ROCK - MAGNETIC STUDY OF THE GOGOŁOW-JORDANOW SERPENTINITE UNIT OF THE PALEOZOIC SUDETIC OPHIOLITE (SOUTH POLAND)

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ABSTRACT

The Sudetic ophiolite is composed of several dismembered fragments of obducted rock series formed in a MOR regime. One of them - the Gogołów - Jordanów massif is built of totally serpentinized ultramafic rocks. The oceanic serpentinization and several later episodes of continental alteration took place in hydrothermal regime and at temperatures lower than the hydrothermal ones. The alteration resulted in the formation of several phases of magnetite partly transformed into martite and maghemite. Some fine-grained magnetites underwent single phase low temperature oxidation leading to formation of a thin maghemite coating around a magnetite core which influenced the rock-magnetic characteristics.

INTRODUCTION

Ophiolites, formed at the oceanic bottom due to spreading processes and emplaced on land, may bring very useful informations about formation and evolution of the oceanic lithosphere. Rock-magnetic study together with geochemical investigation give data concerning alteration of magnetic minerals that leads to formation of secondary components of magnetic remanence due to remagnetization processes. The results obtained play a principal role in interpreting the origin and age of the natural remanence NRM and help in answering questions about the tectonic setting of the studied ophiolitic bodies (see for example Trench et al., 1990; Didenko, 1992; Coulton and Harper, 1995; Gnos and Perrin, 1996).

The present paper discusses the magnetic mineralogy of the Gogołów-Jordanów (GJ) massif of Paleozoic serpentinites in the Sudetes. The thorough study of the magnetic minerals - carriers of natural magnetic remanence - is fundamental for the proper interpretation of paleomagnetic data. The preliminary paleomagnetic report was already presented (Kądziałko-Hofmokl and Jeleńska, 1998); the results discussed in the present paper will serve as basis for their final interpretation which is outside the aim of this study.

GEOLOGICAL SETTING

The Sudetes, the eastern part of the Bohemian Massif form the easternmost portion of the European Variscans (Fig. 1a). They are built of a mosaic of blocks of various origin and lithology, among which some ophiolitic fragments also occur. The most important of them is the so called Sudetic ophiolite consisting of several massifs surrounding the Sowie Góry Mts gneissic block (SG, Fig. 1b). The geochemical study of this ophiolite, shows that it is a „surviving" fragment of an obducted rock series formed in a MOR regime (Dubińska and Gunia, 1997; Żelaźniewicz et al.,1998; Jędrysek at al.,1991; Jędrysek 1995; Abdel Wahad and Mierzejewski, 1998; Abdel Wahad, 1999; Floyd et al., 2000).

The paleomagnetic and rock-magnetic study of this ophiolite began several years ago with investigations of the gabbroic massif of Ślęźa (SL), the gabbroic massif of Ząbkowice (ZA) and gabbros, diabases and pillow lavas of Nowa Ruda (NR) (Jeleńska et al., 1995). The preliminary results obtained for GJ serpentinites are published in Kądziałko-Hofmokl and Jeleńska (1998), the present paper presents more thoroughly the rock-magnetic part of the study.

The studied GJ serpentinite massif covers an area of about 90 km^2 situated between the SL gabbroic massif associated with sheeted dykes and some pillow lavas found recently (Floyd et al., 2000) to the N, and the SG Mts. to the S. To the NW it is bounded by the Strzegom-Sobótka (SS) Carboniferous granitoid intrusion. The Mt Sleza gabbros were dated with the Sm-Nd method (Pin et al., 1989) to 353±21 Ma, with the Pb-Pb on zircons to 420±20 Ma (Oliver et al.,1993). For the serpentinite massif, the only isotopic age is 400±4 Ma (Żelaźniewicz et al., 1998), obtained with the U-Pb method on zircon crystals found in a rondingitized plagiogranite within serpentinite. The Sm-Nd 353 Ma age is now interpreted as the age of the metamorphism rather than the age of the rock. The U-Pb age of gabbros is close to the Pb-Pb age of the serpentinite massif, both pointing to an Early Devonian age of the ophiolite. In the Late Devonian (360-370 Ma), the ophiolite was uplifted together with the GS gneisses (van Breemen et al., 1988; Żelaźniewicz et al., 1998) that are dated through REE concentration in garnet from peridotite to 402 Ma (Brueckner et al., 1996). Whether the ophiolite underlies or overlies the SG block remains still an open question.

The SS granitoids, according to the $^{87}Sr/^{86}Sr$ age determination (Pin et al., 1989) were emplaced in two stages dated to about 280 Ma and 325 Ma. Another author (Jarmołowicz-Szulc, 1987) suggests that the intrusive activity could have even occurred in three phases, at about 280, 310 and 330 Ma, respectively.

