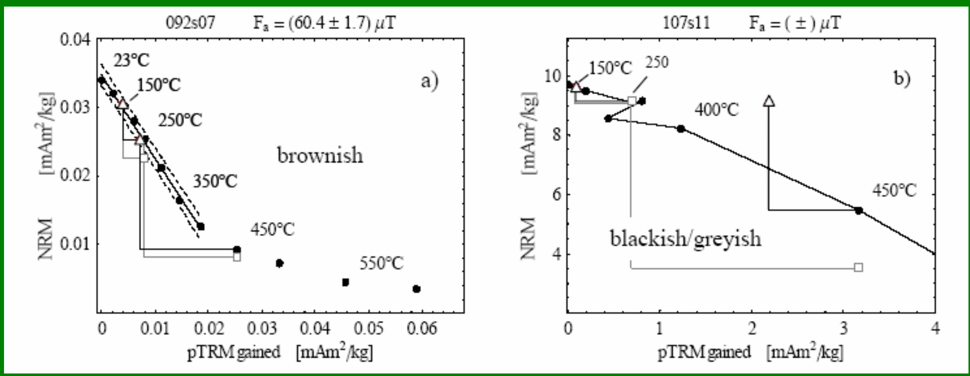
# TRAVAUX GÉOPHYSIQUES
# XXVII (2006)

## Abstracts of the 10th "Castle Meeting"
## New Trends in Geomagnetism
## Palaeo, Rock and Environmental Magnetism

*Castle of Valtice, September 3 - 8, 2006*




**ISSN 0039 – 3169**

GEOPHYSICAL INSTITUTE PRAGUE

ACADEMY OF SCIENCES
OF THE CZECH REPUBLIC

Travaux Géophysiques, XXVII (2006)
ISSN 0039-3169
Published by:
Geophysical Institute, Acad. Sci. Czech Republic
and
StudiaGeo, s.r.o.

Address: Boční II/1401
141 31 Prague 4
Czech Republic
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# NRM MEASUREMENTS OF SHATTER CONES AND RIM DEPOSITS FROM THE SIERRA MADERA IMPACT CRATER IN TEXAS, USA

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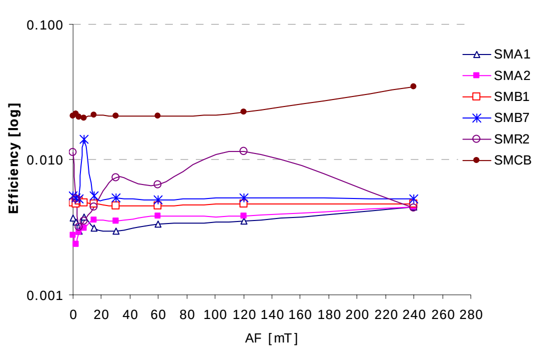
Terestrial rocks with Thermal Remanence Magnetization, TRM and Chemical Remanence Magnetization, CRM have the efficiency (Natural Remanent Magnetization, NRM and Saturation Isothermal Remanent Magnetization, SIRM ratio = REM) of between 1–2% proposed by *Wasilewski (1977)*, and *Kletetschka et al. (2003)*. *Dickinson and Wasilewski (2000*) suggested creations and destructions of magnetic remancence by shock events in iron particle in extraterrestrial rocks. Impact experiments on various minerals discussed by *Kletetschka et al. (2005)* suggested a significant reduction of initial magnetization in impact pressures as low as 1 GPa. Consequences of this demagnetization is a low efficiency value of REM. We show the initial data acquired from Sierra Madera Impact Crater shatter cone, impact breccia, and rim carbonate deposits that indicate the reduction/demagnetization of NRM in the shatter cone samples.

The Sierra Madera Impact crater is located in Texas USA (Latitude: 30°36'N, and 102°55'W), and its diameter is 13 km, the target rocks are carbonates (calcite, dolomite, and carbonates breccia), and the age was estimated less than 100 Ma. The shatter cone, breccia, and rim samples were collected in the slope of centeal uplift, middle, and rim of the crater respectively.

Our measurements of the shatter cone samples show that efficiency is 0.5% (Fig. 1a). These values are lower than the terrestrial efficiency (Fig. 1b) and we interpret this to be demagnetization of the original remanence by impact. On the other hand, the impact breccia (Fig. 1: sample, SMCB show the typical terrestrial rock efficiency of 2% related to terrestrial magnetic acquisition. This 2% efficiency indicates a post magnetization as TRM/CRM that the breccia acquired after the impact shock.

The magnetization direction plotted in Fig. 2, show the overprint of impact. The unidirectional magnetization direction of the shatter cone samples also supports our interpretation for the impact demagnetization of shatter cone.



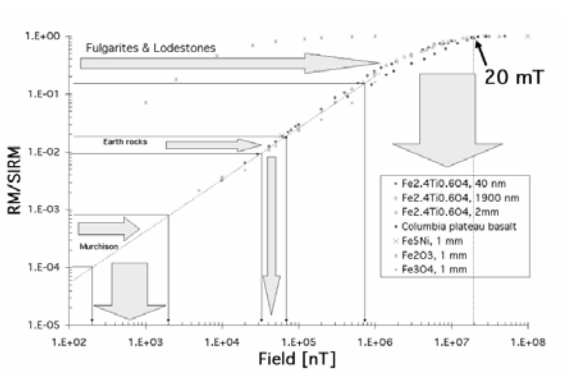




**Fig. 1.** The calculated efficiency (NRM/SIRM ratio) are plotted for shatter cone: SMA1, SMA2, SMB1; and SMB7, rim: SMR2; and breccia: SMCB. All the samples show the efficiency less than 1%, and shatter cone sampes are significantly low. **b)** Efficiency plot adopted from (*Kletetschka et al., 2003*) show the terrestrial efficiency of 1% correspond the geomagnetic field.

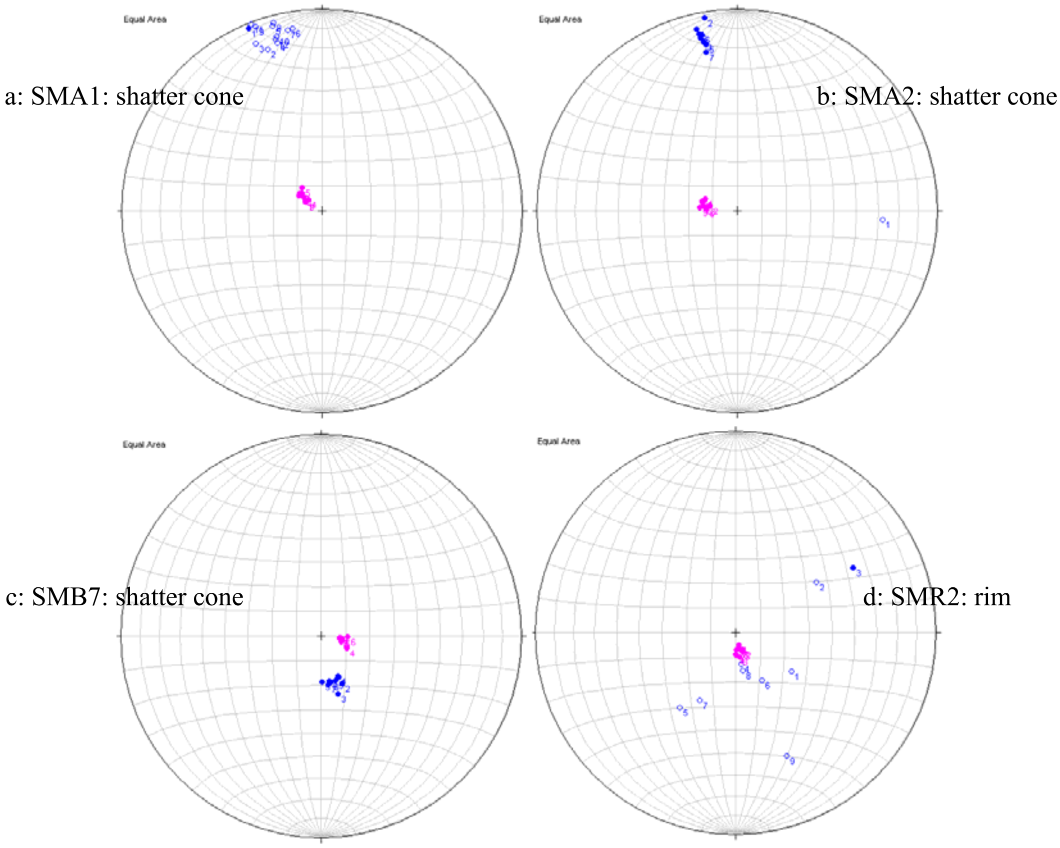



**Fig. 2.** The magnetization direction were plotted with stereogram show the unidirectional orientation of magnetization in the shatter cone.

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# TRANSTENSIONAL OPENING OF THE NORTH ATLANTIC OCEAN CHARACTERIZED BY MAGNETIC FABRIC OF THE KERFORNE DOLERITIC DYKE (BRITTANY, FRANCE)

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The Kerforne active fault, cross-cutting the south Armorican Shear Zone, is related to the last seismic event of Sept. 30th 2002 (Ms = 5.4) ENE of Lorient (*Perrot et al., 2005*). It is composed of several branches trending 130°–140°N, some of them have been intruded by Jurassic doleritic dykes. One of these dykes, the Brenterc'h dyke, is located in the northernmost part of the Kerforne fault. It is a vertical 140°N-trending dyke about 10 m thick. As most of the Bretonian doleritic dykes, its eastern margin is weathered. We collected 115 samples from this dyke for paleomagnetic and AMS (anisotrophy of magnetic susceptibility) analyses in order to study the initial opening of the North Atlantic Ocean. Special care was attributed to sampling the borders of the dyke in order to detect possible shear and/or alteration along them. Three samples were also collected for K/Ar dating, two from each border and one from the central part of the dyke.

Preliminary paleomagnetic results obtained by AF demagnetizations show one component of magnetization that is carried by magnetite (*Sichler and Perrin, 1993*). While this component of magnetization from the western and central parts of the dyke show a Jurassic paleopole, that of the eastern border is much younger than the Jurassic emplacement age of the dyke. The K/Ar dating gives a Jurassic age (190–205 Ma) similar to previous dating by *Caroff et al. (1995)* and *Jourdan et al. (2003)* with no significant difference between the eastern (weathered) border and the central and western (fresh) border of the dyke. AMS results indicate that most of the magnetic fabrics are oblate in shape in the central part of the dyke, while they are oblate and prolate in the borders. Analysis of eigenvectors and eigenvalues show that the degree of anisotropy values range between 0.6 to 4.8%, the highest are in the eastern border. While the paleomagnetic and AMS analyses are sensitive to later processes that cause for remagnetization of the eastern border and AMS overprint, the K/Ar age determinations show only minor effects of these processes. Based on these data we suggest the following sequence of events: 1 - a dextral transtensional regime during dyke emplacement, which is related to the Biscay bay opening (Biscay-Labrador fault), 2 - initial axial flow from NW to SE in the Brenterc'h dyke , 3 - multiple injections (pulses) occurred also within the dyke (central part); and 4 - post-emplacement alteration related to fluid circulations appeared mainly in the eastern border of the dyke. Phases 1 to 3 are nearly simultaneous and corroborate the geochemical results given by *Caroff and Cotten (2004)*.

The geodynamic interpretation concerning the initial opening of the North Atlantic Ocean needs more investigations of rock magnetism and paleomagnetism. Further dating of the secondary pulses may help to understand the nature and origin of the change in the opening mode (mechanism) of the Brenterc'h dyke which developed from symmetric opening (pure extension related to symmetric tiling) to dextral transtensional opening (parallel tiling). A 3D model using the preliminary magnetic fabric and paleomagnetic data will be discussed in the light of previous results (*Aïfa and Lefort, 2000*; *Lefort et al., in press*).

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## MAGNETIC PROPERTIES OF BLED EL HADBA BEARING FORMATION (DJEBEL ONK, ALGERIA). CONSEQUENCES ON THE ENRICHMENT OF THE PHOSPHATE ORE DEPOSIT

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Bled El Hadba is a phosphate ore quarry located in the Djebel Onk (Algeria), close to other actively exploited quarries (Djemi Djema, Kef Es Sennoun), discovered at least in 1873 (*Notholt, 1991*). To improve the enrichment of Thanetian marine phosphate ore deposit from this quarry before its exploitation, we first conducted a joint study using different techniques for comparison (*Bezzi et al., 2001, 2005*) and for the evaluation of economical extraction (*Prian, 1994*; *Kchikach et al., 2002*; *Boujo, 2002*; *Bezzi et al., 2004*).

These studies reveal that magnetic minerals play a role within the matrix of the central productive unit which is squeezed between two other units. Magnetic separation procedures have been addressed and the results obtained show that there are some positive correlations between magnetic susceptibility and grain size fraction (80–250 µm). Upper and lower layers are better separated magnetically (17.67% and 26.94%) regarding the central layer where only 2.44% of the weight magnetic fraction was obtained. Inversely to $P_2O_5$ rates, the rates of MgO (dolomite) are clearly higher in the magnetic fractions than in the non magnetic fractions.

These dolomite-rich fractions are more clearly separated. Different tools were used to characterize the magnetic minerals (X ray, Mircoprobe, Differential Scanning Calorimetry, Thermogravimetric and Thermomagnetic analyses). They show correlations between magnetic phases and the presence of associated magnetic minerals within the matrix or included in the phosphate ore deposit. They enabled us to distinguish a series of magnetic minerals (magnetite, hematite, maghemite, goethite, ilmenite, pyrite, iron titanium oxide and titanium oxide sulphate) and to determine that Fe and Ti are prevalent in the separated fractions, following the same variation as Mg. The Phosphor (phosphate) rate is higher in the non magnetic material, especially in the layers that are rich in dolomite carbonates (Upper and Lower units) which could be trapped within the dolomitic matrix, while Magnesium (dolomite) is more important in the magnetic fraction. Yet, if the rates of dolomite (0.67 to 2.33% in MgO) fit the exploitation requirements perfectly, those of phosphates (19.23 to 22.35% in $P_2O_5$) are markedly unfavourable. So the enrichment of this kind of ore using magnetic separation is realized taking dolomite only into account. The occurrence of magnetic compounds was confirmed through X ray diffraction and microprobe observations (EBM, binocular and polarized microprobe). View captures on such specimens evidenced inclusions of small crystals related with magnetic compounds, especially in Ti-magnetite, maghemite, magnetite, …

The separation of phosphate elements and dolomite carbonates is effective and therefore can be enriched through magnetic procedures. Comparison between products enriched by magnetic separation, flotation (*Houot et al., 1985*; *Soto and Iwasaki, 1996*; *Sis and Chander, 2003*) and calcination (*Bezzi et al., 2004*) showed important differences, chemically, economically and technically speaking. Thus, magnetic separation constitutes the basis of an enrichment which is technically and economically acceptable but with very weak separation performances of carbonates-phosphates. This is related first to carbonate and phosphate elements which outcrop naturally in very distinct grain sizes and then to the presence of associated carbonates to phosphates such as endogangue. Thus even with some convincing results on the laboratory scale, this processing of magnetic separation alone could not enter into industrial development. However, it can be associated with other prior operations such as attrition followed by the omitting of schlamms under 60 μm to clean up the phosphate particles and therefore to reduce the rate of Silicium and carbonates (*Houot et al., 1985*).

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# ROCK-MAGNETIC INVESTIGATION OF LOESS-PALAEOSOL SEQUENCES FROM NORTH BULGARIA

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Magnetic properties of loess/palaeosol sequences are being widely considered as proxies of past environmental and climate changes but still the way these factors influence the rock-magnetic properties of the aeolian silt deposits in terms of soil formation or other types of weathering are disputable. Therefore, detailed and complex examinations of the magnetic properties of two loess/palaeosol sections from the Lower Danube Loess deposits in North-East and North-West Bulgaria have been carried out in order to follow the distribution of hard and soft mineral magnetic fractions as well as the grain size distribution along the two profiles. Temperature dependence of the isothermal remanent magnetization (IRM) carried by magnetically hard minerals has been examined for samples consolidated in non magnetic gypsum matrixes representative of each lithological unit. Mass specific, frequency dependent susceptibilities ($\chi$ and $\kappa_{fd}$) and ratios like ARM/SIRM (the anhysteretic remanent magnetization and the saturation isothermal remanent magnetization induced in 2 T steady field), SIRM/$\kappa$ were calculated for samples taken at 10 cm intervals from both profiles. All data were compared and correlated carefully with the field observations from the sampled outcrops. Thereby a good lithological discrimination between the different loess/palaeosol units has been achieved by analyzing the combined results from both the magnetic mineralogy and grain size controlled parameters like $\kappa_{fd}$, the ratios ARM/SIRM, SIRM/$\kappa$.

# PALAEOMAGNETIC INVESTIGATION OF CRETACEOUS SEDIMENTS FROM NW-INDIA

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Two Cretaceous sedimentary sequences from the NW-Indian plate were studied with respect to magnetostratigraphy, palaeomagnetic dating and diagenetic remagnetisation and its relation to the plate-tectonic movements from the separation from Madagascar in the Early Cretaceous until recent.

The two sequences were located two kilometres apart, yet their magnetic properties were very different. While the A-sequence generally carried only one magnetic component the B-sequence carried a more complicated multi-component magnetisation.

The samples from the A-sequence could be demagnetised completely using alternating field methods. A generally low coercivity indicated that the magnetisation may be carried by Ti-rich magnetite or sulphides. The A-sequence was dominated by normal polarity. A few samples carried a high-blocking component the direction of which could be used for dating. They indicated a Lower Cretaceous age (Barremian and Aptian).

The B-sequence is very different from the A-sequence. Thermal as well as alternating field demagnetisation was used for demagnetisation. Using these two different demagnetisation methods revealed different ages for the magnetic components removed. The components removed by thermal demagnetisation indicated ages consistently younger (Albian-Cenomanian, and Campanian) than the ones found by alternating field demagnetisation (Barremian-Aptian). In addition, the high blocking components showed a larger scatter than the components defined by a.f. demagnetisation which is explained as a result of the diagenesis causing this magnetisation. The thermal demagnetisation removed a component at low temperatures (200–400°C) carried by diagenetic goethite formed at a later stage than the primary magnetisation which was defined by the alternating field demagnetisation. The inclination of this characteristic component corresponds to magnetisation at latitude approximately 10° further from equator than the locality's present latitude at 27°N. It is interpreted as a primary magnetisation formed on the southern hemisphere at approximately latitude −37°S.

The polarity of both sedimentary sequences is generally normal except from 7 samples (out of a total of 75) defining 4 reverse polarity zones which could be correlated to the Barremian and Aptian M-1r, M0r, M2r and M3r.

Correlation of the A and B sequences could not be carried out in detail due to the re-magnetisation of a large part of the A-profile. Based on the few samples with high-blocking components, however, a correlation between the lowermost parts of the profiles could be made. The established local magnetic polarity scale is correlated to chrons M3 to M-1r in the Barremian and Aptian.

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# HIGH RESOLUTION 3D STUDIES OF MAGNETIC PROPERTIES IN POLLUTED SOILS

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Studies show that magnetic susceptibility (MS) can serve as a proxy for anthropogenic heavy metal (HM) load in soils. Analysis of single vertical soil cores reveal that MS and certain HMs, e.g. lead and zinc correlate very well (*Gautam et al., 2005*; *Spiteri et al., 2005*). MS values strongly depend on soil types and show certain variability (*Hanesch and Scholger, 2005*).

Better understanding small scale spatial variability and changes of magnetic parameters in soils is of fundamental interest for approaching quantitative HM pollution assessment using magnetic proxies. Modern sampling techniques and magnetic susceptibility meters allow fast in situ measurement of MS in shallow ground. Soil cores up to 50 cm length can be quickly collected and analysed for spatial MS variations covering areas of variable sizes. For practical application variations within areas of a few m$^2$ are of very high interest as they serve as sampling sites for conventional HM pollution studies as well as single measuring sites in environmental screening.

Our study of shallow vertical soil sections at high resolution comprises an integrated approach including magnetic parameters, physical soil parameters and HM contents. Different industrially affected and natural forest soils in otherwise undisturbed settings were investigated with high numbers of samples for statistical evaluation. Soil pollution at the study sites originates from heavy industries emissions and input into soil by atmospheric transport.

Soil cores and discrete soil samples (3.6 and 10 cm$^3$) collected from areas up to a few m$^2$ reveal high variability of MS values. Highest lateral variation is observed in polluted brown-earth within the upper 15–20 cm, comprising L, Ah and Bv horizons. The Cv horizon reveals only small changes of MS, indicating most probably only natural heterogeneities.

Increased MS values in the upper part of the soil profile depict the anthropogenic input of a magnetite-like phase. MS, frequency dependence of MS and IRM acquisition measurements clearly indicate the magnetic boundary/transition zone between anthropogenically affected and unaffected layers.

High resolution soil density analysis of brown-earth reveals steadily increasing values with depth. The boundaries between O/Ah, Ah/Bv and Bv/Cv horizons show soil density values of approximately 0.8, 1.0 and 1.2 g/cm$^3$, respectively. A sharp decrease of MS is observed near the transition from Ah to Bv horizon ($\rho = 1.0$ g/cm$^3$), marking the lower boundary of pronounced accumulation of translocated ferrimagnetic dust particles. Bulk soil samples collected at high resolution (0.5 cm vertical spacing) were analysed for HMs applying X-ray fluorescence spectroscopy (XRF). HM contents of e.g. Pb and Zn drop very similar to MS values near the boundary between the Ah and Bv horizons.

Excellent correlation of MS with Pb ($r^2 = 0.99$) and Zn ($r^2 = 0.99$) contents is determined from samples covering Ah, Bv and Cv horizons, revealing the very close links between soil density, MS and HM distribution. This suggests that physical parameters predominantly control the distribution of anthropogenic dust particles in the upper soil horizons.

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# HIGH-RESOLUTION HOLOCENE PALEOFIELD RECORD IN SEDIMENTS FROM THE NW AFRICAN CONTINENTAL MARGIN

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Results of comprehensive paleomagnetic and rock magnetic analyses are presented for two Holocene marine sediment sequences recovered from around 900 meter water depth on the upper Moroccan continental slope north of the Agadir Canyon (30°51.0'N, 10°16.1'W). Substantial influx of material originating from the adjacent continent combined with an intense marine productivity result in very high sediment accumulation rates of on average more than 60 cm/kyr at this location. Based on a detailed AMS dating scheme (*Kuhlmann et al., 2004*), directional and relative paleointensity variations of the Earth's magnetic field could therefor be determined at approximately centennial temporal resolution for the last about seven millennia. These data sets are compared with other regional records of sedimentary and magmatic formations as well as with global data compilations and recently developed global field models (*Korte and Constable, 2005*). While short episodic fluctuations, which should mainly reflect regional phenomena, only crudely match respective observations in nearby Western Europe, longer-term intensity characteristics reveal remarkable similarities with mean worldwide trends.

On the other hand, the data sets clearly illustrate that relative paleointensity very critically depends on remanent magnetization acquisition processes in sediments. Only about 50% of the natural remanence appears to be a detrital remanent magnetization (DRM) of essentially syn-depositional origin, the remainder being gradually imparted as a post-depositional remanence (PDRM) over time intervals of some thousand years. High-frequency variations of the Earth's magnetic field intensity are therefore reduced by the same order of magnitude in amplitude dynamics recorded. Frequency analysis of their time series did not reveal any statistically relevant prevalent periodicities, complying with current concepts about processes in the Earth's core, the generation of Earth's magnetic field and their temporal changes. Likewise, parameters delineating variations in concentration of magnetic minerals, which were used as normalizers for the relative paleoinensity, fluctuate at an unsystematic short-term mode. Different for example from Quaternary glacial/interglacial scenarios where they typically show a close correlation to astronomically controlled climate periodicities, no similar cyclic driving mechanisms could be identified during Holocene. Longer-term climate and vegetation shifts in the NW African hinterland causing variations in the predominant aeolian versus fluvial transport from the continent to the ocean are clearly reflected in the different rock magnetic attributes, however, yet they have no sizeable effect on the relative paleointensity record.

As the sediments were recovered from an upwelling region with intense marine productivity and high deposition of organic material, a primary objective of the rock magnetic measurements was to demonstrate that the magnetic mineral inventory, and thus potentially also the paleomagnetic record, had not been affected by diagenetic alteration. This is actually true only for the upper sediment series. At the iron redox boundary the primary fine grained (titano-) magnetite fraction, which predominantly carries the remanent magnetization above this horizon, is drastically dissolved resulting in a complete deterioration of the relative paleointensity data in the deposits older than about 7 ka.

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# ALTERATION OF MAGNETIC MINERAL INVENTORIES IN MARINE SEDIMENTS AT THE ATLANTIC SOUTH AMERICAN CONTINENTAL MARGIN

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For the most part, microbially mediated degradation of particulate organic matter drives both the iron and sulfur cycles in marine sediments. In suboxic milieus, the diagenetic dissolution of iron oxides around the iron redox boundary is a common phenomenon that has been comprehensively studied. In anoxic environments, which are typical of deeper strata, hydrogen sulfide, $H_2S$, needed for the formation of (iron) sulfides will be produced by the reduction of sulfate, $SO_4$, either by degradation of organic matter or by biogenic oxidation of methane, $CH_4$. The depth of the sulfate-methane reaction, called the sulfate-methane transition (SMT), depends on the penetration depth of seawater sulfate into the sediments and on the intensity of the methane flux from deeper layers. Sulfate pore water profiles with constant gradients above the transition zone are indicative of anaerobic oxidation of methane (AOM) controlling the sulfate reduction.

Numerous pore water profiles from the Argentine continental slope off the Rio de la Plata estuary show approximately linear sulfate gradients to unusually shallow penetration depths of only about 4 to 6 m below seafloor (*Riedinger et al., 2005*). At around this SMT horizon, where sulfate diffusing downward from the bottom water is met and reduced by methane rising from deeper in the sediment column, magnetic susceptibility logs, which are routinely measured directly after core recovery on board the research vessel, exhibit pronounced minima. Relative to the sedimentary layers above and below, magnetic susceptibility characteristically decreases by 80% or more over depth intervals of several meters, indicating an intense alteration of the magnetic mineral assemblage. Ultimately this effect is thought to result from a depth fixation of the SMT for prolonged periods of time. A marked change from high sedimentation rates during the last glacial period to low Holocene accumulation has been proposed to cause a rapid rise of the SMT from deeper positions and its stagnation at the present level after steady state conditions for the sulfate-methane reaction were established (*Kasten et al., 1998*).

More detailed magnetic investigations reveal less than 10% of the dominant primary low coercivity ferrimagnetic (titano-)magnetite component remains after alteration in the SMT zone. Already in the suboxic environment underlying the iron redox boundary located at a depth of around 0.1 m, roughly 60% of the finer grained detrital fraction is dissolved. While the high coercivity minerals are relatively unaffected at this stage, large portions (> 50%) become diagenetically erased around the SMT. Nevertheless, the characteristics of the magnetic residue in the sulfidic zone is entirely controlled by a high coercivity mineral assemblage. In stark contrast to observations below the iron redox boundary, where diagenetic alteration produces coarser magnetic grain-sizes, a distinct overall fining is found in the sulfidic environment. Scanning electron microscope (SEM) analyses, combined with X-ray microanalyses, specifically identified fine grained (titano-)magnetite that was protected against alteration as inclusions in a silicate matrix or in between high titanium content titanohematite lamellae. The only secondary iron sulfide mineral detected is pyrite which is present as clusters of euhedral crystals or directly replaces (titano-)magnetite. Thermomagnetic measurements did not provide evidence for the presence of ferrimagnetic sulfides such as greigite or pyrrhotite. This hints at iron limited pyritization processes. Sequential extraction indeed confirmed low concentrations of reactive iron phases in the sulfidic zone. Another interesting issue in the context of iron limitation is maghemitization which proceeds through preferential diffusion of Fe(II) out of (titano-)magnetite as Fe(II) is more easily detached from the mineral structure than Fe(III). SEM observations provided widespread evidence for an advanced maghemitization indicated by surficial cracking within sulfidic zone, whereas in the suboxic sediment series only minor signs of low temperature oxidation are present. These findings suggest that progressing maghemitization should be an important process in sulfidic environments.

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# MAGNETIC SELF-REVERSAL IN MARINE SEDIMENTS

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Sediments from the Argentine continental slope off the Rio de la Plata estuary have recently been analyzed in detail for their geochemical and rock magnetic characteristics by *Riedinger et al. (2005)* and *Garming et al. (2005)*, respectively (see the contribution by Bleil and Garming, this conference). Principal source of their detrital magnetic mineral assemblage is the drainage area of the Rio de la Plata tributaries in the Mesozoic flood basalts of the Paraná Basin. Magnetite and low titanium bearing, slightly maghemized titanomagnetite carry the remanent magnetization in these rocks. At gravity core location GeoB 6229 (37°12'S, 52°39'W) suboxic conditions are established close to the sediment surface and in a few meters depth anaerobic oxidation of methane (AOM) is observed. In this distinct redox zonation the detrital magnetic iron oxide mineral inventory undergoes a two stage diagenetic alteration. At the iron redox boundary about one quarter of the bulk ferrimagnetic mineral content is dissolved causing a significant coarsening in mean grain-size and diminishing bulk coecivities. This style of reductive diagenesis is a common, well studied phenomenon in marine settings, where the sediments contain elevated amounts of organic matter. On the other hand, diagenetic processes in the intensely reducing environment of the sulfate-methane transition (SMT) zone surrounding the AOM have been scarcely investigated so far. In the present example, less than 10% of the primary (titano-)magnetite persist, mainly as inclusions in a siliceous matrix or as relic intergrowths with high Ti bearing titanohematite lamellae which in contrast are well preserved. *Garming et al. (2005)* discuss these findings with reference to the concept that $Fe^{3+}$ is more tightly bond to the oxide mineral structure than $Fe^{2+}$. Widespread evidence for an advanced maghemitization of titanomagnetite in the SMT section clearly supports this view. It also explicates the superior stability of titanohematite and titanomaghemite under sulfidic conditions which result in decreasing grain-size and increasing coecitivity.

For a more comprehensive understanding of these phenomena various low-temperature measurements have been performed. The magnetic mineral assemblage comprises (titano-)magnetite plus titanohematite present as lamellar intergrowths with (titano-)magnetite originating from high temperature deuteric oxidation of the volcanic host rocks. They were visualized by scanning electron microscopy (SEM) and their variable compositions determined by X-ray microanalysis. Titanohematite with high titanium content ($\geq 0.5$ $FeTiO_3$) has the exceptional property of self-reversal. A negative exchange coupling to an intergrown second titanohematite phase of lower Ti content ($< 0.5$ $FeTiO_3$) was identified as the underlying mechanism. There is no supporting evidence, however, that such a process could be responsible for the drastic drop in room temperature saturation remanence (RT-SIRM) observed around 210 K upon Zero field cooling. The host rocks of the detrital sedimentary magnetic mineral assemblage are basalts which, different from felsic volcanics, typically do not contain two intergrown titanohematite phases. No low Ti titanohematite was actually detected, instead, titanohematite with an approximate composition of TH85 ($0.85\ FeTiO_3 \cdot 0.15\ Fe_2O_3$) intergrown with (titano-)magnetite. TH85 becomes ferrimagnetic below about 210 K and its magnetic moment is coupled antiparallel to (titano-)magnetite, the only constituent carrying a remanence at room temperature. Between such physically decoupled magnetic phases magnetostatic interaction appears the only conceivable mechanism for self-reversal. Compared to exchange coupling, magnetostatic interaction is weak. This explains the absence of any anomaly in the critical temperature interval upon thermal demagnetization of low temperature the saturation remanences (LT-SIRM) to room temperature. The partial self-reversal documented here could most likely not be detected directly in the Mesozoic flood basalts of the Paraná Basin, because titanomagnetite, which is largely dissolved by massive diagenetic alteration and only preserved as minute fractions in the marine sediments, would totally mask the effect.

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# A COMPARISON BETWEEN THE MICROWAVE AND MULTISPECIMEN PARALLEL DIFFERENTIAL PTRM PALEOINTENSITY METHODS

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The San Quintin volcanic field is located in Baja California and consists of 10 eruption complexes with about 30 lava flows. $^{40}Ar/^{39}Ar$ step-heating experiments and $^{3}He$ surface exposure dating experiments suggest eruption ages between 22 and 165 ka. Paleodirections of 23 studied flows are consistent with normal secular variation, with the exception of only one site showing an intermediate VGP latitude of 45°N. Microwave paleointensity (PI) experiments were carried out on 186 samples with 124 interpreted to be successful. The unsuccessful experiments are characterized by decay typical of an IRM, concave curves in the Arai diagram, or too hard remanence to be affected by the microwaves. All site mean PI are smaller than 20 μT, with an average around 15 μT.

Sites with sufficient untreated samples were selected to apply the new PI method based on multiple specimens and the application of different laboratory fields to each sample, parallel to its NRM. This was possible for 13 sites. Temperatures for acquisition of pTRM were chosen between 200–225 °C, according to previous thermal demagnetization data. The experiments provided results for all sites, allthough the number of specimens varied between only 3 and 9, as some specimens showed secondary overprints, and another few were misoriented in the oven. PI values obtained by this method range between 14 and 32 μT, but concentrate around 18 μT. Allthough most PI data are comparable between the two methods, the microwave PI show a tendency to be smaller than those from the multispecimen PI. This is probably due to thermal alteration processes, already starting at those low temperatures and recognized in a general increase of magnetic susceptibility and thus probably as well of the pTRM capacity.

In the case of the San Quintin volcanics, the microwave method therefore may approach closer the intensity of the paleofield, as it heats the samples less and for a much shorter time, only 10–20 compared to 2400 seconds. Our comparison demonstrates the enormeous importance of thermal alteration affecting PI experiments, even at very low temperatures.

## ORIGIN AND IMPLICATIONS OF TWO VERWEY TRANSITIONS IN THE BASEMENT ROCKS OF THE VREDEFORT METEORITE CRATER, SOUTH AFRICA

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Two populations of magnetite exist in the shocked basement rocks of the Vredefort meteorite impact crater: one associated with original crustal genesis and metamophism around 3.0 Ga, and the other related to the impact itself at 2.02 Ga. Pre-impact magnetite is mostly micron to millimeter in size, lying within the multidomain to pseudo-single domain range. The second population of magnetite is less than 10 µm in size and formed within the interstices of planar deformation features or within the reaction rims of biotite, both of which were created during impact. Our study shows that each of these populations possess specific Verwey transition temperatures: one around 124 K associated with pre-impact magnetite and the other around 102 K associated with impact-related magnetite. The high temperature Verwey transition is attributed to stoichiometric magnetite while the low temperature Verwey transition to non-stoichiometric magnetite. Pre-impact rocks containing both Verwey transitions are ubiquitous throughout the crater. Pseudotachylites formed during impact have a single Verwey transition spanning temperatures from 94 to 111 K. Heating the basement rocks above ~550–600°C for three minutes or above ~500°C for one hour irreversibly modifies the 124 K Verwey transition by shifting it to lower temperatures. Based on these findings, it is possible that no wholesale heating of the crater occurred above 550–600°C for three minutes or above 500°C for one hour during or since the time of impact, although some places of more localized heating are identified. An unresolved problem remains to reconcile these data with temperatures thought to persist in the crust during and after impact.

# SUITABILITY OF FIRED CAVE SEDIMENTS FOR ARCHAEOMAGNETIC STUDIES

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In spite of the recent advances in archaeomagnetic research specifically carried on fired archaeological materials in Western Europe, the temporal range covered by these studies still remains limited. In order to extent the chronological frame of the Iberian secular variation (SV) reference curve, we present various archaeomagnetic data from some Neolithic fired sediments in caves.

The cave of “the Mirador” (Atapuerca archaeological sites - North Central Spain), shows a succession of burnt horizons (“burnt layers”) in its stratigraphy from Neolithic to Bronze Age. Theses burnt layers or "*fumiers*", are produced by the periodic and intensive combustion of waste generated by the livestock kept in caves. Each one of these fumiers shows a recurrent in situ sequence of facies in three units: ashes, rubefaction (underlying to ashes) and clays. Particularly the ashen facies seem to be exceptional recorders of the Earth´s magnetic field with well defined and isolated directions for each specific combustion unit. Various archaeomagnetic directions have been determined for a well dated chronological range in the site (~ 5.300 to ~ 6.300 years B.P.)

We have performed several rock-magnetic measurements on these samples in order to asses the magneto-mineralogy of these archaeological items. Moreover, our archaeomagnetic results provide an exceptional example of how archaeomagnetic research can be applied to more ancient times than usually researchers do. Magnetic differentiation in terms of mineralogy, concentration and grain size can also be effective in the characterization of archaeological combustion structures.

# LOW-TEMPERATURE FIRST-ORDER REVERSAL CURVE (FORC) DIAGRAMS FOR SYNTHETIC AND NATURAL SAMPLES

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In the last five years, first-order reversal curve (FORC) diagrams, calculated from partial hysteresis curves, have become an efficient way of characterizing magnetic domain-state in grain assemblages (*Pike et al., 1999*; *Roberts et al*, *2000*). The vast majority of FORC diagrams have been measured at room temperature. However, a number of magnetic properties, e.g., susceptibility and coercivity field, vary with temperature, due to the temperature dependency of the controlling magnetic energies. The main aim of this work was to observe the response of FORC diagrams to the low-temperature changes, and to assess the suitability of low-temperature FORC magnetometry in rock magnetism, by measuring FORC diagrams between room-temperature and 10 K, for both synthetic and natural samples, and for a mixture of synthetic magnetite and natural powdered hematite.

### Examples of the evolution of FORC diagrams with temperature

*Synthetic sample: W3006:* W3006 synthetic powder is almost pure magnetite, with a Curie temperature close to 580°C. The FORC diagram at 300 K is characteristic of a PSD grain distribution, with the innermost contour being closed and the outermost contours intersecting the $H_c = 0$ axis (Fig. 1a). FORC diagrams and hysteresis parameters do not show any significant variations for temperatures ≥ 100 K. The effect of the Verwey transition is seen between 130 and 100 K, where the FORC distribution expands along both axis, and the main FORC peak (MFP) moves towards high coercivities (Fig. 1b). At 50 K, the MFP increases and strong asymmetries develop (Fig. 1c).

*Natural sample: Potsherd:* We measured FORC diagrams on a potsherd sample (TM20) from a native site in Southern Ontario (*Carvallo and Dunlop, 2001*). The room-temperature FORC diagram is characteristic of SP behavior (Fig. 2a). When the temperature is decreased, a SD peak appears, characterized by a higher coercivity and closed-contours. This SD peak progressively replaces the SP peak. The peaks are clearly separately seen at 200, 130 and 100 K (Fig. 2b,c,d). At 20 K, only the SD contribution is left on the FORC diagram (Fig. 2f). In the same time, the FWHM increases between 200 K and 50 K, as well as the spread of the FORC distribution along the $H_c$ axis. This behavior is caused by the fact that the SP/SD size threshold varies as a function of the temperature and the magnetocrystalline anisotropy magnitude is also temperature dependent. When the temperature decreases, the threshold increases, so grains that were SP at room temperature become stable SD.

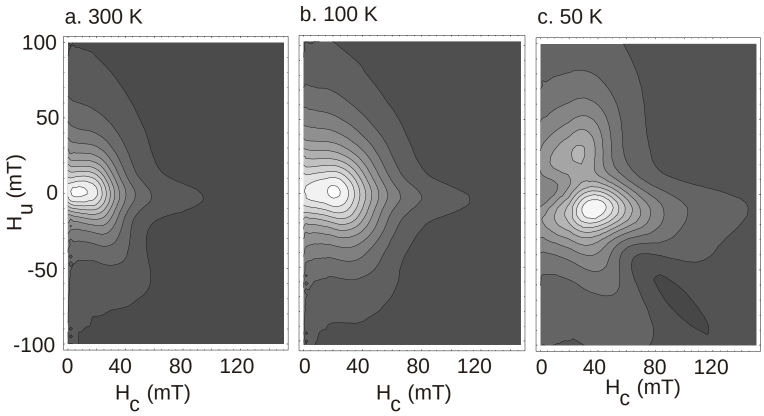


**Fig. 1.** FORC diagrams for sample W3006 at various temperatures. **a)** room temperature; **b)** 100 K; **c)** 50 K. In all three FORC diagrams the smoothing factor SF = 3, and the averaging time = 0.2 s.

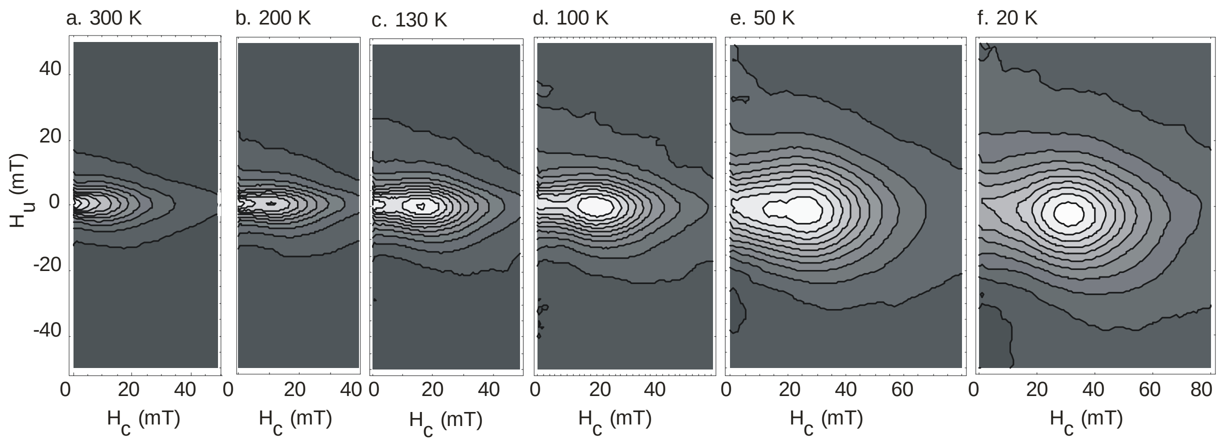


**Fig. 2**. FORC diagrams at various temperatures for a potsherd sample (sample labeled C in *Carvallo and Dunlop*, 2001). **a)** room temperature; **b)** 200 K; **c)** 130 K; **d)** 100 K; **e)** 50 K; **f)** 20 K. In all FORC diagrams SF = 5, averaging time = 0.2 s.

## Conclusions

For synthetic magnetite samples there were abrupt changes in the FORC distribution at the Verwey transition (120 K), whilst in the more complex natural magnetite samples the FORC distribution gradually progressed with temperature. Samples with dominant superparamagnetic signals became single-domain (SD)-like (Fig. 2), SD-like sample stayed SD-like and a PSD-like sample became more SD-like (Fig. 1). In addition to these general features, we also observed some more specialized features. First, in both synthetic and natural magnetite samples, a secondary higher-coercivity peak is occasionally present below the Verwey transition, which we suggest is a twinning contribution. Second, the coercivity increases by a factor 15 between 300 K and 20 K in some of the seamount samples. Third, the effect of field-cooling/zero-field-cooling on FORC diagrams is negligible, with the hysteresis parameters $H_c$ and $H_{cr}$ displaying a greater dependency. Finally, it is shown that in mixtures of magnetite and hematite, the hematite contribution disappears on cooling below the Morin transition leaving a strong, well-defined magnetite signal.

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# MAGNETIZATIONS IN ORDOVICIAN-AGE RESERVOIRS, SW ONTARIO: PRELIMINARY RESULTS

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This study compared and contrasted variations in the paleomagnetic and rock magnetic signatures of the Ordovician Trenton Group within southwestern Ontario, in order to examine the potential reservoir diagenesis and /or regional fluid flow effects. More specifically, this study examined two localities: the Dover Field (wells PPC/ROMA-#12-7-16-IV and PPC/RAM-#12-7-6-IV), which comprises partially dolomitized limestone, and a nearby limestone non-reservoir reference core (well 83-OGS). These results were then compared to the results of a similar study in the Hillman and Goldstone-Lakeshore Fields (*Garner, 2006*), in which the rocks were completely dolomitized. The Dover Field is located within the Chatham Sag, whereas the Hillman Field is located further south on the edge of the Findlay Arch. The Trenton Goup is overlain bythe late Ordovician Blue Mountain Formation and underlain by the Cobocunk Formation of the Black River Group and contains one of the largest hydrocarbon reservoirs in the Michigan Basin and Surrounding areas (*Suk et al., 1993*). The samples underwent alternating field demagnetization, thermal demagnetization, partial anhysteretic remanent magnetization analysis and saturation isothermal acquisition and demagnetization.

In using core, the presence of a drilling induced magnetization (DIRM) can be problematic. In this study, a DIRM appears to have affected a majority of the specimens used; 74% of the Hillman Field was affected (*Garner, 2006*), while 42% of the Dover Field appears to be affected; however, only about 10% of the reference core carried a DIRM. A viscous remanant magnetization correction to the present Earth's magnetic field was not possible on these specimens, therefore inclination-only means were calculated (*Enkin and Watson, 1996*) for the various wells and lithologies.

Dolomites from the Hillman/Goldsmith-Lakeshore Field produced an inclination-only mean of $I = -10.2°$, ($n = 70$, $\alpha_{95} = 1.6°$). In comparison, a completely dolomitized well from the Dover Field was less affected by DIRM, and its segment-based inclination-only mean was $I = -1.0° +3.0°/-3.4°$ ($N = 3$, $k = 378.3$). A single well contained limestone in the Hillman/Goldsmith-Lakeshore Field, and *Garner (2006)* calculated two means: the total ($D = 172.2°$, $I = -0.1°$, $\alpha_{95} = 33.5°$, $N = 5$, $k = 6.2$), and a limited subset mean ($D = 149.3°$, $I = 1.0°$, $\alpha_{95} = 16.6°$, $N = 3$, $k = 56.2$). The reference well and one of the two wells in the Dover Field were comprised of limestone. The reference well had an inclination-only mean of $I = -6.6° +3.7°/-3.8°$ ($k = 48.3$). Two segments from the Dover Field well had inclination-only means of $I = -15.8° +3.8°/-3.6°$ ($k = 83.0$) and $I = -8.3° +5.0°/-5.4°$ ($k = 46.2$).

