# Chapter 28
# Magnetic Stratigraphy of the Bazhenov Suite of Western Siberia and the Surrounding Deposits

**A. G. Manikin, V. A. Grishchenko, A. Yu. Guzhikov and V. V. Kolpakov**

**Abstract** A paleomagnetic and petromagnetic study of the Jurassic-Cretaceous boundary in three wells, located on the territory of Imilorskoye and Severo-Yeguryahskoe deposits of Western Siberia was conducted. The sediments of Bazhenov Formation and underlying, as well as overlaying, deposits are detected in each section. Paleomagnetic and petromagnetic studies were carried out on partially (up-down) oriented core samples. According to the results of alternating field magnetic cleaning characteristic components of magnetization were determined and a paleomagnetic column was compiled, showing the dominant normal polarity in the interval from Bajocian-Bathonian to Berriasian-Valanginian. This contradicts the existing data on the Middle-Jurassic to Early-Cretaceous geomagnetic field regime, but still does not prove the secondary magnetization of rocks. For the definitive solution of the problem of magnetization genesis in oil and gas bearing formations of Western Siberia it is necessary to continue their magnetostratigraphic studies. Anisotropy of magnetic susceptibility (AMS) of 659 samples from the sections of Bazhenov Formation and overlying deposits was studied on the territory of Imilorskoye and Severo-Yeguryahskoe deposits of Western Siberia in 6 wells. The half of the wells represent the classical section of Bazhenov Formation (organic-rich siliceous shales), and another wells represent the anomalous section of

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D. Nurgaliev et al. (eds.), *Recent Advances in Rock Magnetism, Environmental Magnetism and Paleomagnetism*, Springer Geophysics,
https://doi.org/10.1007/978-3-319-90437-5_28

Bazhenov Formation (alternation of black shales and sand-silty rocks). The results of AMS study support an idea of close age of bituminous argillites and terrigenous rocks from anomalous section of Bazhenov Formation.

**Keywords** Bazhenov suite · Western Siberia · Magnetic susceptibility
Anisotropy of magnetic susceptibility · Oil and gas bearing formations
Paleomagnetism · Petromagnetism

## Introduction

Owing to its hydrocarbon prospects, the Bazhenov Formation (BF) is currently among the most intensively studied subsurface objects in Western Siberia. Nevertheless, the BF exact stratigraphic age is still open to discussion, which is accounted for by the formation confinement to the boundary interval of the Jurassic and Cretaceous systems. Detailed Boreal-Tethyan correlation of this interval remains one of the most urgent problems in modern stratigraphy. Due to the separation between Tethyan and Boreal paleobasins at the Jurassic-Cretaceous boundary, unequivocal comparison of the zonal scales from different regions cannot be based only on paleontological data, without involvement of independent methods, specifically, the paleomagnetic one. Moreover, the latest and the only wide-scale magnetostratigraphic study of the Bazhenov Formation was carried out over 40 years ago (Paleomagnetism … 1976). Recently, only a single reference section covering the Jurassic-Cretaceous boundary in the Boreal domain (Nordvik Cape) has been paleomagnetically studied at the present-day level (Bragin et al. 2013; Hosha et al. 2007).

Another debatable problem concerns the genesis and the age of the sandy-silty interlayers in the so-called Bazhenov anomalous section (BAS). BAS is a section of BF, in which a characteristic bundle of dark-colored bituminous argillites is either delaminated by sandstones, siltstones, or completely replaced by them (Nezhdanov et al. 1985). Irrespective of being difficult-to-develop at the present state of petroleum geology in Western Siberia, these interlayers are the most promising objects in terms of oil and gas contents. The current hypotheses of the BAS generation may be divided into two principal types: the “even-aged” models, assuming that the sandy-silty interlayers were shaped in the Volgian time (Zubkov and Portmeister 2005), and the “uneven-aged” models, assuming the Neocomian age of the terrigenous varieties, with their subsequent intrusion into bituminous clays (Grishkevich et al. 2017). Paleontological examinations are still unable to substantiate or disprove any of the standpoints unequivocally; therefore, it is urgent to involve other independent methods to clarify the question. A major part in solving this problem may be assigned to the data on the deposit anisotropy of magnetic susceptibility (AMS), determined by the textural features (shapes, relative positions) of magnetic particles. Magnetic textures of the rocks, formed under different conditions, differ significantly, providing a rationale for using AMS data to determine the genesis of the anomalous section of Bazhenov formation. In particular, the primary magnetic texture of bazhenites would be inevitably changed upon aleurolite and sandstone intrusion.