The parent rock of the GJ serpentinite was harzburgite with minor amounts of lherzolite, dunite and wherlite (Dubińska and Gunia, 1997). The first phase of alteration of these rocks - oceanic serpentinization - started close to the spreading centre shortly after formation of the rocks and took place at temperatures lower than the hydrothermal ones, perhaps even as low as about 230°C. This is supported by presence of rodingites within the serpentinite body (Dubińska and Gunia, 1997) and study of hydrogen and oxygen isotopes (Jędrysek et al., 1991). Later stages of alteration took place in continental conditions, mainly at temperatures of 200 -250ºC, as indicated by lizardite-chrysotile formation (Dubińska and Gunia, 1997) and in weathering conditions. Similar temperatures are suggested by occurrence of ophicarbonates that formed at temperatures of 190-303ºC, partly in an oceanic environment and partly during to continental metamorphism related to the Variscan tectonics: uplift of the SG and intrusion episodes of SS granitoids (Jędrysek, 1995).

The rocks for the present study were sampled in four quarries where exposed serpentinites were relatively fresh (Fig. 1c): Gogołów G - 8 samples, Kiełczyn K - 9 samples, Słupice S - 14 samples and Przemiłów P - 9 samples.

EXPERIMENTAL METHODS

The multiple alteration episodes that affected the studied serpentinites caused their magnetic mineralogy to change several times; good identification of magnetic minerals is therefore a crucial problem in the interpretation of paleomagnetic data. Microscopic and thermomagnetic methods were used for this purpose, their results were combined with the analysis of hysteresis parameters and bulk susceptibility against temperature.

– Microscopic methods consisted in the analysis of polished sections with ore microscope (performed by J. Siemiątkowski from the State Geological Institute, Wrocław, Poland),several representative specimens were analyzed with the electron microscope (SEM) with microprobe (Jeo135 with EDS ISIS, performed by B. Kazimierska and £ącki from the State Geological Institute, Warsaw, Poland) and Stereoscan of Cambridge Instruments with Link Analytical (performed with the help of M. Hanzlik from Freising University, Freising, Germany).
– Thermomagnetic analysis consisted in a study of the decay curve of the remanence (Ir) acquired in the field of 1T during heating to 650-700∞C in the field-free space using the home-made device (Kądziałko-Hofmokl and Kruczyk, 1976). This method gave values of blocking temperature Tb. The same procedure was repeated twice for the same specimen in order to see the influence of