In comparing the two reservoirs, the dolomite inclinations appear to be distinct (a difference of approximately 10°). The paleolatitudinal arc produced by Garner's study passes through the entire Permian and Early Triassic portions of North America (*Garner, 2006*), whereas the arc produced by dolomites in the Dover Field apparently gives a slightly older (late Pennsylvanian – Permian) age. In the Dover Field, the limestone give a slightly steeper inclination, approximately a 7.0° to 14.5° steeper than those from the Hillman/Goldsmith-Lakeshore Field. The DIRM precluded orientation of the limestones, and therefore two options are present for the age of the magnetization - Triassic or early Pennsylvanian. The reference well appears to have a similar inclination mean to the Hillman/Goldsmith Field ($I = -6.6°$) These preliminary results suggest some variation in magnetization age between the two fields that could be attributed to either reservoir diagenetic processes or to regional geological factors ; however, the study is still in progress. Future work includes more petrologic and geochemical analysis to isolate lithology-associated components.

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# MAGNETIC FABRIC OF DIKES AND SILLS OF THE ČESKÉ STŘEDOHOŘÍ MTS. – PRELIMINARY RESULTS

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The preliminary results of the magnetic fabric (AMS) of selected dikes, and sills from the České středohoří Mts. (NW Czech Republic) are presented. The České středohoří Mts. are situated in the NW part of the Czech Republic, in the area of the SW-NE trending Ohře (Eger) Graben. This extensional structure belongs to the European Cenozoic Rift System and separates the Saxothuringian and Moldanubian basement terranes of the Bohemian Massif. The purpose of this magnetic fabric study is to unravel kinematics of the dikes and sills emplacement and to estimate the magma flow directions.

So far, 23 individual sites were sampled yielding more than 500 oriented specimens. The studied rock types included olivine basalt, bostonite, camptonite, phonolite, tephrite, trachybasalt. Quantitative parameters of

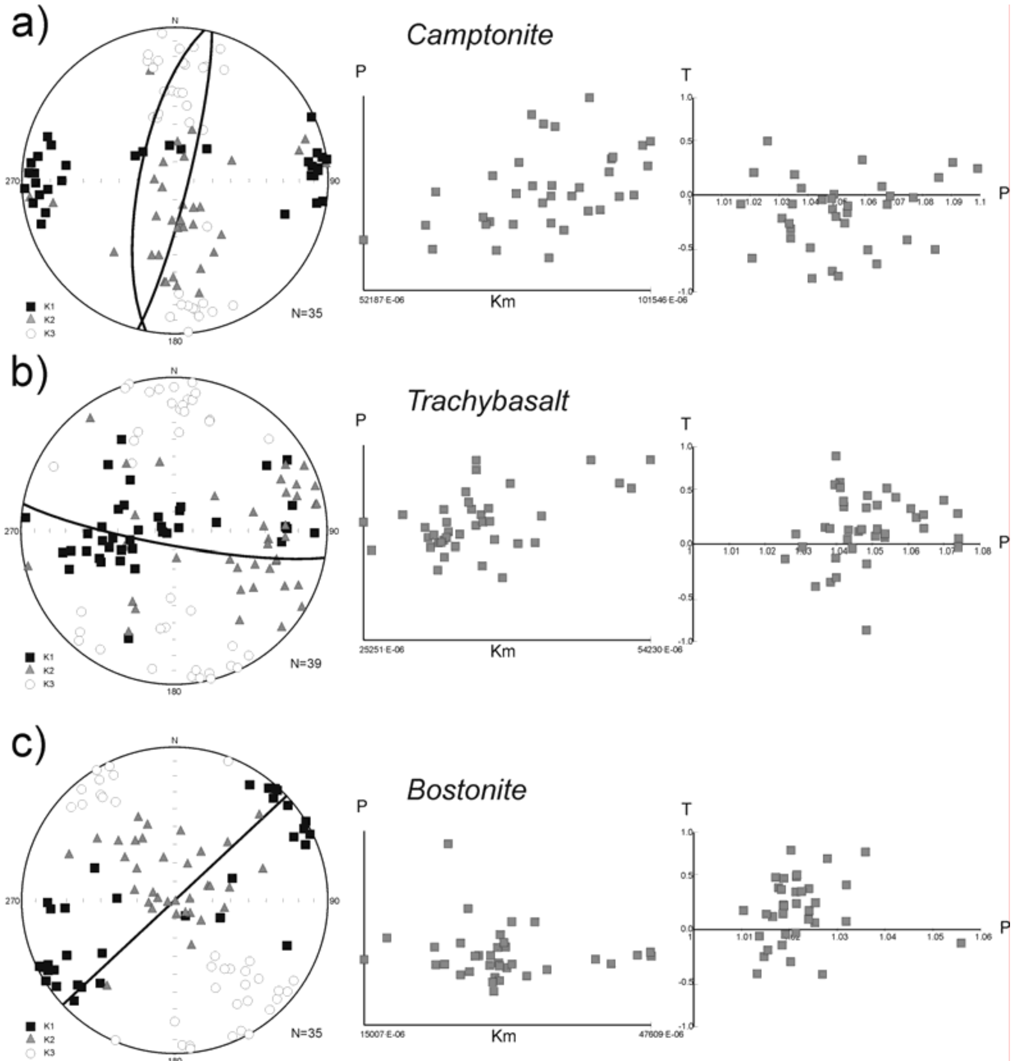


**Fig. 1.** Projection of principal directions (maximum as black squares, intermediate as gray triangles, minimum as white circles) of AMS, $k_{mean}$-$P$ plots, and $P$-$T$ plots for tree select dike of the České středohoří Mts.

magnetic anisotropy ($k_{mean}$, $P$, $T$) were evaluated with regard to individual sites and different rock types. Magnetic susceptibility values, $k_{mean}$, vary according to rock type from about $3000 \times 10^{-6}$ (phonolites) to more than $120000 \times 10^{-6}$ SI (camptonite). The degree of anisotropy, $P$, is generally relatively low, $P < 1.10$, except for some phonolite specimens where $P$ reaches the maximum values of 1.25. This fact reflects the differences in viscosities of the respective magmas (*Hrouda et al., 2005*). Consequently, different mechanisms orienting magnetic minerals should be expected in various rock types studied. The shape of anisotropy ellipsoid ranges from slightly prolate to neutral and oblate.

Several different orientations of the principal AMS directions in relation to dike or sill orientation can be found. An inverse fabric (*cf. Rochette et al., 1999*) with magnetic lineations and magnetic foliations perpendicular to the dike margins was found in camptonite dike (Fig. 1a.). Normal magnetic fabric with magnetic foliations and magnetic lineations subparallel to the dike margins was found in trachybasalt and bostonite dikes (Fig. 1b,c.). In the former the magnetic lineations are subvertical whereas in the later subhorizontal magnetic lineations can be observed. Comparing all studied sites it seems that the type of magnetic fabric is lithology-dependent (e.g. bostonite possessing normal fabric and camptonite possessing inverse fabric). Whether predominant occurrence of normal/inverse fabric reflects the presence of MD/SD grains or results from different orientation mechanism of magnetic minerals remains unclear. This question must be answered before any successful geological interpretation of magnetic fabric can be made.

*Acknowledgement:* This study was generously supported by J. William Fulbright Commission, Prague, Grant # 2005-28-02.

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# REMASOFT 3.0 – A USER-FRIENDLY PALEOMAGNETIC DATA BROWSER AND ANALYZER

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The presented 32-bit MS Windows software serves as a basic viewer and analyzer of paleomagnetic data acquired during alternating field or thermal demagnetization procedures. Even though Remasoft 3.0 was mainly written for the purpose of AGICO JR5/JR6 spinner magnetometers (*.jra, *.jr6 data formats) it features routines for importing various data formats (e.g. 2G cryogenic magnetometers of paleomagnetic laboratories of Zurich, Torino, Honolulu; this list can be easily extended). Besides generic data formats, general import routine allows reading column-based data from text files or inserting data manually in a spreadsheet-like interface. After opening or importing the paleomagnetic data for each specimens are stored in separate file allowing for easy manipulation and combining of different data sets.

The software consists of two main windows: 1) Individual specimens viewing, editing and analyzing window, and 2) Group statistics window. These windows can be opened simultaneously allowing for switching between display of individual specimen and group of specimens. Individual specimen window (Fig. 1) was designed as a browser-like interface allowing for a rapid screening through a large number of analyzed specimens. Using a tab-strip several different options can be selected for each specimen: i) Overview containing Stereoplot, Zijderveld plot, Module plot, and if available, magnetic susceptibility plot; ii) Module plots, iii) Orthogonal component plots, iv) Editing table. Furthermore principal component analysis can be performed for each specimen using the least-squares line and plane method of *Kirschvink (1980)* or analysis of remagnetization circles of *McFadden and McElhinny (1988)*. Calculated principal components can be viewed for a group of specimens in a stereo plot (Fig. 2). Mean direction using *Fisher (1953)* statistics and virtual geomagnetic pole can be calculated for any selected group of specimens. All graphical displays can be either directly printed or exported into portable graphic formats (WMF, BMP). Presented software can be downloaded from Agico, Inc. web site (www.agico.com).

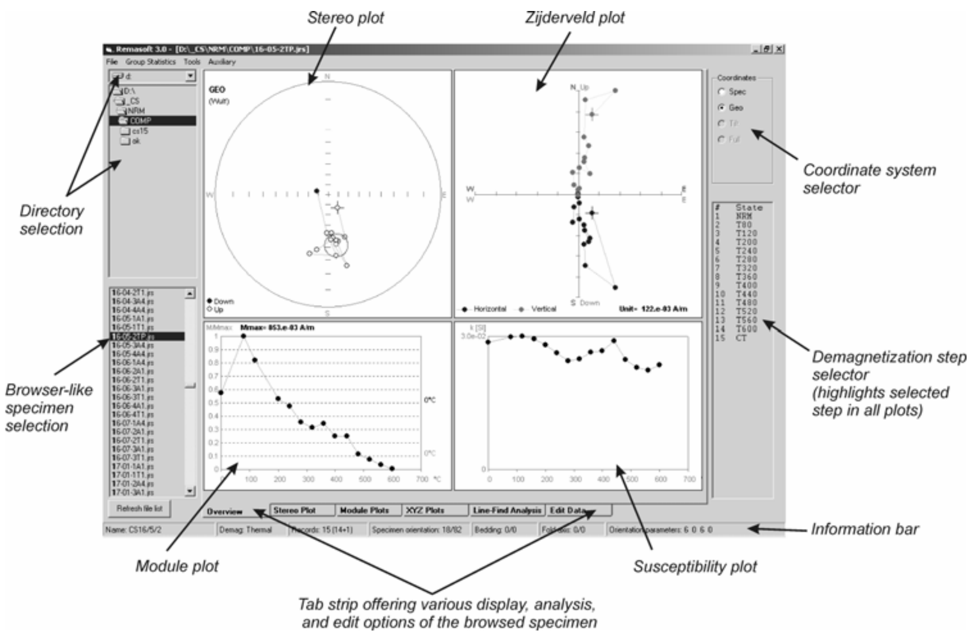


**Fig. 1.** Induvidual specimen window with its basic features.

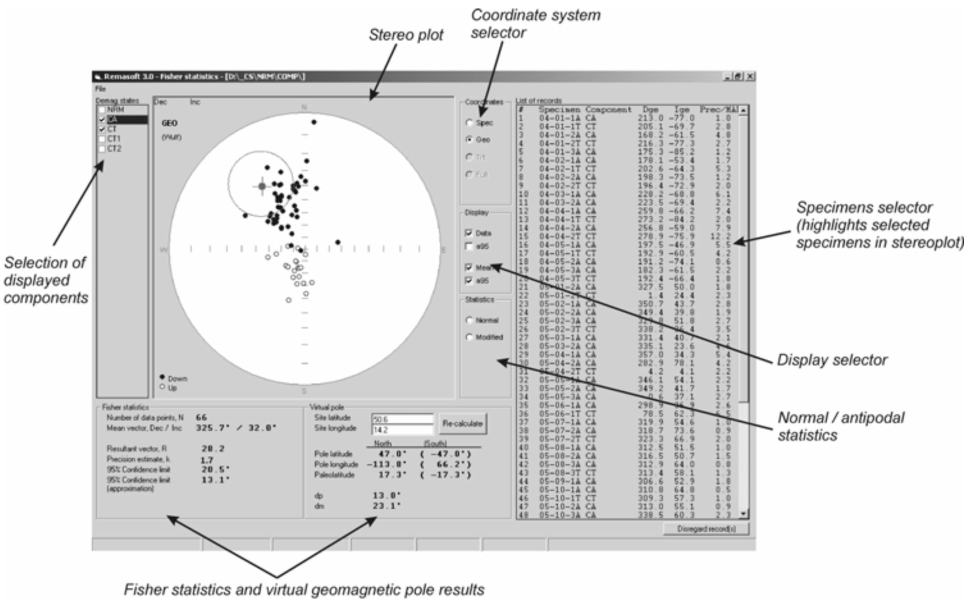


**Fig. 2.** Group statistics window with its basic features.

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# A NEW PALEOMAGNETIC POLE FOR CENTRAL EUROPE AS DERIVED FROM SELECTED TERTIARY VOLCANIC ROCKS OF THE BOHEMIAN MASSIF

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In this study we present the results of a rock magnetic and paleomagnetic study of the Tertiary volcanics from the České středohoří Mts. (Czech Republic). The studied rock types included olivine basalt, basanite, bostonite, camptonite, monzodiorite, phonolite, tephrite, trachybasalt, and trachyte. Sampling was performed from 33 individual sites of dikes, sills, domes, volcanic conduits and apical parts of the larger intrusive bodies. Sampling yielded 260 oriented cores and, after laboratory cutting, more than 900 individual specimens.

The České středohoří Mts. are situated in the NW part of the Czech Republic, in the area of the SW-NE trending Ohře (Eger) Graben. This extensional structure belongs to the European Cenozoic Rift System and separates the Saxothuringian and Moldanubian basement terranes of the Bohemian Massif. The available radiometric dates indicate that the main volcanic activity occurred between 36 and 9 Ma (Late Eocene-Late Miocene) culminating during the Oligocene.

Petrographic characteristics of the studied rock types were described in thin sections. The nature of the magnetic carriers was investigated using different rock magnetic techniques. Magnetic susceptibility ($k$), low-field variation of magnetic susceptibility ($k_{HD}$), NRM, SIRM were measured for each specimen. Later, several specimens representing each sampling site and/or particular rock type were analyzed using temperature variations of magnetic susceptibility, IRM acquisition and back-field demagnetization, thermal demagnetization of the tree-component IRM (*Lowrie, 1990*), and hysteresis parameters. In most of the specimens the low

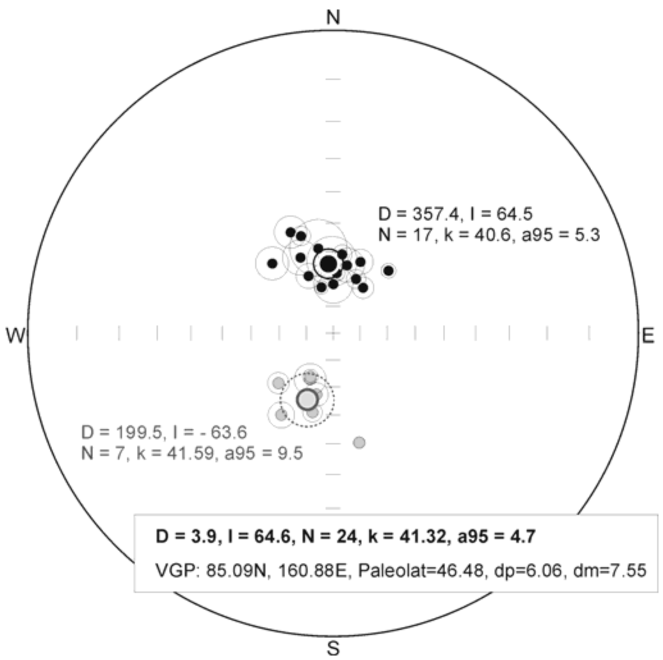


**Fig. 1.** Mean directions for 17 normal- and 7 reverse-polarity sites (plotted as black or gray circles, respectively) with respective cones of confidence, $\alpha_{95}$ (thin circle around each point). Normal polarity and reverse polarity mean directions are plotted as large black and gray circles with respective cones of confidence, $\alpha_{95}$ (thick solid and dashed circles, respectively). Mean direction combining normal- and reverse polarity sites and corresponding virtual geomagnetic pole (calculated for $\varphi = 50.66$ºN and $\lambda = 14.04$ºE) is given in inset rectangle.

coercivity ferrimagnetic mineral corresponding to titinomagnetite with variable Ti-content was identified. In some cases minor amounts of hematite and/or pyrrhotite may be present. The increasing amount of substituted Ti in titanomagnetite, as revealed by low-field variation of magnetic susceptibility, decreases the Curie temperature of the studied rock (*e.g. Hrouda et al., 2006*) and may influence some hysteresis parameters (*Dunlop, 2002*). Consequently, the unblocking temperature (when TRM was acquired) varies significantly according to the rock type studied.

Stable characteristic remanent magnetization (ChRM) directions were obtained from 27 sites by stepwise alternating field (AF) and thermal (Th) demagnetization methods and subsequent principal component analysis. In most cases both methods yielded comparable results. The mean direction was calculated by combining the means from 24 sites (715 specimens). The site selection was based on the following criteria: number of specimens with stable ChRM greater than 10, precision parameter $K > 10.0$, and $\alpha_{95} < 10.0°$. Both normal- and reverse-polarity sites were present, the angle between respective means is 170.34° (Fig. 1). After transposition of reverse-polarity sites, the common mean direction is: $D = 3.9°$, $I = 64.6°$, $k = 41.32$, $A_{95} = 4.7°$. This gives a virtual geomagnetic pole (VGP) of 85.09°N, 160.88°E ($d_p = 6.06°$, $d_m = 7.55°$) with a corresponding paleolatitude of 46.48°, which agrees well with the Late Tertiary apparent polar wander path (APWP) for Europe (*e.g. Krs, 1968*; *Irving and Irving, 1982*; *Van der Voo, 1990*; *Besse and Courtillot, 1991*; *Schott et al., 1994*).

*Acknowledgement:* This study was generously supported by J. William Fulbright Commission, Prague, Grant # 2005-28-02.

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# THE ROLE OF PARAMAGNETIC MINERALS IN CLAY SEDIMENTS MAGNETIC ANISOTROPY: CORRELATION BETWEEN MAGNETIC FABRIC AND CHLORITE PREFERRED ORIENTATION

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In this study we investigate the mechanism that is responsible for the magnetic lineation in apparently homogeneous clay sediments where deformation is not visible at the outcrop scale. We integrate low-field, high-field and low-temperature AMS analyses with neutron diffraction pole figures analysis as an alternative approach to studying the deformation mechanisms that act in sedimentary basins in the incipient phases of tectonic processes.

The studied rocks are Neogene clay sediments sampled from different tectonic settings: the Calabrian Arc (Southern Italy) and the Rif Chain (Morocco). Notwithstanding the lack of strain markers available at the outcrop scale, these fine-grained sediments possess a magnetic fabric that is consistent with the regional deformation.

High-field AMS measurements carried out on a large number of samples show that, independent of the relative percentage of the ferrimagnetic contribution (generally < 10%) and paramagnetic contribution (generally > 90%) to the total high-field AMS, the principal axes of both components coincide with those of the low-field AMS at room and low temperatures. These results indicate that the magnetic anisotropy of the studied samples is predominantly carried by the paramagnetic phyllosilicates, i.e. chlorite, as deduced by X-ray diffraction.

In order to correlate the observed magnetic fabric with the spatial distribution of chlorite, the orientation tensor of chlorite (002) planes were calculated from the neutron goniometry pole figures. Neutron texture analysis confirms that the AMS ellipsoid reflects the spatial distribution of the basal planes of chlorite, which have been modified in the acting strain field.

These results demonstrate the great potential of the AMS to determine the mineral orientation fabric. The combination of these different approaches enables to establish a more accurate qualitative and quantitative correlation between the chlorite fabric and magnetic anisotropy and yields valuable information about the meaning of the magnetic fabric.

# MAGNETIC PROPERTIES AND PARAMETERS OF LAKE ERIE BEACHES: EXAMINING SHORELINE PROCESSES AND GEOMORPHOLOGICAL FACTORS

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A series of studies (e.g. *Igbokwe, 2004*; *Vickers, 2006*) is being conducted on the magnetic properties of beach and coastal watershed sediments on the northern shore of Lake Erie (Canada). The studies investigate the variations of magnetic parameters in order to evaluate the potential of environmental magnetic techniques for examining shoreline geomorphological processes such as erosion, accretion, and longshore drift, as well as sediment source tracing. Methods vary from study to study, but normally incorporate measurements of susceptibility (field and/or laboratory), anhysteretic remanent magnetization, saturation isothermal remanent magnetization, magnetic ratios such as *S*-ratio and SIRM/ARM, hysteresis parameters, and the temperature dependence of magnetization or magnetic susceptibility. The instrumentation used includes a 2G cryogenic magnetometer, Sapphire Instruments AF demagnetizer with ARM coil and pulse magnetizer, Magnetic Measurements variable field translation balance, AGICO Kappabridge and Bartington MS2 susceptibility meter.

In the earliest study, *Igbokwe (2004)* focused on the beaches of Point Pelee National Park (PPNP), a 'triangular shaped cuspate foreland' (*Trenhaile et al., 2000*), and examined the spatial and temporal (seasonal) variations of magnetic minerals on the beaches. This work determined that magnetite was the dominant magnetic mineral present on the beaches, and that the eastern (eroding) beaches had significantly higher magnetic susceptibility than the western (accreting) beaches. The intrabeach variability was high, with the magnetic minerals concentrated in long narrow bands on the beach as well as in layers well away from the wavefront. *Vickers (2006)* investigated the area to the immediate northeast of PPNP, focusing on the shoreline, Hillman Marsh drainage basin and a creek draining part of the southeastern section of Essex County. In that study, while the dominant magnetic mineral along the shore was magnetite, the creek sediments were dominated by a higher-coercivity mineral - either hematite or goethite. However, very little of the high coercivity mineral reached the beaches. A third study examined magnetic properties and parameters of beach sand and nearby till bluffs and glaciofluvial sands from nine beaches along an 80 km section of shoreline from PPNP to Rondeau Park. Susceptibility values on the beaches were typically at a minimum near the shoreline, and increased towards the land, with magnetic parameters and Curie temperatures indicative of magnetite. The glaciofluvial sands showed similar results, whereas the glacial till samples were quite different in having no magnetite, and only a very small amount of high coercivity material.

The combined results of the studies have a number of implications. First, the magnetite is typically associated with red/purple sand that contains significant amounts of heavy minerals, which suggests that the susceptibility values are tracking heavy mineral concentrations. Second, the magnetite provenance appears to be glaciofluvial sands and beach ridges rather than till bluffs - an implication supported by the soil susceptibility map of Essex County (*Shi and Cioppa, 2006*), which has a positive anomaly corresponding to a sand-rich recessional moraine oriented NW/SE through the centre of the county. Third, the difference in magnetic properties between the creek samples in the *Vickers (2006)* study and the material found along the beaches suggests that stream sediments do not contribute significantly to the beaches, and that local geomorphological features and longshore currents determine the spatial distribution of the magnetite in the beach sands.

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# COMPOSITION AND ORIGIN OF LAMINAE IN HOLOCENE SEDIMENTS FROM THE SOUTHERN GULF OF CALIFORNIA – GEOCHEMICAL, ELECTRON MICROSCOPY AND ROCK MAGNETIC STUDY

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The sediment sequence of Alfonso Basin in the southern Gulf of California spanning the last 8000 years is characterized by a laminated structure. In contrast to the varved sediments from basins in the central part of the Gulf, the Alfonso Basin laminae are non-annual sediments. To characterize these sediments and investigate on its genesis, X-ray, scanning electron microscopy, microfossil, geochemical and magnetic mineral analyses have been conducted on dark and light laminae. The purpose of the study is to investigate on sediment sources, depositional processes and the formation of the laminated structure of this Holocene marine sedimentary sequence.

The laminated sediments consist of alternating millimeter to sub-millimeters bands of different shades of olive gray. On average, dark laminae are thicker than light laminae, resulting in the dominant dark color of the sequence. Sediment rate is about $0.3 \pm 0.04$ mm/yr, which results in an average 11.2 years for the dark-light laminae.

Light laminae contain more radiolarian microfossils (up to 45%) and less terrigenous and organic material; they predominantly contain quartz and calcite minerals. The dark laminae contain more terrigenous material, dominated by clay and quartz. In general, almost all chemical elements (Si, Al, Fe, Mg, K, S) analyzed, except Ca, are always higher in the dark laminae and show positive correlation to organic carbon. Ca is higher in the light laminae and mostly represents biogenic input and shows a negative correlation to organic carbon. Si correlate with typical terrigenous elements (Al, Fe, K and Mg), this suggests that most of Si has terigenous origin, which can be related to the volcanic rocks, particularly siliceous tuffs, surround Bay of La Paz. Smectite and illite are present in dark and light laminae in similar proportions.

Magnetic hysteresis loops and IRM acquisition and saturation IRM AF demagnetization indicate the presence of low-Ti titanomagnetites in the dark and light laminae. In dark laminae magnetic hysteresis loops show saturation at low fields and relatively high saturation magnetization values, which suggest increased contribution of very fine-grained superparamagnetic minerals.

The laminated slope sediments of the Alfonso Basin are an example of nearshore depositational system dominated by sedimentation of terrigenous input. The basin receives an episodic pulse of biogenic material which results in light laminae.

## ABSOLUTE PALAEOINTENSITY INDEPENDENT OF MAGNETIC DOMAIN STATE

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Knowing intensity variations of the Earth's magnetic field as function of geological time provides essential constraints for understanding geodynamo action. This significantly constrains numerical geodynamo models. To date however, most palaeointensity determination methods are characterised by rather low success rates. Moreover they are laborious are demand substantial processing time. The rocks under investigation must obey stringent criteria to yield faithful palaeointensities: the magnetic particles must be single domain, the natural remanent magnetisation must be a thermoremanent magnetisation, and during the successive heating steps in the laboratory no chemical alteration should occur. Here, we describe a new method that allows all magnetic domain states to be processed, i.e. it does not require single domain particles, an important asset. The method makes use of the linearity of pTRM with the applied laboratory field. Multiple specimens are used so that every sample is exposed only once to a laboratory field, warranting that all samples experienced the same magnetic history. Through the limited number of thermal steps alteration effects are reduced as well. The natural remanent magnetisation (NRM) of the specimens is oriented parallel to the laboratory field, minimizing the effects of high-temperature tails that affect multidomain minerals. The pTRM acquisition temperature is selected below the temperature at which chemical alteration sets in and above the temperature trajectory where secondary viscous NRM components occur.

The procedure requires a lower number of steps than any other palaeointensity method, reducing significantly the total time needed per rock unit. We propose to name the new protocol 'multispecimen parallel differential pTRM method'. It provides the correct answer to within 5% for artificial samples and natural intrusive rocks containing large multidomain magnetic particles that were given a laboratory TRM of known intensity. Application to the Paricutin September-December 1943 lava flow (three sites, 7 specimens per site) yields a weighted mean of 45.9 ± 1.25 μT, within uncertainty margin of the expected value of 45.0 μT.

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# MINERAL MAGNETIC PROPERTIES OF CAVE SEDIMENTS FROM THE MORAVIAN KARST, CZECH REPUBLIC: RECORDS OF ENVIRONMENTAL CHANGE

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The cave environment, both the entrance as well as the interior, offers an enormous richness of well preserved clastic and chemogennic sediments. In many instances the character of these sediments reflects the environmental conditions at Earth's surface at the time of deposition which is then preserved in the cave's protective environment. These sediments can span significant intervals of time making them ideal for environmental magnetic studies, yet very few researchers have availed themselves of this opportunity. To test the suitability of cave deposits to record an environmental magnetic signal we have studied the entrance facies sediments of Kůlna Cave (*Šroubek et al., 2001*) and the interior facies sediments of Spirálka Cave. At both caves, magnetic susceptibility and a host of other mineral magnetic and non-magnetic properties were determined to whether susceptibility variations in the sediments were responding to environmental changes occurring on Earth's surface during their formation and if so how was the surface environment influencing these variations.

Kůlna Cave is an approximately one hundred meters long tunnel-shaped cave forming the upper level of the large Sloupsko-Šošůvske cave system. The entrance facies sediments in Kůlna consist of interbedded layers of limestone talus with a silty matrix and silts which were redeposited by slope processes from the vicinity of the cave and/or were directly blown into the cave entrance during the Last Glacial Stage. The layers overlie fluvial sands and gravels deposited during the Last Interglacial. Mineral magnetic measurements (frequency and temperature dependence of magnetic susceptibility, magnetic grainsize, and coercivity characteristics) suggest that magnetic susceptibility variations ($\chi$) in the Kůlna sediments are controlled by the concentration of pedogenically formed magnetite and/or maghemite. After removal of the effects of fine carbonate debris and detrital ferromagnetic minerals on the bulk $\chi$ record, we obtained a record of pedogenic susceptibility ($\chi_p$) that shows variations both on long and short time scales. The long term trends are in good agreement with the deep sea SPECMAP record while the short term oscillations correlate well with rapid climatic events recorded by changes in the North Atlantic sea surface temperatures. These results suggest that during the Last Glacial Stage Central European climate was strongly controlled by the sea-surface temperatures in the North Atlantic.

Spirálka Cave is a more than one kilometer long cave which consists of a 60 meters deep vertical entrance cavities and extensive horizontal passages. The lower part of the cave is occasionally flooded by the Bílá Voda Stream which links it with the largest cave system in the region, the Amateurs cave, lying further downstream. The five meter high sedimentary profile we studied is located in an intermittently flooded chamber deep in the interior of the cave. The profile consists of interbedded layers of silt, sand and gravel with occasionally present flowstone laminae and organic rich lenses. Radiocarbon dating of charcoal found within the sediments indicates these sediments were deposited over the last several centuries during anomalously high stands of the Bílá Voda Stream. Mineral magnetic measurements (ferromagnetic $\chi$, frequency and temperature dependence of $\chi$, magnetic grainsize, and coercivity characteristics) suggest that $\chi$ variations in the Spirálka profile are controlled by concentration of detrital magnetite and by grainsize. This is especially true for the upper 1.5 meters of the profile. In this portion of the profile, susceptibility and magnetite concentration variations also show a positive correlation to the Ti and Zr records and to changes in the 10-year running average of winter temperature anomalies for the last 200 years as calculated from instrumental measurements at Prague's Klementinum Observatory. These observations lead us to surmise that mineral magnetic variations are depositionally controlled by factors affecting the catchment area of the Bílá Voda Stream, i.e., namely spring floods induced by melting of the snow cover, forest clearance and cultivation episodes, and forest fires. Therefore, magnetic susceptibility in the upper 1.5 meters of our profile is a sensitive indicator of environmental events (interplay of man and changing climate) happening in the catchment area.

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# MAGNETIC RESPONSES ON HEAVY METAL POLLUTION IN BEIJING AREA

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Magnetic methods, as a fast and cost-effective measurement technology, have been successfully applied in environmental pollution research. However, most cases were only related to one environmental target. As a big city, the environment of Beijing area is not only affected by different geology background, pedogenesis and climate, but also influenced by industry, agriculture, traffic and other urbanization factors. which has made the distribution and behavior of heavy metal pollution in this area more complex.

Selecting soils and tree leaves as targets in Beijing, combining pedosphere, atmosphere with biosphere, the aim is to investigate heavy metal pollution in this area and build the relationship between magnetic parameters and heavy metal contents. At the same time, it is attempted to separate different environment responses of human activities and expected to find an economical, fast and feasible magnetic method for heavy metal pollution screening.

Magnetic susceptibility (MS) distribution in three dimensions have been investigated from top soil measurements at 223 sites and 68 cores (20–50 cm deep) scanned from each sites in Beijing urban and suburban area. The high resolution results show that magnetic susceptibility has a significant regional difference not only on surface but in different depth. Top soil measurements show that MS is highest in the western Beijing industrial area (steel mill, coal-fired power plants), lower within the city centre, and lowest in the eastern countryside. MS values from different depths in the western industrial area exhibit the highest values of $400–1000 \times 10^{-5}$ SI in the upper 5cm layer. There is a gradual decrease to $250–300 \times 10^{-5}$ SI at 15–20 cm depth, followed by background values of $150–200 \times 10^{-5}$ SI below 20 cm. The values from the city centre and eastern countryside are much lower (around $150–200 \times 10^{-5}$ SI in the upper 5 cm layer), and relatively stable along the profile. Additionally, more detail magnetic investigation and geochemical analysis were carried out on three selected soil profiles from the steel mill area, the airport highway and a site with dumped soil. Data from three soil profiles reveal significant correlation between MS and heavy metal contents. It shows a linear positive correlation with Pb, Zn, Cu ($R^2 > 0.8$) at all the profiles. However, for different sites, other heavy metals (i.e., Fe, Mn, Cr) exhibit different linkage, which suggests that the soils might be affected by different pedogenic, biogenic processes, and different inputs of anthropogenic sources.

Rock magnetic experiments show MD magnetite is the main magnetic carrier both in soil and leave samples of western and eastern areas, which indicates using magnetic domain can not separate pollution information in Beijing, but can use MS denote pollution information.

MS from 391 leave samples decreases from western to eastern Beijing. MS is highest in Steel Mill area of the western area, indicating a major pollution source for Beijing; Lower within Power Plant area providing information of recent environmental improvement. The lowest MS in eastern suburb may be taken as a “background”. The general consistence of MS and Fe content of the leaves, as well as MS between leave and soil, confirms that leave is a suitable target for atmospheric pollution study.

With the help of multivariate statistics and a few geochemical analyses, magnetic method can separate pollution sources ,detect environmental response of different kind of human activity and characterizes the accumulation depth of pollutants i.e., enrichment, migration and background.

Nevertheless, compared to the background values, the magnetic enhancement can provide information about pollution by heavy metals. Correlation analyses also indicate relationship between magnetic parameters and heavy metals. Our work demonstrates that magnetic parameters not only can be used to delineate anthropogenic pollution in soil profiles and to characterize the migration depth and the depth of unpolluted soil but also can detect environmental response of different kind of human activities in atmospheric environment.

# INVERSE THERMOREMANENT MAGNETIZATION

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Inverse thermoremanent magnetization (ITRM) is reversed to the thermoremanent magnetization (TRM) process: ITRM results from warming from low temperature $T$ in a magnetic field while TRM results from field cooling from high $T$. The development of ITRM was studied in magnetites of 9 grain sizes from submicron to 135 μm, in pyrrhotites, and in hematite crystals. Although all three minerals acquired ITRM after warming through their magnetic transitions (35 K for pyrrhotite, 120 and 130 K for magnetite, 250 K for hematite), magnetite is the most likely candidate for acquiring ITRM when an impacting meteorite's cold interior warms to ambient $T$ in the geomagnetic field. The ITRM blocking temperature distribution was determined from 12 neighbouring partial ITRMs in nested field-on warming + field-off cooling cycles (300–20 K). The largest partial ITRMs were produced in $T$ intervals around magnetite's Verwey transition ($T_V$ = 110–120 K) and isotropic point ($T_K$ = 130 K). Both transitions involve large changes in crystalline anisotropy and renucleation of magnetic domains. ITRM is blocked when initially broad domain walls narrow and are pinned by dislocations. ITRM has contrasting properties to TRM, which is mainly due to blocked single-domain moments. ITRM is strongest for 3–20 μm grains, whereas TRM peaks for submicron magnetites. Only 10–20% of ITRM survives low-temperature demagnetization (LTD) at 77 K or AF demagnetization to 10–15 mT, compared to 30–90% for TRM. ITRM decreases quasi-linearly with $T$ in thermal demagnetization. The median unblocking temperature $T_{UB}$ is ≈ 300°C and 20–25% survives at 550°C. The low-$T_{UB}$ part of ITRM could mimic extraterrestrial NRM of low $T_{UB}$, cited as evidence of negligible heating of meteorites in their transfer to Earth. The high-$T_{UB}$ ITRM would contaminate paleointensity determinations up to the highest $T$ steps. The best cure for ITRM contamination is AF or LTD pre-treatment.

# ROCK MAGNETIC AND PALEOMAGNETIC PROPERTIES OF IMPACTITES FROM DEEP DRILL CORES OF BOSUMTWI IMPACT CRATER, GHANA

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The Bosumtwi impact crater, Ghana, Central Africa is the youngest (age of 1.07 Million years) of the large impact craters known on the Earth. The crater is very well preserved and accessible, and is almost totally filled by Lake Bosumtwi. In 2004, the Bosumtwi Crater Drilling Project, carried out by International Continental Scientific Drilling Program (ICDP), was performed. The drilling project consisted in several sites including 14 sedimentary and two hard rock (impactite) cores. Hereby, we report rock magnetic and paleomagnetic data from impactite cores of Bosumtwi impact crater.

Results of magnetic susceptibility show that most of the samples, despite of lithology, hold relatively low ferromagnetic component of magnetic susceptibility ($200 - 500 \times 10^{-6}$ SI). Few metasediments, however, show some magnetic susceptibility highs ($\leq 1600 \times 10^{-6}$ SI). These data correlate positively also with NRM values.

Data from paleomagnetic measurements reveal mainly two magnetic components: (i) viscous (low coercive) and (ii) high coercivity component. Low coercivity component of magnetization has random directions. This component is totally removed by 15 mT AF field. Second component is removed between 50 and 100 mT, in some cases its more stable than 130 mT. This component has shallow normal (in few cases shallow reversed; Fig. 1) magnetization what possiby points to the Lower Jaramillo N-polarity chron.

Rock magnetic measurements (including thermal behavior of magnetic susceptibility and magnetic hysteresis) were carried out in order to detect magnetic minerals present in samples. Investigations show that most common mineral seen is pyrrhotite ($T_C \approx 300$°C; see Fig 1.), which is also carrying out the remanence. In some cases the minor traces of titano-magnetites are observed. Rock magnetic parameters show also no significant differences between different lithologies.

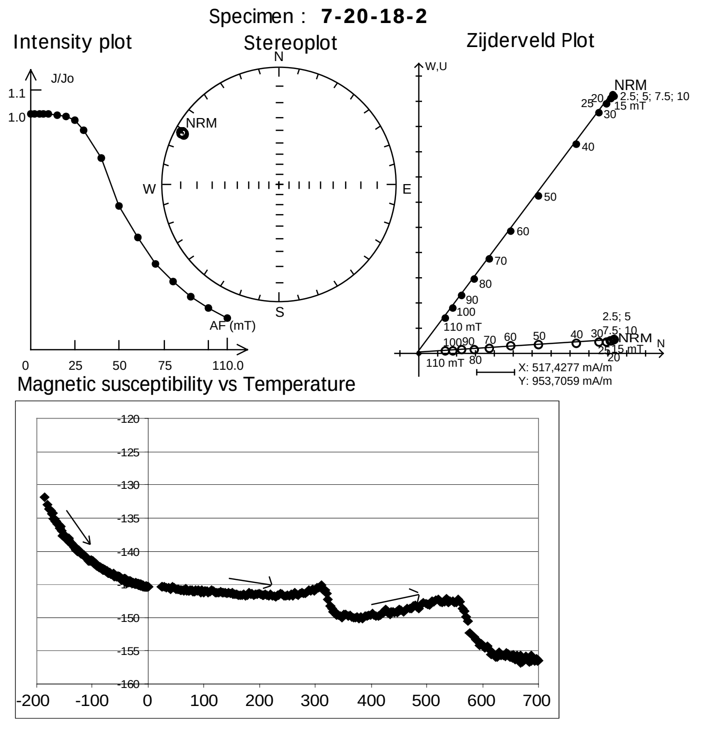


**Fig. 1.** Example of paleomagnetic and rock magnetic studies. Figure shows alternating field (AF) demagnetization curves (up) and magnetic susceptibility changes during heating (down) of sample from LB-07A impactite drill core.

# TESTING THE GEOMAGNETIC DIPOLE THROUGHOUT GEOLOGICAL TIME

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The morphology of the geomagnetic field plays a central role in palaeomagnetic investigations and in geodynamo simulations. But it has turned out to be remarkably difficult to demonstrate observationally what its dominant morphology has been throughout geological time. One early test was based on the idea that the overall sum total of palaeomagnetic sampling combined with plate tectonic movements has, over time, provided a random sample of the geomagnetic field. If this is so, then different frequency distributions of palaeoinclinations are expected for different field morphologies (dipole, quadrupole etc., see Fig. 1).

This random palaeogeographic test (RPT) initially gave the encouraging result that the field was dipolar throughout the entire Phanerozoic (0–600 Ma). However, the efficacy of the RPT has recently been questioned. Different approaches lead to strongly divergent conclusions, all the way from the view that (a) a few hundred million years is enough to furnish a statistically adequate sample to the assertion that (b) a time interval greater than the age of the Earth would be required. In an attempt to shed further light on this conundrum, the way in which a spherical cap (representing a super-continent) samples the earth's surface as it executes a random walk at a typical plate velocity has been investigated. The results strongly favour viewpoint (a) and suggest that there is a high probability that the RPT furnishes a suitable test over intervals of a few hundred million years.

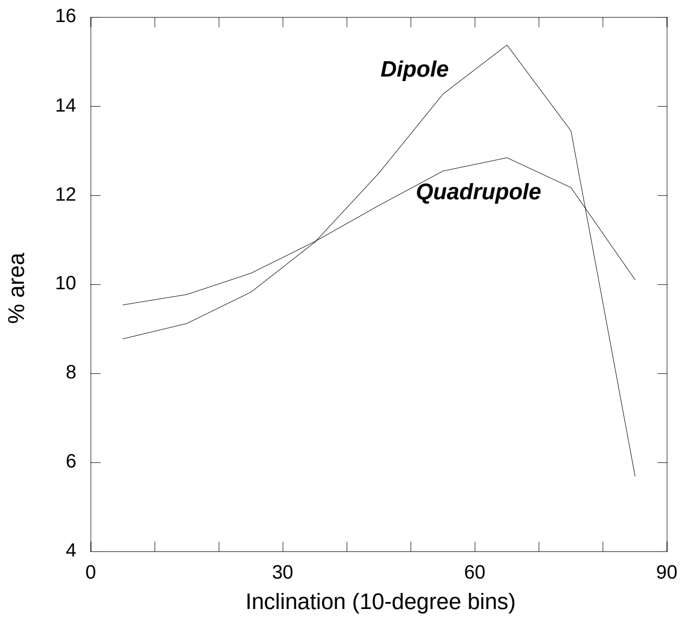


**Fig. 1.** Frequency polygons indicating the percentages of the Earth's surface occupied by 10- degree bands of dipole and quadrupole geocentric axial magnetic fields.

# A THREEDIMENSIONAL MICROMAGNETIC STUDY OF VISCOUS MAGNETIZATION PROCESSES IN PSEUDO-SINGLE DOMAIN PARTICLES

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We present the first quantitative calculation of viscous remanence acquisition and decay in pseudo-single domain magnetite particles. The calculation is based on a statistical evaluation of exactly determined energy barriers between local energy minima (LEM). This requires to find all possible LEM states for a given particle geometry and then to determine the energy barriers between all pairs of these LEM states. To achieve the latter, we developed a fast relaxation algorithm for finding the optimal transition paths between two LEM states in a three-dimensional micromagnetic model. The algorithm combines a nudged elastic band technique (*Dittrich et al., 2002*; *Henkelman et al., 2000*) with action minimization *(Berkov, 1998)*. Fig. 1 shows one final result which was used to determine the two energy barriers between a flower state aligned with the cubic <111> axis (F-111) and a vortex state whose central moment aligns with <111> (V-111).

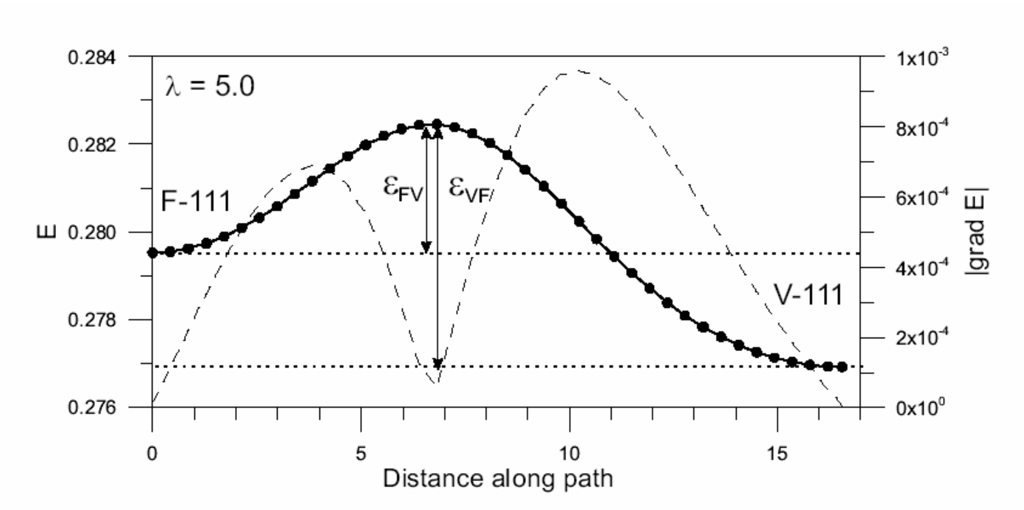


**Fig. 1.** Energy variation along the optimal transition path from a F-111 flower state to a V-111 vortex state for a cubic magnetite particle. Each circle represents a 3D magnetization state used for the calculation. The dashed line shows the absolute value of the energy gradient. Because the energies of F-111 and V-111 are different, also the energy barriers of the transitions from F-111 to V-111 ($\varepsilon_{FV}$) and from V-111 to F-111 ($\varepsilon_{VF}$) differ.

