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New Trends on Paleo, Rock
and Environmental Magnetism
10-16 June 2018, Chęciny, Poland
16th CASTLE MEETING

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Preface

Dear Colleagues,

This year we have the pleasure to attend already the 16th "Castle Meeting" on Paleo, Rock and Environmental Magnetsim. Although 16 is not the right reason to celebrate, these meetings started exactly 30 years ago as meeting on Paleomagnetism, Rock Magnetism and Database Usage.

The very first one was held in Liblice (Czechoslovakia) in 1988, being motivated by discussions held during the International Association for Geomagnetism and Aeronomy (IAGA) Assembly in 1985 in Prague. Actually, since the beginning in 1988, the meetings have been recognized by and sponsored by IAGA. I remember the first one in 1988 pretty well – I gave my very first oral presentation on paleomagnetism of rocks from Cap de Chevre (France). My shirt got completely wet and I had barely idea what I was tolking about. However, I met several great personalities in our field of research, such as legendary Vit Jelinek (who otherwise practically did not attend any meetings). One year later, in 1989, the political situation in our country changed dramatically. This change resulted in exit of several of my co-workers, including my supervisor, to private business and I was left almost alone with the decision of the first meeting to continue the organization of these events on regular bi-annual basis. Thus, I had to organize the second one in 1990 in Bechyne. At that meeting we agreed with colleagues from Bratislava (Slovakia) to hold the meetings alternately in both new countries – Czech and Slovak Republics (see the list of meetings held until now at the end of this text). As a result, it has been my privilege and great pleasure to organize, or be at hand to organizers, of these great meetings for 3 decades.

These meetings got a worldwide reputation in particular for the atmosphere, which has always combined scientific work with excellent social programme, consisting of local tours, cultural performances, food and drinks tasting, etc. I especially appreciate very much that the attendees varied from regular, well recognized experts to young Ph.D. (or even master) students; many of the latter ones developed later on to well established and known scientists. All the participants easily got the idea that the meetings represent ideal training for young colleagues – acting as chairs of sessions, being evaluated for their performance and nominated for the IAGA award, etc. And one could not count how many working cooperations, projects and good personal friendships were established at these meetings. To conclude, we successfully "survived" three decades of these bright events. Four years ago we moved for the first time outside former Czechoslovakia and no doubts local organizers (Pedro Silva in Portugal in 2014 as well as Simo Spassov in Belgium in 2016) proved that they got these meetings deeply uder their skin. I only wish this trends remains also for the future, having meetings of this size, with relaxed atmosphere and participants from about 25 countries worldwide, combining various ages and cultures. It will be always my great honour and pleasure to attend them.

Wishing the meetings and the community behind them promising and prosperous future

In Prague, 9 May 2018
Eduard Petrovsky

List of the “Castle Meetings”:

1988	Liblice	Czechoslovakia
1990	Bechyne	Czechoslovakia
1992	Smolenice	Slovakia
1994	Trest	Czechia
1996	Topolcianky	Slovakia
1998	Hruba Skala	Czechia
2000	Moravany	Slovakia
2002	Zahradky	Czechia
2004	Javorina	Slovakia
2006	Valtice	Czechia
2008	Bojnice	Slovakia
2010	Nove Hrady	Czechia
2012	Zvolen	Slovakia
2014	Evora	Portugal
2016	Dinnant	Belgium

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Investigation of the Magnetic Properties and Trace Elements in Sediments from Thermaikos Gulf, NW Aegean Sea

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A b s t r a c t

In the present study sediments cores from the inner part of Thermaikos Gulf are examined by means of magnetic properties. The investigated area covers the gulf and the bay of Thessaloniki, the second biggest city of Greece and metropolitan center in the Balkans. The bay of Thessaloniki is a shallow embayment while the gulf of Thessaloniki is a wider marine area. The main characteristic of both areas is the very shallow zone across the western coast resulting from Axios river supply. In order to investigate the anthropogenic impact sampling of the top 2 cm of the surface sediment was carried out on a monthly basis (January–December 2016) at five measurement stations (S1-S5) situated within the investigated area. Measurements of the magnetic susceptibility have been performed on all core samples with a Bartington MS2C sensor in order to identify possible seasonal variations and differences of the magnetic content between the five measurement stations. Magnetization and coercivity data (Ms, Mrs, Bc, Bcr) have been determined using an induction coercivity me-

ter (Jasonov *et al*. 1998). Additionally, DC magnetometry was performed on selected samples with a MPMS3. Finally the concentration of trace elements has been determined for all studied samples using flame atomic absorption spectrometry.

The spatial distribution of the magnetic susceptibility values reveals the presence of a magnetically enhanced zone (stations S2, S3) in the western part of the study area close to the river outfall. These high values appear to be rather constant throughout the whole year, but with few exceptions during spring time. The Day plot confirms the specific character of these two stations as a differentiation toward the MD fraction is obvious. All magnetic measurements are combined with the concentration of the trace elements and their correlation will be discussed.

Keywords: magnetic properties, trace elements, pollution, Greece.

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Using Thermomagnetic Curves as Indirect Indicator of Residual Pollution on Fluvial Sediments Affected by Mining Activities

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Abstract

This work aims to evaluate the use of thermomagnetic curves to identify the presence of iron oxyhydroxysulfates (jarosite type minerals) by their transformation at high temperatures to ferrimagnetic iron oxides. Samples consist of fluvial sediments from a creek that was affected by a leak of sulfuric acid solution coming from a mine leachates dam, in Cananea, Sonora, Mexico. Measurements of volume magnetic susceptibility (κ) vs temperatures were performed in air, heating samples from 30 to 700 °C, and cooling back to 50 °C. Samples of the acid solution dam precipitates exhibited an important increase of magnetic susceptibility during heating, starting at 330 °C, and reaching its maximum (4 times the initial κ values) at 430 °C, followed by a drastic decrease; an even bigger increase of magnetic susceptibility during cooling was also observed. A very similar behavior was observed in samples of fluvial sediments from the affected basin, showing increases from 3 to 6 times the initial κ value during heating. Samples of not affected materials from the same area exhibited a contrasting behavior, presenting a decrease of κ during heating at 550 °C, and lower susceptibility values during cooling. The temperature at which the magnetic susceptibility increase occurs in affected samples coincides with the temperature reported for the desulphation of jarosite and its transformation to maghemite (Frost *et al*. 2005, 2007). This transformation at high temperatures can be used to infer the presence of material coming from the leak and delineate the affected area along the basin.

Keywords: thermomagnetic curves, jarosite, mine wastes pollution.

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Publications of the Institute of Geophysics, Polish Academy of Sciences
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Per-component Thellier-Thellier

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Abstract

Obtaining reliable paleointensities from lavas is a notoriously difficult task. Methods to obtain absolute intensities, e.g., Thellier-Thellier or Multi-specimen-style techniques, rely on heating a specimen to demagnetize their thermally acquired Natural Remanent Magnetization (NRM) and replace it with a partial Thermoremanent Magnetization ((p)TRM) arising from an applied external lab field.

The most common Thellier-type protocols require heating a specimen to each temperature at least twice (‘double heating’) to assess the NRM left or the partial TRM gained individually for each temperature step. The double heating of the specimen is performed once for the demagnetization of the sample in a field free thermal demagnetizer, and once with an external field to acquire a partial TRM in the direction of the applied field. The heating temperature in both steps must be similar and the accuracy of the temperature control of the furnace used is crucial for the experiment to work. pTRM checks and pTRM-tail checks can be performed to see if the sample underwent alteration. Tails of the pTRM can, however, also show as an effect of the non-repeatability of the set temperatures in the lab, which will falsify the results.

Here we propose a new Thellier-style protocol to obtain reliable paleointensities from lavas that will reduce the number of heating steps and potentially eliminate the effects of pTRM tails. This protocol relies on interpreting the demagnetization of the NRM from the two orthogonal axes to the applied field axis, that can be isolated from the pTRM steps. The zero-field steps are therefore no longer necessary and can be removed from the measurement protocol since the magnetic vector is decomposed in three components along the three Cartesian axes, with the applied field direction along one of them. The main assumption underlying our per-component protocol is that the applied field only leads to an induced magnetization along the applied field-axis – but this is hardly an extension of the rules of additivity and independence that form the basis of all Thellier-type paleointensity protocols. Here we will discuss the mathematical derivation of the paleointensity information, the first results using this newly proposed measuring scheme, and a broader assessment based on reinterpreted literature data to shed light on, e.g., the limitations on the direction of the NRM with respect to the applied field and possible overprints on the NRM.

Keywords: paleointensity experiments, Thellier-Thellier, new protocol, per-component.

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Thermal Fluctuations in FORC Diagrams: the Missing Link Between FORC Diagrams and Natural Remanence Acquisition

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Abstract

First-order reversal curves (FORC) have become an extremely successful method to assess domain states such as single-domain (SD), pseudo-single-domain (PSD), and multi-domain (MD) grains as well as magnetostatic interactions and are therefore an invaluable tool for basic sample characterization. There use to predict remanence acquisition behaviour, however, has traditionally been limited and mostly qualitative. Traditionally, FORC diagrams are interpreted in terms of Preisach theory that breaks the magnetic behaviour of the different domain states down into individual elementary hysteresis loops (hysterons). These effectively depend on a grain's coercivity and an interaction field, but do not contain any information about a grain's thermal or viscous (thermoviscous) behaviour. In the case of igneous rocks, natural remanence (NRM) acquisition is, however, (chemical alterations apart) almost always thermoviscous in nature. Hence, in order to use FORC diagrams for NRM analysis, the inclusion of thermal fluctuations in the model is essential.

Recently, Muxworthy and Heslop (2011), measured and interpreted FORC to simulate and predict thermoremanence (TRM) acquisition of the given sample in order to obtain paleointensity estimates from alternating field (AF) demagnetization data. This work, the first attempt at predicting remanence behaviour from FORC diagrams, yielded some encouraging results, although their interpretation of FORC diagrams completely neglects thermal fluctuations and obtains TRM behaviour purely from model assumptions.

This work extends the hysteron-model by a thermal fluctuation field that allows to account for and interpret thermoviscous effects in FORC diagrams in order to obtain better NRM predictions from FORC diagrams. It is shown that thermal fluctuations have a visible effect in FORC diagrams that is similar to a magnetostatic interaction field in appearance and can hence easily be misinterpreted. It is shown how thermal fluctuations manifest in the diagrams for single-domain (SD) and multi-domain (MD) grains and that accounting for them is essential to predict NRM acquisition such a s paleointensities.

Secondly, a new type of FORC measurements, termed time-asymmetric FORC (TAFORC) diagrams is proposed which allows to quantify thermal fluctuations and to distinguish them from interactions. It makes use of two different (asymmetric) timescales for the reversal field H_a and the FORC measurement field F_b: the reversal field H_a is applied for an extended period of time (e.g., 100 s) to allow grains to thermoviscously relax, but the measurement field H_b of the FORC is kept for the commonly used short interval (e.g., 150 ms), inhibiting thermoviscous relaxation. This results in a measurable shift along the H_u (vertical) axis of the FORC diagram that is dependent the on mineralogy, grain shape, microcoercivity, etc. – quantities contribute to the TRM acquisition behaviour. Hence, while traditional FORC diagrams only provide information on the domain states and coercivities of a sample, TAFORCs may provide much more information, and in particular those quantities that determine TRM acquisition.

Keywords: FORC diagrams, thermal fluctuations, viscous remanent magnetization.

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Paleomagnetic Field Reconstruction from Mixtures of Titanomagnetites

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A b s t r a c t

Stepwise thermal demagnetization and alternating field (AF) demagnetization are commonly used in paleomagnetic studies to isolate remanent magnetic components of different origins. The magnetically hardest, i.e., highest unblocking temperature/peak field component is often interpreted as the primary magnetization and magnetically softer components as subsequent remagnetizations due to geological events posterior to the formation of the rock, such as reheating or formation of new magnetic minerals. The correct interpretation of the sequence of the geological events such as tectonic rotations from paleomagnetic data often relies on correctly attributing the observed magnetic directions to the remanence carriers and acquisition mechanisms. Using a numerical model to simulate remanence acquisition and stepwise thermal and AF demagnetization experiments, we show that the presence of mixtures of different magnetic minerals, such as magnetite and titanomagnetites of varying titanium – content can have very significant effects on Zijderveld plots. In thermal demagnetization experiments a spurious third component at intermediate temperatures or a continuous curvature may arise from an overlap of the primary remanence with a subsequent thermal or viscous remagnetization carried by small-grained iron-rich magnetite and large-grained titanium-rich titanomagnetite. AF demagnetization plots of magnetic mixtures are even more complex: primary and secondary remanences carried by different minerals may appear as either three or four components in Zijderveld plots. During alternating field demagnetization, the highest coercivity component is not necessarily equivalent to the primary remanence and does not necessarily correspond to the highest temperature component in an analogous thermal demagnetization experiment, i.e., the primary remanence direction cannot be recovered. The effects are shown to be due to the different responsiveness of magnetite and titanomagnetites towards viscous or thermoviscous remanence acquisition: remanent magnetizations with long acquisition times are more effectively recorded by titanium-poor minerals, while short acquisition times are equally well recorded by titanium-rich minerals. In demagnetization experiments on laboratory timescales, the relative contribution of two minerals to Zijderveld plots differs to the relative contribution of remanence acquisition over geological timescales, leading to overlapping components in Zijderveld plots. The model was also used to simulate paleointensity (ancient magnetic field intensity) experiments and it was found that the grain distribution affects the slope of Arai plots, but is negligible compared to the effect of the cooling rate of NRM acquisition. The simulations suggest that for slowly cooled rocks a cooling rate correction of up to 1.5 to 1.6 may be required depending on the mineralogy (Berndt *et al*. 2017).

Keywords: titanomagnetite, magnetic mineral mixture, Zijderveld plot, paleointensity.

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Magnetic Anisotropy of Ferromagnetic Grains – Comparison of Different Methods

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A b s t r a c t

Anisotropy of magnetic properties is related to the crystallographic or shape preferred orientation of minerals, or the distribution of strongly magnetic grains. The preferred alignment of ferromagnetic or remanence-carrying grains is particularly important for paleomagnetic studies, because their anisotropy can deflect the magnetization away from the inducing field, and affect the intensity of magnetization. Hence, a reliable characterization of this anisotropy is crucial for correcting paleodirectional and paleointensity data. Several methods have been developed to characterize the magnetic fabric of ferromagnetic grains or those ferromagnetic grains that carry remanence: anisotropy of anhysteretic remanent magnetization (AARM), isothermal remanent magnetization (AIRM), thermal magnetization (ATRM), or partial remanent magnetizations applied over certain windows of the coercivity or blocking temperature spectra (ApARM, ApIRM, ApTRM). One method that allows separation of the contributions from paramagnetic, ferrimagnetic and antiferromagnetic minerals, is torque magnetometry. Here, we compare these different ways of characterizing magnetic fabrics of ferromagnetic grains for a suite of rocks of different composition. Samples include layered intrusions (Bushveld Complex, South Africa; Duluth Complex, MN, USA), red bed sediments (Mauch Chunk Formation, PA, USA) and metamorphic rocks (Thomson Formation, MN, USA). A set of 7 A(p)ARM tensors has been measured on each sample using coercivity windows of 0–20, 20–50, 50–100, and 100–180 mT as well as 0–50, 0–100, and 0–180 mT. Nine A(p)IRM tensors, and three A(p)TRM tensors have been determined on each sample of a subset of these. These remanence anisotropy results will be compared to the isolated ferrimagnetic and antiferromagnetic contributions as determined by torque measurements.

Initial results show that principal axes' directions as well as the shape and degree of anisotropy can vary significantly when measured with different methods, or over different coercivity ranges. Our results indicate that the magnetic fabrics of remanence-carrying grains, or ferromagnetic grains in general, cannot be described by a single tensor, because they vary between methods and depend on the coercivity range. This is likely related to distinct fabrics of different generations of grains all contributing to a rock's remanence, and has important consequences for paleomagnetic and magnetic fabric studies. Care has to be taken to correct paleomagnetic data for the most appropriate anisotropy tensor or set of anisotropy tensors.

Keywords: magnetic fabric, remanence anisotropy, AARM, AIRM, torque magnetometry.

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Detecting Externally Forced Long Term Palaeomagnetic Variations: Insight from Dynamo Simulations

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Abstract

The internal geomagnetic field varies over a huge range of timescales but it is only at the longest of these (10^7 to 10^9 years) that we expect to encounter a signature of geodynamo forcing from mantle convection and Earth's secular cooling. Precise and accurate identification of such variations and their causes represents one of the great outstanding challenges for palaeomagnetism and deep Earth science.

Here we assess for the first time a broad swathe of new and published geodynamo simulation outputs (Davies *et al*. 2008, Heimpel and Evans 2013) using palaeomagnetic techniques. These simulations span a wide range of input parameters and boundary conditions producing magnetic field variability at Earth's surface that ranges from highly unstable, through nonreversing, to fully "locked" by mantle heterogeneities (Fig. 1). Nevertheless a common feature of the displayed behavior is a tendency for "low frequency secular variation": variations in directional scatter and intensity that change over the equivalent of hundreds of thousands of years. Such variations are also an observed characteristic of the geomagnetic field over the last 2 million years (Valet *et al*. 2005) and reflect the highly nonlinear nature of the geodynamo process.

We will present evidence that low frequency secular variation has the potential to bias previous attempts to recover properties of the time-average field and also to confound efforts to detect the even longer timescale variations that promise to yield information about the evolution of the deep Earth. We will also discuss what needs to be done to avoid such problems in future analyses and outline a strategy for palaeomagnetists to follow in the future.

Keywords: palaeomagnetism, geodynamo, secular variation, palaeointensity, reversals.

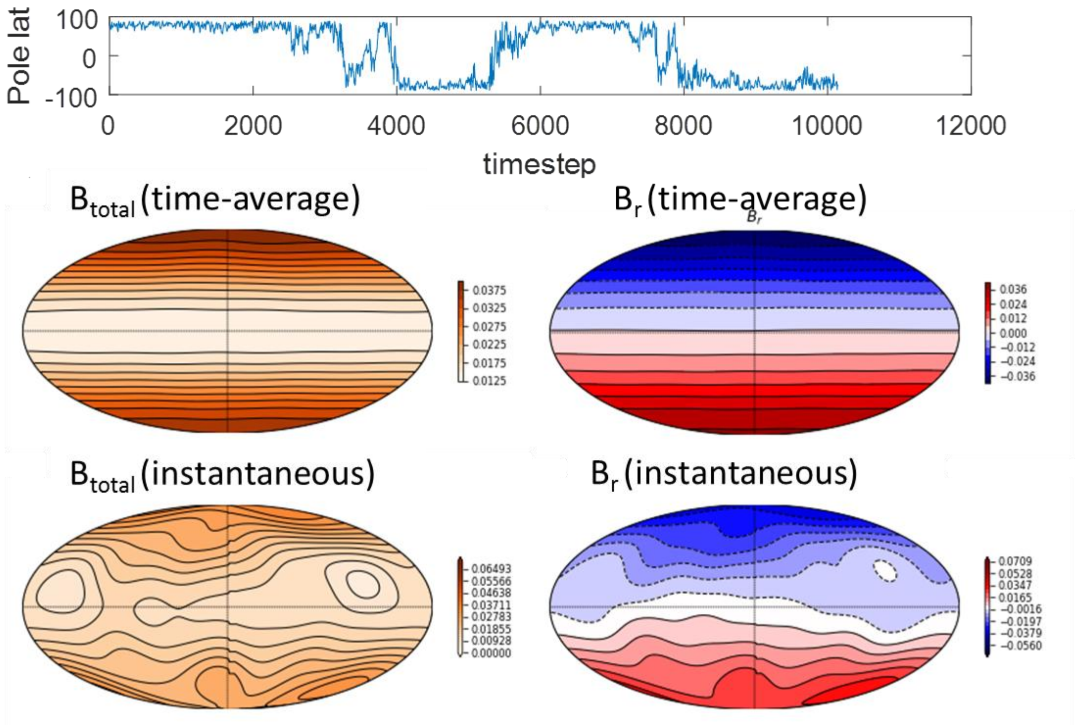

Fig. 1. Time series of pole latitude and visualizations of total and radial field intensity in a numerical simulation with the following parameters: magnetic Prandtl number, 10; Ekman number, 5×10^{-4}; Rayleigh number, 350. Note that both field strength and time are non-dimensional but that the total duration would scale to approximately 3 million years.

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Magnetic Carriers in Metasediments of the Jack Hills (Western Australia): Constraints on Thermal History

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Abstract

Understanding Earth's earliest magnetic field is of critical interest in part because of the necessary protection provided by the field against solar wind erosion of the atmosphere, allowing for the preservation of liquid water on Earth's surface (Tarduno *et al.* 2014). Paleomagnetic studies document a geomagnetic field with strengths comparable to the modern field as early as the Hadean (Tarduno *et al.* 2015), on the basis of high unblocking temperature (~550 to 580 °C) components of magnetization carried by magnetic carriers within zircon grains. However, the oldest records are restricted to the Jack Hills, Western Australia, where the oldest terrestrial zircons (>4 Ga) have been recovered from the host metasediments. Therefore, it is necessary to understand the thermal history of the Jack Hills to determine whether these high unblocking temperature components, and their corresponding paleointensities, are primary in origin. Several independent lines of evidence, including an inter-laboratory comparison study, have been presented supporting both the primary origin of the high unblocking temperature component (Tarduno and Cottrell 2013, Tarduno *et al.* 2015, Dare *et al.* 2016) as well as the recognition of lower temperature (<500 °C) unblocking components acquired as overprint directions during metamorphic reheating events (Cottrell *et al.* 2016, Bono *et al.* 2018). Herein, we will discuss the recognition of coherent signals of overprinting events in otherwise highly scattered directional data using novel contouring/clustering analyses (Bono *et al.* 2018), the resulting thermal history model for the Jack Hills, and recent characterization of single/pseudo-single domain magnetic carriers likely responsible for the high unblocking temperature magnetization components in Jack Hills quartzite clasts.

Keywords: Archean, Hadean, paleomagnetism, Jack Hills, geodynamo.

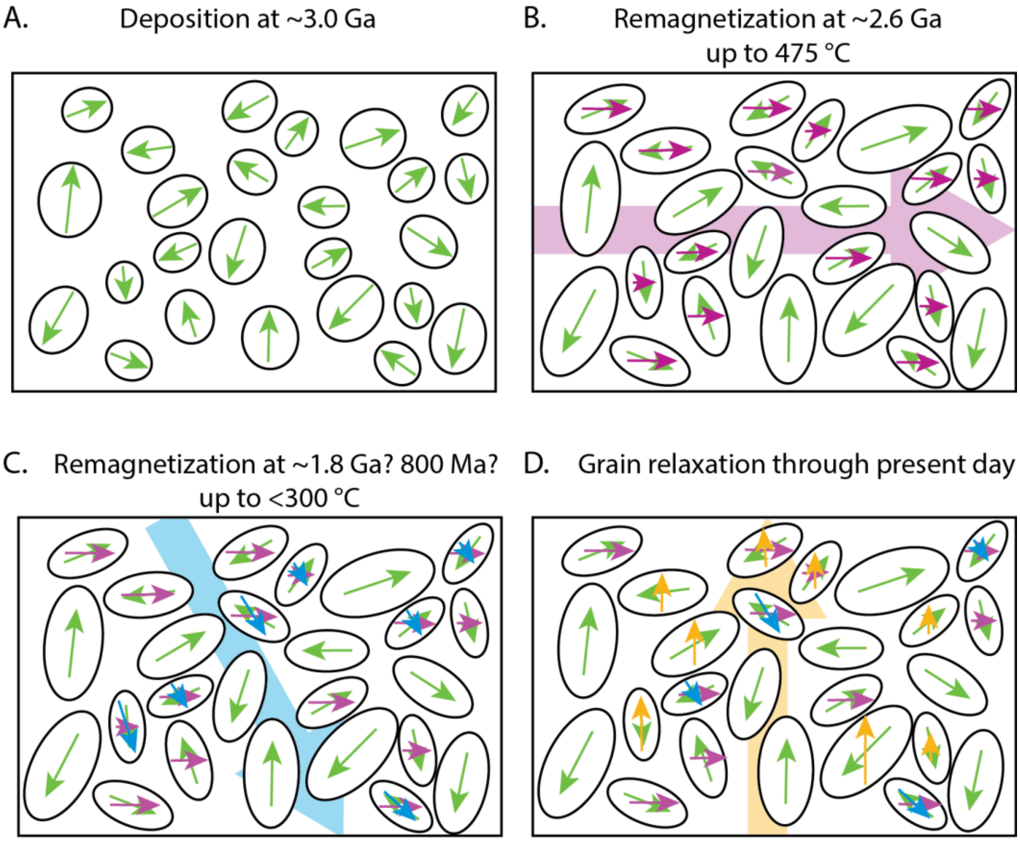

Fig. 1. Acquisition of low unblocking temperature magnetizations in Jack Hills quartzite cobble clasts. From Bono *et al.* 2018.

