their tracing and correlation, should be much smaller than the duration of the GSS unit itself.

The first four postulates are well known, although items 3 and 4 are still far from being easily used in terms of the GSS available, whereas the last point seems to be important and worthy of a more detailed discussion.

As applied to the stratotypes of any paleontological substantiation, the term "global" does not mean their planetary extents because of the existence of climatic zoning, and also in sea and land areas. For this reason, any paleontological scale is, to some or other extent, provincial. Moreover, even in the case of one and the same paleobiochoria situation the boundaries of the same biostratigraphic units are more or less asynchronous. The legitimacy of the latter is demonstrated here not only for the case of the Aptian ammonite zones, but also in a number of other publications [*Channell and Erba,* 1992; *Leahy and Lerbekmo,* 1995]. In terms of these results, zones cannot be used as the main units of the General Stratigraphic Scale (GSS), because differences in the absolute time between the bases of identical zones in different regions are comparable with the stratigraphic volumes of the zones themselves.

In spite of the fact that the stage boundaries may also be the boundaries between the zones, the use of stages and higher-rank stratigraphic boundaries as GSS stratotypes is justified, because the time interval, corresponding to the asynchronism of the zonal boundaries is about an order of magnitude lower than the duration of an epoch and is negligibly small compared to the duration of epochs and periods. Where substage boundaries are traced in different regions, the time shift can be only a few times (less than an order of magnitude) different from the duration of the stratigraphic unit itself, which, in our opinion, is unacceptable for GSS units. For this reason substages (except for the cases where they correspond to the "longest" stages) cannot be used as the GSS units, unless their boundaries are established by the methods providing this isochronism. As regards the Cretaceous stratigraphy, with the common views as to the number of the stages, the number of substages is often revised by the working groups, as, for example, in the cases of the Barremian, Aptian, and Cenomanian stages [*Biske and Prozorovskii,* 2001; *Cretaceous zones...,* 1989; *Proceedings...,* 1996]. In our opinion, this situation confirms indirectly the conclusion that a stage should be chosen as a basic CSS unit and invalidates the recommendations to use zones for this purpose.

A question remains concerning the statutes of zones and substages that correspond to the epochs of the maximum transgressions and less contrasting climate (e.g., the Late Cretaceous). It is likely that during such periods of time marine fauna had been spread more rapidly and, in this case, the synchronism of the paleontological boundaries might be sufficient for ranking some substages and zones as GSS units.

However, this does not mean that zones (in the sense of chronostratigraphic zones rather than lithostratigraphic ones) should be canceled as the main potential GSS units. In the case of the development of methods capable of substantiating the isochronism of their boundaries in the areas remote from one another, and located in different paleoclimatic zones, they will be able to be used as the main smallest GSS units.

The comparison of the Tethyan (Mediterranean) and boreal (Russian Plate) Barremian/Hauterivian, Lower/Upper Barremian, and Barremian/Aptian boundaries (Figures 15

and 16) shows that the time difference between the substage and stage boundaries may be as great as about a million years, which is not good for the GSS units. It is likely that in spite of any great efforts the correct correlation of the boreal and Tethyan Barremian only on a paleontological basis will remain an insoluble problem, taking into account the paleogeographic isolation of these basins [*Baraboshkin,* 2001, 2002].

A reasonable solution of this problem can be achieved through the tracing of the Hauterivian and Barremian boundary in the General Stratigraphic Scale (GSS) along the top of the M3 chron, and of the Barremian substage boundary along the base of the M0 chron. This version seems to be preferable because the generally recognized stratotypes of the Hauterivian, Barremian, and Aptian rocks are located in the Tethys region.

The paleomagnetic criterion cannot be used as the only possible one for substantiating the GSS stages or for estimating the degree of the asynchronism of the biostratigraphic boundaries in different regions. Theoretically, this criterion can be replaced by any isochronous events of a planetary scale, such as an ash layer, an anoxic level, or an isotopic peak, where they are recorded. However, these phenomena are extremely rare compared to geomagnetic inversions whose number is comparable with the number of paleontological zones. The modern version of the global curve of the World Ocean level oscillations, seemingly comparable with the above condition, also has a rigid paleontological control and, hence, is not protected from the diachronous behavior of biostratigraphic boundaries during their tracing. Moreover, regional and local geologic events introduce a high "noise" into the identification of the boundaries between rock sequences (especially in epicontinental basins), so that this curve cannot be so far easily used as a universal "ruler". Moreover, the Haq-Vail curve cannot be used for continental rocks.

Absolute age determinations based on radioactive isotopes are still far from being used in the practice of detailed regional correlations done for the purpose of estimating the synchronism of stratigraphic boundaries. They cannot always be easily obtained. Moreover, it is well known that different authors use different dates for the same boundaries, differences between which being comparable with the duration of the stages themselves.

Hence, there is still no alternative to paleomagnetic methods for proving the isochronism of events or stratigraphic boundaries. For this reason we have to admit the importance of paleomagnetic criteria for substantiating and tracing GSS units and using them, along with paleontological data, for deriving a General Stratigraphic Scale (GSS).

An example of the attempts of this kind was the recommendation of an International Working Group for the Aptian stage [*Erba et al.,* 1996] to use the base of the M0 chron as the main criterion for substantiating a Barremian-Aptian boundary. However, this proposition was not supported by biostratigraphers, because of the uncertainty not only in the choice of a paleontological group whose evolution change corresponds to the M0 level, but also in the choice of a rock sequence where the orthostratigraphic fauna/flora groups, and the M0 level itself, are represented equally well.

It is well known that there is still no technology for the integrated use of paleomagnetic and paleontological methods for the development and improvement of the General Stratigraphic Scale (GSS). Yet, the new data proving the substantial asynchronism of paleontological boundaries justify the urgency of research in this line.

Conclusions

This study resulted in the collection of complex data on the biological and magnetic stratigraphy of the Hauterivian-Aptian rocks of the Middle Volga region. These data provide a documental support for the diachronism of the boundaries between the biostratigraphic units, as well as of those between the substages and stages, during their tracing in various paleoclimatic belts. These results provide a basis for the critical approach to the use of biostratigraphic methods in deriving General Stratigraphic Scales (GSS):

– a stage should be used as a basic GSS unit, because it records the natural periodization of the Earth's geological history, the diachronism of its boundaries in remote correlations being negligibly small as compared with its duration. A stage must be a unit of complex substantiation;

– where the independent, other than paleontological methods (primarily a paleomagnetic one), prove the global isochronism of the boundaries, lower than the stage (substages and zones), they can and must be used as the boundaries between the units of the General Stratigraphic Scale (GSS);

– where a stage (or substage) boundary is defined relative to a geomagnetic inversion (or any other event), preference should be given to the inversion which, first, is easily identifiable and, second, is most close to the paleontological boundary in the stratotype;

– concerning the Hauterivian-Aptian interval of the GSS, we recommend to use the base of the M3 chron for identifying the Hauterivian-Barremian boundary, the top of the M3 chron for the Barremian substage boundary, and the base of the M0 chron for the base of the Barremian-Aptian boundary (in accordance with the recommendations of the International Working Group for the Aptian Stage [*Erba et al.,* 1996].

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Table 1. Paleomagnetic data for the Barremian–Aptian rocks (members VII to XXII) of the Khvalyn and Syzran areas and information for the coordinates of the Early Cretaceous virtual magnetic poles (VGP) based on literature sources

Location of sections	Polarity	Average vector D_{av}, °	I_{av}, °	K-grouping	a_{95} — confidence circle radius, °	Number of samples	No. of stereogram in Figure 10	Distance between the average N and R vectors, °	geographic coordinates lat., °	long., °	VGP coordinates lat. FI, °	long. L, °	confidence circle semiaxes teta-1, °	teta-2, °	geomagnetic latitude, °
Forfos Mt.	N	13.8	51.8	40.1	4.0	31	2		52.97	48.49	67.2	197.2	3.7	5.5	32.4
Chernyi Zaton	N	25.3	53.0	19.3	7.0	21	3	165.7	52.74	48.33	63.7	175.0	6.7	9.7	33.6
	R	225.6	−47.0	9.6	16.0	8									
Fedorov Site	N	26.9	49.6	23.5	5.9	24	4	159.7	52.63	48.20	60.4	176.1	5.2	7.8	30.4
	R	236.2	−44.9	10.35	21.7	4									
Height 246 m	N	18.8	49.7	29.2	5.6	21	5	170.0	52.60	48.16	64.0	188.9	5.0	7.5	30.5
	R	208.0	−42.0	3.3	38.7	4									
Ershov Site	N	25.5	43.8	30.1	6.8	14	6	161.1	52.57	48.13	56.9	182.8	5.3	8.5	25.6
	R	230.0	−39.0	12.3	20.0	4									
All sections	N	21.0	50.3	26.2	2.6	111	10	162.4			63.5	184.8	3.0	4.4	32.2
	R	225.7	−44.4	8.2	10.9	20			52.7	48.3					
clay	N	20.4	50.1	29.9	2.8	82	11A				63.6	186.0	2.3	3.5	30.9
silt, sand	N	22.2	50.8	19.0	6.0	29	11B				63.4	182.3	5.5	8.1	31.5
Average poles for North European Plate (former USSR area)									110 MA		67	159			
									121 MA		70	167			
									129 MA		71	170			
[*Molostovskii and Khramov*, 1997]															
Pole for the Lower Aptian in Mount Sengiley, Uliyanovsk area, after [*Bazhenov and Shipunov*, 1985]											64	174			

