

*Magdalena Kądziałko-Hofmokł<sup>5</sup>, Jadwiga Kruczyk<sup>1</sup>, Jacek Siemiątkowski<sup>6</sup>*

### **IDENTIFICATION OF MAGNETIC MINERALS IN PALEOMAGNETIC INVESTIGATIONS**

Paleomagnetic investigations are performed in order to study the magnetic field of the Earth in its geological past. The object of the study are rocks containing minerals called, for the sake of simplicity, magnetic minerals. To this family belong ferri- and antiferrimagnetic minerals which, due to its structure, are able to acquire and retain for the long time magnetic remanence directed along the external magnetic field. They are able to acquire and retain for the long time magnetic remanence which the direction is the same as direction of the ambient magnetic field. The most commonly encountered magnetic minerals are the Ti-Fe oxides Fe – hydroxides, Fe-sulphides. The remanence that they acquire in the Earth's magnetic field is called the Natural Remanent Magnetization NRM and has direction of this field. The NRM acquired during formation of the rocks: cooling from high temperatures in the case of magmatic rocks and deposition in the case of sedimentary rocks, is called the primary remanence. Its age is the same as the age of the rock and direction reflects the direction of the Earth's field from the time and place of the rock formation. In the course of investigations paleomagneticians are able to obtain this direction and calculate from it geographic coordinates of the paleomagnetic pole and the paleolatitude of the sampling area in this time. The numerous paleomagnetic results obtained since the beginning of paleomagnetic research on the large scale show that the polarity of the geomagnetic field changed many times during the Earth's past, that the position of geomagnetic pole changes apparently with time along the so called Apparent Polar Wandering Paths (APWP) and the APWP's obtained for different tectonic units, differ. Unfortunately, the rocks very often undergo various chemical, physical and tectonic changes during their geological history. These events result in alteration of primary magnetic minerals and/or formation of new ones from the non-magnetic minerals. The

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<sup>5</sup> *Institute of Geophysics, Polish Academy of Sciences, 01-452 Warsaw, ul.Ks.Janusza 64, e-mail magdahof@igf.edu.pl*

<sup>6</sup> *Polish Institute of Geology, 53-123 Wrocław, Al.Jaworowa 19*

rocks acquire new, secondary components of remanence that become added to the primary NRM. Performing numerous experiments paleomagneticians try to isolate successive components and assign them to various geological events. This task is resolved due to investigations comprising set of magnetic and non-magnetic methods. In this presentation we will show the methods that are most commonly used in paleomagnetic laboratories (see for example Dunlop and Özdemir, 1996).

The rock-magnetic methods consist in most cases of various types of thermomagnetic analyses:

- the method based on the decay curves of saturation remanence  $J_r$  during heating in the non-magnetic space to  $700^\circ\text{C}$ ; it gives the blocking temperature of magnetic minerals  $T_b$ . Fig.1a presents an example of the  $J_r$ -T curve for the sample of limestone containing pyrrhotite with  $T_b$  of about  $325^\circ\text{C}$  and magnetite with  $T_b$  of about  $580^\circ\text{C}$ .
- the method based on the decay curves of saturation magnetization  $J_s$  during heating to  $700^\circ\text{C}$ ; it gives Curie temperatures of magnetic minerals  $T_c$ . Fig.1b shows examples of results obtained by these methods. Fig.1a presents an example of the  $J_r$ -T curve for the sample of limestone containing pyrrhotite with  $T_b$  of about  $325^\circ\text{C}$  and magnetite with  $T_b$  of about  $580^\circ\text{C}$ . Fig.1b shows example of  $J_s$ -T curve for a greenstone sample in the field of 8T containing magnetite with  $T_c$  of about  $580^\circ\text{C}$
- the composite thermal analysis based on thermal decay of three mutually orthogonal components of remanence imparted on specimen in magnetic field of different intensities. This method helps to identify minerals by their blocking temperatures and coercivities. Fig.1c presents example obtained for a sample of metasandstone. The rock contains pyrrhotite ( $T_b$  of about  $330^\circ\text{C}$ ), magnetite ( $T_b$  of about  $580^\circ\text{C}$ ) and hematite ( $T_b$  of about  $670^\circ\text{C}$ ).
- the analysis of thermal changes of magnetic susceptibility  $K$  during heating in the low temperature range (from  $-196^\circ\text{C}$  to room temperature) and in the high temperature range (from room temperature to  $700^\circ\text{C}$  in air or in argon). It gives temperatures of low and high temperature transitions characteristic for magnetic minerals  $T_c$ . Fig.1d presents the high temperature  $K$ -T curve obtained for specimen of iron ore during heating to  $700^\circ\text{C}$ . It contains maghemite (the hump in  $300$ - $350^\circ\text{C}$ ), magnetite with  $T_c$  of  $580^\circ\text{C}$  and hematite with  $T_c$  of  $670^\circ\text{C}$ .