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Meta-igneous Rocks from South-Western Oscar II Land (Western Spitsbergen) and their Usefulness in Palaeomagnetic Investigations

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Abstract

In this study, more than 200 oriented cores were selected for palaeomagnetic investigation of six metaigneous and one metacarbonate sites from metamorphic Proterozoic – Lower Palaeozoic complex of South-Western Oscar II Land (Western Spitsbergen). Additionally, a comprehensive set of petrological, structural and rock-magnetic methods were applied to obtain detailed information about ferromagnetic carriers and their origin. To increase the resolution of the petro-magnetic data, standard "whole rock" analyses were enhanced by experiments conducted on Fe-containing separates. The results revealed that all primary magmatic ferromagnetic phases of the meta-igneous rocks has been completely replaced by remineralization related to Caledonian (*sensu lato*) and younger metamorphic events. The dominant ferromagnetic carriers are representing by low/medium coercivity fraction such as pyrrhotite and Ti-magnetite/maghemite. The examination of separated magnetic phases allowed to accurately pointed out ferromagnetic carriers and connected them with particular tectono-thermal stages of investigated rocks. Multiphase metamorphic history of the region corresponding to the complex pattern of the natural remanent magnetization (NRM) of meta- igneous rocks. Obtained palaeomagnetic directions demonstrated no convergence with reference path of Laurussia for syn- to post-Caledonian time. However, the same trend of shifting the palaeomagnetic directions to the east was observed almost in all meta-igneous sites. Similar behavior was noted during previous investigations conducted on other meta-igneous sites from Oscar II Land. To explain this phenomenon several tectonic models were proposed. Our conclusions will be useful for further palaeomagnetic and petrographic interpretations of this region.

Keywords: palaeomagnetism, Caledonian metamorphism, Western Spitsbergen.

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Integrated Stratigraphy of the Jurassic-Cretaceous Marine Sequences: Contribution to Global Boundary Definition

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Abstract

The definition of the Jurassic-Cretaceous (J-K) boundary is still not fully established and the boundary is the last system boundary without a GSSP. Conclusions on the calibration of calpionellids, magnetostratigraphy, ammonites and nannofossils are to define a stage base using *C. alpina* in the middle of M19n.2n (Wimbledon 2014). Recently we have been able to compare paleomagnetic polarity zones of several studied sections and demonstrate, using high-resolution magnetostratigraphy, that the J-K boundary sections in the sub-Boreal Realm can be correlated with the Tethyan ones. Currently, we conduct detailed study of the following localities: Štramberk and Kurovice (Czech Republic); Swanage, Cheif Beef, Peveril Point, Portland, Jordans, Bowers, Fresh Water Bay (England); and Le Chouet, St Bertrand's Spring (Elbra *et al*. 2017), Charens, Belvedere and Tre Maroua (France). The data are correlated with well-recognized deep-water sections (Brodno) as well as shallow water sections (Le Chouet and Tatric succession) with poorly developed chronostratigraphy.

The new Kurovice section belongs to the Magura Group of Nappes within Carpathian Flysch Belt. The results (Elbra *et al*. 2018) of studied samples reveal very low remanent magnetization and susceptibility. Acquisition of remanent magnetization suggests presence of low (magnetite) and high (goethite and/or hematite) coercivity fractions. The span of the studied sections is from M21r to M17r. Increased abundance of sphaerical species of *Calpionella alpina* Lorenz was observed along the J/K boundary interval, which helped to interpret the magnetostratigraphic column and correlated it with the magnetozone M19n.2n. The characteristic remanent component holds dual polarity. The mean direction, after tectonic correction, for normal polarity component is $D = 208.2°$, $I = 39.2°$, $\alpha_{95} = 4.2°$, and for reverse polarity is $D = 18.7°$, $I = -50.3°$, $\alpha_{95} = 6.9°$. The value of the virtual geomagnetic pole calculated for tilt corrected data is Plat = 13.2°N, Plon = 7.4°W (Elbra *et al*. 2018). This primary Tithonian/Berriasian direction of Kurovice section implies a counter-clockwise rotation and obtained paleolatitude of ca. 24°N. Latter is in good agreement with data given by other authors for nearby localities.

Keywords: Tethyan Realm, Outer Western Carpathians, rock magnetism, magnetostratigraphy, Jurassic-Cretaceous.

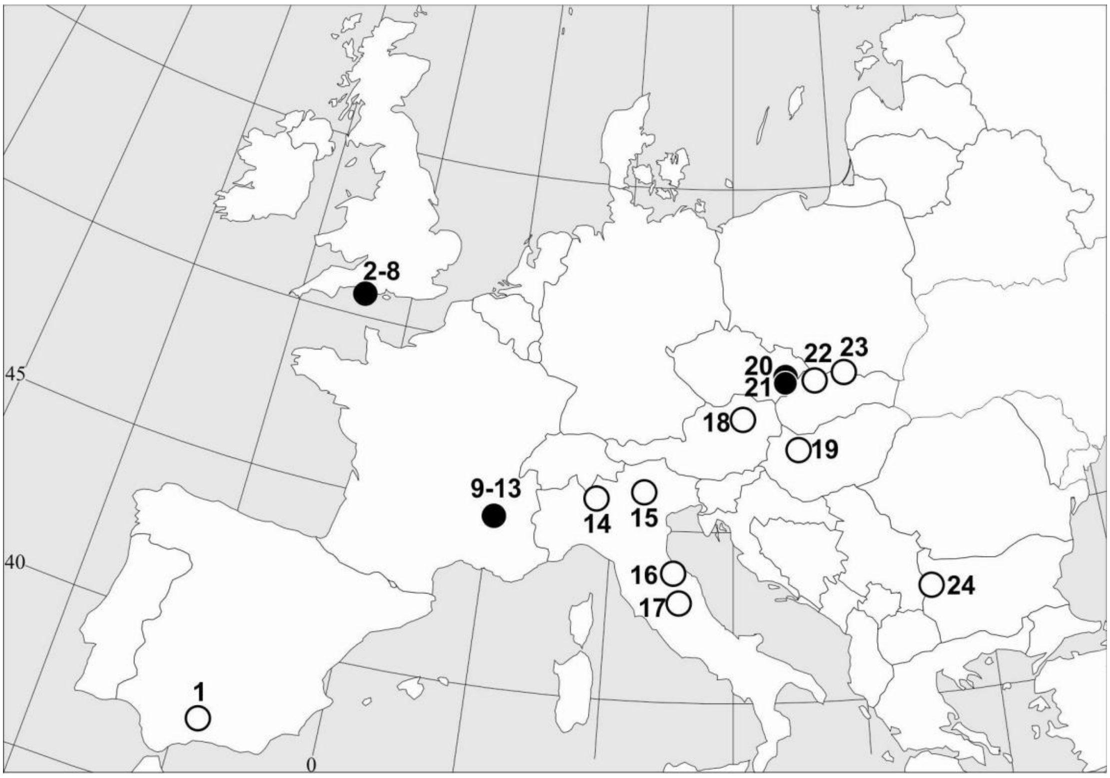

Fig. 1. Schematic map of our ongoing study sites (black), and selection of European J-K comparison sections (white). 1 – Puerto Escano; 2 – 8 Swanage, Cheif Beef, Peveril Point, Portland, Jordans, Bowers, Fresh Water Bay; 9 – 13 Le Chouet, St Bertrand's Spring, Tre Maroua, Belvedere, Charens; 14 – Torre de Busi; 15 – Foza; 16 – Bosso; 17 – Salto del Cieco; 18 – Nutzhof; 19 – Lókút; 20 – Kurovice; 21 – Štramberk; 22 – Brodno; 23 – Western Tatra; 24 – Barlya.

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Isolating Magnetic Moments from Individual Grains in an Assemblage – Upscaling Towards Analyzing Natural Samples

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A b s t r a c t

Methods to derive paleodirections or paleointensities from rocks currently rely on measurements of bulk samples (typically ~10 cc). The process of recording and storing magnetizations as function of temperature, however, differs for grains of various sizes and chemical compositions. Most rocks, by their mere nature, consist of assemblages of grains varying in size, shape, and chemistry. Unraveling the behavior of individual grains is a holy grail in fundamental rock magnetism.

Recently, we showed that it is possible to obtain plausible magnetic moments for individual grains in a synthetic sample by a micromagnetic tomography (MMT) technique. We use a least-squares inversion to obtain these magnetic moments based on the physical locations and dimensions of the grains obtained from a MicroCT scanner and a magnetic flux density map of the surface of the sample. The magnetic flux density map was acquired using a Scanning SQUID Magnetometry (SSM) set-up at the University of Twente, the sample and the sensor are both submerged in liquid Helium (at 4 K) while measuring. Furthermore, the sample used for this proof of concept was optimized for success: it had a low dispersion of the grains, and the grains were large enough so they were easily detected by the MicroCT scanner. To make our MicroCT assisted Micromagnetic tomography technique applicable to real lavas, it is necessary to acquire the magnetic flux density maps at room temperature,

and to be able to handle much higher dispersions of magnetic markers in natural lavas compared to our synthetic sample.

To analyze the magnetic flux at the surface of the sample at room temperature, we used the Magnetic Tunneling Junction (MTJ) scanner at the University of Cambridge. As this machine is less sensitive than the SSM used before, we analyzed our synthetic sample in an IRM state. We were able to recover the pulsed field direction from a limited number of grains reliably. The MTJ, however, is not capable of scanning with small step sizes that would yield enough data to reliably invert for the much higher number of magnetic markers per volume in a natural sample. Moreover, natural lavas are much more complex than the synthetic sample analyzed so far: the grains differ more in composition and size, and many small (submicron) magnetic markers may be present that go undetected by the MicroCT scanner. To scan at room temperature and attain the necessary step size we turned to the Quantum Diamond Magnetometer (QDM) at Harvard University. We scanned a natural volcanic sample from the 1907-flow at Hawaii in two different states; an untreated state, and after a 25 mT AF demagnetization step. In our contribution we will present the results obtained with the QDM scanner and elaborate on the potential of the MicroCT assisted Micromagnetic Tomography technique applied to natural samples. Moreover, we will compare the SSM, MTJ and QDM methods in terms of work flow and quality of the results.

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A Detailed Study on the Magnetic Mineralogy of the Lower Triassic Sedimentary Rocks from Spitsbergen

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Abstract

The rock magnetic, mineralogical and Mössbauer spectroscopy studies were undertaken on the Lower Triassic sediments from the West Spitsbergen Fold and Thrust Belt (Bellsund) and the foreland of this orogen (Sassendalen) for a better-constrained interpretation of paleomagnetic results. Magnetic mineralogy here only partly depends on the lithology. SEM and Mössbauer spectroscopy indicated the presence of magnetite and pyrrhotite, both the most probably of secondary origin. Thermomagnetic curves of whole-rock samples show that these rocks exhibit almost pure paramagnetic behavior whereas ferromagnetic separates indicate the presence of magnetite. IRM component analysis (Kruiver *et al*. 2001) shows three main contributors – magnetite, pyrrhotite, and titanomagnetite or maghemite to the remanence with the significant contribution of iron oxides. Identified ferromagnetic minerals display a wide range of grain-size and magnetic behavior with the domination of PSD particles following the SD-MD mixing line on the Day-Dunlop plot. However, the minor influence of SP and SD particles is also observed. Although presented here, rock magnetic characteristic of both areas is similar, sites in the fold belt the most likely were remagnetized, whereas those in the foreland carry the primary magnetization. Due to many potential carriers of the magnetic remanence displaying a broad range of grain size and various magnetic properties, the paleomagnetism of Triassic rocks in Spitsbergen might be difficult in interpretation.

Keywords: Svalbard, West Spitsbergen Fold and Thrust Belt, Lower Triassic, magnetic mineralogy, Mössbauer spectroscopy.

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Passive Dust Samplers as More Effective Study Material than Street Dust for Characteristic of Traffic Derived Pollution

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Abstract

This study covered investigation of properties of street dust collected from 248 sites in Warsaw. The results revealed that magnetic susceptibility (χ) was in the range of 49–1025·10^{-8} m^3kg^{-1} and for most locations reflected traffic intensity. The lowest values were obtained for single-lane, suburban streets and recreational areas. The highest values were obtained for high traffic crossroads with traffic lights and along transition roads from center to residential areas. Generally, the results confirmed that street dust is a good proxy of pollution level but isn't universally applicable because complication in estimation how long the enhancement of magnetic fraction and heavy metals concentrations were accumulated on road. Using street dust also requires considering different geological properties. Awareness of these difficulties encouraged us to look for new material devoid of disadvantages. As an alternative we offer tool – "passive dust samplers" effectively accumulates traffic pollution and overcomes street dust imperfections.

Drainage pipes of 20 cm length and diameter of 10 cm were used to construct samplers. In order to obtain the mixture effectively accumulating pollution, sand (coarse and fine) and peat in different proportions were tested (Fig. 1). The best accumulation capacity showed mixture of coarse sand and peat in a 1:1 ratio for which $\chi_{total} = 449 \cdot 10^{-8}\ m^3kg^{-1}$ was measured after 12 months exposition at high traffic crossroad.

The next stage of study was validation and confirmation of effectiveness of passive samplers in 24 locations and comparison their accumulation capacity with street dust collected at the same sites. The concentration of Fe (Fig. 2a), Zn, Pb, Al, Cd, Co, Cr, Ni, As, Ba and Mn showed the same decreasing trend with depth as χ. Moreover, the correlation between χ and PLI index expressing collective concentrations of heavy metals confirms the effectiveness of developed filling of passive samplers (Fig. 2b).

The temperature changes of induced magnetization (M(T)) curves revealed in samplers and street dust magnetite as the main magnetic phase (Fig. 3a) and in some samples presence of the second magnetic phase identified as metallic iron (Fig. 3b).

The results confirms that passive samplers reflects the degree of pollution and overcomes the street dust disadvantages. We designed, accomplished, optimized and validated a

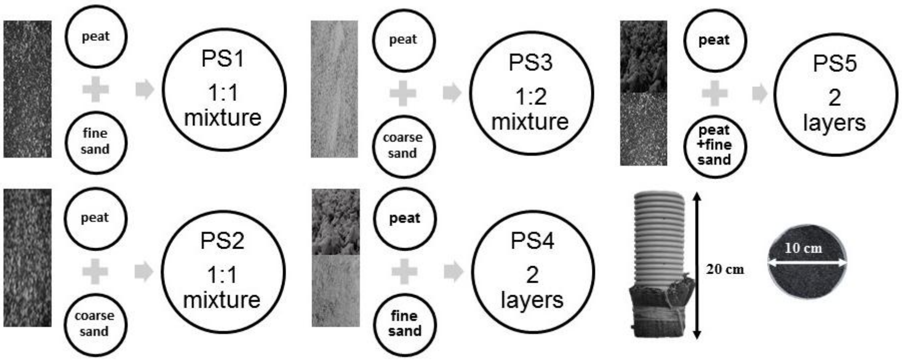

Fig. 1. Five types of tested mixtures and example of prepared sampler.

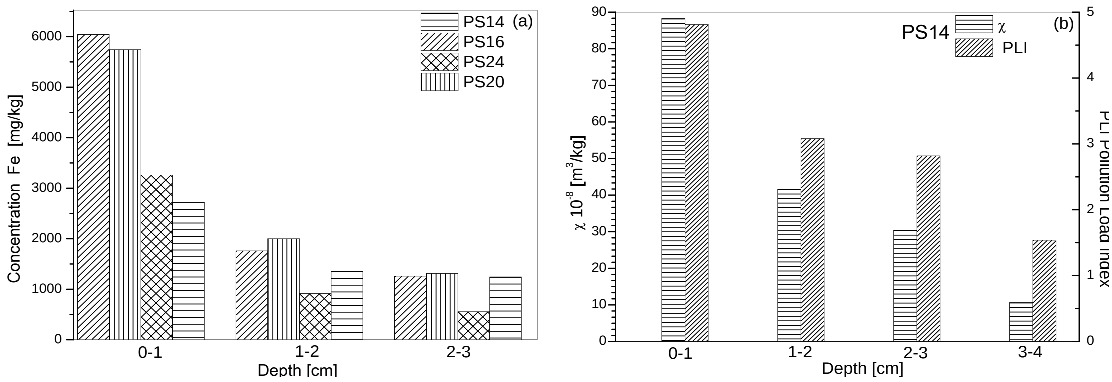

Fig. 2. Depth distribution of Fe concentrations for PS14, PS16, PS20, PS24 (a) and PLI index and χ for PS14 (b).

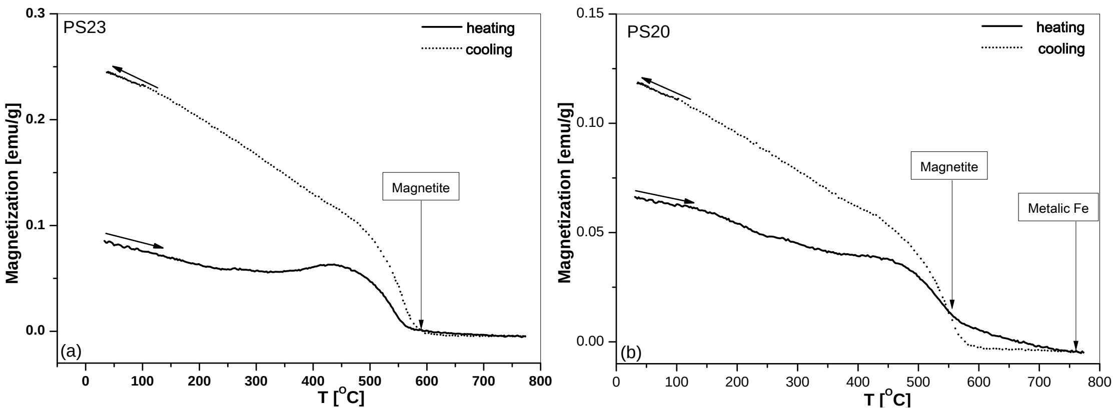

Fig. 3. The curve of M(T) for: PS23 (a) and PS20 (b).

new tool effectively used as a proxy to assess the pollution level. Additionally, we developed effective preparing strategies and experimental protocols for conducting a study using mixture of sand and peat as natural pollution collector.

Keywords: passive dust samplers, street dust, heavy metals, magnetic susceptibility.

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Discrimination of Ferri- and Antiferromagnetic Iron Oxides and Oxyhydroxides of Pedogenic Origin

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Abstract

Ultrafine iron oxides and oxyhydroxides are generated through a variety of processes during soil formation such as for instance weathering or redox cycling. Among these minerals, ferrimagnetic magnetite or maghaemite often dominate the magnetic signature of soils, clearly marking humid periods in loess/paleosol sequences, due to their large spontaneous magnetisation. Most pedogenic iron, however, occurs in anti-ferromagnetic minerals such as haematite and goethite, whose magnetic contribution is easily over-looked, because of their weak spontaneous magnetisation and high coercivity. Because of their different formation paths, a correct discrimination between ferri- and antiferromagnetic pedogenic minerals is important for the correct interpretation of palaeoclimatic archives involving pedogenesis.

Current rock magnetic methods do not provide satisfactory results, in particular with respect to the relative contribution of various iron minerals to the magnetic susceptibility. Preliminary results will be presented of a combined approach for the discrimination of ferri- and antiferromagnetic pedogenic minerals based on temperature dependent measurements of the frequency dependence of magnetic low-field susceptibility and of high-field hysteresis. These techniques are combined with selective pedogenic iron oxide dissolution, i.e., with the citrate-bicarbonate-dithionite method (cf. Mehra and Jackson 1960) in order to eliminate the contribution of primary minerals. Frist results obtained from different palaeosol horizons of the loess/palaeosol sequence of Lingtai, central Chinese Loess Plateau will be discussed before and after CBD extraction.

Keywords: loess/palaeosol, pedogenesis, frequency dependence of magnetic low-field susceptibility, CBD-extraction, palaeoclimate.

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Rock Magnetic and Paleomagnetic Research of the Miocene Sediments in the Teplice–Ústí nad Labem Part of the Most Basin (Czech Republic)

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Abstract

The Most Basin (Fig. 1) is a part of the European Cenozoic Rift System, and formed during late Eocene – early Miocene within the Ohře (Eger) Graben structure (Mach *et al*. 2013, Ziegler and Dèzes 2007). The erosion remnants of the Most Basin sediments are thickest in several “depocentres” in the former graben axis between cities of Most, Teplice, and Ústí nad Labem. Three drill cores from Teplice and Ústí nad Labem part were sampled at 1 m sampling step. Cored samples were subjected to rock and paleomagnetic analyses, e.g., natural remanent magnetization (NRM) and alternating field demagnetization, magnetic susceptibility (*k*), its’ anisotropy (AMS) and dependence on field, frequency and temperature, and acquisition and demagnetization of isothermal remanence (IRM).

The characteristic remanent magnetization component was identified from paleomagnetic data. Combined magnetostratigraphy showed 2 reversed and 1 normal polarity zones (incl. one excursion) which were interpreted as magneto(sub)zones C5Cr to C5Dr.2r (Matys Grygar *et al*. 2017). Rock magnetic results of this study show that (i) magnetic susceptibilities and NRM exhibit decreasing downward trend, (ii) magnetic fabric seems to be mostly depositional, (iii) magnetite carries the remanent magnetization, and (iv) occasional higher coercivity fraction is seen.

Keywords: Most Basin, drill cores, rock magnetism, magnetostratigraphy, Miocene.

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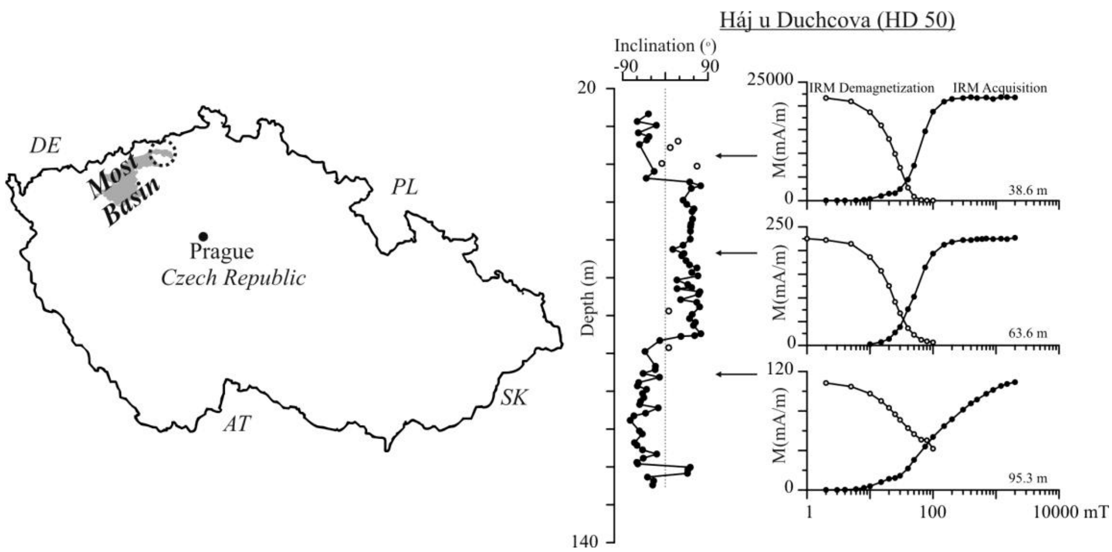

Fig. 1. Location of the Most Basin. Teplice–Ústí part is circled by dashed line. Inclination (after Matys Grygar *et al.* 2017) and acquisition-demagnetization of isothermal remanence of the HD50 drill core.

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Uniqueness of Magnetic Moment Reconstruction from Combining Surface Scanning with Tomography: Towards a Revolution of the Paleomagnetic Measurement Technique

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Abstract

In 1877 Gauss proved a now famous theorem that allows to uniquely separate external from internal sources of the geomagnetic field via its spherical harmonic expansion. Based on a far-reaching generalization of this theorem it is possible to accomplish an unexpected breakthrough in rock magnetic research. Using potential field theory a new uniqueness theorem is proved, which guarantees for an astonishingly large class of prior source localizations that it is possible by potential field measurements on a surface to differentiate between signals from the separate source regions within. The well-known non-uniqueness of potential field inversion only prevents that the source distributions within the individual regions can be uniquely recovered.

This theorem provides the basis for a new measurement technique in paleomagnetism and underpins the claims in Fig. 1. It confirms that individual dipole moments from a large number of magnetic particles, localized by density tomography (micro-CT), can be *uniquely* recovered from surface magnetic field scanning measurements. This is hugely different from previous interpretations of surface scanning alone, which have no possibility to ensure the correctness of their result in terms of uniqueness. When scanning a sample in its natural-remanent magnetization state, and again after standard stepwise demagnetization procedures, the resultant data set can be individually studied to select stable and unaltered remanence carriers. By using only optimally preserved particles from a large selection, reliable statistical average directions or intensities can be calculated from terrestrial or extraterrestrial rocks which currently have to be discarded as recorders of the magnetic history. In this respect the new theorem provides the foundation for a revolution in paleomagnetism that relies on individual magnetic grain measurements, as opposed to bulk measurements, to reconstruct the paleomagnetic field.

