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Multiple remagnetizations in the Devonian carbonates in the northwestern part of the Kielce region (Holy Cross Mts., southern part)

Givetian dolomites from Laskowa and Frasnian limestones from Kostomłoty (NW part of the Kielce region, Holy Cross Mts., southern part) were the subject of palaeomagnetic study. Post-folding age of characteristic remanent magnetization was confirmed at Kostomłoty and two new Late Carboniferous and EarlyPermian components were revealed that had not been described in the previous palaeomagnetic studies. The two components of magnetization in Laskowa dolomites are also most probably (fold test has not been applied) of Late Carboniferous-EarlyPermian age. Their acquisition was slightly shifted in time in relation to those of Kostomłoty limestones. The age of remagnetization is estimated as 315–275±10 Ma. Thermoviscous burial magnetization can not be unambiguously identified. A link between multicomponent remagnetization and Late Variscan ore mineralization is tentatively suggested. All palaeomagnetic poles from the investigated area are matched with the reference European apparent polar wander path after 13± 4.6° counter-clockwise intra-block rotation. This implies that the area was affected by Early Permian or later tectonic movements which modified the direction of the Late Carboniferous fold structures.

INTRODUCTION

Palaeomagnetic studies of Devonian and Carboniferous carbonate rocks were carried on by M. Lewandowski (1981, 1985). The author established, that the fold structures in the Holy Cross Mts. originated mainly during Variscan diastrophic cycle and the palaeomagnetic poles of characteristic components of magnetization roughly coincide with the apparent polar wander path (APWP) for Eurasia. However, the progress of analytical methods in palaeomagnetism and accumulation of new data (M. Lewandowski, 1993; J. Nawrocki, 1993) during last decade caused that some informations and conclusions presented in the older papers should be reinterpreted.

One of the problems was the mechanism and age of remagnetization of the Frasnian limestones cropping out at the "Kostomłoty" quarry. The Kostomłoty limestones revealed very consistent post-folding magnetization (M. Lewandowski, 1981). The palaeomagnetic pole (DS6) corresponded well with the inferred palaeomagnetic pole position for European Platform for 350 Ma (M. Lewandowski, 1993). This time of remanence acquisition (Tournaisian/Visean boundary) was obviously too early, because the main Variscan unconformity in the Holy Cross Mts. occurs above the Upper Visean, i.e. not earlier than 333 Ma and there is no geological evidences for the onset of folding already in Tournaisian. M. Lewandowski (1981, 1985) did not consider the possible mechanisms of remagnetization. According to Z. Bełka (1990) the carbonate rocks in the Kostomłoty area reveal one of the highest CAI values (3) in the Holy Cross Mts. Thus it would be possible that the Kostomłoty limestones acquired their remanence due to a thermal event of magnitude 150–200°C, related to burial and higher than contemporary heat flow regime during the Variscan orogeny (Z. Bełka, *op. cit*). However, preliminary palaeomagnetic data from equally heated rocks (CAI = 3–3.5) in the neighbouring "Laskowa" and "Mogiłki" quarries (J. Grabowski *et al.*, 1994) revealed well defined characteristic components which significantly deviate from the DS6 direction of M. Lewandowski (1993) from Kostomłoty (the results were presented at the EUROPROBE meeting at Kielce, 1994, at the poster session). Therefore the urgent need emerged to solve the following problems:

1. What is the real age of magnetization of the Kostomłoty limestones?

2. How was the thermal event recorded by palaeomagnetism and what were the other possible origins of remagnetization?

In this study the revision of palaeomagnetism of Kostomłoty limestones, and new data from Laskowa dolomites are presented.

GEOLOGICAL SETTING AND SAMPLING

The Holy Cross Mts. is the horst of Palaeozoic rocks emerging from below the Meso- and Cenozoic cover. The area was uplifted and exposed mainly due to vertical movements at the end of Cretaceous and in the Miocene (J. Kutek, J. Głazek, 1972). Palaeozoic core consists of two distinct tectono-stratigraphic units (the northern — Łysogóry region and the southern — Kielce region; Fig. 1), separated by a major Holy Cross Fault (for details see M. Szulczewski, 1977; E. Stupnicka, 1992).

Middle-Upper Devonian carbonate rocks in the southern region of the Holy Cross Mts. are the part of a syn-Variscan structural unit. The Emsian clastic sedimentation started after tectonic movements, uplift and erosion in the Late Silurian/Early Devonian. Afterwards a carbonate platform developed with variable littoral, reef and basinal facies (M. Szulczewski, 1977). The epigenetic dolomitization phenomena also took place (M. Narkiewicz, 1991). In the Early Carboniferous pelagic sediments prevailed, in the Late Visean they were replaced by thick clastic deposits. After the Visean the region was folded and uplifted. Flat lying or gently dipping Permian conglomerates covered the Palaeozoic structure.

The sampled localities are situated in the northwestern part of the Kielce region (Fig. 1). They belong to the westernmost termination of the great Kielce–Łagów Synclinorium, just south from the Holy Cross Fault. This is the area of most prominent fold structures