Figure 1. Schematic map for the locations of the sections: (I) cities, (II) natural outcrops, (III) boreholes. Cross-sections: (1) Zakhariev Mine, (2) Polivna Settl., (3) Uliyanovsk City [*Baraboshkin et al.,* 1999], (4) Kremenki Vil. [*Baraboshkin et al.,* 1999], (5) Kremenki Vil., (6) Sengiley Town, (7) Russkaya Bektyashka Vil. (all of the Uliyanovsk region), (8) Novokashpirskii Stl., (9) Forfos Mt. (both (8) and (9) are in the Syzran district of the Samara region), (10) Chernyi Zaton Vil., (11) Fedorov Site, (12) Elev. 246 m, (13) Ershov Site (all in the Khvalyn district of the Saratov region), (14) Ust-Kurdyum Vil., (15) Dubki Stl. (both in the Saratov region), (16) Sokolov Mt., Saratov City [*Grishanov,* 1984], (17) Hole 120 (Pugachev area), (18) Hole 204 (Oza area) (both in the Saratov region).
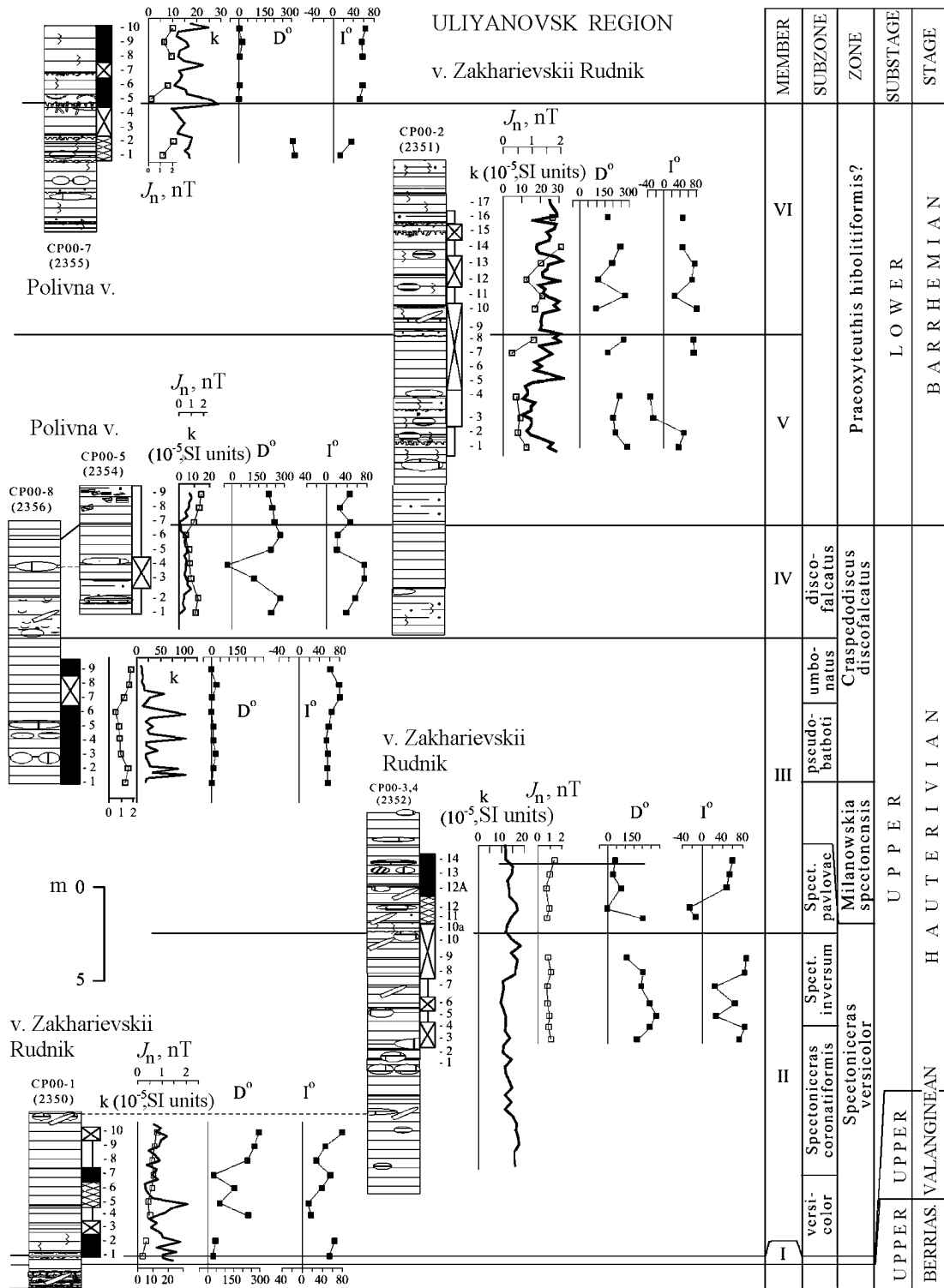
Figure 2. Magnetostratigraphic sections for the Upper Hauterivian and Lower Barremian rocks of the Zakhariev Mine and Polivna areas (Uliyanovsk district).
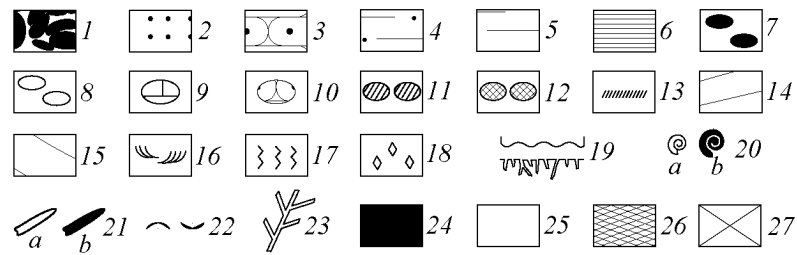
Legend for Figures 2–16: (1) phosphorite conglomerate and condensation area, (2) sand and loose sandstone, (3) sandstone, (4) silt and siltstone, (5) argillite, (6) clay, (7) phosphorite pebbles and concretions, (8) pebbles of various rocks, (9) carbonate concretions, (10) sand-carbonate concretions, (11) iron-sulfide concretions, (12) iron carbonate concretions, (13) ferruginous rocks, (14) diagonal cross-bedding, (15–16) cross bedding, (17) bioturbation, ichnobedding, (18) gypsum crystals, (19) loose/solid floor erosion surface (20) monomorphic ammonite finds, (21) belemnite finds: (a) in-situ, (b) redeposited, (22) shell detritus, (23) plant remains, (24–26) geomagnetic field polarity: (24) normal, (25) reversed, (26) anomalous; (27) no polarity data.
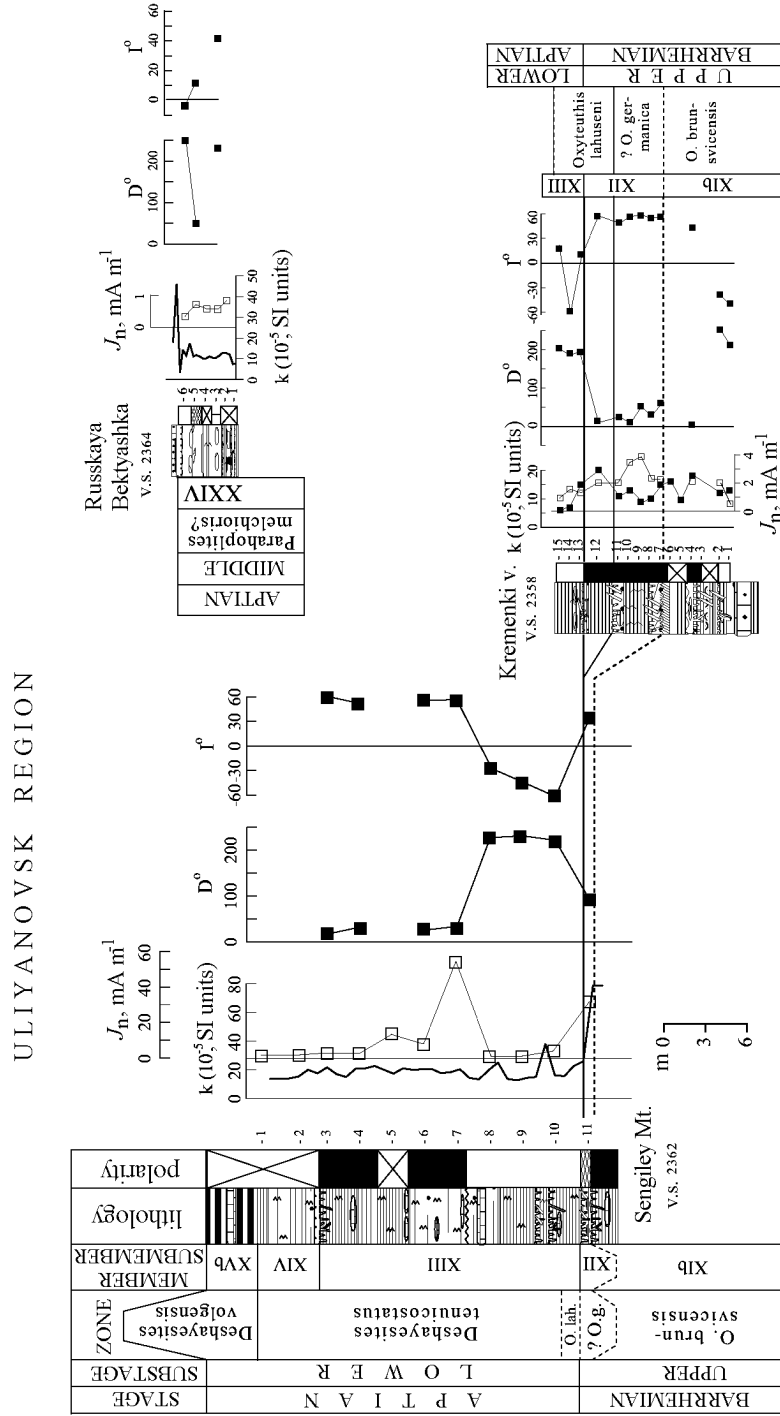
Figure 3. Paleomagnetic stratigraphy of the Upper Barremian and Aptian deposits in the Kremenki, Sengiley, and Russian Bektyashka areas (Uliyanovsk region).
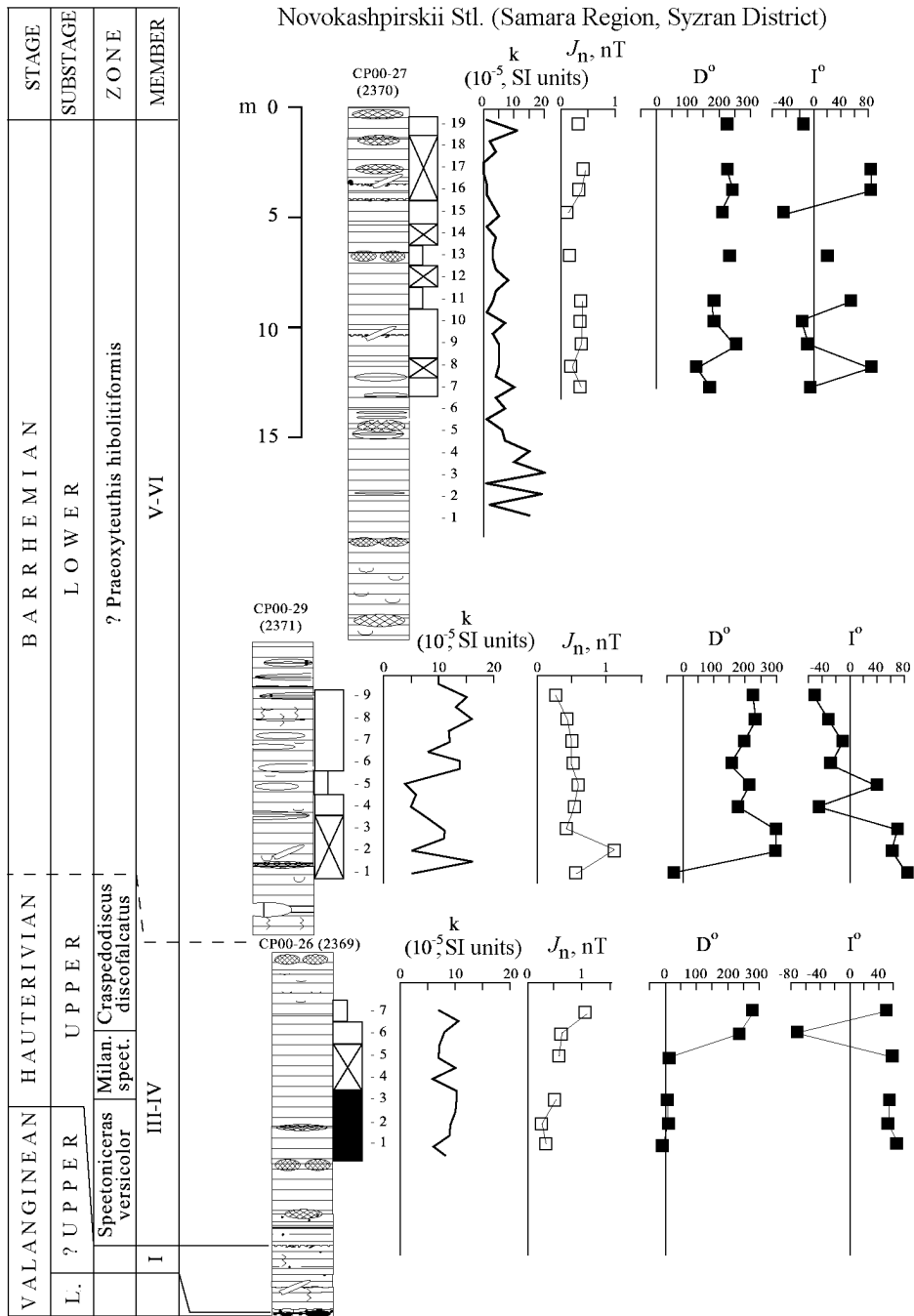
Figure 4. Paleomagnetic stratigraphy of the Upper Hauterivian and Lower Barremian deposits in the Novokashpirskii Stl. (Syzran area).
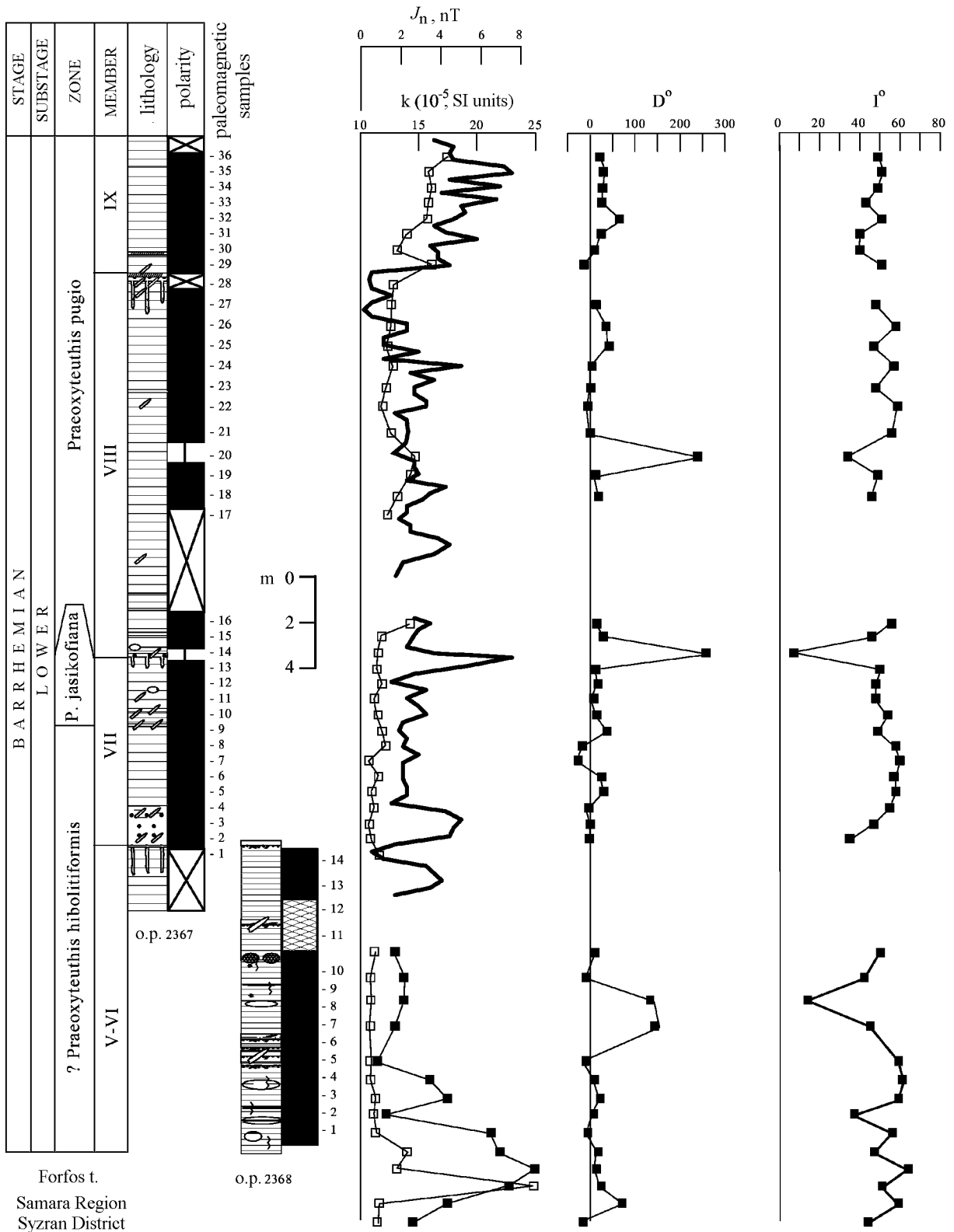
Figure 5. Paleomagnetic stratigraphy of the Lower Barremian rocks in the Forfos Mt. (Uliyanovsk region).
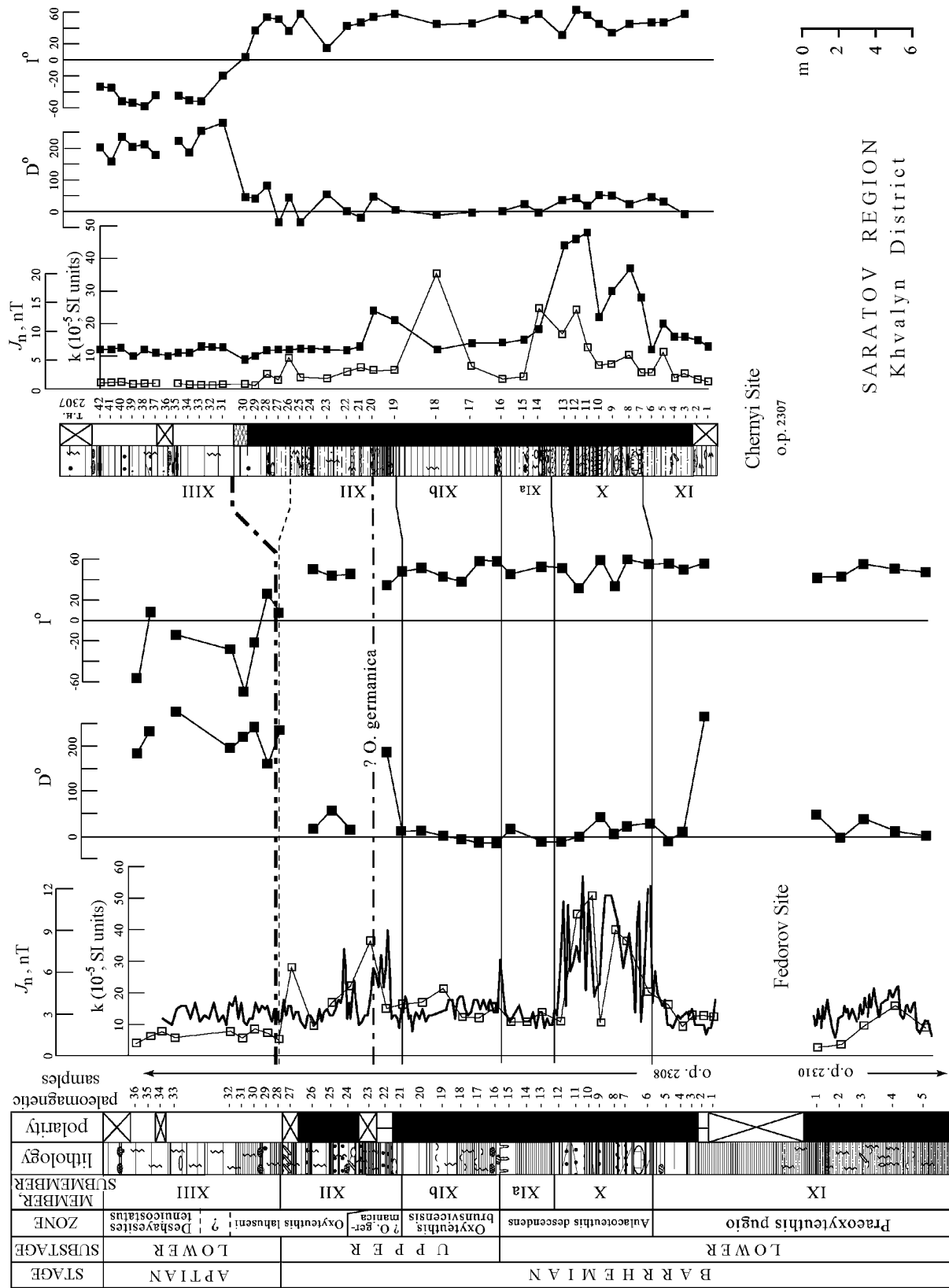
Figure 6. Paleomagnetic stratigraphy of the Barremian-Lower Aptian rocks at the Chernyi Zaton and Fedorovskii Sites (Khvalyn area).
