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The local magnetostratigraphic scale for the supra-evaporitic Miocene deposits in the northern part of Carpathian Foredeep and its stratigraphic implications (drill-core Jamnica S-119)

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The purpose of this study — to elaborate the local magnetostratigraphic sequence in the complete Jamnica S-119 core of Miocene marine sediments representing the time span from the Upper Badenian to Late Sarmatian/beginning of Pannonian(?), has been solved positively. The obtained results fulfill 6 of 10 criteria deciding about the proper quality of magnetostratigraphic data. The ferrosulphides — greigite and smythite — being the carriers of chemical magnetic remanence of secondary origin, had been identified for the first time in the examined Miocene sediments in Poland. Although the remanent magnetization has the secondary character — it has been acquired in short time after deposition of studied sequence of sediments — the obtained polarity sequence of the Earth magnetic field correlates properly with the fragment of the Global Polarity Time Scale between polarity chrones C3Br.3r and C5n.2n (~7.4–10.7 Ma). In spite of conducting the additional biostratigraphic studies of the investigated profile in the frame of this project there still exists unsolved question of the more precise location of the stratigraphic boundaries between the substages of the Middle Miocene against the time scale.

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GEOLOGICAL SETTING

The Polish part of the Carpathian Foredeep is filled by the very thick (up to 3500 m) and monotonous complex of mainly clayey, marine deposits. These deposits belong to the Middle Miocene: Langhian, Serravalian and Tortonian (or, using the regional nomenclature to Badenian and Sarmatian stages).

According to the current stratigraphical subdivision of this complex — the sub-evaporitic strata are attributed to the Lower Badenian, the evaporitic series to the Middle Badenian and the supra-evaporitic strata to the Upper Badenian and Sarmatian. The Sarmatian sequence consists of the thick complex of clays, marls and mudstones, called the Krakowiec Clay Formation (G. Czapowski, 1994), intercalated by sandy layers.

In spite of the realised biostratigraphical studies of benthic microfossils, nannoplankton and palynological data (E. Gaździcka, 1994; B. Studencka, 1996; J. Paruch-Kulczycka, 1999; A. Sadowska, 1999) the radiometric determination of absolute age and the application of independent methods of stratigraphical correlation, e.g. the magnetostratigraphy, is urgently required. Only such a complex study let us to re-interpretate the local stratigraphical sub-divisions on the discussed area. We try to solve the important question of stratigraphical correlation of the Central Paratethian sedimentary complex in Poland with the deposits of the same Middle Miocene age from the Vienna Basin and of the Mediterranean region, as well as, of the Eastern Paratethyan region — to compare them within a global correlation scheme more precisely than previously.

The core of Jamnica S-119, selected for the magnetostratigraphic analysis, is located in the northeastern part of the Carpathian Foredeep, in the area of Polish native sulphur deposits (Fig. 1). In this marginal part of sedimentary basin the total thickness of supra-evaporitic deposits is lowered to 250–300 m.

The studied profile consists mainly of marine deposits of the Middle Miocene for Central Parathetys with the total

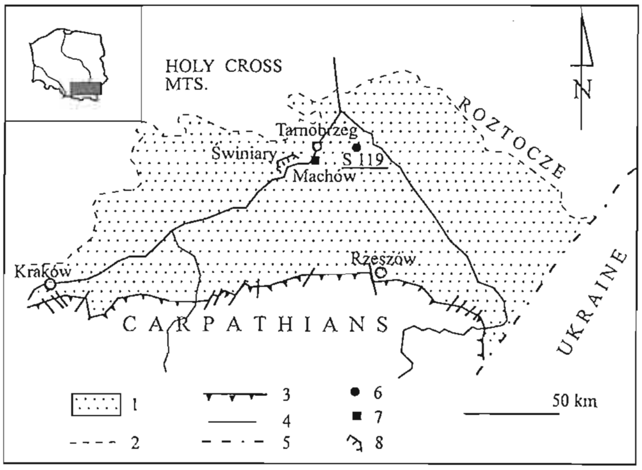


Fig. 1. Location of the borehole Jamnica S-119 in the Carpathian Foredeep

1 — Miocene of the Carpahian Foredeep; 2 — extent of Miocene deposits; 3 — Carpathian nappes overthrust; 4 — faults; 5 — state boundary; 6 — borehole; 7 — sulphur mine; 8 — outcrops of Miocene deposits

thickness 230 m (Fig. 2). They are subdivided on Late Badenian and Early Sarmatian and probably Early Pannonian — as finds e.g. J. Paruch-Kulczycka (1999). The top part of the core (30 m) build of Quaternary deposits was not studied.

Discussed borehole was placed in the locally tectonically undisturbed area (Z. Krysiak, 1994), different from tectonised surroundings. It has been confirmed by the detailed analysis of anisotropy of magnetic susceptibility, as the minimum value of susceptibility was detected perpendicular to the foliation of deposits along the whole core. The equatorial distribution of maximum and intermediate axes of magnetic susceptibility ellipsoid (on the spherical projection) fortify this conclusion. It indicates a primary sedimentary fabric, undisturbed by post-sedimentary neotectonic movements there.

The biostratygraphy of Jamnica S-119 profile has been especially studied during this project. The obtained results are presented by: E. Gaździcka (1994), J. Szczechura (1995), B. Studencka (1996), J. Paruch-Kulczycka (1999) and A. Sadowska (1999). The frequency analysis of occurred calcareous nannoplankton species from this borehole is reported by E. Gaździcka (1994) and NN zones are presented in Figure 2. The presence of ostracode genus *Xylocythere* in the bottom part of Jamnica S-119 profile and its biostratigraphic significance has been reported by J. Szczechura (1995). These results, together with the found benthic microfossils assemblages widely reported by J. Paruch-Kulczycka, B. Studencka and the results of pollen analysis along the core obtained by A. Sadowska (1999), offer the local biostratigraphic subdivision (Fig. 2). The deep-water (outer neritic/epibathical) ostracods were recognised in the lower part of the profile (from 240 m of the core deposits), defined as Late Badenian by J. Paruch-Kulczycka (1999), as well as, characteristic for the same period species of molluscs (B. Studencka, 1996). The results of nannoplankton classification, indicate the higher part of NN6 (in so-called chemical deposits and *Pecten* Beds) and NN7/NN8 in Krakowiec Clays. The higher zones, which should be expected at the top part of this profile, are poorly represented. So these results are not fully satisfactory, because the majority of nannoplankton species are either recycled many times from older deposits, part of them belongs to the long-lasting species or the frequency of characteristic species for the above mentioned zones is poor. The age of the bottom part of studied profile after nannoplankton zonation may be estimated not older than 11.0 Ma. The top part of it ascribed to NN9a zone should not be younger than 9.5–8.0 Ma and cited time intervals depend on position of these zones in the different stratigraphic subdivisions of Miocene, related to the standard time scale (e.g. in the stratigraphical table by W. A. Berggren *et al.* (1995).