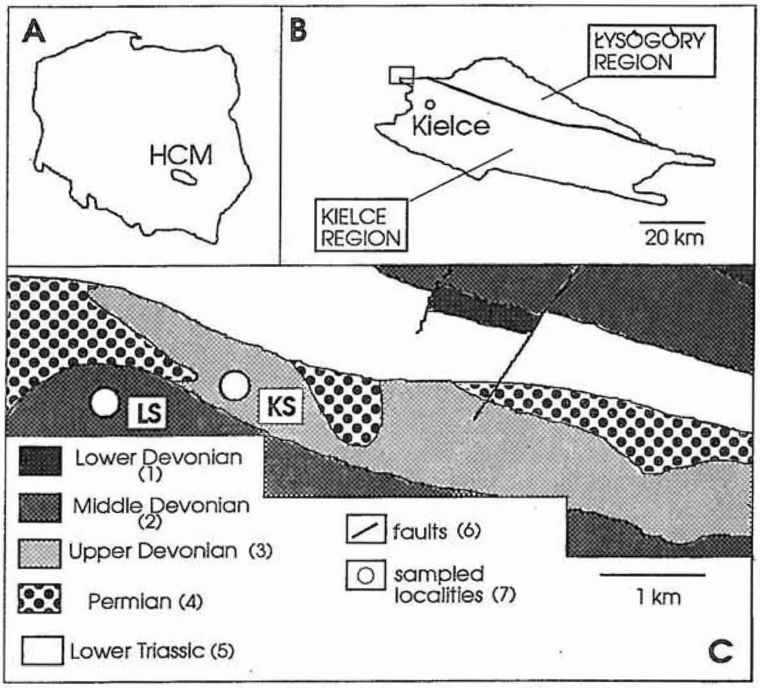


Fig. 1. Geological sketch of the investigated area (after S. Salwa, 1995, modified): A — general position of the Holy Cross Mts. (HCM), B — tectonic division of the Palaeozoic core of the HCM (little box indicates the area pictured in Fig. 1C), C — geological sketch map of the Kostomłoty Hills

LS — Laskowa, KS — Kostomłoty

Szkic geologiczny obszaru badań (według S. Salwy, 1995, nieco zmieniony): A — położenie Gór Świętokrzyskich (HCM), B — podział tektoniczny trzonu paleozoicznego Gór Świętokrzyskich (prostokąt wskazuje obszar pokazany na fig. 1C), C — szkic geologiczny Wzgórz Kostomłockich

1 — dewon dolny, 2 — dewon środkowy, 3 — dewon górny, 4 — perm, 5 — trias dolny, 6 — uskoki, 7 — miejsca opróbowania; LS — Laskowa, KS — Kostomłoty

developed during the Variscan movements (i.e. Kostomłoty) and the highest degree of thermal alteration (CAI = 3–3.5). In the western part of the Kielce–Łagów Synclinorium the occurrence of ore minerals (zinc, lead and copper compounds) are known. The mineral deposits were exploited in XV–XIX centuries. According to Z. Rubinowski (1971) there were two main phases of mineralization. The older "Variscan" was terminated before the deposition of Upper Permian conglomerates started. The younger phase is regarded as post-Triassic related to syn-Alpine tectonic events (Z. Rubinowski, *op. cit.*). The region is cut by NW–SE trending faults which disturb the WNW–ESE facing Variscan tectonic structures and down-thrust the Palaeozoic rocks to the west, where they disappear under the Mesozoic cover.

Table 1

Description of sampled localities

Locality	Lithology	Tectonic position*	Number of samples
Kostomłoty	dark limestones	16/52, 6/12, 145/15, 190/22, 10/70	8
Laskowa	dark dolomites (epigenetic)	355/40	10

* strike/bedding dip

LABORATHORY METHODS

Natural remanent magnetization (NRM) was measured by means of the *JR-5* spinner magnetometer. The rock specimens were thermally demagnetized with the MMTD oven. Alternating field (AF) demagnetization was carried out using a device produced at the Institute of Geophysics, Polish Academy of Sciences. Characteristic directions were calculated mainly using the principal component analysis (J. Kirschvink, 1980), but other methods (stable end vector, differential vectors) were also applied. Magnetic susceptibility was monitored with *KLY-2* bridge. Magnetic minerals were identified with thermomagnetic analysis. It consisted of thermal demagnetization in nonmagnetic space of isothermal remanence (IRM) acquired in the field of about 0.1 T (the first curve in appropriate Figs. 3a and 4a). Then the sample was cooled, magnetized and demagnetized again (the second curve in the Figs. 3a and 4a). This method gives values of blocking temperatures of magnetic minerals and shows what new minerals originate in the rock due to its heating in the air (J. Kruczyk *et al.*, 1995).

CONSTRUCTION OF THE REFERENCE APWP

Reference European APWP for Devonian-Permian periods was constructed using mean palaeopoles calculated by R. Van der Voo (1993, tab. 5.1) and calibrated according to A. R. Palmer's (1983) time scale. The calculation and smoothing of the path was done with the GMAP for Windows program (T. H. Torsvik, M. A. Smethurst, 1994), with smoothing parameter 100. The obtained reference curve, together with the data is shown in Figure 2. The relatively large error of the curve is observed within its Early Devonian-Middle Carboniferous segment, while the Late Carboniferous-Triassic segment is better defined. The dating of characteristic components was performed by comparing the palaeomagnetic pole with estimated age of calibrated segment of the APWP. The age estimation error should be about 10 Ma for Late Carboniferous-Early Triassic directions but it amounts to 35 Ma for Middle Devonian-Middle Carboniferous components.

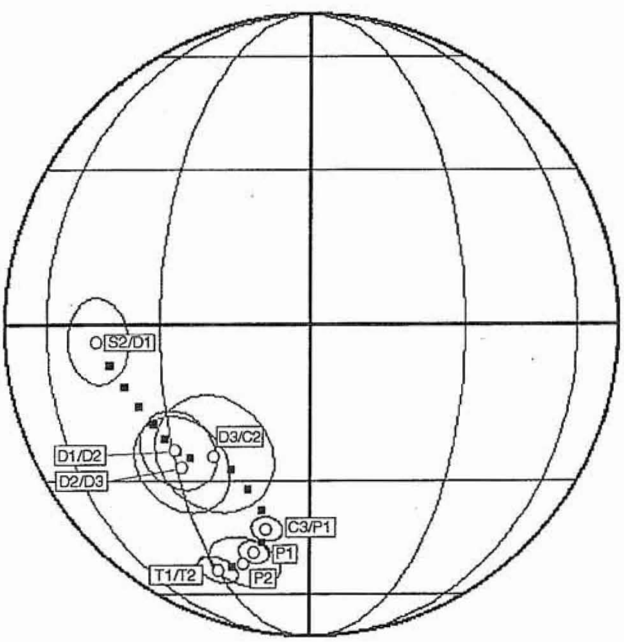


Fig. 2. European Apparent Polar Wander Path (APWP) based upon the Late Palaeozoic/Early Mesozoic data of R. Van der Voo (1993); mean poles are plotted with their error ovals of 95% confidence; the projection is centred in the origin of the geographic coordinates