## Examination Procedure

The total of 311 partially oriented (top-bottom) and 1730 non-oriented core samples from 6 well Sections (4 well from the Imilorskoye and 2 well from the Severo-Eguryakhskoye fields) were selected for paleomagnetic and petromagnetic measurements. In the wells 280, 405 and 412 from the Imilorskoye field, the Bazhenov anomalous section is represented, in other wells the BF is composed only of classic clayey-bituminous deposits. Samples for paleomagnetic measurements were collected every 0.5–0.75 m, those for petromagnetic studies—every 0.3 m. Selection gaps of several meters occasionally occurred because of the lack of core material.

Petromagnetic measurements were aimed at estimating the sample usability for paleomagnetic determinations and for acquiring an additional information on the deposit material composition and generation environments. Those included kappametry—measuring of initial magnetic susceptibility ($K$), thermokappametry—measuring the initial magnetic susceptibility upon sample incremental heating up to 500 °C for one hour in a muffle furnace ($dK = Kt - K$, with $Kt$—magnetic susceptibility measured after heating), measuring the anisotropy of magnetic susceptibility and natural remanent magnetization ($\mathbf{J_n}$), differential thermomagnetic analysis (DTMA) of selected samples.

Oriented cores were sawn into two or three 2-cm cubic samples. Later on, those samples were subjected to kappametry, thermokappametry, paleomagnetic measurements and AMS measurements. Non-oriented samples of random shape were subjected only to kappametric and thermokappametric examinations.

Paleomagnetic examination consisted of the $\mathbf{J_n}$ measurements after magnetic cleanings with alternating field (h-cleanings), from 5 mT to 50–60 mT, in 5 mT increments, and temperature (t-cleanings) from 100 to 300 °C, in 50 °C increments. No cleanings with higher temperatures were made because of the sample laboratory magnetic biasing resulting from the phase transformations of iron sulfides above 300 °C. The acquired data were subjected to component analysis (Kirschvink 1980) with the purpose of distinguishing the characteristic remanent magnetization (**ChRM**) and providing interpretations in terms of its magnetic polarity.

Magnetic susceptibility was measured by means of a MFK1-FB kappabridge, remanent magnetization—with a JR-6 spin-magnetometer. Thermal magnetic cleanings were made in a home-made furnace designed by V. P. Aparin. Magnetic cleanings with alternating field were made with a LDA-3AF unit. DTMA was made with a TAF-2 thermoanalyzer of magnetic fractions (« magnetic balance »). The AMS data was analyzed by means of the Anisoft 4.2 software, component analyses of paleomagnetic materials were made by means of the Remasoft 3.0 software.

## Research Results

**Petromagnetism**. Magnetite presence was recorded in the samples from the DTMA data. Magnetite was diagnosed from magnetization loss close to the Curie temperature of 578 °C (Fig. 28.1). At the first heating, after 600 °C a new ferromagnetic phase forms in the samples. This follows from an increase of magnetization after 600 °C and from the Curie point above 700 °C (probably, the iron formed by reduction of magnetite in the presence of organic matter). Iron sulfides of the pyrrhotine and/or pyrite type, clearly recorded in the second-heating thermomagnetic curves from magnetization growth during the phase transformations of those minerals to magnetite close to the temperatures of 300–350 °C and/or 400–450 °C (Fig. 28.1), may represent the products of interaction of the newly formed ferromagnetic phase with the hydrogen sulfide released upon organic matter burning.

Sections of the three most complete well logs are petromagnetically well-differentiated. The petromagnetic characteristics acquired from them allow more elaborate well-section divisions and correlations (Manikin et al. 2017; Samarin et al. 2016) (Fig. 28.2).