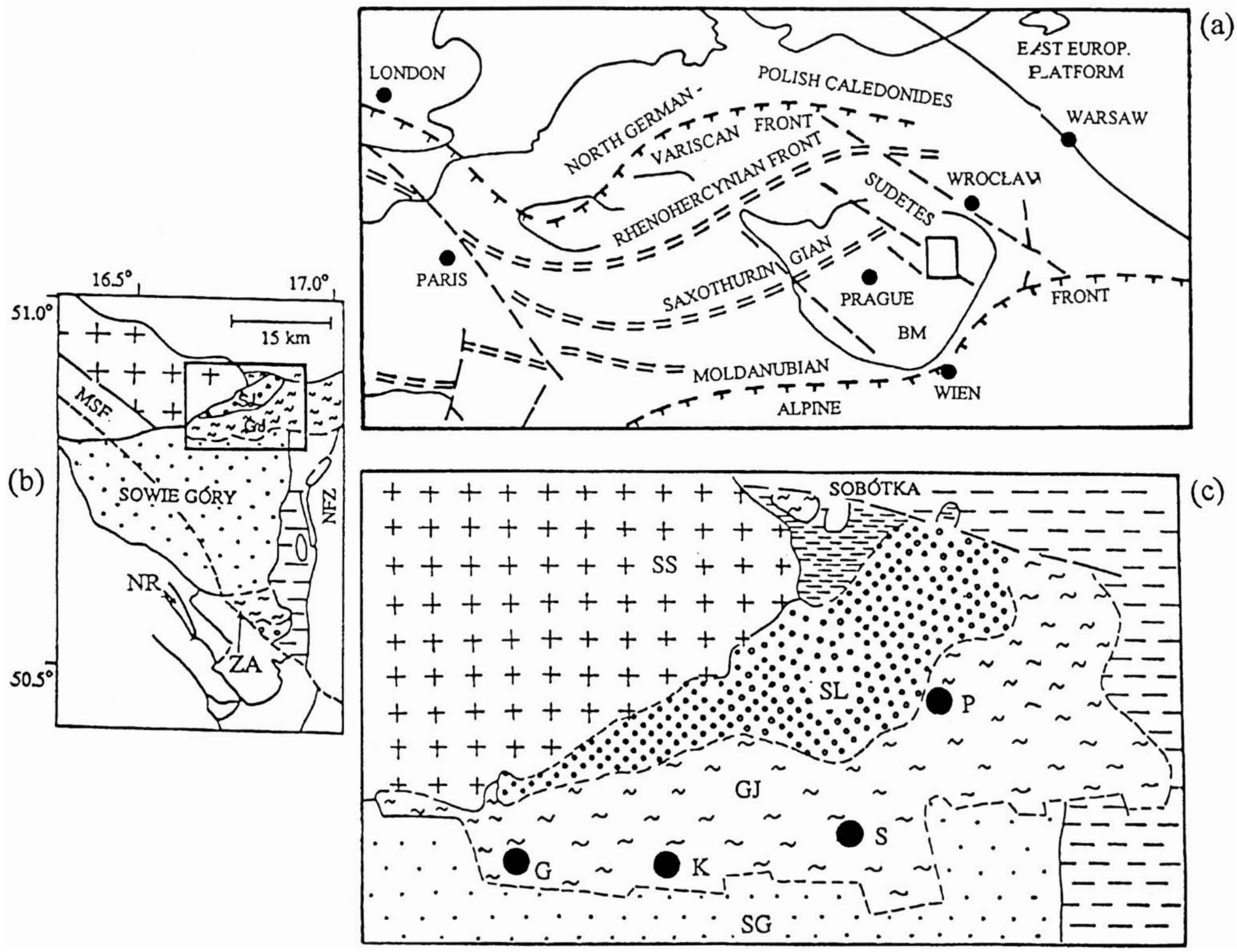


Fig. 1 - Geological sketch maps of the studied area. a) Location of the Sudetes in the European Variscan Belt. b) Fragments of Sudetic ophiolite surrounding the Sowie Góry Mts. block. SL- Ślęźa gabbroic massif; GJ- Gogołów - Jordanów serpentinite massif; ZA- Zabkowice massif; NR- Nowa Ruda massif; SS- Strzegom - Sobótka granitoids; MSF- Marginal Sudetic Fault. Inset: Sampling area. (c)- sampling sites: G- Gogołów, K- Kiełczyn, S- Słupice, P- Przemiłów, SG- Sowie Góry Mts. Block. 1- serpentinite, 2- gabbro, 3- diabase, 4- granitoids, 5- gneisses.

heating in the air on its mineral state (curve 1 and curve 2 on respective plots). For few specimens thermomagnetic analysis of magnetization in different external fields was performed (performed with help of N. Petersen in University of Muenchen, Muenchen, Germany.

– Measurements of hysteresis parameters were conducted for three typical specimens before heating and after heating to several chosen temperatures with a vibrating magnetometer VSM by Molspin Ltd
– Changes of magnetic minerals influenced by heating were monitored by measurements of bulk magnetic susceptibility (Km) before beginning of heating procedure and after consecutive heating steps with the KLY-2 bridge by Geofyzika Brno.

MICROSCOPIC AND ROCK-MAGNETIC STUDY

Microscopic investigations

A study of polished sections revealed presence of several varieties of magnetite. The serpentinites are rich in chromite grains which are of magmatic origin. During serpentinization they became partly altered to magnetite; often intermediate phases of chromium magnetite, „ferritchromium", were also visible. Other magnetite varieties present as well belong to: blastic magnetites formed by recrystallization, post-pyroxene magnetite lamellae, fine grained (1mm and less) magnetite grains disseminated within serpentines, olivines and pyroxenes; in some cases post-pyroxene magnetites form parallel successions of grains of various sizes. Part of magnetite grains was formed due to serpentinization and chloritization processes in oceanic conditions, part of them - later in continental environments. Presence of small amount of magnetite grains remaining from the magmatic stage is also possible. Some small magnetite grains are partly oxidized to martite, some maghemite is not excluded. In some specimens, especially from the K quarry, small post-pyroxene hematite plates occur. As minor minerals, some Fe-hydroxides, and sulphides (pyrite and chalcopyrite) were identified. A typical result obtained with SEM showing a partly altered chromite grain and a succession of magnetite grains is presented in Fig. 2.

Thermomagnetic study

The method applied to isothermal remanence Ir revealed the presence of magnetite with Tb of about 570-580°C, accompanied in most specimens by a more or less distinct phase that became demagnetized between 150°C and 200°C (Fig. 3a). In order to interpret this low-temperature phase the same specimens were investigated with the Curie balance method when heated in the external field. The curves of magnetization (M) vs temperature (T) reveal presence uniquely of magnetite when heated in fields of several tens of mT or higher (Fig. 3c). Magnetization M of the sister specimens heated in field of several mT behaves differently: it increases during heating to about 300-400ºC, and afterwards it decreases following a characteristic pattern for magnetite (Fig. 3b and d). The mean low field susceptibility (Km) measurements after consecutive heating steps and, for one specimen, during heating (performed by O. Orlicky from the Institute of Geophysics of SAS, Bratislava, Slovak Republic) also reveal increase of Km values up to 300°C, before their decrease at higher temperatures (Fig. 4a and b). The cooling curve in Fig. 4b shows an important decrease of susceptibility due to heating. According to Orlicky (private comm.) this indicates presence of maghemite rather than magnetite in the studied specimen.