S2 — Late Silurian; D1 (D2, D3) — Early (Middle, Late) Devonian; C2 (C3) — Middle (Late) Carboniferous; P1 (P2) — Early (Late) Permian; T1 (T2) — Early (Middle) Triassic

Pozorna wędrówka paleobieguna (APWP) dla Europy, od wczesnego dewonu do wczesnego triasu, na podstawie danych R. Van der Voo (1993); wokół średnich biegunów zaznaczono owale 95% ufności; środek projekcji znajduje się w początku geograficznego układu współrzędnych

S2 — późny sylur; D1 (D2, D3) — wczesny (środkowy, późny) dewon; C2 (C3) — środkowy (późny) karbon; P1 (P2) — wczesny (późny) perm; T1 (T2) — wczesny (środkowy) trias

ROCK MAGNETISM

Thermomagnetic analyses revealed that the magnetic minerals had maximum blocking temperature 500–550°C (Figs. 3a, 4a), which was tentatively interpreted as characteristic for magnetite, although these temperatures are lower than the Curie temperatures for that mineral. It can not be excluded, that another magnetic minerals such as pyrrhotite and maghemite could also contribute to the NRM. However, there was no reliable method at authors disposal to identify these minerals. Obviously goethite and hematite do not occur in the investigated rocks, because kinks at the Curie temperatures characteristic for these minerals (100–200°C for goethite and 680°C for hematite) are not observed at the thermomagnetic curves. During thermal treatment secondary magnetite originate, as can be seen from the shape of the second heating curves and large increase of the IRM intensity after the first heating (Figs. 3a, 4a).

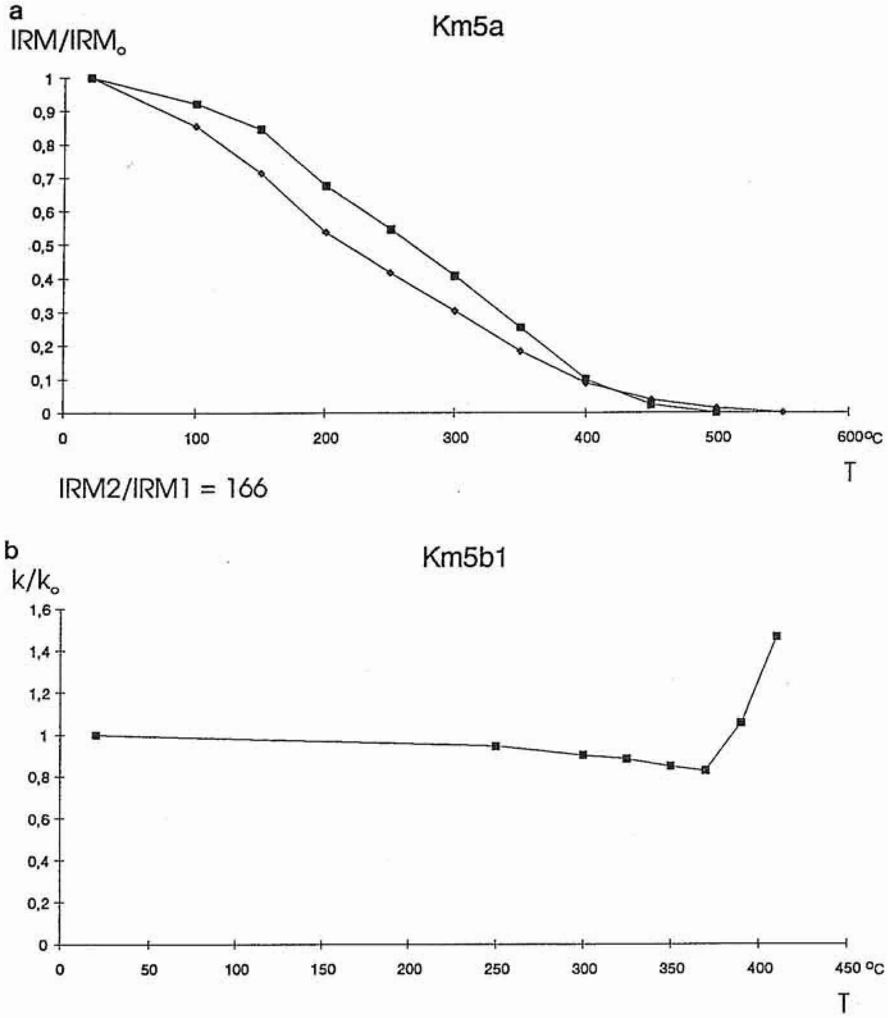


Fig. 3. Rock magnetic properties of the Kostomłoty limestones

a — thermal demagnetization of the isothermal remanent magnetization (IRM) (thermomagnetic analysis): squares — first heating curve, diamonds — second heating curve, IRM2/IRM1 — ratio indicates the increase of the IRM intensity after first heating; b — changes of magnetic susceptibility *k* during thermal demagnetization

Własności petromagnetyczne wapieni z Kostomłotów

a — termiczne rozmagnesowanie izotermicznej pozostałości magnetycznej (IRM) (analiza termomagnetyczna): kwadraty — krzywa pierwszego grzania, romby — krzywa drugiego grzania, IRM2/IRM1 — wzrost natężenia IRM po pierwszym grzaniu; b — zmiany podatności magnetycznej *k* podczas rozmagnesowania termicznego

Magnetic susceptibility amounts to 100–160 · 10^{-6} SI units at Kostomłoty and Laskowa. The mineralogy of investigated carbonates differs between localities in some details, because the production of secondary magnetite, as inferred from the increase of magnetic