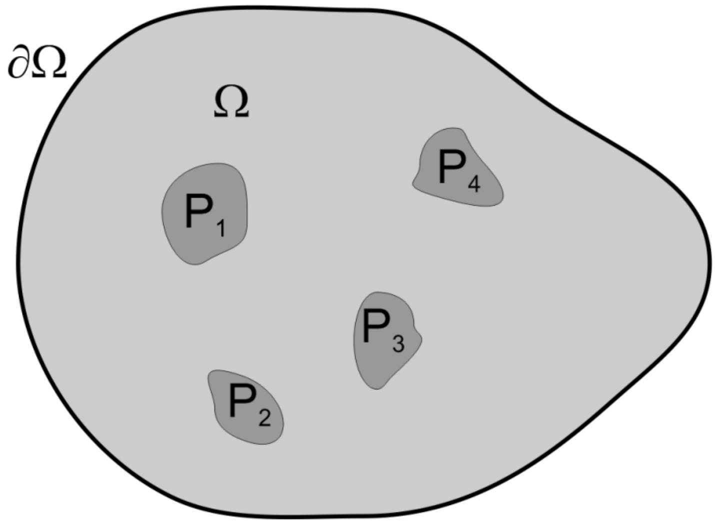

Fig. 1. If the magnetic sources are known to be constraint to the regions $P_1, ... , P_4$ then a potential field measurement on the surface $\partial\Omega$ can be *uniquely* decomposed into potentials which define the spherical harmonic expansions for each of these regions.

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Late Pleistocene Magnetostratigraphic Records from the Western Svalbard-Barents Sea Margin

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Abstract

Largely hemipelagic sediments intercalated with a few dropstones (IRD) have recently been collected from the western Svalbard-Barents Sea margins as long Calypso piston cores and MeBo drillcores. Using the automated 2G cryogenic magnetometer at the Geological Survey of Norway, these cores are used to develop a magnetostratigraphic framework for the late Pleistocene in this area. The lack of calcareous organisms in some of the sediment sequences makes it difficult to provide a continuous biostratigraphic framework based on stable oxygen and carbon isotopes. Instead, the available stable isotope stratigraphy is supplemented with new paleomagnetic results, including relative paleointensity variations in the time interval of ca. 10-200 ka. Relative paleointensity variation is obtained by dividing Natural Remanent Magnetization (NRM) intensities by suitable normalizers like derived from magnetic susceptibility, anhysteretic magnetization, or isothermal magnetization. The results indicate that the documented geomagnetic excursions are linked to large fluctuations of the relative paleointensity. The data indicate that paleointensity measurements are a useful additional stratigraphic tool in this climate-sensitive region of the high latitudes.

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A Quantitative Model for the Thermochemical Remanent Magnetization of the Ocean Floor

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A b s t r a c t

The ocean floor covers more than 70% of the Earth's surface and its magnetization patterns preserve plate tectonic motions as well as geomagnetic field variations over the last 180 Ma. The natural remanent magnetization (NRM) of ocean floor basalts is a thermochemical remanent magnetization carried by titanomaghemite and acquired during the very quick cooling of basaltic flows. Its complex nature was already recognized by Nagata and Kobayashi (1963) and triggered a large amount of rock magnetic research on thermochemical remanent magnetization. Bleil and Petersen (1983) discovered the importance of low temperature single-phase oxidation of titanomagnetite for the NRM of ocean floor basalts. Oxidation starts at the grain surface and develops an inhomogenous distribution of the vacancies whereby the outer parts of a particle are more oxidized than its inner core. The corresponding decrease of lattice constant towards the oxidized grain surface generates excessive internal stresses which can generate shrinkage cracks. Such shrinkage cracks have been observed by Gapeev and Tselmovich (1983) and were studied by Petersen and Vali (1987). The diffusion properties of oxidation in titanomagnetite have afterwards been carefully studied by Gapeev and Gribov (1990), who found that – like in magnetite – the diffusion coefficient sharply decreases with increasing oxidation parameter. Although these results qualitatively clarify many aspects of TCRM acquisition in ocean floor basalts, a quantitative model is still missing. Here we develop a theoretical framework that connects all the above details and provides a consistent model of the oxidation process in titanomagnetite grains in oceanic basalts, including the development of the stresses and generation of cracks. Using this theoretical approach also the acquisition and evolution of NRM within the oceanic crust can be studied.

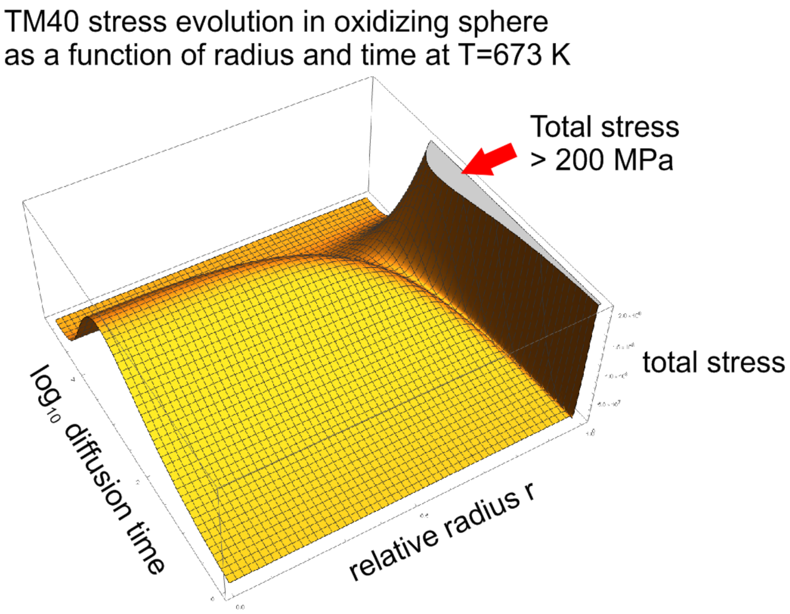

Fig. 1. Stress evolution in an oxidizing titanomagnetite sphere (TM40) as a function of radial distance and time. Note that excessive stress can develop only near the surface at a relative radius of > 0.87. Only in sufficiently large grains this can lead to fracture formation.

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Magnetic Properties of Brake Wear Emissions – Preliminary Results

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Abstract

Airborne pollution poses a serious threat to human life due to its associations with a variety of health issues, including damage to not only respiratory and cardiovascular health, but also neurodevelopment and cognitive functions. Metal-based fine (< 10 μm) and ultrafine (< 0.1 μm) particles might be considered as especially hazardous as they can easily invade the human body via inhalation. Due to the large surface area of nanoparticles and their high reactivity with biomolecules and tissues, they may generate adverse health impacts related to potential oxidative stress, inflammation and generation of reactive oxygen species (e.g., Shuster-Meiseles *et al*. 2016).

Urban airborne particulate matter (PM) is often a complex mixture of phases derived from multiple sources. Many researchers have addressed traffic combustion-derived emissions and the automotive industry has made a considerable effort to limit tail-pipe emissions. However, investigation of the pollution originating from non-exhaust sources has received relatively little attention. Studies by Querol *et al*. (2004) showed that the non-exhaust particles constitute a similar proportion of the airborne PM as exhaust emissions. Perricone *et al*. (2016) quantified brake wear emissions and reported that ‘low-metallic’ brake pads (commonly used in Europe) generate 8 – 91 × 10^{10} particles/stop/brake. Moreover, a great majority of the emitted particles are smaller than 100 nm. Magnetite nanoparticles found in the human brain (Maher *et al*. 2016) are comparable in size, shape and composition to those originating from brake wear (Kukutschová *et al*. 2011), see Fig. 1. The major exposure to airborne PM for many people is from vehicles. Investigation of the sources, contributions, composition and properties of traffic-derived PM is therefore timely and important.

Here, we show the magnetic properties of three types of commercially available brake pads (‘high metallic’, ‘low metallic’ and ‘non-asbestos organic’). The analysis reveals considerable differences in magnetic properties between the different pads, especially in the contribution of ultra-fine, superparamagnetic grains. The results are also compared with magnetic properties of roadside dust, from our earlier studies.

Keywords: environmental magnetism, traffic-derived pollution, non-exhaust emissions.

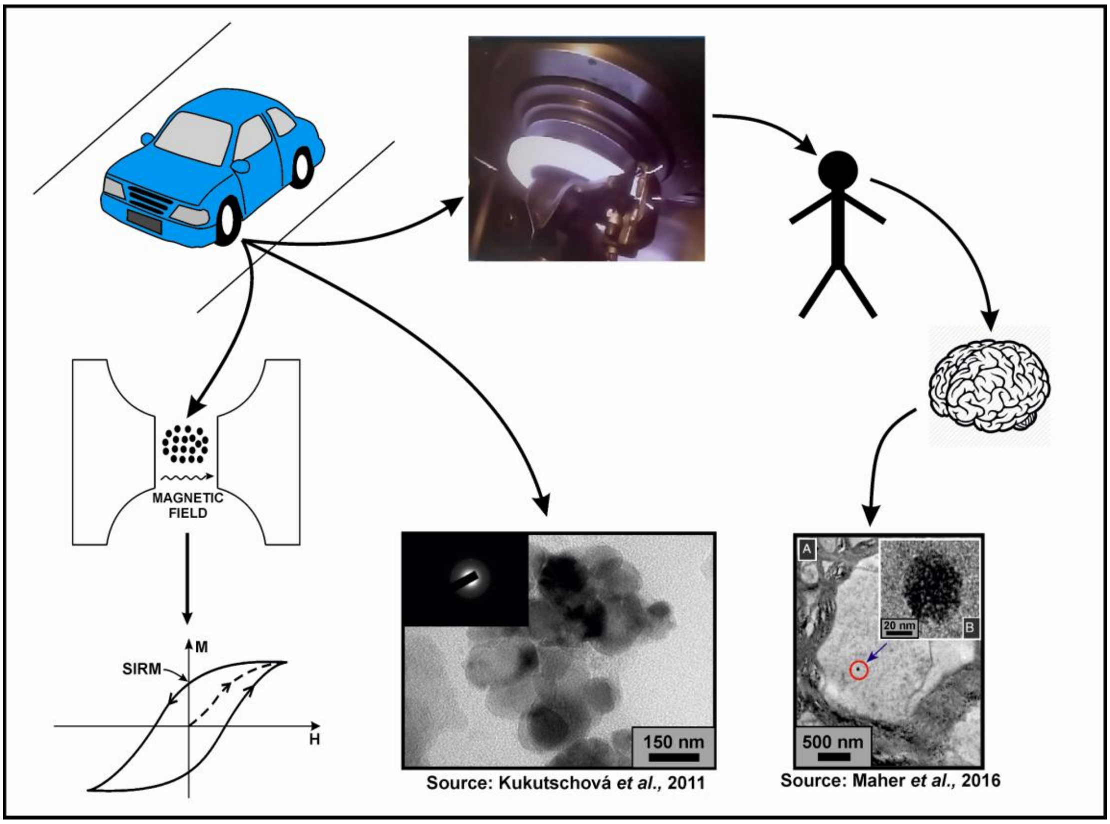

Fig. 1. Rationale behind the studies of brake wear emissions (Kukutschová *et al*. 2011, Maher *et al*. 2016).

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Assessment of Topsoil Contamination Near the Stanisław Siedlecki Polish Polar Station in Hornsund, Svalbard, Using Magnetic Methods

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Abstract

The area of South Spitsbergen National Park is exceptionally vulnerable to degradation caused by human activity due to the pristine condition of the natural ecosystem. Therefore, both environmental assessment and its thorough monitoring is of vital importance.

The present research is concerned with the assessment of topsoil contamination near the Stanisław Siedlecki Polish Polar Station (PPS) in Hornsund, Svalbard. To achieve this, we employed magnetic methods supplemented by chemical analyses and microscopic observations. Laboratory experiments were used to evaluate the concentration, magnetic mineralogy and grain-size distribution of anthropogenic magnetic particles.

Fig. 1 presents the spatial distribution of topsoil magnetic susceptibility in the PPS area. It indicates that heavy-metal contamination near the PPS originates primarily from local sources – the station's main building and scrapyard (A1 in Fig. 1), as well as the fuel station (A2 in Fig. 1). The range of the soil contamination does not exceed 50 meters. The comparison between the results of this study and an earlier investigations of soil contamination in the PPS area (Luks and Głowacki 2007) shows that the areal extent of the PPS impact on the environment has not expanded significantly since 2004 (although a new contamination source, the scrapyard, is now present).

Further analyses showed that anthropogenic spherical, magnetite-like particles are present near the station, whereas uncontaminated topsoil is devoid of such particles. Magnetite and goethite are the primary magnetic phases, with magnetite levels being higher in the polluted area. Magnetic fraction of contaminated topsoil consists of a mixture of single-domain and multi-domain grains, while uncontaminated topsoil contains smaller grains.

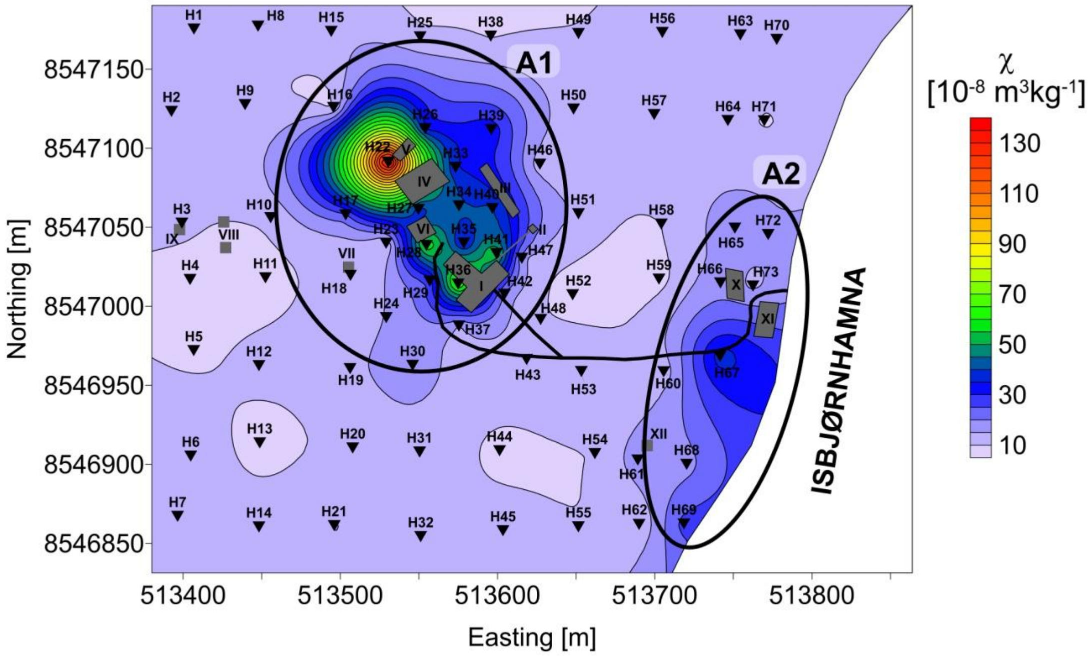

Fig. 1. Spatial distribution of the magnetic susceptibility (χ) of topsoil near the Stanisław Siedlecki Polish Polar Station in Hornsund, Svalbard (grey polygons represent various building of the station: I – the main building, II – sewage treatment plant, III – snowmobile parking, IV – storage hall with waste incinerator, V – scrap yard, VI – workshop, VII – meteorological station, VIII – magnetics stations, IX – seismological station, X – fuel station, XI – harbor warehouse, XII – fuel depot for helicopters; thick black line indicates the road between harbor warehouse and the main building; black triangles represent sampling sites with sample numbers: H1, H2, etc.).

Results show a clear correspondence between Pollution Load Index and magnetic susceptibility anomalies in the area. This study demonstrates that topsoil magnetic susceptibility in the PPS area reflects the heavy-metal contamination. Consequently, magnetic methods offer a relatively rapid, inexpensive, non-invasive and sensitive tool for the evaluation of topsoil contamination in environmental monitoring programs.

Keywords: topsoil contamination, magnetic susceptibility, heavy-metal content, Polish Polar Station, Arctic.

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Identification of Metallic Iron in an Urban Dust Using Magnetometry, Microscopic Observations and Mössbauer Spectroscopy

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Abstract

Thermomagnetic experiments for indoor dust, outdoor dust, street dust and dust from cabin air filters from cars were conducted for identification of magnetic mineralogy. Firstly, the temperature changes of magnetic susceptibility κ(T) in the range of 30–700°C were determined. Secondly, the induced magnetization M(T) in the wider temperature range of 30–800 °C was obtained with applied magnetic field of 500 mT.

Both κ(T) and M(T) thermomagnetic curves revealed the Curie temperature (T_c) of ~585°C which confirms the presence of magnetite as the primary magnetic phase. The “tail” on the heating curves visible as substantial decreasing of κ between 600°C and 700°C was the attribute of the second magnetic phase. The curves of M(T) for samples heated up to 800°C revealed the second magnetic transition at 760°C characteristic for metallic iron and/or iron-based alloys.

The microscopic observation coupled with energy-dispersive X-ray spectroscopy and Mössbauer spectra confirmed the presence of metallic iron fraction in non-heated samples. The magnetic extract of dust from different environments contained the elongated shaving-like particles comprised of metallic iron.

The “tail” appearing on the heating curve of κ(T) between 600°C and 700°C is often interpreted as the effect of presence of hematite. Probably in other studies that phase is not recognized as iron due to 700°C limit of heating. Our study shows that heating samples up to 800°C and measuring magnetic properties is the effective method to distinguish between hematite and metallic iron in dust.

The study was also concerned on the process of oxidation of metallic iron to magnetite by measuring the hysteresis parameters during heating-cooling treatment and after step-wise

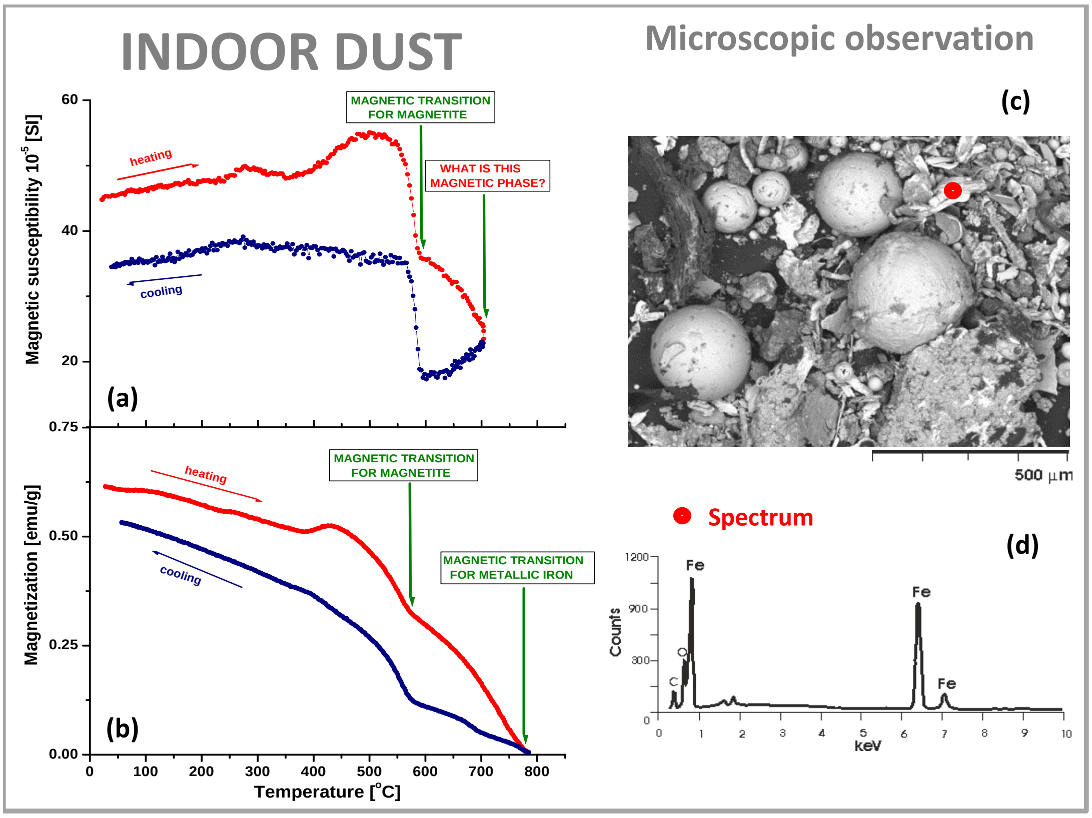

Fig. 1. Temperature changes of magnetic susceptibility κ(T) in the temperature range of 30–700°C (a), changes of induced magnetization M(T) in the temperature range of 30–800°C (b), electron scanning microscopy observation (c), energy-dispersive X-ray spectra (d).

annealing. It was found that the process of oxidation of metallic Fe is responsible for the changes of hysteresis parameters of samples after heating-cooling cycle and relocation of hysteresis parameters ratios on the Day-Dunlop diagram. This is due to the fact that both hysteresis parameter ratios M_{rs}/M_s and H_{cr}/H_c do not depend on the concentration of magnetic particles but only on the magnetic mineralogy and domain state.

Airborne particle matter may have adverse health effects because with breath millions of solid particle including metallic iron can enter our respiratory system. Iron plays substantial role in many cellular functions, in particular in electron and oxygen transport, nitrogen fixation and deoxynucleotide synthesis. It can be also toxic to cells by acting as a catalyst for the production of free radicals that are reason of damage of lipid membranes and other cellular constituents.

Keywords: magnetic methods, thermomagnetic curves, magnetite, metallic iron.

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Upper Berriasian Magnetostratigraphy in the Mészkemence Section, Mecsek Mts (Southern Hungary)

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Abstract

The Mecsek Mountains (southern Hungary) constitute a part of Tisia–Dacia megatectonic unit (Haas and Péró 2004, Császár *et al.* 2013), one of the key-area for the paleogeographic reconstructions of the Carpathians. Tisia was a separate tectonic unit since the Middle Jurassic after its rifting from the European Platform and prior to the beginning of the nappe-thrusting process in the Late Cretaceous (Turonian–Coniacian).

Paleomagnetic investigations in the Mecsek Mts have been applied so far only for paleotectonic reconstructions (e.g., Márton 2000). However, presence of primary magnetization was confirmed in the uppermost Jurassic–Lower Cretaceous sediments which was an indication for a possibly successful magnetostratigraphic study. The Mészkemence section is situated in the eastern part of the Mecsek Mts, a few kms to the NE of Komló. Continuous ca. 30 m thick section of pelagic limestones (Márévár Formation) is outcropped in a natural ravine. Biostratigraphical investigations based on calpionellids revealed the Late Berriasian age of the section, covering the upper part of Calpionellopsis Zone (Oblonga and Murgeanui Subzones). Two components of natural remnant magnetization (NRM) were identified. The component A of normal polarity (unblocking temperatures 20-250°C) is a viscous remanent magnetization while the component B (unblocking temperatures 300-550°C) of mixed polarity is interpreted as primary. Four successive intervals of normal and reversed magnetization were interpreted as magnetozones M16n, M15r, M15n, and M14r. S-ratio indicates presence of magnetite as the principal magnetic mineral. Magnetic susceptibility reveals a

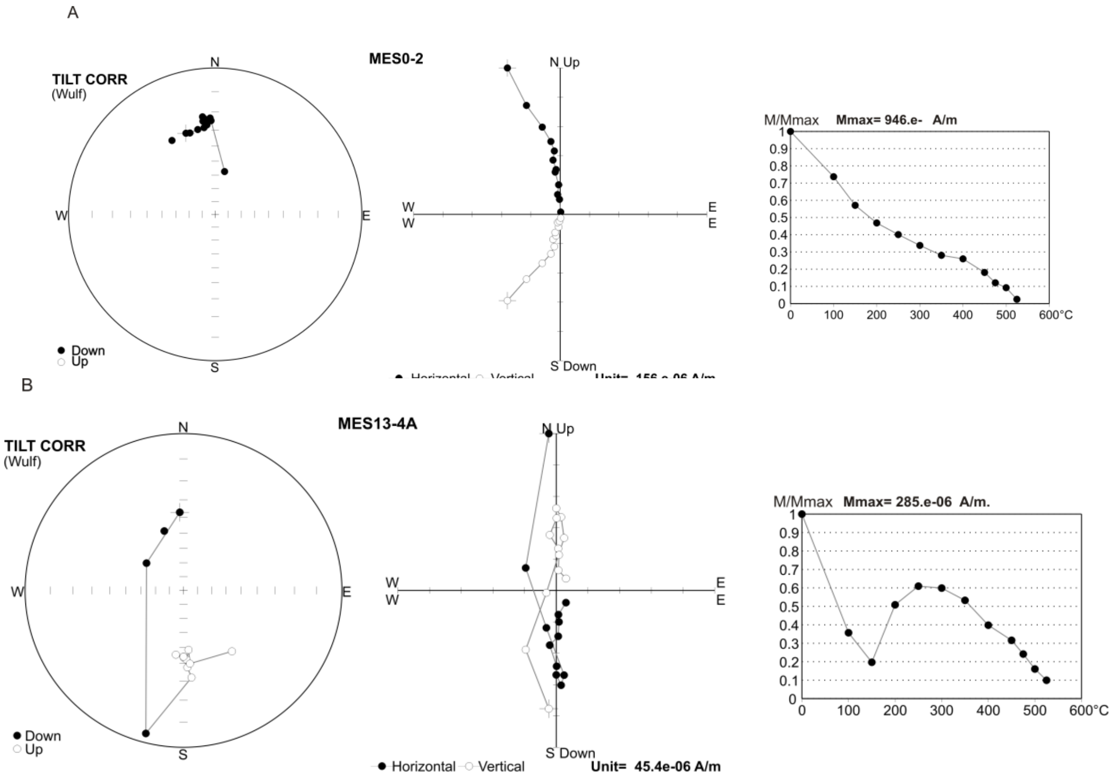

Fig. 1. Thermal demagnetization of typical specimens of normal and reversed polarity samples. Left: stereographic projection of demagnetization path; middle: orthogonal projection of demagnetization path; right: NRM intensity decay during thermal treatment. A – sample MES 0.2; normal polarity; magnetozone M16n. B – sample MES 13.4A; reversed polarity; magnetozone M15r.

substantial peak in the upper part of M16n magnetozone which is correlated with regional increase of lithogenic influx in the Upper Berriasian related most probably to the early phases of Alpine orogeny at the southern margins of the Tisia microplate and/or sea-level fall.