Study of hysteresis parameters

In order to explain this unexpected behaviour of remanence, magnetization and susceptibility, hysteresis parameters before heating and after consecutive heating steps were measured for specimens from the same hand samples as used for thermomagnetic experiments. Hysteresis parameters obtained for investigated specimens before heating: saturation magnetization (Ms), saturation remanence (Mr), coercive force (Hr), remanent coercivity (Hcr) and the saturation field are characteristic for magnetite (Table 1). Heating was done at temperatures from 100°C to 600∞C with heating steps of 100∞C. Fig. 5 shows the results for specimen n. 13; results obtained for other specimens are similar.

The heating procedure yields an increase of Ms up to 300º C before its successive decrease, Mr decreases due to heating, attaining the lowest value at 300ºC, Hc and Hcr both decrease and are the lowest between 200 and 300ºC. These temperatures are close to the temperature ranges of decrease of Ir (Fig. 3a) and increase of M (Fig. 3b, d). Very similar results for changes of remanence, magnetization and coercivities due to heating were obtained for ophiolitic rocks from the Mongolian ophiolite (Petchersky and Tikhonov, 1988; Didenko, 1992) and also for marine sediments by van Welzen (1992). This work, although performed on sediments, shows very clearly the characteristics of the same process as observed in ophiolites. All cited authors interpret the observed results as connected to the presence of very small grains of magnetite that became surface oxidized to thin maghemite coating due single phase oxidation of magnetite (Colombo et al., 1964, Gapeev et al., 1991, Gallagher et al., 1968) at temperatures as low as 200°C and less, even during weathering. Maghemite that has smaller crystalline parameters than magnetite induces stresses on the magnetite core of oxidized grains that leads to an increase of remanence and coercivity and decrease susceptibility and magnetization. Heating reduces strains and leads to an increase of susceptibility and magnetization and decrease of remanence, Hc and Hcr, as observed in this study. This configuration may lead to formation of piezomagnetic remanence, viscous or chemoviscous remanence often with recent field direction (Dunlop and Özdemir, 1996).

CONCLUSIONS

– The prevailing magnetic mineral in serpentinites is secondary magnetite occurring in various phases, formed in various times from various minerals , but always at low temperatures.
– Magnetite is accompanied by maghemite partly due to single-phase oxidation of small magnetite grains, and minor amount of hematite, often in the form of martite.
– The presence of small amounts of magmatic magnetite formed at high temperatures before or during extrusion of the ophiolitic rocks is also possible.
– The diversity of magnetic phases is reflected in the diversity of components of natural remanence present in the studied serpentinites (see Kądziałko-Hofmokl and Jeleńska, 1998). Their interpretation needs further study.