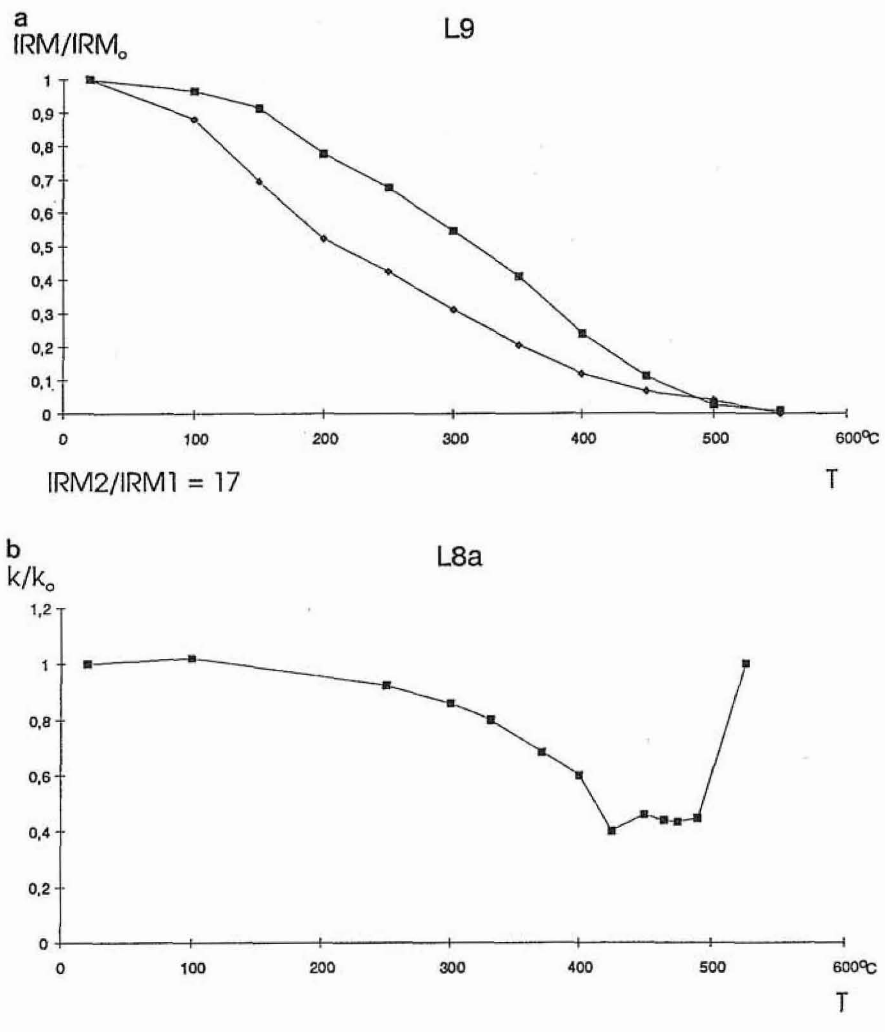


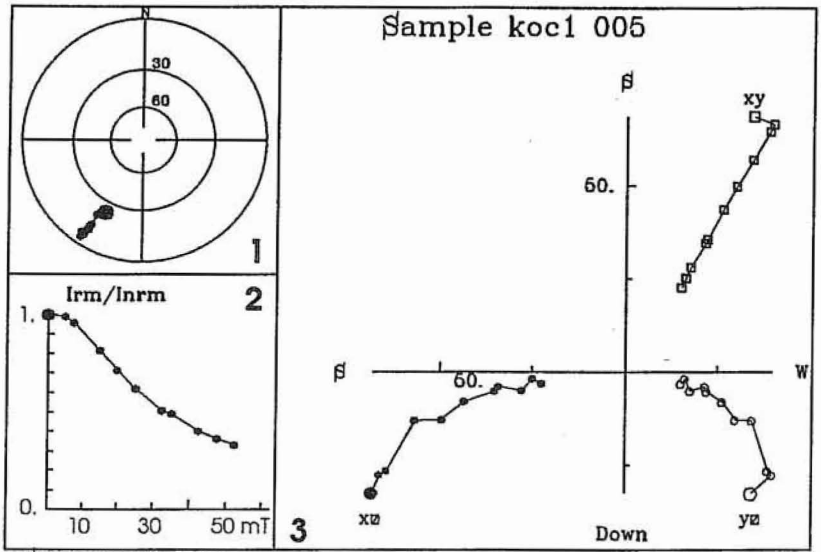
Fig. 4. Rock magnetic properties of the Laskowa dolomites

a — thermomagnetic analysis, b — changes of magnetic susceptibility *k* during thermal demagnetization; other explanations as in Fig. 3

Własności petromagnetyczne dolomitów z Laskowej

a — analiza termomagnetyczna, b — zmiany podatności magnetycznej *k* podczas rozmagnesowania termicznego; pozostałe objaśnienia jak na fig. 3

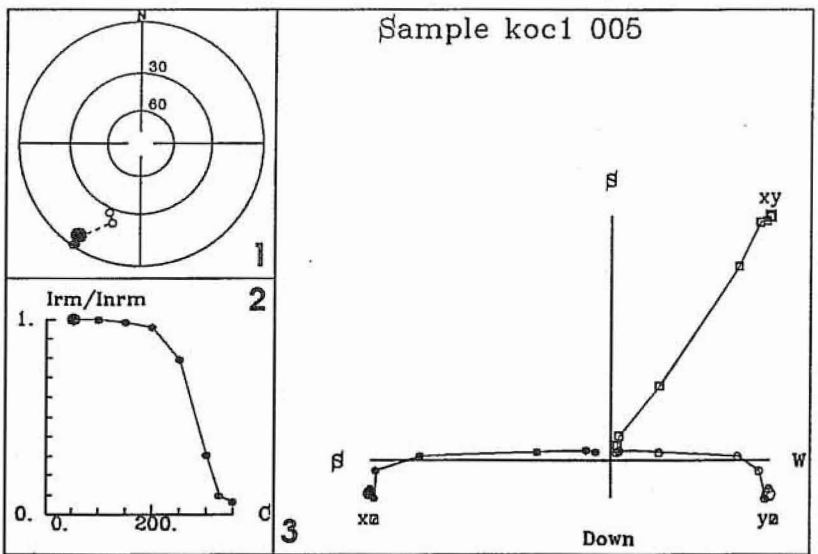
susceptibility in Kostomłoty limestones, is observed already at 375°C, while in Laskowa it occurs between 450 and 500°C (Figs. 3b, 4b). A peculiar feature is a dramatic decrease of magnetic susceptibility in the temperature range 250–425°C in many specimens from Laskowa. That could be attributed to goethite dehydration (J. Kruczyk *et al.*, 1995), however, in the investigated carbonates that mineral apparently does not occur. Another a