The Badenian and Sarmatian deposits of the Carpathian Foredeep contain thin tuffite intercalations. The thicker and most widespread marker is a tuffite bed located within the Chodenice Beds (near Cracow). It has been dated on 11.2±0.8 Ma (J. A. Van Couvering *et al.*, 1981) by the fission-track age determination of zircons (separated from the corresponding youngest Bochnia tuffite layer). The new absolute age determinations of tuffites from the Carpathian Foredeep are still in progress. However, for example, the data reported by K. Bukowski *et al.* (1996) and M. Banaś (1996) for the tuffite layer WT-1 from the Wieliczka Salt Mine indicated on the impressive discrepancy of datings within the obtained ages of extracted hornblenda (by K-Ar method). It resulted from the difficulties of proper and precise determination of the amount of potassium in the studied hornblenda specimens. The obtained age varies in the wide range from 11.4±0.9 and 12.5±0.9 Ma to 18.3±1.7 and 28.3±2.7 Ma, what depends only on the evaluation of potassium percentage content. These relatively new results illustrate the difficulties of the K-Ar method application for such young tuffites.

M. Banaś reported that in studied tuffites from supra-evaporitic deposits the K-Ar radiometric dating of the sanidine seems to be promissible for stratigraphic purposes only, because this mineral is unsubjected to diagenetic transformations. The attempt to date the tuffites from the bottom part of Jamnica S-119 profile was failed, as the general amount of sanidine has been insufficient for the proper K-Ar analysis and the applying the other isotopes offered uncorrected data (M. Banaś, 1996). In such situation, consequently the radiometric age of the tuffites from the bottom part of Jamnica S-119 core could be only estimated unprecisely and indirectly, by comparing with the ages of tuffites from Wieliczka and Bochnia area, located also in a bottom of supra-evaporitic series.

The youngest radiometric data of the mentioned set of the order of 11 Ma — they disagree with the time ranges of the Lower Sarmatian and Upper Badenian substages in the assumed stratigraphic scheme. The limit between them is placed at 13.0 Ma (W. A. Berggren *et al.*, 1995; F. F. Steininger *et al.*, 1996; R. W. Jones, M. D. Simons, 1996; F. Rögl, 1996). It means, that in the case that the bottom part of our core (the lowermost 20 m) really belongs to the Upper Badenian, the probable Sarmatian/Badenian boundary should be shifted up in time from the previously fixed point in the stratigraphic time tables to the younger point (~11 Ma). Checking such a hypothesis requires applying the independent stratigraphical method, such as magnetostratigraphy, especially in a case of unsatisfactory quality and amount of radiometric datings. Also the hypothesis about the redeposition of Upper Badenian species in the lowest strata of Jamnica S-119 profile as well as considering presence of depositional hiatus in some levels of this sedimentary complex should be taken into account.

Chemical conditions in the Middle Miocene sea within the Carpathian Foredeep favoured the generation of magnetic minerals characteristic for an anoxic environment. In this marine basin of normal salinity the sediments rich in an organic matter frequently were submitted to an anoxic or/and oxygen-defficient conditions. It was proved by the common abundant of ferrosulphides in almost all the core, among which a paramagnetic pyrite is widely recognised. The continuous supply of sulphur ions from the underlying evaporite deposits favours the transformation of primary ferrooxides into secondary ferrosulphides. The low-oxygen environment was probably typical of the whole region of the Central Paratethys during Late Badenian–Early Sarmatian, resulted from the expansion of the oxygen deficit in the groundwaters of this sea, what was controlled by global oceanic changes in this period (J. Szczechura, 1995).

SAMPLING AND MEASUREMENTS OF MAGNETIC PARAMETERS

The Jamnica S-119 core was subivided into 230 fragments 1 m long. The every fragment was only oriented top–bottom. In spite of certain difficulties related to the mechanical state of some parts of core, which had been dried completely before sub-sampling, unequal numbers of small specimens from different fragments of the core was obtained. About 2500 small, cylindrical or cubic specimens have been cut from more than 90% length of the whole core. The specimens number was not less than 10 per metre, but usually it reached about 30 per metre. Sometimes, in the best preserved, clay layers up to 50 small specimens from an one metre were taken.

The measurements of magnetic properties of samples were divided in 3 groups:

a — the measurements of natural remanent magnetization (NRM) vectors together with their demagnetization procedure using the thermal treatment or alternating magnetic field techniques;

b — the measurements of magnetic susceptibility and its anisotropy;

c — the group of measurements and experiments to study the magnetic carriers of remanence, i.e. the chemical composition of the main ferrimagnetic minerals and to estimate the dimensions of their grains.

The intensity of NRM was measured with the *SQUID* magnetometer (2G — Enterprises, USA), to which the AF demagnetizer is attached. The thermal demagnetization has been performed with the automatic thermal demagnetizer (Magnetic Measurements, UK). The data were analysed to plot the components of RM in the Zijderveld orthogonal projections and to calculate the directions from the line-fitting least squares analysis (J. L. Kirchvink, 1980).

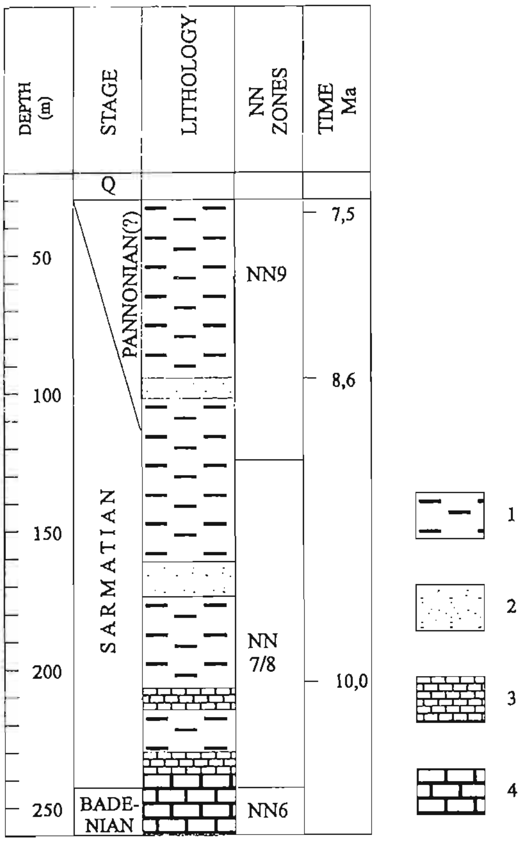


Fig. 2. Stratigraphy and lithology of the Jamnica S-119 profile in the frame of actual subdivisions of the Late Miocene and the results of biostratigraphic analysis