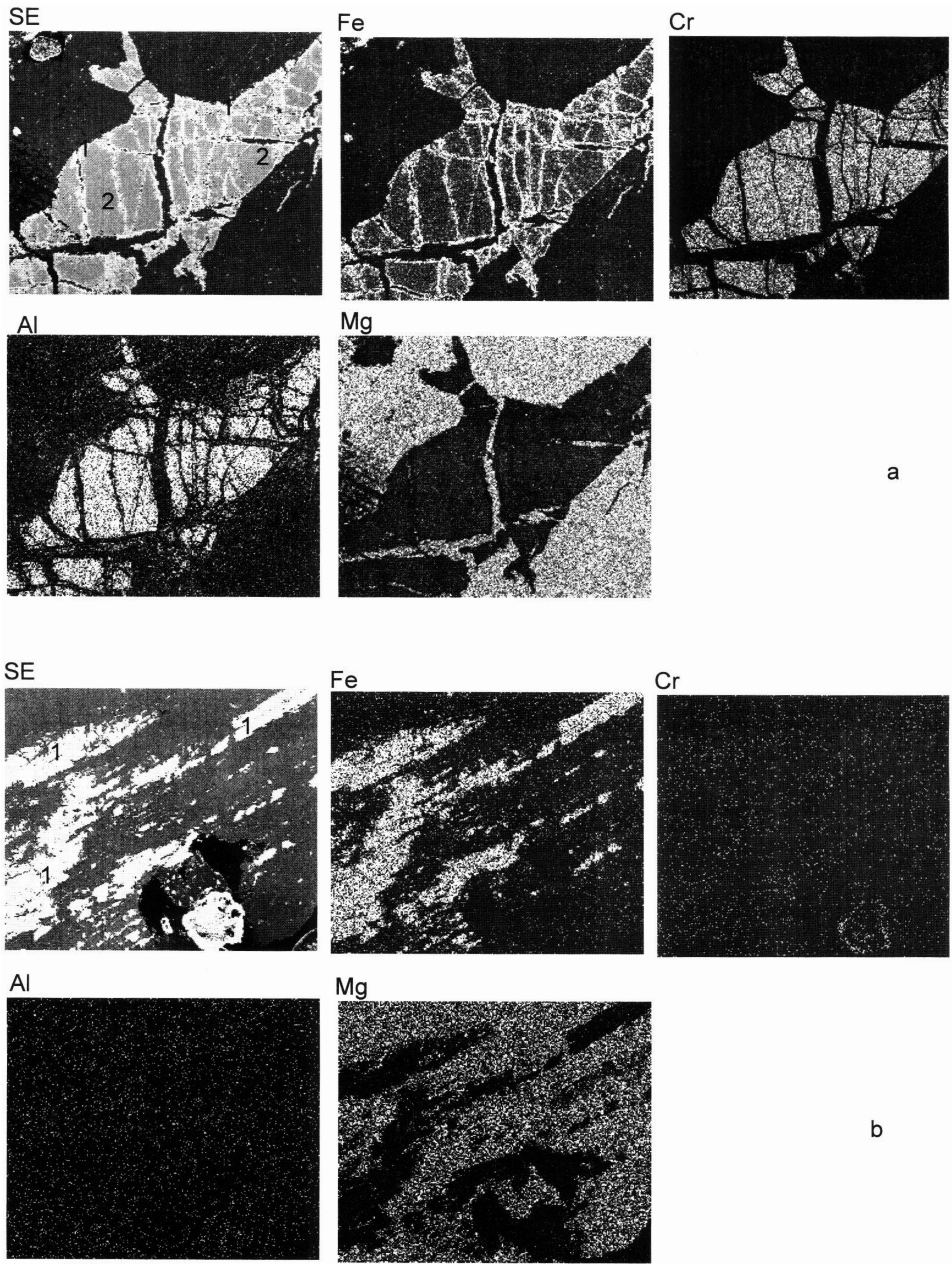
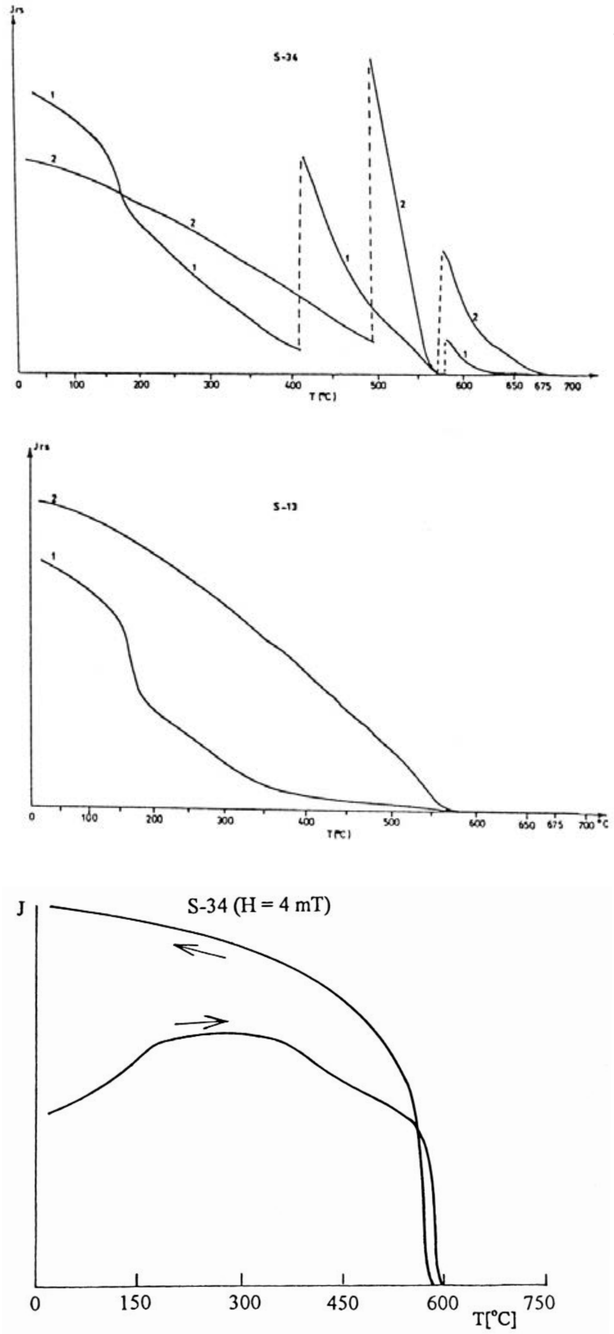


Fig. 2 - Typical SEM and microprobe results for a serpentinite specimen showing: (a) chromite grain partly altered to magnetite x 550. (b) parallel succesion of post-pyroxene magnetite grains x 300. SE- secondary electrons, maps show distribution of Fe, Cr, Al. and Mg. magnetite (white) is labeled 1, chromite (dark grey) is labeled 2.