Geographical position.
Fitted lines of sample: koc1 5°

RANGE	D	I	INT	A.S.D
50 TO 525	211.3	13.8	.082	9.4

b



Geographical position.
Fitted lines of sample: koc1 5°

RANGE	D	I	INT	A.S.D
100 TO 350	213.3	3.6	.027	5.1

explanation of this phenomenon could be a convertion of maghemite to hematite. That process occurs at temperature above 350°C (F. D. Stacey, S. K. Banerjee, 1974) and may result in decrease of magnetic susceptibility: the spontaneous magnetization of maghemite is about 100 times greater than that of hematite (F. D. Stacey, S. K. Banerjee, *op. cit.*). If the occurrence of maghemite as a natural magnetic carrier in the investigated carbonates could be proved, it would be of great importance for interpretation of characteristic magnetizations. Maghemite is always a secondary mineral originating by slow oxidation of magnetite in temperature 150–250°C (F. D. Stacey, S. K. Banerjee, *op. cit.*). However, it cannot be excluded that maghemite in our samples originated in the laboratory during thermal demagnetization.

DEMAGNETIZATION RESULTS

KOSTOMŁOTY

The NRM intensities range from 5.03 to 20.3 · 10^{-4} A/m. Thermal and alternating field demagnetization methods were applied. The best results were obtained using combined both methods: up to 50 mT with AF and then thermally up to 350–370°C (Fig. 5). A very soft, randomly oriented component was removed between 0 and 5 mT. This is probably a viscous component of no further significance. Afterwards a KS1 component emerged, which was demagnetized mostly in the ranges of 5–50 mT and 250–300°C. After demagnetization to 50 mT usually 20–30% of the initial NRM intensity was left, what indicated the presence of other high coercivity components. Indeed, thermal demagnetization revealed two other components: KS2 and KS3 of blocking temperatures 200–350°C and above 350°C, respectively. All three components are post-folding because the cluster of characteristic direction is much better before unfolding of the beds (Tab. 2, 3). The values of the *k* parameter are

Fig. 5. Demagnetization of the Kostomłoty limestone (before tectonic correction): a — alternating field demagnetization, b — further thermal demagnetization of the same specimen

1 — stereographic projection of the demagnetization path: black (open) symbols — lower (upper) hemisphere directions, bigger symbol — NRM direction; 2 — intensity decay curve: *Inrm* — the intensity of the NRM, *Irm* — the intensity of the remanent magnetization after thermal treatment; 3 — orthogonal projection (Zijderveld diagram): *x*, *y*, *z* — planes of projection, bigger symbols — the NRM components, one unit is 10^{-4} A/m; RANGE — temperature or alternating field interval of calculated line, *D* — declination, *I* — inclination, *INT* — intensity (x10^{-2} A/m), *A.S.D.* — angular standard deviation of the best fitted line

Rozmagnesowanie wapieni z Kostomłotów (układ przed korekcją tektoniczną): a — rozmagnesowanie polem zmiennym, b — dalsze rozmagnesowanie termiczne tej samej próbki co w (a)

1 — projekcja stereograficzna ścieżki rozmagnesowania: symbole pełne (puste) — projekcja na dolną (górną) półsferę, symbol większy — kierunek naturalnej pozostałości magnetycznej (NRM); 2 — krzywa spadku natężenia podczas rozmagnesowania: *Inrm* — natężenie NRM, *Irm* — natężenie pozostałości magnetycznej po wygrzaniu; 3 — projekcja ortogonalna (diagram Zijdervelda): *x*, *y*, *z* — płaszczyzny projekcji, symbole większe — składowe NRM, jedna jednostka na osi — 10^{-4} A/m; RANGE — przedział temperatury lub zmiennego pola magnetycznego dla wyróżnionej linii (kierunku), *D* — deklinacja, *I* — inklinacja, *INT* — natężenie (x10^{-2}A/m), *A.S.D.* — kątowe odchylenie standardowe linii najlepszego dopasowania

Table 2

Characteristic directions from the Kostomłoty limestones (Frasnian), before tectonic correction

Component	*D*	*I*	α_{95}	*k*	Pole		*n/N*
					lat. S	long. E	
KS1	220	8	4.2	42.1	–25	336	29/8
KS2	219	–8	3.3	65.2	–33	333	29/8
KS3	216	–24	5.1	26.3	–42	331	29/8

D, *I* — declination and inclination of palaeomagnetic direction, α_{95}, *k* — Fisher statistics parameters, *n/N* — number of specimens/samples used for the calculation of the mean direction

Table 3

Characteristic directions from the Kostomłoty limestones (Frasnian), after tectonic correction

Component	*D*	*I*	α_{95}	*k*	Pole		*n/N*
					lat. S	long. E	
KOS 1	227	22	12.0	5.9	–16	333	29/8
KOS 2	224	7	11.4	6.3	–24	332	29/8
KOS 3	219	–10	11.7	5.8	–34	332	29/8