1 — clays and mudstones of Krakowiec Formation, 2 — mudstones with sand, 3 — marls with *Syndesmya*, 4 — marls with *Pecten*

The anisotropy of magnetic susceptibility was measured for all specimens with the *Kappa Bridge KLY-2* (Geofizyka N.P., Czech Republic) in 15 positions. It reveals the deposition fabrics with the vertical minimum susceptibility axes and the horizontal maximum/intermediate axes for the majority of core. Such fabrics is characteristic for magnetic and paramagnetic minerals in studied core and confirms that the borehole was located in tectonically undisturbed area (Fig. 3).

The trend of mean magnetic susceptibility and intensity of NRM and the mean values of magnetic inclination (after demagnetization) along the Jamnica S-119 core are presented on Figure 4. The average values of the first two parameters, calculated for all specimens representing the successive metres of core, have been used to show the changes of them depended mainly on the variable lithology. For clay leyers intercalated by sand and sandy layers values of susceptibility and intensity of NRM sharply decreases, for instance between 80 and 102, 150 and 190 m of core (Fig. 4). The highest values

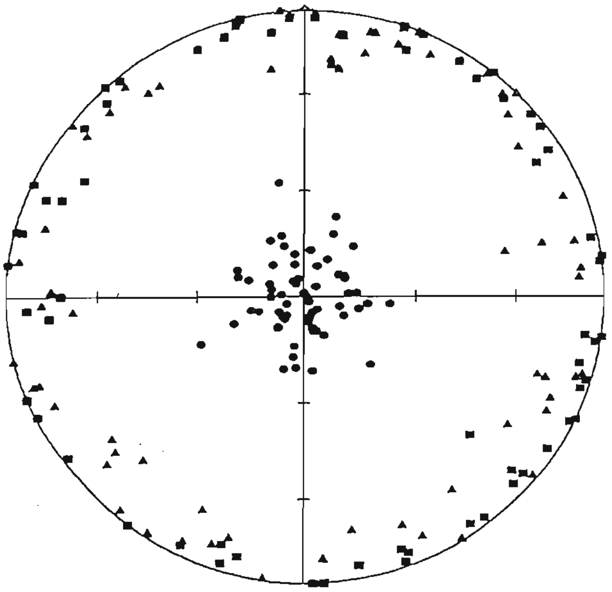


Fig. 3. The example of the distribution of the axes of anisotropy of magnetic susceptibility for the specimens from 55 m of Jamnica S-119 profile

circles — k_{min}, squars — k_{max}, triangles — k_{int}

of these parameters were noted for clays and mudstones with high content of ferrimagnetic minerals.

The general diminishing tendency of the mean susceptibility and intensity of NRM values downward the core resulted mainly from the lithologic differentiation and also from the composition changes of magnetic fraction therein. The sharp increase of mentioned parameters was observed in more clayey strata, enriched in ferrosulphides.

The lower part of core, between 230 and 260 m, comprised mainly limestones, with the lowest values of mean magnetic susceptibility and intensity of NRM. They contain almost paramagnetic material and are characterized by a more viscous and weak remanence.

The detailed study of the composition of magnetic fraction was performed to explain an acquisition and a character of magnetic remanence, with special attention to study the post-depositional magnetic remanence (PDRM). PDRM could be connected with magnetic minerals formed in reductive conditions within sediments just after deposition.

The determination of ferrimagnetic minerals from the rocks of Jamnica S-119 profile was described in details in the other paper (E. Król, M. Jeleńska, in preparation).

All experiments identifying these magnetic minerals are grouped for:

a — measurements of saturation magnetization, magnetic remanence and susceptibility of natural rocks and extracted magnetic fraction vs. temperature; these experiments enable us to discriminate between the true Curie temperatures of different magnetic carriers and the characteristic temperatures for chemical transformations;

b — X-ray and SEM/microprobe analysis of separated magnetic fraction; these two mentioned methods, applied for chosen samples taken from characteristic levels of core, have precedes a composition of ferrimagnetic and paramagnetic fraction and let to estimate a size and shape of magnetic particles;

c — study of parameters of hysteresis loop along the core-as the method of fast detection of sedimentary greigite (A. P. Roberts, 1995) and to evaluation of the kind of ferrimagnetic particles (SD — single domain, MD — multi domain or PSD — pseudo-single domain).

All above mentioned procedures of identifying magnetic minerals reveal the occurrence of ferrosulphides, among which the greigite and the smythite (both long-lived) are the main ferrimagnetic minerals responsible for the RM in marine clays and muds of Jamnica S-119 profile. A small amount of a primary fine-grained magnetite and titanomagnetite is only accessory in a character. The variations of hysteresis loop parameters along the core enabled the subdivision of studied rocks for two classes: first one with strong, stable component of remanence and second one, almost paramagnetic, characterized by highly viscous and weak remanence — which was present in limestone of bottom part of profile. The typical ferrimagnetic grain size belonged to the single or pseudo-single domain range.

CHARACTER OF THE NRM OF ROCKS IN THE LIGHT OF MAGNETIC MINERALOGY

ALTERNATING FIELD (AF) DEMAGNETIZATION

The specimens were demagnetized by AF in a two-coils system connected with the 2G cryogenic magnetometer *SQUID*. The demagnetization was performed in three directions without tumbling a specimen. The great amount of specimens taken from the most clayey and muddy fragments of studied profile (in its main segment from 30 to 230 m) have registered the big increase of intensity of RM during the AF demagnetization (Fig. 5). The mentioned effect starts usually about 60 mT of AF and continues up to the end of demagnetization process (150 mT). The sharp changes of magnetic inclination and declination have been noticed in this fragment of demagnetization process. The observed effect seems independent from the used type of demagnetizer (with or without tumbling), what has been specially tested on the chosen specimens from Jamnica collection in palaeomagnetic laboratories abroad. This effect is also independent of the position of sample in relation to the direction of demagnetizing field. The observed increase of intensity is caused by the spurious remanence (a gyromagnetic effect described by A. Stevenson, 1993).