Keywords: magnetostratigraphy, Berriasian, pelagic limestones, Tisia unit.

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Berriasian Magnetic Stratigraphy in Northern Calcareous Alps (Tirolicum, Northern Calcareous Alps)

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Abstract

In contrast to the Western Carpathians, magnetic stratigraphy in the Tithonian–Berriasian has not been applied in the Northern Calcareous Alps (NCA). All formerly investigated sections in the NCA are localized in the Tirolic units and reveal multiphase, syntectonic remagnetization (Pueyo *et al*. 2007). However, our results from a Tithonian–Berriasian deep-water succession in the Salzburg area confirmed preservation of primary magnetization (Grabowski *et al*. 2017). Detailed sampling of relatively undeformed latest Tithonian to Early Valanginian succession (Krische *et al.* 2013) was performed in the Leube quarry SW of Salzburg. Here we present the results from the middle to upper Berriasian part of the succession, 130 m thick (= upper part of the Oberalm Formation and lower part of the Schrambach Formation). Magnetite is the main magnetic mineral in the studied section. However several horizons in the succession are enriched in hematite. Magnetic fabric reveals a simple compactional pattern with bedding parallel foliation and weak lineation in the SE–NW direction. Characteristic component of magnetization of dual polarity with unblocking temperature spectra between 400-550°C was isolated during thermal demagnetization. In combination with high-resolution biostratigraphy the magnetization component could be interpreted as primary and attributed to the magnetozones M17r to M14r (close to the Berriasian/Valanginian boundary). The magnetostratigraphic interpretation correlates perfectly with calpionellid and ammonite age dating (Krische *et al.* 2013, Bujtor *et al.* 2013) as well as with newly obtained high resolution δ^{13}C curve. It must be concluded that remagnetization of Mesozoic sedimentary rocks in the NCA (Pueyo *et al*. 2007) was not complete. Due to the fact that in this part of the NCA relatively thick deep-water successions were deposited in contrast to the mostly condensed sections in the Western Tethyan realm there is an enormous potential for application of magnetic stratigraphy and to refine our knowledge of this still controversial early Alpine orogenic events on the base of multiproxy studies.

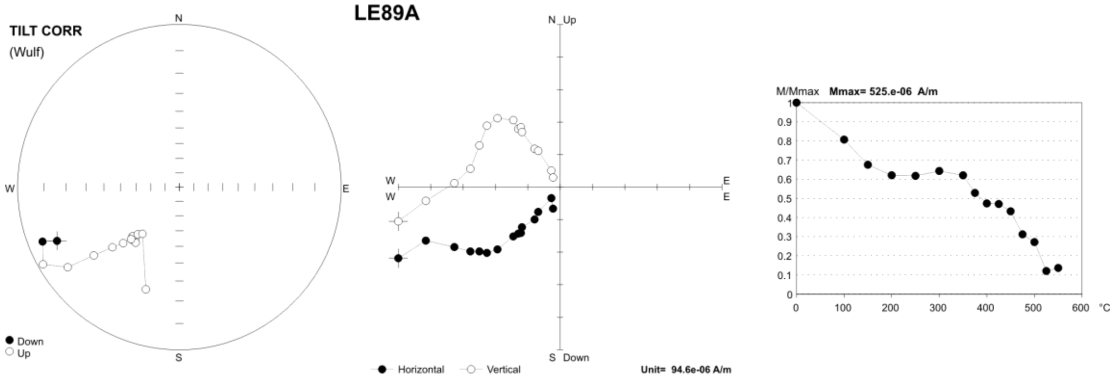

Fig. 1. Thermal demagnetization of typical specimen with reversed polarity. Left: stereographic projection of demagnetization path (after bedding correction); middle: orthogonal projection of demagnetization path (after bedding correction); right: NRM intensity decay during thermal treatment.

Keywords: magnetostratigraphy, Western Tethys, Eastern Alps, Early Cretaceous.

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How Magnetic Susceptibility Reflects the Distribution of Major and Trace Elements in Forest Andosols in the French Massif Central

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Abstract

Mineral magnetic properties are sensitive indicators for evaluation of mechanisms influencing soil formation. The interpretation of magnetic contribution focuses on discrimination between the lithogenic, pedogenic and anthropogenic origin of minerals. In case of Andosols the interpretation is limited because the lithogenic magnetic signals are masking the anthropogenic and pedogenic magnetic contributions. The main aims of this study are: (i) to assess the link between the distribution of 21 elements on the one side, and mass-specific magnetic susceptibility (χ) and frequency-dependent magnetic susceptibility (χ_{FD}%) on the other side, along soil depth profiles; (ii) to analyse the relationship between soil organic carbon (Cox) and the χ_{FD} and χ_{FD}% with respect to particle-size distribution. We studied 9 profiles (81 soil samples) of Alu-andic Andosols from the French Massif Central, developed on highly magnetic basaltic parent rock (Grison *et al*. 2017). The statistical evaluation was performed by the principal component analysis and linear regression.

The results showed that while anthropogenic elements, such as Pb, As and S, showed meaningful correlation with χ_{FD}%, the concentration of lithological elements, such as Fe, Ti, Cr and V, was associated with χ. The content of Cox was associated with the fine sand (0.05–2 mm) and fine silt (0.002–0.02 mm) fractions. Furthermore, the Cox correlates positively with χ_{FD}% and negatively with χ. Our findings suggest that the development of Andosols, formed on basaltic parent material in climatic conditions of the French Massif Central, can be studied using magnetic parameters reflecting the concentration and grain-size of iron-oxides in combination with geochemistry.

Keywords: iron oxides, pedogenesis, basalts.

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The Geological and Paleomagnetic Evidence for a Late Neoarchean to Early Paleoproterozoic Supercontinent

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Abstract

Late Neoarchean to early Paleoproterozoic cratons have traditionally been grouped into ‘clans’ distinguished by their basement ages and supracrustal volcanic-sedimentary cover successions (e.g., Bleeker 2003). However, with the recent development of the large igneous province (LIP)-barcode method of craton juxtaposition, which is based primarily on coeval U-Pb ages of mafic dyke swarms and sill provinces, has suggested a continuity of ancient crust that brings together members of separate clans. One such reconstruction is presented in Gumsley *et al*. (2017): the Vaalbara supercraton is presented immediately adjacent to the western part of Superior Craton, along with the Wyoming Craton in its rotated reconstruction south of the Superior Craton. However, it is likely that Vaalbara supercraton never existed in its present form, and that instead, one or two large continents existed at this time. If such a scenario, or ‘Kenorland’ supercontinent amalgamation existed in Paleoproterozoic time, it likely assembled during Neoarchean accretion. Such a model predicts a single paleomagnetic apparent polar wander (APW) path for all the constituent cratons, where all of the individual paleomagnetic poles are rotated quantitatively into the reconstruction for the duration of their tectonic continuity. This contribution evaluates the rates and styles of the

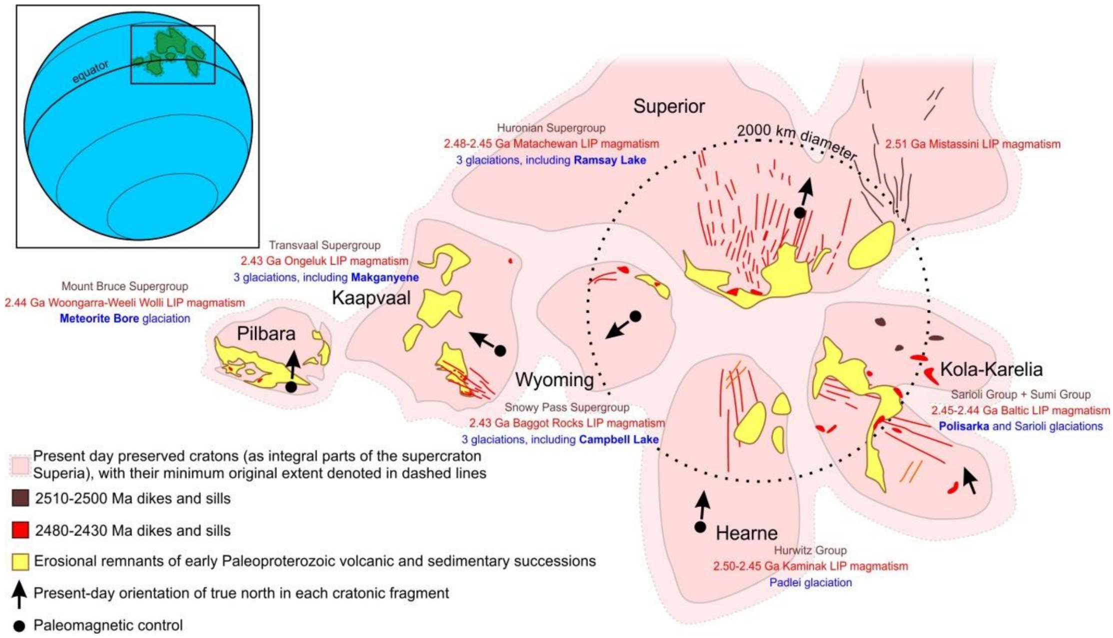

Fig. 1. The early Paleoproterozoic paleogeography of the Superior, Kola-Karelia, Hearne and Wyoming cratons as integral parts of the supercraton Superia, with the addition of the Kaapvaal and Pilbara cratons in the supercraton Vaalbara configuration. Available paleomagnetic studies indicate that the majority of the cratonic fragments (as part of supercraton Superia) were positioned near the paleo-equator. Inset: The hypothesized paleolatitude of these Archean cratons in the early Paleoproterozoic.

APW implied by the Kenorland model scenario. While the model is consistent with geology, and a few published paleomagnetic poles of broadly similar ages, relevant high-quality data, and especially key paleomagnetic poles are sparse. Some of the motions implied by the aggregate APW path are rapid relative to typical Phanerozoic plate movement rates, but not to the extreme. One challenge to the Kenorland supercontinent model scenario is its post-breakup kinematic evolution. Cratonic juxtapositions via the LIP-barcode method present intriguing hypotheses that demand quantitative evaluation in the continuous kinematic framework provided by visualizable software packages such as GPlates.

Keywords: Archean-Paleoproterozoic, supercontinent, APW, LIP-barcode.

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Environmental Conditions in the Werenskiold Glacier Basin (Spitsbergen, Arctic): Magnetic Study

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Abstract

For the recognition of the glacier dynamics, it is important to determine its drainage type. For this purpose, hydrological models are applied, that show direction of subglacial water movement, based on supraglacial topography and the results of radar-sounding of the glacier bed. This enables distinguishing main catchments, flow patterns and the main drainage pathway. To define main sources of eroded material we performed independent and multidisciplinary experiments: magnetometry and granulometry providing wider interpretation that include phenomena connected to glacier movement.

Surface sediment and water samples were carried out from the Nottingham Bay and the Werenskiold Glacier basin in Spitsbergen, Arctic Ocean. Magnetic analyses such as measurements of mass magnetic susceptibility, anhysteretic susceptibility, hysteresis parameters and volume magnetic susceptibility dependence on temperature, served to determine the magnetic properties and identify the magnetic carriers of investigated material. Results of magnetic method have been supported by grain size and mineralogical analysis. We selected two main groups of deposits. The first group consists of magnetite and pyrrhotite with predominantly finer grains of single-domain structure. In the second group only magnetite occurs with larger multi-domain grains. The obtained results allowed to recognize different source rock of studied material.

Heterogeneous magnetic susceptibility distribution along streams and the bay, independent of the magnetic composition, suggests the inhomogeneity of the parent rock, including different sources of the investigated material. On the other hand, variations in the speed of glacier melting might be responsible for differentiated sorting of the material. In this research, we tried to answer on these new questions.

Keywords: environmental magnetism, glacier environment, surface sediments, Svalbard.

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The Magnetization History of Sills from the Early Cretaceous Diabasodden Suite, Svalbard

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Abstract

Early Cretaceous sills constituting the Diabasodden Suite (DBS), crop out all over Svalbard, Arctic Canada and Franz Josef Land. They have also been identified offshore on seismic in sedimentary basins in the North Western Barents Sea. Resent dating of the sills using U-Pb and Ar-Ar methods suggest a magmatic event around 125 Ma. The magnetization history of the DBS is rather complex. Sills from eastern Svalbard carry Early Cretaceous paleopoles (reverse polarity).

Demagnetization and magneto mineralogical studies on a new suite of samples from central Svalbard reveal two well defined clusters of paleomagnetic directions. The paleopoles of these two clusters are interpreted to represent the 125 Ma event and a complete post Early Cretaceous overprint. Sills collected in or near the Billefjorden fault zone in central Svalbard carrying steep magnetization directions (reverse polarity), are suggested to represent a post Early Cretaceous magnetization overprint that may be related to fault activity prior to and during the Eocene West Spitsbergen Fold-and-Thrust Belt.

Steep magnetization directions (both polarities) are also found in sills outside the Billefjorden fault zone and in eastern Svalbard. Preliminary results from the Kong Karl Land lavas, also show steep magnetization directions. Published paleomagnetic results of the Devonian, Permian and Triassic sedimentary rocks of Svalbard reveal partial remagnetization.

Svalbard and the North Western Barents Sea have seen regional uplift in the late Cretaceous and flank uplift caused by the Paleocene-Early Eocene sea floor spreading. The entire Barents shelf was uplifted and eroded during Neogene time. The North Western Barents sea and Svalbard are characterized by high heat flow, young magmatism and a thin lithosphere.

It is discussed if the regional remagnetization found in magmatic and sedimentary rocks on central Svalbard was due to uplift, erosion and tectonics in the Late Cretaceous or in the Cenozoic.

Keywords: Paleomagnetism, remagnetization, Early Cretaceous, Svalbard.

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Mössbauer Analysis of Iron Oxides in Topsoil

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Abstract

Analysis of the reports of the Regional Inspectorate for Environmental Protection in Katowice, allows the exact location of critical points associated with increased emissions of PM10 and PM2.5, consequently also technogenic magnetic particles (TMPs) in Upper Silesia. TMPs are ferrimagnetic iron minerals which arose during high temperature technological processes. Their presence in soils can indicate the soil contamination by potentially toxic elements (PTE) because TMPs due to their structure and well developed surface area have the ability to bind metals and metalloids. In iron analysis very effective tool is Mössbauer spectroscopy because of the high sensitivity of this method and precise phase analysis capabilities. It enables the determination of iron speciation in environmental samples and provides very precise information about the chemical, structural and magnetic properties of material.

The main objective of this study was identification of iron (hydro)oxides occurring in soils being under deposition of industrial dusts for long time period. Topsoil samples collected in the vicinity of power station, metallurgical and coke plants were subjected to this investigation. After standard initial preparation, samples were divided into granulometric fractions (ø = 0.05–0.1, 0.1–0.25, and 0.25–0.5 mm) which then underwent the magnetic separation using the isodynamic magnetic separator operated on different currents. In such a way each granulometric fraction of an original sample was separated into 6 subsamples (one nonmagnetic and five with increasing magnetic susceptibility).

Afterwards, subsamples were subject of magnetic, morphological and mineralogical analyses (e.g., bulk magnetic susceptibility and temperature dependence of magnetic susceptibility and X-ray powder diffraction and scanning electron microscopy with energy dispersive spectroscopy – SEM/EDS).

The main research method was Mössbauer spectroscopy. The ^{57}Fe Mössbauer spectra were recorded at room temperature with a constant acceleration spectrometer with ^{57}Co:Rh source (activity ~50 mCi). The metallic iron powder (α-Fe) absorber was used for velocity

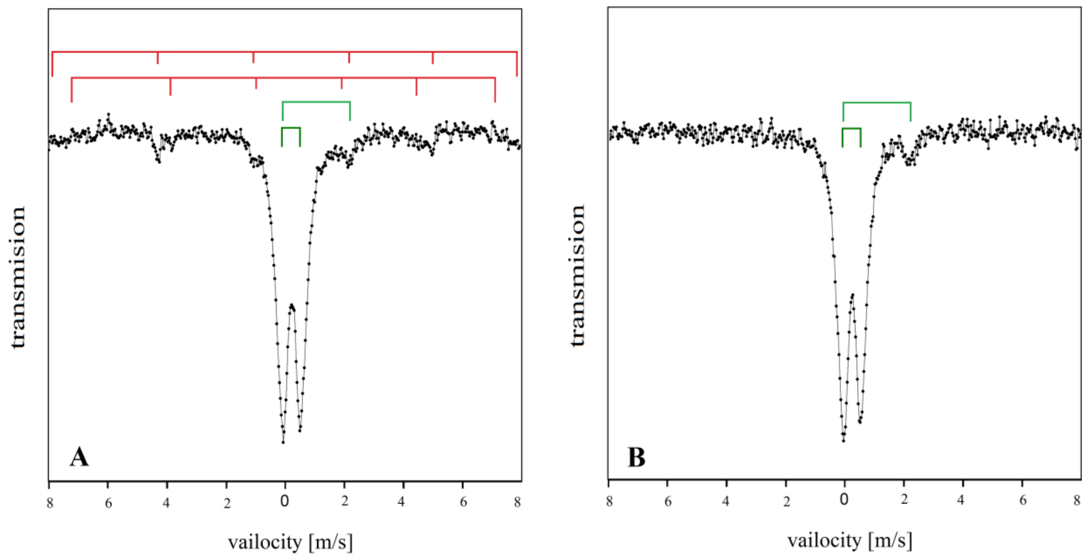

Fig. 1. Room temperature ^{57}Fe transmission Mössbauer spectra with schematic component fitting: for sample A – present both the magnetic and non-magnetic fraction; and B – without magnetic fraction, and present non-magnetic.

and isomer shift calibration of the Mössbauer spectrometer. The mineralogical analysis of the spectra was based on the Mössbauer Mineral Handbook (Stevens *et al.* 2005).

The Mössbauer spectra measured at room temperature were fitted with two quadrupole doublets and one or two magnetic sextets. The paramagnetic doublets may originate from the following sources: (I) Fe^{3+} and Fe^{2+} cations in silicate minerals, (II) $Fe3^{+}$ in oxyhydroxides (β-FeOOH and γ-FeOOH), and/or (III) from iron-containing compounds in the form of ultra-fine particles in the superparamagnetic state (Kopcewicz and Kopcewicz 2001). First Zeeman sextet (H = 29 T) are connected with pyrrhotite, another one (H = 50 T) was identified as magnetite or maghemite.

Keywords: magnetic susceptibility, Mössbauer spectroscopy, TMPs, topsoil.

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AMS: Evolution and Perspectives

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A b s t r a c t

Shortly after the first geological pioneering application of the AMS (Ising 1942), Graham (1954) suggested to open a new way based on this approach. For more than 10 years, AMS use was very limited, due to the heavy conditions of measurement and to the necessary use of large samples. The development of new instruments, like the Digico Anisotropy Delineator (by Molyneux) and the Kappabridges (by Jelinek, Suza, and Pokorny) and the use of standard cylindrical samples offered the possibility to obtain results from fast measurements and easier sampling. AMS is now a routine method used in many laboratories over the world.

Another important evolution was the development of reliable statistical methods, based on determination of AMS mean data (using tensor variability – Jelinek (1978), parametric bootstrap – Constable and Tauxe (1990) – or bivariate analysis – Henry and Le Goff (1995)), but also keeping complementary approaches (e.g., density contours or non-parametric bootstrap, for directions as well as for parameters diagrams). The determination of the magnetic zone axis (Henry 1997) yielded additional structural information.

Magnetic fabric of sediments (Granar 1958) and of deformed rocks (Daly 1959) was first studied. Now, AMS is a standard approach for the determination of emplacement conditions and of deformation of intrusive (plutons, dykes) and volcanic rocks. But numerous other AMS applications have been developed, concerning various domains like for example for the study of the structural evolution in large sedimentary basins or of hydrothermal paleocirculation. Magnetic fabric was also used for correction of the paleodirection and of paleointensity values in paleomagnetism and archeomagnetism. Applications remain to be open for subjects such as study of building materials.

In rocks with visible structural elements, AMS directions (principal axes, magnetic zone axis) appeared sometimes as different from the corresponding visible ones, then highlighting an unknown complex evolution of the studied rocks and the composite character of the fabric (Daly 1967). The main recent AMS developments precisely concern the determination of magnetic sub-fabrics (see Hrouda (2018) – this meeting). To this aim, in very simple cases, statistical treatments were first proposed. Another possibility was the comparison of the AMS (using difference tensor) measured before and after physical or chemical modification of the samples by application of magnetic field or by heating. Direct measurements

of parts of some magnetic sub-fabrics are now possible (based on frequency dependence, high field, low temperature, out of phase susceptibility experiments…). Other approaches, maybe like measurements at different temperatures, will be probably proposed during the next years with development of new equipments, giving for example the generalization to standard samples of high field or low temperature experiments. Ending, future perspectives will be the combination of data from all these different approaches, including complementary data like anisotropies of remanent magnetization, in a simple way to obtain usable and detailed results associated to each of all the AMS sub-fabrics.

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Rock Magnetic Techniques Applied to Environmental, Material and Life Sciences

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A b s t r a c t

Rocks and sediments are composed of various minerals, but ferromagnetic minerals contribute only a small amount to their total volume. The low concentration can make detection through microscopic methods difficult. Since the first studies to understand the remanent magnetization carried by ferromagnetic minerals in volcanic rocks by Koenigsberger (1938) and Thellier (1938), a variety of techniques have been developed to aid in identifying ferromagnetic phases in rocks, sediments and soils, by exploiting the material properties of these minerals. For example, thermomagnetic curves, which are used to define Curie or Néel temperature, help determine mineral composition, whereas hysteresis properties can provide information on domain state, i.e., particle size and concentration. Because geophysical instrumentation and rock magnetic methods allow for detection of very small concentrations, techniques have a validity in other research areas that are interested in identifying ferromagnetic phases with respect to their composition, concentration, and particle size. Methods that aid in distinguishing whether the ferromagnetic particles are either dispersed so as to act as individual particles or in clusters, in which particles magnetically interact, are also of interest in many applications. The number of rock magnetic studies has grown exponentially over the past 20 years (Fig. 1). Examples will be shown on how rock magnetic methods can be used in applications that are related to environmental studies and material development.

Magnetic methods have become important in environmental studies because all material possess some form of magnetism, whether diamagnetic, paramagnetic or ferromagnetic. Distinguishing between these basic classes of magnetism already provides information about the types of minerals or materials that are present in the environment. For example, in a study that uses leaves, tree barks or other organic material as a type of collection site for aerial pollution, show that unpolluted sites are diamagnetic and polluted sites are ferromagnetic. In contamination studies, iron is often found in association with Pb, Zn Cd or As. Rock magnetic techniques help not only in correlating the degree of contamination with a magnetic property, but also the pathways that lead to the relationship.

In material science the synthesis of magnetic nanoparticles has become a major global industry with a predicted compound annual growth rate of 21% from 2016 to 2022 (https://www.researchandmarkets.com/research/4299cg/global). Applications range from sensor and

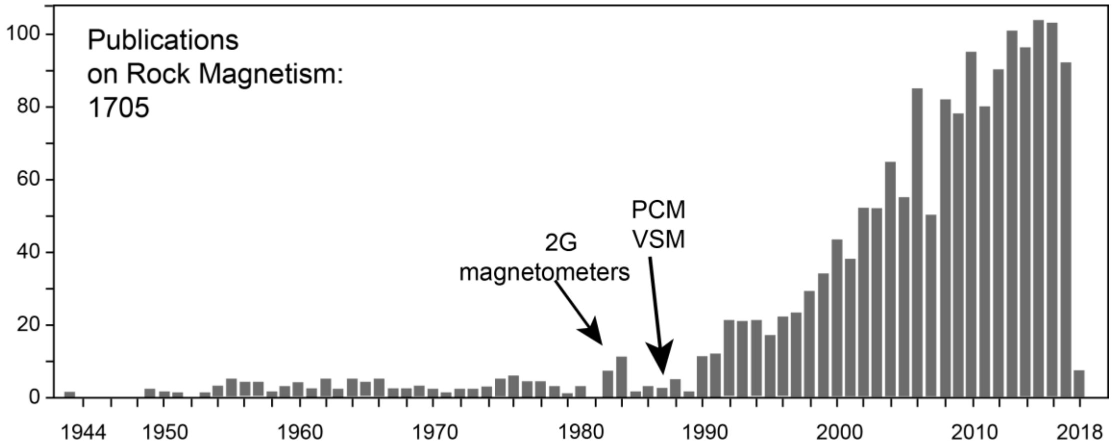

Fig. 1: Number of publications in the area of rock magnetism according to Thompson Reuters SCI (20 February 2018) and introduction of new instrumentation for determination of rock magnetic properties.

actuators, information storage, water treatment, and biomedical applications. Important in the synthesis of magnetic nanoparticles is their long-term chemical stability, which guarantees that their magnetic properties do not change with usage. Furthermore, it is important to understand the long-term fate of these particles. In biomedical applications magnetic nanoparticles are being used not only in magnetic and particle resonance imaging, but also in drug delivery systems. In these latter applications, it is important to understand the way in which a magnetic body responds to an external field. Composition, particle size, and degree of particle interaction all contribute in determining the efficiency of delivery. For this reason it is very important to monitor magnetic properties of the materials in the synthesis process.