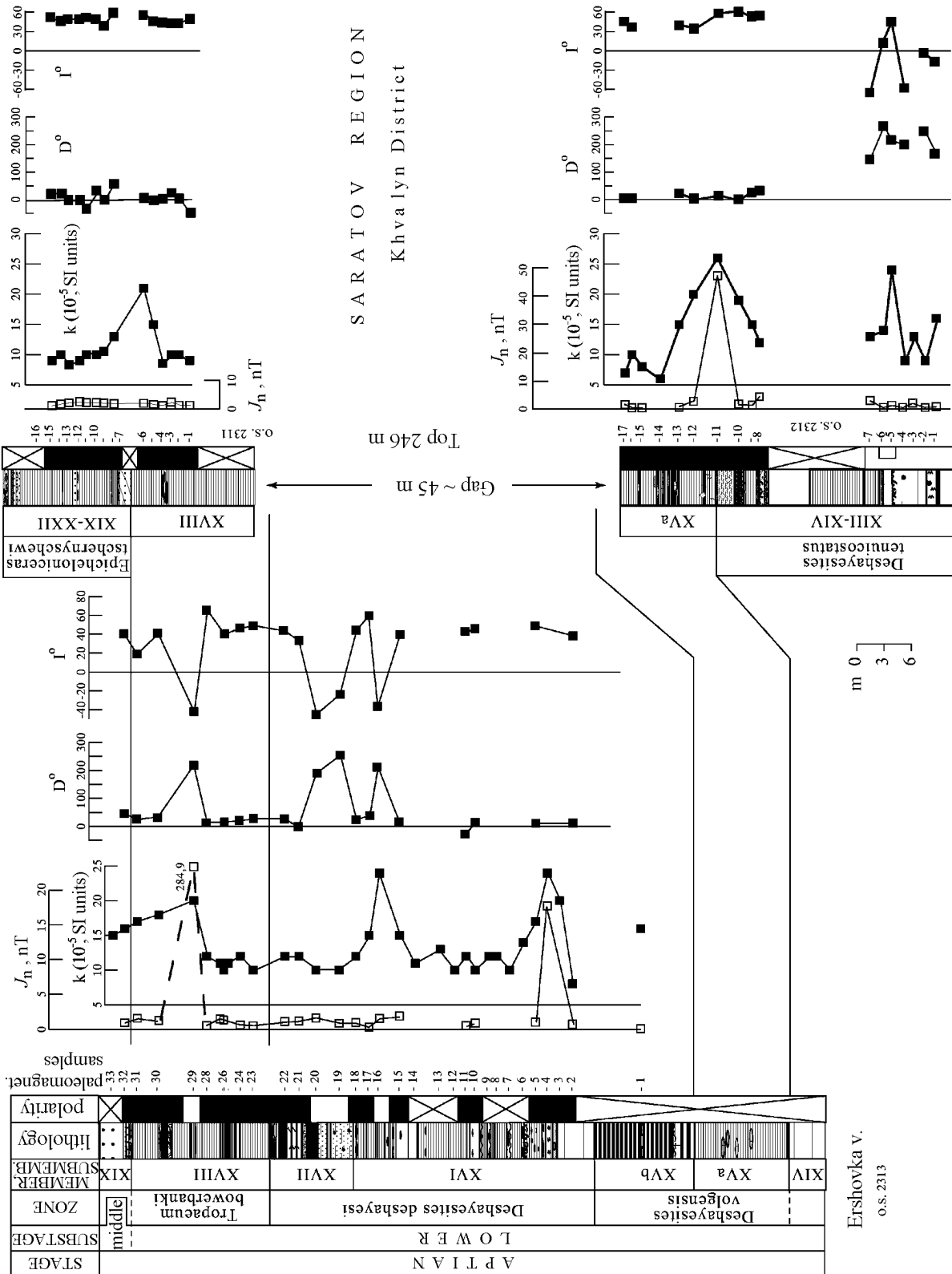
Figure 7. Paleomagnetic stratigraphy of the Aptian rocks in the areas of Elev. 246 m and Ershov Site (Khvalyn region).
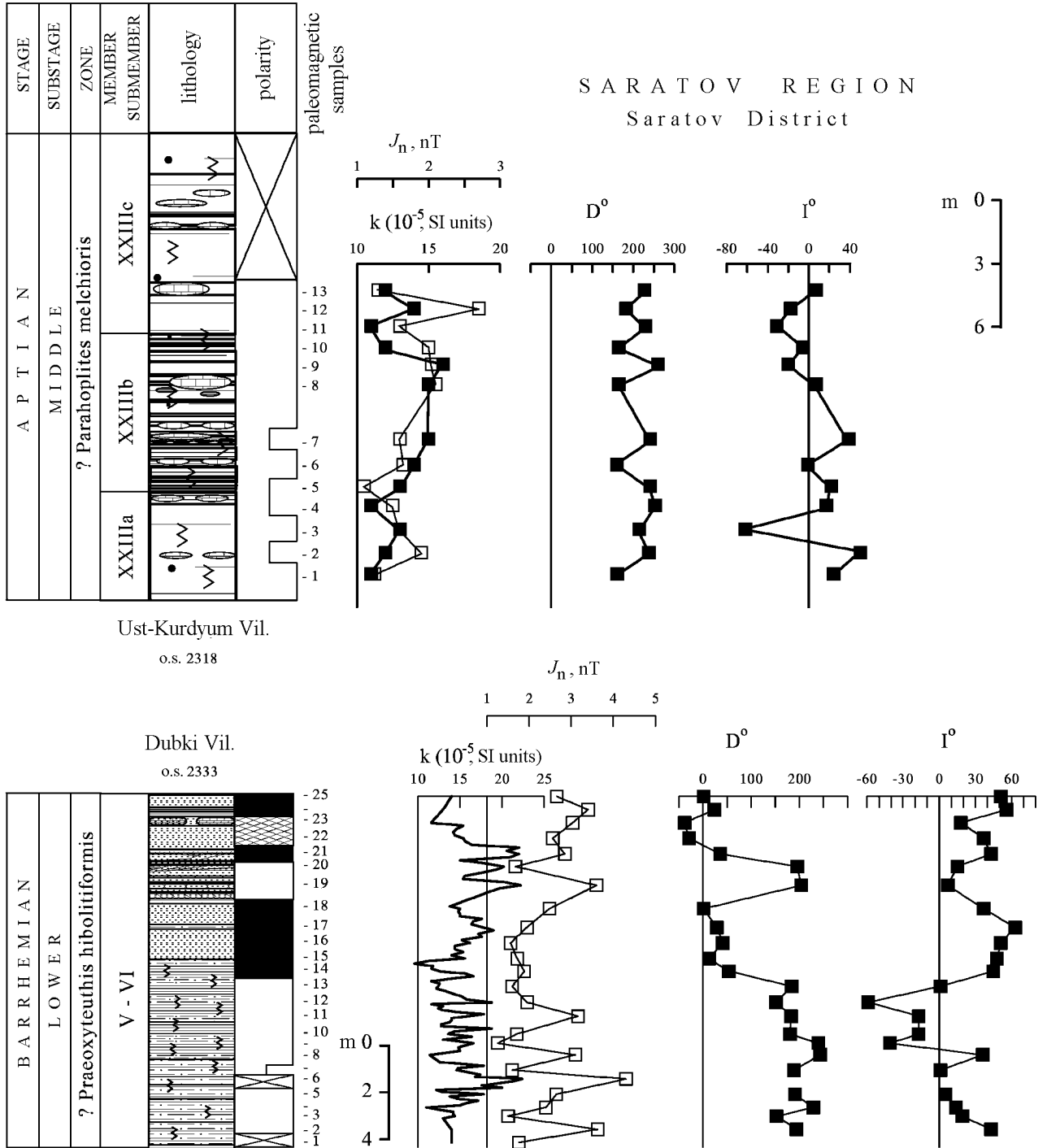
Figure 8. Paleomagnetic stratigraphy of Lower Barremian and Middle Aptian rocks in the Dubki and Ust-Kurdym districts (Saratov region).
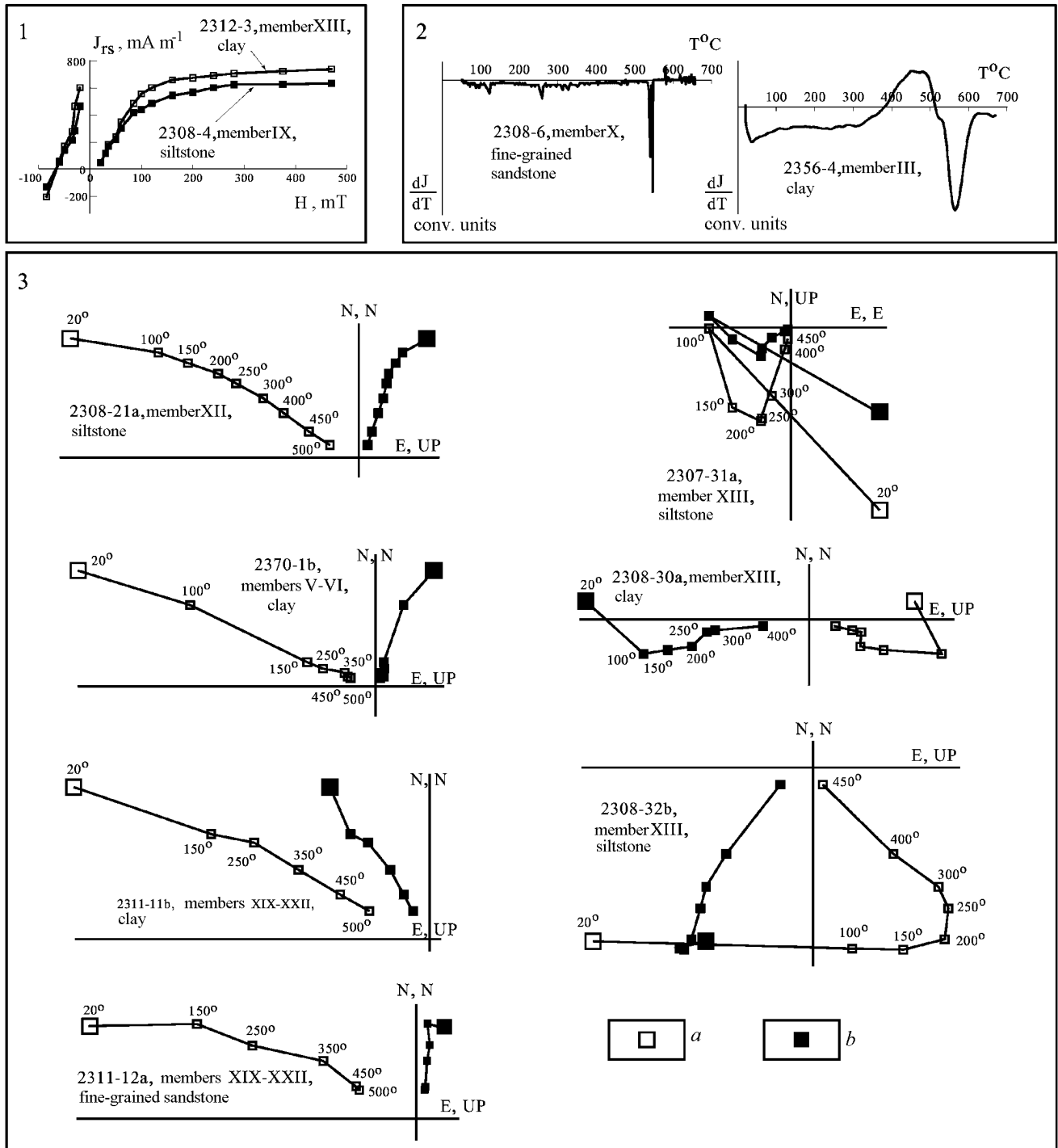
Figure 9. Results of magnetic, mineralogic, and component analyses: (1) magnetic saturation curves, (2) DTMA curves, (3) Zijderveld diagrams: (a) and (b) are the projections of the EOH vectors in the horizontal (a) and vertical (b) planes.
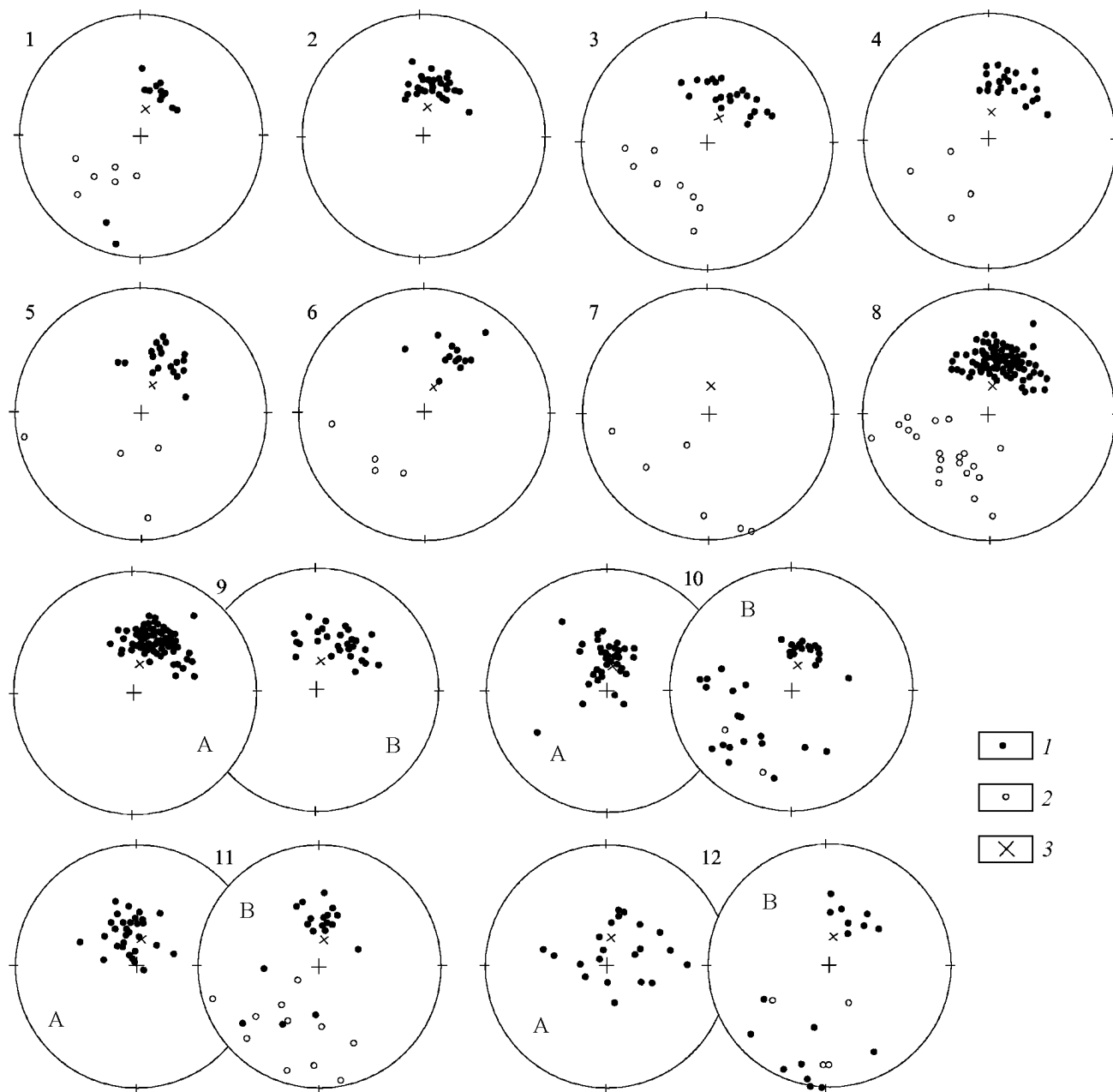
Figure 10. Stereographic projections of the EOH directions (without anomalous ones) for the investigated Hauterivian-Aptian rock sequences.