However, the statistical evaluation of viscous magnetization acquisition and decay for this particular cubic pseudo-single domain (PSD) magnetite particle requires to calculate all energy barriers between 60 different local energy minima. All optimal transition paths between them have been numerically calculated to obtain the respective transition probabilities in zero and weak external field. These probabilities in turn are used to set up a linear matrix differential equation for viscous decay and remanence acquisition. Solving this matrix equation enables us to model viscous magnetization curves for arbitrary initial states over all time scales. For our PSD particle the calculations in Fig. 2 show an unexpected intermediate remanence overshooting during VRM acquisition between $10^2 - 10^3$ s when starting from an initial equi-distribution over all LEM states. A detailed investigation of this effect reveals that it is not an artifact, but results from the fact that the decay of field aligned flower states into vortex states is slower than the decay of antiparallel flower states. This leads to an intermediate residual flower state moment which is larger than the finally reached pure vortex magnetization.

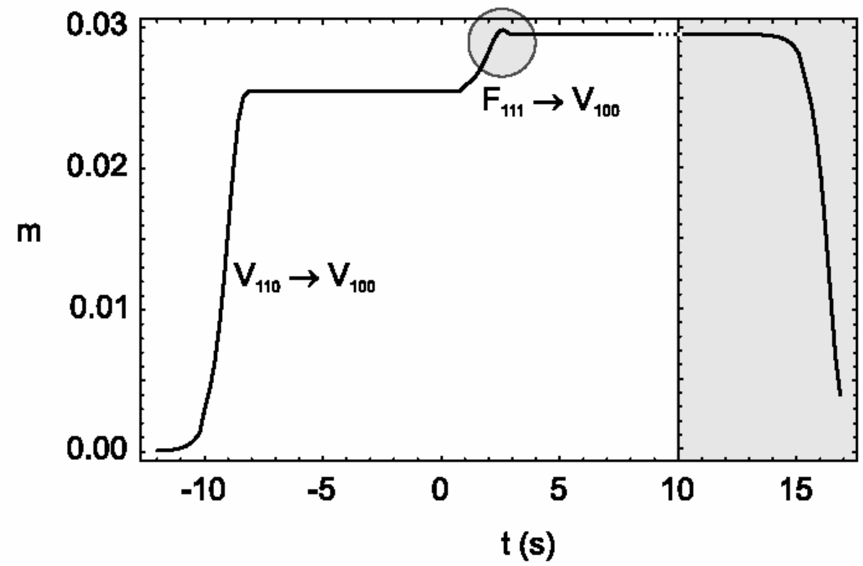


**Fig. 2.** Modeled acquisition of viscous magnetization in a cubic PSD magnetite particle. The initial state is an equi-distribution over all possible LEM states with zero net magnetization. In a small external field the first acquisition process is the immediate decay from V-110 type states into V-100 type states, which occurs within about $10^{-9}$ s. Due to the field induced asymmetry of the energy barriers, a remanence is acquired during this process. The second process is a decay of F-111 type states into V-100 type states. This occurs between about $10^2$s and $10^3$ s and shows an intermediate overshooting of remanence. The shaded area beyond $10^{10}$s plots the zero field decay of the previous VRM and demonstrates its extreme stability.

Another important outcome of the viscosity calculation in Fig. 2 is the extremely high stability of the finally acquired VRM. While its acquisition occured within about $10^3$ s, zero-field decay of VRM sets in only beyond $10^{13}$ s. This difference between acquisition and decay is due to the asymmetry of the energy barriers as shown in Fig. 1. Such a stable VRM also cannot be thermally demagnetized at low temperatures and therefore provides a major source of persistent magnetic overprint in paleomagnetic studies.

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# SMALL UNMANNED AERIAL VEHICLES AND AN ONBOARD MAGNETOMETER FOR AEROMAGNETIC SURVEYS - CONTRIBUTION TO THE EFFICIENT PALEOMAGNETIC SAMPLING IN ANTARCTICA

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When paleomagnetic samples are collected in the area where investigation of geology has not been undertaken, aeromagnetic map contributes to more efficient sampling based on discriminations of the formation and magnetic properties in the area. However, the acquisition of aeromagnetic data is not easy due to ensuring of the safety flight, transportation of aircraft and economy in savage lands as Antarctica.

We have developed the technology of small unmanned aerial vehicles (UAV) and an onboard magnetometer focused on the aeromagnetic surveys under the Ant-Plane project. The UAV consists of 2 m span and 1.8 m length with 2-cycles and 2-cylinder 85 cc gasoline engine, GPS navigation system by microcomputer and radio telemeter system, in case of Ant-Plane #2. The total weight is 15 kg including 2 litter fuels and the coursing speed is 130 km/h with maximum height of 2000 m. The magnetometer system consists of a 3-component magneto-resistant magnetometer (MR) sensors, GPS and data logger. Three components of magnetic field, latitude, longitude, altitude, the number of satellite and time are recorded in every second during 6 hours. The sensitivity of the magnetometer is 7 nT and we use a total magnetic field intensity for magnetic analysis due to unknown heading of the plane.

Since autonomous navigation succeeded by Ant-Plane #2 in Dec. 2003, we made 4 UAV (Ant-Plane #2 - #5) and tested the autonomous navigation at Mt. Sakrajima Volcano and Mt. Chokai Volcano in Japan and Western Australia. Consequently, the flight continued more than 500 km and the maximum altitude up to 5700 m were achieved by Ant-Plane #4. Due to the angular accuracy of the *x*-, *y*- and *z*-components of MR magnetometer, the magnetic data were unstable when the wind speed was strong, while reasonably good data were obtained under the calm wind. The principal technique of the aeromagnetic survey by Ant-Plane was almost established. The Ant-Plane #4 will be operated in Antarctica for the aeromagnetic survey and meteorological observation by the 48$^{th}$ Japanese Antarctic Research Expedition in January 2007.

## PALEOMAGNETIC DATING OF HOMINID BEARING DMANISSI ANTHROPOLOGICAL SITE (SOUTHERN CAUCASUS)

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We report further results on a paleomagnetic study at the locality of Dmanissi (Georgia), which has yielded human remains and evidence of lithic industry associated with Late Pliocene-Early Pleistocene fauna. The site is composed of Plio-Pleistocene volcanogenic sediments overlying a thick succession of basaltic lava flows. In the view of the age controversy, and keeping in mind the achievement that paleomagnetism has had in other archaeological sites such as Atapuerca (Spain), we carried out a magnetic survey at the Dmanissi site aimed to clarify the relative position of the site in the Plio-Pleistocene chronologic framework. The lithostratigraphic sequence comprises two basic depositional units. Unit A directly overlies the basalt floor and is overlain by unit B, with a calcrete layer located between both. A new paleomagnetic study has been carried out on samples from the basaltic flow directly underlying the prehistoric site and from continuous sections in the A and B units and the calcrete layer. The study consisted of paleomagnetic measurements including thermal and AF demagnetisation of about 100 samples as well as measurement of susceptibility-versus-temperature curves and IRM acquistion and demagnetisation experiments. The basaltic flow and all unit-A samples provide normal polarities, while reversed polarities are observed in the calcrete layer. Unit B is characterized by the presence of reversed polarity directions, although the reversed components cannot be completely isolated in some cases. As human remains have been found both in units characterized by normal as well as reversed polarity, and display some differences among them, our palaeomagnetic results point to the possibility of two different human occupations of the Dmanissi site at different moments.

# PALEOMAGNETISM OF THE EASTERN ALKALINE PROVINCE (SOUTHWESTERN GULF OF MEXICO)

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In this study, we report a detailed rock-magnetic and paleomagnetic investigation of lava flows associated with Eastern Alkaline Province. A NNW-trending belt of mafic volcanic fields parallels the Gulf of Mexico from the U.S. border southward to Veracruz state, in eastern Mexico. 153 oriented samples coming from 19 independent cooling units were collected. These sites were recently dated by means of 'unspiked' K-Ar (mostly) and $^{40}Ar$–$^{39}Ar$ geochronological methods. We studied in details four of the six recognized fields: 1) the lava flows of Tlanchinol area (7.3 – 5.7 Ma), 2) The Alamo monogenetic field and Sierra Tantima (7.6 – 6.6 Ma), 3) the Poza Rica and Matlatoyuca lava flows (1.6 – 1.3 Ma) and 4) the Chiconquiapo-Palma Sola area (6.9 – 3.2 Ma). Rock-magnetic experiments which included continuous susceptibility and hysteresis measurements point to simple magnetic mineralogy. In most of cases, the remanence is carried by Ti-poor titanomagnetite of pseudo-single-domain magnetic structure. The characteristic paleodirections are successfully isolated for 16 out 19 cooling units. The mean paleodirection obtained in this study, discarding intermediate polarity sites, is $I = 36.1°$, $D = 359.6°$, $k = 36$, $\alpha_{95} = 6.4°$. These directions are practically undistinguishable from the expected Mio-Pliocene paleodirections, as derived from reference poles for the North American polar wander curve and in agreement with previously reported directions from nearby lavas of Trans-Mexican Volcanic Belt. This suggests that no major tectonic deformation occurred in studied area. The paleosecular variation is estimated trough the study of the scatter of virtual geomagnetic poles giving $S_F = 15.8$ with $S_U = 20.1$ and $S_L = 12.6$ (upper and lower limits respectively). These values are consistent with the value predicted by the latitude-dependent variation model of *McFadden et al. (1991)* for the last 5 Ma. The interesting feature of the paleomagnetic record obtained here is an occurrence of intermediate magnetic polarity for two consecutive lavas dated as 2.04 ± 0.04 and 1.97 ± 0.04 respectively, which may correspond to the worldwide observable Reunion event.

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# REMAGNETIZATION IN THE LOWER CRETACEOUS ROCKS IN THE ORGANYA BASIN (PYRENEES, SPAIN)

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Building on earlier work by *Dinarès-Turell and Garcia-Senz (2000)* we carried out a paleomagnetic and rock magnetic investigation into the remagnetization processes that have acted on Early Cretaceous limestones and marls in the Organya Basin (Pyrenees, Spain). The Organya Basin forms part of the Boixols thrust sheet, the topmost sheet of a series of three sheets that form a piggy back structure. The Monsec and Sierres Madrigales sheets are situated to the South of the Boixols unit. A backthrust on the North side of the Boixols unit is the youngest fault. The thrust sheets and the backthrust are the consequence of shortening during the Alpine phase in the Pyrenees. The Organya Basin consists of a large-scale synclinal structure, characterized by platform style carbonates of Berriasian through Barremian age. On top of those Albian-Aptian marls are deposited. These are unconformably capped by the Santa Fe limestones, of Cenomanian age.

The Berriasian-Barremian limestones, all of normal polarity, are remagnetized while the marls are argued to be not remagnetized. The limestones have a declination of 300° trending in the topmost lithological unit (Prada II Formation) to 310–320°. The remagnetization is older than the Morreres backthrust as shown by a positive breccia test. The not remagnetized marls have a declination of 340–350° and plot on the APWP of Iberia. Inclinations are always ~ 55°. We will show results based on approximately 70 paleomagnetic sites (c. 600 specimens) and grouped into 3 main transects, each approximately 15–20 km apart. So-called component analysis of IRM and ARM shows subtle differences between remagnetized and non-remagnetized rocks, supporting the inferences made from the paleomagnetic data. Also scanning electron microscope data indicate differences between the marls and limestones. Possible relation of the remagnetization to a thermal event in Northern Spain postulated in the Middle Cretaceous will be discussed.

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# LATE VARISCAN REMAGNETIZATION OF THE DEVONIAN CARBONATES IN THE KIELCE REGION (HOLY CROSS MTS., CENTRAL POLAND): THERMAL OR DIAGENETIC EVENT?

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Late Variscan (Late Carboniferous/Early Permian), magnetite-related remagnetization in the Kielce region has been known for years. To find its causes and answer the question what kind of geological event was dated by, Middle and Upper Devonian carbonate rocks were involved by integrated analysis. Great part of those complexes underwent two stages of mezogenetic dolomitization in deep burial and elevated temperature conditions (*Narkiewicz, 1991*). The dolomitization occurred most probably in the Late Devonian/Early Carboniferous, before the main phase Variscan deformations in the Late Carboniferous.

In order to reveal the origin of remagnetization we decided to check what kind of rocks is most strongly affected by the secondary Late Variscan components. Basic lithological types (dolomicrites, dolosparites and variably dolomitised limestones) were sampled in the Łagów region, in Janczyce IG1 borehole and in the Budy quarry. These localities were chosen on account of location in zones with different stage of thermal alteration (*Belka, 1990*; *Marynowski, 1999*). Samples underwent standard palaeomagnetic analysis (magnetic susceptibility, natural remanent magnetization) as well as petrologic and geochemical investigations (polarization and electron microscopes, cathodoluminescence, stable isotopes of $^{18}$O, $^{13}$C and $^{87}$Sr/$^{86}$Sr analysis).

An Early Permian magnetization based on magnetite was documented in the sites which revealed more intense thermal alteration: Łagów region and Janczyce IG1 borehole. These sites represent diversified lithological types, stratigraphic horizons and different stages of dolomitization. In the Budy quarry, which was hardly thermally altered, Early Permian remagnetization was found, neither in limestones nor in dolomites. Generally dolomites are characterized by stronger magnetic properties. Mesogenetic dolomites were highly susceptible to remagnetization, due to high Fe content and higher porosity than limestones.

Dolomitization is usually accompanied by intense pyritisation and the Early Permian magnetite could be a product of partly oxidized pyrite.

Geochemical investigations do not support previous thesis that dolomitization processes were straight dated by post-Variscan remagnetisation (*Grabowski et al., 2002*). Radiogenic strontium isotopes occur in both remagnetised and unremagnetised dolomites what implies that Early Permian magnetic signal had no direct relation to basin solutions, which were responsible for dolomitization processes.

Occurrence of the Late Variscan remagnetization is spatially relevant to northern part of the Kielce region, which reveals more intense dolomitization and increased thermal maturity. Both, the Late Devonian/Early Carboniferous dolomitization and Early Permian remagnetization were probably conditioned by long lasting regional heating processes close to the Holy Cross Fault which constitutes the northern boundary of the Kielce region. Preservation of the magnetic signal ensued as a result of post-orogenic cooling and (?)uplift.

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# THE IMPRINT OF MULTISTAGE TECTONIC EVOLUTION OF THE POVAŽSKÝ INOVEC MTS. IN THE MAGNETIC FABRICS OF ITS ROCKS

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Považský Inovec Mts. (PI) represent a Miocene (16–13 Ma) mega-anticlinal horst elongated in the NNE-SSW direction bordered by normal faults. The northern part of the mountains is built by Infratatric complex - the lower structural unit of the Western Carpathians (*Putiš, 1992*) - which overlay Jurassic-Cretaceous sediments and the Upper Cretaceous flysch layers. The Infratatricum Unit is composed of the Alpine metamorphic and sheared mostly mica-schist complexes, which is on the eastern part covered by the Inovec unit - Mesozoic sedimentary cover unit. On the southern part is the Infratatric unit overridden by higher crystalline structural complex of the Tatric Superunit, built mainly by basement (various granitic rocks, orthogneisses, amphibolites, paragneisses, mica-schist) and its Mesozoic sedimentary cover. Boundary between the both mentioned crystalline complexes forms the Hrádok - Zlatno line. On the western border and somewhat also in the SW part of the mountains are the crystalline complexes covered by the rests of the Late Paleozoic - Mesozoic formations of the Krížna (Fatric) and Choč (Hronic) nappe systems.

The aim of our study is to contribute to understanding the multistage tectonic development of the Považský Inovec Mts., using the method of measuring the anisotropy of magnetic susceptibility (AMS) of the rock. The first research work in this area was carried out by *Hrouda and Hanák (1986)*. Together with our recent investigation, 700 oriented rock samples were collected and measured.

In the majority of studied localities, the planar magnetic fabric prevails over the linear one, i.e. the degree of magnetic foliation is higher than that of magnetic lineation. The highest values - up to 1.3 - are shown by the schistose metamorphic rocks: gneiss, shale. The degree of magnetic foliation of granitoids ranges up to the value of 1.08. The maximal degree of magnetic lineation in the metamorphic rocks reaches the value of 1.12.

Bulk susceptibility values show large differences not only between the different rock types - ranging from low negative values in some diamagnetic limestones and leucogranites up to as much as $700 \times 10^{-6}$ [SI] in amphibolites - but they surprisingly vary also between samples from the same locality. The results confirm the rather complicated tectonic structure: neither the directions of magnetic lineation, nor the magnetic foliations offer a comprehensive picture in any of both crystalline complexes.

Magnetic fabric of rocks of the southern Tatric complex is slightly more homogenous: in granitic rocks the magnetic foliations predominate, with relatively steep dips to the NNW or NW. Orientation of weakly developed magnetic lineation varies, but in general the SW-NE direction prevails. Such magnetic fabric may reflect the Alpine northwestward shifting and SW-NE contraction and folding of the complex. The magnetic fabric in schists and gneisses, coinciding with the metamorphic schistosity, reflects its syn-metamorphic character.

The magnetic fabric of the northern part of Považský Inovec Mts. - of the lower Infratatric crystalline complex - does not allow any straightforward interpretation. The magnetic structures vary not only between different geological units, but also within localities of the same unit. Although a more precise analysis must take into consideration the geological and geographical details, our results allow us to draw a general conclusion for the entire complex: its observed magnetic structure is mostly of syn-metamorphic origin, and was later, in accordance with local geological and tectonic conditions, influenced by the Alpine orogenesis.

Based on our field and AMS study as well as present knowledge it is obvious that fabric of the Považský Inovec Mts. reflects multistage tectonic evolution since the Late-Paleozoic (Neo-Variscan) times - the first exhumation of the Tatric basement, through Paleo- and Meso-Alpine (Upper Cretaceous) structuralization of the Fatric and Hronic basins and their thrusting as nappes to the final Neo-Alpine (Miocene) horst formation.

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# ANISOTROPY OF MAGNETIC SUSCEPTIBILITY IN SILLS FROM THE DIABASODDEN SUITE (EARLY CRETACEOUS), SVALBARD LOCATED INSIDE AN AREA OF EARLY TERTIARY TECTONIC ACTIVITY

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The results reported here is part of a study of the paleomagnetic, rockmagnetic and anisotropy of magnetic susceptibility (AMS) properties of Cretaceous magmatic rocks from Svalbard. AMS provides an estimate of the preferred orientation-distribution of minerals. In the Diabasodden suite magnetite preferred dimensional orientation are reflected in the alignment of minimum and maximum susceptibilities. *Halvorsen (1974)* measured the AMS of rocks of the Diabasodden Suite in eastern Svalbard outside the area affected by Tertiary tectonic activity. The magnetic foliation plan (assumed to coincide with the flow plane in the sill) was found to be close to the horizontal plane in the Lomfjorden sill and the Bastian and Rønnbeck dolerite island. Within the magnetic foliation plan the distinction between the maximum ($\kappa_1$) and intermediate ($\kappa_2$) susceptibility axes was not so clear. Both structures investigated reveal a similar but quite week preferred orientation of the $\kappa_1$ axes in the E-W direction and $\kappa_2$ axes in the N-S direction. The study is now extended to the Isfjorden area in central Spitsbergen inside the area of tectonic activity. Samples were collected in three main localities: The Hatten-Diabasodden locality, the Ekmanfjorden-Dicksonland locality and the Gåsøyane-Gipshuken locality. The latter is situated very close to the Billefjorden fracture zone (BFZ) while the other two have a position further away from the fracture zone. Samples were also collected in the De Geer dalen which lies close to the BFZ. The results of the AMS study can be described as follows:

1. The Hatten-Diabasodden locality reveal scattered distribution of the $\kappa_1$, $\kappa_2$ and $\kappa_3$ susceptibility axes with a week preferred orientation of the $\kappa_1$ axes in the N-S direction.
2. The Ekmanfjorden-Dicksonland locality showed scattered directions with no preferred orientation of the susceptibility axes.
3. AMS measurements on samples from the Gåsøyane-Gipshuken locality revealed triaxial orientation of the susceptibility axes. $\kappa_1$ directed towards the east dipping with shallow angles. $\kappa_2$ pointing towards the south nearly flatlying and $\kappa_3$ nearly vertical. The sill sampled on Gipshuken is folded. The age of the folding is probably Early Tertiary. When corrected for folding the $\kappa_1$ and $\kappa_2$ axes move to the horizontal while the $\kappa_3$ axes become nearly vertical. A few samples show exchange of the $\kappa_2$ and $\kappa_3$ axes.
4. The orientation of the susceptibility axes measured on samples from the De Geer dalen locality show that $\kappa_2$ and $\kappa_3$ axes defines a planar magnetic fabric trending N-S with the $\kappa_2$ axes concentrating in the vertical direction while the $\kappa_3$ axes show low to moderate plunge values. $\kappa_1$ defines a lineation in the E-W direction.

The results of the investigation reveal a significant difference in the orientation of the magnetic susceptibility axes between the area outside and inside the region of Tertiary tectonic activity. In the Hinlopenstretet (eastern Spitsbergen) the orientation of the AMS axes defines a horizontal magnetic foliation plane which parallels the bedding in the intruded sediments. The results from the measurement of the samples collected in the Isfjorden area gives a quite different picture. The orientation of the susceptibility axes in samples collected far from the fracture zones display scattered AMS results with no preferred orientation. This is interpreted as irregular magma flow due to the great thickness of the sills in this area. The AMS orientation found in samples collected close to the Billefjorden Fracture Zone show an E-W lineation caused by preferred orientation of the $\kappa_1$ axis. The $\kappa_2$ and $\kappa_3$ axes define a planar fabric in which the $\kappa_2$ and $\kappa_3$ axis shows variation between vertical and horizontal orientation. This is interpreted to be caused by E-W transtension in the early Tertiary caused by interacting of Svalbard and Greenland during Arctic sea floor spreading.

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# THE MONO LAKE GEOMAGNETIC EXCURSION RECORDED IN LOESS FROM AN UPPER PALAEOLITHIC ARCHAEOLOGICAL SITE AT KREMS-WACHTBERG

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The Mono Lake geomagnetic excursion (MLE) is among the youngest and one of the earliest found and better-documented excursions in the Brunhes Chron. It has been detected worldwide in marine and terrestrial sedimentary archives as well as in lavas from Hawaii. Recent age determinations and age estimates for the MLE centre around an age interval of approximately 32–35 ka. (*Laj et al., 2002*; *Mankinen and Wentworth, 2004*).

Loess/Palaeosol sequences (LPSS) provide valuable palaeoclimatic information from continental areas, especially where other archives are rare or even absent. Loess is not only an excellent recorder of environmental changes but also a unique archive for the variations of the Earth's magnetic field and palaeolithic archaeology (e.g. *Evans and Heller, 2003*).

Here I report the first results of a rock and palaeo-magnetic investigation of the Upper-Würmian loess from an archaeological excavation at Krems-Wachtberg (Wachau, Austria). At this site an Upper Palaeolithic cultural layer is developed in and covered by loess. The age of the cultural layer is about 27 ka ($^{14}$C B.P. $\geq$ 31 ka cal. $^{14}$C B.P.). Beginning of September 2005, 264 carefully oriented samples (cubes of 2 cm, 2.1 cm spacing) were taken from the north-western corner of the excavation pit. Thus, a continuous section of 5.56 m of Upper-Würmian loess has been recovered. The investigations are still in progress and field as well as laboratory work will continue until 2007 at least.

Magnetic susceptibility (MS) as function of depth resembles generally the lithology. Low MS-values represent pure unaltered loess, whereas higher values represent the enhancement of magnetic minerals caused by incipient pedogenesis. Thus, the MS-variations with depth are taken as a palaeoclimatic record representing the climatic variations between drier and slightly more humid conditions at the transition from Middle to Upper Pleniglacial. Based on the MS-record I can establish a correlation of the loess pile at the Krems-Wachtberg site with the NORTH-GRIP isotopic record (*NORTH GRIP MEMBERS, 2004*) and with sedimentological data from Maar-lake sediments of the Eifel area, Germany (*Schaber and Sirocko, 2005*). This correlation corroborates the dating of the loess at the excavation site to a time interval between 22 and 31 ka. Hence, the age of the cultural layer is slightly higher than 30 ka, both in NORTH-GRIP and ELSA time scales.

The directional palaeomagnetic record is of high quality showing in the upper part and near the bottom of the section variations in the bandwidth of secular variation, whereas from 0.5 to 2 m shallow negative inclinations and oversteep inclinations reveal the record of a geomagnetic excursion. The shallow inclinations are preceded by and go along with westerly declinations, whereas the steep inclinations are preceded by easterly declinations. Almost the same pattern was reported by *Liddicoat (1992)* for the MLE from western North America.

The detection of the MLE at Krems-Wachtberg is to my knowledge the first evidence for this excursion in Central Europe. This finding is of great importance for the study of geomagnetic excursions and for the chronology of Upper Palaeolithic archaeology.

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# THE INFLUENCE OF CHERNOZEM SOILS' COMPOSITION ON HIGH-TEMPERATURE SUSCEPTIBILITY CHANGES

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Investigation of susceptibility changes during heating up to 700°C ($\kappa(T)_{HT}$) in the soil samples generally gives similar characteristics that can be simplified to susceptibility rise about 300°C, then decrease and another upward trend with the peak about 500°C. All samples demagnetise in the Curie temperature of magnetite. In this study we attempt to describe the character of susceptibility changes caused by heating and to correspond the $\kappa(T)_{HT}$ features to the composition of the chernozem soil samples.

The examined specimens, that show or miss some of the variations mentioned above, were divided into three groups: the first with $\kappa(T)_{HT}$ shape described above, the second that miss the first slope, and the third that present more abrupt susceptibility increase about 300°C. In the third group, there are also samples that miss the second hill about 500°C. For samples unheated and heated to temperatures corresponding to switches of the trend of the $\kappa(T)_{HT}$ curves, the alteration factor quantifying percentage change in susceptibility after executing the cycle of heating and cooling, measured at 40°C ($A(40)$), low-temperature susceptibility changes ($\kappa(T)_{LT}$) and hysteresis parameters ($H_{cr}$, $H_c$, $M_{rs}$ and $M_s$) were examined.

For the samples from the first and second groups, the rise of $A(40)$ is not observed up to 400°C. The increase at about 300°C, characteristic of the first group, is accompanied by the insignificant formation of fine grains that give the slightly SP-like trend of $\kappa(T)_{LT}$. Further heating to 380–400°C generates MD magnetite that expresses through the Vervey-transition at −150°C. Those changes support the dehydratation of oxyhydroxides to hematite with intermediate magnetite formation, observed for goethite by *Özdemir and Dunlop (2000)*.

The abrupt increase of susceptibility at about 300°C observed in the third group is the best pronounced for the samples with prevailing paramagnetic content and results in significant rise of $A(40)$ values. Such increase is caused by the formation of the new SP fraction, however low susceptibility of input matter should be also considered as a factor influencing relative increase of $A(40)$. On the base of the $\kappa(T)_{LT}$ shape, the presence of the MD magnetite cannot be excluded though it is masked by the prevailing contribution of SP fraction. The presence of coarser magnetite would suggest that similar mineral transformations of paramagnetics take place in samples from the first and the third groups. On the other hand, the maghemite formation during lepidocrocite conversion to haematite is also probable (*Gendler et al., 2005*).

The increase of susceptibility between 400 and 500°C is observed for the samples with the considerable presence of organic matter and is absent for the samples containing less than 0.2% of organic carbon (some from the third group). This points at the formation of the new ferrimagnetic mineral in the aftermath of the thermo-induced decomposition of organic matter. It is followed by the significant increase of $A(40)$ that is observed up to 600°C. In such temperatures SP magnetite becomes the main magnetic component of the heated material. Heating from 650 to 700°C leads to coarser textures (drop of the $A(40)$, increase of $M_{rs}/M_s$ ratio and decrease of $H_{cr}/H_c$ ratio). Simultaneously, the growth of $H_{cr}$ and $H_c$ together with the fall of $M_{rs}$ and $M_s$ point at the mineralogical transformations of ferrimagnetic fraction to antyferromagnetic one.

The last significant transformation takes place above 600°C in the samples with significant contribution of paramagnetics and it results with very high values of $A(40)$ especially above 650°C. The significantly enhanced susceptibility after thermal treatment is most probably attributed to the transformation of Fe-rich clay minerals to SP magnetite.

The described alterations induced by heating of the soil samples may occur with different intensity due to the variability of the environmental material. The observed $\kappa(T)_{HT}$ shapes result from the effects of transformations that may overlap as the different magnetic and non-magnetic fractions are involved into the process.

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# LINKS BETWEEN MAGNETIC PARAMETERS AND HEAVY METAL POLLUTION - AN INTERDISCIPLINARY APPROACH

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Mapping of magnetic susceptibility as an indicator for heavy metal pollution was intensively used in recent years and polluted areas can be delimited quickly and at low cost. This study, funded by the Austrian Science Fund (FWF P 16314), focussed on the natural influences on the soil magnetic susceptibility to determine threshold values for non-polluted soils as well as on the links between heavy metals and magnetic pollution particles.

Dried and sieved soil samples from the soil archives of east-austrian provinces were investigated by means of magnetic measurements as well as mineralogical and chemical analyses.

The natural magnetic susceptibility of soils is influenced by several factors; one of the most important is the water regime, independent of the parent material. Soil types that are formed by (partial) waterlogging have low susceptibilities (gleysol, stagnosol, stagnic phaeozem). A second group with generally low values are those with low pH-value and high amount of organic matter which may form complexing agents that release and relocate iron (podzol, half-bog soils). The analysis of the influence of the parent material showed that for example soils formed on rocks of the Bohemian Massif (granitoide, gneiss and granulite) display significantly distinct susceptibility distributions. The highest susceptibility values occur within Carinthia, where rocks of the Central Alps dominate, and in the Vienna basin on loess and other fine sediments where chernozem, parachernozem and colluvium are the main soil types. Soils formed on siliceous sandstone in the flysch zone have the lowest susceptibility values.

Polluted soils show medium to high values of saturation remanence, high susceptibility and low values of remaining saturation remanence after alterning field demagnetization (< 5%). Three axis coercivity/ unblocking temperature spectra are dominated by a magnetically soft component (< 70 mT) with corresponding unblocking temperatures of 570°C. Unpolluted sites are indicated by low values for magnetic susceptibility and saturation remanence and medium (5−10%) to high (> 10%) remaining saturation remanence.

X-ray diffraction patterns were obtained from bulk samples. The main minerals were Quartz, Chlorite, Muscovite and Hornblende. In some samples calcite, dolomite or magnesite was present.

Magnetic extracts were used for scanning electron microscopy. Polluted soils were dominated by spherules with diameters ranging from 6 to > 100 µm, scale was detected in limited amount. Elemental analysis displayed spherules built of iron oxides or geometrically formed iron oxides embedded into a silicate matrix in samples near steel works. Calcium- based matrix was only found in magnetic spherules in samples close to a cement plant. The heavy metals Cr, Mn, Ni, Ti, Cu, and Zn were found in elemental analysis, either in flakes attached to the surface of the spheres or within their internal structure. Extracts from unpolluted soils primarily consist of strongly weathered bed rock minerals. Samples from Carinthia contained some well preserved magnetite octahedrons.

In addition to the total elemental content determination a three-stage extraction procedure was performed on the bulk soil samples. This modified (BCR) three-stage extraction procedure allows to quantify metals in following bonds: 1. Exchangeable metals, water soluble and carbonates; 2. Metals bound to iron and manganese oxides (reducible); 3. Metals bound to organic matter and sulphides (oxidizable). The metals still bound after the 3rd extraction step are referred to as residuum. The determination of metals in the extracts was performed by ICP-MS. The major proportion of Cr, Co, Cu and Zn was found in the residuum, nevertheless samples near steel works contain significant amounts of Cr in the fraction bound to organic matter. Cadmium was mainly leached in the first and second extraction step.

The consistent results of the analyses indicate that heavy metals in the soils are present mainly in chemical stages unlikely to be leached under natural soil conditions, although some heavy metals, such as Cr and Cd, appear in bonds where they can become bioavailable.

# CHANGES IN MEAN MAGNETIC SUSCEPTIBILITY AND IN ITS ANISOTROPY DURING AF-DEMAGNETIZATION

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Measurements of low-field magnetic susceptibility during stepwise alternating field (AF) demagnetization revealed mostly an increase of the mean magnetic susceptibility Km, as already observed by *Kapička et al. (2003)* in some samples from the KTB borehole. Studied collections of loess/paleosol samples from different sections in Belgium, Bulgaria, China, Siberia and Tadjikistan and diorites, granites and gneisses from Antarctica show systematic Km-increase, between 2 and 27% as compared to the initial values, after AF-demagnetization up to 100 or 200 mT maximum amplitude. The relationships between magnetic susceptibility increase and magnetic hysteresis parameters and their ratios, indicate that the Km-increase during AF-treatment is due to changes in magnetic domain configuration of the initial natural remanent magnetization state of the remanence carriers.

We also studied the evolution of anisotropy of magnetic suceptibility during stepwise AF demagnetization (*Bathal and Stacey, 1969*; *Violat and Daly, 1971*; *Kapička, 1981*; *Potter and Stephenson, 1990a,b*; *Liu et al., 2005*) on the same various samples, which present very different degree of magnetic anisotropy. The variation of the magnetic fabric appears to be related both to the direction of AF application (*Potter and Stephenson, 1990a,b*) and to the magnetic fabric before AF treatment. The anisotropy change remains controlled by the initial magnetic fabric. The more anisotropic is the initial magnetic fabric, the less is the effect of the direction of field application. This can be clearly shown by determination of difference of the susceptibility ellipsoids after and before AF application. Even for weak magnetic anisotropy, the effect of the initial AMS is significant. The difference ellipsoids can allow in particular cases to point out that the initial magnetic fabric is composite.

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# FULL VECTOR ANALYSES OF CRYPTOCHRON C2R.2R-L (CA. 2.514+/- 0.039 MA) RECORDED ON KOOLAU VOLCANO AT HALAWA, OAHU, HAWAII: EVIDENCE FROM DIRECTIONS, ABSOLUTE PALEOINTENSITY DETERMINATIONS AND $^{40}$AR/$^{39}$AR STUDIES

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New paleomagnetic measurements (directions and paleointensity determinations), coupled with precise $^{40}$Ar/$^{39}$Ar radioisotopic dating, are revolutionizing our understanding of the geodynamo by providing detailed terrestrial lava records of the short-term behavior of the paleomagnetic field. As part of an investigation of the evolution of Koolau Volcano (one of the volcanoes comprising Oahu Island) and the short-term behavior of the geomagnetic field, we have sampled a long volcanic section located on the buttressed flank of the volcano within Halawa Valley. Prior paleomagnetic and K-Ar investigations of the Koolau (Volcano) Series revealed excursional directions (Site F of *Doell and Dalrymple, 1973*). The alkaline composition of lava flows, easy access, and close geographical proximity to K-Ar dated lava flows made this newly studied 120 m thick sequence of flows in Halawa valley an excellent candidate for detailed paleomagnetic analysis. At least eight samples collected from each of 28 successive flow-sites were stepwise demagnetized by both alternating field (5 mT to 100 mT) and thermal (from 28°C to 575–650°C) methods, and the mean directions obtained by principal component analysis. All samples yielded a strong and stable ChRM trending towards the origin based on no less than seven to nine steps, with thermal and AF results agreeing to a very high degree. Low field susceptibility versus temperature ($\kappa$-$T$) analyses were conducted for individual lava flows, and the majority of them show reversible curves. Curie point determinations revealed a temperature close to or equal to 580°C, indicative of almost pure magnetite for most of the flows. Magnetic grain sizes analysis indicated SD-PSD sizes. The mean directions of magnetization of the entire section sampled indicate that about 10 m of the section are characterized by excursional directions (5 lava flows). In addition to the directional analyses we performed absolute paleointensity determinations on the 28 lavas sampled. We used the modified Thellier-Coe double heating method to determine paleointensities. pTRM checks were performed systematically one temperature step down the last pTRM acquisition in order to document magnetomineralogical changes during heating. The temperature was incremented by steps of 50°C between room temperature and 500°C and every 25–30°C. The paleointensity determinations were obtained from the slope of the Arai diagrams. Special care was taken to interpret the Arai diagrams within the same range of temperatures lower than 300°C unless a clear and unique slope would be present. Our paleointensity results indicate a near-zero reduced strength of the field during the excursional period ranging from 5 to 9 µT. The corresponding VGPs are located off the southeast part of Africa, close to Madagascar. $^{40}$Ar/$^{39}$Ar incremental heating experiments on groundmass from nine flow-sites located at different stratigraphic levels yielded isochron ages ranging from 2.64 +/– 0.25 to 2.40 +/– 0.46 Ma indicating that the excursion may correlate with the C2r.2r-l Cryptochron of *Cande and Kent (1995)*. This is potentially the first terrestrial record of the ca. 2.514 +/– 0.039 Ma Cryptochron, a finding that will place important constraints on evolution of the entire Koolau shield edifice also.

# PALEOMAGNETISM OF THE PRINGLE FALLS POLARITY EPISODE RECOVERED FROM THE DESCHUTES RIVER (PRINGLE FALLS, OREGON) AREA: A REVISITED STUDY

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We have studied a total of 827 samples drilled from five widely spaced profiles sampled along the Deschutes River Oregon. The five profiles sampled recorded a high-resolution paleomagnetic record of the Pringle Falls magnetic polarity episode (ca. 218 +/– 10 ka) and are characterized by diatomaceous lacustrine sediments. This sedimentary sequence was sampled as part of an extensive prehistoric fluvial and lacustrine complex that formed east of the Cascade Mountains during the last 1.0 Ma. The lake appears to have resulted from a late Pliocene/Pleistocene rise in the base level to the east of the sampling area near the western margin of the Basin and Range structural province and is related to the development of the extensive volcanism associated with the Newberry volcano. We have conducted paleomagnetic and rock magnetic studies in order to investigate the reproducibility of the paleomagnetic signal throughout the 5 km of the sampling of the five profiles. We conducted low-field vs. susceptibility analysis to determine the magnetic carriers of the sediments and we found that the main magnetic carrier is pure magnetite (Curie point 575°C). The magnetic grain size indicated SD-MD magnetite. The demagnetization of the sediments was done by means of alternating field methods and the determination of the mean directions by principal component analyses. The level of detail of the paleo-signal of these five records is highly consistent since they are characterized by rapidly deposited sediments (greater than 10 cm/kyr) that provide detailed representation of field behavior during the excursion. The VGP paths are highly internally consistent and are defined by a clockwise loop traveling from high northern latitudes over the eastern part of North America and the North Atlantic to South America and then to high southern latitudes and that return to high northern latitudes through the Pacific and over Kamchatka. This last clockwise looping is characteristic of other recently found excursions like the Iceland basin excursion (IBE, 188 ka). The published age of the Pringle falls excursion (ca. 218 +/– 10 ka) and the most recent radiometric ages (weighted mean 211 ± 11 ka, *Singer et al., 2005*) indicate that the dominance of such VGP paths (i.e. clockwise looping) of the Pringle Falls, the IBE, Jamaica and other excursion of the same age show that the excursional paleofield had a relatively simple geometric characteristic. A corollary of the latter option is that paleomagnetic polarity episodes of different ages may have similar transition polar paths, a conclusion implying that a common mechanism of the generation of the paleofield is involved.

# ANISOTROPY OF MAGNETIC SUSCEPTIBILITY STUDY OF LACUSTRINE SEDIMENTS RECOVERED FROM THE DESCHUTES RIVER (PRINGLE FALLS, OREGON, USA) AREA

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We have studied a total of 827 samples drilled from five widely spaced profiles sampled along the Deschutes river Oregon . The five profiles sampled recorded a high-resolution paleomagnetic record of the Pringle Falls magnetic polarity episode (ca. 213 +/– 10 ka) and are characterized by diatomaceous lacustrine sediments. This lacustrine sedimentary sequence sampled was part of an extensive prehistoric fluvial and lacustrine complex that formed east of the Cascade Mountains during the last 1.0 Ma. The lake appears to have resulted from a late Pliocene/Pleistocene rise in the base level to the east of the of the sampling area near the western margin of the Basin and Range structural province and is related to the development of the extensive volcanism associated with the Newberry volcano. Present outcrops and subsurface distribution of these lakes are to the west and north of the volcano, and their distribution appears to have been influenced by the development of streams and rivers systems draining the Newberry volcanic center as well as the Cascades themselves. We have conducted anisotropy of magnetic susceptibility (AMS) measurements in order to investigate if the acquisition of their fabrics during their formation was primary or secondary as well as the intrinsic characteristics of such fabrics. We conducted low-field vs susceptibility analysis to determine the magnetic carriers of the sediments and we found that the main magnetic carrier is pure magnetite (Curie point 575°C). The magnetic grain size indicated SD-MD (Single and Pseudo-Domain) magnetite. The magnetic fabrics of the 5 different profiles indicated that the sediments were deposited with the minima axes (Kmin) perpendicular to the bedding plane of the sediments. The obtained results of the sediments under study are characterized by a strongly oblate fabric that is confined to the bedding plane of the sediments. In addition, since the fabric is entirely foliated without a superimposed lineation indicating that the sediments were deposited almost on a horizontal surface in a quiet and calm water conditions (current less than 1 cm/s).

# MAGNETIC PROPERTIES AND ABSOLUTE PALEOINTENSITY OF THE UPPER OCEANIC CRUST GENERATED BY SUPERFAST SEAFLOOR SPREADING, ODP LEG 206

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We investigated the magnetic mineralogy and absolute paleointensity of oceanic basalt samples from Hole 1256D, cored during Ocean Drilling Program (ODP) Leg 206. Hole 1256D is located on the Cocos Plate about 5 km east of the transition zone between marine magnetic anomalies 5Bn.2n and 5Br (~15 Ma). During Leg 206, the hole penetrated 502 m into basalts of the upper oceanic crust that was generated by superfast seafloor spreading (> 200 mm/yr) along the East Pacific Rise. Rock magnetic investigations included continuous low field ($\kappa$-$T$) thermomagnetic analyses, alternating field (AF) and thermal demagnetization, optical microscopy, saturation isothermal remanent magnetization (SIRM), and magnetic grain size analyses. Following the removal of a drilling overprint, AF and thermal demagnetization paths for most samples decay linearly to the origin on orthogonal vector end point diagrams, suggesting that a stable characteristic remanent magnetization component can be resolved. Optical microscopy and $\kappa$-$T$ (Curie points) identified titanomagnetites and titanomaghemites as the main magnetic carriers and grain size studies indicate that the carriers are either single domain (SD) and/or pseudosingle domain (PSD) in nature. Using the modified Thellier-Coe double heating method, we determined absolute paleointensity determinations for 51 specimens sampled from different "stratigraphic" levels of the core. pTRM checks were performed systematically one temperature step down the last pTRM acquisition in order to document magnetomineralogical changes during heating. The temperature was incremented by steps of 50° C between room temperature and 500°C and every 25–30°C for higher temperatures. The paleointensity determinations were obtained from the slope of the Arai diagrams. Special care was taken to interpret the Arai diagrams within the same range of temperatures lower than 300°C unless a clear and unique slope was present over a higher range of temperatures. Only about 10% of the samples yielded acceptable results. The paleofield estimated from these samples ranges between 28 to 16 μT (i.e., VADM of 6 to $4 \times 10^{22}$ A/m$^2$), which is concordant with the average paleofield intensity for the period between 0–160 Myr (4 +/– $2 \times 10^{22}$ A/m$^2$) and half of the strength of the present field (~$8 \times 10^{22}$ A/m$^2$).

# MAGNETIC RELAXATION IN NANOPARTICLE SYSTEMS

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The use of magnetic nanoparticles for epitaxial thin films and magnetic recording media, drug targeting and hyperthermia therapy, or biosensors has spurred research on the magnetic properties of nanomaterials. One of the most studied iron nanoparticles, which is found in nature, is ferritin. Ferritin is an iron storage protein that consists of an outer protein shell with 12 nm diameter and an inner space with 7–8 nm diameter, filled with a hydrous iron oxide thought to be ferrihydrite ($5Fe_2O_3 \cdot 9H_2O$). Its average blocking temperature ($T_B$), determined from DC magnetometry, is around 12 K and it is totally unblocked by 22 K. There have been numerous studies examining the magnetic properties of ferritin, but these assume that the core contains a single iron phase. Several attempts have been made to model the behavior of initial magnetization curves as a function of temperature using two approaches: (i) a modified Langevin function that considers an additional linear component to the magnetization (e.g., *Kilcoyne and Cywinski, 1995*; *Makhlouf et al., 1997)*; and (ii) a random magnetic orientation model, which takes into account the fluctuation of spins between the two antiparallel directions along the antiferromagnetic axis (*Gilles et al., 2000*). These often show a poor fit of the measured data in low fields. *Resnick et al. (2004)* proposed an alternative model using maghemite nanoparticles, which takes into account the crystalline anisotropy. This approach does not improve the fit to the ferritin data. Microscopic studies on ferritin have shown that nanoparticles of magnetite/maghemite are often found associated with the ferrihydrite in the protein shell and may make up to 30% of the core (*Quintana et al., 2004*).

In this study we have modelled initial magnetization curves of 2-line ferrihydrite (FH2) and 6-line (FH6) ferrihydrite and horse spleen ferritin (HoSF). Initial magnetization curves of FH2 and FH6 can be modeled by a single modified Langevin function. Treating HoSF as a two-component system a model using a sum of Langevin functions permits significant improvement to the fit, compared to earlier single component models. The one phase has low coercivity with a saturation field around 300 mT; the second phase does not saturate in fields up to 5 T. The two-component model is compatible with a mixture of ferrimagnetic magnetite/maghemite and antiferromagnetic ferrihydrite.