In the last 30 m of profile, where limestone prevail, no spurious magnetization during AF demagnetizations was observed (Fig. 6). This can be explained by different composition of magnetic carriers (less ferrosulphides, more

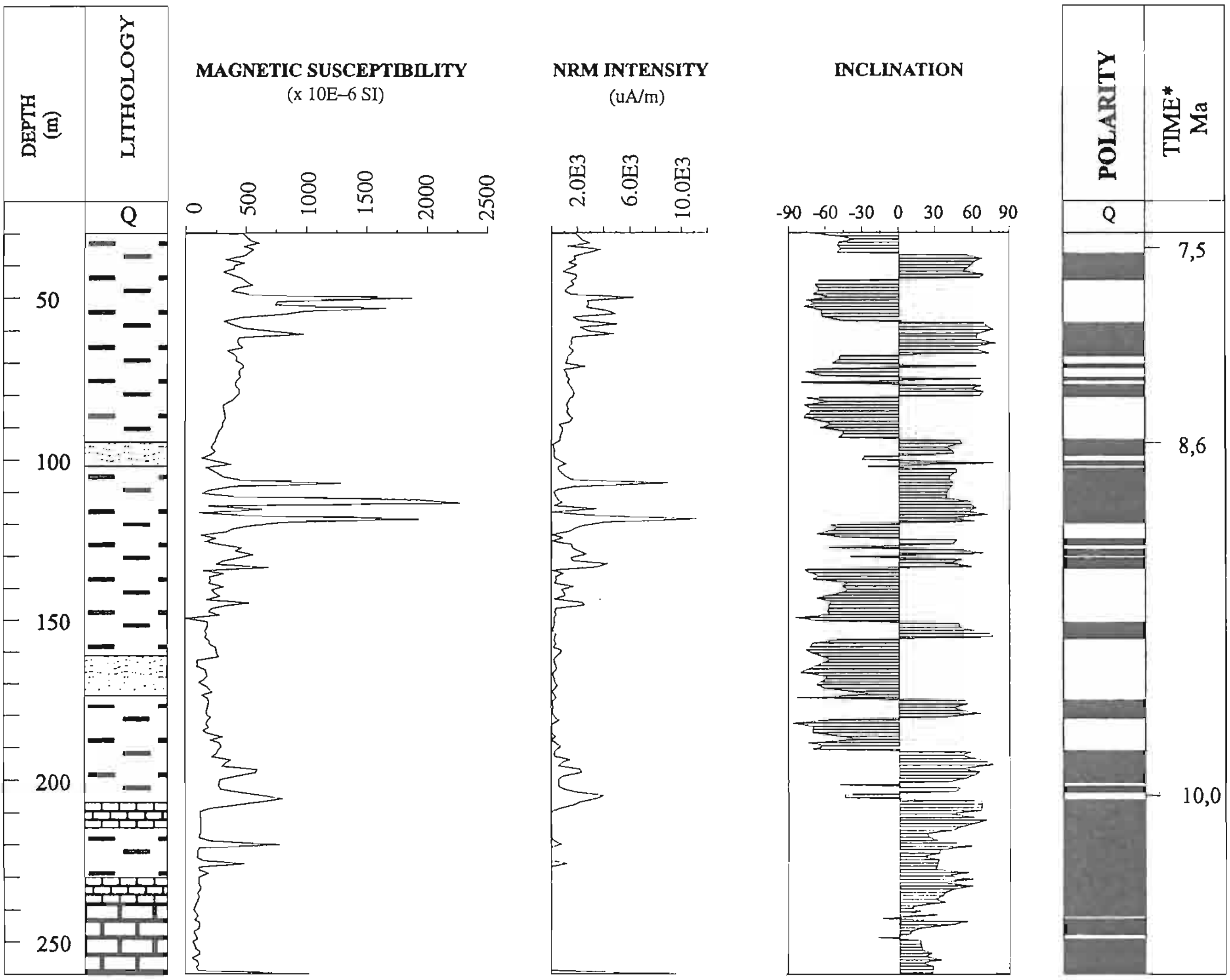


Fig. 4. Changes of the intensity of natural remanent magnetization, the main magnetic susceptibility and the averaged magnetic inclination (after AF or thermal demagnetization) along the Jamnica S-119 profile

* — the time scale is based on probable absolute age of the thin tuffite layers, present in the last metres of core, which can be compared with the youngest tuffites from Bochnia or Wieliczka area (11±0.9 Ma)

ferrooxides). The intensity of NRM is much weaker for these rocks which contain much more paramagnetic minerals.

ACQUISITION AND AF DEMAGNETIZATION OF ANHYSTERETIC REMANENT MAGNETIZATION (ARM)

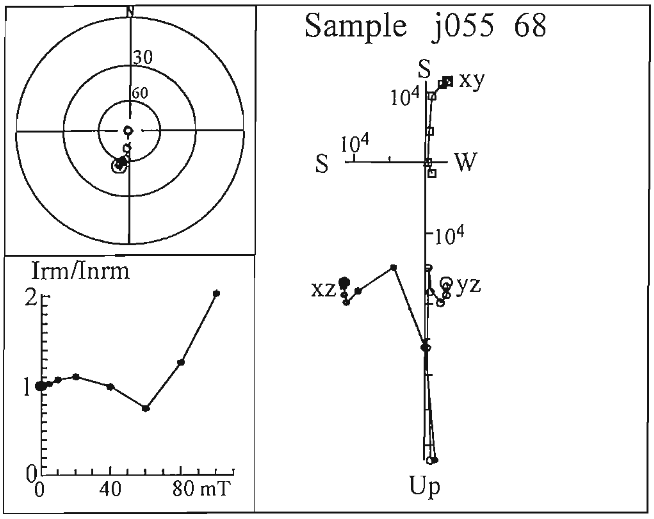
The acquisition of ARM done in the constant field of 0.5 Oe indicate the alternating field of about 60 mT, as a specific value in which the ARM increases rapidly. During AF demagnetization of the ARM within this field gyromagnetic effect was observed as well. This effect was similar as during AF demagnetization of NRM reported above, but the observed increase of intensity of ARM was relatively smaller.

The mean values of H_c (coercive force) and H_{cr} (coercivity of remanence) were determineted by measurements of hysteresis loop parameters along the core (about 50 and 70 mT, respectively) and they overlap with the characteristic range of the magnetic field for the acquisition and the demagnetization of ARM.