Anisotropy of magnetic susceptibility was measured in 659 paleomagnetic samples.

Short axes of magnetic ellipsoids (K3) in the *Sortymskaya and the Megionskaya formations*, overlying the BF, tend towards vertical (projection of the K3 average direction statistically coincides with the stereogram center), while the long (K1) and the medium (K2) axes are distributed over the stereogram margins (Fig. 28.3a).

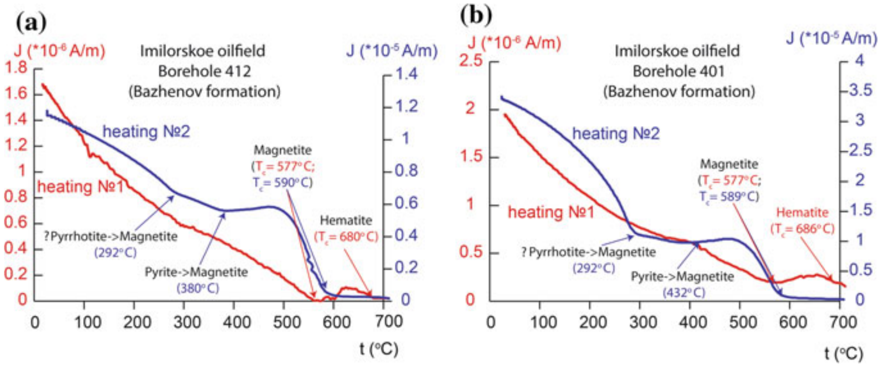


**Fig. 28.1** Results of differential thermomagnetic analysis (DTMA)

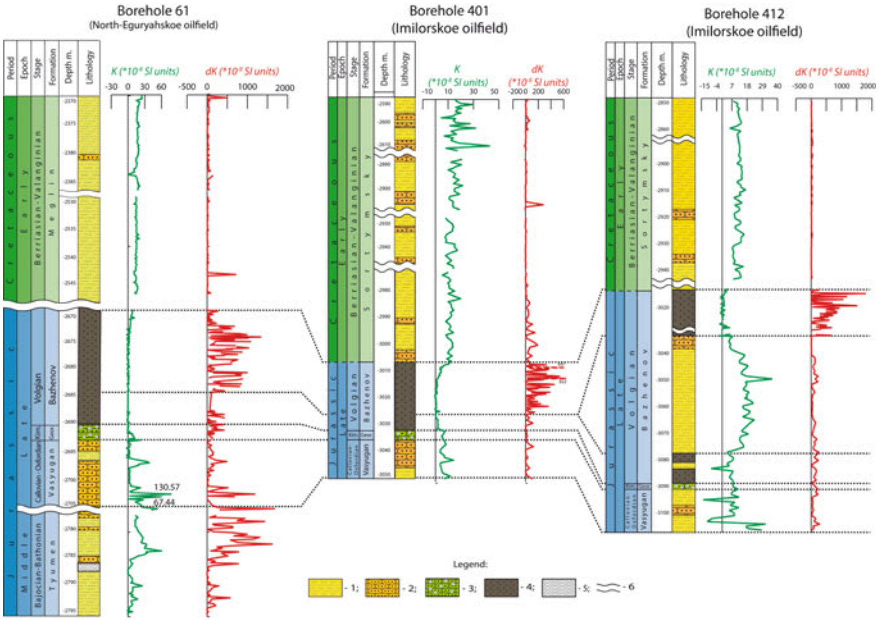
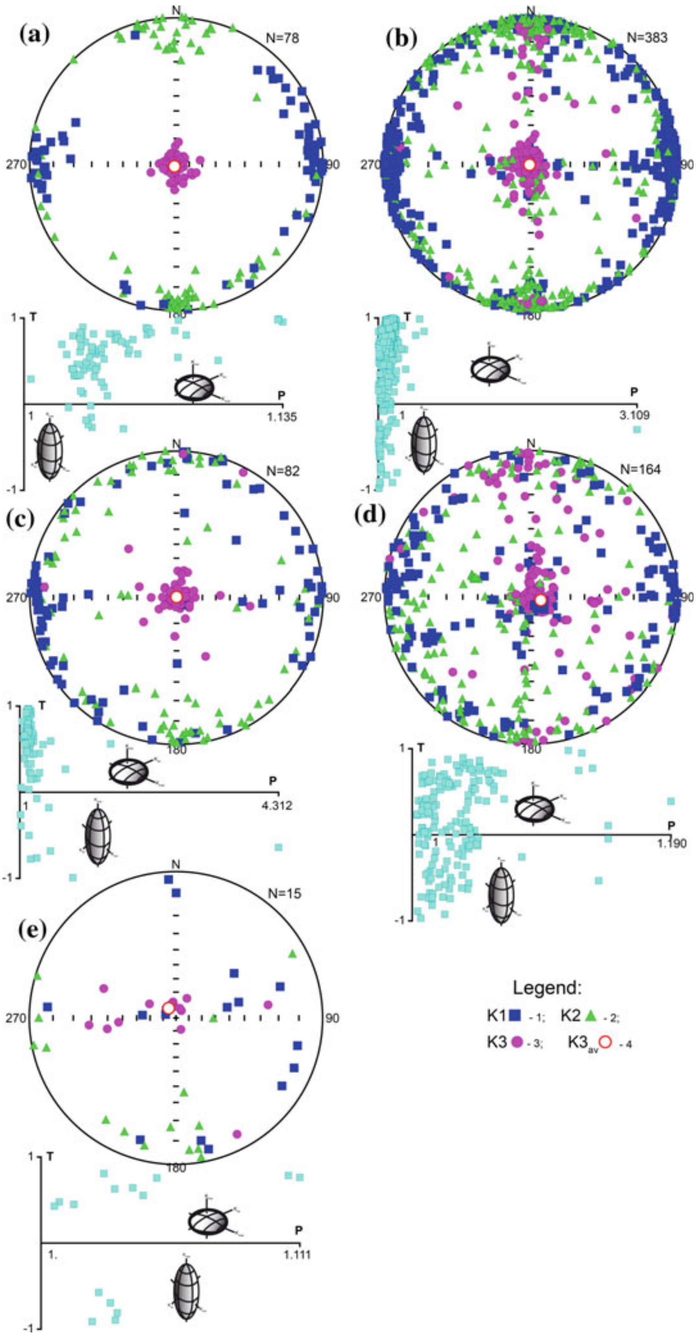