In a further experiment HoSF was combined with magnetite nanoparticles (MNP) with 10–20 nm diameter. MNP has a $T_B$ of 56 K, and is totally unblocked by 125 K as determined by DC magnetometry. Initial magnetization curves above $T_B$ of both phases show that the combined system can be modeled by a sum of modified Langevin functions, demonstrating the superparamagnetic behavior of both phases. Measurement of AC susceptibility as a function of temperature shows that MNP is dominant and has a strong frequency dependency. The peak temperatures of both in-phase and out-of-phase susceptibility of HoSF and MNP are shifted compared to the pure components. The peak susceptibilities are described by Vogel-Fulcher law, or modified Arrhenius law, which suggests that non-negligible interactions are responsible for the shift in blocking temperature. This is further supported by FORC analysis.

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# COMPARATIVE MAGNETIC SIGNATURE OF MARTIAN METEORITES YAMATO 000593, YAMATO 000749, YAMATO 000802, YAMATO 980459, YAMATO 793605 AND ALH 77005

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Strong magnetic anomalies due to crustal magnetisation/remanence have been a major unexpected discovery of the Mars Global Surveyor (MGS) mission. It is generally believed that these anomalies are due to magnetite-bearing rocks which cooled in an Earth-like strong magnetic dipole-field (10–100 μT), in analogy to the magnetization of the Earth oceanic crust. There is some speculation about plate-tectonic-like processes on Mars which could have produced these magnetic lineament-like anomalies. A strong magnetic dipole-field is believed to have existed for about 1 Gyr on Mars being the cause for the strong magnetisation as well as representing a major precondition for the possible development and existence of life (or at least prebiotic structures) on Mars.

Meteorites from Mars are the only rock samples which we have from this planet. Magnetic measurements of meteorites are non destructive techniques allowing to investigate in the case of SNC's: the type of magnetic minerals (accessories); the possible in situ remanence in order to interpret the observed crustal magnetization; the intensity of the magnetic field in which the natural remanent magnetization (NRM) is acquired; and the petrofabric through the anisotropy of magnetic susceptibility.

A systematic investigation of the Martian meteorites by paleo-, rock- and mineral magnetic means will help to unreveal and understand the record about the Martian magnetic field and the crustal anomalies. Iron sulfides may also play an important role in the prebiotic phase of the origin of life. The different SNC meteorites offer magnetic material of different ages beginning with the 4.5 Gyr-old SNC meteorite ALH84001. Shock metamorphism features on the magnetic phases have to be taken into account as a result of the ejection of the SNC from Mars due to large impacts. Potential alteration effects due to processes on Mars as well as on Earth during the residence time are studied in detail. The SNC magnetic signature is used to develop a well constrained magneto-mineralogical model.

We have started to investigate the magnetic signature of all NIPR Martian Meteorite specimens. First data about Yamato 000593, a nakhlite, were published by *Funaki et al. (2002)* and *Rochette et al. (2006).* Here we report data of new magnetic experiments on the following NIPR specimen: Yamato 000593, Yamato 000749 and Yamato 000802, all classified as nakhlites, Yamato 793605 and ALH 77005, both lherzolitic shergottites, and Yamato 980459, an olivine-phyric shergottite.

For the nakhlites Yamato 000593, Yamato 000802 and Yamato 000749 mass specific magnetic susceptibility (measured with AGICO KLY3) was found to be slightly higher than for most of the other nakhlites. Much lower values were found for the lherzolitic shergottite Yamato 793605, in the range of other lherzolites. ALH 77055, however, showed the highest values which also differ significantly from other lherzolites and Yamato 793605. Anisotropy of magnetic susceptibility (AGICO KLY3), here the *P* factor, is in the range of 1,01–1,05 which is typical for volcanic or shallow subsurface intrusive rocks.

This is confirmed by the values of the intensity of NRM (Natural Remanent Magnetization, 2G Cryogenic) and its alternating field demagnetization (AF-Demag). In addition, IRM (Isothermal Remanent Magnetization) and ARM (Anhysteretic Remanent Magnetization) experiments were performed on the same samples.

Optical microscopy, magnetic microstructure analysis, thermomagnetic analysis and Raman Spectroscopy revealed the presence of a low-titanium magnetite phase, a ferrimagnetic pyrrhotite phase and ilmenite (exolution lamellae and individual grains) in the Yamato 000593 nakhlite. For the first time, graphite as a carbon phase was detected by Raman Spectroscopy in SNC meteorites.

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# PECULIAR MAGNETIC SIGNATURE OF FE-SILICIDE PHASES AND DIAMOND/FULLERENE CONTAINING CARBON SPHERULES

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### Background

There are reports about the potential existence of an impact stray field in SE Bavaria, Germany (*Hoffmann et al., 2004*; *Fehr at al., 2005*). However, all the known findings do not provide a clear picture of the situation in this area, many results are very puzzling and there is no accepted proof of any impact up to now. One of the crater structures of 11m in diameter is characterized by strong geophysical anomalies of surface magnetic susceptibility and gradient magnetic field (*Hoffmann et al., 2004*). However, the physical and mineralogical background of these magnetic anomalies cannot be explained by the bedrock geology. The southern part of SE Bavaria near the Austrian border is of geologically of Holocene age (< 9000 yrs), mainly glacial till is found which originated from the Alps located in the South. The rocks consist mostly of limestone and weak to medium metamorphic rocks, and some granites and very minor volcanic rocks. The magnetic signature of the bedrocks does not account for the strong magnetic anomalies of the crater.

In the same area puzzling metal findings were also made. *Schryvers and Raeymaekers (2004)* described the material as consisting of Fe-Si components (Fe-silicide) with varying Fe-contents containing Xifengite, Gupeite and TiC. These Fe-silicide phases were also detected in the highly magnetic rocks of the crater revealing the strong magnetic anomalies. Terrestrial Fe-silicide components are only known from highly reducing environments such as fulgurites. Finally, *Rösler et al. (2005)* report findings of a new type of carbon materials of spherulic shape of up to several mm in size first detected in deeper soil layers from the same area, afterwards also jointly with the Fe-Silicide phases in thermally severely altered rocks from the 11 m crater (*Hoffmann et al., 2005*). The carbon spherules were found to contain nano- and micrometer sized diamonds (up to 0.5 in size) and fullerenes (*Yang et al., 2006*: Raman spectroscopy and HR-TEM/SAED/EDX/EELS analysis). The geology-independent occurrence of such kind of high temperature/high pressure polymorphs of carbon are indicative for high energy processes such as impacts.

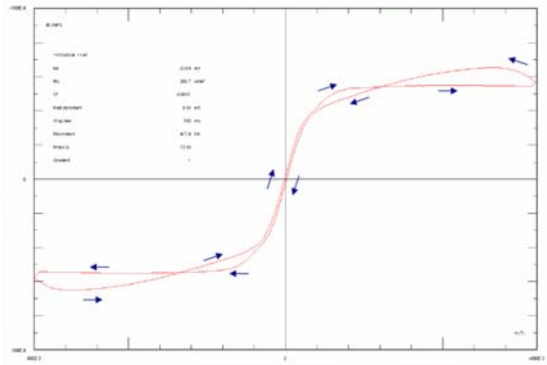
Preliminary data about the magnetic signature of the Fe-silicides were reported by *Hoffmann et al. (2004)* and of the carbon spherules by *Rösler et al. (2006)*.

### Experiments and results

Here we report data about more systematic investigations on the magnetic signature of a series of Fe-silicide samples and carbon-spherules from various locations. The following set of investigations was performed on the specimen: magnetic susceptibility (MS, room-temperature), field and frequency dependence of MS; magnetic remanences (NRM, IRM, ARM) and AF-demagnetization respectively; magnetic hysteresis, IRM acquisition and DC backfield demagnetization, thermomagnetic experiments (MS −190°C – 800°C); low-temperature experiments from 1.9 K – 300 K; micromagnetic observations.

### Fe-silicides

Generally, the Fe-silicides reveal very complex magnetic pattern. This can find an explanation in the very complicated intergrowth of several Fe-silicide phases as observed by optical and electron microscopy The Curie temperature of the Fe-silicides depends on the silicon content and is highest for the Fe-rich end members (values between 400 and 650°C). MS is low at room-temperature but the magnetic moment is quite high. An unstable, fluctuating magnetic behavior is found below Curie temperature. The magnetic hysteresis curve is absolutely unique and it can be used as a tracer for the occurrence of Fe-silicides (Fig. 1) This Type of hysteresis loop is not known and nowhere described in literature (to our best knowledge). Typical characteristics are for example several cross-overs within the loop or „negative“ $H_c$, $H_{cr}$ and $M_{rs}$ values. We believe that this magnetic behaviour might be due to extremely strong magnetic interactions (exchange coupling) of the various Fe-silicide phases. Summarizing, the magnetic signature of the Fe-silicides which are found in the highly altered crater rocks can provide an explanation for the strong magnetic anomalies of the crater. However, a high-energy, plasma-like and highly reducing process is required for the formation of the Fe-silicide phases.



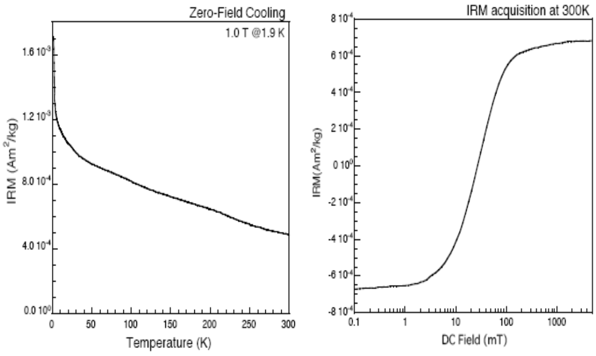



**Fig. 1 (left side).** Complex magnetic hysteresis curve of Fe-silicide.
**Fig. 2a,b (right side).** Low-temperature experiments on carbon spherules (zero-field cooling ZFC, IRM acquisition at 300 K).

**Carbon spherules**

By theory pure carbon materials should exhibit diamagnetism only. A variety of analyses which were done on these samples revealed a purity of nearly 99.9% carbon with only minor contents of N or O. Most of the carbon is amorphous, only diamonds were found as a crystalline phase. However, all investigated spherules can carry magnetic remanences (NRM, IRM, ARM) although the remanence signature often is quite complex. During hysteresis experiments the carbon spherules exhibit a variety of magnetic properties, diamagnetism, paramagnetism and ferromagnetism or combinations were found. Generally, the magnetic signature (remanences and in-field measurements) is very unstable in directions. During thermomagnetic runs sometimes some kind of transition can be observed of which the explanation is not clear. Low temperature experiments gave no transition, however at 1.9 K and 300 K stable IRM acquisition curves were obtained (Fig. 2). We propose that the peculiar and non-expected magnetic behaviour of the carbon spherules might be related to the presence of fullerenes, another high-energy/zero-oxygen C compound known as “bucky balls”. In nature fullerenes are only known from fulgurites and in relation to known impacts (e. g. Sudbury crater, KTB boundary fish-clay). Synthetic fullerenes which exhibit significant magnetism were synthesized in the laboratory under very restricted conditions. It is reported that magnetic fullerenes might be present in impactite rocks from Arizona crater. Further experiments are required to study in more detail the magnetic structure of the C spherules.

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# THE USE OF THE ANISOTROPY OF MAGNETIC SUSCEPTIBILITY OBEYING THE RAYLEIGH LAW IN SOLVING SOME GEOLOGICAL AND ENVIRONMENTAL PROBLEMS

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In multi-domain titanomagnetite grain, the maximum susceptibility direction in the anisotropy of magnetic susceptibility (AMS) is parallel to the maximum grain dimension, while the minimum susceptibility is parallel to the minimum grain dimension. In single-domain grain, the inverse relationship holds, i.e. the maximum susceptibility is parallel to the minimum dimension, while the minimum susceptibility is parallel to the maximum dimension. In the anisotropy of magnetic remanence (AMR), the relationship is simpler, the maximum and minimum remanences are parallel to the maximum and minimum grain dimensions, respectively. In some volcanic rocks, the predominating carrier of AMS are single-domain titanomagnetites and these rocks show inverse magnetic fabrics. In environmental materials, it is important to know the frain size of the magnetic particles, e.g. discriminate between multi-domain and single-domain particles. In order to find out whether a magnetic fabric is due to single-domain or multi-domain grains, field- and frequency-dependent AMS should be investigated. The field-dependence of AMS is inherently a multi-domain phenomenon, while the frequency-dependence is a single-domain phenomenon.

The AMS within the Rayleigh law range was investigated theoretically, using mathematical modelling. It was revealed that the orientations of the principal susceptibilities are field independent and the shape parameter varies with field so weakly that this variation can be regarded as negligible from the practical point of view. The degree of AMS increases with field according to the degree of anisotropy of initial susceptibility and according to the intensity of susceptibility change with field of the mineral considered. The degree of AMS calculated using linear theory is very near to the degree of AMS following from the analysis of AMS within the Rayleigh law range. Through measurement of the AMS in two fields within the Rayleigh law range, the field-dependent degree of AMS can be converted into field-independent degree of anisotropy of initial susceptibility. In rocks containing magnetic mineral that obeys the Rayleigh law (pyrrhotite, haematite, titanomagnetite) and the mineral with low-field independent susceptibility (magnetite, paramagnetic minerals), the respective magnetic fabrics can be separated from measurement of the AMS in two fields within the Rayleigh law range.

Recently, the MFK1-FA Multi-Function Kappabridge was developed that enables rapid and sensitive measurement of the AMS to be done in variable low fields corresponding to or slightly exceeding the Rayleigh law region and at three different operating frequencies. The selectable frequencies are 976 Hz, 3,904 Hz and 15,616 Hz. The field ranges (in peak values) are: 2 to 700 A/m at 976 Hz, 2 to 350 A/m at 3,904 Hz and 1 to 220 A/m at 15,616 Hz. Examples are shown of using this instrument to solving the above problems.

# ESTIMATING BAKING TEMPERATURES IN A ROMAN POTTERY KILN BY ROCK MAGNETIC PROPERTIES: IMPLICATIONS OF THERMOCHEMICAL ALTERATION ON ARCHAEOINTENSITY DETERMINATIONS(*)

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Absolute past geomagnetic field intensity determinations requiring laboratory heating are laborious and the success rate is rather low, mostly because of induced thermochemical magnetic mineral alterations. Archaeomagnetic intensity determinations in western Europe are mainly limited to displaced ceramics produced in kilns (*Genevey and Gallet, 2002*). In the present study the suitability of an in situ baked structure is investigated. The aim is to assess the onset of magnetic mineral alteration during repeated laboratory heating by means of rock magnetic measurements, in order to determine baking temperatures and to preselect suitable material from in situ baked structures for archaeointensity analyses.

Different magnetic properties such as magnetic susceptibility, coercivity spectra, and short-term viscous remanent magnetisation decay of baked material taken from the combustion chamber wall and floor of a Roman pottery kiln, with variable colouring, are examined in dependence of the distance to the combustion chamber. The ancient baking temperature distribution is re-constructed based on the rock magnetic experiments and agrees fairly well with a mathematical heat conduction model demonstrating the penetration of heat into the combustion chamber wall.

The rock magnetic results show that blackish and greyish coloured kiln parts, that had been in close contact with the fuel, during ancient kiln operation, are not suitable for intensity determinations. Although sufficiently baked, they strongly alter during laboratory heating and new remanence carrying minerals are formed. The brownish coloured material at a distance 65–80 mm away from the combustion chamber seems to be most suitable as its magnetic properties remain nearly unchanged during laboratory heating. Preliminary archaeointensity determinations on brownish and blackish/greyish baked material support these conclusions (Fig. 1).

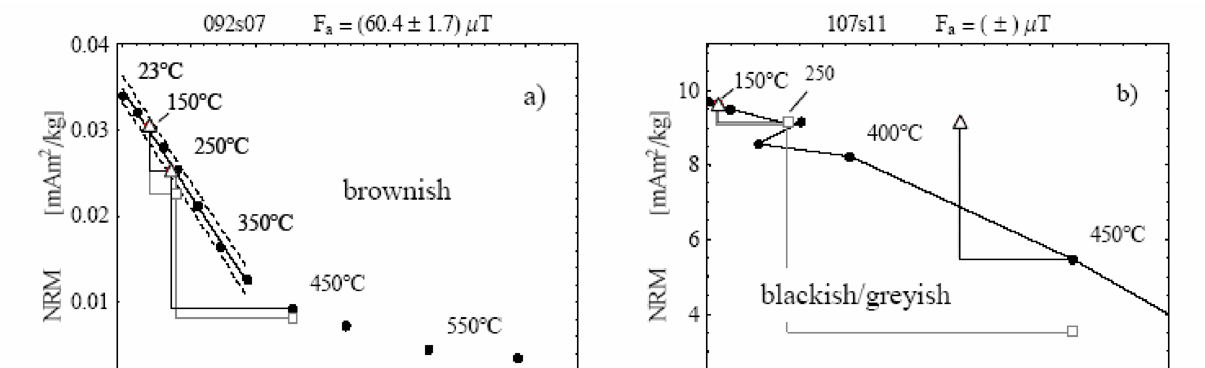


**Fig. 1.** Arai plots of preliminary archaeointensity determinations on well-baked brownish **(a)** and blackish/greyish coloured baked clay **(b)** from a Roman pottery kiln in Bruyelle (Belgium) after applying the Thellier-Thellier double heating technique (*Thellier and Thellier, 1959*). The blackish/greyish specimen, strongly changes its TRM capacity during the procedure and shows non-linear behaviour, hence yielding unreliable intensity results. The brownish specimen shows linear behaviour up to 400°C. Grey squares represent residual NRM checks, i.e. the residual NRM at a certain temperature should be similar after a second heating to lower temperature.

(*) from Spassov S. and Hus J., Estimating baking temperatures in a Roman pottery kiln by rock magnetic properties:

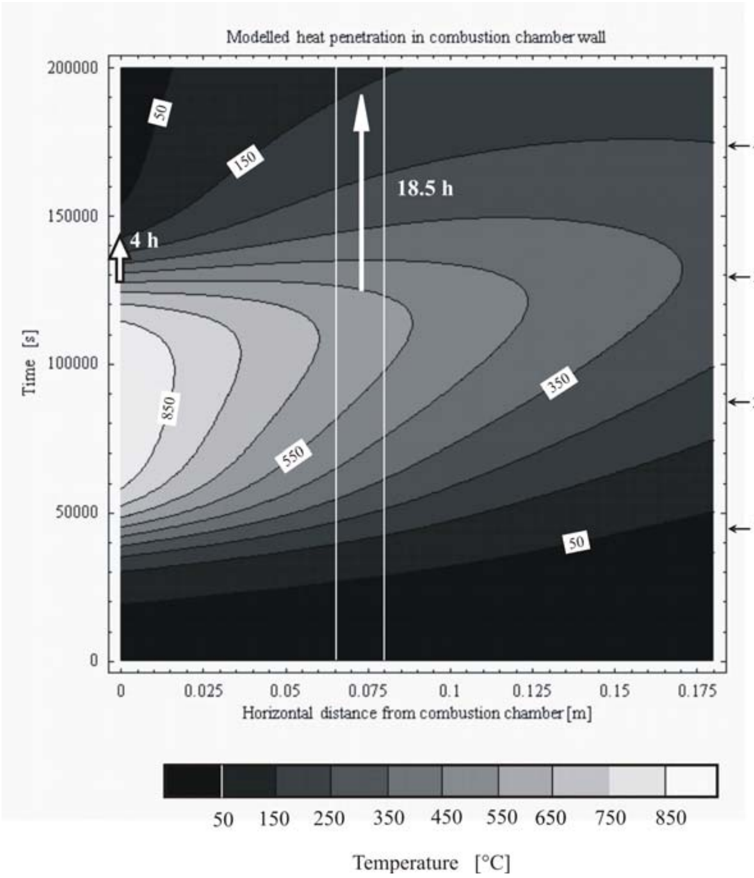


**Fig. 2.** Modelled heat conduction in the combustion chamber wall during a typical heating and cooling cycle of a Roman pottery kiln, lasting for about two days. Cooling in the combustion chamber from 550 to 150°C takes 4 h, while at the optimal profile distance of 65–80 mm (vertical lines) it amounts to 18.5 h (arrows).

The heat conduction model demonstrates that cooling takes longer in the inner parts of the combustion chamber wall (Fig. 2). Retarded cooling affects the blocking temperatures and hence the strength of the thermoremanent magnetisation. In single domain (SD) grains, slow cooling blocks the magnetisation more efficiently at lower temperatures. A SD thermoremanent magnetisation is therefore stronger in samples at intermediate distances from the heat source than close to the combustion chamber. The variability of cooling rates should be taken into account when investigating archaeointensities of specimens cut from large samples, or of samples taken from different parts of a kiln.

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# PALEOSECULAR VARIATIONS 12-20 KYR. AS RECORDED BY SEDIMENTS FROM MORENO LAKE (SOUTHERN ARGENTINA)

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Paleomagnetic and sedimentological studies carried out on five cores Lmor1, Lmor2, Lmor3, Lmo98-1, Lmor98-2 from the bottom sediments of Moreno lake (southwestern Argentina) are described. The results obtained are integrated with the data from *Gogorza et al. (2000)*.

The length of the cores varies from 0.5 m to 4 m and 450 samples were collected. Measurements of directions (declination $D$ and inclination $I$) and intensity of natural remanent magnetisation (NRM), magnetic susceptibility at low and high frequency (specific $\chi$ and volumetric $\kappa$), isothermal remanent magnetisation (IRM), saturation isothermal remanent magnetisation (SIRM), and back field were carried out. Stability of the NRM was investigated by alternating-field demagnetisation.

The correlation between cores was based on magnetic parameters as $\chi$ and NRM. The tephra layers were identified from the lithologic profiles and also from the magnetic susceptibility logs. Due to their different chronological meaning and their rather bad behaviour as magnetic recorder, these layers were removed from the sequence and the gaps that were produced along the profiles by the removal were closed, obtaining a “shortened depth”.

The Declination and Inclination logs of the characteristic remanent magnetization for the cores as function of shortened depth are obtained.

Comparison between stacked inclination and declination records of Moreno lake and results obtained in previous works, Escondido lake (*Gogorza et al., 1999*) and El Trébol lake (*Irurzun et al., 2006*), shows a good agreement. This agreement allowed adjusting the new obtained records with those from Escondido and El Trébol lakes in order to transform them into time series.

The secular variation (SV) of the geomagnetic field was studied using spectral analysis and precession analysis of the magnetic vector. In order to test the stability of the obtained periodicities, spectral analysis has been applied at intervals of 500 yr. for both records. Both clockwise and counterclockwise precession of the geomagnetic vector is evident from analysis of Bauer plots.

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# MAGNETIC IRON OXIDES OCCURRING IN SOIL AS INDICATORS OF PEDOGENIC PROCESSES

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The aim of this presentation is to recognize type and structure of magnetic iron oxides occurring in soil through their magnetic properties. Formation of iron oxides in soil appears to be related to pedogenic, lithogenic and anthropogenic processes. We examine the variation in ferrimagnets distribution along soil profiles and their magnetic properties in relation to pedogenic parameters such as pH, organic matter and iron content. To eliminate parent material and anthropogenic influence we studied unpolluted czernozem profiles formed on loess taken from two climatic zones of Ukraine and from southern Poland. The profiles differ in chemical parameters - pH and organic carbon and iron content. Magnetic susceptibility shows enhancement in the upper part of profiles except soil from the steppe-forest zone of Ukraine where susceptibility decreases slowly with depth. Examination of saturation remanence decay during heating identifies soil-formed ferrimagnets as oxidized magnetite and hematite with increasing hematite content with depth. Unoxidized magnetite is present only in topsoil of Polish profile. Ferrimagnetic contribution to total signal estimated from hysteresis loop varies from 30–60% for topsoil to less than 20% for loess. Coercivity of remanence has higher values in the lower part of profiles reflecting increasing contribution of hematite. Frequency dependent susceptibility ($\chi_{fd}$) has high values for upper part of profiles indicating a substantial amount of superparamagnetic grains characteristic for pedogenic magnetic material (*Dearing et al., 1996*). From a depth of 60–80 cm coarser grains prevail except profile from steppe-forest zone where $\chi_{fd}$ value stabilized at about 8%. This is confirmed by $\kappa/M_s$ ratio which shows maximum for a depth between 20 and 60 cm of profiles except MTS for which the ratio is almost constant. ARM/SIRM ratio was used to determine the relative abundance of single domain (SD) particles. The ratio reaches the values about 0.07 for MD and A1 indicating a significant amount of SD grains. It decreases for loess being relatively high for MTS and small for MD. Our study shows that pedogenic magnetic component responsible for enhancement of magnetic susceptibility in A soil horizons consists of fine-grained, SP and SD ferri- and antiferromagnetic minerals (*Fine et al., 1995*; *Geiss et al., 2004*). The value of susceptibility is linearly related to humus content and the maturity of soil characterized by the ratio $Fe/Fe_t$ where $Fe_d$ is CBD-soluble iron oxides and $Fe_t$ is total amount of iron in soil (*Cornell and Schwertmann, 2003*). High pH value hinder formation of pedogenic minerals resulting in lower value of susceptibility.

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# MAGNETIC SUSCEPTIBILITY MAPPING AND MINERAL MAGNETIC PROPERTIES OF TOPSOILS DEVELOPED ON HIGHLY MAGNETIC ROCKS

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The aim of the investigation was to study the possibility to employ the magnetic method for pollution detection in a region where strongly magnetic volcanic/volcanoclastic rocks are widely spread. Field magnetic susceptibility mapping was carried out on a regular 4km grid in an area of about $50 \times 50$ km. Hot-spot industrial pollution in the Burgas region is concentrated in the Burgas big town and includes several major enterprises: Neftochim Lukoil Chemical and Oil Processing Industry Treatment Plant, Neftochim power plant and Burgas Port Treatment Plant. Some Cu-containing ore deposits were exploited in the southernmost part near the village of Rosen. Burgas region falls within the Mediterranean soil province. In the negative relief forms the very specific relict soil type Smolnitza (Vertisols), has wide occurrence in combination with Luvisols, Planosols, Solonchaks and Chernozem-Smolnitzas. Higher altitude terrains are covered by shallow soils - Rankers. Several complete soil profiles of Smolnitza, Ranker and Alluvial soil were also sampled in detail in order to reveal the magnetic properties in depth. Rock magnetic measurements were carried out on bulk soil material, as well as on magnetic separates. Hysteresis loops, thermomagnetic analyses, frequency dependent magnetic susceptibility, thermal demagnetization of composite IRM, pARM acquisition and demagnetization, etc. were performed on pilot samples in order to investigate grain-size related behavior of the soils. Scanning Electron Microscopy was applied on magnetic extracts from several soils in order to study the composition and morphology of the Fe-containing grains. The main results indicate that field magnetic susceptibility as measured in the field is not an appropriate indicator of the pollution level. Rather, it reflects the geological background, presented mainly by strongly magnetic volcanites and volcanoclastic sediments. An attempt for evaluation of the lithological contribution to the total magnetic susceptibility signal was carried out comparing the relation between the topsoil susceptibility and parent rock susceptibility. Magnetic mineralogy is largely dominated by coarse grains of (titano)magnetite, while the pedogenic contribution of fine magnetite/maghemite grains is not well expressed in the total signal. Correlation between the content of certain heavy metals and the magnetic parameters do not show straightforward relations, probably due to the different origin of the magnetic Fe-containing minerals and heavy metals.

# MINERAL MAGNETIC PROPERTIES OF THE MORAVA RIVER FLOODPLAIN DEPOSITS (CZECH REPUBLIC)

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Thickness of the flood deposits exposed in the erosion banks of the Morava River ranges between 400 and 600 cm. Three vertical sections were sampled. At each section, triplicate samples were collected at each stratigraphic level using plastic boxes (6.7 cc) with a vertical separation of <0.5 cm. Mineral magnetic parameters such as mass specific susceptibility ($\chi$), ARM, SIRM and their ratios (ARM/SIRM, *S*-ratio) all show similar variations from section to section. The values of magnetic susceptibility are highest in the upper 50 cm of the sections. Below the 50 cm level $\chi$ values show a noticeable decrease downward to 200 cm depth and then stay low. *S*-ratios near 0.9 in the upper 50 cm suggest the presence of a low coercivity mineral as the cause of the highest susceptibility values but drop to values of near 0.6 by 200 cm depth and then decrease to 0.5 at 300 cm depth. These low values of the *S*-ratio indicate the presence of a high coercivity mineral and may be the cause for the low susceptibility values seen in this portion of the sections. Hysteresis data gained at room temperature indicate that paramagnetic or high-field susceptibility components dominate especially in the lower portions of the sections. Both low and high temperature VSM measurements verified a significant paramagnetic contribution. AC suscptibility as a function of temperature also indicates a predominance of paramagnetic component in the magnetic signal. This paramagnetic influence often masks the ferrimagnetic signal. However, the paramagnetic susceptibility variations are rather flat documenting increased ferrimagnetic content in horizons, where $\chi$ record shows distinct peaks. High temperature dependent magnetic susceptibility variations follow a pattern common in young soft sediments. Maghemite formed from lepidocrocite (?) after heating to 280°C is later converted to hematite, which is than reduced to magnetite between 480 and 510°C. The magnitude of these magnetic phase changes is higher in the sediments deposited in the uppermost 50 cm of the floodplain sequences, where the goethite and free Fe-oxide contents are low.

To diagnose the magnetic carriers in the sediments we used MPMS measurements to evaluate (1) the magnetization acquired in a 2.5 T field while cooling a portion of the sample from 300K to 20K (FC), (2) the thermal demagnetization of a 2.5 T IRM imparted at 20K (ZFC), (3) the low-temperature cycling of a 2.5 T IRM acquired at room temperature (RTSIRM). RTSIRM-ZFC sweeps show the presence of an oxidized magnetite in the upper ca 50 cm in all sections and in several underlying coarser horizons. Drops in RTSIRM-ZFC magnetizations at 120K indicate a suppressed Verwey transition suggesting the presence of low temperature oxidized magnetite. The presence of low-temperature oxidized magnetite was documented by the $T_C$ value (578°C) revealed by magnetization verses temperature experiment on the magnetic extract from the stratigraphic horizon 32.8 cm bellow the floodplain surface. However, at depths greater than 50 cm in the ZFC-RTSIRM and FC-ZFC-RTSIRM sweeps, goethite starts to appear and below 200 cm depth in the sections goethite becomes the predominant magnetic phase. The large difference (~4×) in the FC magnetization at 20K and the ZFC magnetization at 20K as well the duck-billed shape of the RTSIRM sweep is very diagnostic of goethite.

An interpretation of gained mineral magnetic data allows us to sketch following conclusions:

1. The paramagnetic influence dominates in the flood sediments through all three sections often masking the ferrimagnetic signal. The paramagnetic iron is most probably carried by clay minerals. Expandable clay minerals smectite and vermiculite were identified in the sediments by the X-ray diffraction.
2. Goethite is a common iron oxyhydroxide presented in the flood sediments. The concentration of goethite increases downward in the sections. The goethite could be a product of dissolution of iron oxides and consequential iron precipitation under redox conditions in the flood plain environment.
3. Detrital magnetite grains are partly oxidized to maghemite, which suppresses the Verwey transition. We surmise that cultivation of arable soil exposed magnetite grains that were then oxidized during erosion, transportation and re-deposition in the flood sequences. The gradual increase of $\chi$ and other magnetic parameters in the uppermost 200 cm of each section is the consequence of more intense erosion caused by agriculture activities, which was triggered by medieval colonization in the central Europe and dramatically accelerated during the last 60 years of very intensified land use, when the topmost 50 cm of the floodplain sequences were deposited as verified by the sediment age estimation based on Pb isotopic content and persistent organic substances (DDT, PCB) determined in the sediments.

# MAGNETIC PROPERTIES OF PODIFORM CHROMITITE FROM THE SUDETIC OPHIOLITE

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One of characteristic features of rocks of mantle origin is presence of spinel grains of chromite series $Fe^{2+}$ $(Fe^{3+}{}_x\, Cr^{3+}{}_{2-x})\, O_4$ with $0 < x < 2$,usually containing cations of Mg, Ni, Al or Ti in their crystalline lattice. They are encountered in submarine gabbros, serpentinites, kimberlites, as well as in volcanic rocks and meteorites. In some cases minerals of this series are carriers of natural remanence of rocks (*Fernandes, 1999*; *You et al., 2001*). Our presentation concerns petrological and magnetic study of podiform chromitites encountered in the Jordanow-Gogołów Serpentinite Massif (JGSM) belonging to the dismembered Sudetic ophiolite (*Dubińska and Gunia, 1997*) and Cr-spinel grains disseminated within serpentinized dunite rocks from the same massif. The studied chromitites are composed of Cr-spinels, chlorite and minor magnesite. Petrological investigations revealed two varieties of the JGSM chromitite (described as A and B). They differ from each other due to variation of Cr-spinel chemical composition caused by alterations. The study of magnetic properties proved important differences between both varieties, although both contain magnetic Cr-spinels (ferritchromites). They reveal different values of magnetic susceptibility as well as values of Curie/blocking ($T_c/T_b$) temperatures. We tried to estimate composition of these ferritchromites on the basis of the literature (*Robbins et al., 1971*; *Chahya et al., 1999*; *Ziemniak and Castello, 2001*). The cited authors present relations between amount of Cr (parameter $x$) and Tc of Cr-spinels free of additional cations, and containing Al and Ni in a crystalline lattice.

Sample A contains nearly unaltered chromian picotite ($Fe^{2+}{}_{0,23}Mg_{0,77}Al_{0,96}Cr_{1,04}O_4$), the primary magmatic spinel. It forms grains up to 10 mm in size rimmed with a thin coating of ferritchromite (*Spangenberg, 1943*), which is a submicroscopic association of chromian picotite, Cr-magnetite and chlorite formed during an alteration (*Mellini et al., 2005*). It is characterized by lower Mg and Al content and higher Fe content compared to chromian picotite. Tiny syn- and postserpentinization magnetite grains scarcely occur in the vicinity of spinel grains. They contain less than 4% of Cr. Mean low field magnetic susceptibility of this sample $\kappa_m$ attains ca $12000 \times 10^{-6}$ SI. Thermomagnetic analyses (study of saturation remanence SIRM during heating in the air, Lowrie method, study of bulk susceptibility $\kappa_b$ during heating in air and in argon and in the low temperature range) together with study of IRM acquisition curve reveal predominance of low-coercivity phase with $T_b/T_c$ ca 520°C and small amount of phases with $T_b/T_c$ ca 200°C and 570°C. Heating in the air to 700°C results in appearing of new phase with $T_b$ of ca 400°–425°C on SIRM-T curve. $\kappa_b(T)$ cooling curves after heating in air and in argon reveal a peak (Hopkinson peak?) at about 500°C, an increase beginning at about 400°C and, in the case of heating in the air - a second increase of susceptibility between 150°C and room temperature. This pattern is repeated during subsequent heating - cooling to 700°C in the air. Low temperature curves do not present any transitions. The results suggest presence of two types of ferritchromite: one with $T_b$ of ca 200°C and the other with $T_b/T_c$ ca 500°C, as well as $T_b/T_c$ of magnetite (Fig. 1, Fig. 2).

Cr-spinels of sample B are strongly altered. They are mainly composed of spinels progressively replaced by Cr-magnetite rims. The Cr-spinel usually forms, together with chlorite, spongy pseudomorphs after chromian picotite. Tiny droplets of relic chromian picotite scarcely occur in the centers of Cr-spinel grains. The strongly

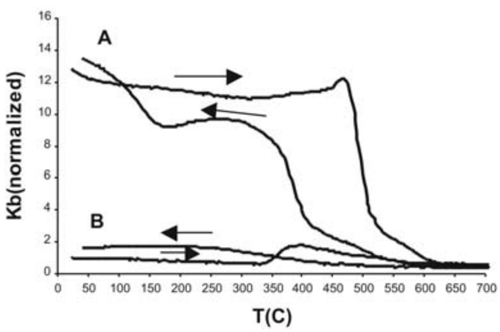
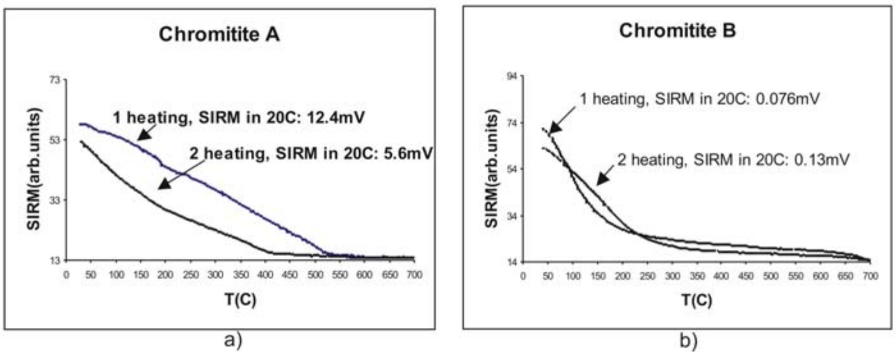



**Fig. 1.** Variations of low-field susceptibility $\kappa_b$ of chromitites A and B during heating in the air.




a) b)

**Fig. 2.** Variations of SIRM acquired in 5 T during heating in the air of chromitite A and chromitite B. Samples were heated two times, values of SIRM before consecutive heatings are shown.

altered grains are characterized by decrease in Al and Mg content from the center to the rim and increase in Fe. The Cr content decreases starting from Cr-spinel to Cr-magnetite rim. Cr-magnetite contains up to $1 \times Fe_{0,23}Mg_{0,77}Al_{0,96}Cr_{1,04}O_4$% of Cr. Neither serpentinization magnetite (up to 4% Cr) nor hematite have been observed, but they are probable submicroscopic phases. Mean susceptibility $\kappa_m$ attains ca $1000 \times 10^{-6}$ SI. SIRM($T$) curves reveal quick decrease of SIRM up to about 150°C and presence of the second phase with $T_b$ of about 680°C. $\kappa_b$ during heating in air reveals an important hump in the temperature range of 350°C–600°C with a peak at about 450°C. The hump disappears during cooling, although $\kappa_b$ increases during cooling to the room temperature. No hump is present during an argon heating, the observed $T_c$ is close to the $T_c$ of magnetite (ca 570°C), so perhaps the hump reflects oxidation due to heating in the air. Low-temperature curves of $\kappa_b$ do not show any transitions. The Lowrie curves show predominance of low-coercivity fraction ($H_c < 0.12$ T) with one phase with $T_b$ ca 450°C and the second, of lower intensity, with $T_b$ ca 530°C, as well as small amount of high-coercivity fraction with $T_b$ of 650°C ($0.4\ \mathrm{T} < H_c < 1.5$ T), characteristic for hematite (Fig. 1, Fig. 3). IRM acquisition curve supports this conclusion.

Summarizing, our investigations show that Sudetic podiform chromitites are not homogeneous, but one finds among them nearly unaltered and strongly altered ones. We tried to estimate amount of Cr ($x$ in the chemical formula) in the observed chromitites by their $T_b/T_c$ values using data of the cited papers. They suggest that nearly unaltered chromitite A contains a ferritchromite with x of about 1.7 ($T_b$ ca 200°C, the region 2 of Robbins where part of $Fe^{2+}$ ions is displaced from sublattice A to sublattice B) and ferritchromite with $x$ of about 1.9 ($T_b$ ca 530°C, the region 3 of Robbins where amount of $Fe^{3+}$ ions is higher than in the region 2). Heating leads to formation of spinel enriched in Cr with $T_b$ of about 420°C ($x$ about 1.6). Altered chromitite B contains probably ferritchromite with $x$ ca 0.9–1.1 (region 2 of Robbins). Heating of sample A leads to ferritchromite variety of intermediate amount of Cr, while heating of sample B leads to formation of ferritchromite enriched in Fe. In the serpentinized dunite a ferritchromit with Tc of ca 510°C ($x$ ca 1.8) accompanies magnetite.

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# THE ORIGIN OF ANOMALOUS MAGNETISM OF TITANOHEMATITE LAMELLAE IN RHOMBOHEDRAL OXIDE ASSEMBLAGES INSIDE IGNEOUS AND METAMORPHIC ROCKS

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Remanent magnetization of titanohematite lamellae within oxide assemblages in crustal rocks has been proposed to be a source for intense magnetic anomalies both on Earth as well as Mars. In an attempt to explain the origin of such strong magnetization in titanohematite bearing rocks, two hypotheses have been proposed. First hypothesis (*Robinson et al., 2002*) proposes a new type of magnetization (lamellar magnetization) associated with the contact zone between the ferrian ilmenite and titanohematite. Second hypothesis proposes that the intense magnetization is a consequence of an "empirical law" related to the low saturation magnetization of titanohematite (*Kletetschka et al., 2006*).

We evaluate these two hypotheses in light of further rock magnetic tests. Namely, we compare thermal demagnetization (TD) of Natural Remanent Magnetization (NRM) with TD of Saturation Isothermal Remanent Magnetization (SIRM). We observe that the blocking temperature of small titanohematite lamellae is visible during the TD of SIRM but not during TD of NRM (Fig. 1). Numerical modeling of the magnetization of a titanohematite grain (this grain hosts small grains that originate after this host grain is already magnetized) indicate that these small grains are exposed to weaker magnetic fields due to interaction of the already magnetized host with the terrestrial field. SIRM, however, magnetizes these small grains within geomagnetic field and therefore their blocking temperature becomes visible during this test. TD of various grain size fractions further supports this interpretation. Small grain sizes of titanohematite are thermally demagnetized at lower blocking temperature than coarser grains.

Magnetite-bearing crustal material has low level of magnetic remanence (<5% efficiency). However, the Ti-free end member of hematite - ilmenite solid solution series minerals residing in crust has efficiency >10% and the magnetization intensity comparable to single domain magnetite.

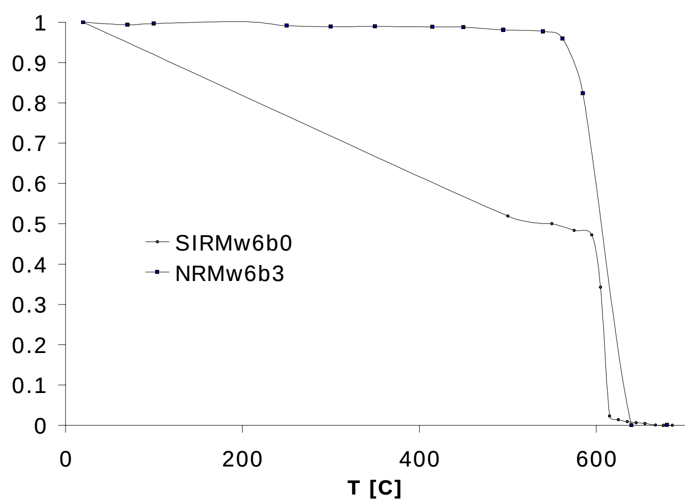


**Fig. 1.** Diagram shows thermal demagnetization of two representative sub samples (w6b0 and w6b3) containing titanohematite exsolution. Additional sub samples are described in *Kletetschka et al. (2002).* Sub sample w6b0 is saturated before demagnetization. Sub sample w6b3 contained its original natural remanent magnetization before demagnetization. Data were obtained from superconducting magnetometer at GSFC/NASA, MD, USA.

We show that remanent magnetization of titanohematite has been acquired prior to the exsolution of the titanohematite (*Kletetschka, 2000*). According to the empirical law titanohematite should acquire intense TRM as a fairly large homogeneous grain where the low demagnetizing energy allows acquisition of intense magnetization. We suggest that any occurrence of hematite-ilmenite solid solution in a rock, cooled slowly in a terrestrial magnetic field (or during the formation of Martian crust), will have an intense magnetic signature characterized by large magnetic efficiency.

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# MAGNETIC SUSCEPTIBILITY OF TOPSOILS POLLUTED BY HEAVY METALS IN THE VICINITY OF NICKEL FACTORY DUMP IN THE SLOVAK CITY OF SEREĎ

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In topsoils, heavy metals are predominantly fixed on/in ferro- and ferrimagnetic minerals. Therefore, measurement of the magnetic susceptibility can be employed as a simple and rapid screening method to asses the level of soil pollution. This approach was successfully applied in several European cities, and can be used in all situations, where it is reasonable to assume that magnetic particles and pollutants (mainly metals) coexist.

We tested the applicability of magnetic susceptibility measurement for the detection of industrial soil pollution in the surroundings of a large dump from the (by now closed) nickel factory in the city of Sereď, situated in the south-western region of Slovakia. The environmental load here represents approximately $5.5 \times 10^6$ tons of material with nickel as the most important pollutant. The study locality was a $6 \times 6$ km$^2$ area situated mainly in the southern and southeastern direction from the dump (including the dump itself). Altogether 183 soil samples were taken from three horizons (20 cm, 40 cm and 60 cm, respectively), air-dried and measured for the mass susceptibility on the KLY-2 kappabridge.

The results show that the topsoils in the studied area are characterized by enhanced magnetic susceptibility $\kappa$, with highest values, as expected, directly in the dump. In general, $\kappa$ decreases with increasing distance from the dump, as well as with increasing depth from the surface.

Previously, the geochemical mapping of this area was carried out by *Čurlík and Šefčík (1997)*. Their results make it possible to correlate the magnetic susceptibility values with the concentration of heavy metals, particularly that of nickel. This results comparison revealed the high positive correlation. Therefore the measurement of magnetic susceptibility of soils can be - in this case - used as a supplemental method to the geochemical mapping; method, which allows to assess, in a simple, cheap and rapid way, the level of soil pollution in sites, where the geochemical data are missing.

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# TESTING THE NATURE OF NATURAL REMANENT MAGNETIZATION USING REM(AF) METHOD

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The new method for testing the nature of the remanent magnetization has been developed by *Kletetschka et al. (2005)*. The technique utilizes a detailed AF (Alternating Field) demagnetization of NRM (Natural Remanent Magnetization), followed by AF demagnetization of the SIRM (Saturation Isothermal Remanent Magnetization) in the very same AF steps. The REM ratio (NRM/SIRM) is determined for each demagnetization step and is plotted against AF demagnetization field. The slope of the REM(AF) curve contains information about the nature of NRM (magnetomineralogy, acquisition process, shock effects). In the case of the TRM (Thermo-Remanent Magnetization) or CRM (Chemo-Remanent Magnetization) the coercivity spectrum of NRM should cover equally both the SD and MD particles resulting in the constant REM (AF) ratio. In the case of the IRM (Isothermal Remanent Magnetization) the low coercivity grains are much more susceptible to the magnetizing field that the high coercivity grains resulting in the increase of the REM(AF) ratio in the low coercivity (low AF field) region (*Kletetschka et al., 2004*).