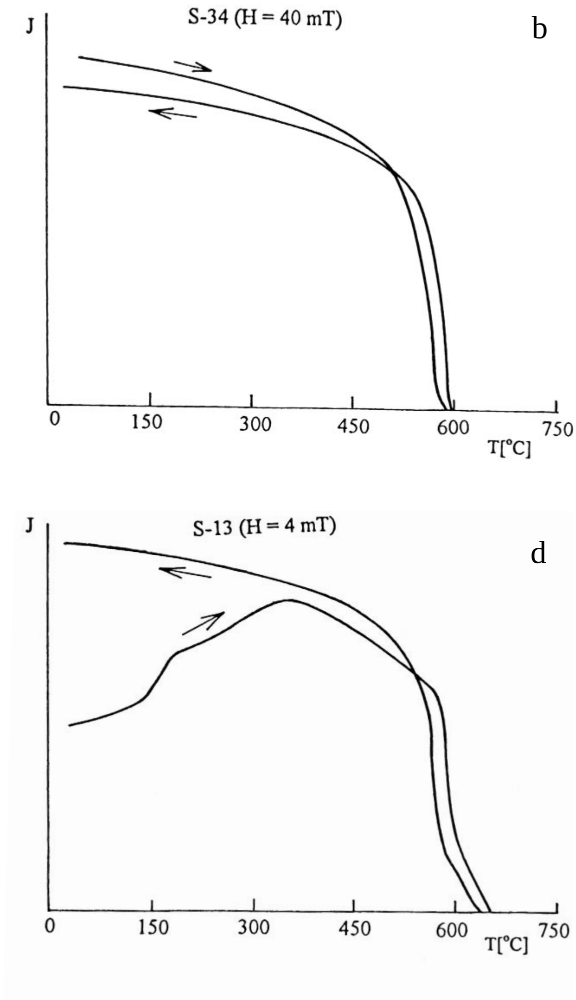
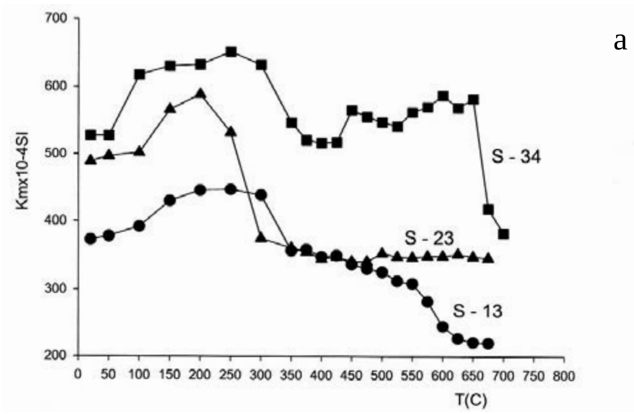


Fig. 3 - Results of thermomagnetic analysis. (a). Ir- T curves for specimens 13 and 34 magnetized in 1T. 1- curve of the first heating; 2- curve of the second heating. Ir2/Ir1 (remanence before heating/remanence after first heating) is 5 for the sample 13 and 0.9 for the sample 34. Stippled lines in the plot for specimen 34 indicate change of range. (b). M - T curves for the specimen 34 obtained in the field of 4 mT. (c). M - T curves for specimen 34 obtained in the field of 40 mT. (d). M - T curves for the specimen 13 obtained in the field of 4 mT. M in arbitrary units.



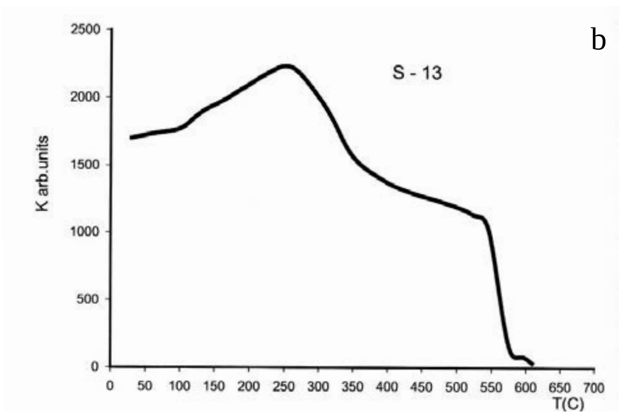


Fig. 4 - (a). Mean susceptibility Km measured after consecutive heating steps for specimens 13 (circles) 23 (triangles) and 34 (squares). (b). Bulk susceptibility K against temperature for the specimen 13.Fig. 4 - (a). Mean susceptibility Km measured after consecutive heating steps for specimens 13 (circles) 23 (triangles) and 34 (squares). (b). Bulk susceptibility K against temperature for the specimen 13.