**Fig. 28.2** Correlation of studied wells using petromagnetic parameters. Legend: 1—siltstone; 2—sandstones; 3—glauconitic sandstone; 4—bituminous mudstones; 5—coals; 6—stratigraphic breaks

Similar magnetic texture is characteristic of sediments formed in quiet hydrodynamic conditions (Tarling and Hrouda 1993). Positive values of the T-shaped parameter are indicative of flattened ferromagnetic particles. The effect of flatness is likely to be associated with magnetic mineral aggregation on the scale of clayey minerals. The fraction of elongated (cigar-shaped) ferromagnetic particles does not exceed 7% (Fig. 28.3a).

*Clayey-bituminous deposits from the Bazhenov Formation*. Distribution of the AMS-axes projection in the stereograms, corresponding to bituminous argillites (in the zones of both classical and anomalous BF sections), is also indicative of their generation in quiet hydrodynamic conditions: the K3 axes tend towards vertical, while the K1 and K2 axes are distributed over the stereogram margins. The unchanged classic sedimentary texture of the rocks is incompatible with the hypothesis of the BAS formation proposed by A. A. Nezhdanov and co-authors (1985), which assumes that terrigenous interlayers result from the activity of the Valanginian landslides, highly pressurized and wedged into the underlying deposits, producing contortions and ruptures.