The initial REM value depends on the magnetizing paleofield (*Wasilewski, 1977*; *Cisowski et al., 1983*; *Cisowski and Fuller, 1986*) and on the saturation magnetization ($M_s$) of the magnetic mineral (*Kletetschka et al., 2004*). Thus the REM (AF) method can be used for the paleofield estimate in the case of known magnetomineralogy or for the magnetomineralogy analysis in the case of known paleofield.

We applied this method on terrestrial samples (precambrian diabase from Arizona) and on three chondritic meteorites (Avanhandava H4, Bjurböle L4 and Neuschwanstein EL6).

The diabase samples (magnetized by geomagnetic field) show different REM values in low and high coercivity region (Fig. 1). The REM value of low coercivity region (~0.01) is characteristic for magnetite. The order of magnitude increase in REM values (~0.4 – 0.6) in the high coercivity region (high AF fields) can be

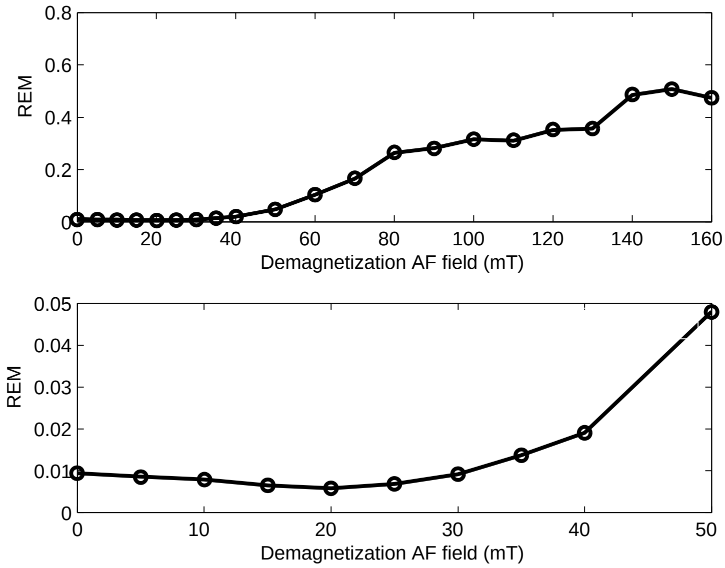


**Fig.1.** The REM(AF) plot of the precambrian diabase from Arizona. The plot show different REM values in low and high coercivity region pointing on two kinds of magnetic carriers.

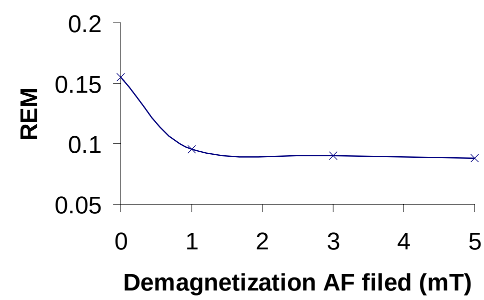


**Fig.2.** The REM(AF) plot of Neuschwanstein meteorite. The negative slope of the REM(AF) curve in low coercivity region reveals the IRM overprint.

explained either by presence of low $M_s$ mineral (i.e. hematite) or by the presence of the elongated magnetite grains. The XRD analysis and optical microscopy revealed elongated magnetic grains to be the high coercivity high REM fraction (*Kletetschka et al., 2004*).

The Neuschwanstein (EL6) reveals significant IRM component characterizied by negative REM(AF) slope in the low AF fields (Fig. 2). The chondrules of Bjurbole (L4) reveal either constant or negative REM(AF) slope ratio pointing on either TRM (or CRM) or IRM origin of the NRM. The interesting feature was observed on chondrules from the Avanhandava (H4) meteorite. Systematically lower values of the REM(AF) ratio in the low AF range points to partial demagnetization of MD grains what can be explained as an effect of the impact demagnetization of the parent body or as an effect of the time-decay of the magnetization.

The method can serve as fast tool to determine the nature and origin of the magnetic record of the extraterrestrial and terrestrial materials and has potential application in the paleointensity studies.

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# ANALOGUE NON-SCALE MODELLING OF AMS FABRICS: EXAMPLES OF MAGMA EMPLACEMENT

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An experimental method to characterize the internal fabric pattern based on analogue modelling of anisotropy of magnetic susceptibility (AMS) is presented. The liquid plaster of Paris containing small amount of homogeneously admixed fine-grained magnetite (< 0.07 mm) is forced to intrude the overlying sand layers using a simple hydraulic apparatus. The development of AMS is correlated with the complex flow pattern indicated by the coloured and originally horizontal plaster layers. Despite the complex rheological behaviour of the plaster, the results provided by our models can serve as a semi-quantitative map of fabrics throughout similar natural bodies. We show in our experimental work that the AMS can be successfully applied to unravel the directions and shapes of viscous flow/deformation in 3D.

We discuss the first geological models related to the ascent and emplacement of magmatic bodies. Although the evolution of shapes of such bodies has been modelled for the ideal Newtonian fluids (*Talbot and Jarvis, 1984*; *Koch et al., 1981*), the evolution of internal fabric pattern is still poorly understood. The aim of this study is to investigate the evolution, final shapes and the internal fabric development within the various volcanic bodies (laccoliths and extrusive domes), dykes and diapir-like plutons.

In our analogue experiments, the liquid plaster intrudes the sedimentary sequence formed by the pure sand strata or by the sand with clay layers simulating the presence of mechanical anisotropy. The map of AMS provides complex pattern showing the constrictional convergent upward flows which is further reworked by the vertical flattening and subhorizontal divergent flows associated with the flat-lying oblate and intensive fabrics. This study suggests the importance of fabric overprints for the final fabric pattern in deeper crustal levels and the sensitivity of AMS to the successive deformation (intrusive) events.

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# MAGNETIC SIGNAL OF PEAT BOGS AS PALEOCLIMATE RECORD ? AN EXAMPLE IN WESTERN FRANCE

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Peat bogs have been commonly considered as magnetic sterile environment for paleoenvironment reconstitution. Indeed, acid condition is known to favor iron dissolution and so magnetic carriers dissolution. Recently, further magnetic studies put forward magnetic variation interpreted as industrial fly ash pollution (*Strzyszcz and Magiera, 2001*; *Kapička et al., 2001*) or paleoenvironment record (*Berquó et al., 2004*).

On one hand, interest in peat record for high resolution paleoclimate reconstruction is indubitable. On the other hand, meaning of peat magnetic signal for such aim has still to be demonstrated.

Dynamics of littoral marshlands is directly driven by local sea level changes. Disadvantage of littoral sedimentary record is the temporal distortions on millenial scale due to tidal influences or sporadic events such as storms. During the Holocene sea level elevation, some parts of the littoral drainage pattern become inactive, which allow for development of peat bogs. Then, these basins are not directly influenced by high frequency of sea level variations, and one may expect more regular temporal record.

In order to explore the potential of such environment, we have made a preliminary magnetic study of two peat bogs of Charente-Maritime (Western France), not directly connected to the same river and distant of 30 km.

If we compare the two records without considering the difference in peat depth, variations in both saturation anhysteretic and isothermal remanent magnetizations (ARM and IRM) are very similar (Fig. 1). We assume that the same temporal record implied different temporal dilatation. The Trezence record, related to the border of large peat bogs, seems to ne condensed compared to the Arnoult record, related to the centre of a narrow valley. Clay levels, froming the bottom part of the cores, also show high values. Lower peat layer show variations before magnetization in the middle part of peat column stabilizes. The upper part is characterized by progressive increase of magnetization up to ploughed soil horizon. The Arnoult peat, which seems to exhibit dilated record, sho lower values than the Trezence peat. This may correspond to a dilution effect.

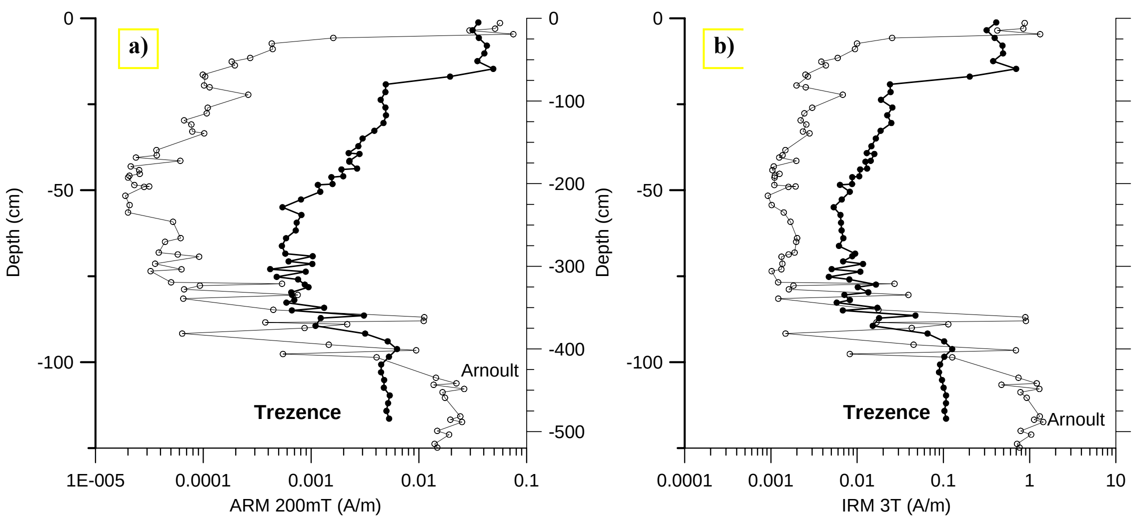


**Fig. 1.** Magnetic variations in the two peats studied. **a)** Anhysteretic remanent magnetization acquired in 200 mT alternating field and 0.1 mT D.C. field, **b)** Isothermal remanent magnetization acquired in 3 T. An ASM $^{14}C$ dating gives the age of the base of the Trezence peat of 4030 ± 35 years BP.

Does the similarity of both records means that they correspond to a local paleoenvironmental forcing, or to an intrinsic behavior of peat bogs? In order to answer this question, new cores from the two bogs will be analysed soon. The choice of Trezence is determined by the fact that geophysical study allows us to expect 5-m deep peat in a paleochanel identified in the basin and the peat shows the highest magnetization. It is possible that this argument is not valid if the dilution hypothesis holds true. Indeed, low magnetization of some Arnoult peat samples did not allow determination of partial magnetization. Geochemical and palynological indicators will help in solving this incertainity.

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## SOIL TILLAGE IMPACT ON MAGNETIC PROPERTIES

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In the 1950's, during a magnetic survey for geologic purposes, Le Borgne noticed that magnetic susceptibility values of soil surface were generally higher than that of parent rocks. He put forward that it corresponded to a topsoil ferrimagnetic enhancement and noticed no distinction between the studied soils from Central Brittany (France), whether cultivated or non cultivated (*Le Borgne, 1955*). Half century later, *Hanesch and Petersen (1999)* presented contradictory results on cultivation effects based on para-brown soil study from southern Germany. Indeed, this soil, which had been cultivated until five years before the study, showed lower magnetic susceptibility values in the ploughed horizon compared to lower soil horizon. This induced magnetization decrease of ploughed topsoil is not observed with isothermal remanent magnetization. Grain-size variation, multidomain industrial fly ash contribution and growth of extracellular bacterial magnetite are evoked to explain this behavior.

Technological development since Le Borgne's studies allows one to perform magnetic survey with a decimetric resolution and a sensitivity better than 0.1 nT. We have investigated the potential of such a high resolution magnetic survey for topsoil heterogeneity monitoring on cultivated pseudo-gley soils from marshland of Western France (*Mathé and Lévêque, 2003*; *Mathé et. al, 2006*). The negative magnetic anomaly lineations detected are attributed to local effects of soil compaction, probably induced by the overload under the wheels during soil tillage. Compaction reduces soil aeration and generates local anoxic conditions, which favor iron reduction and, hence, Fe(II) dissolution. This phenomenon has also been observed on forest soil through a chemical approach (*Herbauts et al., 1996*).

The magnetic anomaly approach comprises measurements of both the magnetization induced by the local earth magnetic field, and the natural remanent magnetization. The anomaly intensities of 1 or 2 nT measured are generated by magnetite content variations less than 0.1 mg/kg. Hence, this method allows one to detect magnetic variations with a sensibility greater than magnetic susceptibility measurements.

The question is: is the magnetic anomaly structure observed, specific to pseudo-gley marshland soils, which are considered as an extreme nature of soil (sodic soil with clay content of about 60%)? If this approach could be applied to other kinds of soil, it could be a new tool to evaluate the impact of agricultural practices on physical and chemical soil properties. Indeed, it is estimated that 4% of European soils are affected by compaction and reduction of plough in agriculture practice could reduce this impact.

Different kinds of soil from North-Eastern of France, potentially subjected to compaction (clay content of about 20%) have been studied. The anomaly pictures obtained appear to be noisier than those from marshland soil. Nevertheless, some of them clearly present linear structures similar to those of the first study. In order to search for a periodic linear signal, which would have been generated by plough, spectral analysis has been realized through the correlogram method. Even if it could be difficult for unaccustomed people to distinguish parallel linear structures in the anomaly picture, all the correlograms of the cultivated soils studied clearly demonstrate the existence of such geometric structures. The pseudo-periodic structures brought forward are always parallel to plot limit.

Fig. 1 shows an example of a high resolution magnetic survey. It has been a fallows for almost five years, located some 30 km to the east of Orléans (France). This soil has developed on Quaternary silty clay loam.

Direct modelling based on *Battacharyya and Navolio (1976)* algorithm shows that the main linear magnetic anomalies detected are located in the topsoil directly above the compacted zone. Such an information is in good agreement with the hydromorphy observed directly above the compacted zone. The influence of the high spatial frequency of microtopography variations, which could not be smoothed by the protocol of measurement, appears to be the main artifact in magnetic mapping. For this reason, the state of the soil surface must be as smooth as possible. Hence, the best time for measurement is just before sowing or just after harvesting.

The kinetics of magnetic mineral depletion induced by local anoxia generated by the reduction of hydric conductivity above compacted zone is still unknown. Experimental compaction will be realized on the field plot and the temporal evolution will be observed with high resolution magnetic mapping.

a)

b)

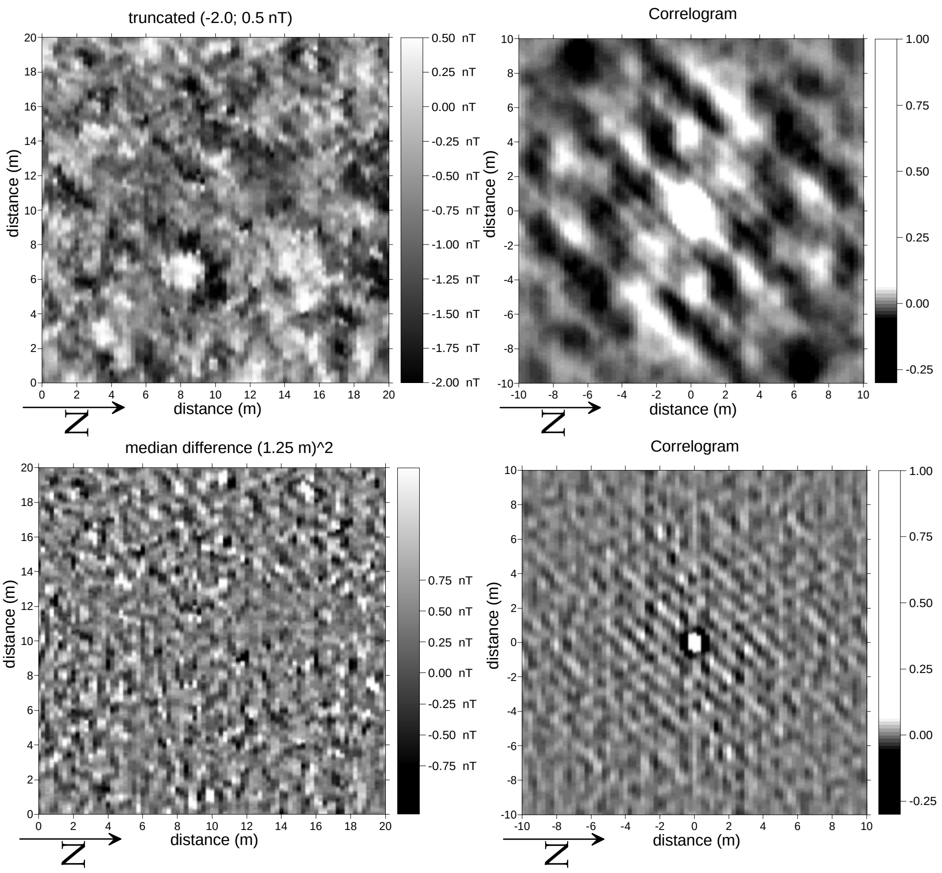


**Fig. 1.** Magnetic anomaly of a follow from South of Paris (France) **a)** Magnetic gradient truncate below –2.0 nT and 0.5 nT on left and correlogram associated on right, **b)** metric background remove by median difference on square of about 1.25 m of side and correlogram associated on right

Rich organic soil, which present a low compaction risk, seems to present weak linear positive magnetic anomalies, which may correspond to direct effect of compaction on density increase and so magnetization.

The results presented suggest that compaction phenomena seem to have a higher extent that usually admitted but the incidence on crop is still to evaluate. Moreover, as natural grasslands are rare, it appear important to know plot use to interpret magnetic soil signature.

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# PRELIMINARY PALEOMAGNETIC DATA FROM THE PALAEOZOIC OF ISTANBUL, W PONTIDES, NW TURKEY

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NW Turkey is a tectonic mosaic of continental and oceanic assemblages, tectonic evolution of which is highly debated. Specifically, two tectonic models were proposed for the origin of the Istanbul Fragment during the Palaeozoic. First model considers the Istanbul Fragment as a Gondwanan fragment that rifted off in Early Palaeozoic, drifted northward and accreted to the Eurasian margin in Late Palaeozoic. An alternative model advocates that the Istanbul Fragment was part of Eurasia during the Palaeozoic but rifted and drifted southward to its present position during the opening of Black Sea in Late Cretaceous period.

During this study, we aimed to test alternative tectonic models by studying palaeomagnetism of Early to Late Palaeozoic transgressive sedimentary succession, known as the Palaeozoic of Istanbul in NW Pontides. The Palaeozoic of Istanbul starts with Early Ordovician continental clastics (red-beds) and passes upwards first to shallow (Silurian-Mid-Devonian) and then into deeper marine clastics and carbonates (Late Devonian to Early Carboniferous). The Palaeozoic of Istanbul was deformed and intruded by granitic intrusions in Late Palaeozoic time. Permian red-beds are thought to unconformably overly the deformed Palaeozoic sediments in the eastern areas. Thus, stratigraphy of the Palaeozoic of Istanbul allows us to detect palaeo-latitudes of the Istanbul Fragment during this wide time period.

The samples were collected at 37 sites. On average, 10-13 cores were collected at each site. Distribution of the sites according to the age is as follows: 16 are collected from Ordovician, 2 from Silurian, 6 from Devonian, 5 from Carboniferous, 7 from Permian. We have applied several field and laboratory tests during this study. The samples were demagnetized using thermal demagnetizer and the results showed stable magnetization.

Our results show that overall, the Istanbul Fragment drifted northwards during the Palaeozoic. We obtained a palaeolatitude of $-23°$ for Early Ordovician. The Istanbul Fragment then drifted northwards to a position of $+12°$ in Silurian and $+30°$ in Devonian. Then a change occurred in drifting direction and the Istanbul Fragment moved to a southerly position ($\pm 8°$) between Carboniferous to Permian period. We think that this was resulted from collision of the Istanbul Fragment with the Eurasian margin in Early Carboniferous time and subsequent strike-slip translation.

This study was supported by Research Fund of Istanbul University, project no:31/03092002.

# A COMPREHENSIVE INTERPRETATION OF MAGNETOSTRAGRAPHIC DATA BASED ON THE PATTERN RECOGNITION TECHNIQUE

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The present paper deals with the dating stratigraphic sections by comparing the polarity of the observed primary NRM with a template provided by the Geomagnetic Polarity Time Scale (GPTS) (cf. *Opdyke and Channell, 1996*).

The processing of the data is running in two main steps: 1. Directions of the primary NRM observed along a section are resolved into polarity zones that can be compared with the polarity intervals given by the GPTS, i.e., not affected by field excursions and short-lived reversals. 2. The polarity zones are identified and the history of deposition is inferred. These steps are described in more details bellow.

1. The distribution of the directions that are considered axial vectors is characterized by the orientation matrix (cf. *Fisher et al., 1987*). Its eigenvector corresponding to the greatest eigenvalue is taken for the principal axis, which is oriented so that the corresponding virtual pole is situated on the northern hemisphere. The directions are classified according to the cosine of the angle they form with principal axis. To begin with, they are divided into two groups, those of positive and negative value of this function, respectively. If the secondary components of NRM were completely removed, the mean directions in these groups roughly coincide with the positive and negative polarities of the principal axis, respectively. Assuming the major part of the directions in both groups to satisfy the Fisher distribution, the concentration parameter in each group is found so as to maximize the significance of the Kolmogorov-Smirnov test; this estimate is less affected by the transient directions, not satisfying this distribution. Finally, the positive or negative polarity is assigned to the directions inside the cones of, say, 99% confidence, while the directions outside these cones are considered transient. The samples of transient polarity being ignored, the polarity zones are defined by the intervals including only the samples of the same polarity, may be except for isolated samples of the opposite polarity.
2. The sequence of the complete polarity zones in the stratigraphic section and that of geomagnetic polarity intervals are equally transformed so as to eliminate the scale effect and shifted each other to achieve their best resemblance indicated by the maximum of their cross-correlation function. The thickness, being known for the moments of polarity reversals, is interpolated by the smoothing spline so that the sedimentation rate is expressed by a continuous, piecewise quadratic function. On the other hand, considering the sedimentation rate a stationary Gaussian random process, we can estimate its parameters by the maximum likelihood method.

The above processing, leaving almost no space for man-made decisions, was implemented into a program, whose exe file is available on the address http://home.gli.cas.cz/man/ along with the tutorial file and examples of the input data.

The program was tested using the data from three different stratigraphic sections located at Brodno, western Slovakia (245 samples, *Houša et al., 1999*), Bosso Valley, Marche, Italy (235 samples, *Houša et al., 2004*), and Puerto Escaño, Andalucía, Spain (227 samples, not yet published), covering the similar time intervals including the J/K boundary. The directions were resolved into sequences of 10, 8 and 8 complete polarity zones, respectively. The age of the sections inferred from the biostratigraphy having been ignored, the polarity reversals were unambiguously identified by the maximum of the cross-correlation function that had been evaluated in a wide range 165 Ma (Middle Jurrassic) to 124 Ma (Early Cretaceous, Fig. 1). A question if these results are representative is to be replied by the mathematical modeling. Considering the length of polarity intervals an uncorrelated gamma-distributed random process and the sedimentation rate a stationary Gaussian random process, the probability of misidentification increases with the variability of the sedimentation rate and decreases with the number of complete polarity zones the stratigraphic section spans. If it spans at least five such zones and includes the complete succession of strata, this probability is negligibly small.

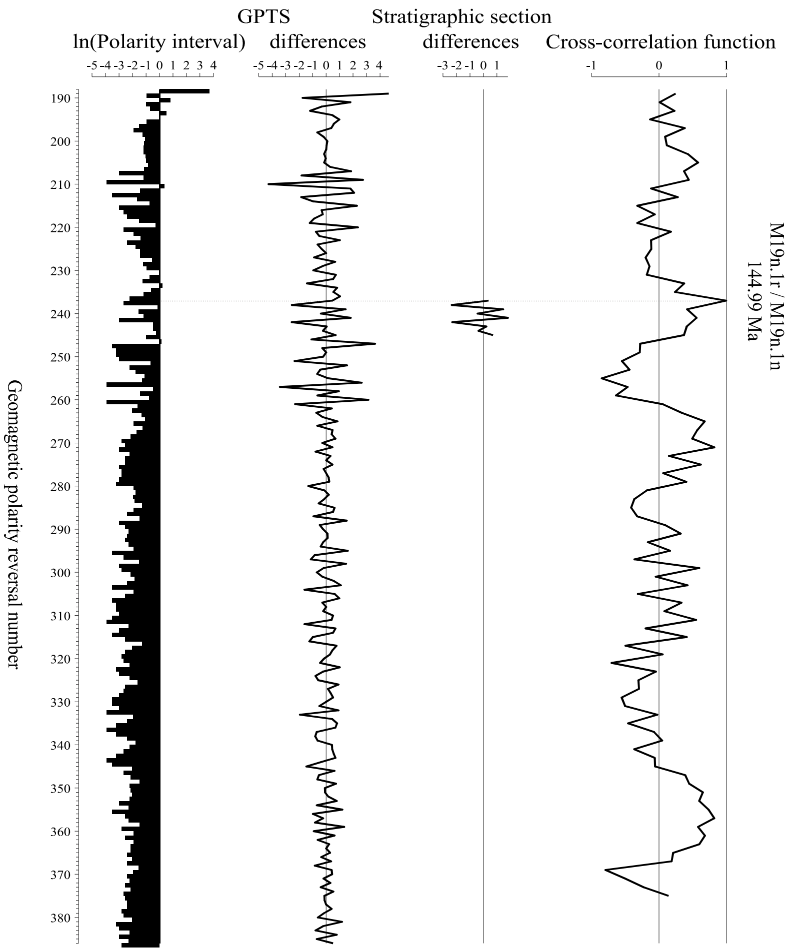


**Fig. 1.** Identification of a sequence of ten complete polarity zones found in stratigraphic section Brodno. The sequence of lengths of the geomagnetic polarity intervals given by *Gradstein et al. (2004)* (on the left) is replaced by the differences of logarithms of its successive terms (the second diagram from left). The terms are numbered back from the present. The sequence of the complete polarity zones is transformed in the same way and shifted (in the middle). The resemblance of both sequences, being a function of the shift, is expressed by the cross-correlation function (right). The figure supports the main thesis raised by the present paper: Though having been modified by the sedimentation rate varying in a wide range, the pattern given by a succession of five or more geomagnetic polarity intervals is so specific that it can be unambiguously recognized.

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# DO WE HAVE A SATISFACTORY LATE CRETACEOUS-TERTIARY STABLE EUROPEAN REFERENCE FRAMEWORK?

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In contrast to mobile Alpine-Mediterranean Europe, stable Europe is seen during the late Cretaceous-Tertiary as a plate sailing majestically towards north without any substantial rotation. In geodynamic interpretation of Tertiary paleomagnetic results from mobile Europe, stable Europe is represented nowadays by paleomagnetic poles compiled by *Besse and Courtillot (1991, 2002)*. The wide acceptance and high practical value of these poles make us to forget that painfully few direct observations from stable Europe were entered into the compilations.

In the course of systematic paleomagnetic studies at the contact between stable and mobile Europe, in Poland and in Czechia, we observed significant Neogene counterclockwise rotations on both sides: rotations were larger in the Western Outer Carpathians (*Tokarski et al., 2006*; *Márton et al., 2006*), smaller, but still significant in the molasse sediments of the Carpathian foredeep. Counterclockwise rotations were also measured in the molasse zone north of the Eastern Alps. As the molasse sediments sit firmly on stable European basement, declinations should have been slightly clockwise rotated. An interesting aspect of the rotations is that they are practically the same for different segments of the Carpathian foredeep and for the East Alpine molasse zone, between the Polish-Ukrainian boundary and the longitude of Salzburg (*Márton et al., 2003*). As the total length of the molasse belt characterized by similar rotations is several hundreds of kilometers and envelopes the southern part of the Bohemian Massif from both sides, the question arose if the Bohemian Massif (or an even larger part of stable Europe) was involved in the rotation.

In order to obtain direct information relevant to the problem, we sampled Neogene sediments from the Bohemian massif and also late Cretaceous ones for comparison. The results are mixed. They mostly show counterclockwise rotation of the same magnitude as sediments in the molasse zone. However, some of the site-mean directions are aligned with expected stable European directions. We are inclined to think that the latter were remagnetized, although there is no proof for it. The indicated counterclockwise rotation of the Bohemian Massif eliminates the problem of a several hundred km long molasse belt rotated with respect to its basement, but obviously creates a new one. This is the geography of stable Europe with its widely accepted paleomagnetic reference frame for the late Cretaceous-Tertiary.

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# OLD CONGLOMERATE TEST APPLIED TO A NEW PROBLEM

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Epekés Hill in the Transdanubian Range, Hungary, is a thoroughly studied classic exposure, yet facies interpretation is still debated. The issue is if Upper Triassic - lowermost Jurassic carbonates are regular beds or blocks embedded into the Kimmeridgian–Berriasian limestones. The answer to this question is important for the interpretation of the structural evolution and paleogeography of the Transdanubian Range at the Jurassic-Cretaceous boundary, therefore we decided to contribute to the solution by applying paleomagnetism to the problem.

We tested several regular beds and suspected olistoliths from two artificial exposure. We found that magnetic parameters, like NRM intensities and susceptibilities were distinctly different for Upper Jurassic-Aptian beds of "normal" stratigraphic setting, on one hand, and for suspected olistoliths and a Dachstein Limestone "bed", on the other. The first group was characterized by NRM intensities of 2.1–12.5 mA/m and positive susceptibilities, while the same parameters for the second group were 0.04–0.43 mA/m and negative values, respectively. Despite of low NRM intensities specimens from the second group also provided good demagnetization curves.

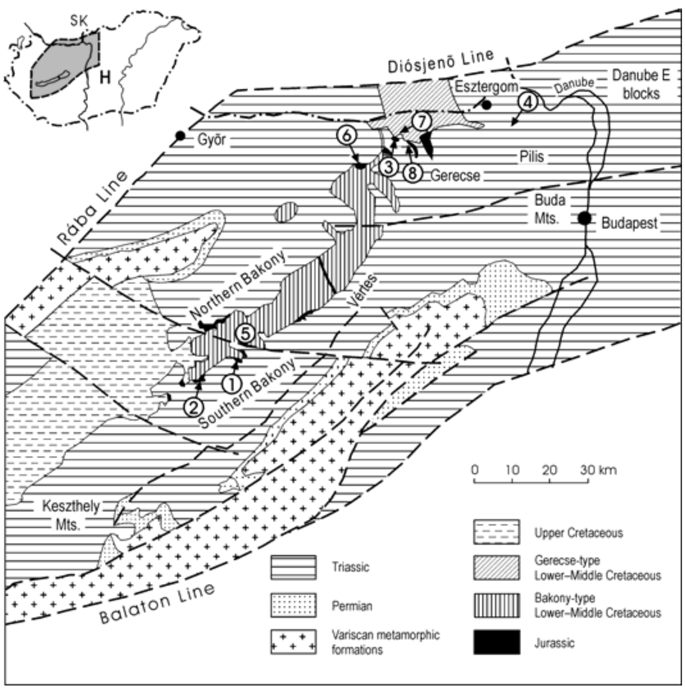


**Fig. 1.** Jurassic - Lower Cretaceous "megabreccia" horizons in the Transdanubian Range: 1. Kericser (Bakony Mts) Sinemurian - Lower Pliensbachian (*Galácz, 1988*), 2. Fenyveskút (Bakony Mts) Upper Bajocian (*Galácz, 1988*), 3. Hosszú - Vontató (Gerecse Mts) Upper Oxfordian - Lower Kimmeridgian (*Bárány, 2004*), 4. Kétágú Hill (Pilis Mts) Upper Oxfordian - Lower Kimmeridgian (*Palotai et al., 2005*), 5. Eperkés Hill, Olaszfalu (Bakony Mts) Kimmeridgian - Middle Tithonian (*Galácz, 1989*), 6. Kálvária Hill (Tata) Kimmeridgian - Lower Tithonian (*Fülöp, 1976*), 7. Asszony Hill (Gerecse Mts) Lower Tithonian and Lower Valanginian (*Bárány, 2004*), 8. Gyökér Valley (Gerecse Mts) Lower Tithonian and Lower Valanginian (*Bárány, 2004*).

Site mean directions calculated from the components decaying towards the origin were excellent or good (with one exception).

Beds below and above the suspected megabreccia horizon yielded highly consistent site-mean paleomagnetic directions. In contrast suspected olistoliths exhibited considerable within-site scatter. The scattered site mean paleomagnetic directions (each of them characterized by consistency within the site) in the “megabreccia” horizon is a kind of positive conglomerate test for the Dachstein Limestone occurrences of the Transdanubian Range. This is an encouragement to apply paleomagnetism also to other sections in the Transdanubian Range (Fig. 1) with suspected megabreccia horizons.

*Acknowledgement:* The work was supported by the Hungarian Scientific Research Found (OTKA) project no. T049616.

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# PALEOMAGNETIC INVESTIGATION OF THE IGNIMBRITIC COMPLEXES IN NORTHERN HUNGARY AND SOUTHERN SLOVAKIA

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Ipolytarnóc, the famous site of fossil foot prints of mammals and birds and of subtropic-tropic plants is situated in the Cserhát Upland, close to the Hungarian-Slovak boundary. The landscape in the area is dominated by elongated hills and ridges, not only on the Hungarian, but also on the Slovak side (Cerová Vrchovina Upland). The hills and ridges are built of Oligocene and Miocene sediments and of the products of felsic volcanism, and are topped by Pliocene-Pleistocene basalts.

Paleomagnetic studies of the ignimbritic complexes in Northern Hungary (*Márton and Márton, 1996*; *Márton and Pécskay, 1998*; *Karátson et al., 2000*; *Póka et al., 2004*) and in Southern Slovakia (*Márton et al., 1996*) lead to the definition of the three complexes as paleomagnetic marker horizons, characterized by about 90°, 30° counterclockwise rotation, and no rotation, respectively. The significant differences in declinations of the different complexes are attributed to block rotations affecting the area of the ignimbritic volcanism in the time intervals of 18.5 – 17.5 Ma and 16 – 14.5 Ma, respectively.

Paleomagnetic declinations measured for a number of ignimbritic sites and related sedimentary localities from the Nógrád-Novohrad basin were indeed westerly and about 90°, thus coming up to expectations. However, the few sites from Ipolytarnóc yielded only about 30° westerly declinations (*Márton and Márton, 1996*), suggesting that the ignimbrites there formed after the first Miocene rotation. These paleomagnetic observations were generally regarded as anomalies, as the younger than erlier postulated age caused serious problems for stratigraphic correlation with the rest of the Nógrád-Novohrad basin and also for climatic reconstruction during the Miocene. It was suggested that this "anomaly" was due to local tectonics or to an excursion of the geomagnetic field. In order to decide if the Ipolytarnóc ignimbrites are really younger than earlier thought or their paleomagnetic directions are anomalous, we collected a large number of samples from all the outcrops in the area, also on the Slovak side. Most important outcrops were in a gorge, where the section consisted of three ignimbrite levels separated by intercalated sediments.

The footprint sandstone and sites belonging to the first and second ignimbritic cycles and those not correlated to the "master" section have normal polarity. Some of the latter are quite distant (a few km) from the "master" section, thus are important for demonstration the consistency in space of the paleomagnetic directions. The two sites representing the third cycle have reversed polarity. The average declination calculated from all sites is around 330°.

From the study of a large number of samples which are properly distributed in time and space we have to conclude that the paleomagnetically observed rotation on the Ipolytarnóc ignimbrites prove that the formation age was younger that the first Miocene rotation (between 18.5 – 17.5 Ma) of the Nógrád-Novohrad basin.

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# INCLINATION SHALLOWING IN SCAGLIA ROSSA

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Scaglia Rossa have been a popular target for paleomagnetic investigations since the 1970's. Results obtained for it were rated excellent, due to several reasons, like good demagnetization behaviour (fairly strong NRM intensity) good statistical parameters, tight age control, well-defined tilt, normally positive response to untilting, magnetite as the principal carrier of NRM. In contrast, results from platform carbonates were regarded as inferior, since their extremely weak NRM rarely allowed to produce perfect demagnetization curves and excellent statistical parameters. Nevertheless, platform carbonates could not have been excluded from Alpine-Mediterranean paleomagnetic investigations for they are widespread and represent enormous volumes, especially in the Mesozoic. Renewed effects lead to the recognition that the key to improving the quality of paleomagnetic results for platform carbonates is the careful selection of the material to be sampled.

This strategy worked very well for the Eocene (*Márton et al., 2003*) and more recently we collected new data for the Cretaceous of stable Istria. Simultaneously, we sampled Scaglia Rossa from the foreland of the Southern Alps. As a results of careful laboratory measurements and analysis, we obtained good data sets for both areas belonging to stable Adria. The overall-mean paleomagnetic directions of the two sets agree perfectly in declination, but inclinations are significantly shallower for the Scaglia than for the platform carbonates. The difference can not been explained by the northward shift of the South Alpine foreland with respect to Istria. A more likely explanation is that Scaglia suffered strong compaction while the platform carbonates (due to early diagenesis) better preserved "true" inclinations.

*Acknowledgement:* The field work was financed by Italian–Hungarian Intergovernmental Scientific and Technological project no. I-12/2003 and Croatian–Hungarian Intergovernmental Scientific and Technological project no. HR-18/2004. Additional support was provided by the Hungarian Scientific Research Found (OTKA) project no. T049616.

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# NEOGENE TECTONIC EVOLUTION OF THE CALABRIAN AND GIBRALTAR ARCS: NEW CONSTRAINTS FROM PALEOMAGNETIC STUDIES

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The Mediterranean area shows a large number of unusually narrow arcs, defining an irregular and rather diffuse plate boundary. In particular, the boundary between Africa and Eurasia runs parallel to the North African coast and then turns northward forming the tight arcs of Gibraltar and Calabria, at the western and eastern side of the western Mediterranean, respectively.

The Gibraltar and the Calabrian Arcs show many similarities in their geometry and structure. However, despite the mechanism leading to the formation of the two arcs is similar, deriving from the retreat of the subduction zone in a backarc -trench system, some differences exist, such as the time of formation and the different rotational pattern distribution.

In this talk, we present new paleomagnetic data from the Gibraltar and the Calabrian Arcs. These data confirm that the opposite vertical-axis rotations measured on the limbs of these arcuate mountain belts represent a first-order surface signature of the kinematic evolution of rollback processes. Moreover, our paleomagnetic data are here compared with the numerous paleomagnetic data available in literature and their tectonic implications are discussed in order to give a further contribution to reconstruct the geodynamic evolution of the Calabrian and Gibraltar Arcs from Miocene to present-day.

# MINERAL CHEMISTRY, AND HIGH- AND LOW-T MAGNETIC PROPERTIES AFTER EXPERIMENTS AT DEEP CRUST CONDITIONS ON ALLARD LAKE HEMO-ILMENITE: PERSISTING MAGNETIC MOMENTS RELATED TO NANOSCALE PHASE INTERFACES

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A small specimen from the hemo-ilmenite Lac Tio deposit (AL36b) was subjected to a temperature of 580°C (853K) and pressure of 10 kbar for 30 days to simulate behavior under deep crustal conditions. The sample was jacketed in a powder of its own composition to inhibit oxidation/reduction during the run. Microprobe and transmission electron microscopy (TEM) analyses were made on the starting material and the heated sample. Based on the 1-atmosphere phase diagram, one would predict that this sample with bulk composition “ilmenite 73” (including a geikielite component) would have undergone major resorption and destruction of fine CAF hematite lamellae, yielding a coarse intergrowth of $R\bar{3}c$ hematite of composition ilmenite 38 and $R\bar{3}$ ilmenite of composition ilmenite 84. Contrary to this, the natural ilmenite with composition “ilmenite 98” showed little tendency for chemical change, whereas the natural hematite showed two changes, resorption of small ilmenite lamellae near grain contacts, and an increase in ilmenite content from “ilmenite 14 to 16”, indicating adjustment toward a new equilibrium composition of CAF hematite of about “ilmenite 16”. This contrasting ilmenite and hematite behavior probably relates to steep and shallow phase saturation boundaries, respectively on the diagram. These results may possibly be interpreted as an effect of pressure in broadening the CAF hematite plus $R\bar{3}$ ilmenite 2-phase field, and raising the temperatures of the $R\bar{3}c$ > CAF + $R\bar{3}$ eutectoid, the ilmenite Fe-Ti ordering curve, and the magnetic ordering curve. Such pressure-induced shifts could have significant effects on the depth preservation of remanent magnetization in the crust.

High- and low-temperature hysteresis measurements were made to characterize the nature of the heated material and compare it to the natural starting material. Hysteresis measurements show an increase in magnetic saturation, saturation remanence and coercivity particularly at low temperatures. At temperatures below 40K measurements of AC frequency of susceptibility show a slight dispersion in the data set. This was not observed in the starting material. Above 40K the AC susceptibility measurements are nearly identical. The experimental results support previous work showing a stable hematite-ilmenite intergrowth at crustal conditions (580°C, 10 kbar) where magnetite would be expected to be paramagnetic.

# THE MAGNETISM OF TYPOMORPHIC UKRAINE SOILS IN CONNECTION WITH THE INCREASE IN THE EFFICIENCY OF THE MAGNETOMETRY INVESTIGATIONS

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In the past, soils were accepted only as layer-hindrance at geophysical investigations. But it is not right. The most magnetic types of soils (such as chernozems, grey forest soils, chestnut soils) can be the main source of the anomalous magnetic field of the investigated area, if soils superpose low-magnetic rocks *Sukhorada and Menshov (2005)*. It is a common situation in Ukraine, especially in perspective oil and gas provinces. Thus, the information about magnetic properties of soils is very important not only for ecological geophysics or agrogeophysics (agriculture and pedology) but for geological exploration too. It is a study for relationship between hydrocarbon migration and soil magnetism above oil and gas fields in Ukraine. Interpretation of the low amplitude magnetic anomalies is very important for prospecting of the deposits of diamonds.

For magnetic analyses of the soil cover we use different parameters of magnetic researches and the main ones are as follows: magnetic susceptibility MS (or induced magnetization *Ji*), natural remanent magnetization (NRM), summary and effective magnetization ($J_\Sigma$, $J_{ef}$), the vertical gradient of the magnetic field. The magnetic parameters are measured in the laboratory and under the natural conditions with the astatic magnetometer LAM-24, rock-generator JR-4, cappabridge KLY-2, dual frequency magnetometer MS-2, field cappameters KT-5 and PIMV-2, a special magnetic gradiometer.

The original investigations of the summary magnetization *Sukhorada and Menshov (2004)* and other magnetic parameters are very important. They are basic factors of creating the magnetic anomaly which is generated with a soil cover. And it is only with the summary magnetization that we can estimate the contribution of the soil cover to the formation of the anomalous magnetic field. These parameters are very important for magnetic modelling.

It is necessary to keep information about distribution of magnetic properties of soils at the magnetometry investigations on vertical line (along the soil profiles) and distribution of magnetic properties of soils on lateral (spatial distribution). Just we have to take into account changes of magnetic properties at crossing of different forms of landscapes because of the so-called landscape magnetic anomalies. Geomorphological situation forms appropriate distribution of magnetic properties of soils. Mostly flood plains, ravines, meadows which are characterized with bog, meadaws - hydromorphic soils, forms low values of the magnetic parameters. Their effective magnetization is little. The summary magnetization of the top soil humus horizons (A, B horizons) is approximate to the parent rocks (C horizon) and these soil covers can't to create appreciable contribution of the soil cover to the formation of the local anomalous magnetic field. The similar situation is for the magnetic properties of the soil covers of the alluvial terrace, pine-forest terrace, flood-plain terrace. Soddy pintwood soils, soody soils and soddy-podzolic soils are generally little magnetic. The soil covers of the ground water devides, uplands, high terrace are the most magnetic. Depending on agroclimatic Ukraine zone such as chernozems, grey forest soils, chestnut soils can to create magnetic anomalies closed to 4-8 nT. Such magnetic anomalies (and even less intensive) can be generated for example with oil and gas fields.

Thus, we have examined some cases of the distribution of magnetic properties of soils at the magnetometry investigations on the polluted areas (for ecological geophysics), on the non-polluted areas (for agriculture and pedological investigations) and on the perspective oil and gas provinces of Ukraine. Results of the investigations will be presented.

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# MAGNETIC HYSTERESIS PROPERTIES OF INTERACTING AND NON-INTERACTING MICRON-SIZED MAGNETITE PRODUCED BY ELECTRON-BEAM LITHOGRAPHY

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There is a growing requirement in paleo- and environmental magnetism to understand the relationship between the magnetic signal of a mineral and its grain-size properties. For example, palaeoclimatic information is often revealed by subtle changes in grain-size distribution, while the same grain-size variations can complicate determination of the relative palaeofield intensity from the same sediments.

The relationship between grain size and magnetic signature is highly complex, particularly near size-dependent transitions between different types of magnetic domain state, e.g., single domain (SD) to multidomain (MD), where there is an abrupt change in the magnetic properties. Characterizing the magnetic behavior near these critical sizes has historically been achieved both numerically and experimentally, however, both approaches have their limitations. Numerical models can often be over simplified and limited by available computing capacity. Experimental studies are strongly dependent on the quality and character of the samples. Features which can strongly affect sample behavior are: (1) stoichiometry, (2) shape and width of grain-size distributions and (3) spatial distributions of the magnetic particles. Closely spaced grains can give rise to inter-grain magnetostatic interactions, which are known to strongly affect behavior (*e.g., Dunlop et al., 1990*).

Most previous experimental rock-magnetic studies have used powdered samples to investigate grain-size dependencies (*e.g., Day et al., 1977*). Powdered samples commonly have wide grain-size distributions, and are difficult to disperse giving rise to high-levels of magnetostatic interactions even when distributed in a non-magnetic matrix. This dispersion problem is particularly common for small SD or pseudo-single domain (PSD) grains, which have a tendency to ‘clump’. The wide grain-size distributions and magnetostatic interactions associated with powder samples make it difficult to quantify the ‘true’ grain-size dependency for non-interacting grains.