Table 1 - Hysteresis parameters of the GJ serpentinites

sample	Ms μAm²	Mr μAm²	Hc mT	Hcr mT	Hsat mT
S - 13	723	71	8	23	150
S - 23	2171	122	4.5	16	150
S - 34	1262	151	6	15	150

Ms- saturation magnetization; Mr- saturation remanence; Hc- coercivity; Hc- remanence coercivity; Hsat- saturation field.

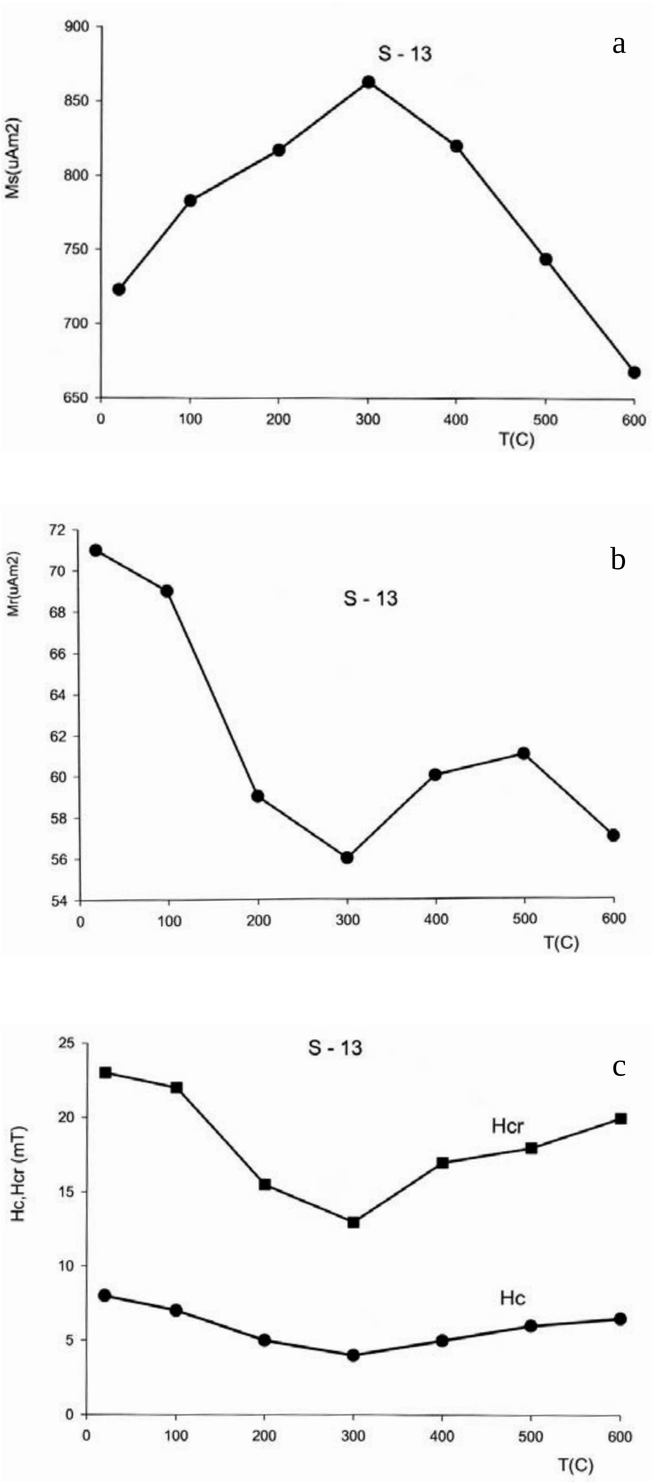


Fig. 5 - Hysteresis parameters after consecutive heating steps for the specimen 13. (a). saturation magnetization Ms. (b). saturation remanence Mr. (c). coercivity Hc and remanence coercivity Hcr.

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REFERENCES

Abdel Wahad M., 1999. The Ślęźa ophiolite (SW Poland): Petrological and structural evolution, Thesis. Inst. Geol. Sci., Univ. Wroclaw, Poland.

Abdel Wahad M. and Mierzejewski M.P., 1998. A new discovery of ilmenite mineralization within the Ślęźa Mt. metagabbro, Lower Silesia (SW Poland). Prz. Geol. 46 (8): 684-688 (in Polish).

Brueckner H.K., Blusztajn J. and Bakun-Czubarow N., 1996, Trace element and Sm - Nd „age" zoning in garnets from peridotites of the Caledonian and Variscan mountains and their tectonic implications. J. Metam. Geol., 14 (1): 61-73.

Colombo U., Fagherazzi G., Gazzarini F., Lanzavecchia G. and Sironi G., 1964. Mechanisms in the first stage of oxidation of magnetites. Nature, 202: 175-176.