Meanwhile, there are levels with abnormally large K3 axes shifts from the vertical, from 15° to 89° (Fig. 28.3b, c), in the clayey-bituminous beds, both in classic BF sections and in the BAS. The "anomalous" samples (their share may be as high as 11%) are not confined to the boundaries between bituminous argillites


(a)
N
N=78
270
90
180
1 T
P
1
1.135
-1
(b)
N
N=383
270
90
180
1 T
P
1
3.109
-1
(c)
N
N=82
270
90
180
1 T
P
1
4.312
-1
(d)
N
N=164
270
90
180
1 T
P
1
1.190
-1
(e)
N
N=15
270
90
180
1 T
P
1.
1.111
-1
Legend:
K1 ■ - 1; K2 ▲ - 2;
K3 ● - 3; K3av ○ - 4

◂**Fig. 28.3** AMS stereograms and P-T AMS diagrams as an indicator of magnetic ellipsoid shape of overlaying formations (**a**), clayed-bituminous sediments of classical (**b**) and anomalous (**c**) sections of Bazhenov formation, of terrigenous layers in anomalous section of Bazhenov formation wells 405 and 412 (**d**) and well 280 (**e**). Legend: 1,2,3—directions of long (K1), medium (K2), and short (K3) axis of magnetic ellipsoids, respectively; 4—mean direction of short axis ($K3_{av}$) of magnetic ellipsoids

and terrigenous interlayers, but occur sporadically within bituminous argillites. Their magnetic texture may be determined by siderite or single-domain magnetite in the ichnofossil infillings. The latter statement is supported by the highly elongated shapes of ferromagnetic particles, recorded from the *T* negative values and the *P* ($T = (2\ln K2 - \ln K1 - \ln K3)/(\ln K1 - \ln K3)$—shape parameter; $P = K1/K3$—degree of anisotropy) increase up to 4.31 (Fig. 28.3b, c).

*In the BAS sand-and siltstones*, the magnetic texture differs drastically from both the BF bituminous argillites and terrigenous beds of the Sortymskaya and the Megionskaya formations. In the AMS stereograms from the sections of wells 405 and 412, in more than a half of the samples, strong shifts of the K3 axes from the vertical to the first and second quadrants of the stereogram are recorded, and the projection of the average K3 axis is shifted by 5.3° eastwards from the vertical (Fig. 28.3d). The *T* shape parameter indicates the presence of both flat and cigar-shaped magnetic particles, the latter ones comprising up to 36% from the total sample number. Such distribution of the short axes directions may be associated with an effect of strong storm waves on the non-lithified sediment. Their activity is expected to roil the bottom sediment and disturb its primary magnetic texture (Lanza and Meloni 2006).

Anisotropy of magnetic susceptibility of the BAS terrigenous interlayers from the well 280 reveals the K3 sublatitudinal distribution (Fig. 28.3e). Regular “stretching” of the AMS short axes directions along the E-W line, alongside with the shift of their average position from the vertical is observed during the sediment transfer as high-density turbidite flows (Lanza and Meloni 2006; Popov and Zhuravlev 2012). Diagrams of the dependence of the *T* shape parameter from the anisotropy degree *P* indicate the possible presence of both disc-shaped and elongated magnetic particles (Fig. 28.3e).

The AMS data does not comply with the sedimentological model by O. M. Mkrtchyan and co-authors (1987). According to this model, formation of the band-shaped sand- and siltstone bodies is associated with the avandelta and bar channels. Neither the regularities in the K1 orientation, associated with the near-bottom currents in the avandelta channels, nor the specific magnetic textures of the cross-bedded deposits from the sea bars are observed in the ABS terrigenous rocks.

**Paleomagnetism**. 317 samples from the sections of the wells 401, 412 (the Imilorskoye field) and 61p (the Severo-Eguryakhskoye field) were examined paleomagnetically. The h-cleaning results are peculiar for good quality: in most samples, the characteristic remanent magnetizations (**ChRM**) are isolated in the fields from 5 to 40 mT, their maximum deviation angle is <15° (Fig. 28.4a).