In the last 10-15 years it has been possible to produce samples with two dimensional arrays of identically sized particles and controlled spatial distributions using various electron beam lithographic (EBL) techniques. EBL uses an electron beam writer to create patterns on thin films, and produces samples with very tight grain-size distribution and controlled/known spatial distributions. Although many EBL studies have been made, only one study has produced magnetite (*King, 1996*; *King et al., 1996*; *King and Williams, 2000*), arguably the most important geological magnetic mineral.

In this paper we report the magnetic hysteresis behavior of six micron magnetite particle arrays produced using EBL by *King (1996)*. In addition to standard magnetic hysteresis parameters coercive force, remanent coercive force, saturation magnetization and the saturation remanence needed to produce “Day plots” (*Day et al., 1977*), we report first-order-reversal-curve (FORC) diagrams for these well-defined samples.

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# REALISTIC INTERPRETATION OF MAGNETIC AND PALEOMAGNETIC RESULTS OF BASALTS FROM SOUTHERN SLOVAKIA (WESTERN CARPATHIANS)

OTO ORLICKÝ

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Basalts of the Pleistocene to Quaternary age from 38 localities were studied. It is interesting that basalts from 33 localities (87%) were originally magnetized reversely and only rocks from 5 localities were of normal polarity. It has been shown that basalts with a different Fe-Ti compositions (different $T_c$) have different magnetic properties, including the stability and the direction of the remanent magnetic polarization (RMP).

- Basalts with dominantly nearly-stoichiometric magnetites have high magnetic and directional stability and only normal polarity of RMP. Basalts of only 4 localities belong into this group.
- Basalts with primary Ti-rich Ti-Mt-es: these Fe-Ti minerals are not characterized by thermodynamically stable domain structure. They are probably of a superparamagnetic-like (SP) nature. In contrast with high portion of softly magnetic ulvöspinel (68–70%) in Ti-Mt, its bulk magnetic susceptibility ($\kappa$) is relatively very hihg. These basalts acquired originally relatively low self-reversed intensity of RMP, probably of the thermo-viscous origin, with the low magnetic and directional stability. Dominant proportion of such basalts was widely displaced at the beginning of basaltic activity in the investigated area.
- Basalts with the low-temperature oxidized Ti-Mt phases were developed very heterogeneously in the area or in different parts of basaltic bodies. The samples have regularly lower, sometimes extremely lower values of $\kappa$ compared to the unoxidized samples. Stability and the reversed directions of RMP are similar to those of unoxidized rock samples. Classical domain structure did not develop in the rocks below about 150ºC during low-temperature oxidation. In such types of basalts, direction of original reversed RMP was mostly preserved.
- Basalts containing high-temperature oxidized Ti-Mt phases (in the neck, dykes and large domatic volcanic bodies). Cooling of magma, from which such bodies were formed, might take longer time. It may result in the high-temeprature oxidation of part of the Ti-Mt. The original Ti-Mt were partly oxidized, part of them were preserved in its original form. In such types of basalts, the original Ti-Mt were partly oxidized also by the low-oxidation process. Magnetic component with the high-temperature oxidized magnetic phases carries normal RMP. Very large deviation of the direction of RMP is evident in the basalts with both original and the high-temperature oxidized magnetic phases. In a large basaltic neck of Šomoška locality, the two dominant magnetic phases are present. One phase with a primary Ti-rich Ti-Mt is a source of high values of $\kappa$. The second phase originated due to high-temperature oxidation of original Ti-rich Ti-Mt. Thermo-remanent magnetization (TRM) of normal polarity was acquired during cooling of the basaltic magma in the geomagnetic field. Third titano-maghemite phase also developed, and acquired only normal-polarity RMP. Many samples from the Šomoška locality show high values of NRMP. This behaviour is typical for high-themperature oxidized primary Ti-Mt with a presence of low-temperature oxidized phases.
- Basalts with the remagnetized Ti-Mt magnetic phases had originally Ti-rich Ti-Mt and self-reversed RMP. Now they have normal or anomalous direction of RMP. The secondary Fe-Ti magnetic phases of high $T_c$, near to stoichiometric magnetite with stable domain structure were developed during re-heating of original volcanic material in the field. A new remagnetized component with the normal polarity and direction of RMP, corresponding to normal-polarity geomagnetic field, was created during this re-heating process. The resulting direction of RMP of the respective basalts is the vector summ of this newly magnetized part of Fe-Ti oxides and that of original reversed RMP in the basalts. Very importan aspect of this re-heating process is creation of new, frequently very intense RMP. This magnetization is dominantly of a viscous origin (VRMP), or a combination of a VRMP, chemical CRMP and TRMP, of normal polarity.
- Basalts containing dominantly the Ilm-Hem solid solutions of 11 localities belong into the relatively large lava flow with the radiometric age of about 1.16 to 1.6 Ma. The large lava flow was probably formed from the hot more oxidized magma. The Ilm-Hem (with about 15% of Ilm) originated from the original Ti-Mt during ascending of hot magma on the Earth's surface. The rocks of all localities have exclusively reversed RMP. Generally there is better magnetic and directional stability of RMP of basalts with the Ilm-Hem associations, compared to Ti-Mt bearing rocks. Radiometric ages of some basalts are available, but because the correlation between the age of remanence and the age of rock is uncertain, their application is supposed to be problematic.

# MAGNETIC HYSTERESIS PROPERTIES OF HEMATITES

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Room-temperature hysteresis loops were measured for submicron hematite powders with grain sizes between 0.12 and 0.52 µm and on 2 to 5 mm natural hematite single crystals. The maximum field of 1.5 T was not sufficient to saturate the magnetization of the submicron SD hematites. Their hysteresis loops did not close. Bulk coercive forces $H_c$ ranging from 140 to 670 mT were determined from the unsaturated loops but the coercivity spectrum extends to fields at least an order of magnitude higher. Shape and *c*-plane magnetocrystalline anisotropies are inadequate to explain these high coercivities. Their main source must be magnetoelastic anisotropy arising from internal stresses. Remanence ratios $M_{rs}/M_s$ for all but one of the SD hematites ranged from 0.603 to 0.805, intermediate between the random-orientation values of 0.5–0.637 for uniaxial (magnetoelastic) anisotropy with an easy plane and 0.75–0.955 for triaxial (magnetocrystalline) anisotropy with an easy plane. An exception is acicular hematite produced from lepidocrocite with $M_{rs}/M_s = 0.5$.

Hysteresis was measured in the (0001) plane for the large single crystals. The loops closed in fields of a few hundred mT. $H_c$ values were between 0.63 and 30.4 mT, an order of magnitude lower than SD values, although the coercivity spectrum again tailed upward to values much higher than $H_c$. Coercivity is determined by the motion of pinned domain walls and is much lower than in the SD case where domains must be bodily rotated. Walls are usually pinned at crystal defects such as multiple twins or dislocations. Saturation remanence ratios $M_{rs}/M_s$ are 0.605–0.895, higher than for the SD hematites because measurements are made within the (0001) easy plane.

Low-temperature hysteresis measurements were made on a mm-size natural single crystal of hematite at selected temperatures from 300K to 20K. The shape of the hysteresis curves showed remarkably different features below and above the Morin transition $T_M$. Above $T_M$, the crystal has typical hematite hysteresis curves. In the vicinity of $T_M$, the loops were slightly constricted, indicating coexisting weakly ferromagnetic (WF) and antiferromagnetic (AF) phases with vastly different coercivities. The hysteresis effects are still observed well below $T_M$, although the crystal is nominally in a purely antiferromagnetic state. The observed low-temperature moment is probably due to a small fraction of spins pinned magnetoelastically by lattice defects. These spins do not participate in the general rotation from the WF *c*-plane to the AF *c*-axis on cooling through the Morin transition of the bulk crystal.

# MAGNETIC PROPERTIES OF THE BALABANLI VOLCANIC UNITS IN BIGA PENINSULA (NW TURKEY)

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The grain size analyses and magnetic measurements are reported for Miocene ignimbrite, andesite and rhyolites collected from Balabanlı volcanic units in Biga Peninsula (NW Turkey). The area is occupied by Late Oligocene and Miocene (*Borsi et al., 1972*) volcanic rocks. According to *Ongur (1973)*, volcanism was in three main center; Ayvacik, Babakale and Behram (Assos). The ignimbrites coming out of the Behram (Assos) volcanic center generated a thick ignimbrite cover in Biga Peninsula, Ayvalik and Midilli. The samples were collected from these ignimbrite formations.

The rock magnetic studies took place at Institute for Rock Magnetism in Minnesota, USA. To determine the magnetic minerals and the grain sizes that causes the magnetization we conducted detailed rock magnetic investigations on 108 samples representing the 40 sites. We have used VSM1 to obtain the hysteresis loops for 40 samples. We have applied 1.25 T magnetic field and obtained the histeresis parameters of $M_s$, $M_r$, $B_c$ and $B_{cr}$. These parameters plotted on Day Plot and the results showed that most of the samples are pseudo-single domain and a couple of multi domains. To obtain the Curie temperatures of 12 geological formations, we have used Kappa Bridge. The curie temperatures ranged from 547°C to 618°C showing that most of our samples contain magnetite and a few maghemite. We determined the low-temperature suseptibilities of each one of the geological formations using MPMS. The results showed the presence of the Verwey transition (low temperature behavior of magnetite) in the cooling curve in most of the samples. As a whole, results show that the Balabanlı volcanic units have a stable magnetic memory convenient for paleomagnetic studies.

The present work was supported by the Research Fund of Istanbul University. Project No. T-579/17032005

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# ROCK MAGNETIC PROPERTIES OF SELECTED LOESS-PALEOSOL LAYERS FROM ROMANIA

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We have investigated four loess-paleosol sections from the southern part of Romania: Costinesti (Black Sea shore), Mircea Voda (central part of Dobrogea), Mostistea (south-eastern part of the Danube Plain) and Turnu Magurele (near the confluence of the Olt River with the Danube River). From each section we sampled the recent soil (S0), the loess deposited during the last glacial (L1), the chernozemic paleosol corresponding to the last interglacial cycle (S1), the loess deposited during the marine isotope stage 8 (L3) and the brown forest soil formed during marine isotope stage 9 (S3). For each sample several rockmagnetic parameters were measured: temperature-dependence susceptibility, thermomagnetic curves, hysterezis parameters ($M_S$, $M_{RS}$, $B_C$, $B_{CR}$), anhysteretic remanent magnetization, frequency dependent magnetic susceptibility, viscous decay coefficient.

Magnetic mineralogy is dominated by low coercivity minerals (*S*-ratio grater than 0.85), with a higher proportion of hematite in loess layers. Temperature-dependent susceptibility curves show that the main carrier is magnetite. Maghematite seems to be present in the recent soils, S0, and in only one of the paleosols S1. Its presence is suggested by a significant change in slop between 300°C and 400°C. Acording to the model presented by *Dunlop (2002)*, the hysteresis measurements show that both paleosol and loess data are in the pseudo-single-domain region. Loess data are more dispersed and spread toward the SP + SD region. Indication about the presence of SP fraction in paleosols comes mainly from time dependent IRM measurements and from frequency dependent susceptibility. Rock magnetic parameters at room temperature (*Peters and Dekkers, 2003*) show that pedogenetic processes has changed the main population of magnetite grains from relative coarse crystals in loess layers, in the range SD-MD, to a dominant population with fine crystals in the SP-SD range. Magnetic parameters indicate that domain state have smaller variation inside paleosols than in loess layers.

There are only minor differences between rockmagnetic properties of the loess layers. The same is true for the paleosol layers or between the chernozemic paleosol S1 and the brown forest paleosol S3. All the results point toward a dominant climatic control for the variation of concentration dependent parameters (magnetic susceptibility, isothermal remanent magnetization or anhysteretic remanent magnetization).

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# ROCK MAGNETISM OF MESOPROTEROZOIC GRANITIC PEGMATITES (1.8GYR) FROM S-FINLAND: MAGNETITE BEARING FERROTAPIOLITES ($FETA_2O_6$) AS A MAGNETIC RECORDER?

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## Background

Testing of the Proterozoic supercontinent assembly with paleomagnetic data requires well defined apparent polar wander paths (APWP) for each continent. In the Fennoscandian APWP there is a pronounced gap between 1840–1650 Ma. Granitic pegmatites emplaced during this interval may provide data to this gap since they can be accurately dated using radiometric methods and there exist numerous such dykes in Fennoscandia. Pegmatites have traditionally been neglected due to their magnetic instability. Preliminary paleomagnetic data of pegmatites from SW Finland were presented by *Pesonen et al. (1999)*. The first case comes from pegmatite dykes from Somero with an U-Pb zircon age of 1731 ± 15 Ma. The Kemio pegmatite dykes are the second case, with U-Pb ferrotapiolite ages ranging from 1807.0 ± 2.9 to 1802.9 ± 1.3 Ma. The most reliable results come from the aplitic parts of these pegmatites. Rock magnetic studies reveal that the occasionally very hard NRM is probably due to ferrotapiolite $(Fe,Mn)(Ta,Nb)_2 0_6$ and/or to hematite. The remanence of the pegmatites is complex showing multi-component and frequently dual-polarity NRM. The magnetic record often is very hard, thermal demagnetization usually is more successful than AF demagnetization.

## Samples and experiments

We have studied rock samples from several pegmatitic dykes in SW Finland as well as a mm sized ferrotapiolite crystals from the same dykes. In addition, a powdered sample was obtained by crushing rock samples and performing magnetic extraction. These ferrotapiolites could be directly dated to 1.7–1.8 Gyr as they contain some U. For parallel investigations the same experimental setup was used for ferrotapiolites from pegmatitic dykes from Minas Gerais, Brasil (large crystals and crushed samples). The following set of investigations was performed on all specimens: NRM/AF-demagnetization, ARM and IRM experiments followed by AF-demagnetization, hysteresis measurements including IRM-acquisition and DC demagnetization, thermomagnetic measurements (magnetic susceptibility, MS) between liquid $N_2$ temperature and 700°C, frequency and field dependence of MS, low-temperature experiments between 1.9 and 300 K (zero-field and field cooling of IRM, IRM acquisition at ± 5 T at 300 K and 1.9 K). Optical microscopy and SEM/EDX was done on polished sections.

## Results

Ferrotapiolite belongs to the tapiolite mineral group and is a Fe-rich component with an average chemical formula ($Fe^{2+}$, $Mn^{2+}$) $(Ta, Nb)_2$ $O_6$. The mineral belongs to the tetragonal crystal system and is often found in granitic pegmatites together with some other rare oxides such as tantalites (*http://webmineral.com/data/ferrotapiolite.shtml*). Presently the knowledge about the magnetic properties of the ferrotapiolite is very poor. A neutron diffraction study (performed at 4.2 K) suggests that the mineral is ferrimagnetic at very low temperatures, the Néel-temperature was estimated to about 13–14 K for stoichiometric ferrotapiolite (*Weitzel and Klein, 1974*). Consequently ferrotapiolite is paramagnetic at room-temperature and cannot carry any magnetic record. The results of all our experiments with various types of magnetic remanences (NRM, IRM, ARM) indicate the presence of a stable and hard magnetic remanence at room-temperature which can be removed only partly using AF-demagnetization. Thermal demagnetization gave blocking temperatures in the

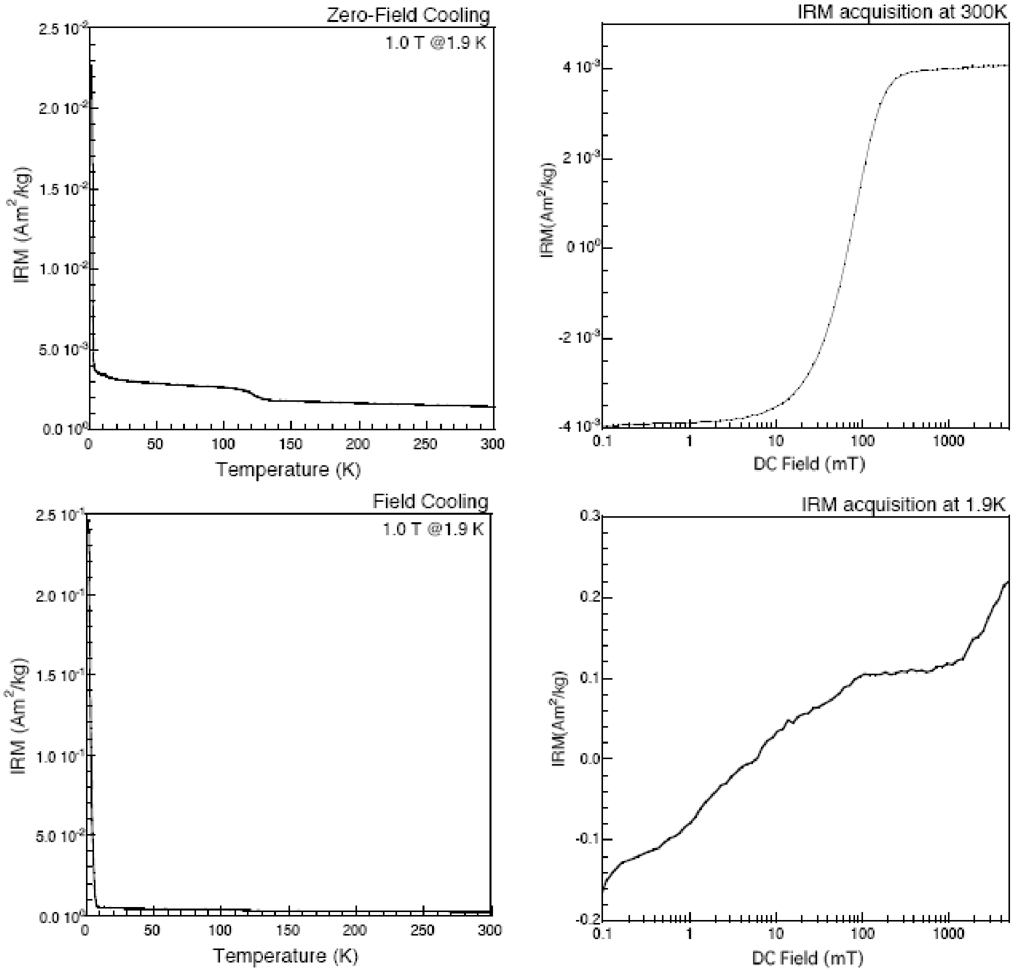


**Fig. 1.** Very low temperature investigations on ferrotapiolite magnetic extract: (a, left up): zero-field cooling, (b, right up): IRM acquisition at 300 K, (c, left down): field cooling, (d, right down) IRM acquisition at 1.9 K.

range of 400, 600 and up to around 700°C which suggests magnetite-maghemite like and maybe hematite phases as remanence carriers. Hysteresis, IRM acquisition and DC backfield demagnetization data point towards PSD-range magnetic recorders. Thermo-magnetic curves at high and low temperatures show the presence of magnetite and hematite-like phases. By the very low temperature experiments with MPMS between 1.9 and 300 K transitions around 120–130 K and around 7–10 K were detected of which the first can be interpreted as due to the Verwey transition of a magnetite-like phase. Below 7–10 K a very strong magnetism was found. This transition is attributed to the Néel temperature of the ferrotapiolite (Fig. 1a–d).

The results of our magnetic investigations indicate that very tiny exolution of substituted magnetite phases in a paramagnetic ferrotapiolite matrix could be the carriers of the strong and stable magnetic remanences of the pegmatitic dykes from SW Finland. Qualitative SEM/EDX analyses showed the presence of very small Mg-Mn substituted magnetite particles (sizes of sereval 100nm up to few microns) in a ferrotapiolite matrix (average composition Fe-Ta-O with some minor contents of Nb, Mn and other elements.

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# FLOW DIRECTIONS OF THE MT. SOMMA (VESUVIO, ITALY) DIKES INFERRED FROM AMS, FIELD AND THIN SECTION ANALYSES

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Defining the propagation path of dikes within an active volcano is crucial to understand its structural setting and eruptive behavior. Somma–Vesuvio volcanic district (Italy) is characterized by the remnants of an older edifice (Mt. Somma), partly surrounding the presently active cone (Vesuvio) in a densely inhabited area. Mt. Somma displays ~100 dikes emplaced between ~18–30 Ka. The dikes mostly have a NNW-SSE to NE-SW strike. The kinematics (direction and sense of flow) of 19 dikes is determined through a combination of field (8 dikes), AMS (Anisotropy of Magnetic Susceptibility) (16 dikes), and thin section analyses (15 dikes). Magnetic investigations have demonstrated that the dikes contain mainly magnetite and titanomagnetite, and titanomaghemite in minor content, as main magnetic carriers. The shape of the AMS ellipsoids ranges from strongly prolate to moderate oblate. The shape changes also within the same dike, if we consider the edge or the inner part of the dike. In most of dikes, the magnetic foliation is parallel to the dike margins and the magnetic lineation is well defined and lies close to the dike plane. The geometric orientation of the magnetic lineation and foliation with respect to the dike plane allows to infer the magma flow direction. In some cases AMS reveal an imbrication of the magnetic lineation with respect to the dike margins, which is used to infer the sense of flow. The preferred orientation of minerals, obtained by optical analysis, was in agreement with the AMS measurements. The results show that thirteen dikes have a vertical upward flow, whereas six have an oblique-subhorizontal flow, suggesting a lateral propagation from the summit or eccentric vents of the former Somma edifice. These propagation paths differ from those deducible from the recent activity, as all the 7 fissure eruptions between 1631–1944 were related to the lateral propagation of radial dikes. We propose that these different behaviors in dike propagation may be mainly related to the open or close conditions of the summit conduit.

# SHALLOW PALAEOMAGNETIC INCLINATIONS FROM HISTORICAL HAWAIIAN LAVA FLOWS - AN INVESTIGATION ON THREE DIFFERENT SCALES

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The historic eruptions of Kilauea and Mauna Loa on the Big Island of Hawaii have provided material for numerous palaeomagnetic analyses. In directional studies, many authors report ambiguously shallow inclinations compared to those extrapolated from the magnetic observatory at Ewa Beach, Oahu and the International Geomagnetic Reference Field (IGRF). Current suggestions for the cause for the deflection of the magnetic direction are the magnetisation of the underlying terrain and the unknown underlying topography, block rotation and flow deformation. We investigated these anomalies using data on three different scales: palaeomagnetic flow data, island-wide magnetometer data, and aeromagnetic and satellite data. We have compiled all the published palaeomagnetic directional data for the historical Hawaiian lava flows and see that inclination is systematically 3º shallower than the global geomagnetic model gufm, which is itself consistently shallower than the IGRF value at the same latitude and longitude over the period 1900–1990 A.D. truncates at polynomial degree 14 and therefore the information lost in the higher order polynomials could explain this shallowing characteristic of recent Hawaiian secular variation. An island-wide magnetometer survey was conducted using a three-component fluxgate magnetometer mounted on a modified aluminium camera tripod. Our ground survey included measurements on historical age palaeomagnetic sites and older flow sites on the Mauna Kea and Kohala volcanoes to ensure good island coverage. The inclination was not found to be systematically shallow at this scale when compared to the IGRF. However, we did see significant effects from topographic features such as cliff edges, road cuttings and gentle slopes as predicted by model calculations. Magnetometer measurements were also taken at three heights (0.5, 0.8 and 1.2 m above the flow surface) and confirmed that magnetic terrain-induced effects are of short wavelength that attenuate quickly. In addition, the ground survey provided an opportunity to assess the amount of scatter seen in the directions. Groups of measurements taken in a tight cluster on one fork of a particular flow gave inclinations that differed by 4 μT to measurements taken on a different fork of the same flow 8km away. Many palaeomagnetic drill sites have limited spatial coverage; our results reinforce the need to take large numbers of measurements across a large area in order to average out any bias encountered at one particular site. Comparisons between the magnetometer survey, downward continued aeromagnetic data and the new CHAMP lithospheric field model will also be discussed.

# PALEOMAGNETIC AND PETROMAGNETIC INVESTIGATIONS ACROSS THE J/K BOUNDARY STRATA: POSSIBILITY OF MAGNETOSTRATIGRAPHIC CORRELATION BETWEEN THE BOREAL AND TETHYAN REALMS

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The principal results of this study were to extend the detailed magnetostratigraphic, investigation of the Jurassic/Cretaceous (J/K) boundary from the Tethyan realm to profile in the Boreal realm. Especially the results from the Tethyan realm carried out at the Brodno (Western Carpathians, W. Slovakia) (*Houša et al., 1999*), Bosso Valley (Umbria, Central Italy) (*Houša et al., 2004*) and Puerto Escaño (Province of Córdoba, S Spain) enable correlation between magnetostratigraphic data. The limestone samples are generally characterized by three components of NRM. Paleomagnetic HTC (C-components) of NRM were reliably inferred for most of the limestones after thermal demagnetization in the range of 420 (440)°C to 540 (580)°C. Progressive thermal demagnetization employing a MAVACS apparatus proved to be very effective. The unblocking temperatures of between 540 to 560°C suggest the presence of magnetite. A few samples also exhibited a small fraction of a mineral with an unblocking temperature below 680°C, evidently due to a small admixture of hematite. The study detected and precisely defined two narrow reverse subzones inside magnetozones M20n and M19n in all of the Tethyan sections studied. At the locality of Brodno, the transition from N (R) to R (N) polarity of the Earth's paleomagnetic field was inferred indicating the duration of transition within a time interval of ± 5 ka. All the magnetozones and subzones are well correlated with the M-sequence of marine magnetic anomalies, thereby providing a high-resolution magnetostratigraphic data across the J/K boundary in the Tethyan Realm. The localities in the Tethyan realm at Brodno (Slovakia), the Bosso Valley (Italy) and at Puerto Escaño (Spain) provided very detailed to high-resolution magnetostratigraphic data across the J/K boundary.

The Boreal Realm studies were to carry out on the suitable continuous J/K which is located in the north of Siberia on the Nordvik Peninsula, cape of Paksa, eastern shore of the Anabar bay. The section consists predominantly of marine black shales with abundant concretions and several diagenetically cemented layers. The natural remanent magnetization was investigated to establish a magnetostratigraphy. Progressive alternating field (AF) demagnetization, up to the maximum field of 100 mT, was performed with a 2G Enterprises degausser system in the Geological Research Centre, Potsdam. After the AF treatment, all samples were successfully demagnetized usually to less than 1% of the original NRM value. Two stable components of the NRM were isolated where the high-field component is regarded as the characteristic remanent magnetization (ChRM). Both magnetic polarities are present for the high coercivity ChRM, and this group represents approximately 85% of the whole sample set from the studied section (*Chadima et al., 2006*). The detailed magnetostratigraphic and biostratigraphic investigation of the Nordvik section (27 m) precisely determined the boundaries of two reverse magnetozones (M18r, M19r) including two reverse subzones M20n.1r in M20n, and M19n.1r in M19n, and established a correlation between magnetostratigraphic data (reflecting global events) and the Boreal ammonite zonation. It is shown, that using magnetostratigraphy together with micro- and macropaleontological methods, the Boreal and Tethyan Jurassic/Cretaceous (J/K, 145.5 ± 4.0 Ma) boundary strata were successfully correlated for the first time.

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# 30 YEARS OF MAGNETIC SUSCEPTIBILITY MEASUREMENTS ON THE DANUBE DELTA LAKE SEDIMENTS (ROMANIA, 1976–2006). SEDIMENTOLOGIC APPLICATIONS TO ENVIRONMENTAL MAGNETISM

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The magnetic susceptibility (MS) investigation of the lake sediments started in Romania in 1977, during a complex scientific cruise, carried out in the Razim (Razelm) – Sinoie lagoonal Complex (RSLC). The first MS tests were performed on the ship board, using a KT-3 kappameter, directly on the bottom sediments sampled in two lakes (i.e., L. Golovița and L. Sinoie) of the lagoonal complex. The sediment sub-samples were subsequently measured in laboratory, using a Kappabridge KLY-1. A collection of bottom sediments, sampled in 1976 in the Lake Razim (RSLC), was investigated in laboratory, thus, completing the MS information in the mentioned lagoonal area. In 1978, sediments from the forth main lake of the RSLC (i.e., L. Zmeica) were sampled and the MS measured. Simultaneously, the MS study of the bottom sediments from the Danube Delta interdistributary depressions (lakes, channels and canals) began. In 1983, the first stage of the MS investigation of the Danube Delta and the RSLC lake sediments was actually finished. The MS results, as a part of the integrated geological–biological–geophysical studies with specific goals related to the Danube Delta economical potential, mainly demonstrated the quality of the measured magnetic parameter as sedimentogenetic index in areas covered by water. Yet, the environmental context was implicitly recorded. The enviromagnetic signatures printed in the lake sediments were later recovered, and used in the second stage of the research, when geoecological aims were explicitly stated in the framework of a complex monitoring, started in 1992. This is still going on, and up-to-date MS results are presented in the article. Since 1995, the MS measurements have been performed by the KLY-2 Kappabridge. Some „case-studies" and/or „history cases", based on hundreds of MS measurements carried out before (i.e., in the 1976-1982 period) and after (i.e., in the 1987–2006 period) the aggressive human intervention in the Danube Delta ecosystems, are given. The validity of the *Verosub and Roberts (1995)* statement, i.e. „many types of studies that are now classified as environmental magnetism have been in existence for some time", is clearly proved and illustrated by examples in the paper. A series of articles and their chronology support this remark (e.g., *Mihăilescu et al., 1981, 1983*; *Rădan and Rădan, 2004*).

Another aim of the paper is to present a series of methodological, instrumental and conceptual problems related to the developing of the use of magnetic techniques in the aquatic area, particularly in the Danube Delta - Danube River - Northwestern Black Sea geosystem. So, the spatial frame in which there have been obtained MS data is enlarged in the paper presentation, as compared with the region in which the MS investigation has extended along three decades, a performance emphasized by the authors from the very beginning. On the other hand, the aspect regarding the magnetic methods that were applied and/or experimented in the above mentioned area must be revealed. The diversity of that area exceeds the limits suggested by the article's title that are defined by the MS measurements only. A schematic diagram supporting these and other aspects is given in Fig. 1.

The authors use instead of conclusion a paraphrase to an assertion of Oldfield (1991), i.e. the Danube Delta lake sediments provided the initial impetus for the development of environmental magnetism in Romania.

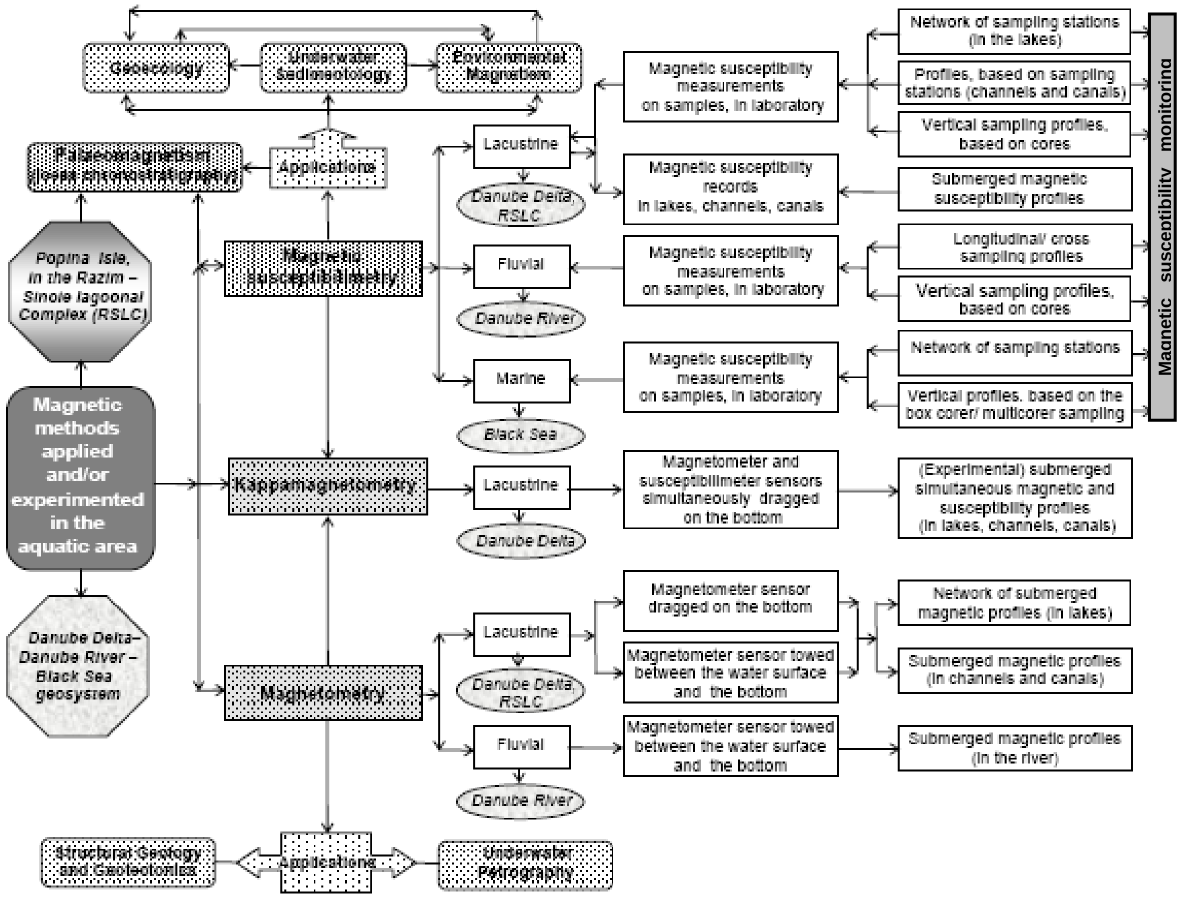


**Fig. 1.** Schematic diagram showing the magnetic methods applied and/or experimented in the aquatic area, particularly in the Danube Delta–Danube River–Northwestern Black Sea geosystem.

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# A MAGNETIC SUSCEPTIBILITY SCALE WITH A LITHOLOGICAL SUPPORT ORIGINATED IN THE LAKE SEDIMENTS FROM THE DANUBE DELTA AND THE RAZIM – SINOIE LAGOONAL COMPLEX (ROMANIA). AN ENVIRONMENTAL AND GEOECOLOGICAL APPROACH

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Magnetic susceptibility (MS) research carried out in Romania, since 1977, are based on the measurements by the KLY-1 and KLY-2 Kappabridges on thousands of bottom sediment samples collected from deltaic, fluvial-deltaic, lagoonal, fluvial and marine environments of the Danube River - Danube Delta - Black Sea geosystem. The acquired data have demonstrated that the MS ($\kappa$) values mainly reflect the lithological variations of the deposits. On the other hand, the results have shown that the $\kappa$ values can reveal in the finer sediments the metallic contamination levels; the most important of these are clearly evidenced by high magnetic susceptibilities. Taking into consideration the noticeable connections between the $\kappa$ values, measured in the laboratory, and the lithological description of the bottom sediment samples (which were first completed aboard the ship and which were later confirmed by the granulometric and mineralogical analyses), a data sorting based on several susceptibility classes was feasible. It must be emphasized that for the Danube Delta and the Razim (Razelm) - Sinoie lagoonal Complex (RSLC) area, more than 2000 values have been measured. In the first stage, three $\kappa$ limits related to certain lithological types of bottom sediments have been identified. They subsequently became "magnetic susceptibility classes". Particularly, the first two "basal classes" were defined by $\kappa$ values lower than $10 \times 10^{-6}$, and lower than $75 \times 10^{-6}$, respectively; another class ("upper"), generated by elevated $\kappa$ values, has initially been suggested by the values higher than $200 - 300 \times 10^{-6}$ (*Rădan et al., 1996*). In the following stage, 5 "magnetic susceptibility classes" have been established. The first applications of the "$\kappa$ scale" (Table 1a) concerned the calibration of the bottom sediments that have been investigated in the framework of the geoecological monitoring phases carried out in the Danube Delta and the RSLC during 1995 and 1996 (*Rădan et al., 1997*). When the enviromagnetic method was applied to the main Danube Delta Branches, the use of the $\kappa$ scale from Table 1a to calibrating the sedimentary systems from the fluvial-deltaic environments, which are defined by sandy deposits with variable grain size, led to the necessity of subdividing the last ("upper") class (V; Table 1a) into 4 sub-classes: Va, Vb, Vc and Vd (Table 1b).

The lower classes (i.e., I and II) correspond to the fine sediments, usually rich in organic material and/or carbonates, the intermediate class III is characteristic for the fine clayey up to silty sediments, and the higher classes (i.e., IV and V) are commonly recorded for the coarser silts and sands.

An example is given in Fig. 1, where the pattern integrates - through the $\kappa$ classes (Table 1b) - all the $\kappa$ values (over 2000) that have been used for characterisation of the bottom sediments in the Danube Delta, its main Branches, as well as in the Razim - Sinoie lagoonal Complex (their location, in Fig. 1). A comparative

**Table. 1.** Magnetic susceptibility scales used for calibrating the lake sediments of the Danube Delta and the Razim - Sinoie lagoonal Complex (Romania). **a)** first version; **b)** version in use (the class **V s**ubdivided).

| Magnetic susceptibility scale | | | |
|---|---|---|---|
| a) | | b) | |
| Class | $\kappa$[SI] | Class | $\kappa$[SI] |
| V | $> 275 \times 10^{-6}$ | Vd | $> 1000 \times 10^{-6}$ |
| | | Vc | $675 \div 1000 \times 10^{-6}$ |
| | | Vb | $575 \div 675 \times 10^{-6}$ |
| | | Va | $275 \div 575 \times 10^{-6}$ |
| IV | $175 \div 275 \times 10^{-6}$ | IV | $175 \div 275 \times 10^{-6}$ |
| III | $75 \div 175 \times 10^{-6}$ | III | $75 \div 175 \times 10^{-6}$ |
| II | $10 \div 75 \times 10^{-6}$ | II | $10 \div 75 \times 10^{-6}$ |
| I | $< 10 \times 10^{-6}$ | I | $< 10 \times 10^{-6}$ |

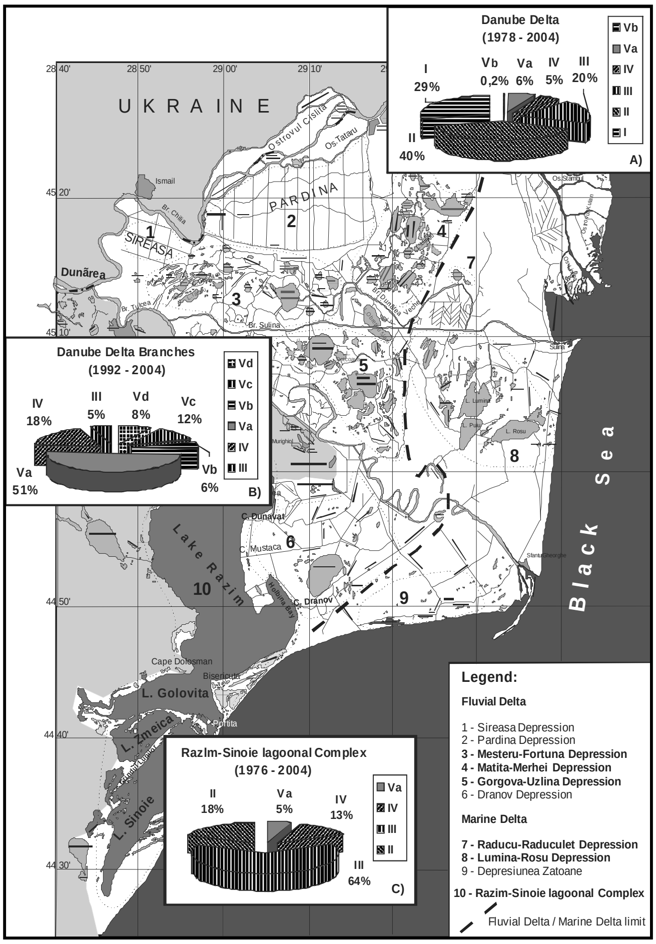


**Fig. 1.** Magnetic susceptibility characterisation, based on percentage distribution of the $\kappa$ values (according to the correlation to the $\kappa$ scale classes), for the bottom sediments of the Danube Delta (A; 3, 4, 5, 7 and 8), Danube Delta Branches (B) and the Razim - Sinoie lagoonal Complex (C; 10).

analysis of the percentage weight distribution of the $\kappa$ values that characterise the sedimentary deposits from the deltaic, fluvial-deltaic and the lagoonal aquatic environments is done. Moreover, there are other cases which exemplify the way the elaborated and experimented $\kappa$ scale works (*Rădan and Rădan, 2004*).

Finally, the correlation of the $\kappa$ scale to the geochemical scale that has previously been used for the sediment quality evaluation within the Danube Delta water system, as well as to the scale with the normative definitions of the ecological status classification is pointed out.

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# MAGNETIC PROPERTIES OF HYDROCARBON CONTAMINATED SOILS: FIRST DATA FROM LABORATORY AND FIELD STUDIES

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A correlation of magnetic parameters with the presence of hydrocarbons in soils was demonstrated in several studies (*Morris et al., 1994*; *Hanesch and Scholger, 2002* and *Aldana et al., 2003*). Soil microorganisms can play a significant role for the transformation of iron minerals in the presence of hydrocarbons (*Lovley et al., 1989*). Our study aims to investigate the change of magnetic properties of hydrocarbon-contaminated soils, both in natural field conditions and in laboratory batch setups simulating hydrocarbon contamination.

The laboratory study is being performed in batch experimental setups using about 15 g of surface soil, suspended in 5 ml of a bacterial growth medium, and kept at 30°C. The setups vary in soil type, soil microbiology (sterilized, untreated, addition of iron-metabolizing bacteria) and substrate addition (lactate-acetate mixture, low and high concentration of diesel and unleaded petrol). The experiments are planned for several months to monitor changes in magnetic mineralogy under the influence of geo-microbiological processes and hydrocarbons. Weekly monitored magnetic susceptibility data, magnetic characterization of untreated soil and final products will be compared at the end of the experiment. After four weeks of monitoring, it seems that there is a slight increase of magnetic susceptibility with time in several of the non-sterilized experimental setups.

The study areas with natural oil outcrops are located at the former oil fields Wietze and Hänigsen in Northern Germany. Oil has been exploited for more than 400 years in small scale by collecting it from 1 to 2 m deep pits. The study areas consist of sandy soils with sections which are contaminated with hydrocarbons. Therefore, the hydrocarbon-induced changes of magnetic properties of the contaminated soils can be discriminated from clean soils. The initial measurements of magnetic susceptibility show moderately increased values in the hydrocarbon-polluted soil.

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# CHEMISTRY, EVOLUTION AND MAGNETIC PROPERTIES OF HEMO-ILMENITE, ALLARD LAKE, QUEBEC: A CASE FOR LAMELLAR MAGNETISM

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In 1959, R.B. Hargraves worked on hemo-ilmenites from Allard Lake, Quebec and later returned with great interest to these samples in relation to the concept of magnetism related to exsolution. Because the hemo-ilmenite ores produce large negative magnetic anomalies that can only be modeled with a significant remanent component, he saw that they are good analogs for the Martian magnetic anomalies. Ore samples typically have MDFs $\gg 100$ mT, well above fields required to demagnetize magnetite. The hysteresis properties vary significantly with presence or absence of minor magnetite. Magnetic saturation (*Ms*) values range from 620 to 23500 A/m, coercivity (*Hc*) from 3.7 to 169 mT, and the coercivity of remanence (*Hcr*) from 4 to 247 mT. The large range in ratios of magnetic saturation of remanence to *Ms*, from 0.062 to 0.842, and *Hcr*/*Hc* from 1.1 to 11.5, reflect the mineralogy, the domain sizes, and the magnetic characteristics of the exsolution lamellae. The production of the lamellae and lamellar interfaces by exsolution is believed to produce a defect ferrimagnetism. It results in a chemical remanent magnetization (CRM) that we call lamellar magnetism. Thermoremanent magnetization (TRM) experiments made by Hargraves years earlier showed the TRM of Allard Lake samples to be far lower than the NRM, supporting a CRM mechanism for the NRM, such as lamellar formation.

In order to gain greater understanding of the many properties of Allard Lake hemo-ilmenite, we made a concentrated study on sample AL36b from the Lac Tio deposit using SEM and TEM images, EMP and TEM chemical analyses, Mössbauer spectroscopy, and high- and low-temperature magnetic experiments. This sample was chosen because all evidence showed it was free of magnetite that does occur in some Allard Lake samples, and would thus yield clear information of properties purely related to the hematite-ilmenite solid solution. The host mineral is ilmenite and the coarsest lamellae are hematite up to ~ 40 µm thick. Exsolution lamellae of hematite and ilmenite continue down to the nanometer scale. Most small lamellae are fully coherent, which could enhance coercivity.

EMP and TEM analyses of the margins of ilmenite host areas close to the coarse hematite lamellae gave close to end-member compositions and are consistent with TEM images showing that the ilmenite is for the most part free of very fine hematite exsolution, although it does occur in restricted locations. By contrast there is a several percent difference of “ilmenite” content in EMP and TEM analyses of the margins of hematite lamellae indicating that all areas accessible to the probe beam contain fine ilmenite exsolutions. This is confirmed in TEM images showing ubiquitous ultrafine ilmenite exsolution.

Sample AL36b was characterized in magnetic experiments and Mössbauer spectroscopy at room *T*, and low *T*. A nearly reversible thermomagnetic run made in a field of 1 T from room temperature to 650°C showed one discrete Néel temperature at 610°C. Frequency and temperature dependence of AC susceptibility were measured for seven frequencies from 0.1 to 1000 Hz in the temperature range of 10–300 K with an MPMS. A sharp peak, lacking frequency dependence, occurs at 40 K, indicating the two-layer magnetic ordering temperature of magnesium-doped near-end member ilmenite. This is confirmed by a typical ilmenite magnetic sextet in Mössbauer spectra at and below 40 K. Absence of a frequency-dependent peak at the higher expected temperature for insipient one-layer ferromagnetic ordering, leading to superparamagnetic behavior, is thought to be due to the nearly $Fe^{3+}$-free ilmenite composition.