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Position of the Matuyama-Brunhes Boundary in Pleistocene Subaerial Formation of Ukraine

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Abstract

Pleistocene subaerial deposits in Ukraine have been paleomagnetically studied in several dozens of loess-paleosol sequences. In some sections the results were frequently fairly contradictory, for example, different authors placed the Matuyama-Brunhes (M/B) boundary – a key magnetostratigraphic benchmark of Pleistocene – in different stratigraphic horizons even within the same sections (Bakhmutov *et al*. 2017). Independent investigations concerning the magnetic parameters of the rocks and paleomagnetic study of loess-paleosol sections in Volhynian Upland (Boyanychi and Korshiv sections), Black Sea Lowland (Roxolany section) and Dnieper Lowland (Vyazivok section) by the same experimental procedure for comparing the formation of the magnetic properties for these regions and revealing the magnetostratigraphic markers were obtained by the author. According to new results for Roxolany section the M/B boundary is located at a depth of 46.6 m at the contact of buried soils of Lubny (lb) and Martonosha (mr) horizons (Fig. 1). The M/B boundary in Vyazivok section lies at a depth of 56.2 m in the lower part of Shyrokino (sh) paleosol horizon (Hlavatskyi 2016). The position of the M/B boundary in Roxolany and Vyazivok sections is controversial following by local stratigraphic schemes, which can be explained both of peculiarities of "magnetic record" in soil and incorrect stratigraphic subdivision of Roxolany section. There are evidences of magnetic event, probably Emperor/Big Lost (560-570 kyr), in both sections, which was detected in Zavadivka (zv) soil. The same zone of reversed polarity was fixed in Zavadivka horizon in other sections of the south of Ukraine (Bakhmutov *et al.* 2017). The M/B boundary is not revealed in the Volhynian Upland sections and short reversed-polarity episodes or excursions are absent; therefore, magnetostratigraphic correlation of Boyanychi and Korshiv sections with other loess- paleosol sequences is impossible. New correlation stratigraphic scheme of the subaerial formation of Ukraine is proposed.

Keywords: the Matuyama-Brunhes boundary, loess-paleosol sequence, Pleistocene, magnetostratigraphy, Ukraine.

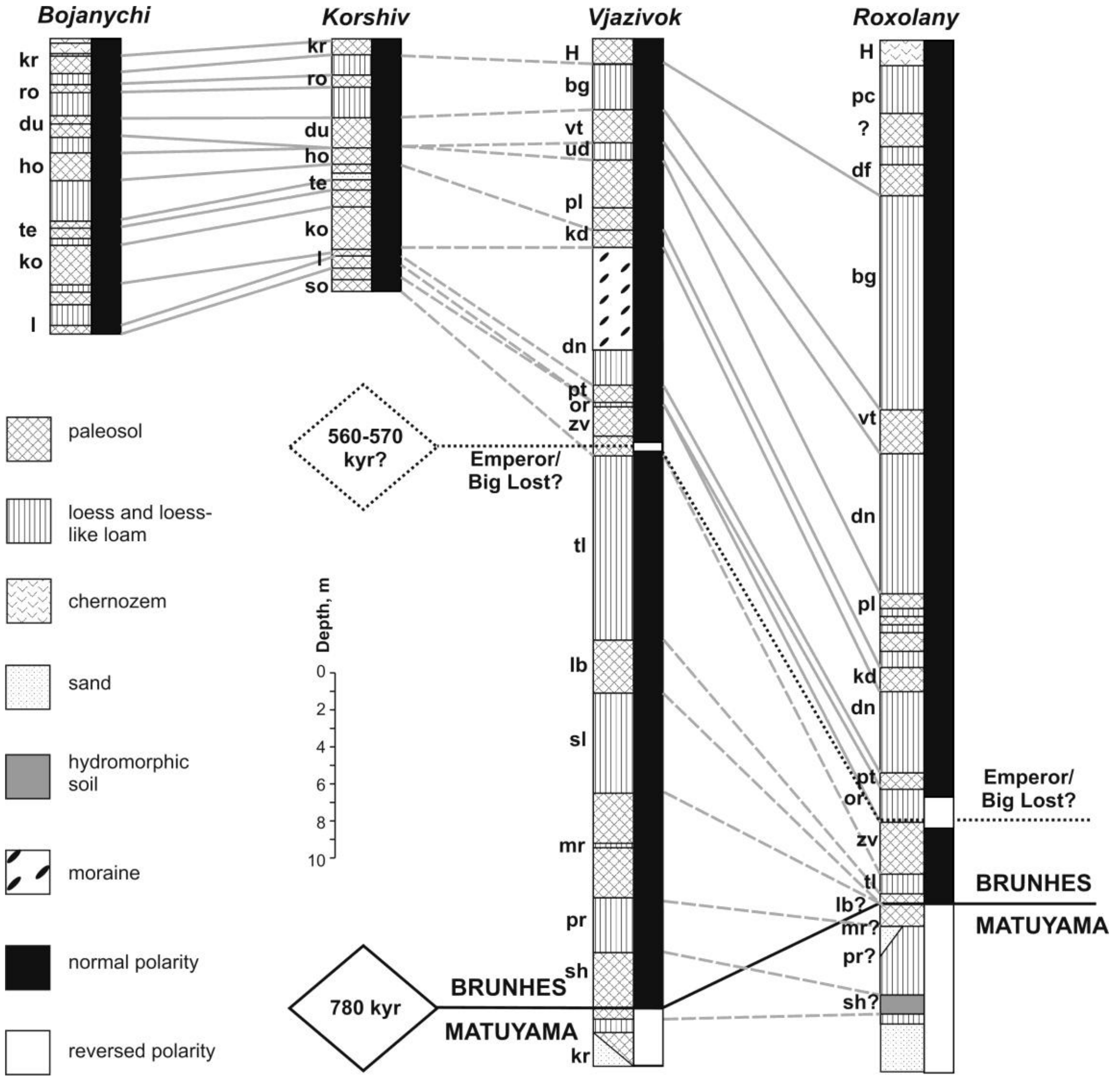

Fig. 1. Stratigraphic and magnetostratigraphic correlation of subaerial sequences of Ukraine studied by the author.

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Magnetic Sub-fabrics in Rocks: Measuring Techniques and Geological Interpretation

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Abstract

The Anisotropy of Magnetic Susceptibility (AMS) is in general controlled by all minerals present in a rock. However, the individual magnetic minerals or their groups may behave in different ways in various geological situations and it is therefore desirable to resolve the rock AMS fabric into components corresponding to individual magnetic mineral sub-fabrics. The resolution is based on specific behaviour of suscep-tibility of individual minerals in variable magnetic fields or at variable temperatures.

Variation of susceptibility of paramagnetic minerals with temperature is represented by hyperbola, while in ferromagnetic minerals it is a complex curve characterized by acute susceptibility decrease at the Curie temperature and at the Verwey or Morin transition. In strong magnetic fields of the order of tesla, the difference between principal susceptibilities is proportional to squared field in paramagnetic minerals, to field in ferrimagnetic/antiferromagnetic minerals of pyrrhotite/hematite type and field independent in ferrimagnetic minerals of magnetite type. In weak magnetic fields, some minerals, such as titanomagnetite, pyrrhotite, hematite for instance, show low-field variation of susceptibility, while the susceptibility of paramagnetic minerals and pure magnetite is field independent. At variable operating frequencies, the low-field susceptibility is frequency-dependent in ultrafine (in the order of tens of nm) magnetically viscous grains of magnetite or maghemite, while in larger grains it is frequency-independent. The out-of-phase component of susceptibility is non-zero in titanomagnetite, pyrrhotite, hematite and in ultrafine magnetite, and effectively zero in multidomain magnetite and paramagnetic minerals. In addition, the anisotropy of magnetic remanence (AMR), which is solely controlled by the ferromagnetic minerals, can also be used to determine the preferred orientation of these minerals uninfluenced by paramagnetic minerals.

Unfortunately, there is no universal method for determining the magnetic fabric of individual minerals or mineral groups. Nevertheless, the above specific behaviours offer us at least partial solutions. Techniques were developed for separating the magnetic sub-fabrics of magnetite and paramagnetic minerals as well as those for separating the magnetic sub-fabric of the minerals of pyrrhotite/hematite type from paramagnetic mineral sub-fabric. Besides, techniques were developed for direct determination of the magnetic sub-fabrics of the minerals that exhibit low-field variation of susceptibility such as titanomagnetite, pyrrhotite, hematite and those showing frequency-dependent susceptibility such as magnetically viscous grains of magnetite or maghemite. The direct determination of the magnetic sub-fabrics of the same minerals can also be made through the anisotropy of out-of-phase component of susceptibility. The last anisotropy can be used in the determination of magnetic sub-fabric of weakly magnetic, but strongly conductive minerals like graphite. Through suitable selection of magnetizing fields in the AMR, one may investigate sub-fabrics within ferromagnetic minerals differing in magnetic viscosity.

As known since the first half of the 20th century, the sub-fabrics of individual rock-forming minerals can possess more or less identical symmetries or differ in symmetry considerably. The former fabrics, called homotactic by Sander, are indicative of very similar configurations of the stress fields controlling the formations of individual sub-fabrics, while the latter fabrics, called heterotactic, indicate changing configurations of the stress fields that control formation of the individual sub-fabrics probably originating in different stages of rock fabric formation. Similar situation exists in magnetic anisotropy components. The present paper shows some applications of the above resolution techniques to solving various geological problems.

Keywords: magnetic sub-fabric, low-field anisotropy, high-field anisotropy, remanence anisotropy.

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Magnetometry Used for Comparison of Heavy Metals Air Pollution Inside and Outside Home; Case Study from Warsaw

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Abstract

The aim of this study is to compare pollution of air inside a building (Jeleńska *et al.* 2017) with pollution of soil and dust street around the building. Magnetic properties such as hysteresis parameters and magnetic susceptibility values, and magnetic mineralogy identification were used for characterization of magnetic particles present in indoor dust, street dust and in soil. Study was carried out in the flat in residential biulding located in the center of Warsaw between two very busy streets and one smaller but very narrow. Dust samples (ID) were collected inside the buildings with a vacuum cleaner. Street samples (DD) were swept up from the surface of the roadway. Soil samples (DS) were digged from the lawns along the street. The samples were taken from 2 or 3 layers: surface, 0-10 cm and 10-20 cm of depth. Two samples of soil were taken from the lawn in the inner yard of the building. 3 samples were taken from the flat located on first floor. Magnetic parameters measured include mass susceptibility, hysteresis loops and volume susceptibility during heating to 700 °C. The values of susceptibility showed that soil taken from the inner yard is contaminated approximately similarly to soil taken along the small street. The highest values of susceptibility are for soil taken around crossroad. Contamination of street dust is lower than soil around crossroad and higher along the streets. Susceptibility of indoor dust is approximately the same as for soil samples taken by the nearest street.

Keywords: magnetic parameters, street and indoor dust, soil contamination.

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Enhanced Magnetic Susceptibility of Burnt Soils – Does it Evolve with Time?

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Abstract

A well known outcome of fire on soil magnetism is extremely high magnetic enhancement of top-most soil depths (Tite and Mullins 1971) compared to non-burnt soil. It was anticipated that due to thermal transformations in iron oxyhydroxides (mainly goethite) during heating a strongly magnetic maghemite is produced. This mechanism is further considered as one of the possible processes causing widely observed soil magnetic enhancement (e.g., Dearing *et al*. 1996, Evans and Heller 2003). Several studies, however, evidence that vegetation ashes also exhibit high magnetic susceptibility, typical of ferrimagnetic substances (McClean and Kean 1993, Lu *et al*. 2000, Jordanova *et al.* 2006, Petrovsky *et al*. 2018) in spite of diamagnetic nature of the raw vegetation. Thus, it could be supposed that magnetic signature of burnt soils reflects a more complex enhancement processes than previously thought. Apart from this, another major question arising in considering the magnetic properties of fire-affected soils is whether their magnetic enhancement is stable in time since the firing event, or it changes. In order to answer this question, an experimental fire was set up and magnetic susceptibility of samples taken from two depth levels (ash-rich level (0-3 cm) and soil mineral level (3-6 cm)) immediately after the fire was monitored during 2.5 years period. In addition, several samples from these two depth levels were taken after different time span since the firing event and their magnetic susceptibility again was monitored during that period. Besides, soil samples were taken one week after natural wildfires in 2017 year and magnetic susceptibility of samples from different depth intervals was tracked during the following 8 months. Reference soil samples from non-burned soils from the respective sites were included in the collection well. The main results from the study show that: 1) Magnetic susceptibility of burnt soil changes since the firing event and this change depends on the intensity and duration of fire, being more pronounced in soils suffering low-severity fire; 2) Magnetic susceptibility increases in soil samples taken immediately after the fire during the first ~10 days and slowly decreases afterwards for ash-rich samples or remains semi-constant in mineral-rich samples; 3) Magnetic susceptibility increase with time varies in a wide range between 2–3% and almost 40% with respect to the initial value, being higher in mineral-rich samples; 4) Magnetic susceptibility of soil samples taken after high-severity natural wildfire show a weak decrease (varying between 0–4%) with time which is the most pronounced in top-most depths; 5) Magnetic susceptibility of reference non-burnt soil samples practically does not change with time. The most probable reason for the observed fast changes in magnetic susceptibility after fire is related to soil dehydration as revealed by the data of weight loss with time. It is supposed that severe wildfires lasting several days produce more stable new magnetic minerals, while experimental fire and low-severity natural fires generate ultra-fine unstable magnetic grains which continue growing and further oxidize during laboratory monitoring period. Different implications of the observed changes in magnetic enhancement of fired soils related to environmental applications in practice will be discussed.

Keywords: soils, wildfires, magnetic susceptibility, temporal changes.

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Magnetic and Geochemical Discrimination of Wildfire Affected Soils

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Abstract

Magnetic enrichment of fire-affected soils is a long – known phenomenon, observed at the birth of environmental magnetism and it was suggested that fire may be responsible for the soil magnetic enhancement of well aerated soils (Tite and Mullins 1971). Since then, several rock magnetic parameters have been proposed for discrimination between natural magnetic enhancement and burnt soils' enhancement, based on the observation that fire-affected soils show systematically higher concentration of fine grained superparamagnetic magnetite particles (Oldfield and Crowther 2007, Roman *et al.* 2013). The aim of the present contribution is to examine the effect of complex variations in fire severity, type of vegetation, time since fire and natural soils' properties on the observed magnetic and geochemical signature of burnt soils from Bulgaria. For that purpose, nine couplets of burnt-natural forest soils under pine forest; four couplets under mixed/broadleaf forest and three soil couplets with grass/bush vegetation have been studied. The wildfire events happened at different times before sampling, encompassing the period 2000–2017. In all profiles sampled, clear distinction of the burnt layer was possible based on the presence of abundant ashes and charcoal. Systematic magnetic enhancement is observed in all fire-affected soil levels, which is expressed not only in increased SP-content, but also enhanced concentration of stable SD particles. It is suggested by the experimental data, that the relative contribution of the two fractions depends on the fire severity in terms of both maximum firing temperature reached in the surface soil and the duration of fire event. Maximum fire-induced magnetic enhancement of susceptibility is obtained for soils developed under pine forest, suffered by strong wildfires. Less intense fire events and mixed or broadleaf vegetation cover induced weaker magnetic enhancement. Along with the enrichment with strongly magnetic iron oxides of the burnt layers, significant increase in the content of total concentration of elements – micronutrients such as Mn, Cu, Zn, P is observed, in line with other studies (Certini 2005, Pereira *et al*. 2012). Much better log-linear correlation is obtained between total carbon content (Ctot) and anhysteretic remanence (ARM) for burnt soil levels (R^2 of 0.85) as compared to non-burnt and Ctot – magnetic susceptibility relationships.

These findings suggest that wildfire affected soils' magnetic signature is dominated by magnetic signal of vegetation ashes.

Keywords: burnt soils, magnetism, fire severity, mineralogy.

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Loess-palaeosol Magnetism as a Tool for Reconstruction of Past Environmental Processes: Examples from the Czech Loess Regions

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A b s t r a c t

Loess-palaeosol sequences provide one of the most widespread palaeoenvironmental records. Aeolian dust deposition and loess formation dominated in glacial Pleistocene stages, whereas during temperate interglacial (or interstadial) periods the loess surface was altered to soil. The pedogenic processes caused diagnostic changes of iron minerals present in primary loess (e.g., Maher 2011). Primary magnetic fabric of the loess, described by anisotropy of magnetic susceptibility principal directions, fabric magnitude, and a fabric shape, was deformed due to neo-formation of ultrafine superparamagnetic (SP) particles and sediment bioturbation (e.g., Tarling and Hrouda 1993). Additionally, the interglacial (interstadial) flash precipitation events could trigger slope processes and the soft sediment reworking.

Mid- to Late Pleistocene loess-palaeosol sequences, located in the central European loess belt, were investigated using a spectrum magnetic techniques. Magnetic mineralogy and grain size generally follow common Eurasian magnetic susceptibility pattern – i.e., palaeosols reveal magnetic enhancement due to formation of the SP particles, which significantly reduce the anisotropy degree in the palaeosols. The AMS directions differ between sedimentary horizons formed in glacial and interglacial climates. The magnetic lineation and foliation in the loess indicate dominating wind directions from W (SW) to E (NE) across south Moravia. This is in agreement with recent results by Lagroix *et al*. (2011). We identified the loess magnetic fabric deformation independent on the pedogenic SP particle formation. The decreasing trend in the anisotropy degree is, most probably, connected with periglacial freezing/melting cycles affecting the loess deposits. The magnetic fabric in the paleosol horizons was strongly altered by reworking due to unconcentrated slope runoff controlled by local morphology.

Keywords: loess, palaeosol, magnetism, environmental reconstructions.

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Fe-Cr Mixed Binary Spinels as Accessory Magnetic Minerals in the Sudetic Ophiolitic Rocks

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A b s t r a c t

Sudetic ophiolite is formed of three serpentinite massives situated around the Sowie Góry Mts Block: Jordanów-Gogołów Massif (JGSM), Braszowice-Brzeźnica Massif (BBSM) and Szklary Massif (SZM). Chromite Fe-Cr spinels occur in chromium ore (chromitites) in JGSM and BBSM (ore fragments on waste heaps) and as scattered grains in ultramafic rocks. The Fe-Cr chromite series have a general formula of $(Fe^{2+}_{1-x} Fe^{3+}_{x})[Fe^{2+}_{1-x}Fe^{3+}_{2-2y-x}Cr^{3+}_{2y}]_2O_4$ is built of mixed spinels with end members: primary chromite $(Fe^{2+})[Cr_3^{+2}]O_4$ (y = 0) with normal ordered spinel structure (x = 0) and magnetite $(Fe^{3+})[Fe^{2+}Fe^{3+}O_4]$ (y = 1) with inversed ordered spinel structure (x = 1). Fe-Cr spinels are called ferrichromites for $0.31 < y < 0.63$ and Cr-magnetites for $y > 0.63$. The composition affects substantially Curie temperatures: T_c of primary chromite is -202°C, T_c above r.t. for ferrichromites up to T_c of 585°C for magnetite. The primary chromites crystallize from mafic melt in upper mantle-lower crust environments. They are very stable against metamorphism and retain primary composition of their cores long during later metamorphism. Under cooling below ca 600°C chromite begin to alter: magnetite starts to replace chromite, with subsolidus exsolutions and oxidations processes. The core of the grain retains its primary composition with typical T_c of -180° up -120°C, around it ring 1 composed of Fe-Cr solution grains of ferrichromite and ring 2 of Cr-magnetite formed during metamorphism were observed (Fig. 1). Apart of changes in composition additional alterations, namely order – disorder transformation takes place (e.g., described by Harrison and Putnis (1999)). Such transformation is caused by electron hopping between tetrahedral and octahedral sublattices with help of oxygen ions (x in the above formula presents a fraction of 3+ cations in tetrahedral sublattice). Chromites were studied with magnetic methods as determinations of the magnetic susceptibility upon temperature curves (km-T) at the range -190°C up to 700°C for fresh and previously heated samples as well as with hysteresis properties studies. The Km-T experiments for fresh samples showed a wide spectrum of Km(T) curves depending on the composition (Fig. 2). Changes in composition influence changes in Tc observed on the heating branch of km-T curve, changes in ordering impart changes in Tc observed on the cooling branch. Therefore k-Tc curves are irreversible and Tc of samples observed in Cr-magnetites during heating is higher by 10–20°C than observed during cooling. During next heating – cooling cycles both branches become reversible. The observed thermal hysteresis

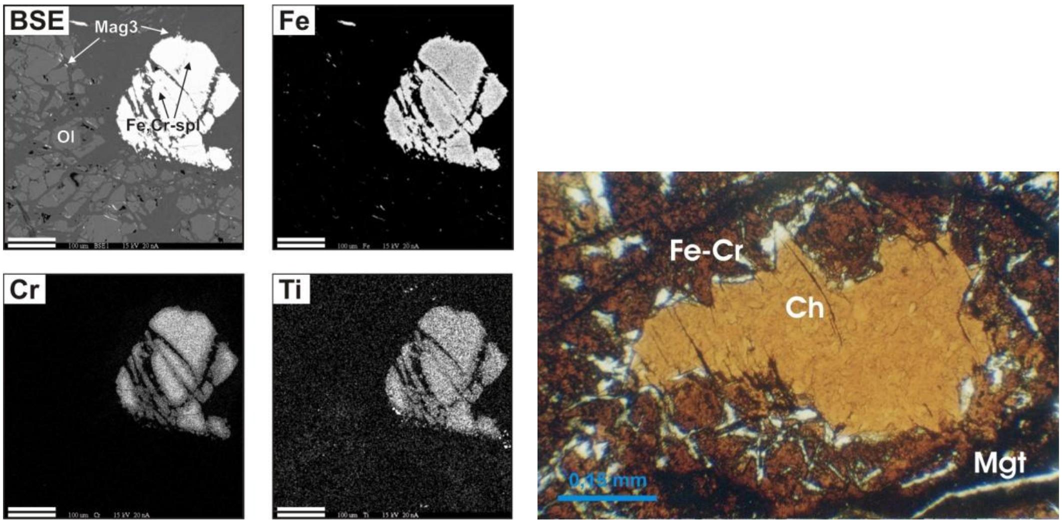

Fig. 1. BSE-SEM maps for chromite grains from chromite ore (JGSM, Tąpadła, ferri-chromite).

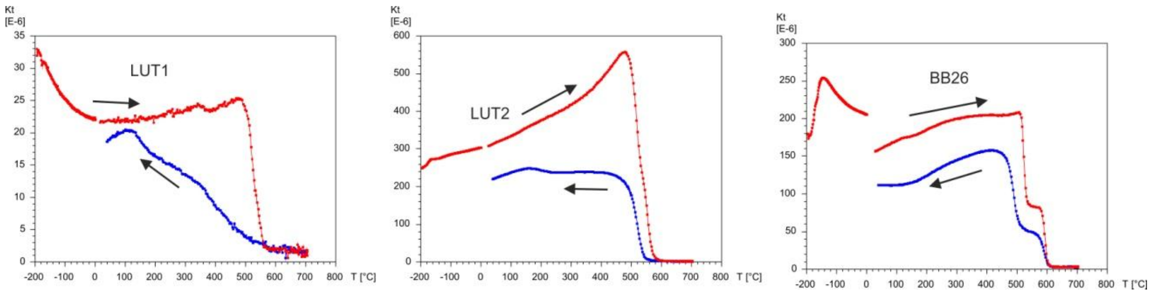

Fig. 2. Magnetic susceptibility Km-T curves -190°C up to 700°C) for chromites of different composition.

during heating-cooling cycle is due to kinetic lag in cation ordering during cooling (Harrison and Putnis 1996). The coercivity usually increases due to heating suggesting subsolidus exsolutions.

Keywords: chromites, magnetic susceptibility, ophiolite.

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Preliminary Rock Magnetic and Paleomagnetic Results of the Holešice and Libkovice Member Transition of the Most Basin (Burdigalian, Czech Republic)

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Abstract

The Most Basin (Fig. 1) is the largest basin within the Ohře Rift in Czech Republic. The Early Miocene Most Formation (topmost part of Most Basin) is divided into 5 members, spinning from Duchcov up to Osek members (Mach *et al.* 2014), and comprise of lacustrine-, alluvial and fluviodeltaic sediments with interjected coal seams.