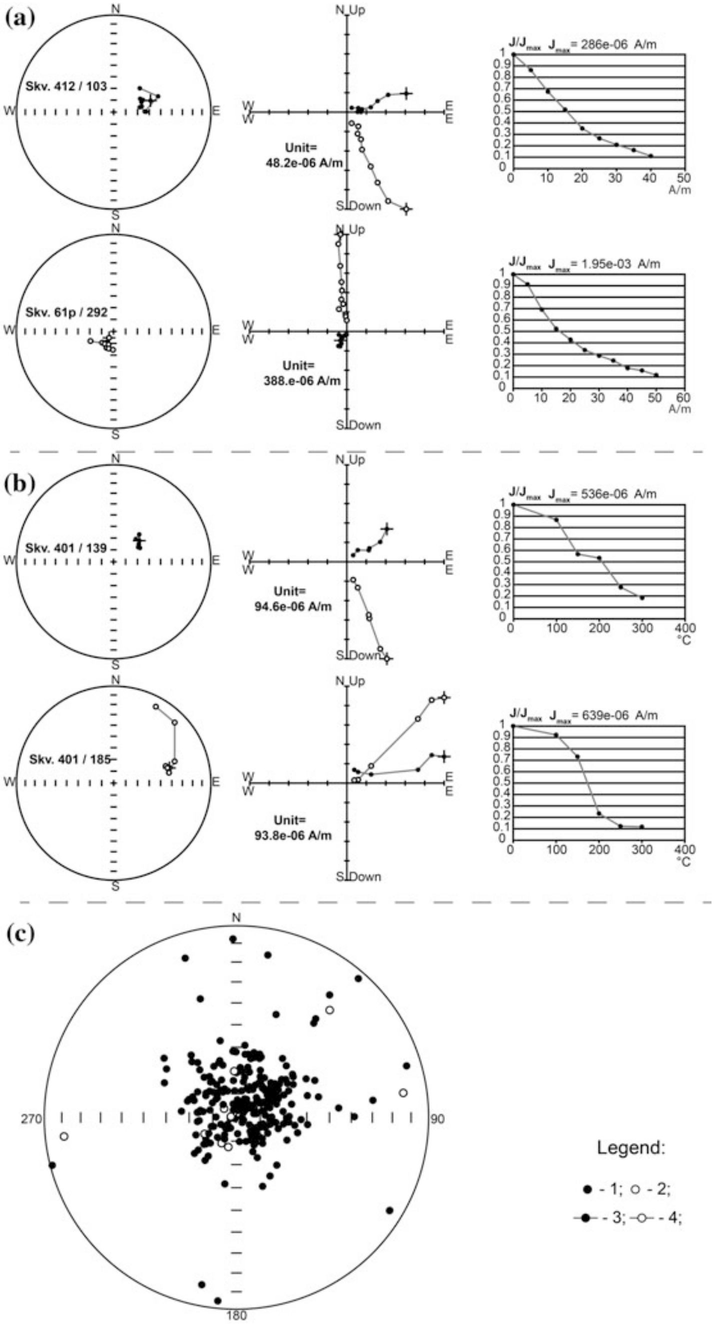


**Fig. 28.4** Results of magnetic cleaning with alternating field (**a**), temperature (**b**) and summary stereograms of **ChRM** (**c**) on the studied wells. Legend: 1,2—stereographic projections of $\mathbf{J_n}$ directions on the lower semisphere and upper semisphere respectively; 3,4—projection on the horizontal and vertical plane respectively