Some authors favored a magnetization in these samples carried by the large ~ 40 µm thick multidomain lamellae of hematite, but failed to take proper account of the ilmenite-hematite phase diagram. The first coarse generation of titanohematite lamellae, produced from composition “Ilm 72.5” around 700°C, if not further exsolved, would be paramagnetic until ~ 225°C. However, with further exsolution of ilmenite lamellae, the Ti-depleted paramagnetic hematite can reach a eutectoid reaction near 525°C, below which the stable assemblage is canted antiferromagnetic (CAF) hematite with ilmenite. Either stable exsolution or rapid precipitation following metastable undercooling below the eutectoid, produces fine lamellar intergrowths with abundant interfaces between CAF hematite and PM ilmenite.

## PALEOMAGNETIC STUDY OF EGYPTIAN CRYSTALLINE ROCKS TO BETTER UNDERSTAND THE GEOLOGIC EVOLUTION OF EGYPT

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The crystalline bedrock geology of Egypt is exposed over more than ten-percent of the surface of the country, and it is rich with a variety of rocks that were formed in various geologic environments. It includes Precambrian-age basement rocks consisting of gneisses, granites, meta-volcanics, meta-sediments, and volcanics, as well as younger post-Precambrian volcanic rocks. Although the geology of the Egyptian crystalline bedrock is generally well described, debate still exists over the geologic and tectonic history captured in the rocks. However, to understand how and when these processes affected the Egyptian basement rocks the timing and style of the geologic events must be known through careful paleomagnetic and geochronologic studies. Unfortunately, few modern geochronologic and paleomagnetic data exist for Egyptian rocks, and for the data that do exist, there are inconsistencies. We propose to conduct a modern paleomagnetic, Paleointensity and geochronology study of the crystalline bedrocks of Egypt.

40Ar/39Ar age and Paloemagnetic study for the Early Paleozic rocks from Wadi Hafafit area, Eastern desert of Egypt will be presented in this study. Detailed rock magnetic investigations including the variation of magnetization with temperature and hystersis loops shows that pseudo single domain (PSD) grain size magnetite is the main magnetic mineral in the studied rocks. Alternating field and thermal demagnetization identify stable and unstable characteristic remanences.

## PALEOINTENSITY DETERMINATIONS OF SOME EARLY PALEOZOIC GRANITE ROCKS FROM SINAI PENINSULA, EGYPT

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New paleointensity determinations of the past geomagnetic field in Egypt are presented in this paper. We have collected oriended granite samples from 11 sites in Saint Chatrina area in Sinai Peninsula and subjected to rock magnetic and ore microscopic investigations. The rock magnetic properties such as Curie temperatures and hystersis parameters as well as microscopic observations point to magnetite as the main carrier of the remanent magnetization. According to the rockmagnetic properties, suitable samples were selected for the application of the Thellier-Thellier paleointensity method. A total of 55 granite specimens from 11 locations of Early Paleozoic age (590 M.Y) were analyzed and yielded 34 successful paleointensity determinations improving the paleointensity data base of Early Paleozoic. As no paleointensity results were yet obtained from these rocks, a preliminary survey has been conducted in Sinai to test the suitability of Granite for paleointensity experiments.

# MAGNETOSTRATIGRAPHY AND PALAEOMAGNETISM OF THE MIOCENE FORMATIONS OF CHIOS ISLAND, GREECE

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Previous palaeomagnetic results in Eastern Aegean, an important but poorly documented area, show a complex pattern with coexisting clockwise and counterclockwise rotations. In order to investigate this pattern, a combined magnetostratigraphic and palaeomagnetic study of Miocene sediments and volcanics respectively has been undertaken in the island of Chios. 99 sites from a 130 m thick section have been sampled for a magnetostratigraphic study. Thermal demagnetization of the samples allowed to identify the presence of two components of magnetization. IRM and thermomagnetic analyses showed that the main magnetic carrier in the sediments is magnetite. The section presents a succession of 16 normal and reverse polarity zones. This polarity succession is characterized by a 42 m thick reverse zone in the middle part; below, short normal zones are in alteration with reverse ones and near the top of the section two normal zones reach a thickness of 33 m. The mean declination of the reverse polarity is $154 \pm 8°$ which implies an about 25° counterclockwise rotation since Middle Miocene. The study of the volcanics has revealed either the presence of a stable normal component with mean declination of about 300° or an intermediate component. The above results are in agreement with the independent deformation models which predict counterclockwise rotations for this part of the Aegean and the neighbouring Western Anatolian Plate.

# TO THE TEMPERATURE DEPENDENCE OF THE NET MAGNETIC MOMENT OF THIN HAEMATITE-ILMENITE LAMELLAE

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The concept of "lamellar magnetism" (*Robinson et al., 2002*) is based on the discovery of numerous nanoscale haemetite-ilmenite lamellae in slowly cooled rocks containing heamoilmenite. Two different types of lamellae were considered: haemetite in ilmenite host and vice versa. The first ones were linked to the observation of intensive NRM, stable to AF and thermal demagnetization. The key role in generation of net magnetization of a lamella is presumably played by the uncompensated contact layers (CL) neighbouring both phases. Because of lamellae of the size of about 1–2 nm contains only a few (say, from 7 to 15 cation layers, including two CLs) the question arises how much the temperature dependence of the spontaneous magnetization $M_s(T)$ and in particular, the Neel's temperature ($T_N$) of haematite lamellae embedded in paramagnetic ilmenite will be affected in comparison with a bulk sample. Due to low number $N$ of layers, the magnetization $M(i)$ of the $i$-th layer may substantially depends on its position in the lamella. The simplest way to get an insight into the magnetic structure of such the small unit, is the mean field approximation applied by Neel in his theory of ferrimagnetism. According to this method, in order to calculate $M(i)$, it needs to solve a system of $N$ equations

$$x(i) = B\left[A(i)/kT\right],$$

where $x(i) = M(i)/M_S(T=0)$ is the normalized magnetization, $B(x)$ the Brillion's function, $A(i)$ is the average exchange energy acting to a cation located in the $i$-th layer. Because of hematite lamellae contact to paramagnetic inlmenite, the exchange energy of a CL above the $T_N$ of ilmenite is potentially twice less then that of within the lamella. In addition note, that the CLs consist of a mixture of $Fe^{3+}$ and $Fe2^{+}$ ions what further decreases their exchange energy.

As the result, $T_N$ of the hematite lamellae decreases with $N$ decreasing. As seen from this Fig. 1, left, the decrease amounts to 80 degrees for $N = 7$. Another distinctive feature seen there is substantial flattening of $M_s(T)$ curve in comparison with the bulk sample.

When considering the opposite case of ilmenite lamellae in the haematite host, the existence of powerful exchange bonds between the CL and haematite lead to appearance of persistent nonzero magnetic moment of the ilmenite lamellae far above its $T_N$ as illustrated in Fig. 1, right. The sharp rise of $M_s(T)$ below 200 K is due to the contribution of inter-lamella exchange interactions. The hump at the elevated temperature appears because of the exchange interactions between CLs and heamatite host.

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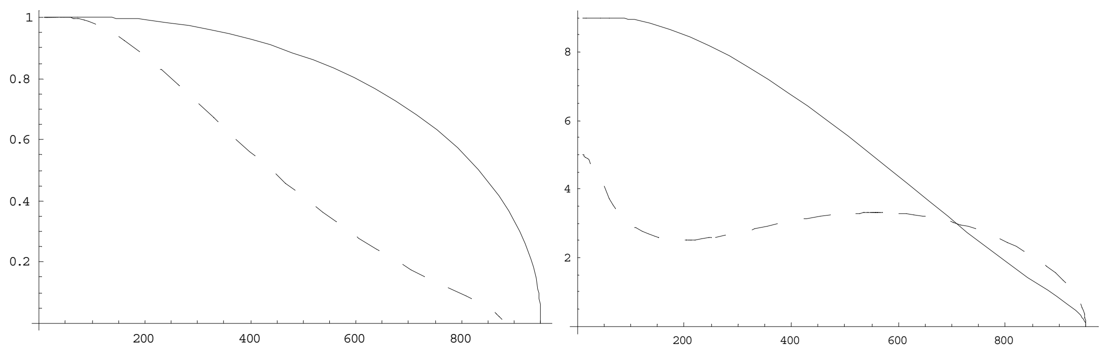


**Fig. 1.** Normalized magnetization against the temperature (in K). Left. Magnetization of a bulk heamatite sample (full line). Magnetization of 7 layers heamatite lamella (dashed line), Right. Magnetization of the CL (full line). Magnetization of 15 layers ilmenite lamella (dashed line).

# PALEOINTENSITY DETERMINATIONS IN THE PALEO- AND MEZO-PROTEROZOIC

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The scarcity of data on the paleointensity $H_{anc}$ in the Precambrian significantly hinders the development of the geological history of the Earth as a planet. By present time there are only about 30 Thellier determinations which satisfy the minimal criteria of reliabilty: determinations must be obtained by the Thellier method; not less than three samples must be used for the VDM calculation; the relative error of the determination should not exceed 15% (the criterion of internal convergence). Fig. 1 displays the summary of the Thellier results available for the period 1–2 Ga. Note that until recently there was a complete lack of data for the time interval 1.35–2 Ga. For the last two years we reported results of paleointensity determinations carried out just for this interval (Fig. 1); below is a short summary of these works. All the ages cited below obtained by stratigraphic correlation with the rocks having absolute dating.

a) Rybreka, South Karelia, gabbro-dolerite sill, 1770 Ma age (*Shcherbakova et al., 2004*). The Thellier experiments proved to be successful on 21 from 50 samples: the high-temperature component of NRM of these samples, taken in the 400–600°C interval, yilded the average VDM = $1.8 \times 10^{22}$ Am$^2$.
b) South of the Siberian platform, granite intrusion, 1850 Ma (*Shcherbakova et al., 2006a*). A peculiarity of this collection is that the blocking temperatures of NRM are grouped in narrow interval near the Curie temperature $T_c$ = 560–575°C of the samples. The average VDM determined on 11 successful samples, amounts to $5 \times 10^{22}$ Am$^2$. Because of the huge thickness of the intrusion, the paleointensity estimates were corrected for the slow cooling rate.
c) Salmi, South Karelia, lava flows, 1460 Ma age (*Shcherbakova et al., 2006b*).

From 14 successful samples we obtained rather low average VDM = $1.2 \times 10^{22}$ Am$^2$. Note, that the low VDM values in Middle Proterozoic are not a surprise: *Maquoin et al. (2003)* reported the similar value of $1.2 \times 10^{22}$ Am$^2$ for the volcanics from dike swarms of 1140 Ma age.

Herewith we report the paleointensity determinations obtained from Sortavala region, North Ladoga, Karelia. The samples were collected from dike swarms of 1450 Ma age. The Thellier experiments were carried out in the Coe's version. After each two heating steps, pTRM checks were made. For the majority of samples the

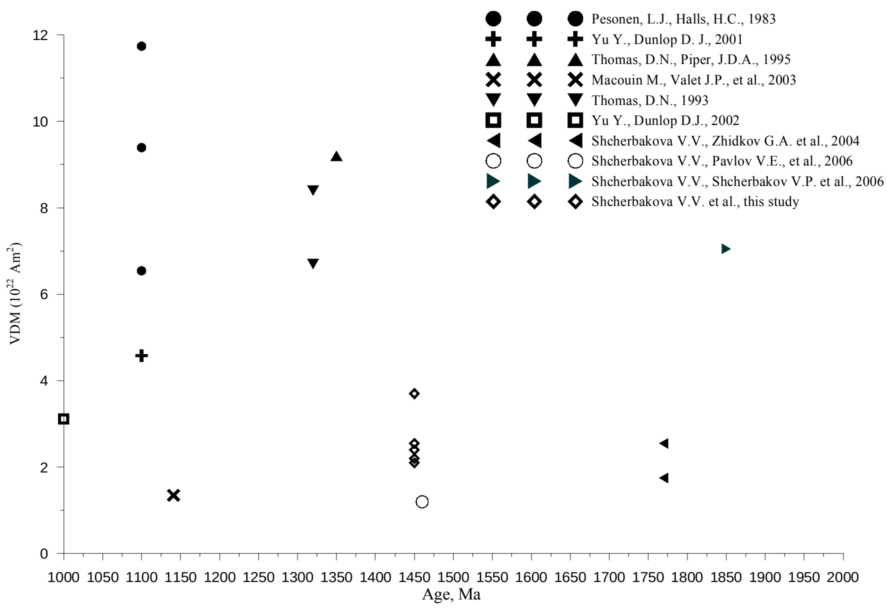


**Fig. 1.** Results of Thellier paleointensity determinations for the time interval 1–2 Ba.

paleointensity was estimated also by the Wilson method when the thermodemagnetization curves of NRM are compared to those of TRM. In the case of similarity of the curves in a certain temperature interval, the paleointensity was estimated from the relative intensity NRM/TRM over this interval. To assess the magnetic hardness and mineralogy of the samples, the common hysteresis loop parameters, like coercive force $H_c$, remanent coercive force $H_{cr}$, saturation magnetization $M_s$ and remanent saturation magnetization $M_{rs}$ were measured. The DS of the samples was determined from the ratios $M_{rs}/M_s$ and $H_{cr}/H_c$ and by measuring the pTRM tails. Judging by this, the ferrimagnetic grains are mainly of PSD sizes. The electronic microscopic observations confirmed this conclusion. The thermal stability and the Curie temperatures were estimated by a series of heating sister specimens in strong fields to gradually increasing temperatures. For the samples selected for the further paleointensity analysis, the consecutive $M_s(T)$ curves differ only a little, witnessing a high thermal stability of rocks. The Curie points lie in the interval 520–580°C pointing at (low titanium) magnetite as the NRM carrier. Five sites from the collection gave successful Thellier results yielding the average VDM = $2.6 \times 10^{22}$ Am$^2$. Each site is represented by more than 10 samples.

In all, the average VDM value for the time interval 1.35–1.85 Ga inferred from our studies is $2.7 \times 10^{22}$ Am$^2$ which is at least twice less than that of the average of the Phanerozoic. Note that below this time interval a tendency to increase VDM may be speculated (Fig. 1). Being real, this tendency can be interpreted in favor of the hypothesis that the solid inner core was formed only in Late Paleo- or Middle- Proterozoic (*Labrosse et al., 2001*). Indeed, the nucleation and growth of the inner core can strongly enhance the geomagnetic dynamo efficiency, which thus should be reflected in the VDM increase. However, it is preliminary to treat the paleointensity data as supporting this hypothesis, because of the dispersion of the data overall the Proterozoic and Archean is too big while the number of the data is too small.

This study is supported by INTAS grant 03-51-5807.

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# DEVELOPMENT OF DIAMAGNETIC AND PARAMAGNETIC ANISOTROPY IN DEFORMED SYNTHETIC CALCITE-MUSCOVITE ROCKS

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Deformation of carbonate rocks leads to a crystallographic preferred orientation (CPO) of calcite. Measurement of the anisotropy of magnetic susceptibility (AMS) is a fast tool to determine the strength and orientation of this CPO in pure calcite rocks. However, the weak diamagnetic AMS due to the calcite is often overprinted by paramagnetic and ferromagnetic contributions in natural rocks. Therefore the low-field AMS of natural carbonate rocks may not reflect the preferred orientation of calcite and a quantitative correlation between AMS and deformation is not possible.

In this study it is shown that separation of paramagnetic and ferromagnetic sub-fabrics from the total fabric can reveal the AMS due to the diamagnetic (calcite) fabric alone. The ferromagnetic sub-fabric is separated by high-field torque measurements in several fields. The paramagnetic sub-fabric can be separated by torque measurements at liquid nitrogen temperature (77 K), because the susceptibility and the AMS of the paramagnetic minerals are increased at low temperature, whereas the magnetic properties of the diamagnetic minerals remain the same (Fig. 1.). After the separations the diamagnetic AMS can be correlated with deformation in impure carbonate rocks.

To prove the validity of this method, synthetic samples were prepared to exclude as many unknown contributions to the magnetic fabric as possible. Calcite and muscovite powders were compacted under known conditions to generate CPOs of different strengths. The texture (CPO) of both calcite and muscovite was determined by neutron diffraction. The samples show a *c*-axis preferred orientation of both minerals which increases with the applied strain. The AMS was measured on a high-field torque meter at room temperature and at 77 K to separate the ferromagnetic and the paramagnetic AMS. Then the AMS due to calcite and muscovite was calculated from the texture and compared to the measured values. The calculated AMS and the CPO of calcite agreed very well in orientation and strength for samples with muscovite content up to 30%. The measured AMS of some samples is slightly higher than the calculated values, which could be due to hematite inclusions. In samples with 50% muscovite or more the paramagnetic AMS is more than ten times stronger than the diamagnetic AMS. A proper separation of the dominant paramagnetic sub-fabric from the diamagnetic sub-fabric was no longer possible. A higher sensitivity of the instrument and better knowledge of the intrinsic AMS of the paramagnetic minerals would be needed to isolate the diamagnetic fabric of samples with lower calcite content. The results show that diamagnetic sub-fabrics can be investigated by the AMS method, even if they are overprinted by stronger sub-fabrics of paramagnetic or ferromagnetic minerals.

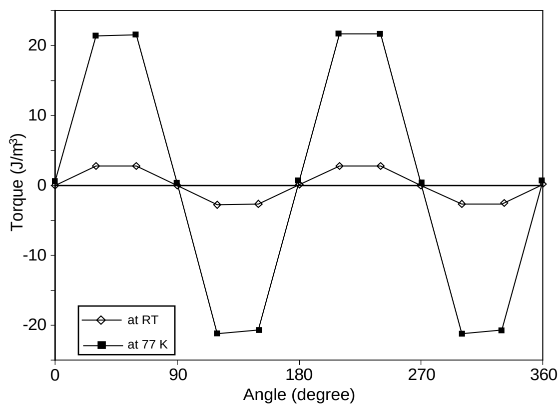


**Fig. 1.** Torque curve of sample 50-200-2 at room temperature (RT) and 77 K. Sample contains 50% calcite and 50% muscovite.

# PALEOGEOGRAPHY OF THE DEVONIAN ROCKS OF THE PRAGUE BASIN

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In paleogeographic reconstructions based on new inferred paleomagnetic data on the pre-Variscan formations in the territory of the Barrandian are solved in the Paleomagnetic laboratory in Průhonice. The centre of field work is represented by carbonate of the Prag (lower Devonian). From the paleomagnetic point of view, these rocks constitute an uneasy problem of their generally low magnetization at the time of Variscan orogeny and generally because of number of secondary magnetization components that originated in the course of geological history discused in *Mauritsch and Pruner (1990)*, *Krs and Pruner (1995)* and *Krs et. al. (2001)*. For this reason, an appreciable volume of work was devoted to studies of the origin of individual magnetization components, their separation and inference of the pre-Variscan components of remanent magnetization. The thermal demagnetizer MAVACS (Magnetic Vacuum Control System) which provides a highly non-magnetic demagnetization environment or AF (alternating field) LDA 3A demagnetizer were used to laboratory investigations.

Samples were collected in such a manner to allow fold tests to be made in inferring pre-Variscan paleomagnetic directions. Paleomagnetic data shown that the majority of Devonian rocks of the Barrandian had been totally remagnetised at the time of Variscan orogeny, or that Devonian rocks contained strong magnetization components which originated at the time of Variscan folding For this reason, the multicomponent analysis of the magnetization components was necessary and the sample collection was made accordingly. Under the term site we understand a collection site involving several layers within a locality or an exposure, separate sites being different geographically. The primary devonian paleomagnetic directions could be inferred only on 3 sites (out of 15). All samples were subjected to a detailed analysis of magnetization components, predominantly with the use of thermal demagnetization so that in a number of cases minerals – the magnetization carriers could be identified. In the samples of reddish colour, haematite pigment was proved. In some grey and white limestones, the presence of magnetite (of very low content) was proved. The *A*-component of remanence, Recent in origin, was interpreted in the temperature interval of 20–120°C, the *B*-component, corresponding to the Late Variscan overprint, was interpreted in the interval of 120 (160) – 360 (400)°C and the *C*-component, corresponding to paleomagnetization, was separated in the interval of 360 (400) – 550°C. The devonian *C*-component was acquired on 7 oriented limestone samples collected at the Srbsko-Karlštejn road cut, 4 samples collected at The Čeřinka Quarry and 1 sample at the "Zbuzanská (Chýnická) mramorka" Quarry. These samples produced relevant data for the inference of the paleomagnetic pole position and clearly indicate prominent horizontal paleotectonic rotations during the Variscan orogeny. The above data were inferred only for the Pragian Basin. Peri-equatorial paleolatitude of 18°S was derived from data obtained from the Devonian rocks.

This investigation was fund by grant GAAV ČR no: IAA3013406. We woulkd like to thank to J. Drahotová, D. Venhodová and J. Petráček for help with data processing.

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# AN IMPROVED TECHNIQUE FOR OBTAINING ORIENTED PALAEOMAGNETIC SAMPLES FROM UNCONSOLIDATED MATERIALS

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Oriented palaeomagnetic samples of unconsolidated materials like loess, clay, pit or baked clay in archaeological sites are taken either by pushing plastic boxes into the material, gluing plastic discs on the material (English technique) or stabilising big samples with plaster of Paris or plaster bandages (Thellier technique and modifications). With the first two methods small samples are obtained in the field, which need little further preparation in the laboratory. The disadvantage of such samples is that it is not possible to use thermal demagnetisation as the plastic material and the glue doe not support more than 200°C during heating. The plaster samples can either be measured entirely or more often they are consolidated and cut into specimens. Depending on the material and the applied hardener these specimens can be treated thermally up to 500 – 700°C which is sufficient for obtaining a proper thermal demagnetisation. But here the hardening process may be expensive and very time consuming, which holds also for the preparation of the specimens. The poster presents a method to obtain cores of the soft material which can be cut into standard one-inch specimens as usual for palaeomagnetic sampling of hard rocks.

For obtaining the core, a very thin non-magnetic stainless steel tube is pushed into the soft material. About half of the tube remains outside. Then, with a modified ASC orientation device fitting exactly on the tube, an orientation mark is drawn on the tube. The magnetic azimuth can be measured with magnetic as well as sun compass. After removing, the core is pushed into a plastic holder and the orientation mark is transferred to this holder. After consolidation of the core, the orientation mark is finally drawn on the core. After removing holder the core is cut into standard specimens, which allow AF as well as thermal treating.

The method was tested for several archaeological sites in comparison with block samples as well as plastic box samples. It is demonstrated that a comparable precision is obtained. The only limitation is that only fine grained material can be sampled which should not contain any pebbles or debris.

This work was supported the FWF, project M187-N11 and by the BM:BWK ministry for education, science and culture of Austria.

# MAGNETIC PROPERTIES AND COMPOSITION OF THE IRON HYDROOXIDES RICH LENSES IN THE MIDDLE DEVONIAN OF ESTONIA

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Lense-shaped interlayers of strongly cemented platy iron-rich sandstone are found in a weakly cemented yellowish sandstone of Burtnieki Regional Stage of Middle Devonian in the ancient valleys Ahja and Lutsu southeastern Estonia. They occur in a limited area that measures 10 km from west to east and 8 km from north to south. The thickness of these lenses, which consists of 2–3 cm plates, is 5–10 cm and their diameter reaches 1.3 m. The lenses are may also contain interlayers of weakly-cemented red-coloured sandstone between strongly cemented plates. In contrast to the weakly cemented Burtnieki sandstones with 5% clayey cement that are found in outcrops and in boreholes, the iron-rich sandstones are cement-supported. The cement forms 30–35% of the rock in the middle part of the lense and is made up of hematite and goethite and on the surface by goethite. The sandstone consists mainly of subrounded to angular, often fractured grains of quartz. The grain size decreases from east to west. For the first time such a strongly cemented iron-rich sandstone was also found in a form of concretions in the Quaternary cover of the same region. In the Quaternary deposits the cement consists of goethite (*Kleesment et al., 1993*).

A sample of iron-rich sandstone was taken from the Kooskora quarry (Ahja valley) and analysed together with other 50 Devonian samples taken from the south-Estonian boreholes and north-eastern Estonian outcrops. These were further compared to 95 Devonian samples from an earlier study (*Shogenova et al.*, 2004). The rocks are represented by dolomitized carbonate, siliciclastic and dolomite-cemented mixed carbonate-silicilastic rocks (*Kleesment and Shogenova, 2005).* The rocks were studied for their magnetic, mineralogical and chemical properties. Magnetic measurements included the magnetic susceptibility, measured at room (293 K) and nitrogen liquid (77 K) temperatures (Fig. 1a,b), IRM acquisistion in the fields from −1250 mT to 1250 mT, and thermal demagnetisation of a three-component IRM. Bulk chemical composition was studied by X-ray fluorescence and by carbonate analysis. Mineralogical composition was studied by X-ray difractometry and thin-section analysis (Fig. 2). Chemical and mineralogical composition, magnetic properties, density and porosity and thin-sections were then interpreted together to characterize the rocks.

The bulk chemical composition of the Kooskora iron-rich sandstone consists mainly of 50.7% of $SiO_2$, 39.5% of total iron, 2.22% of $Al_2O_3$ and 1.03% of $K_2O$. All iron occurs in the form of $Fe_2O_3$ (Fig. 1a); measured FeO content was only 0.3%. The mineralogical composition of the rock, determined by XRD, consists of quartz, K-feldspar, goethite and hematite (Fig. 2a). The muscovite contenet was determined in the thin-section (Fig. 2b).

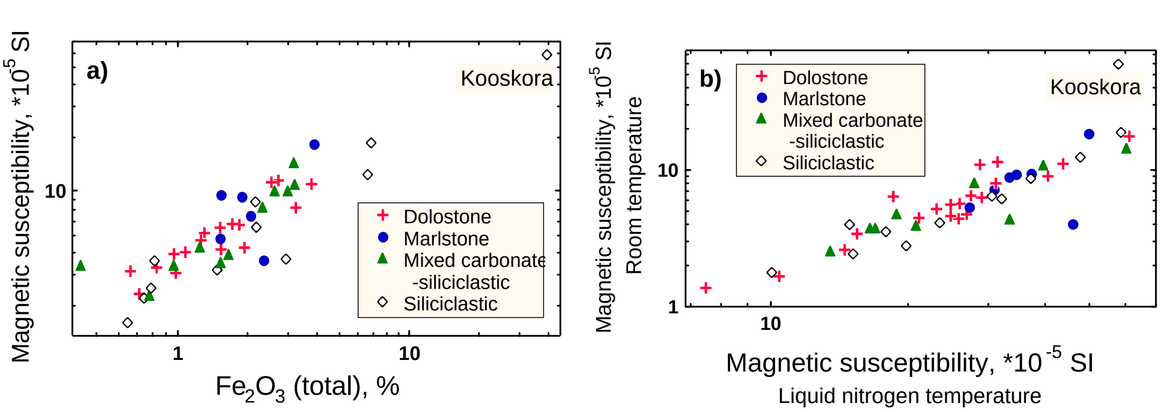


**Fig. 1.** Magnetic susceptibility of the Kooskora iron-rich sandstone compared to the other Devonian rock samples from boreholes and outcrops. **a)** Magnetic susceptibility versus total iron content, **b)** Magnetic susceptibility measured at room temperature versus measured at liquid nitrogen temperature.

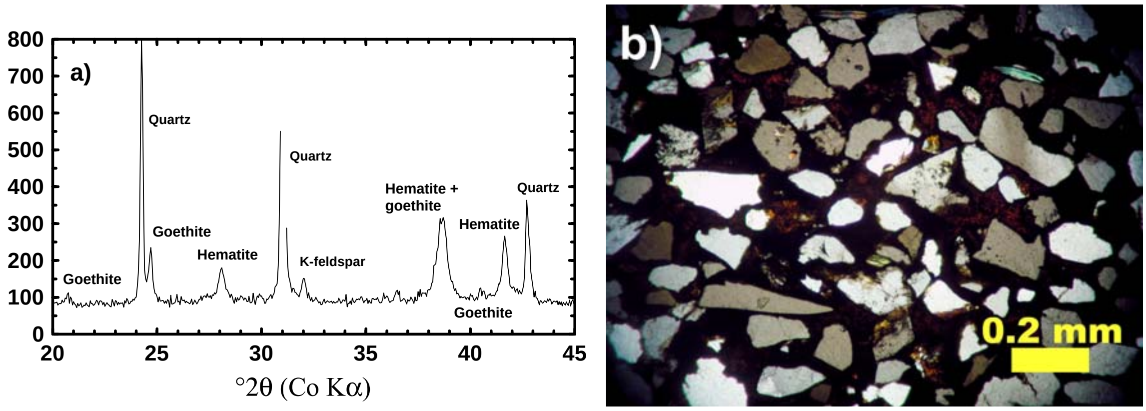


**Fig. 2**. Composition of Kooskora iron-rich sandstone. **a)** Mineralogical composition by X-ray difractometry. **b)** Thin-section. Very fine to fine grained medium sorted silty sandstone, cemented by hematite and goethite. By mineralogical composition sandstone is quartzarenite. Grains are represented mainly by quartz (75–80%), feldspar (15–20%) and muscovite - 5%.

Hematite and goethite make up the cement of the rock. Rock porosity, which was measured by water saturation method, is 0% and the total density is $3.14 \times 10^3$ kg/m$^3$.

Devonian sandstones usually have an iron content in the range of 0.5–9.1%, and porosity of the cemented sandstones in a range of 13–37.1% and density in the range of $2.2–2.48 \times 10^3$ kg/m$^3$ (*Kleesment and Shogenova, 2005*), while the yellowish loosly cemented sandstones usually include less than 1% of total iron, their porosity is higher than 40% and density is lower than $2.2 \times 10^3$ kg/m$^3$.

The magnetic susceptibility of Kooskora iron-rich sandstone that was measured at 293 and 77 K, was nearly the same (58.8 and $58.0 \times 10^{-5}$ SI respectively), while magnetic susceptibility of the other Devonian rocks was in a range of $2–29 \times 10^{-5}$ SI (Fig. 1a, *Shogenova et al., 2004*) and increased by a factor of 2.7 to 7.8 at 77 K (Fig. 1a,b). Magnetic susceptibility, measured directly at the Kooskora outcrop, showed that the surrounding yellowish sanstones had a susceptibility of zero, but $20–43 \times 10^{-5}$ SI in the iron-rich layers, whereby higher values were found in thicker lenses.

IRM of the Kooskora samples did not reach saturation in fields of 1200 mT. IRM acquisition and subsequent thermal demagnetization of the three-component IRM of the other Devonian samples show that they often include magnetite, and in the red-colored rocks they also have hematite. Goethite was not identified in theses rock samples.

The pronounced difference in the composition and magnetic properties of the studied iron-rich sandstone with surrounding it rocks allows for mapping of the iron-rich lenses using magnetometer. Taking into account the relatively small sizes of such geological objects, it is possible only to identify these in outcrops.

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## THERMAL, MECHANICAL AND CHEMICAL ALTERATIONS PROMOTED ON SEDIMENTARY ROCKS HOSTING DYKE BODIES

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This work is focused on flow and propagation of magma along thick Jurassic dykes and the effects of such intrusive processes on the magnetic properties of host sedimentary rocks, which are still poorly understood. Therefore, an exhaustive study of rock magnetic and petrography analyses were performed on dolerite rocks collected along several sections across the Foum Zguid (FZD - Southern Morocco) and Messejana-Plasencia (MPD - Iberia) dykes, complemented with several sections across the sediments hosting the FZD. The study has been completed with the evaluation of the magnetic fabric carried by these sedimentary rocks after laboratory application of sequential heating experiments.

The present study shows that: i) magnetic analyses of dolerite rocks are sensitive to low to moderate metasomatic processes and cooling rate underwent by ferromagnetic minerals; ii) intrusive processes at both dykes occurred for a brief period; iii) oblique magma flow regime, rising from SW to NE, is inferred for FZD; iv) sub-vertical magma flow episodes, without discarding some sub-horizontal magma flow regimes are inferred for MPD; v) variations of the bulk magnetic parameters and of the magnetic fabric observed for sedimentary rocks hosting FZD is strongly related with re-crystallization and Fe-metasomatism intensity, with newly formed hematite as the main product; vi) the magnetic fabric obtained for sedimentary samples near the contacts with FZD was acquired during the intrusion, and could reflect either flattening in the host rock due to the stress field induced during the intrusion or the materialization of microfractures; vii) the strong compression promoted during magma emplacement leads to bulk rotations for domains nearest the contact; viii) thermal experiments of AMS on sedimentary samples collected farther from the dyke and, thus, less affected by heating, indicate that 300–400ºC is the minimum temperature needed to trigger appreciable transformations of the previous magnetic fabrics. Therefore, such changes in orientation should not be unequivocally interpreted as the result of a stress field.

# MINERAL MAGNETIC STUDY OF LOESS/PALEOSOL SEQUENCE IN MOKRÁ AT BRNO (CZECH REPUBLIC)

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Studied sedimentary section, located in the southern part of the Moravian Karst ca 10 km east of Brno, exposes several loess and paleosol layers. The topmost bed of the sequence is formed by 0.5 m thick brown soil underlain by 3.5 m thick loess containing weekly developed thin soil. A reddish brown strongly clayey fossil soil is exposed at the base of the section. Oriented samples were collected from two separate vertical sections using plastic boxes (6.7 $cm^3$) with a vertical separation of less than 0.5cm between sampling horizons for a total of 400 samples.

Mineral magnetic characteristics were diagnose using different methods (both volume and frequency dependent magnetic susceptibilities, temperature dependent magnetic susceptibility, IRM, SIRM) with the aim to explain how climatic and post-depositional processes affected mineral magnetic assemblage of both loess and soil material. The soils reveal higher volume magnetic susceptibility (MS) values than the loess deposits due to a magnetic enhancement reflecting more intense weathering during pedogenesis. This is a common MS pattern typical for most central European loess/paleosol sequences. The studied soils contain four time higher concentration of superparamagnetic particles than the loess. High temperature dependent magnetic susceptibility variations follow a pattern common in young soft sediments. Maghemite formed from Fe oxihydroxides after heating to ca 300°C is later converted to hematite, which is than reduced to magnetite between 480 and 510°C. The magnitude of these magnetic phase changes is the highest in the topmost soil bed. Low temperature dependent magnetic susceptibility variations show a dominance of paramagnetic component in loess deposits, which is caused by increased content of chlorite and muscovite in the loess.

Diffuse Reflectance Spectrophotometry allows us to compare the color of sediments influenced by concentration of Fe-oxides. The reflectance is lower in the soil horizons due to higher content of Fe-oxides representing the weathering products. A voltametry of microparticles revealed a higher content of low crystalline Fe-oxides as well as a higher hematite/goethite ratio in the soils.

The age of sequence is estimated based on reversed geomagnetic polarity detected at the top of the basal paleosol layer. This reversed polarity could be correlated with the Blake Excursion. Based on this knowledge we assign the studied sedimentary sequences to the last climatic cycle. The youngest soil covering the section has been developed during the Holocene.

# TECTONIC APPLICATION OF NEW PALEOMAGNETIC DATA FROM UPPER PALEOZOIC CARBONATES OF THE HOLY CROSS MOUNTAINS

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Paleomagnetic investigations has been carried out in the Devonian carbonate rocks of the Kielce Unit of the Holly Cross Mountains. The general aim of the study was to investigate time relationships between remagnetizations and successive stages of the tectonic deformations.

The paleomagnetic study of the Devonian carbonates reveal occurrence of three components of the characteristic remanent magnetization (ChRM). Two magnetic bearing components display reversed (component *A*) and normal (component *B*) polarity. The third component (component *C*) is recorded on hematite and shows reversed polarity. Such outcomes are in line with previous observations of *Zwing (2003)*. The paleoinclination dating ChRM components gives Middle Carboniferous age of the *B* component, Late Carboniferous time of the *A* component acquisition and Permian age of the *C* component.

The conglomerate test performed in Wietrznia quarry reveal that the age of the conglomerate is younger then both *A* and *B* components. Fold tests documents that *B* component has been recorded before tectonic deformations. The paleomagnetic direction of the *B* component is akin as known from the stable parts of the Baltica Continent. The synfolding character of *A* components enable to determinate the age of specific tectonic structures and permit to separate the Variscan and Alpine deformations.

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# A PRELIMINARY ITALIAN SECULAR VARIATION CURVE: COMPARISON WITH GLOBAL GEOMAGNETIC FIELD MODELS AND APPLICATION TO ARCHAEOMAGNETIC DATING

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Preliminary secular variation (SV) curves for declination and inclination have been constructed using archaeomagnetic directional data from Italy. The proposed curves are derived by Bayesian statistical modeling and they span to the last 3 thousand years. Comparison with available SV curves of the western and central Europe shows a good agreement in the general features even though some differences are also observed, mainly at the time periods where only few data exist. The Italian curves have been also compared with the predictions of global geomagnetic field models. Such a comparison shows that the curves reasonably agree with the model and the model predictions for declination and inclination are included in the error envelope of the Italian curves. However, they do not completely coincide in the whole period examined but for some periods the geomagnetic model results to a smoother description of the SV changes.

Archaeomagnetic directional data obtained from volcanic rocks of well known age, i.e. those of the Mt. Vesuvius 1631 AD (pyroclastic flow), Mt. Arso (Ischia) 1302 AD, Pollena (Vesuvius) 472 AD and Pompeii (Vesuvius) 79 AD eruptions have been used in order to check the Italian SV curve as a dating tool. Archaeomagnetic dates obtained are very close to the expected ones. The same eruptions have been also archaeomagnetically dated using the SV curves of nearby to Italy countries; results are compared and implications about westward drift are discussed.

The preliminary Italian SV curves succeed in describing the variations of the Earth's magnetic field in the past and can be used for archaeomagnetic dating, even though caution must be paid for the time periods characterized by large error envelops. Undoubtedly more data are still required in order to be able to draw a more detailed SV curve that will be necessary for improved dating reliability as well as further defining geomagnetic variation properties.

# LARGE SCALE VERTICAL AXIS ROTATIONS AND SLAB-PULL TECTONICS: EXAMPLES FROM THE CARPATHIANS AND THE ALPS

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Results from our previous study (*Thöny et al., 2006*) indicate two major vertical axis rotations of Northern Calcareous and Central Alps in Oligocene to Miocene times. The Southern Alps were also part of the rotating block. The exact boundaries of the rotating unit could not yet be defined.

The mechanisms of large scale vertical axis rotations are a matter of debate. Paleomagnetic results are presented and two possible models for large scale vertical axis rotation are discussed.

During subduction the downgoing plate is subject to the slab-pull force resulting from the negative buoyancy of the cooler, denser lithosphere of the sinking slab. In case the slab-pull force is laterally changing it is speculated that the overlying plate is rotated during subduction. The slab-pull force may differ with the amount of oceanic crust that is affected by subduction. The sense of rotation is defined by the location of the area of increased extent/volume of oceanic crust, where slab-pull forces and roll back rates are higher causing higher shortening rates and therefore rotation towards these regions.

At the stage of continent-continent collision no oceanic crust is available for subduction. At the basal thrust plane the overriding plate is thrusted over the oceanic/continental crust of the subducted slab. The geometry of the slab may still be similar to the stage of active subduction with possibly laterally different amounts of oceanic crust. Slab retreat may support thrusting due to diminished friction values at the basal thrust plane as the lower plate is retreating and the contact between lower and upper plate gets loose. In case of laterally different values of retreat the upper plate should show a large scale vertical axis rotation while thrusting. When the slab breaks off the rotation of the upper plate may finish due to increasing friction at the basal thrust plane. Magmatic intrusions related to slab break off should not show any rotation.

These two models of large scale rotations and slab-pull tectonics are applied on geodynamics of the Carpatho-Pannonian region and the E-Alps.

In the Carpatho-Pannonian region the North Pannonian block (NPB) and the Tiza-Daza block (TDB) can be distinguished. The Mid Hungarian Line is separating the two crustal units that are rotating differently during Miocene subduction processes. These different rotation senses are interpreted using the the first model that is related to subduction processes. It is speculated that the approximately NW-SE striking oceanic zone has it`s maximum extent/volume of oceanic in a medium position at the crossing with today`s Mid Hungarian Line. Such a geometry of an oceanic basins may cause counterclockwise rotation for the NPB in the north and clockwise rotation for the TDB in the south during subduction.

In the E-Alps 60° of clockwise vertical axis rotation affecting Northern Calcareous, Central and Southern Alps could be detected and dated to 35 Ma to 30 Ma (*Thöny et al., 2006*). Subduction of the Penninic ocean finished in the Early Eocene. Periadriatic intrusive rocks related to slab break off and dated to about 30 Ma do not show this characteristic clockwise rotation values (*Thöny et al., 2006*). Using the second model, we interpret that slab retreat, acting before slab break off, is possibly enabling this large scale rotation at a stage of continent-continent collision by lowering the friction values between the overlying and the subducted plate.

Paleomagnetic studies from large scale units are indicating values of vertical axis rotation up to 90°. We think, models that identify subduction related processes as motors for such large scale geodynamics might be an interesting contribution in the ongoing debate.

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# GEOMAGNETIC DIPOLE MOMENT VARIATIONS AND PLEISTOCENE CLIMATES

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Paleomagnetic directions and relative paleointensities (RPI), as well as cosmogenic nuclide concentrations (authigenic $^{10}Be/^{9}Be$ ratio, i.e. cosmogenic vs lithogenic isotopes adsorbed on the sedimentary particles) were measured along sedimentary clayey-carbonate sequences deposited during the last 1.3 Myr in high accumulation rate continental margin locations of the North-East Atlantic (Portuguese margin: 0–400 kyr BP) and of the West-Equatorial Pacific (Euripik dome: 600–1300 kyr BP). Series of high and low RPI features are chonologically contrained by radiocarbon dates, $\delta^{18}O$ record correlation with the SPECMAP stack and by ages of idenitfied reversals B/M, Jaramillo and Cobb moutain subchrons boundaries. During the low RPI phases three types of directional signatures occur: i) large amplitude deviations of the paleosecular variation, ii) excursions and iii) polarity reversals. Excursions or short reversed events such as Laschamp, Blake, Icelandic basin, Jamaïca, Portuguese margin, Levantine, …, Delta, Brunhes-Matuyama precursors, Kamikatsura, Santa Rosa appear at their own recognized age windows. Significant peaks of the authigenic $^{10}Be/^{9}Be$ ratio have been deciphered at the same stratigraphic level as low RPI phases. Plotted against RPI data the $^{10}Be/^{9}Be$ ratios statistically follow the expected power law, which strongly establishes the unique and direct link between the recorded cosmogenic enhancement and dipole moment loss, allowing us to univocally interpret our $^{10}Be/^{9}Be$ ratio and RPI records in terms of geomagnetic dipole moment lows and highs (DML and DMH) alternation. Having established this constraint on our data sets, we noted that the $\delta^{18}O$ records established on the same set of Portuguese cores, allow interpreting the position of the DML vs interglacial stages documented in the same cores, i.e. with strict stratigraphic criteria. We notice that most DML of the last 400 kyr fall in the end of interglacial stages; conversely, the dominant regime of DMH is related with glacials stages. This intriguing coincidence has been checked over the last 800 kyr interval. The SINT-800 curve, backed by the South East Pacific near Sea Floor magnetization record, was compared with the high resolution $\delta^{18}O$ record of the Indian Ocean: the chonological coincidence of DML and interglacials (or interstadials) holds along the complete 0–800 kyr interval. Analysing this relation beyond 800 kyr, in out West-Pacific record, we find that DML, excursions and reversals of the late Matuyama do not present such relationships. It must be emphasized that prior 900 kyr BP, i.e. prior the time of maximum extension of ice caps, «interglacial/glacial» alternations presented much smaller amplitudes and followed the obliquity (41 ka) period. Analyses of paleointensity and VDM proxy records with Complex Wavelet transform, using both modulus and phase, reveals periods ranging from 80 to 120 kyr, and around 40 kyr. However, DML and DMH do not present relation with eccentricity low or highs; we only note a tendency of some DML to loosely fall at time of low obliquity. Comparison of SINT-800 and Indian Ocean $\delta^{18}O$ phases near the 100 kyr period points indicates that the ice volume signal leads the geomagentic moment signal: this is in coherence with the occurrence of DML and excursions near the end of interglacials. The coupling between DML and interglacials over the last 800 kyr - if further confirmed - would support an hypothesis of geodynamo power triggered by the large pleistocene fluctuations of the polar ice volume (at the ~100 kyr period) probably through rotational constraints. Such rotational/geomagnetic coupling was already signaled about geomagnetic jerks.

# ARCHEOMAGNETIC INVESTIGATION OF THE NEOLITIC CERAMICS FROM THE WESTERN AND SOUTHERN SLOVAKIA

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The archeomagnetic investigation was performed on the 45 specimens of 10 ceramic potcherds from 4 localities of Western Slovakia and on 31 specimens of 8 ceramic potcherds from 8 localities of Southern Slovakia. Classical Thelier method, or method of double heating, was used (*Thelier and Thelier, 1959*). All these measurements were carried out in Paleomagnetic laboratory of the Geophyisical Institute SAS. Different amount of specimens (from different localities) was caused by extension of archeological artefacts. After each thermal steps of Thelier method the magnetization as well as magnetic susceptibility were measured. In archeomagnetism an acqusition of thermoremanent magnetization (TRM) of baked artefacts is generally linked with the presence of magnetic minerals. To reveal an origin of TRM of respective artefacts a study of magnetic minerals is important. The Curie temperature measurement method of crushed samples was used as the most effective way for the qualitative determination of the magnetic minerals. It was performed partly in AGICO Brno and partly in GPI SAS Bratislava. From these measurements it has been evidenced that the carriers of magnetism are Fe-oxides - the association of magnetite and hematite.

The samples were heated till to temperature 600 – 700°C but because they desintegrated in the middle temperatures, measurements were performed only till to 450°C. This fact gives an idea that ceramic artefacts from which investigated samples are coming were heated not much higher than 400°C.