The question of generation of gyromagnetic RM in the fields close to the coercive force of ferrosulphides in these marine sediments requires further study.

THERMAL TREATMENT OF NRM AND MAGNETIC SUSCEPTIBILITY

The thermal demagnetization of specimens from the top and central part of core (Fig. 7) shows only one component, removed up to 350–370°C, with the same or similar directions to those obtained by AF treatment up to about 60 mT. At higher temperatures the oxidation process rebuilds completely the composition of ferromagnetic fraction, what was confirmed also by the rapid increase of the mean magnetic susceptibility in the same temperature range. Figure 8a pre-



After tectonic correction
Fitted lines of sample: j055 68

RANGE	D	I	INT (mA/m)	A.S.D.
0 to 10	200.6	86.7	1.77	2.9
20 to 60	193.0	-35.2	8.49	7.4

Fig. 5. The example of typical alternating field demagnetization for clay specimen (with greigite); notice the strong gyromagnetic effect in the AF higher than 60 mT

sents continuous record of the magnetic susceptibility change for separated magnetic fraction obtained from the clay specimen (taken from 55 m of profile) during heating and cooling. The enlarged fragment of Figure 8a shows the increase of susceptibility more detailly (Fig. 8b). The contribution of paramagnetic minerals to the total magnetic susceptibility could be neglected. The similar behaviour of NRM during AF and thermal demagnetization has been observed for marine sediments, containing greigite-smythite for the Miocene marine deposits exposed in Czech lignite open pits (M. Krs *et al.*, 1990, 1992, 1993).

The comparison of demagnetization data (by thermal and AF methods) allow to assume the component of NRM, removed during heating from a room temperature up to 350–370°C or by the AF field up to 50–70 mT, as the component with the characteristic direction of remanence. This component carried mainly by greigite and smythite is of chemical origin and is probably related to the early diagenesis of sediments within an unoxic environment, with a continuous sulphur supply and enriched in organic matter and bacteria. It was impossible to define precisely the time of greigite and smythite origin and, consequently, the delay time of remanence acquisition.

The above mentioned component of NRM was applied for reconstruction of a local geomagnetic polarity sequence in the studied core. But only the comparison of constructed this way local magnetostratigraphy with the GPTS is a method of estimation the existence of time delay in acquisition of the chemical remanence.

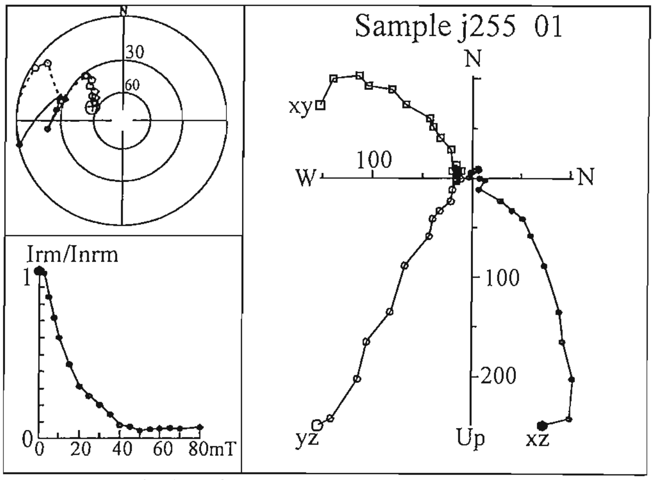
MAGNETOSTRATIGRAPHY OF MIOCENE DEPOSITS FOR THE JAMNICA S-119 BOREHOLE

Special version of reliability index for palaeomagnetic studies suggested by R. Van der Voo (1990) was elaborated by N. E. Opdyke and J. E. T. Channel (1996) for magnetostratigraphic study. Ten criteria listed in this paper should be checked to decide about the quality of magnetostratigraphic data. It is obvious that only few studies could be able to fulfil all these criteria. For example a lack of radiometric data or a field test, which can not be applied for horizontal or/and low inclined strata or for deep-sea cores of sediments, eliminates the using a part of them. However, ratings of at least 5 (out of 10 criteria) should be achieved by modern magnetostratigrafic studies.

In this study all these criteria were considered and are commented as follows:

1. The biostratigraphic studies of the Jamnica S-119 profile have been initiated and preliminary results are presented on Figures 2 and 4 and in the papers printed in this number of *Geological Quarterly*, as it was mentioned above. Therefore the stratigraphic is known adequately. The new, more precise biostratigraphic data let us to pose new questions about the limits of more accurate subdivision of the studied sequence and probability of the presence of sedimentary hiatus in it.

2. The specimens number was unequal. About 90% of the whole core has been sampled, but with not equal number of specimens per metre of core. For this reason the mean values of magnetic inclination (after demagnetization) calculated for



Geographical position
Fitted lines of sample: j255 1
ASD = 10.0

RANGE	D	I	INT (microA/m)	A.S.D.
65 to 80	177.2	-29.8	4.11	2.6
0 to 70	307.0	-56.9	299.00	9.0

Fig. 6. The typical example of AF cleaning of limestone specimen with ferrooxides

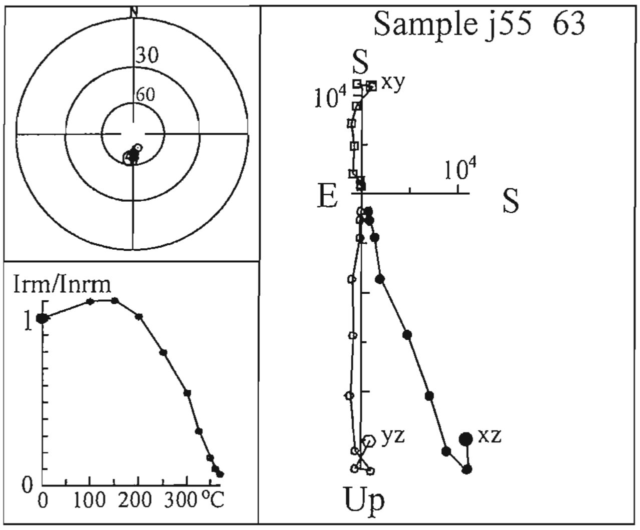
the all specimens from the following metres of the core, have been used — to show the general pattern of magnetic polarity changes along the core (Fig. 4). The applied method of averaging the data is satisfactory to obtain the reasonable accuracy between the recorded polarity zones in the Jamnica S-119 section and the fragment of GPTS.

3. The essential condition of making complete thermal or alternating field demagnetization together with the analysis of magnetization components has been fulfiled for this collection. The results has been analysed using the Zijdervel orthogonal projections.