Explanations as in Table 2

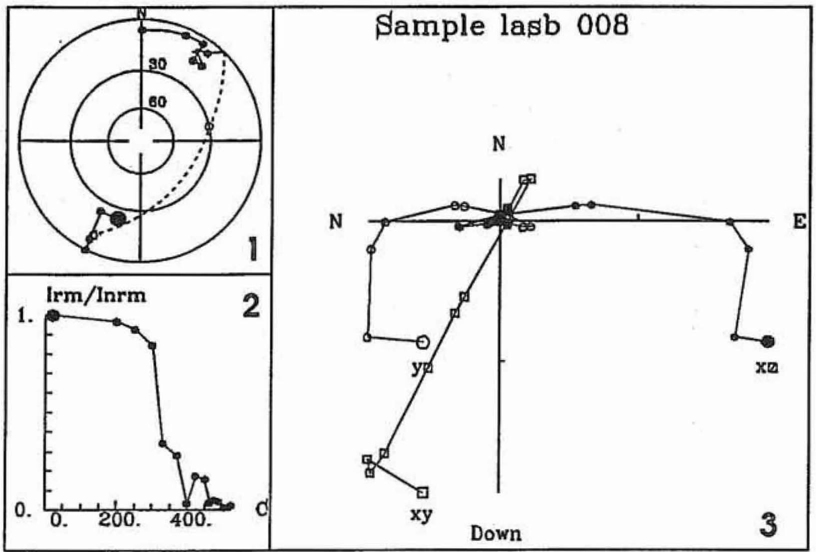
4–10 times higher before tectonic correction, thus the simple fold test of M. W. McElhinny (1973) is sufficient for establishing the age of remanence.

It should be noted that thermal demagnetization alone does not enable to separate the KS1 and KS2 components. These components have overlapping blocking temperature spectra but different coercivities. Combined alternating field and thermal cleaning is needed for identification of all components.

LASKOWA

Most of the NRM intensities range between 1 and $5.51 \cdot 10^{-3}$ A/m. Thermal demagnetization was applied to bulk of collection (Fig. 6). Single specimens were demagnetized using AF or combined method. These methods, however, did not lead to good separation of characteristic components, as in the previous locality. Usually about 10% of the initial NRM intensity was left after demagnetization up to 50 mT.

The soft, viscous component is removed between 20 and 300°C. The LS1 component (Tab. 4, 5) occurs in most of samples and it constitutes the main part of the NRM. It is demagnetized between 250 and 400°C. The LS2 component, almost anti-parallel to the LS1, reveals the blocking temperature spectrum 400–500°C.



Geographical position.
Fitted lines of sample: lasb 8

RANGE	D	I	INT	A.S.D
475 TO 505	36.9	13.1	.004	11.3
425 TO 465	33.7	4.5	.015	7.2
300 TO 425	208.3	−.6	.112	4.5
200 TO 300	269.1	83.1	.042	10.7

Fig. 6. Thermal demagnetization of the Laskowa dolomites (before tectonic correction)
Explanations as in Fig. 5
Rozmagnesowanie termiczne dolomitów z Laskowej (układ przed korekcją tektoniczną)
Objaśnienia jak na fig. 5

AGE OF REMANENCE

Although the sampling localities were not very distant from each other (1 km only) and they belong to the same tectonic structure (southern limb of the Miedziana Góra Syncline), considerable variety of characteristic directions is observed.

Post-folding age of remanence could be established at Kostomłoty because only there a fold test could be performed. The KS1 component is identical to the DS6 component of M. Lewandowski (1993) and its pole is situated exactly on the reference APWP near an inferred date 350 Ma (Fig. 7a). Palaeopoles KS2 and KS3 lie to the NW from the Permian sector of the European APWP. Their age must be of Early Permian, because inclination of KS2 and KS3 components corresponds to the expected Early Permian inclination of the area. After counter-clockwise rotation of 13±4.6° around a vertical axis situated in the sampling locality, the KS2 and KS3 components are matched with the reference path with

Table 4

Characteristic directions from the Laskowa dolomites (Givetian), before tectonic correction

Component	D	I	α_{95}	k	Pole		n/N
					lat. S	long. E	
LS1	213	–10	4.4	39.5	–36	338	28/9
LS2	34	16	5.0	42.9	–36	335	15/6

Explanations as in Table 2

Table 5

Characteristic directions from the Laskowa dolomites (Givetian), after tectonic correction

Component	D	I	α_{95}	k	Pole		n/N
					lat. S	long. E	
LS1	216	19	4.3	40.4	–22	342	28/9
LS2	34	–14	5.3	39.1	–25	343	15/6

Explanations as in Table 2

the inferred dates 305 and 275 Ma, respectively (Fig. 7c). The same rotation applied to the KS1 pole matches it with the 316 Ma pole of the reference curve (Namurian/Westphalian boundary).

The age of magnetization at Laskowa has to be established by comparison with the reference APWP only. Poles LS1 and LS2 after tectonic correction falls near the date 336 Ma (Fig. 7b). However, it must be born in mind that they should be subjected to rotation around the vertical axis, the same as was applied to the post-folding Kostomłoty poles. It is authors presumption that the rock formations in Laskowa did not stay fixed while rotation was taking place 1 km to the east at Kostomłoty. After that rotation the pre-folding LS1 and LS2 poles would be situated well outside the reference curve. One could argue that the Devonian-Middle Carboniferous segment of the European APWP is poorly defined (see Fig. 2) and the pre-folding age of LS1 and LS2 cannot be totally rejected. However, post-folding age of these components seems more probable. Before tectonic correction the poles are situated between the post-folding KS2 and KS3 poles (Fig. 7a) and the counter-clockwise rotation of 13° around the vertical axis matches them with the Early Permian segment of the reference curve (Fig. 7c) at 300 (LS1) and 285 Ma (LS2). They become also very similar to a pole of the A direction of J. Nawrocki (1993) obtained from remagnetized carbonates in the Cracow region and synchronous with intrusions of Lower Permian volcanites in the area.