Computed ratios $H_P/H_L$ are for the case of collection from Western Slovakia in the interval 0.58 – 1.04 and for the case of collection from Southern Slovakia in the interval 0.37 – 0.68 ($H_P$ means paleofield and $H_L$ laboratory - present geomagnetic field). Comparison of obtained data with archeomagnetic scales (*Bucha, 1975*; *Wagner, 1998*) shows that ages of ceramics remnants from Western Slovakia are from 1800 to 5800 years B.C. and from Southern Slovakia from 3750 to 4900 years B.C.

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# MICROSCOPIC MAGNETIC FIELD DISTRIBUTIONS OF TYPE-3 ORDINARY CHONDRITES: A NEW MAGNETIC MICROSCOPY

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A new highly sensitive magnetic sensor utilizing a magneto-impedance (MI) effect in the FeCoSiB amorphous wire was developed in Japan (*Mohri et al., 2001*). The MI sensor has a sensitivity of 10 nT that is next to SQUID sensors (~ 0.1 nT, *Weiss et al., 2002*). The driver circuit of MI sensor is simple and operable at room temperature. These advantages suggest that MI magnetic microscope offer an inexpensive, low-maintenance alternative to SQUID microscopes for mapping remanent magnetic fields. Here, we report spatial distributions of a stray magnetic field associated with natural remanent magnetizations (NRMs) in a primitive type-3 ordinary chondrite using a custom-made scanning MI magnetic microscope.

Petrologic type-3 chondrites have provided information of the early solar nebula because of their low metamorphic temperatures. In particular, primitive ordinary chondrites (e.g. Bishunpur LL3.1) preserve metallic phases formed during solar nebular processes (*Lauretta et al., 2001*; *Lauretta and Buseck, 2003*). The metallic phases of Fe-Ni grains appear to simultaneously preserve a magnetic environment of the early solar nebula as NRMs. An experimental study suggested that abundant submicron-sized kamacite grains in a reduced "dusty" olivine acquire magnetically stable pre-accretional NRMs when the chondrules were formed (*Uehara and Nakamura, 2006*). *Lauretta et al. (2001)* suggested that silicon-bearing Fe-Ni grains in the matrix of Bishunpur (LL3.1) were formed in the reducing environment of chondrule melts. It implies that such Fe-Ni grains in the matrix also acquired pre-accretional NRMs. If these metal grains were magnetized before incorporation into chondrites, their NRMs should be randomly oriented. Therefore, the correlation between magnetic grains and their NRMs is interesting, because it constraints a thermal, chemical and magnetic environment of the solar nebula, and the origin of NRMs. However, there is no study focused on the NRMs of these Fe-Ni grains in the primitive ordinary chondrites.

We examine a 3 mm thick slice of NWA1756 (LL3.0/3.2). The scanning MI magnetic microscope obtained images of the out-of-the-page component of the magnetic field 300 μm above the sample. The spatial resolution and magnetic sensitivity of the microscope is 400 μm and 50 nT, respectively. The maximum scanning area is 32 mm square. The measurements were made in a three-layered mu-metal magnetic shield.

Magnetic images of the NWA1756 sample reveal a spatially heterogeneous pattern of remanent magnetizations showing eight distinct magnetized points, suggesting pre-accretional NRMs. A superposition with the magnetic mineral distribution shows that magnetized points are associated with kamacite in the matrix, which is often surrounded by FeS, and also shows that large (~ 300 μm) kamacite grains were strongly magnetized. Although a chondrule contains dusty olivine grains, we detect only a slight magnetic signature from this chondrule. These preliminary results suggest that the scanning MI magnetic microscopy is able to decide the NRM carriers in the primitive ordinary chondrites.

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# EFFECTS OF HEATING ON MAGNETIC MINERALOGY AND LOW-FIELD SUSCEPTIBILITY ANISOTROPY OF IMPACT BRECCIAS FROM THE CHICXULUB MULTI-RING CRATER

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We report results of a magnetic fabrics study of the impact breccias of the Chicxulub crater, which is a large complex multi-ring structure formed in the Yucatan carbonate platform at the Cretaceous/Tertiary boundary. Impact breccias are highly heterogeneous, composed by clasts of melt, limestone and basement rocks within a carbonate-rich or melt-rich matrix.

Interest on investigating effects of heating on the low-field magnetic susceptibility anisotropy (AMS) is slowly increasing, and studies on a wider range of lithologies are recently being conducted. Initial studies on sedimentary rocks documented enhancement of the AMS fabrics with laboratory heating, and subsequent studies show potential in isolating fabric components in composite fabrics. Here we concentrate on the anisotropy of magnetic susceptibility of impact breccias measured at low magnetic fields; in particular, on the effects of laboratory heating on the AMS and potential use in component separation of composite fabrics and in enhancing the magnetic fabrics. Samples are recovered from cores recovered in the Yaxcopoil-1 borehole, which was drilled in the southern inner sector of the crater at about 60 km radial distance from the crater center at Chicxulub Puerto. The impact breccia sequence at Yaxcopoil-1 lies at about 795–895 m depth, and is conformed by six subunits: (1) re-deposited melt-rich, clast-size sorted, fine-grained suevites, (2) melt-rich, no clast-size-sorting, medium grained suevite, (3) coarse suevitic melt agglomerate, (4) coarse melt-rich heterogeneous suevite, (5) brecciated suevite, and (6) very coarse, carbonate and silicate melt suevite. Chicxulub breccias present carbonate-rich and melt-rich matrix, with clasts from a large range of lithologies from the Yucatan basement units and melt material. Main magnetic carriers of remanent magnetization in the breccias are magnetite and low-titanium titanomagnetites.

In general, study of the anisotropic properties of magnetic susceptibility and remanent magnetizations of impact lithologies has received relatively little attention in paleomagnetic research. These studies have implications for the cratering processes, generation and deposition of breccias, and hydrothermal metamorphism. Mineralogical changes resulting from heating samples have been recognized, but no data on impact lithologies including breccias and melt rocks have been reported. The use of temperature induced effects to investigate composite magnetic fabrics in heterogeneous materials such as the impact breccias is discussed.

# HIGH PRESSURE COMPLEX MAGNETIC SUSCEPTIBILITY MEASUREMENTS OF MAGNETITE UNDER LOW TEMPERATURE

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We show a high pressure complex magnetic susceptibility measuring system and provide a low temperature magnetic diagnostic of high pressure history of magnetite in association with a possible application for shocked rocks. Impact shock stress introduces a large strain and defects in crystals including magnetite in shocked rocks. *Carporzen (2004)* have found unusual low-temperature behaviour of remanence in shocked granite at Vredefort, which shows two distinct Verwey-like transitions. Some researches claim that magnetite exhibits multiple low temperature transitions due to residual stress (*Matsui et al., 1977*) or impurity (*Walz and Kronmueller, 1991*). In addition, pressure effect on low temperature transition in magnetite was studied experimentally by Mössbauer spectroscopy (*Pasternak et al., 2003*). The spectra showed a coordination crossover from inverse to normal spinel at slightly higher temperature than the Verwey transition under high pressures, implying magnetite would exhibit two distinct low temperature transitions under pressure. However, the magnetic consequence of the proposed coordination crossover has not been investigated. Therefore, we conducted low temperature complex magnetic susceptibility measurements of a natural magnetite sample in a diamond anvil cell down to 100 K. The in-phase component of complex susceptibility is considered to be almost equal to the direct current susceptibility, and the quadrature component is the measure of energy loss during magnetization. Up to 1.1 GPa, we observed a normal single Verwey transition as a sharp drop of in-phase magnetic susceptibility and a maximum of quadrature magnetic susceptibility. Under pressure larger than 1.6 GPa, the drop of in-phase susceptibility at the Verwey transition was suppressed, whereas quadrature component still indicates the transition. At pressures of 1.6 GPa and 4.5 GPa, we newly observed another rise of quadrature susceptibility at slightly higher temperature than the Verwey transition. The decompression from 4.5 GPa to 0.5 GPa did not erase the splitting of low temperature transition, suggesting the transition is a permanent property. This result is interpreted as due to permanent change in magnetic domain wall structure, resulting from internal stress by compression. The presence of splitting after decompression explains the natural observation of the Vredefort rocks (*Carporzen, 2004*). Therefore, the splitting of low temperature transition could be a high pressure memory of magnetite, being included within some meteorites and impact crater rocks.

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## MATHEMATICAL MODEL FOR THE MOTION OF DOMAIN WALLS IN ROCKS WITH INDUCED MAGNETIC ANISOTROPY

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When re-heated to temperatures below the Curie temperature and subsequently cooled in a constant magnetic field, rocks samples, which contain magnetic minerals, acquire an induced magnetic anisotropy (IMA). As the result of acquiring the IMA, a constriction develops in the hysteresis loop of the magnetization of these rocks at the values of the magnetizing field close or equal to the $H_T$. The constriction on the hysteresis loop is caused greater Barckhausen's jumps, occurring on the "giant" energy barriers. These barriers to appear on way of the moving the domain walls in the places, which depend on value the $H_T$. Suggested model motion of the domain walls in ferromagnetics with induced magnetic anisotropy. That is in magnetic material, in which exist the greater Barkgauzen's jumps. Produced and solved equation for dynamic movement of domain walls in magnetic material in which exist the "giant" potential barriers. The decision of this equation applicable for analysis of movement of domain walls (or its part), which meets on its way relatively large obstacles formed admixture, vacancies, microcracks or their accumulation.

## INDUCED MAGNETIC ANISOTROPY OF ROCKS: OBSERVABLE EFFECTS AND METHODS OF STUDY

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It is known that, when rocks containing ferromagnetic minerals (for example, magnetite, minerals of the titanomagnetite series, pyrrhotite, and so on) cool from various temperatures in a constant magnetic field, they can acquire induced magnetic anisotropy (IMA) of a special type observable as constricted and asymmetric minor magnetic hysteresis loops. As has been shown in various studies, the IMA of rocks is capable of storing information on the magnetic field, as well as on the temperature and pressure of the IMA acquisition. The IMA is caused by the diffusion stabilization of domain walls in multidomain samples. The IMA, acquired by many rocks during their heating and cooling in the Earth's magnetic field under the pressure of surrounding rock masses, carries information on the geomagnetic field, the rock heating temperature, and pressure. The IMA in even deep-seated rocks should fix a temperature very close to the rock heating temperature, but its determination is a considerably more difficult task compared to rocks occurring at shallow depths. At present, many IMA-related effects have been studied. Here, we present an approximate classification of these phenomena. The properties of the IMA magnetic memory were studied on samples of rocks ranging in age from a few tens of years (for example, lavas of the latest eruption of the Tolbachik Volcano) to many millions years. Samples of lavas and tuffs of Armenia, Scotland, Mongolia, the Far East, Kamchatka, the Kurile Islands, the Yana-Kolyma fold area, and the Mid-Atlantic Ridge were examined. The majority of these rocks contained magnetite and titanomagnetite with Curie points ranging from 170 to 570°C. Some samples rocks containing pyrrhotite and synthetic samples of magnetite and titanomagnetites with various Ti contents were also examined.

# CRETACEOUS REMAGNETIZATIONS IN NORTH IBERIAN BASINS: CONTRIBUTION TO EXTENSIONAL BASIN EVOLUTION - PALEOMAGNETISM AND ROCK MAGNETISM

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Previous palaeomagnetic studies (i.e. *Juárez et al., 1998*) have indicated widespread remagnetizations in Jurassic limestones of the Iberian Ranges (Northeastern Iberia). Some of these studies suggest Cretaceous ages for these overprints considering their palaeodirections. We are developing systematic palaeomagnetic studies in different areas of the chain in order to characterise the extension and timing of these remagnetizations. A previous detailed palaeomagnetic study developed by our group in the northern border of the Cameros basin showed that the well-exposed and thick sequence of red beds of Lower Cretaceous age shows a normal polarity remagnetization carried by hematite (*Villalaín et al., 2003*). Several fold and conglomerate tests indicated that remagnetization was acquired before compressional deformation and post-dates the main extensional stage of basin formation (Berriasian-Albian), suggesting an acquisition related to burial of sediments.

In this work we interpret the remagnetized directions to determine the syn-extensional geometry of inverted basins. To analyse the geometry of syn-extensional deposits in a sedimentary basin, field and subsurface data are necessary. If the sedimentary basin has been inverted, to elucidate the geometry related to its previous extensional stage is a more complex process. This is because many features linked to the extensional regime appear modified or hidden. As the remagnetization were acquired during the extensional stage of basins, the paleodirections underwent deflection because of the folding related to the inversion of basin. The analysis of remagnetization directions allow to obtain the tilting of beds at the moment of the acquisition of the overprint, filtering the subsequent compressional deformation. The results in Cameros basin (*Villalaín et al., 2003*) displayed a typical extensional geometry, reflecting the original geometry of the northern basin border, later modified during the Tertiary inversion stage.

The Iberian ranges and the Basque Cantabrian basin contain other basins with a thick Mesozoic syn-rift series, several thousands meters thick, inverted during Cenozoic compression. In this work we present paleomagnetic results obtained in Mesozoic syn-rift series of different basins from North Iberia. The paleomagnetic results indicate that the different studied lithologies (Triassic red beds, Jurassic marine limestones and Cretaceous red beds) are dominated by a normal syn-tectonic overprint of extraordinarily high intensity (0.3 A/m in limestones). The directions of this remagnetization agree with the pattern observed in the Cameros basin, showing also a consistent extensional geometry previous to the Tertiary folding. In this work we also show rock magnetic and mineralogy results of the different remagnetized rock types.

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# SMALL CIRCLE METHODS IN PALEOMAGNETISM

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A remanence small circle is the path on which the remanence moves during tilt correction. It is defined by the bedding attitude of the site and the presumption of a horizontal tilt axis parallel to bedding strike. Small circle methods are the key to the tectonic interpretation of synfolding remanences, but they can also be used for prefolding remanences, e.g. to cross-check conventional fold tests and to examine tectonic deformation in more detail. There is moreover the feature of the small circle distribution: remanence vectors, acquired at different stages of tilting, will be distributed on a small circle parallel to the π-circle of bedding. Such small circle distributions are found in directionally folded sequences, but also in single sites and even in individual specimens, a point which should be kept in mind already during the identification of the remanence components.

Currently there are the following methods/approaches with small circles (Fig. 1):

1 Paleofield estimate from intersecting small circles (*McClelland-Brown, 1983*; *Surmont et al., 1990*; *Shipunov, 1997*) with associated fold testing (*Waldhör and Appel, 2006*).
2 Small circle reconstruction (partial tilt correction) of synfolding remanences (*Waldhör et al., 2001*).
3 Occurrence and distribution of small circle intersections to assess validity and robustness of small-circle paleofield estimates and to recognize regular/irregular tectonic settings (*Waldhör and Appel, 2006*).

Small circle methods shall not replace any conventional method in paleomagnetism. They are geometrically alternative to tilt correction and, applied in addition, they allow for a more detailed and more reliable interpretation of the data.

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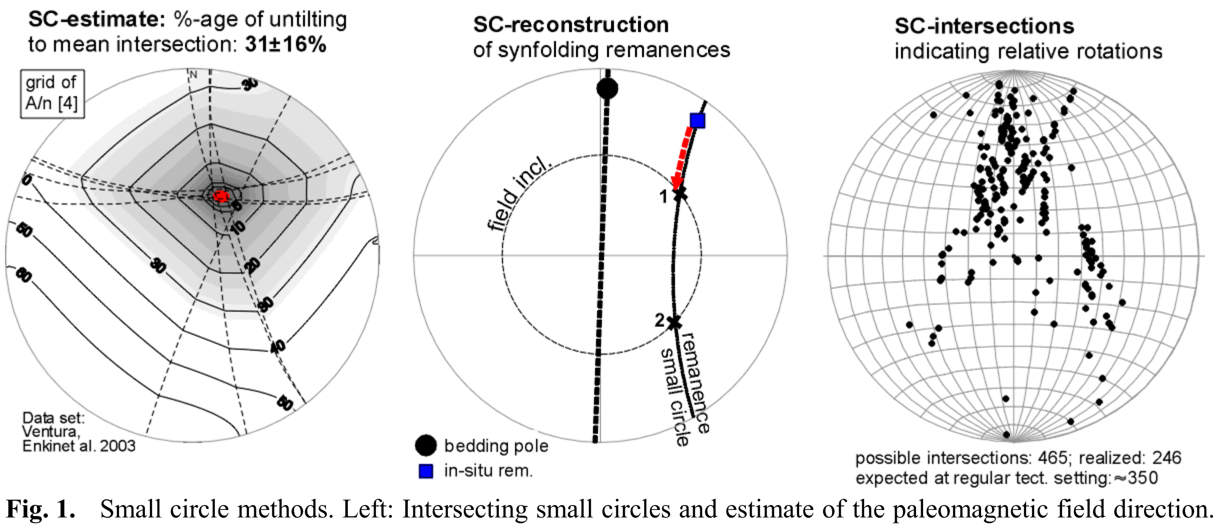


**Fig. 1.** Small circle methods. Left: Intersecting small circles and estimate of the paleomagnetic field direction. Center: Small circle reconstruction of synfolding remanences to obtain vertical-axis rotation. Right: Occurrence of small circle intersections to recognize regular/irregular tectonic settings.

## SP-GRAIN PRODUCTION DURING THERMAL DEMAGNETIZATION OF SOME CHINESE LOESS/PALEOSOL

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Progressive thermal demagnetisation of natural samples to above 300°C may cause significant alterations of magnetic mineral phases. Such changes are commonly monitored by magnetic susceptibility determinations at every demagnetisation step. In an attempt to characterise in more detail alterations products created during thermal demagnetisation of some Chinese loess/paleosols (L1/S1), susceptibility was measured at both room temperature ($MS_{293k}$) and at liquid Nitrogen temperature ($MS_{77K}$) between each step.

The ratio $R_{MS} = MS_{77K}/MS_{293K}$ varies from a maximum of 3.83 for pure paramagnetic minerals to less than 1.0 for Verwey-transition-magnetites. SP-grains of magnetite that pass from SP- to the SD-state upon cooling to 77 K also have $R_{MS} < 1.0$. Thus $R_{MS}$ is not a unique parameter for identifying SP-SD transitions. However, combining $R_{MS}$ with frequency dependent susceptibility, we observe an inverse linear relationship between frequency-dependent *MS* (%fd) and the ratio $R_{MS}$ indicating that the variations in $R_{MS}$ is controlled by populations of SP grains rather than Verwey-transition magnetites. We also observe Verwey-transition of SIRM, indicating that this population of magnetite grains does not control MS.

$MS_{77K}$ shows a systematic decrease relative to $MS_{293K}$ with increasing demagnetisation temperatures commencing at around 200°C.

We conclude that $R_{MS} = MS_{77K}/MS_{293K}$ combined with %fd may monitor SP-production and that SP-production in loess/paleosol apparently commence at 'surprisingly' low temperatures.

# MAGNETIC FABRICS OF PERMIAN VOLCANIC SUCCESSION FROM NORTH SUDETIC BASIN (SW POLAND) - THE RECONSTRUCTION OF VOLCANIC EVENT SCENARIO

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The AMS technique was employed for reconstructions of the probable location of volcanic centres and possible directions of flows during the eruption within the Wolbromek Graben (southeast part of the North Sudetic Basin, SW Poland). The AMS study was combined with detailed field observations and petrotextural analysis of silica-rich volcanics, both lava and pyroclastic deposits. Five series of volcanic rocks of different genesis (tuffs, ignimbrites, lavas, *Pańczyk and Słaby, 2002*) were researched in three suites.

The North Sudetic Basin developed on the metamorphic basement is located in the West Sudetes, which are situated on the northeast margin of the Bohemian Massive (the eastern part of European Variscides). The North Sudetic Basin is located between the NW trending Sudetic Marginal Fault from the north-east and WNW trending Main Intra-Sudetic Fault. From the Intra-Sudetic Basin and Świebodzice Depression is separated by complicated system of faults and thrusts. The investigations of the silica-rich volcanic succession were concentrated in the southeastern part of the North Sudetic Basin, within the southernmost fragment of the Świerzawa Graben close to Bolków. This part of the Świerzawa Graben is known as Wolbromek Graben. The examined volcanites have been thought to be of Lower Permian age and they were included into Wielisławka Formation in the lithostratigraphical profile of the Rotliegend in the North Sudetic Basin.

The co-existance of different volcanic facies could be related to paleogeography and paleoenvironment prior to the volcanic episode (*Pańczyk 2002, 2003*). Most probably, the surface water of paleofluvial system of the Wolbromek Graben was the source for initial phreatomagmatic eruption. The high-grade ignimbrites (The Świny ignimbrite suite) and deposits of base surges (the first unit of the tuffs suite) were formed at the same period of time. The main difference in the character of the eruption (explosivity) was caused by location of eruptive centre: for tuffs it could have been situated in a paleovalley, whereas for high-grade ignimbrites presumably at a plateau or ridge. This volcanic event scenario is supported by analyses of clasts within the alluvial fan, which is capped by both series of volcanites. There is no evidence for volcanic activity during it formation. Presumably, change from phreatomagmatic to magmatic condition of eruptions took place rather smoothly. Several small-volume eruptions took place forming lavas (the Świny lavas suite) and pyroclastic flows (the Popielowa ignimbrites suite), finally resulting in formation of greater volume of erupted lavas (Popielowa lavas). Due to limited number of outcrops, erosion and alteration of the rocks, it is not possible to estimate number of eruptions. The lateral extend of single lava and pyroclastic flows is unknown due to the discontinuous nature of the outcrops. The eruptions spreaded from elongated fissures. The vent area is known for the lava flows from the Popielowa Hill, where the en-echelon aligned vents occur. On the other hand, for the Świny lavas suite only one fissure near Świny village is preserved. However, according to field observations, several lavas, which make up the hill in the local topography, were connected with different volcanic centres. For the ignimbrites and tuffs the location of the vent area is unknown. Nevertheless, it is assumed that the vents presumably are situated to the south or east south of the Popielowa-Swarna Ridge. Additionally, analyses of the type and size of accretionary lapilli suggest that the volcanic centres must have been located not further than three kilometres from the exposures.

The Popielowa lavas series as well as the Popielowa ignimbrites are characterized by subhorizontal magnetic lineation (trending WWN-EES, *Pańczyk and Werner 2004*, Fig. 1). The maximum axes (kmax) are grouped parallel to macroscopically observed direction of flows (Fig. 2). In these units a steep magnetic foliation plunge to NNE. The magnetic lineation fabric very similar to that for Popielowa units is observed in the Swiny ignimbrite series. Maximum susceptibility axes are quite well defined and reflect the direction of moving of lava and pyroclastic flow. On the other hand, the magnetic lineation in the Swiny Lavas suite is generally similar to those in the other volcanic series, whereas the magnetic foliation appears to be much more scattered, without any clear direction. The tuff series do not display any well-defined lineation fabrics, with kmax scattered in the horizontal plane of magnetic foliation.

Anisotropy of magnetic susceptibility of the silica-rich volcanites from the Wolbromek Graben suggested that the magnetic fabrics correspond to the observed in the field directions of moving lavas and pyroclastic

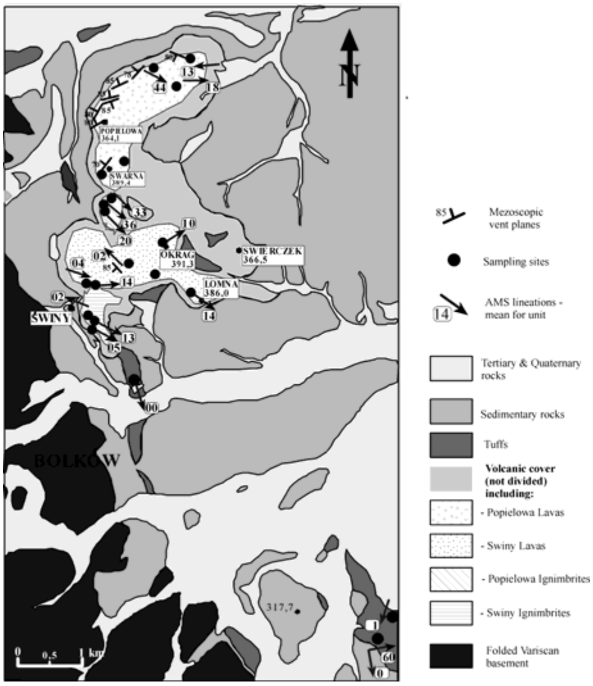


**Fig. 1.** The location of sampling sites and the orientation of AMS lineations (means for sites).

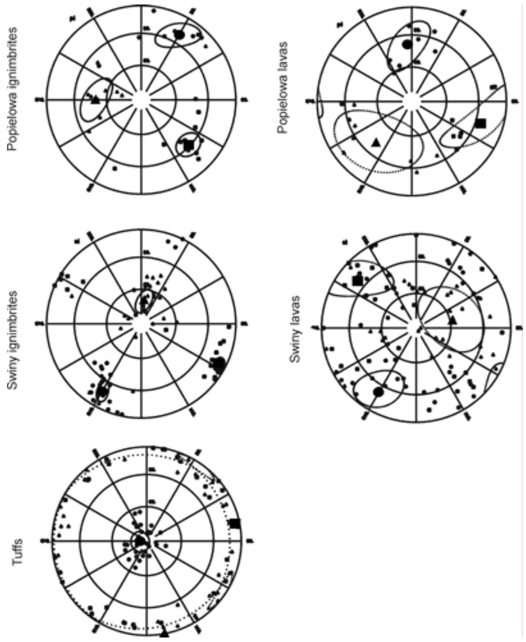


**Fig. 2**. AMS principal axes for ignimbrites, tuffs and lavas. Averaged AMS tensor was calculated for a set of all samples from each unit (mean axes are the same as for mean AMS tensors of single hand samples).

flows, and generally show NW-SE trend for the Popielowa lavas and ignimbrites series as well as for the Swiny ignimbrites (Fig. 1).

Additionally, it seems that the vent area for the Swiny Ignimbrites might be located to the south or west south of the known Popielowa volcanic centres. However, the well-defined mostly steep magnetic foliation remains an open question. Probably, it could be connected with paleo-valley system, which might have been followed by lava and pyroclastic flows. On the other hand, the second scenario, perhaps more realistic, could be suggested. The magnetic foliation might reflect the primary magnetic characteristics of the ascending magma within the conduit system. In the case of the Swiny lavas series the magnetic lineation is generally coherent with dominating trends for the volcanites from the Bolków area as well as with macroscopically observed vesicle foliation. Their sligthly varying trends can be correlated with suspected local vents. The larger scatter for the foliation might be the result of post-magmatic alteration phenomena. The completely dissimilar magnetic fabrics for the tuff series most probably result from the phreato-magmatic origin and consequently different emplacement mechanism. However the poorly defined magnetic lineation can be correlated with the N-S direction of the shapes of the tuff units.

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# MAGNETIC SIGNATURE OF ANTHROPOGENIC POLLUTION OF SEDIMENTS AND CORRELATION WITH HEAVY METALS: CASE STUDY FROM EAST LAKE IN WUHAN, CHINA

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Mineral magnetic measurements have been widely used for delineation of environmental pollution (*Petrovský et al., 2000*; *Hanesch and Scholger, 2002*). It is based on the fact that many anthropogenic impacts on the environment (effluents from power plants, combustion of fossil fuel, metallurgical industries, smelters, traffic, waste-water, etc.) are accompanied by significant emissions of strongly magnetic particles (e.g. magnetite) bearing heavy metals, identification of these particles in various ecosystems can contribute to fast and simple mapping of areas and sites exposed to higher pollution impact (*Petrovský et al., 1998, 2000*; *Hanesch and Scholger, 2002*; *Desenfant et al., 2004*; *Knab et al., 2005*).

The East Lake, Wuhan, China is to the northeast of Wuhan city and close to (in the downwind region) Wuhan Iron and Steel Company and Qingshan Thermal Power Plant. The water area and average depth of the lake are 27.9 $km^2$ and 2.6 m, respectively. With the rapid development of industrialization and urbanization, environmental pollution have been constantly increase during last decades, due to factors such as heavy traffic, emissions from the power plant, factories, cement plants, waste discharge, etc.

In this study, detailed magnetic measurement and geochemical analysis were performed on the sediments from the East Lake, to establish links between enhanced concentrations of anthropogenic magnetic particles, concentrations of heavy metals, and known sources of pollution. Magnetic susceptibility, which has been used in other studies as indicator of increasing pollution levels, show high value with the maximum of $203.9 \times 10^{-8}$ $m^3/kg$ towards the banks of the lake and near the travel line of yachts. But it only links to the concentration of Pb and P (with the correlation coefficient of 0.645 and 0.731, respectively), and negatively or weakly correlate with Zn, V, Cr, Cu and TFe. However, close association between SIRM and Zn, Cr, and Cu was observed. For the same chemical element, SIRM is frequently higher correlated than $\chi$, suggesting that SIRM is a better indicator for pollution in this lake. A poor correlation ($r = 0.46$) between SIRM and $\chi$ suggests that multi magnetic mineral phase exist in the sediments (*Peters and Dekkers, 2003*). Thermomagnetic analysis (Fig. 1) combined with magnetic hysteresis measurements on the selected samples revealed that PSD/MD magnetite-like phase dominate the magnetic phases in the sediments (*Peters and Dekkers, 2003*). SEM/EDX examination of the magnetic extracts presented that these particles are rich in iron-oxides and have various morphologies: orange-peel structure, hollow structure with adhered smaller particles, Zr-rich melted-like irregular particles, pear-shape spherule and spherules with slick surface (Fig. 2). Based on the previous studies (*Petrovský et al., 1998, 2000*; *Hanesch and Scholger, 2002*; *Desenfant et al., 2004*; *Knab et al., 2005*) and combined with the environmental background around the lake, it is inferred that these magnetic particles derive from anthropogenic activities, such as combustion process, abrasion of tires, vehicles emission and building materials, and so on. Thus, the nearby Wuhan Iron and Steel Company and Qingshan Thermal Power Plant, the vehicles on the road along the lake, the yachts on the lake and waste-water outlets can be considered as the major pollution sources. These results suggest that simple, rapid, and non-destructive magnetic measurements could provide useful information about sources of pollution in this lake.

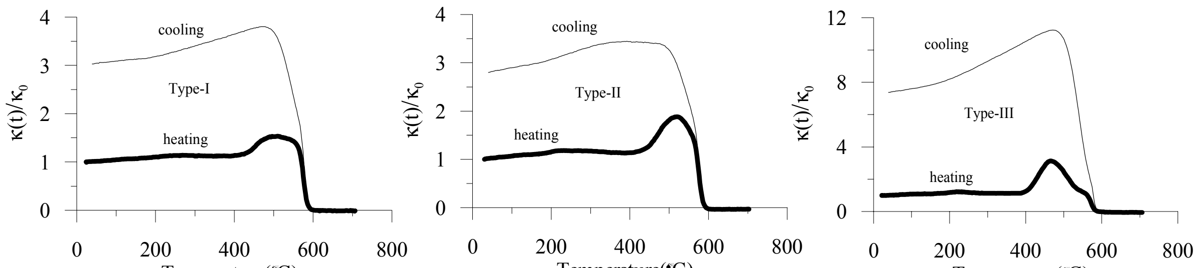
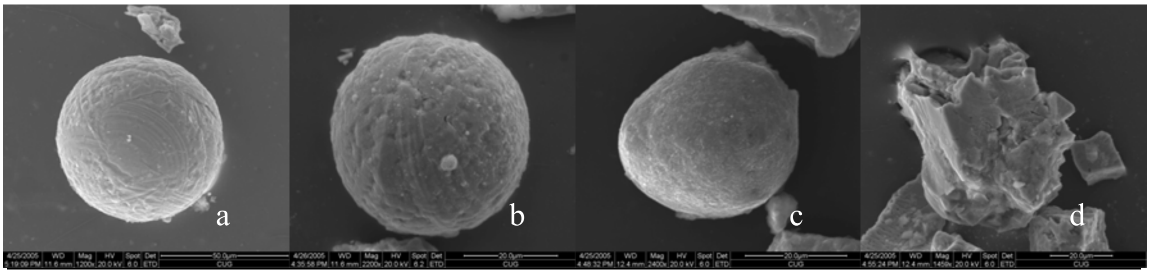



**Fig. 1.** Representative types of temperature dependence of magnetic susceptibility.




| Particles | O | Fe | Mg | Al | Si | Cl | K | Ca | Cd | Zr |
|---|---|---|---|---|---|---|---|---|---|---|
| a | 22.53 | 77.47 | | | | | | | | |
| b | 24.15 | 74.85 | | 0.33 | 0.38 | 0.29 | | | | |
| c | 40.93 | 27.04 | | 12.19 | 19.74 | | | | 0.10 | |
| d | 33.23 | 43.87 | 2.79 | 0.88 | 0.39 | 0.29 | 0.04 | 0.30 | | 18.21 |

**Fig. 2.** Representative SEM micrographes of magnetic extracts and corresponding elements. **a)** Only iron oxides were identified, $d \approx 60$ µm; **b)** Strongly magnetic Fe spherule with 'orange-peel' structure and adhered smaller particles on the surface, $d \approx 43$ µm; **c)** Pear-shape spherule containing Cd, $d \approx 40$ µm; **d)** Zr-rich melted-like irregular particle.

This study was supported by the National Natural Science Foundation of China (No. 40474025).

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# APPLICATION OF MAGNETIC PROPERTIES OF NANOPARTICLES IN DETECTING POLLUTION: THEORY AND A CASE STUDY FROM KOZANI REGION, NW GREECE

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In order to keep the living quality in urban agglomerations as high as possible, political decisions are needed which require robust and cost-effective scientific methods. In this regard, magnetic measurements, such as low-field susceptibility mapping and subsequent laboratory experiments, represent a promising cheap and fast screening technique to substantially reduce the costs of chemical analyses. Such magnetic measurements rely upon (i) the almost ubiquitous occurrence in soils of nanometre-sized iron oxides or sulphides; and (ii) the common association of organic, inorganic and even radioactive pollutants with such nanoparticles. In order to shed some light on the relationship between rock or soil magnetic parameters and chemical concentrations of pollutants, we investigated in detail the Kozani region, where the main source of pollution is fly ash from the emissions of four power plants located in the area. The magnetic susceptibility was mapped with a resolution of $1 \times 1$ km and soil samples were collected from each station. The in situ susceptibility values exhibit significant variation, ranging from very low background values ($7 \times 10^{-5}$ SI) to high values ($730 \times 10^{-5}$ SI), with a mean of $140 \times 10^{-5}$ SI. The same variation arises from laboratory low and high frequency magnetic susceptibility, with a mean frequency dependence of 5%. Additional laboratory experiments were performed to determine the type and size of main magnetic carriers: isothermal remanence acquisition, stepwise alternating field demagnetisation of anhysteretic remanence magnetisation and hysteresis loops. The magnetic analyses were complemented by geochemical measurements and correlations between the various magnetic parameters and the concentration of specific pollutants were established.

# IRON-OXIDE BASED NANOPARTICLES FROM THERMAL PROCESSES BY VIEW OF MÖSSBUAER SPECTROSCOPY

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The Fe-O based nanoparticles and nanocomposites prepared by thermally induced solid-state reactions with using of suitable synthetic and natural Fe-precursors were found to be very effective in various industrial, medical and environmental applications including catalysis, magnetic resonance imaging, drug delivery or water treatment. $^{57}$Fe Mössbauer spectroscopy represents a powerful tool in monitoring the reaction mechanism and structural and magnetic properties of the iron oxide nanoparticles (*Zbořil et al., 2002*; *Tuček et al., 2006*). The significant contribution of a technique to the solution of the solid-state reaction mechanisms will be demonstrated with the examples of the thermal decomposition of Prussian Blue (*Zbořil et al., 2004*), the oxidative conversion of iron(II) oxalate (*Heřmánek et al., 2006*) and thermal transformation of natural pyrope (*Zbořil et al., 2003*). The structural and magnetic properties of various nanoscopic iron oxides prepared by solid-state route will be presented, including rare nanocrystalline β- nad ε-$Fe_2O_3$ polymorphs, ultrasmall (1−2 nm) amorphous iron(III) oxide nanoparticles or magnetic nanocomposites of $Fe_3O_4$ with the biocompatible MgO matrix, which are applicable in medicine for a cancer therapy using hyperthemia or in biomagnetic separation processes (*Schneeweiss et al., 2006*). The magnetic regime of iron oxides below the ordering temperature will be discussed with respect to their in-field Mössbauer spectra yielding superior data on the number of iron atoms in the non-equivalent structural positions, a degree of the spin-frustration and the spin canting angle. Moreover, the method, if applied at low temperatures in the sufficiently high external magnetic fields, offers the unique possibility of distinguishing of the isostructural magnetite ($Fe_3O_4$) and maghemite (γ-$Fe_2O_3$) nanoparticles, which is one of the crucial problems of the recent iron oxide research. A possibility to use the suitable Fe-bearing environmental waste as precursor for thermal synthesis of the Fe-O nanoparticles with interesting properties will be demonstrated on thermal transformation of acid main drainage precipitate (poorly crystalline ferrihydrite) in hydrogen resulting in the formation of the core-shell Fe-FeO nanoparticles which are well applicable in the reduction technologies of the water treatment (*Filip et al., 2006*).

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# ROCK MAGNETIC EVALUATION OF DEEP-SEA IGNEOUS CORES RECOVERED FROM PACIFIC, ATLANTIC, AND THE SOUTHERN INDIAN OCEANS

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Generation of ocean crust and uppermost mantle by seafloor spreading at mid-ocean ridges is the cornerstone of the solid Earth cycle. The ocean crust preserves a record of the direction and intensity of Earth's magnetic field in the past. Understanding the magnetic carriers of oceanic crust is an essential prerequisite for addressing fundamental questions in the variability of the Earth magnetic field in the geologic past and its implications for a broad range of problems in the Earth sciences. Previous rock magnetic investigations of oceanic basement samples have been mainly restricted by single drill holes or dredge collections. In this study, we present new and published data on the paleomagnetic and rock magnetic properties of igneous rock samples recovered during several Ocean Drilling Program (ODP) and Integrate Ocean Drilling Program (IODP) cruises in the Pacific, Atlantic, and the southern Indian oceans. The recovered igneous rocks from these legs are mainly basaltic flows (both submarine and subaerial), diabase sills, lower crustal gabbros, and serpentinized peridotites with approximately ages of 140,000 years, 1.5–2 Ma, 10–12 Ma, 34 Ma, 69 Ma, 100–108 Ma, and 110–121 Ma, which offers an opportunity to investigate magnetic properties and mineral changes attending alteration of basement rocks over a wide range of ages from variable tectonic settings. Our rock magnetic data indicate that the differences in the rock magnetic properties of basaltic rocks are mainly a function of mineralogy and alteration. There is no apparent coincidence between the age of the rocks and the degree of low-temperature alteration, as suggested by the presence of nearly unoxidized titanomagnetite in the Cretaceous aged basalts and by an examination of Curie temperature vs. sample age that does not unambiguously show a positive relationship between the degree of low-temperature oxidation and crust ages.

Titanomagnetite and titanomaghemite are commonly present in igneous rock samples of the Ontong Java Plateau, the Kerguelen Plateau/Broken Ridge, the eastern Equatorial Pacific, the Mid Atlantic Ridge, and the Newfoundland-Iberia rifted margins. For basaltic rock samples, three general groups (A, B, and C, respectively) can be divided in terms of rock magnetic properties. Samples from group A have a single phase of Ti-poor titanomagnetite with Curie temperatures ranging between 480º and 580ºC and exhibit a strong Verwey transition in the vicinity of 110 K. Basalts from this group are most likely good paleomagnetic recorders and probably have preserved original and stable magnetic remanences. Group B is mainly observed in pillow lavas and is characterized by a Curie temperature of 260º–280ºC, which is typical of low-temperature oxidized titanomaghemite or titanium rich titanomagnetite (such as oxidized TM60). The low-temperature curves for group B do not show the Verwey transition. Several fine-grained submarine basalt samples in this group exhibited an apparent partial self-reversing behavior during thermal demagnetization and in a narrow temperature window that corresponds to the titanomaghemite phase determined from thermomagnetic experiments. Group C has more than one Curie temperature, which suggests the presence of multiple magnetic phases. Although the hysteresis ratios for rocks in this group still fall in the PSD region, the cluster is centered toward the multidomain (MD) region. Low temperature curves do not clearly show the Verwey transition. The thermomagnetic signature indicates the inversion of titanomaghemite to a strongly magnetized magnetite, as shown by the irreversible cooling curves. Our preliminary analyses demonstrate that rock magnetic signatures can help answer first-order questions concerning the processes of accretion responsible for generating the lower oceanic crust, thermal evolution of igneous sections, and the source of the marine magnetic anomaly.

# A NEW THEORY FOR THERMOREMANENT MAGNETIZATION ACQUISITION AND NEW APPROACH FOR ABSOLUTE PALEOINTENSITY DETERMINATION: CONSIDERATION ON TEMPERATURE AND INTERACTION-FIELD BLOCKING PROCESSES

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Although Néel's theory (1949) satisfactorily explains the magnetic properties of an isolated single-domain (SD) grain, which is an ideal recorder of both direction and intensity of the past geomagnetic field, numerous subsequent paleomagnetic researches showed that only rarely the magnetic carriers in rocks are pure non-interacting SD grains. In most cases, samples contain mixture of pseudo-single domain (PSD), multidomain (MD), and/or SD particles with strong magnetic grain (or domain) interactions. Our recent investigations indicate that magnetostatic interactions between magnetic assemblages can seriously affect the properties of thermal remanent magnetization (TRM) and generate non-ideal behavior for the Thellier-Coe paleointensity experiment. Here we extend the Néel's SD theory to the case where magnetostatic interactions among particles are generally present. Based on our new theory, we also present a new method for absolute paleointensity determination.

We demonstrate that, with the presence of strong magnetostatic interactions, not only grain's unblocking temperature ($T_{ub}$) will not equal to the blocking temperature ($T_b$), but also significant viscous effect exists: TRM will be unblocked or blocked more at slow cooling or heating rate. When we consider an assemblage of clustered SD particles with uniaxial anisotropy randomly orientated, then the distribution of magnetostatic interaction field ($h_{int}$) can be written as

$$h_{int} = \langle h_{int} \rangle + h_{int-random}$$

$\langle h_{int} \rangle$ is averaged field, which is proportional to existing average remanent magnetization of particles, generally has order of external earth field $h_0$ (~ 50 uT), and create additional TRM. While $h_{int-random}$ has random directions, has order of coercivity of particles (~ 10 mT), is the genuine reason of $T_{ub}$ unequal to $T_b$.

For the particles of coercivity less than the strength of $h_{int}$, they will be completely reset to the direction of $h_{int}$, and the macro remanent magnetization acquired is determined by the distribution of $h_{int}$: generally being proportional to the resulted field of $\langle h_{int} \rangle$ and external field $h_0$. While for particles of coercivity greater than the strength of $h_{int}$, the acquisition of pTRM is little complicated. The thermal activation theory of Néel is extended to this case. Consider a couple of SD particles of same properties but located in opposite $h_{int-random}$ direction. For simplicity, we only consider the case of uniaxial anisotropy located along the direction of external field $h_0$. When the particle reaches the activated state (potential energy wall $E_{min}$ < 25 kT), the pTRM will be acquired proportional to

$$\exp\left\{-E_{min}(+)/kT\right\} - \exp\left\{-E_{min}(+)'/kT\right\},$$

where

$$E_{min}(+) = \frac{1}{2}vJ_s h_c + vJ_s h_{int-random} + vJ_s\left(h_0 + \langle h_{int} \rangle\right),\ E_{min}(+)' = \frac{1}{2}vJ_s h_c + vJ_s h_{int-random} - vJ_s\left(h_0 + \langle h_{int} \rangle\right).$$

Thus, the net TRM acquired will be nearly proportional to $vJ_s\left(h_0 + \langle h_{int} \rangle\right)$, and the $h_{int-random}$ acts similar to coercivity $h_c$. Because the potential energy wall also depends on $h_{int}$, the magnetic moments are also activated or blocked by interaction field, thus causing viscous effect. Only when the system has enough time to reach final thermal equalibrium state, the $h_{int}$ is temperature-determined, otherwise it is depend on magnetization history. Generally the natural samples are blocked or unblocked both by temperature and interacting field.

For the interpretation of $T_{ub}$ unequal to$T_b$, we show that for the case where particles are well-isolated there is an ideal relationship

$$T_{ub0} = T_{b0} = vJ_s\left(T_{b0}\right)h_c\left(T_{b0}\right)/\left(50k\right)$$

and for the case where magnetostatic interacting field ($h_{int}$) is present,

$$T_{ub} = vJ_s\left(T_{ub}\right)\left\{h_c\left(T_{ub}\right)+2h_{int}\left(T_{ub}\right)\right\}/\left(50k\right),\ T_b = vJ_s\left(T_b\right)\left\{h_c\left(T_b\right)-2h_{int}\left(T_b\right)\right\}/\left(50k\right).$$

Thus, the unblocking temperature of grains with interacting field would shift to a higher temperature value compared to that of well-isolated grains, whereas the blocking temperature tends to shift towards a lower value. At the temperature that is higher than the ideal maximum $T_{ub}$ of an assemblage of clustered SD particles, the interacting field will disappear statistically, and the particles will reset and acquire a completely magnetized TRM (CM_TRM) during successively cooling, which is identical to the total TRM (cooled from Curie temperature to room temperature). This is the crucial point of our new experimental method for paleointensity determination: we compare the unblocking temperature spectra of the CM_TRM part of an artificial TRM with that of natural remanent magnetization (NRM) to estimate paleointensity, rather than comparing the unblocking spectra of NRM with blocking spectra of progressive artificial TRM, which is used in the traditional Thellier-Coe method. The premise of our new method is that, if the unblocking spectra of CM_TRM of an artificial TRM can be obtained before significant laboratory physicochemical alteration occurs, a reliable paleointensity can be extracted from samples, even for those samples that contain PSD and MD grains. To illustrate these characteristics and validate our method, we have conducted detailed experiments on several representative artificial magnetite samples.

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