I and II are the projections of the EOH directions onto the lower (I) and upper (II) hemispheres; III is the remagnetization direction by the modern geomagnetic field.

(1–9) distribution of the EOH high-temperature component vectors: (1) Kremenki and Sengiley sites (Uliyanovsk region); (2) Forfos Mt. (Members VII to IX) (Syzran district, Samara region); (3) Chernyi Zaton Village; (4) Fedorov Site (Khvalyn district, Saratov region); (5) 246-m elevation site; (6) Ershov Site (Khvalyn district, Saratov region); (7) Ust-Kurdyum Village (Saratov region); (8, 9) combined stereograms for the Barremian-Aptian rocks of the Khvalyn and Syzran areas (members VII to XXII): (8) for all deposits, (9A) for clay, (9B) for silt, siltstone, and fine-grained sand and sandstone; (10–12) distributions of EOH directions after 100°C (A) and higher-temperature (B) cleanings in members II to VI (Hauterivian-lower Barremian): (10) Zakharievskii Mine and Polivna Village (Uliyanovsk area): members II to VI; (11) Novokashpirskii Stl. and Forfos Mt. (Syzran area) (members III to VI); (12) Dubki Stl. (Saratov region) (members V and VI).
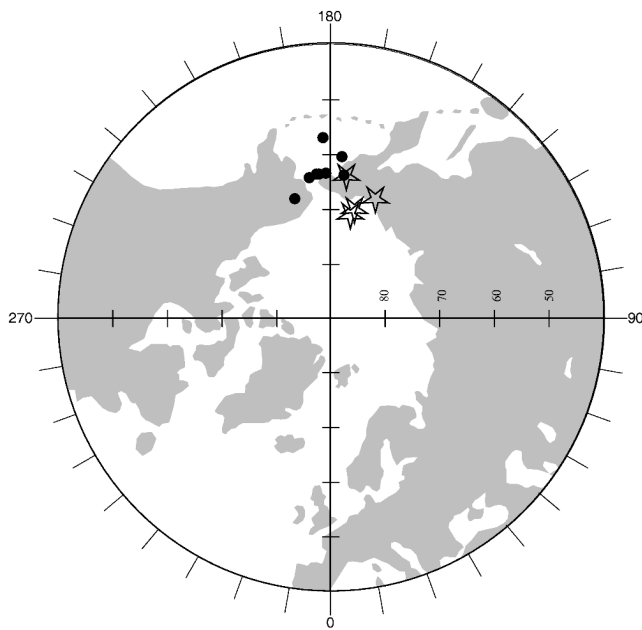
Figure 11. Stereographic representation of the paleomagnetic poles. Black circles show the poles determined in this study using the Middle Volga rocks (see the Table 1): asterisks show the pole sites reported in the literature [*Bazhenov and Shipunov,* 1985; *Molostovskii and Khramov,* 1997] (see the Table 1).