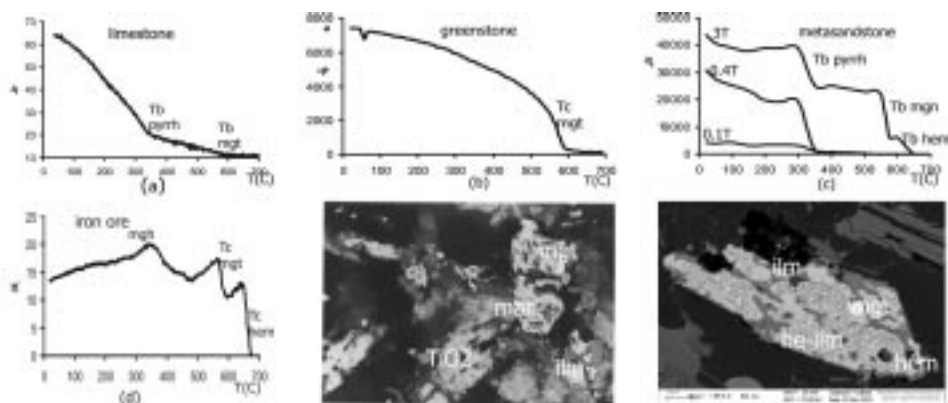
Apart of thermal experiments, in several cases the acquisition curves of isothermal remanence and magnetic hysteresis parameters are measured and analyzed.

The magnetic methods show what magnetic minerals are present in the rock and carry its NRM, but these results say nothing about their origin, alterations and mutual relationships. Without this knowledge we are not able to interpret the origin

of isolated respective components of NRM. To be able to do this we have to look at the results of non-magnetic methods.

The most often applied non-magnetic methods are microscopic analyses in reflected and transmitted light, microprobe analyses, structural Roentgen study, Mössbauer analysis. Fig.1f shows the result obtained for the greenstone sample (the same as in Fig.1b) with ore microscope and SEM. Here we see, apart of magnetite grains also hematite in the form of martite, as well as ilmenite grains very often altered partially into rutile and titanite. The SEM image shows that the central parts of ilmenite grains are often mosaically altered. The X-ray analysis performed for the separated powdered fraction of this rock revealed presence of hemo-ilmenite with 5-8% of ilmenite and 92-95% of hematite (Kaździałko-Hofmokr et al., to be published). Similar results were obtained for anorthosite rock massif (Kubicki and Siemiątkowski, 1979) as well as for amphibolites (Kontny et al., 1997). The observed mineralogical composition may be due to amphibolite and/or greenschist metamorphism. Primary remanence of such rocks is completely erased, they may carry only secondary components connected with various tectonometamorphic episodes or even weathering.

It is difficult to discuss all aspects of complex magnetic and non-magnetic study of minerals – carriers of the NRM, in so short paper. We hope that the few examples presented here show how important is the knowledge of magnetic mineralogy in interpreting paleomagnetic results.



Rys.1 (a) T curve for limestone, (b) J-T curve for greenstone (c) composite thermal curves for metasandstones, remanences imparted in 3T, 0.4T and 0.1T (d) high-field susceptibility thermal curve for iron ore (e) image of greenstone sample in reflected light (x500) (f) SEM image of the same sample

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