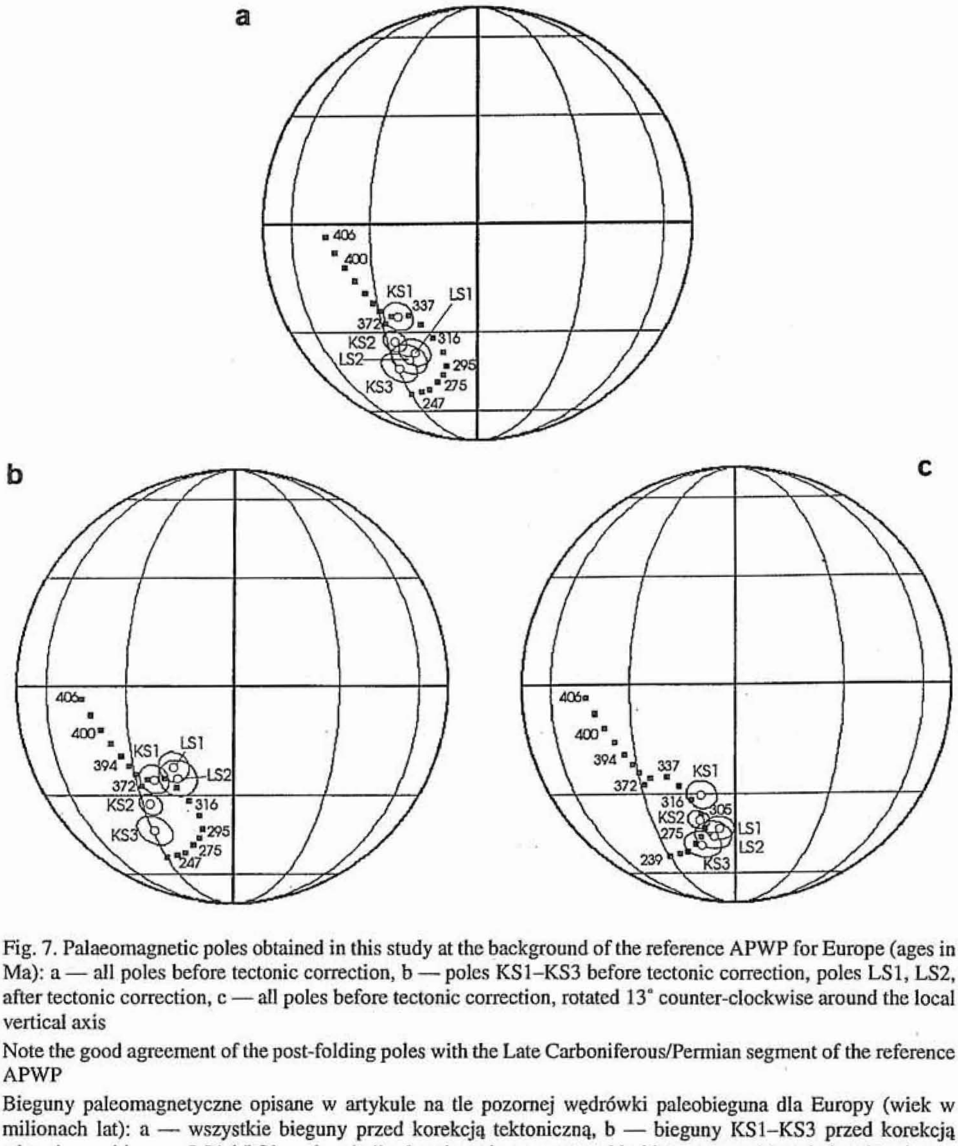


Fig. 7. Palaeomagnetic poles obtained in this study at the background of the reference APWP for Europe (ages in Ma): a — all poles before tectonic correction, b — poles KS1–KS3 before tectonic correction, poles LS1, LS2, after tectonic correction, c — all poles before tectonic correction, rotated 13° counter-clockwise around the local vertical axis

Note the good agreement of the post-folding poles with the Late Carboniferous/Permian segment of the reference APWP

Bieguny paleomagnetyczne opisane w artykule na tle pozornej wędrówki paleobieguna dla Europy (wiek w milionach lat): a — wszystkie bieguny przed korekcją tektoniczną, b — bieguny KS1–KS3 przed korekcją tektoniczną, bieguny LS1 i LS2 po korekcji tektonicznej, c — wszystkie bieguny przed korekcją tektoniczną, zrotowane o 13° przeciwnie do ruchu wskazówek zegara wokół lokalnej osi pionowej

Zwraca uwagę dobra zgodność biegunów pofałdowych z późnokarbońsko-permskim odcinkiem krzywej referencyjnej

GEOLOGICAL IMPLICATIONS

The studied Middle-Upper Devonian dolomites and limestones revealed secondary magnetizations of post-folding (Late Carboniferous/Early Permian) age in Kostomłoty and

Laskowa. The remagnetization phenomena were distributed in time and space. Thermoviscous magnetization that should originate during Variscan burial and uplift event (Z. Bełka, 1990) can not be unambiguously identified because several secondary components are superposed. Chemical remagnetization should also be postulated, related to Pb–Zn–Cu mineralization events, hydrocarbons migration or magnetite authigenesis due to migration of meteoric waters (C. McCabe, R. D. Elmore, 1989; R. D. Elmore *et al.*, 1993). Determining of the mechanism of remagnetization requires more detailed mineralogic and rock magnetic investigations. A causal link between remagnetization and ore mineralization could be tentatively suggested in the light of recent report of S. Salwa (1995). According to this author the Kostomłoty quarry is a "type locality" of occurrence of Variscan calcite mineralization related to hydrothermal copper-polymetallic formation. Indeed he mentions paragenesis of calcite with pyrite, marcasite, quartz, copper sulphides, barite, dolomite, zinc and lead sulphides (S. Salwa, *op. cit.*). It is possible that the same mineralized fluids caused magnetite authigenesis. Z. Rubinowski (1971) accounts for relation of ore mineralization to lamprophyre intrusions in the Kielce region. Similarity of palaeomagnetic poles from Kostomłoty (KS2) and Laskowa (LS1 and LS2) to A pole of J. Nawrocki (1993) could indicate that these remagnetizations were synchronous with the Lower Permian intrusions of volcanites in the Cracow region. Thus the origin of remagnetization in Kostomłoty and Laskowa could be different than that occurring in North American mid-continent, where remagnetization is related to a Zn–Pb–Ba Mississippi-type ore formation and migration of mineralized brines (C. M. Bethke, S. Marshak, 1990).