4. The Kirschvink analysis has been applied for the results of AF and thermal treatment.

5. Because the core was subdivided into 1 m fragments with the orientation limited only to their top and bottom, the data of magnetic declination had arbitrary orientation and could not be analysed statistically. By accepting that an average magnetic declination had the value similar to the contemporary one in Poland (this means close to 0°) the Fisher statistics for calculation of the mean values of magnetic inclination was applied for separated fragments of core. The data are presented as inclination/stratigraphic distance plot (Fig. 4).

6. The composition of magnetic carriers and the character of remanent magnetization in the studied sediments was analysed in detail and the special paper devoted to magnetic mineralogy of the Miocene marine deposits by E. Król and M. M. Jeleńska (in preparation). The characteristic magnetic remanence in the Jamnica S-119 core is mainly of chemical origin and is connected with the secondary ferrosulphides. The observation of long-lasted greigite and smythite is one of the most important conclusion of the mineralogical study of magnetic carriers of these marine deposits.



Geographical position,
Fitted lines of sample: j55 63
ASD = 10.0

RANGE	D	I	INT (microA/m)	A.S.D.
0 to 370	179.4	-69.3	27400.0	4.5

Fig. 7. The example of thermal treatment of specimen with ferrosulphides

7. The field tests could not be applied, because the rocks studied were taken from the stored core. In spite of them, the detailed measurements of anisotropy of magnetic susceptibility confirmed the lack of serious neotectonic disturbances of sedimentary strata in the studied section. Consequently, the inclination data were considered as data not required the correction involved by a tectonic dip.

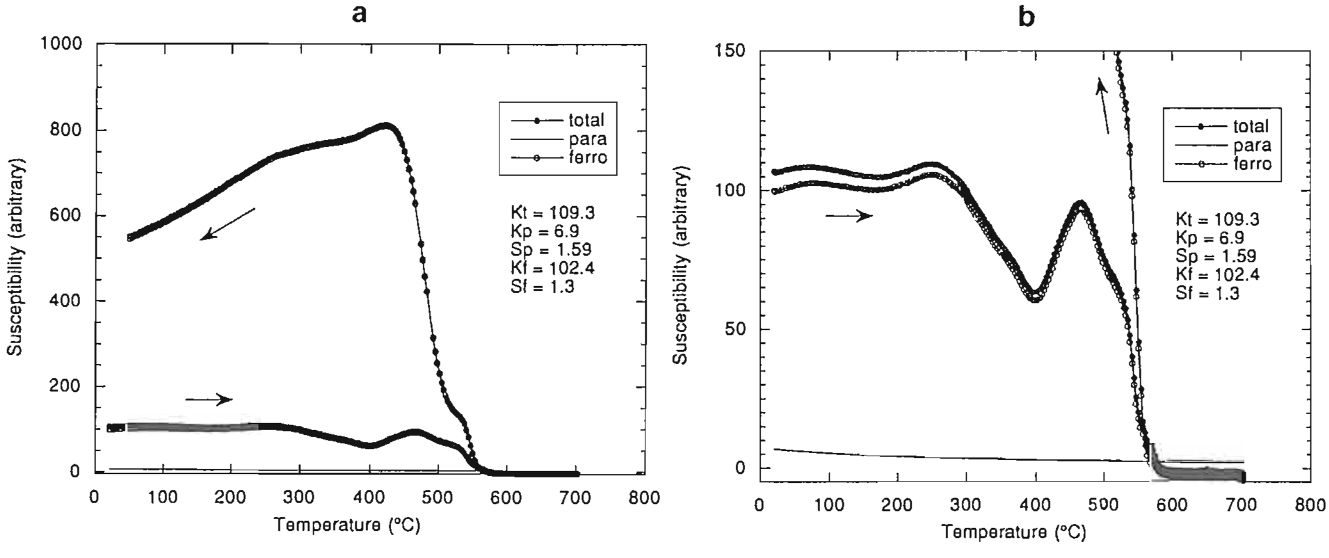


Fig. 8. The example of thermal change of mean magnetic susceptibility connected with the oxidation process of ferrosulphides during thermal treatment: a — the curve of thermal heating and cooling, b — enlarged fragment of Fig. 8a

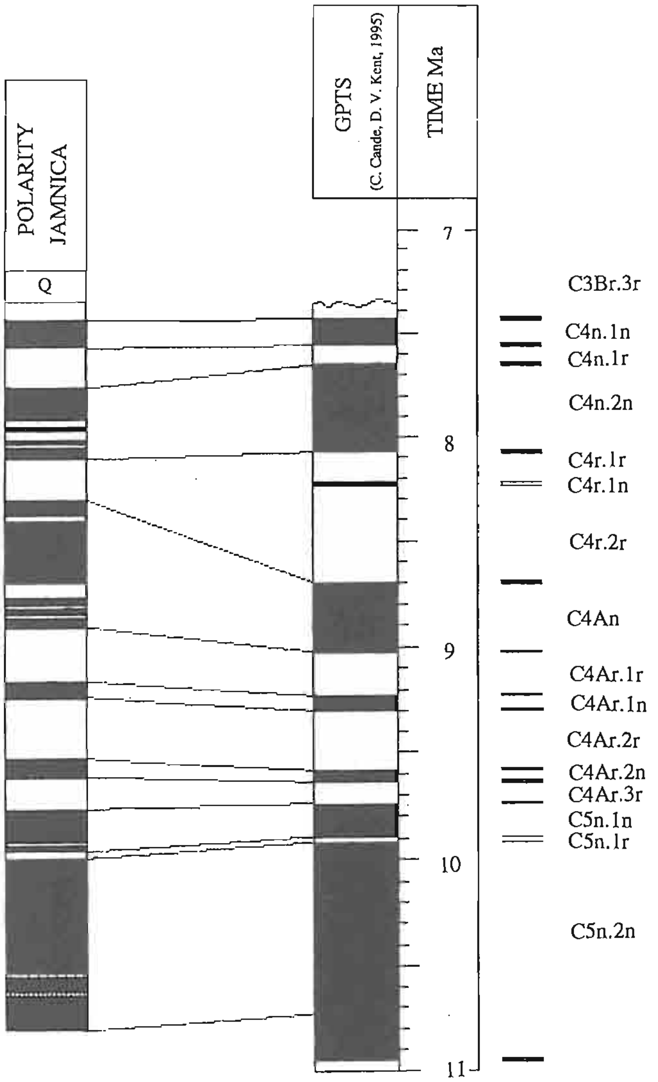


Fig. 9. The correlation of local magnetostratigraphic scale for Jamnica S-119 profile with the fragment of the Global Polarity Time Scale by C. Cande and D. V. Kent (1995)

8. The reverse of magnetic declination in the reversed polarity intervals of profile, noted by negative inclination, could not be checked because the declinations were not measured with a reference to a definite, common strike along the core.