Two drill cores (AL505 and DO565) of the Holešice and the Libkovice Members from the Most Formation are currently studied. The studied sediments consist mostly of monotonous lacustrine silty clays, thus the paleomagnetic research in combination with chemostratigraphy and cyclostratigraphy (Matys Grygar *et al*. 2014) is required for stratigraphic assignment. So far, e.g., Natural Remanent Magnetization (NRM), Magnetic Susceptibility (MS) and its' anisotropy, Alternating Field demagnetization (AF), and Anhysteretic Remanent Magnetization (ARM; for paleointensity estimation) have been acquired. Preliminary results indicate both normal and reversed polarities of characteristic remanent component. Susceptibility and NRM show generally low values. Paleointensity is derived from NRM_{AF30}/ARM_{30} ratio and is shown in the Fig. 2.

The next step will be measurement of IRM (Isothermal Remanent Magnetization) acquisition curves, S-Ratio and other rock magnetic parameters.

Keywords: Most Basin, magnetostratigraphy, rock magnetism, Holešice and Libkovice Mb., Burdigalian.

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Fig. 1. Location of the Most Basin.

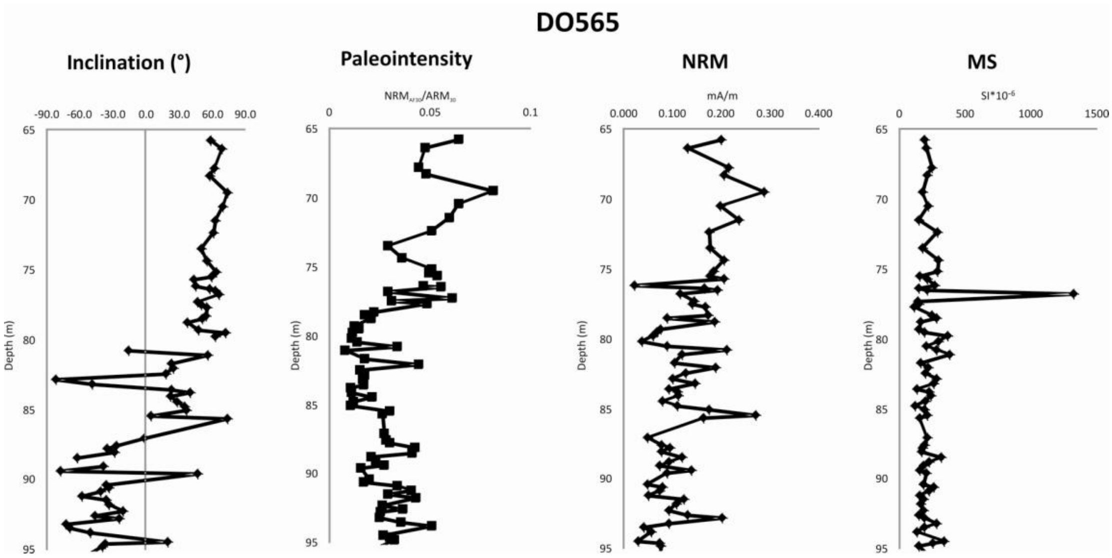

Fig. 2. Inclination, paleointensity proxy, NRM and MS of the Holešice Mb. and Libkovice Mb. transition interval in the DO565 drill core.

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Application of Mössbauer Spectroscopy in Environmental Research

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A b s t r a c t

Mössbauer spectroscopy is the technique of recoil-free resonant emission and absorption of gamma rays. It has the advantage of being sensitive only for one element. In the case of materials formed on the Earth's surface, such as soils and clays, the only propitious element is Fe.

Iron is the fourth most abundant element in the Earth's crust, it is essential for life, and almost all environmental materials contain at least some form of Fe. Not coincidentally the ^{57}Fe Mössbauer spectroscopy is among the most straightforward to operate. ^{57}Fe Mössbauer spectroscopy thus allows the characterization of iron speciation, and thereby of environmental conditions, over a wide range of concentrations, making it an extremely effective environmental technique. Straightforward, as it may seem, Mössbauer spectroscopy nevertheless has many pitfalls. Besides problems arising from the basic physics, complications can arise among other causes from imperfect crystallinity (small particle size), non-stoichiometry, interparticle effects and isomorphous substitutions.

The aim of the study was analysis of Mössbauer spectra of technogenic magnetic particles (TMPs), separated from various industrial dusts emitted from different sources and deposited in soil. TMPs can be used here as indicators of soil pollution with heavy metals, as they are one of the main carriers of metals from the emission source to the environment (soils, sediments, plants) (Magiera *et al.* 2011).

The analyzed samples of TMPs were separated from metallurgical and coke dusts as well as separated from organic horizon of the forest soil in the vicinity of relevant emission sources. Ash samples were obtained after coal combustion in domestic low-power boiler and biomass combustion in laboratory muffle furnace. Different kind of biomass was combusted: wooden pellets, straw pellets, oats, miscanthus. The ^{57}Fe Mössbauer spectra were

recorded at room temperature with a constant acceleration spectrometer with ^{57}Co:Rh source (activity ~50mCi). The metallic iron powder (α-Fe) absorber was used for velocity and isomer shift calibration of the Mössbauer spectrometer. The mineralogical analysis of the spectra was based on the Mössbauer Mineral Handbook (Stevens *et al*. 2005).

Mössbauer spectra analyses revealed that TPMs formed during combustion of coal and biomass are more mineralogically homogeneous and contain mainly magnetite (TMPs after combustion of hard coal) or maghemite (after biomass combustion). It can be assumed that a higher degree of carbonization is associated with a higher concentration of TMPs in ash and as a consequence: higher magnetic susceptibility. The more complex mineralogy is exhibited in TMPs present in other industrial dusts (coking, metallurgy). They are differentiated by specific magnetic features. Steel and metalliferous dusts show significantly higher values of χ and SIRM than coking dusts. The latter, in turn, usually have higher values of coherence parameters due to a much greater share of antiferromagnetic and paramagnetic minerals in TMPs. Magnetite in fly ashes from hard coal combustion and in metallurgical dusts is more stoichiometric than in fly ashes after lignite and biomass combustion. In the second case, the finer maghemite and hematite are also present. The results of Mössbauer spectroscopy analysis showed that the magnetospheres consist of a core composed of magnetic spinels with complex internal structure that contains in addition to oxygen and iron (Fe^{3+}, Fe^{2+}) also Mn, Mg, Al, and Ti atoms. The outer shell of magnetospheres is composed of silica hyaline structure (glassy phase) containing iron. In metallurgical dust, additionally strongly magnetic metallic iron (αFe) and wustite were indicated. Ferrimagnetic sulphides as pyrrhotite are present in dust from coke production.

These results will be complemented with magnetic (bulk magnetic susceptibility and temperature dependence of magnetic susceptibility) and mineralogical (X-ray powder diffraction and scanning electron microscopy with energy dispersive spectroscopy – SEM/EDS) analyses.

Keywords: Mössbauer spectroscopy, technogenic magnetic particles, iron mineralogy.

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Palaeomagnetism of the Czajakowa Radiolarite Formation and the Czorsztyn Limestone Formation: An Example from the Stare Bystre Succession (Pieniny Klippen Belt) – Preliminary Results

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Abstract

Palaeomagnetic studies of the Upper Jurassic rocks were performed in the Polish part of the western fragment of the Pieniny Klippen Belt (PKB). Red and green radiolarites of the Czajakowa Radiolarite Formation and red nodular limestones of the Czorsztyn Limestone Formation represent the Grajcarek succession. More than 80 oriented cores were collected from the 20-m-thick Stare Bystre succession. Laboratory work was focused on recognizing the natural remanent magnetization (NRM) structure and magnetic carriers, involving thermal and alternating field demagnetization, analysis of magnetic susceptibility and its anisotropy, and the Lowrie (Lowrie and Heller 1982) and S-ratio (Bloemendal *et al*. 1992) tests. Thermal demagnetization revealed two main components of natural remanent magnetization (NRM). A low-blocking temperature component S of normal polarity is considered of post-tectonic origin. A stable, high-blocking temperature NRM component P shows dual-polarity distribution and is considered as primary. Unfortunately, only some of the samples from the base and top of the succession show the primary magnetization component – their number is insufficient for Fisher statistics. This requires more sampling for further studies. IRM saturation curves show a rapid saturation up to 100 mT and then a slower pace until reaching the maximum value of 1 T, which suggests the presence of magnetite and hematite. These results are confirmed by the thermal demagnetization of the IRM saturated samples (Fig. 1) – the low coercivity component shows a blocking temperature of ca. 575°C, while the high coercivity component shows the blocking temperature of ca. 675°C. Furthermore, the S-ratio analysis ($S_{-0.3T}$) gives most values close to zero, which suggests a significant contribution of hematite. Magnetic susceptibility values (2.11×10^{-5} [SI] to 1.27×10^{-4} [SI]) during thermal demagnetization are stable over the entire temperature range with the exception of slightly lower values near 320°C, which may suggests a low content of iron sulfides.

Keywords: Pieniny Klippen Belt, Carpathian, Jurassic, palaeomagnetism, Stare Bystre.

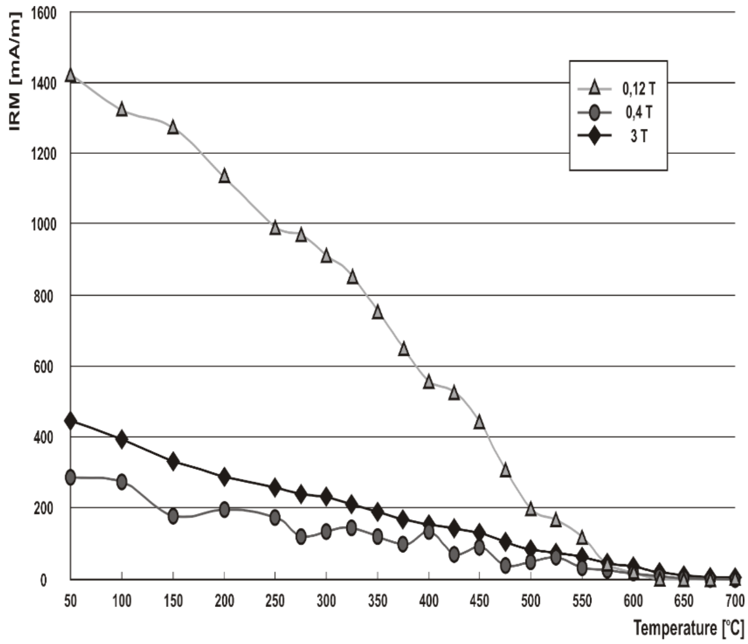

Fig. 1. Thermal demagnetization of the IRM saturated sample (Lowrie test) from the Stare Bystre succession.

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Magnetic Fabric in Ductile Shear Zones: Analogue Modelling

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Abstract

The measurement of anisotropy of magnetic susceptibility (AMS) becomes one of the most popular structural techniques for precise and quick determination of anisotropic fabric in rocks with lack of macroscopically visible structures. Sometimes, the lack of comprehensive information about the governing processes of AMS in rock can make interpretation difficult. Although it is well-established method and the strain-AMS relationship has been long time under investigation, recent publications have brought more attention to this subject. There is considerable discussion concerning origin of the magnetic fabric, its correlation with the bulk deformation and rock strain memory. The aim of our work is to bring new insights into the time and space relationships between finite strain microstructure and AMS fabric by providing new comparative data from analogue shear zones. Relationship of AMS with increasing strain was experimentally studied in deformed sandstones, plasticine, magnetite bearing sand bonded with cement (Borradaile and Alford 1987, Jackson *et al.* 1993), during preparation and compaction of calcite and muscovite aggregate (Schmidt *et al*. 2008a, b) and simple shear experiments on mixture of silicone and wax (Arbaret *et al.* 2013).

The experiment set-up for analogue modelling is designed as a large shear-box enabling strain rate variability. Also shear zones of variable width can be produced. The experiments are carried out with the coloured plaster of Paris with 1wt % of powder retarding the solidification reaction. The used material displays a strain-rate dependent (thixotropic) rheology and is capable to well-reproduce the strain localization and very well corresponds to natural rocks. Experimentally produced shear fabric in plaster is analyzed in terms of AMS due to homogeneously admixed fine-grained magnetite. By varying experimental strain rate we are able to simulate ductile to brittle behavior of the shear zones and document AMS evolution by the strain localization.

Keywords: AMS, magnetic fabric, deformation, strain, shear zone.

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Magneto-spectroscopic Properties of Sediments of Benguela Upwelling System

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A b s t r a c t

Upwelling systems along the western margin of continents are the most productive marine ecosystems on the earth. In such systems the wind along the coast causes off-shore movement of surface water which results in upwelling of cold, highly CO_2 concentrated, nutrient-rich water to the illuminate zone where photosynthesis occurs (Fig. 1a). Nutrients and CO_2 concentrations are essential for photosynthesis and their rise results in increased primary productivity in the water surface (growing amount of organic matter). Dead organisms sink to the water/sediments zone where they are decomposed by microbes. In this process oxygen is consumed and strongly reducing conditions are established. The fate of magnetic phases in such an ecosystem is poorly resolved, despite the fact that upwelling systems are widespread and are active over millions of years. Considering such system magnetic phases can be formed, e.g., by biogenic processes or be destroyed by reductive dissolution.

In our study we use the Benguela upwelling system along the Namibian coast in SW Africa. The sampling sites are showed in Fig. 1b) and we present preliminary magnetic results from a 20 cm profile at the sediment/water boundary in 128 m depth at site 23020 (23°S, 14°04'E).

The content and properties of the magnetic phases in the profile were obtained from freeze-dried samples using Kappa bridge and Ferromagnetic Resonance (FMR) spectroscopy. FMR is a sensitive tool to detect magnetic phases and their anisotropy properties.

The susceptibility varies from $1.36 \cdot 10^{-8}$ to $5.88 \cdot 10^{-8}$ and reaches maximum for sample 5–10. The FMR spectra show a broad signal that is superimposed by sharp signal at around 3.5 kOe. The latter stems from free electrons in clay minerals. The FMR spectra from the upper 3 cm have two relatively broad maxima in the low-field range (left of the sharp peak). With depth this feature disappears and the signals get a Lorentzian-like shape. The two maxima could be an effect of uniaxiality stemmed from Magnetotactic Bacteria or a result of a superposition of a broad signal and a signal from paramagnetic Fe^{3+} species at 1.5 kOe.

All spectra have in common that they lose most of their intensity upon heating to 400°C (Fig. 2b). This indicates that the magnetic phase is unstable at this temperature.

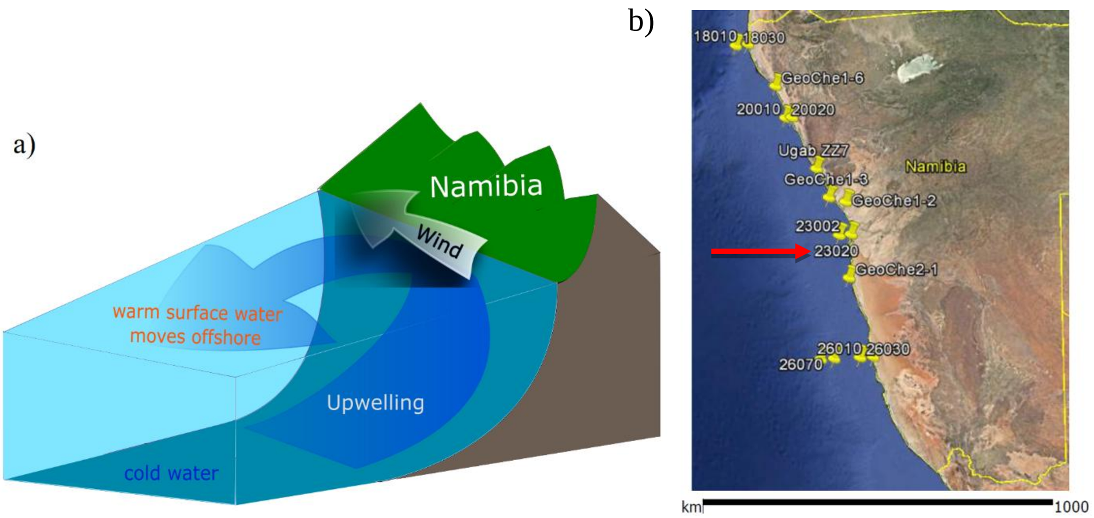

Fig. 1. a) Basic scheme of upwelling phenomena, b) sampling sites along the Namibian coast, red arrow shows analyzed profile 23020.

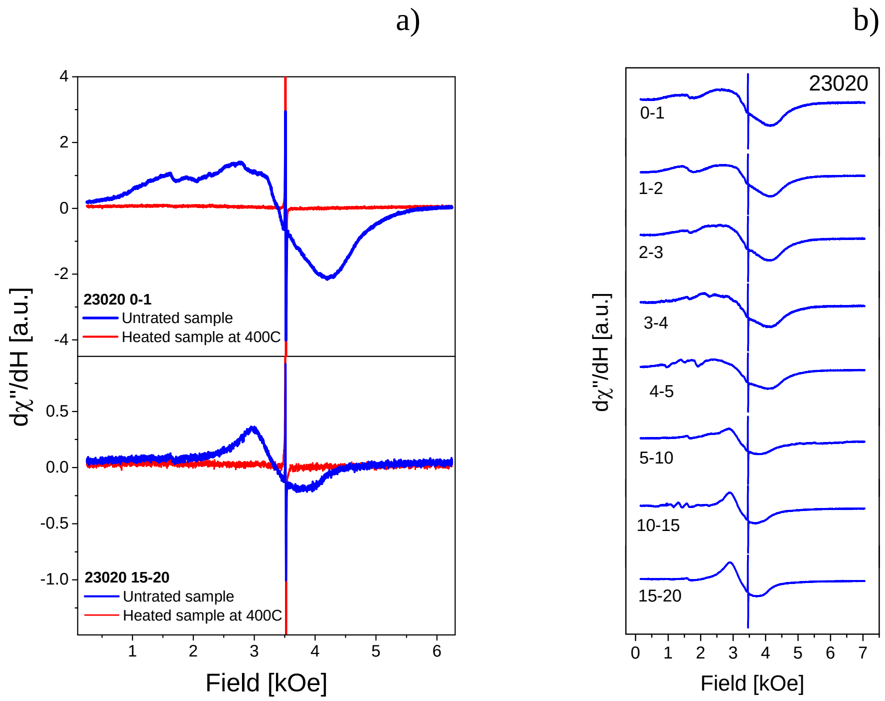

Fig. 2. a) Ferromagnetic resonance spectra profile with depth, b) comparison of signal before and after heat treatment at 400°C for samples 0–1 cm and 15–20 cm.

Among the magnetic minerals that provide a relatively strong FMR signal and are unstable at about 400°C is greigite (Fe_3S_4) or fine-grained maghemite (γ-Fe_2O_3).

In summary, content in the sediments from the Benguela upwelling zone is carried by a phase with a thermal stability of less than 400°C, that could be maghemite or greigite. The prevailing reducing conditions in upwelling systems argue in favor of greigite, because under such conditions maghemite undergoes reductive dissolution.

Keywords: Benguela upwelling, magnetic content, ferromagnetic resonance spectroscopy.

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Palaeomagnetic Inclination Error in the Red-beds Deposits: A Contribution from the Ediacaran Sedimentary Rocks of the Western Part of the East European Platform

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Abstract

A primary goal of this palaeomagnetic study was to determine palaeolatitude of the Ediacaran basin, situated at the western part (present-day coordinates) of the East European Platform (EEP).

Palaeomagnetic samples were cut off from 11 unoriented cores, representing coarse-grained siliciclastic rocks, interlayering with basalts of Volyn Series/Group and equivalent – Sławatycze Formation in Poland. The whole sampled section represents ca 570–541 Ma (Late Ediacaran) timespan, practically post-dating the Ediacaran inertial interchange true polar wander hypothetical event (Robert *et al*. 2017). Fine-grained red mudstones of the Pinsk Series (mid-Riphean, 1.7–1.3 Ga) were also investigated.

We have identified components of the natural remanent magnetization (NRM) in 57 out of 83 specimens. On the basis of the inclination of the characteristic NRM components, we have calculated paleolatitudes for the Ediacaran basin, assuming validity of the geocentric axial dipole (GAD) hypothesis. Most of the characteristic NRM components show shallow-to-moderate inclinations, implying low palaeolatitudes, determining palaeogeographic reconstructions in Ediacaran times. However, basaltic rocks yielded steeper inclinations, in line with outcomes of Nawrocki *et al*. (2004). Since basalts and the sediments are nearly coeval, any explanation of inclination difference based on plate tectonics/continental drift may be excluded. We postulate that the difference is caused by the effect of palaeomagnetic inclination shallowing (Li and Kodama 2016). On the other hand, we have found that characteristic NRM for the mid-Riphean mudstones also show low-to-moderate inclinations, but this time in line with inclinations obtained for Subjotnian (1.6–1.3 Ga) volcanics of Scandi-

navia (Pesonen *et al*. 1989). This outcome suggests that a magnitude of the inclination error may be linked with a size of grains of siliciclastic rocks.

We note that many of paleopoles reported in the literature of last two decades comply all of the well-known, seven reliability criteria by Van der Voo (1990). They also imply subequatorial paleolatitudes, similar to our results obtained from the siliciclastic rocks of the EEP. However, observing important difference between palaeomagnetic inclinations obtained by us from sedimentary rocks and coeval basalts, we postulate that some of these results, obtained from sediments, may also be handicapped by a substantial (although varying between the facies) inclination error. Such conclusion is moreover supported by the fact that none of ChRM inclinations, determined for the Late Ediacaran sediments, show higher palaeolatitudes than these shown by Nawrocki *et al*. (2004) for basalts. This cast doubts on the earlier palaeomagnetic results obtained for the coarse-grained sedimentary rocks (specifically with application to Ediacaran palaeogeographic reconstructions), since they may also be affected by this type of error.

Keywords: Ediacaran, paleomagnetism, inclination error, sedimentary rocks.

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Delineating Individual Ferromagnetic Minerals in Synthetic Mixtures of Magnetite and Hematite

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Abstract

Magnetite and hematite are the most common ferromagnetic minerals in rocks and sediments. Many methods have been developed to identify their occurrence in geological material. Because the saturation magnetization of magnetite is much stronger than hematite, it may not be easy to identify both minerals when using induced magnetic methods, e.g., hysteresis loops or thermomagnetic curves. Frank and Nowaczyk (2008) demonstrated that the hematite concentration must be at least 95 wt% of the mixture before a change in coercivity can be detected, and 99.5 wt% before B_{cr}/B_c is affected. Parameters involving remanent magnetization rather than induced magnetisation, e.g., SIRM or HIRM, noted hematite at concentrations of 90 wt% or higher. In this study, we reexamine mixtures of magnetite and hematite to evaluate the ability of FORC analysis to distinguish mixtures. The end members for the mixtures were magnetosomes of biogenic magnetite (LMU-30) that were provided by the group of Prof. Dirk Schüler from the Department of Microbiology at the University of Bayreuth, Germany. The hematite sample (Hem21) was obtained from Merck. The magnetic properties were defined for these end member samples. Hysteresis loops are closed by 100 mT for mixtures up to 85 wt % hematite; at higher concentration the loop remains open to maximum field. The coercivity, B_c, remains relatively stable with a decrease until above 80 wt % hematite. B_{cr} shows a gradual decrease up to 80 wt % hematite. M_s shows a linear cdecrease with increasing hematite concentration. Acquisition IRM curves are saturated by approximately 60 mT for the mixtures of magnetite and hematite up to 61 wt %. By 70 wt % hematite, it is clear that the IRM is not saturated, and the non-saturated contribution increases with increasing hematite content. S-ratio, however, remains above 0.95 for all mixtures until 95 wt% hematite, similar to what was found by Frank and Nowaczyk (2008).