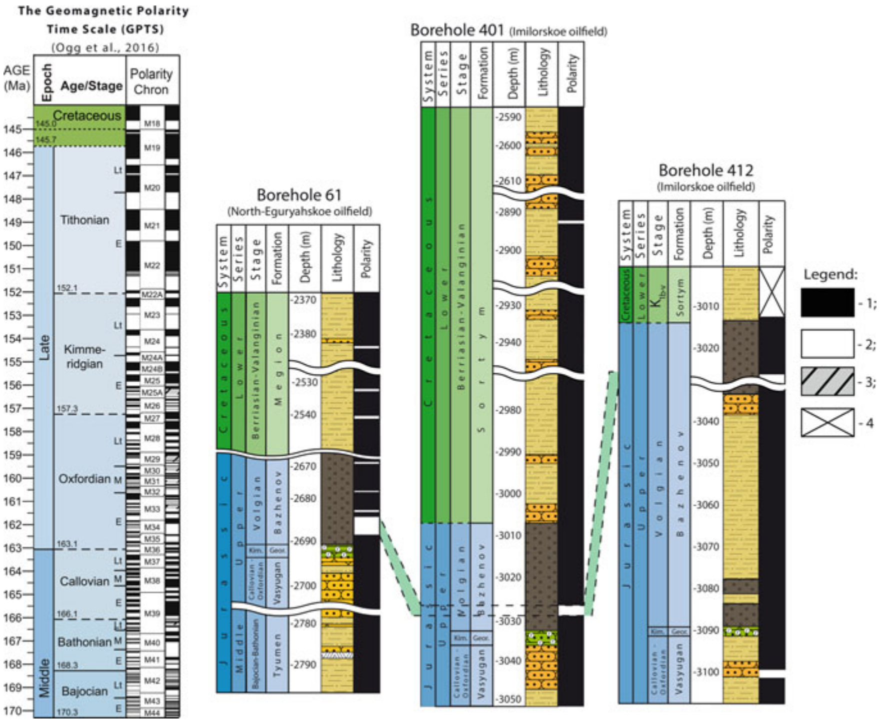


**Fig. 28.5** Comparison of magnetostratigraphic data of well material with the Geomagnetic Polarity Time Scale (GPTS). Legend: 1,2—normal and reverse polarity respectively; 3—uncertain polarity; 4—missing of paleomagnetic data. Other legend symbols: see Fig. 28.2

The results of T-cleanings up to 300 °C agree well with the demagnetization by alternating field (Fig. 28.4b).

The **ChRM,** isolated in the examined samples, correspond to both normal (N) and reverse (R) polarities, with inclinations (I) up to +88° and up to (−84°), respectively (Fig. 28.4c). But negative inclinations are recorded only in 13 stratigraphic levels (in ~4% of samples), and the paleomagnetic columns in all three wells are peculiarly dominated by the normal polarity (Fig. 28.5). Infrequent reversed polarity intervals are substantiated with samples from 1 or 2 levels, and therefore they cannot be formally recognized as independent magnetozones (according to Khramov and Sholpo (1967), a magnetozone must be substantiated with samples from at least three levels).

Dominant normal polarity, recorded in the studied sections, does not comply with the current notion of complicated alternating-sign paleomagnetic structure of the Bajocian-Berriasian (Ogg et al. 2016) (Fig. 28.5). Therefore, irrespective of the good quality of the paleomagnetic data, secondary remagnetization seems to be the most likely. Some circumstances, however, prevent from its absolute acceptance:

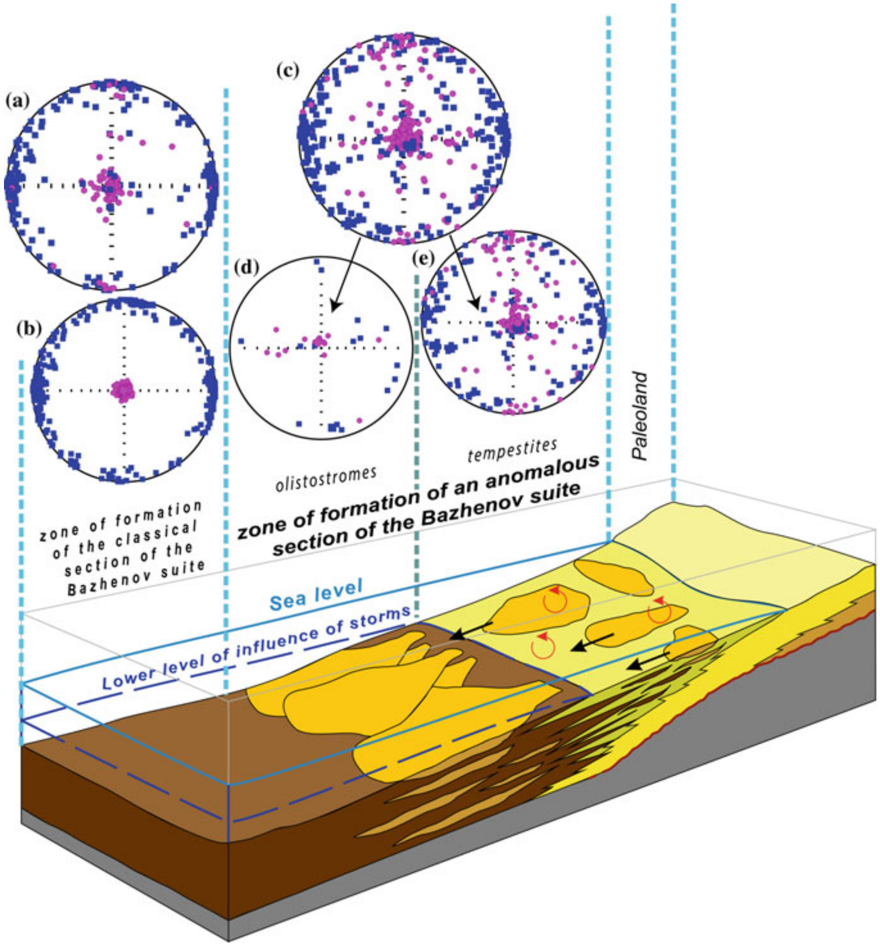


**Fig. 28.6** The proposed model of Bazhenov formation (BF) development on the base of data obtained from AMS. **a**, **b** classical section of BF in well 401: all samples (**a**), after the exclusion of supposedly bioturbated samples (**b**); AMS of anomalous section of BF: all samples (**c**), samples from well 280 (**d**), samples from wells 405 and 412 (**e**)

1. The reversed polarity interval in the lower part of classical Bazhenov formation is observed in the sections from Northern Yeguriahskoe (well 61p) and Imilorskoye (well 401) oilfields that are 180 km away from each other. It is not improbable, that the only reverse interval in the Bazhenov anomalous section (well 412) is coeval to them (Fig. 28.5). Similar lateral persistence is indicative of the **ChRM** ancient nature, and the small thicknesses of the reversed intervals in bituminous argillites may be explained by the sediment high water contents and low lithification rates in the Bazhenov Formation (Bordyug et al. 2010).

The water, squeezed by compaction into the sediment upper layers, could have contributed to reorientation of magnetic particles after a geomagnetic reversal. The normal polarity regime, dominant in the Tithonian, could have caused domination of normal magnetization in the Bazhenov Formation.

2. The sections of oil-and-gas bearing formations of Siberia are condensed (Baraboshkin 2008), and the attribution of sediments to a particular formation does not necessarily yield the exact age of sediments (The regional … 2004). Furthermore, a continental or subcontinental genesis of the Tyumen suite implies extremely uneven sedimentation rates (Kontorovich et al. 2010). Owing to these reasons, a paleomagnetic structure of studied sections may differ cardinally from the real reversal sequence.
3. The acquired data are in good accord with G. A. Pospelova’s (Paleomagnetism … 1976) materials on the Middle Ob Region which register only the normal polarity in the Volgian stage and dominantly normal polarity in the Bajocian-Kimmeridgian. Meanwhile, numerous thick reversed magnetozones are recorded in the Lower Cretaceous (Ogg et al. 2016), which makes the remagnetization rather unlikely.

## Conclusions

Detailed correlations of 3 wells separated by the distance from 20 up to 180 km were made from the kappametry and thermokappametry data.

Results of examining the anisotropy of magnetic susceptibility are at variance with all the versions of “uneven-aged” models of genesis of the Bazhenov anomalous section, but agree with the idea of close ages of terrigenous rocks and bituminous argillites. The acquired AMS data may be used to propose a model whose principal factors are the bottom relief of the Bazhenov basin and the sea-level fluctuations (Fig. 28.6). The essence of the model is that the tempestite sediments, formed during regressions in the shallow-water shelf zone close to the local elevation zones (paleoislands), were partially flushed into the deep-water zone as high-density turbidite flows, and were overlaid at the transgressive stages with clayey silts enriched in organic matter.

Regretfully, the acquired paleomagnetic data does not allow to prove either ancient or recent age of magnetization. Therefore, further magnetostratigraphic studies are required to obtain the magnetic polarity characteristics of the Bazhenov and other oil-and-gas formations in Western Siberia.

**Acknowledgements** The research was financially supported by the RFBR (projects №17-05-00716-a).

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