9. Some attempts were done to determine the radiometric age of the tuffites from the bottom part of the Jamnica S-119 profile. The separated amounts of minerals taken for this purpose appeared insufficient to obtain the valuable radiometric data (M. Banaś, 1996). Only the comparison with the radiometric datings of tuffites from Bochnia (J. A. Van Couvering *et al.*, 1981) and from Wieliczka Salt Mine (K. Bukowski *et al.*, 1996; M. Banaś, 1996) could help to verify our local magnetostratigraphic scale with time.

10. Only the one relatively long core from the Carpathian Foredeep was analysed. The results for the define time span will be compared in the future with the results of magnetostratigraphic studies being in progress now for the Miocene sediments from the Ukraine.

To summarize the discussed above criteria, it is visible that at last six of them were fully achieved, so the magnetostratigraphic study of the Jamnica S-119 core fulfilled the suggested reliability index.

The polarity sequence presented for the core (Fig. 9) corresponds quite well with the fragment of GPTS by C. Cande and D. V. Kent (1995) in the time span between about 11 and 7.4 Ma (Fig. 9) this means between polarity chrons C4n.1n and C5n.2. This result proves that the isolated component of remanent magnetization can be assumed, as the component, which preserved the polarity of Earth's magnetic field from the time, which existed during the deposition of analysed sediments or from a short time after it. This means — a time span required for a chemical reduction of magnetic oxides to secondary magnetic sulphides, which are the carriers of characteristic RM — is in the studied rocks much shorter than duration of magnetic polarity zones.

The position of obtained local polarity scale in relation to results of biostratigraphic study of the Jamnica S-119 profile needs the following comments:

1. The average rate of sedimentation of the whole sequence may be evaluated on the basis of known mean values of subsidence in the studied part of Carpathian Foredeep and measured parameters of specific porosity and compaction of rocks from the Jamnica S-119 borehole. It was estimated by N. Oszczypko (1996*a*, *b*) on 0.07 mm/year. The whole time of the accumulation of studied sequence was calculated not longer than about 3.4 Ma. The time spans of marked polarity zones are indicated in Figure 9. To fit them with local magnetic polarity of Jamnica needs to differentiate the rates of sedimentation along the core from the value so low as for example 0.024 mm/year (in the normal polarity chron named C4n.2n which lasted 422 000 years) to higher values 0.09–1.00 mm/year (as in the normal polarity chron named C4An of duration 326 000 years). The values close to the mean rate of sedimentation (0.07 mm/year) are characteristic in the bottom and central part of Jamnica S-119 profile.

2. The discrepancy between the magnetostratigraphic position of studied complex and its biostratigraphic position *sensu lato* can be explained only by a new and more precise determination of the position of the boundary between the Upper Badenian and Lower Sarmatian. In the Jamnica S-119 core it looks that it should be shifted upward by about 2 Ma. Reviewing of the stratigraphic schemes presented by W. A. Berggren *et al.* (1995) and F. F. Steininger *et al.* (1996) stated, that the existing here nannoplankton zones (from the end of NN6, NN7, NN8 to the begin of NN9a) lasted about 3 Ma (parts of Upper Serravalian and Lower Tortonian) between 11.5 and 9 Ma. This period is named as the Late Sarmatian and Early Pannonian for the Central Paratethys and the Late Sarmatian and Meotian for the Eastern Parathetys area. In the studied profile the boundary between the Badenian and the Sarmatian stages (13 Ma) was placed in the bottom part of the core (at the depth about 240 m), but it disagrees with obtained magnetic polarity record and the time prescribed to this record (11 Ma). The long interval of normal polarity, persisted for almost 1 Ma and characteristic for the time span between 10

and 11 Ma (C5n.2), is there observed. This fact suggests three different explanations:

1. The fauna species described as Upper Badenian from the lower part of profile were redeposited here, in the younger about 2 Ma strata.

2. The studied profile charaterizes with a gap (hiatus in sedimentation) corresponding to the part of Early Sarmatian, but unregistered in sedimentological and magnetostratigraphic record. In such a case, the long chron of normal polarity named C5n.2 could in its lower part joint with the fragment of one of next, older normal polarity chron (in unknown division of time). The presence of anticipated gap of sedimentation implies lack of the whole C5r or even C5An and C5Ar polarity chrons in this profile.

3. The beginning of the Late Badenian should be shifted about 2 Ma upward in the absolute time scale.

To select the most true option, the farther stratigraphic investigations are required in multiple sections in studied and neighbouring area with application of different methods (especially magnetostratigraphy and the radiometric dating). With the special attention the presence of sedimentological gaps should be confirmed or negated.

CONCLUSIONS

The purpose of this study, to elaborate the local magnetostratigraphic sequence in the complete Jamnica S-119 core of Miocene marine sediments representing the time span from the Upper Badenian to Late Sarmatian/beginning of Pannonian (?), has been solved positively. The obtained results fulfill 6 of 10 criteria deciding about the proper quality of magnetostratigraphic data.

The ferrosulphides — greigite and smythite — being the carriers of chemical magnetic remanence of secondary origin, had been identified for the first time in the examined Miocene sediments in Poland.

Although the remanent magnetization has the secondary character — it has been acquired in short time after deposition of studied sequence of sediments — as the obtained polarity sequence of the Earth magnetic field correlates properly with the fragment of the GPTS (C. Cande, D. V. Kent, 1995).

In spite of conducting the additional biostratigraphic studies of the investigated profile in the frame of this project still exists unsolved to the end question of the more precise location the stratigraphic boundaries between the substages of the Middle Miocene in the time scale. An attempt should be directed for farther studies of the next profiles to correlate the data properly as well to obtain new radiometric datings of better quality.