Coulton A.J. and Harper G.D., 1995. Oceanic versus emplacement age serpentinization in the Josephine ophiolite: Implications for the nature of the Moho at intermediate and slow spreading ridges, J. Geophys. Res., 100 (B11): 22245-22260.

Didenko A.N., 1992. Magnetism of South Mongolian Middle Paleozoic ophiolites. Earth Planet. Int., 74,: 263-277

Dubińska E. and Gunia P., 1997. The Sudetic ophiolite; current view on its geodynamic model. Geol. Quart., 1: 1-28

Dunlop D.J. and Ozdemir O., 1996: Rock magnetism. Cambridge Univ. Press, Cambridge, 573 pp.

Floyd P.A., Crowley Q.C., Winchester J.A., Kryza R., Kozdrój W. and Cymerman Z., 2000. Pillow lavas in the Ślęźa ophiolite and their geochemical relationship to other mafic components in the Sudetes. Joint Meet. of Europrobe (TESZ) and PACE Projects, Zakopane, September 2000. Abstr. p. 22-23

Gallagher K.J., Feitknecht W. and Mannweiler U. 1968. Mechanism of oxidation of magnetite to γ - Fe_2O_3. Nature, 217: 1118-1121

Gapeev A.K., Gribov S.K., Dunlop D.J., Özdemir O. and Shcherbakov V.P., 1991. A direct comparison of the properties of CRM and VRM in the low-temperature oxidation of magnetite. Geophys. J. Int., 105: 407-418

Gnos E. and Perrin M., 1996. Formation and evolution of the Masirah ophiolite constrained by paleomagnetic study of volcanic rocks. Tectonophysics, 253: 53-64

Jarmołowicz-Szulc K., 1987. Geochronology of Variscan intrusions Geol.Quart., 31 (4): 531-542 (in Polish).

Jędrysek M.O., 1995. Petrogenesis of ultramafic-hosted carbonates in the light of stable isotopes ratio studies. Przeglad Geol., .43 (12): 1077-1091.

Jędrysek M., Jasińska B. and Boduch M., 1991. Serpentinization of ultramafic rocks of the Gogołów - Jordanów serpentinite massif (SW Poland) in the light of isotope studies of hydrogen and oxygen. Mineral. Pol., 22 (1): 61-76.

Jeleńska M., Kądziałko-Hofmokl M., Edel J.B., Jamrozik L., Petersen N. and Soffel H., 1995. Palaeomagnetic investigations of the Palaeozoic circum - Sowie Góry Mountains ophiolitic belt in the Sudetes, Poland. Geophys. J. Int., 122: 658-674.

Kądziałko-Hofmokl M. and Jeleńska M., 1998. Paleomagnetic overprints and rock magnetism of Paleozoic serpentinites from the Gogołów-Jordanów massif, Sudetes (South Poland). Geol. Carpatica, 49 (3): 197-198 (Abstr., Int. Conf. New trends of geophysics).

Kądziałko-Hofmokl M. and Kruczyk J., 1976. Complete and partial self-reversal of natural remanent magnetization of basaltic rocks from Lower Silesia, Poland. Pageoph., 114: 207-213

Oliver G.J.H., Corfu. F. and Krogh T.E., 1993: U-Pb ages from

SW Poland: evidence for a Caledonian suture zone between Baltica and Gondwana. J. Geol. Soc. London, 150: 355-69

Pechersky D.M. and Tikhonov L.W., 1988: Petromagnetic characteristics of Paleozoic ophiolites from the Altai range. Izv. Akad. Nauk SSSR, Geol. Ser., 10: 46-62 (in Russian).

Pin C., Puziewicz J. and Duthou J.L., 1989. Ages and origins of a composite granitic massif in the Variscan belt: a Rb-Sr study of the Strzegom - Sobótka Massif, W. Sudetes (Poland). N. Jahrb. Miner. Abh., 160 (1): 71-82

Trench A., Torsvik H.T., Walderhaug H. and Bluck J.B., 1990. Paleomagnetic and rock magnetic reliability criteria in ophiolitic rocks: a case study from the Palaeozoic Ballantrae ophiolite, Scotland. Tectonophysics, 184: 55-72.

van Breemen O., Bowes D.R., Aftalion M. and Żelaźniewicz A., 1988. Devonian tectonothermal activity in the Sowie Góry gneissic block, Sudetes, SW Poland: evidence from Rb-Sr and U-Pb isotope studies. Ann. Soc. Geol. Pol., 58: 3-19.

van Welzen A.J., 1992. The influence of weathering on the magnetic properties of single domain magnetite in marine sediments. Geol. Ultraiectina, 122: 45-65.

Żelaźniewicz A., Dörr W. and Dubińska E., 1998. Lower Devonian oceanic crust from U-Pb zircon evidence and Eo-Variscan event in the Sudetes. Terra Nova, 2: 174-176 (SPP - Kolloquium „Orogene Prozesse”, Giessen, 1998).

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