FORC analysis shows that a concentration of hematite (around 90 wt %) visibly influences the FORC distribution. The FORC distribution is confined along $B_u = 0$, but with different spread along B_c. Although the FORC distribution shows different characteristics depending on the hematite concentration, it is still difficult to depict a general change. For a more detailed study of the mixtures, we analyse the FORC data using principal component

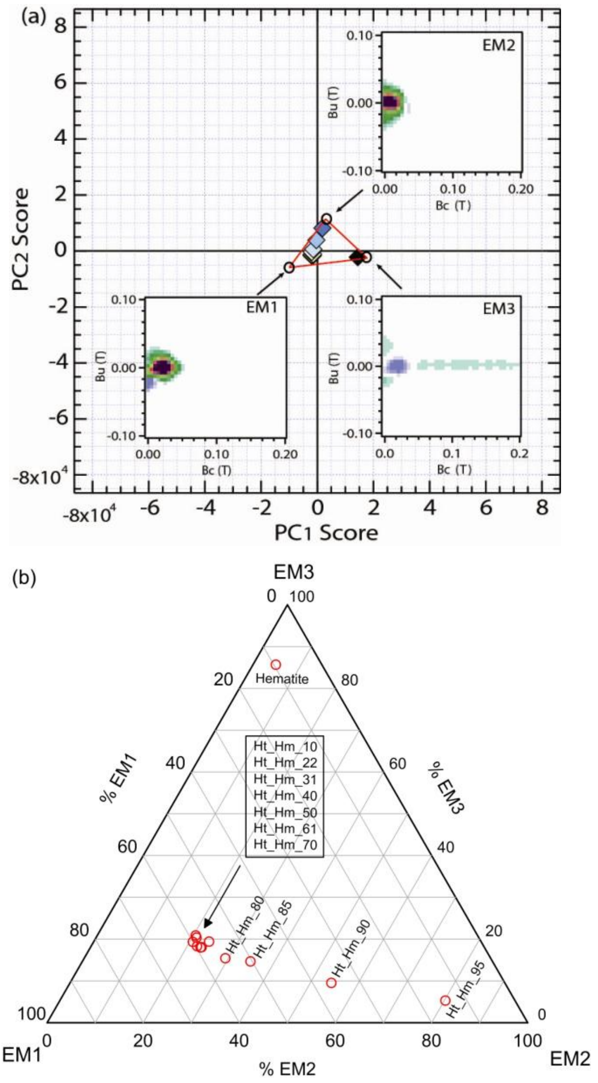

Fig. 1: (a) PCA score plot of the magnetite and hematite mixtures. The resolution for PCA grid on 5 mT; (b) Ternary diagram. Showing relative abundances of the three EMs in each sample.

analysis (PCA) with FORCem (Lascu et al., 2015). The data resolution for the PCA grid is 5 mT. The variability in the mixtures is mainly accounted for by PC1 (Fig. 1), i.e., magnetite, which explains 69% of the data variability. PC2, i.e., the low coercivity hematite component, explains 29% of the variability, and PC3, the higher coercivity hematite component, explains 2% of the variability. Thus, the series can be described as a ternary mixture. This result indicates that hematite influences significantly the magnetic properties at a relative low concentration. Therefore PCA of FORC data can be a powerful technique to detect hematite in mixtures with magnetite.

Keywords: magnetite and hematite, FORC, PCA.

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Enviromagnetism and Palaeomagnetism of Holocene Sediments from Lake Ohau, New Zealand

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Abstract

In early 2016, the Lake Ohau Climate History (LOCH) project recovered an 80-metre sedimentary sequence from Lake Ohau on the south island of New Zealand (Fig. 1), containing a ~17,000-year record of environmental and magnetic variability (Levy *et al*. in press). The LOCH project aims to produce a detailed history of regional palaeoclimate and palaeoenvironment, which are strongly influenced by variations in southern-hemisphere westerly winds. Preliminary palaeosecular variation and relative palaeointensity results were presented at the EGU General Assembly 2017 (Lurcock *et al*. 2017), and proved to be heavily affected by a presumed drilling overprint and gyromagnetic remanences. In order to better constrain and characterize these effects, and to investigate the enviromagnetic record of the Lake Ohau sediments, we are undertaking a detailed rock magnetic study of the 6-metre Mackereth core 6m_1a, retrieved from Site 2 in Lake Ohau preliminary to the main LOCH coring project. Our analyses aim at a thorough rock magnetic characterization of the sediments using measurements of hysteresis loops, temperature dependence of magnetic susceptibility, first-order reversal curves, remanent coercivity spectra, and stepwise IRM demagnetization. Previous NRM demagnetization and ARM acquisition studies on this core have already shown good potential for palaeomagnetic interpretation. Our rock magnetic studies will inform understanding of the palaeomagnetic results from both the 6m_1a core and the full-length LOCH-2A core obtained from the same site. In addition, they will provide a valuable enviromagnetic contribution to the ongoing multi-proxy palaeoenvironmental studies on the Lake Ohau cores. Initial studies have already shown that magnetic parameters in the 6m_1a cores are correlated with palaeoenvironmental proxies such as neodymium isotopes, and our full rock magnetic study will provide further insights into variations in sediment provenance, inflow events, and conditions at the sediment-water interface.

Keywords: enviromagnetism, palaeomagnetism, rock magnetism, New Zealand, Holocene.

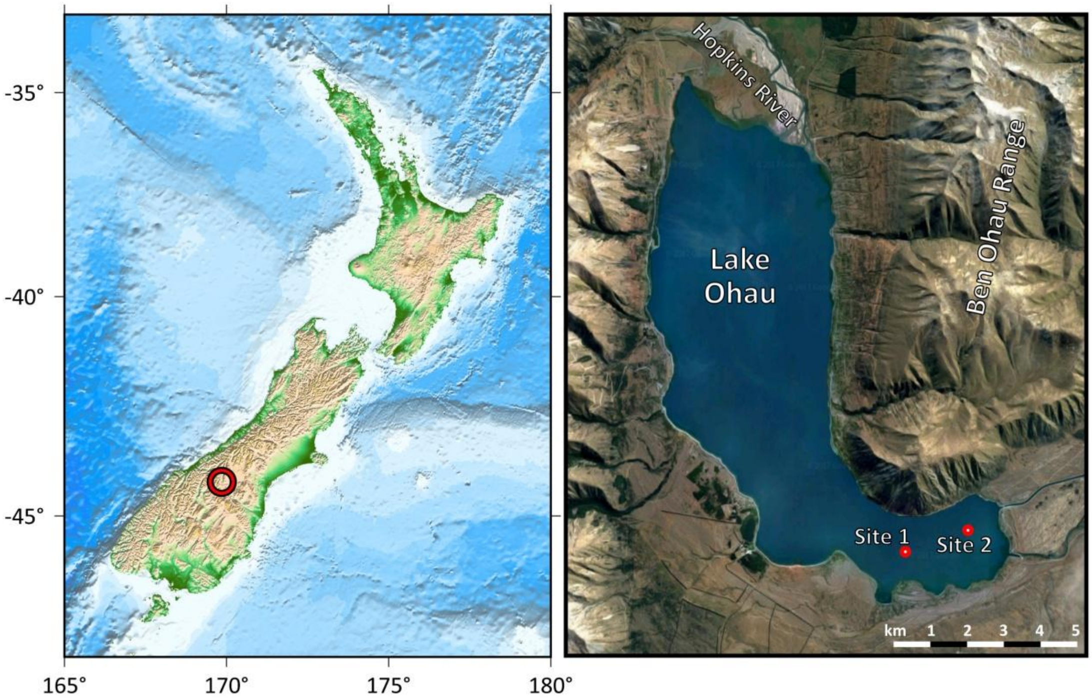

Fig. 1. Location of Lake Ohau and LOCH sampling sites within it.

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The Application of AMS for Deciphering Structural and Sedimentary Evolution of the Orava Basin (Slovakia)

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Abstract

The Neogene infilling of the Orava Basin constitutes a sedimentary record postdating the formation of thrust-and-fold belt of Outer Carpathians and its contact with Inner Carpathians. After the main underlying structural units (Magura Nappe, Pieniny Klippen Belt, and Podhale Synclinorium) were formed, the area underwent uplift and erosion. The considerable horizontal movements including strike-slip tectonics were noted since Lower/Middle Miocene resulting in origin of local depressions. The sedimentary succession and deformation history of the Orava Basin provide an excellent data for the understanding the neo-alpine evolution of the Orava and Podhale regions.

This study (Łoziński *et al*. 2017) combined a sedimentological study, structural measurements and an analysis of large AMS dataset (1930 specimens from 85 locations). The AMS measurements provided data on the presence and directions of tectonic deformation and unravelled the orientation of bedding within massive deposits.

The mineralogy of minerals was obtained from XRD analysis (Łoziński *et al*. 2016) followed by stepwise magnetization and thermal demagnetization of magnetic minerals. The mineral content was dominated by quartz, clay minerals (mixture of illite, chlorite and smectites) and subordinately organic matter. This set of minerals was reflected by magnetic susceptibility falling mostly (>95% specimens) in range 100–500 [$\times 10^{-6}$ SI]. For this group of specimens we assumed the AMS being determined by clay particles orientation.

The majority of 20 specimens examined for magnetic minerals saturated in fields up to 0.3 T. Subsequently, they were almost completely demagnetized in a Lowrie test at temperature between 325 (soft fraction) and 370 °C (medium and hard fraction). The main ferromagnetic minerals (s.l.) were interpreted as greigite and pyrrhotite. The other specimens saturated in fields 1.5–2 T and demagnetized in 575°C and 650°C pointing to the minor content of magnetite and hematite.

The spatial analysis of AMS results revealed that the basin was deformed mostly in its southern part and locally at the margins. Directions of AMS ellipsoid were interpreted as tectonically induced, however the vulnerability for gaining tectonic lineation was higher for

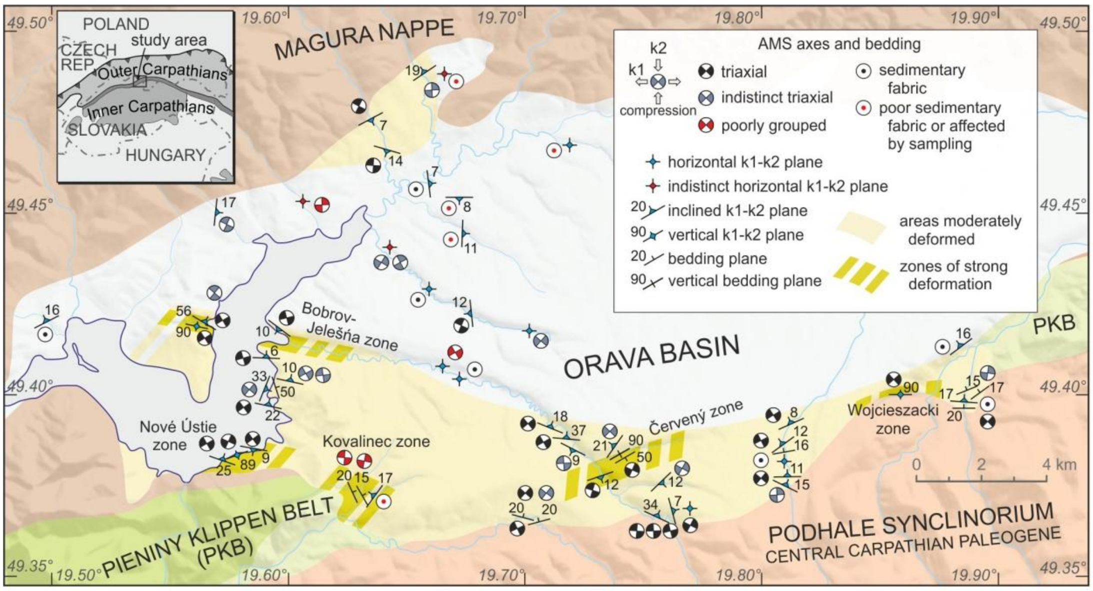

Fig. 1. The AMS fabrics and ellipsoid directions in structural analysis of the Orava Basin (after Łoziński *et al*. 2017, modified).

massive clayey siltstones (floodplain deposits) than for laminated claystones and heterolithic deposits (lacustrine).

The prevailing trend of k1 directions was WNW-ESE. Along with W-E trending bounding faults in the south, it suggested contractional character of deformation in this part of the basin, related presumably with the basin inversion. The NNE-trending contraction agreed with the present-day compression noted in the uppermost part of the lithosphere. Local zones of deformation within the basin confirmed the neo-alpine deformation of the basement, especially along the Pieniny Klippen Belt.

Keywords: anisotropy of magnetic susceptibility, basin inversion, Orava Basin, fine-clastic facies.

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Technogenic Magnetic Particles in Soils Around Different Pollution Sources

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Abstract

Soil magnetic properties mainly reflect the iron-mineral composition. As ferromagnetic properties sensu stricto are exhibited only by metallic iron (αFe), which is not formed under natural environmental conditions, ferrimagnetic minerals like magnetite, maghemite, pyrrhotite or greigite dominate the bulk magnetic properties of natural soils. Only if ferrimagnetic minerals are lacking, antiferromagnetic minerals such as hematite, goethite, lepidocrocite, ferrihydrite or paramagnetic iron containing aluminosilicates noticeably influence soil magnetic properties. Magnetic susceptibility (κ), which is the easiest measurable magnetic parameter in soil, even under field conditions, can be anthropogenically enhanced in areas influenced by industrial and urban dust deposition due to the presence of technogenic magnetic particles (TMPs). TMPs are defined as different mineral forms of iron that exhibit ferro- or ferrimagnetic properties and were formed during wide variety of high temperature technological processes (metallurgy, fuel combustion, ceramics, cement, coke, etc.), when iron contained in raw materials, fuels or additives was transformed into oxide forms. The results of the previous study showed that different technological processes applied in many kinds of industries are a source of very specific morphological and mineralogical forms of TMPs (Magiera *et al*. 2011, Szuszkiewicz *et al*. 2015, Szumiata *et al*. 2017). Their different internal structure is reflected in their magnetic properties, which may be useful for identification of the source of pollution and can serve as an indicator of dust origin when TMPs are found in the topsoil. During these studies we have analyzed TMPs collected from the forest topsoil or arable layer of agriculture soil around different pollution sources (iron mine, Ni-Cu smelter, iron metallurgical plant, Pb-Zn processing waste heaps). Also the topsoil samples from relatively clean area with strong magnetic background located in southern Norway were collected. The sampling areas were chosen on the base of surface magnetic susceptibility measurements using MS2D Bartington sensor. On the base of analysis of the spatial distribution of magnetic susceptibility the magnetic anomalies were identified and topsoil cores from the uppermost 30 cm of soil were collected with application of Humax soil sampler. The vertical distribution of volume magnetic susceptibility were made at intervals of 1 cm with application of MS2C Bartington sensor and then the layers with the highest magnetic values were sampled for the further analyses. The measurements of hysteresis parameters were performed on bulk soil sample using a coercivity spectrometer (J-meter), which synchronously measures induced and remanent magnetization curves at room temperature between -1.5 and 1.5 T. The hysteresis curves were used to calculate the classical hysteresis parameters like saturation remanence (Mrs), saturation magnetization (Ms), remanence coercivity (Hcr) and coercivity (Hc). By relating the ratio Mrs/Ms to the ratio Hcr/Hc one obtains a plot which was developed to identify the average magnetic grain size within a sample. For the further analyses the magnetic fraction was concentrated using hand magnet and the magnetic fraction was divided for 2 parts. The first was used for thermomagnetic analyses and the second was sent for mineralogical analysis performed using transmission ^{57}Fe Mössbauer spectrometry at room temperature. On the Day plot the topsoil samples are grouped in different clusters showed that TMPs from different emission sources have different magnetic properties. The natural particles of geogenic origin are mostly multidomain of stoichiometric magnetite. It was confirmed by Mössbauer spectrometry, since the ratio κ of the contribution of iron ions in the octahedral positions (B) to the contribution of iron atoms in tetrahedral positions (A) is close to the theoretical value 2. The relatively large multidomines of magnetite and/or titanomagnetite are observed also in topsoil around iron mine and metallurgical plant. Close to Bjørnevatn iron mine two slightly different ferrimagnetic minerals are observed magnetite and titanomagnetite with different Ti content. The contribution of titanomagnetite in the magnetic fraction was confirmed by geochemical analyses and Mössbauer spectra (low value of κ ratio of the order of 1.3). The Mössbauer analysis revealed also the presence of magnesium ferrite. The topsoil samples collected around Mo I Rana metallurgical plant are also multidomine magnetite-like phases with good stoichiometry found by means of Mössbauer spectra analysis. The considerably finer fraction of TMPs are observed in arable soil and forest topsoils collected close to Pb-Zn wastes in Piekary Śląskie (Upper Silesia, Poland) and Ni-Cu smelter from Nikel (Kola Peninsula, Russia). The samples contain mixture of sulphides (pyrrhotite) and secondary iron oxides and hydrooxides. In some of these samples the Mössbauer spectrometry have detected the dominance of strongly defected (oxidized) magnetite and hematite, as well as noticeable contribution of goethite - FeO(OH).

Keywords: technogenic magnetic particles, iron mineralogy, Mössbauer spectrometry, hysteresis parameters, thermomagnetic analyses.

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Soil Mapping with Magnetic Methods at the Agriculture Lands of Pechenigy, Ukraine

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Abstract

Magnetic method is suitable instrument in assessment environmental problems. Recently we've received promising results in the studying of hydrocarbon areas (Menshov *et al.* 2016) and polluted territories in Ukraine (Menshov 2017). The correct planning of agriculture areas is fundamental for a sustainable future in Ukraine. The agricultural activities need to be monitored in order to observe if they respect the sustainability principles. Magnetic methods demonstrate potential in soil mapping at the productive agriculture lands for the soil fertility controlling. Jaksik *et al.* (2016) estimated topsoil organic carbon in water eroded soil with measuring of magnetic susceptibility in chernozems in South Moravia (Czech Republic). In present study we focused on magnetic properties of the soils from different catena position from the agriculture land in Ukraine. Soil samples were collected from the genetic horizons at the area of farm enterprise (2 hectares) during a soil survey. The study area is located near the Pechenigi, Kharkiv region, Ukraine and now is used for the perennial plantations – garden. The dominant soils are chernozems (Luvic Phaeozems Albic in WRB classification). The geomorphologic position of the area is a weakly prevailing drainage basin. The soil cut section 1 is performed on the right wing, section 2 at the bottom of the valley, and section 3 on the left wing. The first section corresponds to the conditions of the flat watershed and further means as an etalon chernozem. We registered the sharp change in soil type at the lower part where the section 2 was organized. The hydromorphic processes predominant at this point. The temporary overmoistening, deeper humus layer, the presence of gleying were registered. The third section is located at the steeper slope with the thinner humus horizon, high content of carbonates, and finally short soil profile. Previously, the magnetic studies of chernozems were conducted by Górka-Kostrubiec *et al.* (2016). The authors carried out a detailed magnetic study of four types of Chernozem profiles developed on the loess in the Homutovsky Steppe (Ukraine), Middle Poland, and Moravia (Slovakia). Also Jeleńska *et al*. (2018) presented the results of studies of different soil types from Ukraine and Slovakia. In our case a number of magnetic and mineralogical studies were performed with attracting mass-specific magnetic susceptibility measurements

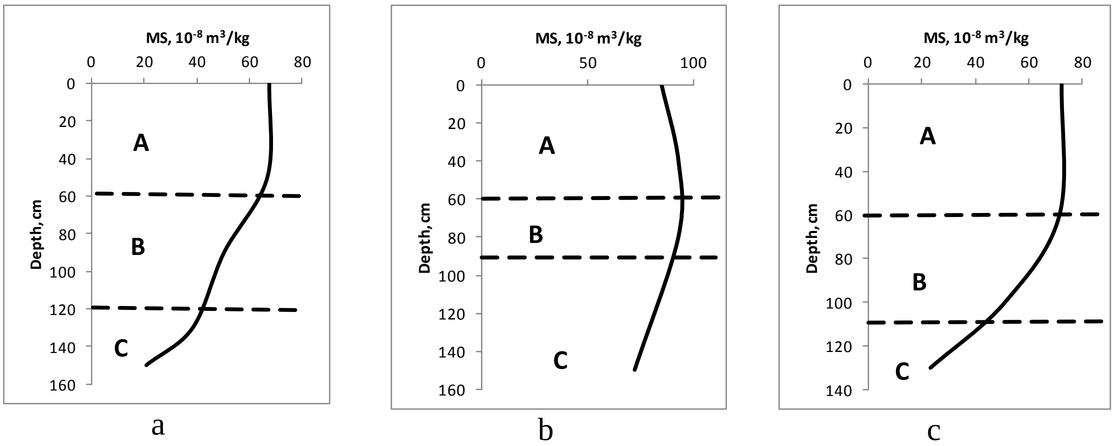

Fig. 1. Magnetic susceptibility distribution in soil horizons of sections 1, 2, and 3 (a, b, and c; respectively) of the Pechenigy agriculture land, Ukraine.

(MS, χ), its frequency dependence (χ_{fd}), temperature measurements (high and low temperature), anhysteretic remanent magnetization (ARM), and isothermal remanence (IRM). The results of MS distributions in the genetic horizons are shown in Fig. 1. Close correlation between genetic horizons, geomorphologic position, and MS values is visible. A deeper magnetic mineralogical interpretation of the obtained results will be considered during the presentation.

Keywords: soil, magnetic susceptibility, magnetization, genetic horizons.

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Palaeomagnetism in the High Arctic. Palaeomagnetic Investigations of Svalbard Archipelago Conducted by the Institute of Geophysics, Polish Academy of Sciences from 1999 to 2018

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Abstract

In the years 1999-2016 Laboratory of Palaeomagnetism of the Institute of Geophysics, Polish Academy of Sciences coordinated numerous palaeomagnetic field investigations in different parts of Svalbard Archipelago. More than 950 independently oriented palaeomagnetic samples were collected from 156 sites representing all three Svalbard Caledonian Terranes (Harland and Wright 1979) as well as post-Caledonian, pre-Eurekan cover of Spitsbergen and Edgeøya. Palaeomagnetic samples were collected during following expeditions: (a) XXII PAS Polar Wintering Expedition to Hornsund (1999-2000; Wedel Jarlsberg Land and Torell Land), (b) IGF PAS palaeomagnetic field investigations of Torell Land (2002), (c) IGF PAS palaeomagnetic field investigations of Wedel Jarlsberg Land, Torell Land, and Sørkapp (2004), (d) Joined expedition of IGF PAS/University of Greenwich (UK) along western and northern coasts of Spitsbergen (2006; Kongsfjorden, Ny Friesland), (e) Palaeomagnetic field investigations of Caledonian Terranes of Svalbard organized in the course of PALMAG NCN project (2012-2013; Oscar II Land, Kongsfjorden, Ny Friesland, Nordaustlandet), (f) “Trias North”project joined expedition of UNIS and Statoil to Edgeøya (2016).

The main conclusions regarding palaeogeographic and geotectonic evolution of the NW Barents Shelf based on interdisciplinary palaeomagnetic – petrological – structural – geochronological investigations (1999-2018) are as follows:

- Palaeomagnetic investigation of the Lower Paleozoic metacarbonates from Hornsund combined with ^{40}Ar-^{39}Ar age determinations of Billelfjorden Fault Zone mylonites confirm that Svalbard constituted part of Baltica already from Late Silurian (Michalski *et al.* 2012);
- Multidisciplinary palaeomagnetic – structural – geochemical – petrological investigations prove intensive Caledonian remagnetisation of Spitsbergen basement and point to important role of listric faults related to opening of North Atlantic system in modifying geometry of the central – western part of Spitsbergen (Michalski *et al.* 2014, 2017; Michalski 2018, Burzyński *et al.* 2017);

- Multidisplinary palaeomagnetic – structural – petrological studies of Neoproterozoic – Lower Paleozoic Murchisonfiord succession suggest that part of Nordaustlandet could constitute foreland of the Caledonian orogenic front were unique pre-Caledonian (primary?) palaeomagnetic record could survive. Preliminary palaeomagnetic results from Murchisonfiord suggest that through at least part of the Neoproterozoic Eastern Svalbard was located min. 10º to the North of the Barents Shelf on the latitudes coeval with NE sector of Laurentia and could constitute separate microplate (in revision);
- Palaeomagnetic investigations of the Lower Triassic sediments of the Torell Land (S Spitsbergen) revealed complicated pattern of the Natural Remanent Magnetization and intensive remagnetization of investigated rocks. At least part of the measured palaeomagnetic vectors can represent a secondary pre-folding magnetic overprint that originated in post-Jurassic Late Mesozoic – Cenozoic time before Eurekan deformations (Dudzisz *et al.* 2018).

Keywords: Svalbard, Caledonian Terranes, Eurekan orogeny, West Spitsbergen Thrust, Fault Belt.

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Changes in Magnetic Mineral Input Across the Subequatorial Atlantic during The Last Glacial Cycle

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Abstract

The North Atlantic Ocean has been an area of intensive research on the causes and effects of climate change on different time scales. This location bias is based on the high sensitivity of this region to changes in continental ice volume, given the high ratio of continental to oceanic surface, and in the vigour of the Meridional Overturning Circulation, whose engine is deep-water mass production in these regions. On the contrary, research in equatorial and tropical latitudes is scarce, despite their high potential of preserving atmospheric signals due to their high sensitivity to meridional shifts in the Inter Tropical Convergence Zone (ITCZ). Dust production and transport from the African Sahel and Sahara Desert is strongly dependent on the position and strength of the ITCZ, with large implications for lithogenic inputs in remote areas of the ocean, cloud formation, as well as albedo and radiative effects.

In this contribution, we address this relative lack of studies by presenting new results from a longitudinal transect across the subequatorial Atlantic ocean. We have analyzed the magnetic properties from 7 Megacores dating back to the early deglacial/last glacial maximum (LGM). We observe a decrease in magnetic susceptibility from South to North, and from East to West (Fig. 1), in both the Holocene and the LGM, with larger differences in the latter period. Water depth also shows a strong linear relationship with magnetic susceptibility, especially in the Holocene. This interglacial/glacial trend is also shown in the coercivity of remanenence, increasing the magnetic hardness in the glacial. Our results agree with an African origin of the magnetic minerals, transported from East to West due to the Easterly winds of the ITCZ. These results also agree with a more arid and dust-rich glacial period, displaced further south due to the cooling of the Northern hemisphere, as shown by higher magnetic susceptibilities during the LGM, especially in the low latitudes. More striking is the liner trend observed with water depth. We hypothesize that this trend is due to the presence at these latitudes of oxygen-rich Antarctic bottom water, which may promote the preservation of magnetic minerals, and to $CaCO_3$ dissolution at these depths, which will increase the proportion of detrital minerals, and thus their magnetic signal.