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LOKALNA SKALA MAGNETOSTRATYGRAFICZNA NADEWAPORATOWYCH OSADÓW MIOCENU Z PÓŁNOCNEJ CZĘŚCI ZAPADLISKA PRZEDKARPACKIEGO I JEJ IMPLIKACJE STRATYGRAFICZNE (JAMNICA S-119)

Streszczenie

Celem stworzenia lokalnej skali magnetostratygraficznej dla utworów środkowego miocenu (górny baden–dolny sarmat) zapadliska przedkarpackiego zbadano osady morskie pozyskane z otworu wiertniczego Jamnica S-119 k. Stalowej Woli. Próbki do pomiarów paleomagnetycznych pobrano z kolejnych, jednometrowych odcinków rdzenia, o określonej orientacji strop–spąg. Kolekcja, wycięta z 230 m bieżących rdzenia, liczy ok. 2500 próbek (bez uwzględnienia 30 m osadów zawierających głównie utwory czwartorzędowe).

Otwór wiertniczy Jamnica S-119 został wytypowany do badań magnetostratygraficznych po szczegółowej analizie lokalnej sytuacji tektonicznej (Z. Krysiak, 1994) w obszarze mało zaburzonym przez ruchy neotektoniczne.

Bezpośrednia obserwacja ułożenia warstw osadów wzdłuż badanego profilu oraz analiza wyników pomiarów anizotropii podatności magnetycznej całej kolekcji potwierdziła poziome lub prawie poziome ułożenie warstw skalnych w badanej sekwencji osadów. Dzięki temu dla pomierzonych wartości inklinacji magnetycznej wektora naturalnej pozostałości magnetycznej wzdłuż całego rdzenia nie było potrzeby wprowadzania poprawek na upad warstw. Średnie wartości inklinacji magnetycznej (po rozmagnesowaniu) obliczone dla poszczególnych części badanego profilu były zatem podstawą wnioskowania o zmianach polarności ziemskiego pola magnetycznego z okresu depozycji i kompakcji badanej sekwencji osadów.

Badania składu frakcji minerałów magnetycznych występujących w badanych skałach stanowiły niezbędny warunek zrozumienia roli postsedymentacyjnych procesów chemicznych (redukcja tlenków żelaza do siarczków) w procesie nabywania chemicznej pozostałości magnetycznej, stanowiącej główną składową trwałego namagnesowania osadów. W badaniach składu minerałów ferromagnetycznych wykorzystano klasyczne metody termiczne (określania ich temperatur blokujących) oraz analizę rentgenowską i obserwacje pod mikroskopem elektronowym z mikrosondą wyseparowanej frakcji ferromagnetyków. Ponadto wykonano szczegółowe pomiary parametrów pętli histerezy dla próbek skał pobranych w równych odstępach wzdłuż rdzenia, co pozwoliło wyznaczyć poziomy litologiczne bogatszego występowania ferromagnetycznych siarczków żelaza: grejgitu i smytytu o jednodomenowych ziarnach, będących głównymi nośnikami chemicznej pozostałości magnetycznej. Pierwotne minerały magnetyczne — detrytyczne tlenki (magnetyt i maghemit) lub wodorotlenki żelaza — występują w badanych skałach w ilościach śladowych, zaś w warstwach o najniższych wartościach podatności magnetycznej i natężenia namagnesowania (np. w wapieniach) dominują paramagnetyki.

Przeprowadzono analizę numeryczną krzywych rozmagnesowania naturalnej pozostałości magnetycznej wszystkich próbek. Rozmagnesowanie wykonano bądź zmiennym polem magnetycznym, bądź też metodą termiczną. Stwierdzono, że do konstrukcji lokalnej skali magnetostratygraficznej należy wykorzystać składową pozostałości magnetycznej wyseparowaną z całkowitego wektora naturalnej pozostałości magnetycznej polem zmiennym nie wyższym niż 50–60 mT (z uwagi na wystąpienie silnego efektu gyromagnetycznego w wyższych polach rozmagnesowujących) albo składową wyseparowaną w trakcie grzania próbek do temperatur nie wyższych niż 350–370°C (tzn. do temperatur gwałtownego utleniania się siarczków żelaza). Jest to postsedymentacyjna składowa NRM pochodzenia chemicznego.

Uśrednione wartości inklinacji magnetycznej tej składowej NRM posłużyły do zestawienia przebiegu zmian polarności magnetycznej wzdłuż profilu. Wartości deklinacji magnetycznej nie mogły być wykorzystane z powodu braku orientacji rdzenia w płaszczyźnie poziomej.

Skalę magnetostratygraficzną opracowano przy zachowaniu 7 spośród 10 kryteriów dotyczących jakości i wiarygodności studium magnetostratygraficznego, zalecanych w nowoczesnych badaniach paleomagnetycznych (N. E. Opdyke, J. E. T. Channel, 1996).

Otrzymany przebieg zmian polarności magnetycznej w profilu Jamnica S-119 został skorelowany z fragmentem globalnej skali zmian polarności ziemskiego pola magnetycznego w czasie, zestawionej przez C. Cande i D. V. Kenta (1995), na odcinku od 11 do ok. 7.5 Ma. Porównanie lokalnej skali magnetostratygraficznej ze skalą globalną zostało zestawione z wynikami szczegółowych badań biostratygraficznych E. Gaździckiej (1994), J. Szczechurowej (1995), B. Studenckiej, J. Paruch-Kulczyckiej (1999) i A. Sadowskiej (1999) oraz pośrednią oceną prawdopodobnego wieku cienkich wkładek tufitów w spągowej części rdzenia (ok. 11 mln lat).

Posłużono się także oceną średniej prędkości sedymentacji badanych utworów (0.07 mm/a) na podstawie rozpatrzenia modelu ich subsydencji i kompakcji, z uwzględnieniem stopnia porowatości badanych skał (N. Oszczypko, inf. ustna).

Wnioski wypływające z porównania pozycji w czasie skali magnetostratygraficznej dla profilu Jamnica S-119 w zestawieniu ze schematami biostratygraficznymi skłaniają do rozważenia trzech możliwych sposobów wytłumaczenia obecności górnobadeńskich skamieniałości w spągowej części profilu Jamnica:

1. Fauna górnobadeńska obecna w spągowej części profilu została tam redeponowana w warstwach młodszych o co najmniej ok. 2 mln lat od warstw, w których pierwotnie była osadzana.

2. Badany profil może mieć lukę stratygraficzną odpowiadającą części dolnego sarmatu, która nie jest zauważalna w zapisie sedymentologicznym i magnetostratygraficznym.

3. Początek dolnego badenu powinien być odmłodzony o ok. 2 mln lat na skali wieku bezwzględnego.

Jedynie przebadanie kompleksowe porównawczych profili stratygraficznych, wraz z wyznaczeniem wieku radiometrycznego i wykonaniem magnetostratygrafii, może w przyszłości roztrzygnąć, która z tych opcji jest najbardziej uzasadniona.