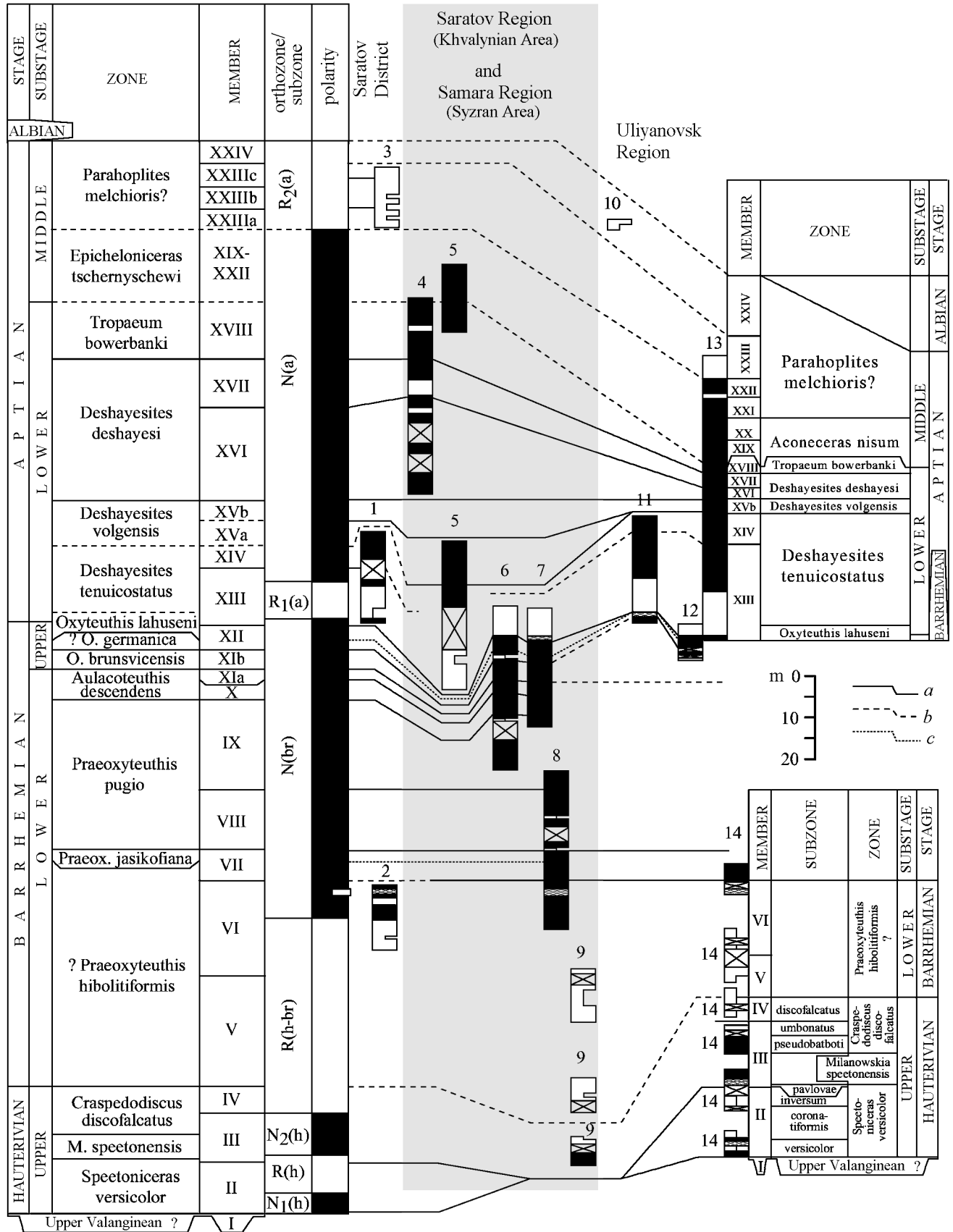
Figure 12. Composite magnetostratigraphic section of the Hauterivian-Aptian rocks of the Middle Volga region. Sites of the local sections: (1) Sokolov Mt. [*Grishanov,* 1984], (2) Dubki Stl., (3) Ust-Kurdyum Vil., (4) Ershov Site, (5) 246-m height, (6) Fedorov Site, (7) Chernyi Zaton Vil., (8) Forfos Mt., (9) Novokashpirsky Settl., (10) Russkaya Bektyashka Vil., (11) Sengiley Town, (12) Kremenki Vil., (13) Uliyanovsk City to Kremenki Vil. [*Baraboshkin et al.,* 1999], (14) Zakhariev Mine to Polivna Vil. (a, b) stratigraphic correlation using lithological and paleontological data: (a) proved, (b) inferred; (c) correlation of zones using paleontological data.
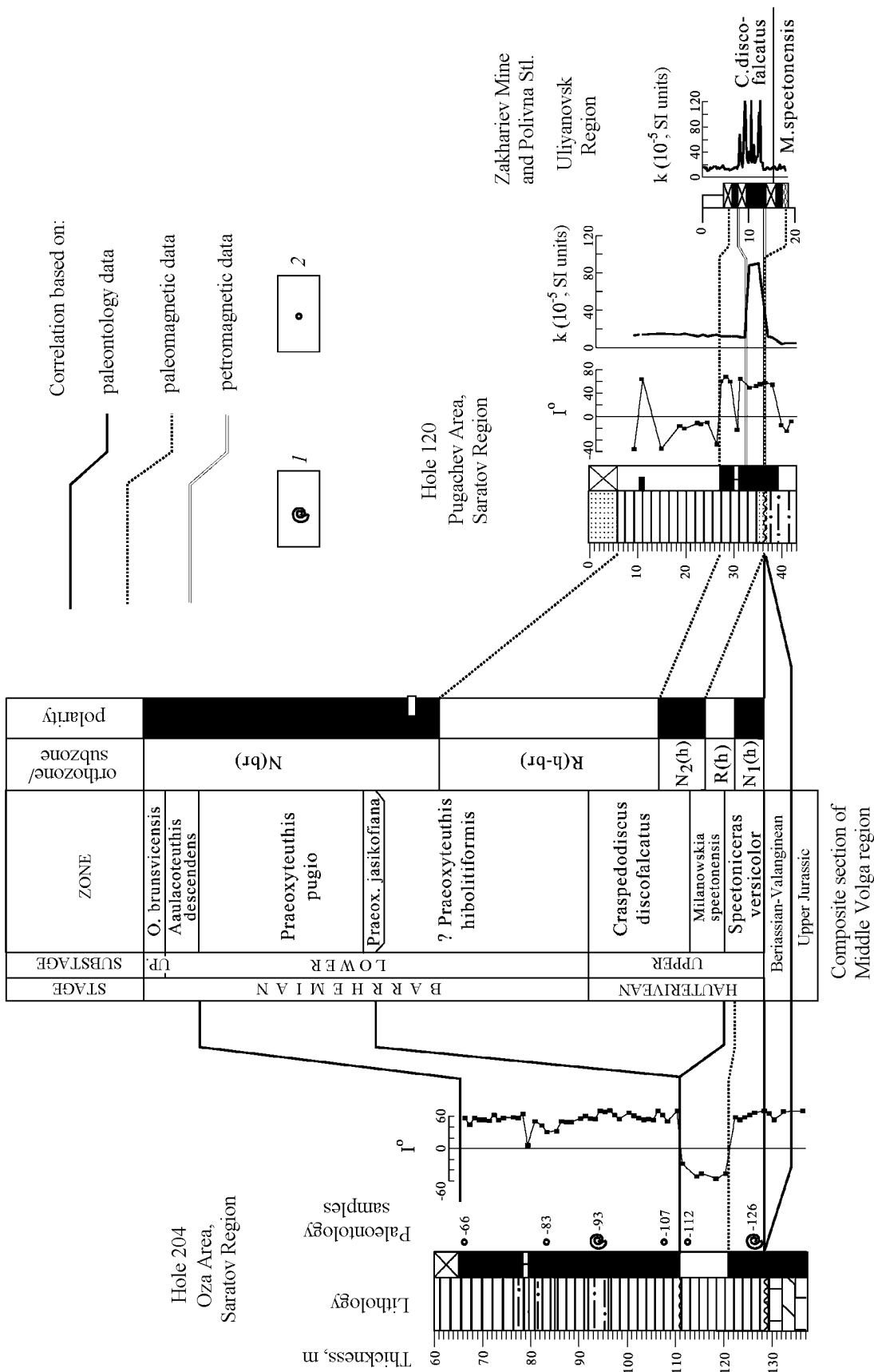
Figure 13. Magnetostratigraphic correlation of the composite Upper Hauterivian–Lower Barremian rock sequence from the Uliyanovsk-Samara right-hand Volga Region with the rock sequences of the Saratov East-Volga region: (1) ammonite finds: Speetoniceras cf. coronatiforme (M. Pavlowa) (depth 126 m) and Aconeceras sp. juv. (depth 93 m); (2) microfauna (foraminifer) samples: Haplophragmoides nonioninoides (Reuss), Cribrostomoides infracretaceous (Mjatl.), C. sinuosus (Bulyn.), C. romanovae (Bulyn.), C. concavoides (Bulyn.), Evolutinella nascens (Kusina), Trochammina neocomiana (Mjatl.), Glomospirella gordialis (Park. et Jones) (depth of 112 m); Haplophragmoides nonioninoides (Reuss), H. barremicus (Mjatl.), H. latidorsatus (Bornemann), H. ustjurticus Mamaeva, H. sp., Evolutinella portentosa (Mjatl. et Koss.), Hyperammina sp., Reophax consonus (Bulyn.), Trochammina neocomiana (Mjatl.), Ammobaculites quadrilocularis (Mjatl.), Glomospira gordialis (Park. et Jones), Lenticulina lideri (Roman.), L. macra (Gorb.), L. munsteri (Roen.), Globulina lacrima (Reuss), Conobrinopsis barremicus (Mjatl.), Gavelinella barremiana (Bettenstaedt) (depths of 107, 83, and 66 m). The microfauna was determined by K. I. Kuznetsova (Geol. Inst., Russian Acad. Sci.).
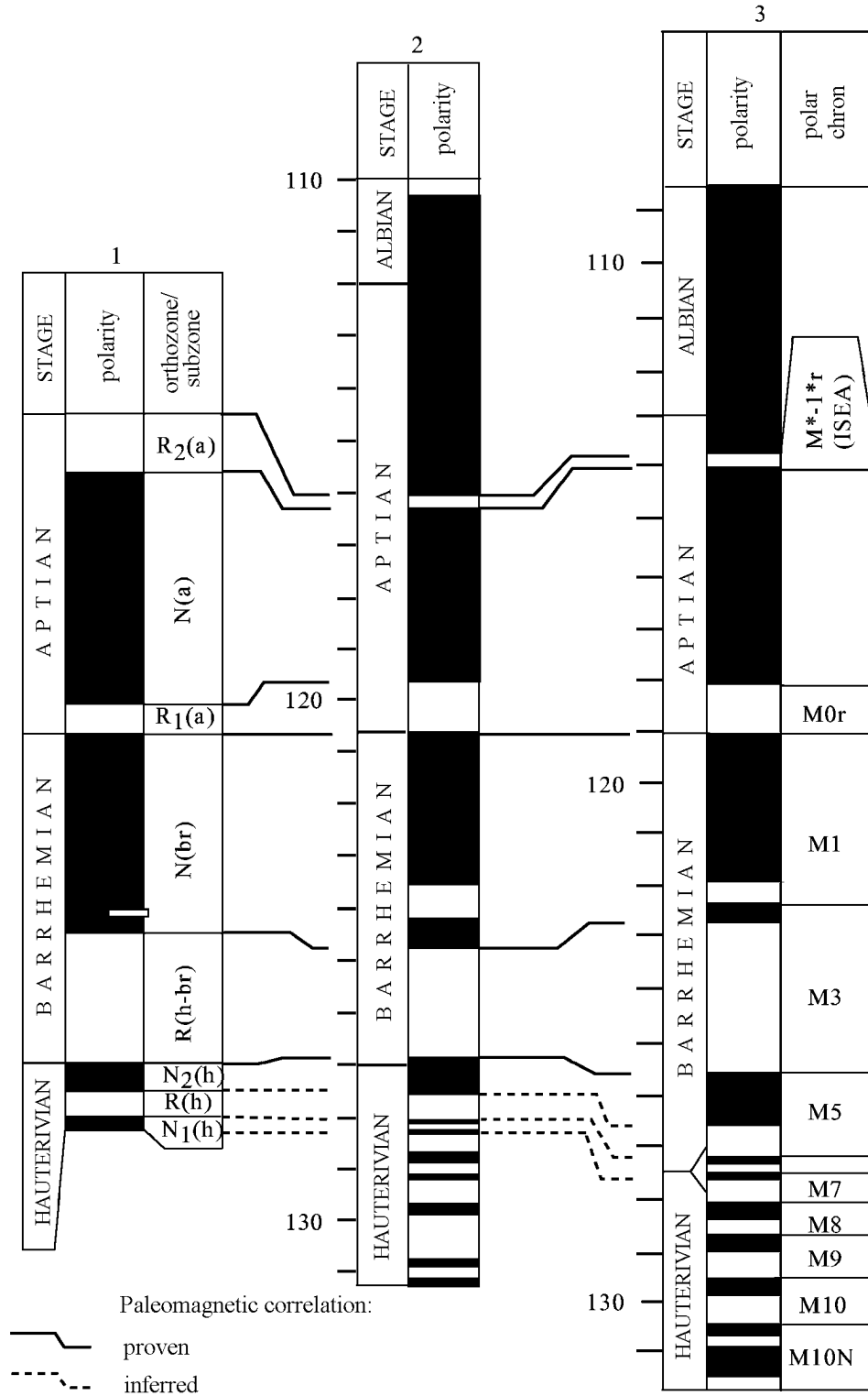
Figure 14. Correlation of the composite paleomagnetic section of the Hauterivian-Aptian rocks of the Middle Volga region (1) with the General Magnetostratigraphic Scale [*Supplement...*, 2000] (2) and with one of the versions of magnetochronological scales [*Ogg*, 1999] (3).
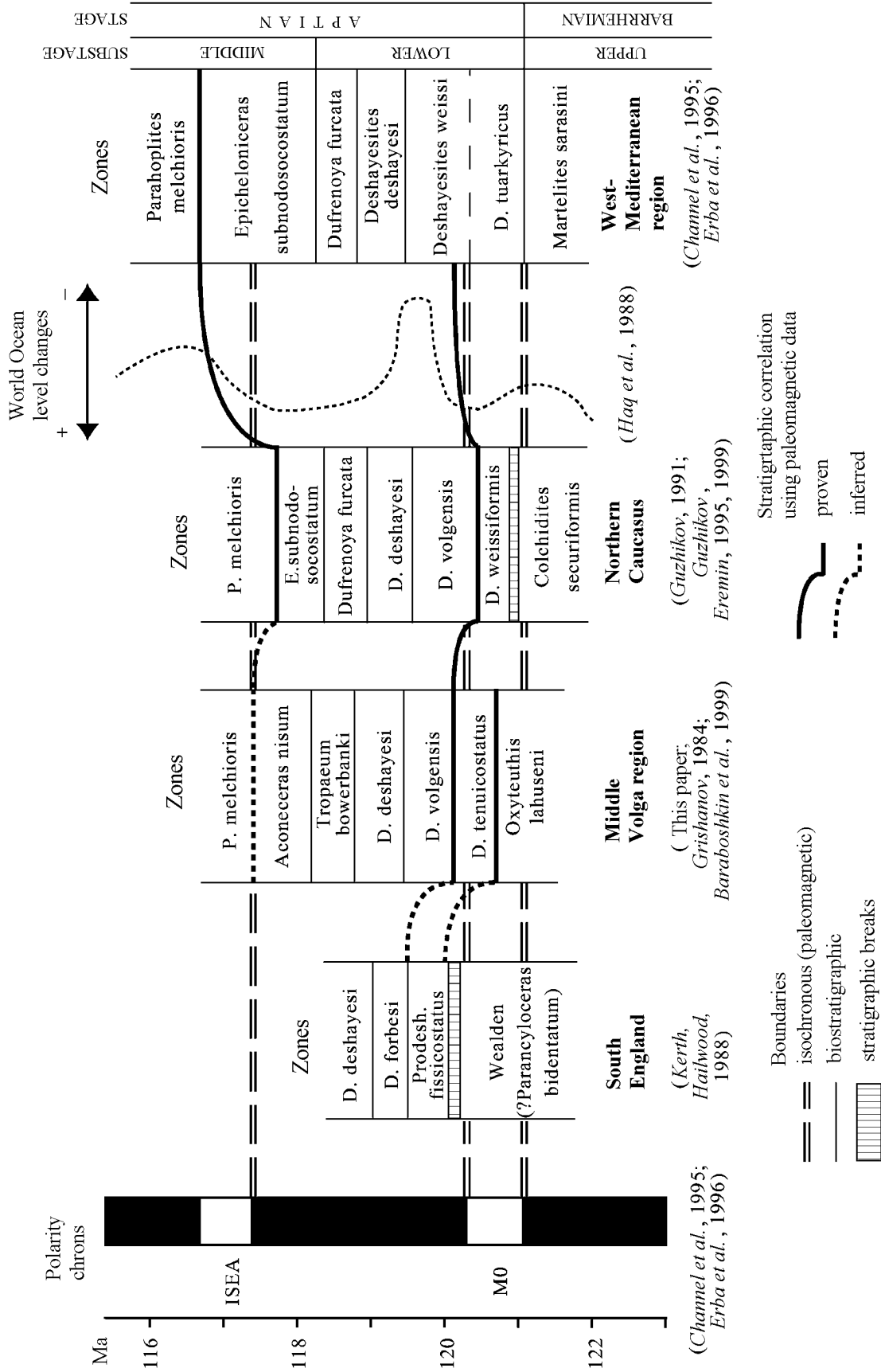
Figure 15. Correlation of the biostratigraphic scales of the Lower-Middle Aptian from the Middle Volga region, Western Mediterranean region, North Caucasus, and South England using paleomagnetic data. The boundaries of the biostratigraphic intervals are provisional.
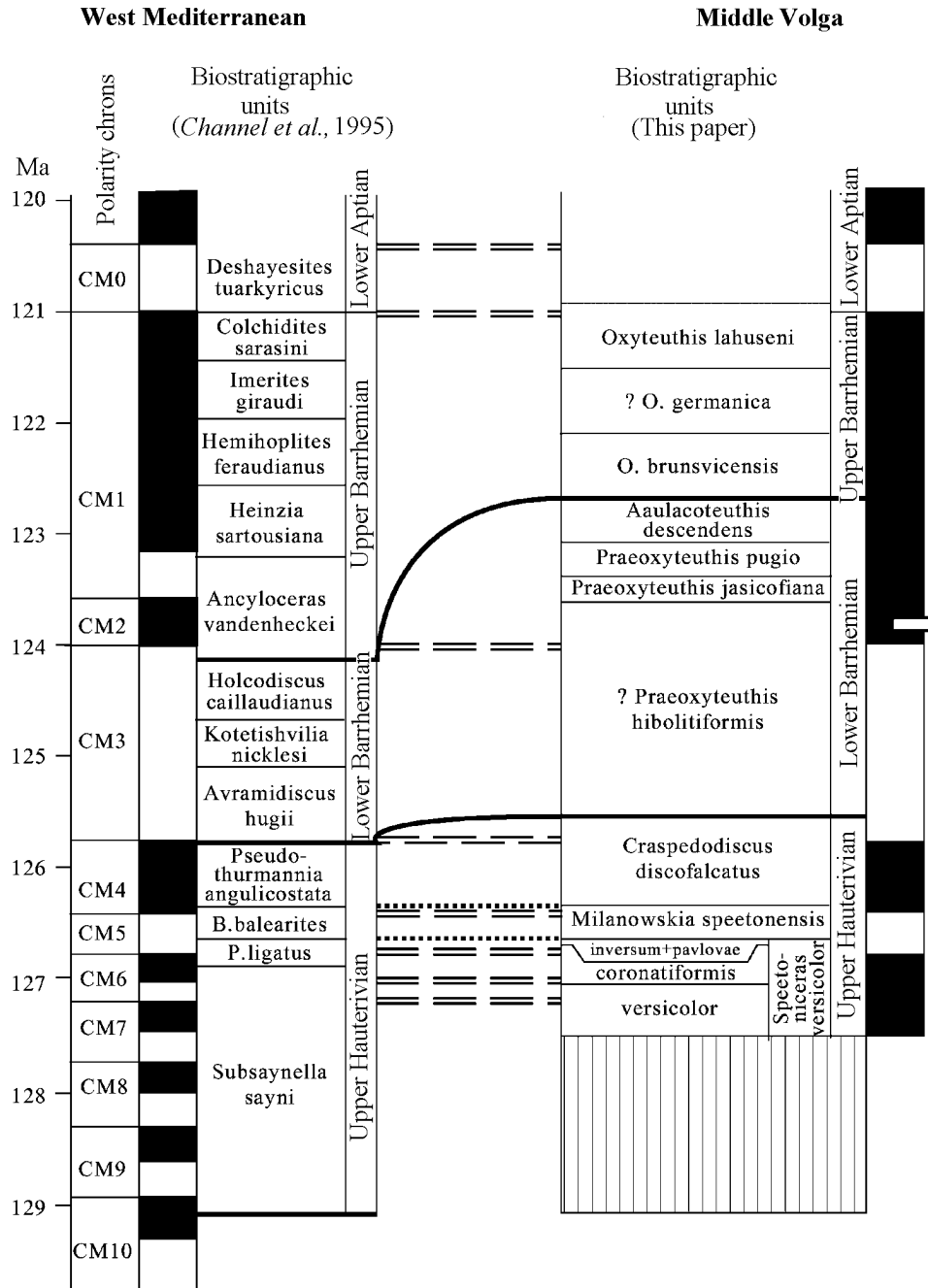
Figure 16. Comparison of the biostratigraphic scales of the Upper Hauterivian-Barremian rocks from the Middle Volga region and from the Western Mediterranean region. The boundaries between the biostratigraphic zones inside the monopolar intervals are conventional. See Figure 15 for the legend.