Late Carboniferous/Early Permian directions from Kostomłoty and Laskowa are rotated and $13 \pm 4.6^{\circ}$ counter-clockwise rotation is needed to match them with expected "European" directions. A tectonic rotation responsible for that discrepancy might have taken place in the Mesozoic, for example during the syn-Alpine uplift of the Palaeozoic core. Examples of tectonic deformations of that age are common in the western part of the Holy Cross Mts.: no more than 5 km to the west from Kostomłoty (Chełmce Anticline) a Palaeozoic rocks crop out with fault contacts from beneath the rocks of Mesozoic cover (J. Czarnocki, 1938). Recently J. Kutek (1995) postulated that the Holy Cross Fault acted in the Jurassic and Cretaceous as a strike-slip fault. Thus some rotational movements in its close vicinity are not unlikely. Restoration of Laskowa and Kostomłoty fold structures to its Early Permian position results in changing of present WNW–ESE tectonic trends to W–E. It is still not possible to establish if the rotation was of local or regional character. Available palaeomagnetic data from the Permian of the Holy Cross Mts. (listed in the paper of M. Lewandowski, 1993) are scarce and its accuracy is too low ($\alpha_{95} = 15–20^{\circ}$) to use them for evaluating subtle tectonic rotation. It is interesting that recently J. Kruczyk *et al.* (1995) described similar amount of rotation (15° clockwise) from the Jurassic rocks of the Mesozoic cover, south from the Palaeozoic core of the Holy Cross Mts., and estimated its age as Oligocene-Miocene.

CONCLUSIONS

1. Middle-Upper Devonian carbonate rocks from the NW part of the Kielce region (Kostomłoty and Laskowa) reveal post-folding magnetizations of Late Carboniferous/Early

Permian age (ca. 315–275 Ma). Magnetite seems to be the main magnetic carrier but the presence of maghemite or pyrrhotite is also possible.

2. A tectonic rotation (13±4.6°clockwise,) in the Kostomłoty and Laskowa area took place after Early Permian.

3. Late Carboniferous/Early Permian secondary components could be thermoviscous as well as chemical remagnetizations. The latter are possibly related to copper-polymetallic ore mineralization.

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ZŁOŻONE PRZEMAGNESOWANIE WĘGLANOWYCH SKAŁ DEWONU W NW CZĘŚCI REGIONU KIELECKIEGO GÓR ŚWIĘTOKRZYSKICH

Streszczenie

Przedmiotem analizy paleomagnetycznej były skały węglanowe środkowego i górnego dewonu z północno-zachodniej części regionu kieleckiego Gór Świętokrzyskich. Opróbowano skały z kamieniołomu „Laskowa" (dolomity żywetu) i „Kostomłoty" (wapienie franu). W wapieniach kostomłockich potwierdzono istnienie pofałdowego przemagnesowania wieku późnokarbońskiego (składowa KS1). Stwierdzono też obecność dwóch młodszych składowych namagnesowania (KS2, KS3) wieku późny karbon-wczesny perm , które nie były opisywane w poprzednich pracach paleomagnetycznych. W kamieniołomie „Laskowa" nie przeprowadzono testu fałdowego, jednak kierunki charakterystyczne uzyskane z dolomitów żyweckich (składowe LS1 i LS2) są podobne (choć nie identyczne) do otrzymanych w Kostomłotach. Można z dużym prawdopodobieństwem przyjąć, że są to również pofałdowe przemagnesowania wieku późny karbon-wczesny perm.

Mechanizm przemagnesowania pozostaje niejasny. Najprawdopodobniej niektóre ze składowych są związane z późnowaryscyjskim wydarzeniem termicznym, które spowodowało przeobrażenie materii organicznej w konodontach — wskaźnik zmian barwy konodontów wskazuje na podgrzanie skał do 150–200°C. Wydarzenie to jest wśród geologów interpretowane jako efekt pogrzebania skał dewońskich pod nadkładem karbonu i zwiększonego wypływu ciepła podczas orogenezy waryscyjskiej. Jednak zgodnie z takim modelem, jednolite przemagnesowanie powinno występować w skali regionalnej. Tymczasem w kamieniołomach odległych od siebie zaledwie o jeden kilometr występuje kilka różnych przemagnesowań utrwalonych między 315 i 275±10 mln lat. Nie negując możliwości, że niektóre z nich mogły utrwalić się w wyniku pogrzebania i wypiętrzenia Gór Świętokrzyskich w późnym paleozoiku, należy rozpatrzyć też inne możliwe przyczyny przemagnesowania. Jedną z nich mogła być cyrkulacja roztworów hydrotermalnych, które doprowadziły do powstania złóż miedzi (formacja miedziowo-polimetaliczna) eksploatowanych m. in. w pobliskiej Miedzianej Górze. Wiek tej mineralizacji oceniany jest właśnie jako późnowaryscyjski, wcześniejszy od sedymentacji permskiego zlepieńca zygmuntowskiego. W kamienioło-

mie „Kostomłoty" opisano niedawno przejawy mineralizacji kalcytowej w paragenezie z pirytem, markasytem, kwarcem, siarczkami miedzi, cynku i ołowiu oraz barytem.

Bieguny paleomagnetyczne z Laskowej i Kostomłotów leżą systematycznie na NW od odpowiedniego odcinka referencyjnej krzywej pozornej wędrówki paleobieguna dla Europy. Niezgodność ta znika po rotacji wokół osi pionowej przechodzącej przez miejsca pobrania próbek, o 13±4,6° przeciwnie do ruchu wskazówek zegara. Możliwa rotacja tektoniczna odpowiedzialna za tę niezgodność mogła mieć miejsce we wczesnym permie lub później. Świadczy to, że ruchy tektoniczne po głównej (sudeckiej) fazie orogenicznej modyfikowały geometrię struktur fałdowych również na obszarze trzonu paleozoicznego Gór Świętokrzyskich.