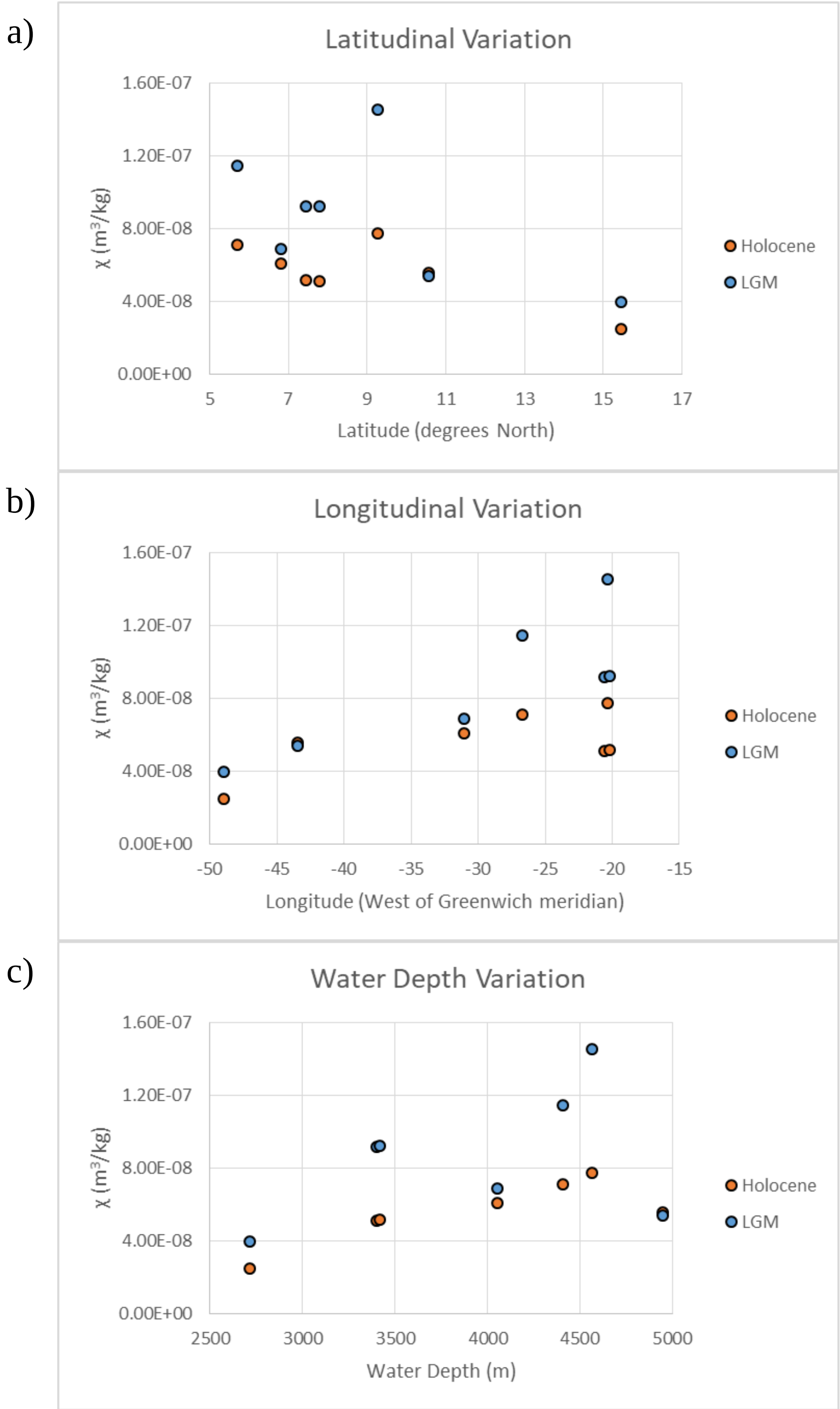

Fig. 1. Variation of magnetic susceptibility across the subequatorial Atlantic in the recent Holocene and LGM as a function of: a) aatitude, b) longitude, c) water depth.

Keywords: environmental magnetism, African dust, equatorial Atlantic.

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Toward a Full-vector Geomagnetic Field Record (~130–550 ka) from the El Golfo Section, El Hierro, Canary Islands, Spain

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Abstract

The Earth's magnetic field is generated in the liquid outer core. So-called absolute paleointensities, i.e., a field intensity in μT for a given location that can be converted to a virtual (axial) dipole moment, are tedious to obtain and therefore remain rather scarce, in particular for periods older than the Holocene. The Holocene field intensity is considered (unusually?) high; it is reasonably well constrained by data from lavas and archaeological artefacts, at least for considerable portions of the northern hemisphere. The average intensity of the Brunhes Chron is ~20% higher than most of the underlying Matuyama Chron (Ziegler *et al*. 2011). Longer term trends within the Brunhes Chron, however, are surprisingly poorly characterised. It seems that the period between ~200 and ~400 ka featured a lower field intensity as determined for Hawaii (Pacific Ocean, USA; Tauxe and Love (2003)) and the Eifel (Germany; Monster *et al.* 2018) but data paucity precludes firm inferences. Regional full-vector PSV curves are essential to further our understanding of geodynamo operation. Such curves typically lack palaeointensity information. Here, we present new paleointensty data from El Hierro, Canary Islands. The Canary Islands are part of the Canary Island Seamount Province which developed on ancient ocean crust, the oldest Atlantic Ocean crust Jurassic in age, relatively close to a continent, Africa. El Hierro and La Palma represent the youngest islands with ages of < 2 Ma (e.g., Guillou *et al*. 1996). We sampled 28 lava flows (age range c. 150 to 450 ka) from a section along the Camino de Jinama, about 4.5 km to the south of a section sampled by Széréméta *et al*. (1999) for an analysis of directional PSV. Individual flows range in thickness between 1 and several meters, and are usually easily distinguished by the presence of scorias, pyroclastic layers, or paleosols. Three groups of flows are recognized, referred to as the upper group (UG), the middle group (MG) and the lower group (LG). In line with earlier results (Széréméta *et al.* 1999), we observe an easterly declination deviation of c. 14° for the middle and lower part of our section. We relate this to under-sampling of the complete PSV spectrum; rotation of El Hierro since c. 500 ka is deemed unlikely. Attempts to date the flows with the $^{40}Ar/^{39}Ar$ method on a state-of-the-art multi-collector instrument were unsuccessful due to the presence of copious amounts of methane in the extracted gases.

Three different paleointensity protocols were utilized, IZZI-Thellier, multi-specimen, and pseudo-Thellier, to provide an additional consistency check and to increase the success rate. Reasonably robust paleointensities could be obtained for 22 flows, a success rate of over 70%. If more than one protocol yielded results for the same flow, the obtained intensities were nearly always within error of each other, testifying to their robustness. Flows with a common true mean direction tend to produce similar intensity values, also adding to the robustness. Obtained paleo-intensity values typically range generally between c. 20 μT and c. 35 μT, somewhat low compared to the present-day (2015) value of c. 38.5 μT but in line with other rather low values obtained elsewhere for this particular time span. However, converting these intensities to Virtual Axial Dipole Moments shows that they are in line with the average value for the past 300 ka and past 300 Ma (Selkin and Tauxe 2000), to the average Brunhes value of $6.2 \cdot 10^{22}$ Am^2 (Ziegler *et al.* 2011). Due to the lack of precise age constraints, we cannot compare our data to geomagnetic field models such as PADM2M (Ziegler *et al.* 2011) or calibrated relative palaeointensity stacks.

Keywords: absolute paleointensity, Brunhes Chron, El Hierro (Canary Islands, Spain).

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New Insights into Iron Reduction Processes using FORC-PCA

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Abstract

Sedimentary environments preserve a record of climate change as reflected in the variations in magnetic mineralogy through time. Deconvolving the complex bulk magnetic signal is one of the primary challanges facing environmental magnetism.

The issue can be resolved by using a principal component analysis based method of unmixing the magnetic components using First Order Reversal Curve diagrams (FORC-PCA) (Lascu *et al*. 2015). The applicability of FORC-PCA is demonstrated in a high resolution case study of a marine sediment core obtained from the Iberian Margin spanning the past two glacial cycles. We identify three magnetic components, where the bulk susceptibility variations are controlled by a previously unreported magnetic mineral phase. Trabecular magnetite, named so for its characteristic skeletal internal structure (Fig. 1), exhibits a stable low coercivity single-domain signature and is prevalent throughout the core over the 200 000 years of sedimentary history in the Iberian Margin. Formed through reductive dissolution of goethite, it preserves a record of climate change as a remarkably sensitive proxy to changes in diagenetic redox conditions in surface ocean sediments.

The rock magnetic results are supported by Transmission Electron Microscopy experiments, which serve as ground-truthing methods for FORC-PCA. The magnetic signature is explained with the help of imaging techniques, electron holography and STEM-HAADF tomography experiments (Fig. 1).

Keywords: environmental magnetism, trabecular magnetite, FORC-PCA.

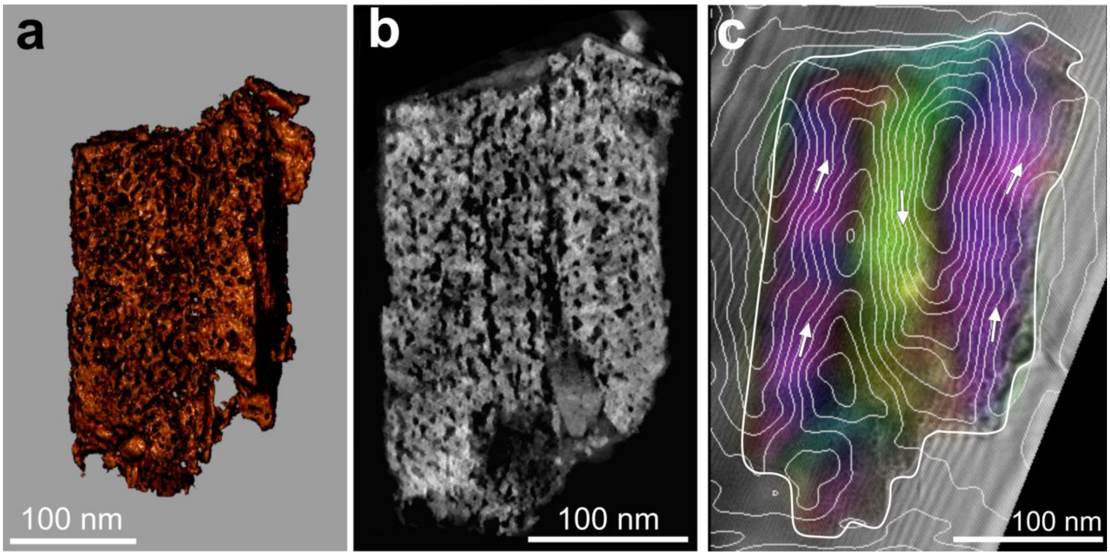

Fig. 1. Trabecular magnetite grain shown in: a) tomographic TEM reconstruction, b) cross section of the STEM-HAADF dataset, and c) electron holography.

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Cosmic Dust as a Carrier of Natural Remanent Magnetisation? A Case Study from the Jurassic Stromatolites from the Zalas Quarry, Krakow Upland, Poland

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Abstract

A paleomagnetic study of a Middle/Upper Jurassic stromatolite section from the Zalas quarry was conducted and revealed a well-defined structure of natural remanent magnetisation (NRM) comprising: (1) a viscous component (20–100°C), (2) a normal secondary component (100–275°C), and (3) normal and reversed primary components (275–500°C) (Fig. 1A). Scanning electron microscopy (SEM) studies of magnetic extracts revealed that the vast majority of the recovered magnetic mineral fraction consists of spherulitic iron-nickel grains of 10 to 300 μm in diameter. These spherules are identified as micrometeorites. We present a comprehensive rock magnetic and microscopy study of the micrometeorites and discuss their potential as NRM recorders.

A suite of over 50 individual micrometeorites within the 100–200μm grain size range were selected for the study. FORC diagrams show a "wishbone" signature characteristic of strong magnetostatic interactions between grains in the stable SD grain-size threshold (Fig. 2A). A SEM study of the micrometeorites reveals a highly complex internal structure (Figs. 2B, 3) of closely packed iron-containing grains which may explain the source of the strong interaction features observed in the FORC diagrams. These grains display high intra- and inter-sample variability. Despite the textural complexity and non-trivial magnetic properties of the micrometeorites they are potentially stable paleomagnetic remanence carriers.

FORC diagrams of bulk stromatolite samples show a low coercivity "central-ridge" SD signature. The source of this SD carrier remains largely unknown with magnetotactic bacteria being a likely explanation. Further examination of the magnetic extracts is required to conclusively determine the main source of the bulk rock magnetisation.

Keywords: micrometeorites, stromatolite, NRM carriers, FORC.

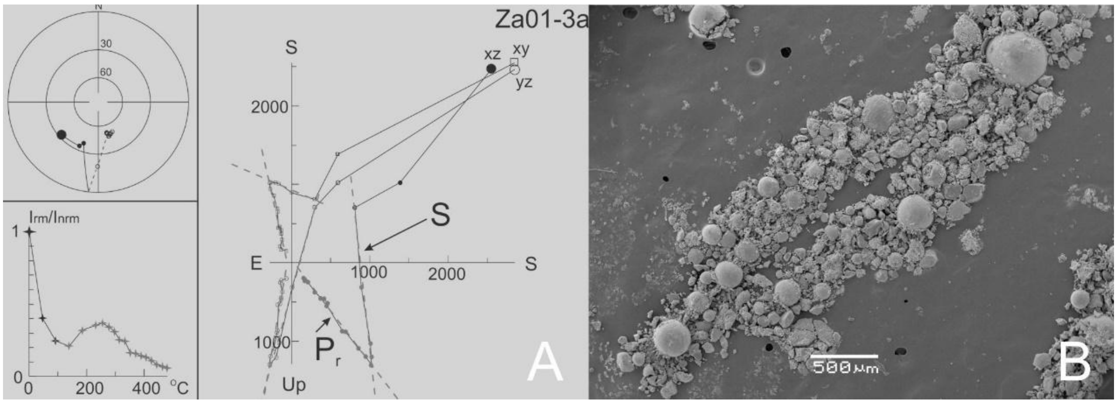

Fig. 1: A) Thermal demagnetisation results of the stromatolite sample. S – secondary component of NRM, Pr – primary (reversed) component of NRM; B) Ferromagnetic grains separated from the Zalas stromatolite.

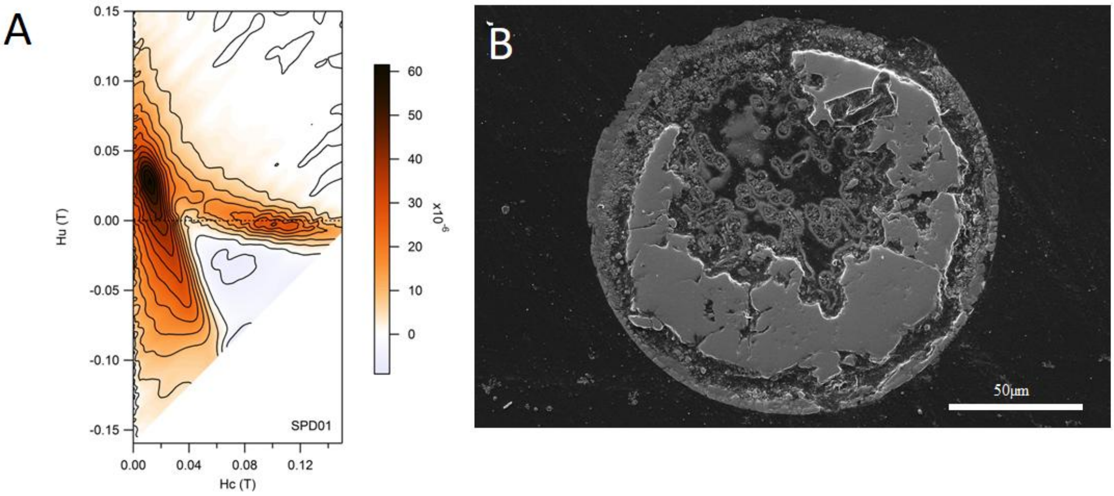

Fig. 2: A) Wishbone FORC diagram measured on an individual micrometeorite; B) secondary electron image of cross-section of micrometeorite.

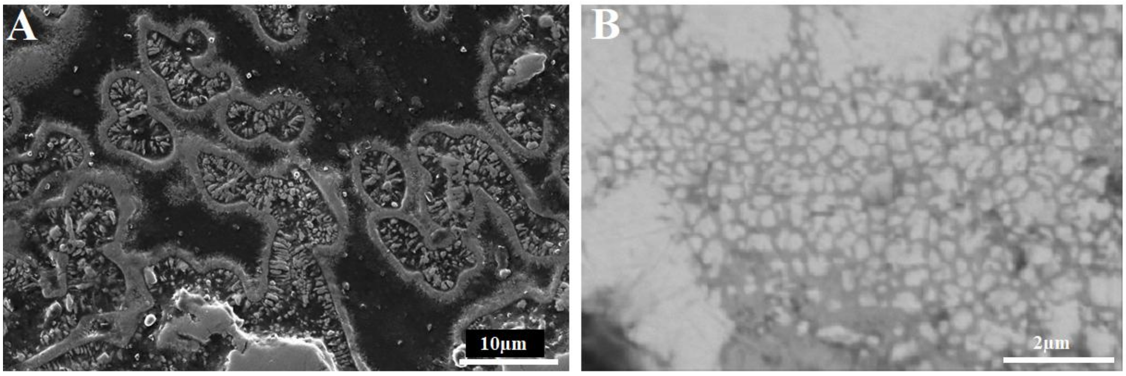

Fig. 3: A) Secondary electron; and B) backscatter electron image examples of internal textural features in two individual micrometeorites.

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The Anisotropy of Magnetic Susceptibility of Loess from Poland and Ukraine

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A b s t r a c t

Measurements of the anisotropy of whole-rock magnetic susceptibility (AMS) have been conducted to define the palaeowind strength and directions. For the AMS studies more than 1000 geographically oriented cylindrical samples were taken from 22 loess sections located in the area between the Vistula and Dnipr rivers, and the Black Sea. In order to define sources of dust and to verify directions of wind obtained from the AMS studies the U-Pb ages of detrital zircons extracted from 20 loess horizons have been also estimated. An oblate magnetic fabric is prevalent in all the horizons of loess studied. Such a feature is characteristic of loess sediments. The value of anisotropy P is proportional to the foliation parameter F, indicating a subordinate role of lineation. There is an inverse relationship between half-angular uncertainty in the direction of maximum susceptibility (ε_{12}) and the magnetic lineation parameter L, and between half-angular uncertainty in the direction of minimum susceptibility (ε_{23}) and the magnetic foliation parameter F caused by increased measurement errors for weak lineations (foliations). On the other hand, the absence of correlation between ε_{12} and foliation indicates that the lineation and foliation sub fabric are probably defined by the orientation distribution of separate minerals. Only part of the samples had statistically significant magnetic lineations, with $F12 > 4$ and $\varepsilon_{12} < 22.5^o$. The AMS of the loess from the Black Sea region is very weak, i.e., almost 5 times weaker than noted in the periglacial loess of Western Ukraine and Poland, and comparable to that noted in the Chinese loess. The imbrication of Kmin axes is not so distinct in the older loess horizons, probably because of compaction. Nevertheless in this case also, the distribution of magnetic susceptibility axes allows to define prevailing wind directions. Migration of the Kmax axes due to variable wind strength limit their usefulness for the determination of aeolian transport directions. They may not be used alone for this purpose, but may support the information obtained from the imbrication directions of the Kmin axes.

Keywords: magnetic susceptibility, anisotropy, loess, wind directions.

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Constraining the Paleoinclination of the Lunar Dynamo

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Abstract

Paleomagnetic studies of lunar samples collected during the Apollo missions suggest the Moon had an active core dynamo for at least 2 billion years (Tikoo *et al*. 2017). The early lunar dynamo (4.25–3.56 Ga) was intense, recording paleointensities of 20–110 μT (Garrick-Bethell *et al*. 2009, Shea *et al*. 2012, Suavet *et al*. 2013, Weiss and Tikoo 2014). The lunar dynamo field subsequently declined to 5±2 μT at 2.5–1 Ga (Tikoo *et al*. 2017). The strength and longevity of this dynamo field is challenging to explain via a single mechanism. Thermal convection could not have driven a dynamo for such a sustained period of time, whilst thermochemical convection during core solidification is unlikely to have started so early (Christensen *et al*. 2009, Nimmo 2009). Alternative mechanisms of dynamo generation, such as mechanical stirring driven by gravitational coupling to the Earth may also be plausible (Dwyer *et al*. 2011).

There is also debate surrounding the dipolar nature of the lunar magnetic field. A recent study of lunar crustal magnetization found paleopoles oriented with both the rotation axis and the equator (Oliveira and Wieczorek 2017). On the other hand, evidence has also been found to support the presence of a dipolar field on the Moon oriented along the present day rotation axis (Cournède *et al*. 2012).

Providing a robust constraint on the direction of the lunar magnetic field over time is essential for establishing: (a) the mechanism by which the lunar dynamo was driven, (b) whether the magnetic field underwent reversals, and (c) whether the Moon experienced true polar wander.

Here we present results for the paleoinclination of the lunar magnetic field recorded 3.8 Ga (Kirsten *et al*. 1973) by sample 75055, collected during the Apollo 17 mission. This sample, along with samples 75035 and 75075 were collected from the Camelot crater. They were sampled from boulders which are thought to represent an overturned flap formed dur-

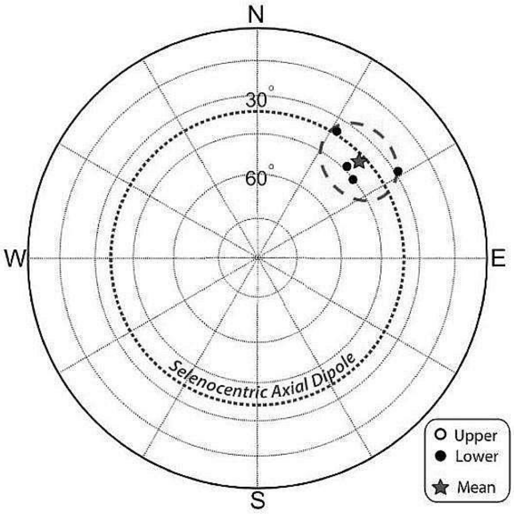

Fig. 1. Preliminary data for sample 75055 suggest that 3.8 Ga, the lunar magnetic field was dipolar and aligned along the Moon's rotation axis (Getzin *et al.* 2018).

ing impact cratering, or may represent in-place subfloor basalts exposed by recent mass wasting (Schmitt *et al.* 2017). Sample orientations were reconstructed in lunar coordinates using astronaut photographs from the Apollo 17 mission and personal correspondence with astronaut H.H. Schmitt.

At the latitude of the Camelot crater (20.19 °N), a dipolar field aligned along the rotation axis should return a paleoinclination of 36.3°. Preliminary results (Getzin *et al.* 2018) (Fig. 1) support this hypothesis, suggesting the Moon had a dipolar, dynamo-generated field that was stable for extended periods of time, undergoing reversals less frequently than the geodynamo.

Keywords: Moon, paleoinclination, dynamo, Apollo 17.

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Magnetic Mineral Assemblage as a Potential Indicator of Depositional Environment in Gas-bearing Silurian Shale Rocks from Northern Poland

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A b s t r a c t

Our goal was to investigate rockmagnetic properties of two lithofacies of Silurian gas-bearing shales from Northern Poland: Pelplin Formation and Jantar Member which both represent a potential source of unconventional hydrocarbons. The studied rocks are characterized by similar burial evolution, but different amounts of organic matter (Jantar – up to 7 percent, while in Pelplin not exceed 1.5 percent). Moreover, in the Pelplin Formation spherical calcareous concretions were examined. The differences in magnetic minerals composition, if any occur, may help better understand the determinants, which control water chemistry at the bottom of sedimentary basin and thus the preservation of organic matter.

Therefore, low temperature measurements of SIRM in the 10–300 K range were performed, in order to recognize nano-particles, which are not detectible in basic rockmagnetic studies. We detected presence of magnetite (Fig. 1), MD and SP, what we attribute most probably with detrital and chemical origin (illitization or organic maturation), respectively. However, the most interesting observation is the occurrence of hematite in the Pelplin Formation (with lower amount of organic matter) and its absence in organic-rich Jantar Member (Fig. 1). We propose that hematite (mostly SD grains) in mudstones and carbonate concretions, was formed as a product of magnetite reaction in oxic conditions (with probable activity of oxidizing bacteria). This hypothesis is in line with the precipitation of calcareous concretions from Pelplin Formation in oxic conditions at the bottom of the sedimentary basin. Moreover, this is also consistent with lower values of organic matter and the presence of hematite. Furthermore, an occurrence of hematite in mudstones and concretions in the Peplin Formation suggests that during sedimentation of clastic material as well as compaction and cementation of concretions, stable oxic conditions were present at the bottom, allowing preservation of this mineral.

As a main conclusion, we suggest correlation between hematite content and organic matter in sedimentary rocks, what may be a useful factor in understanding the preservation

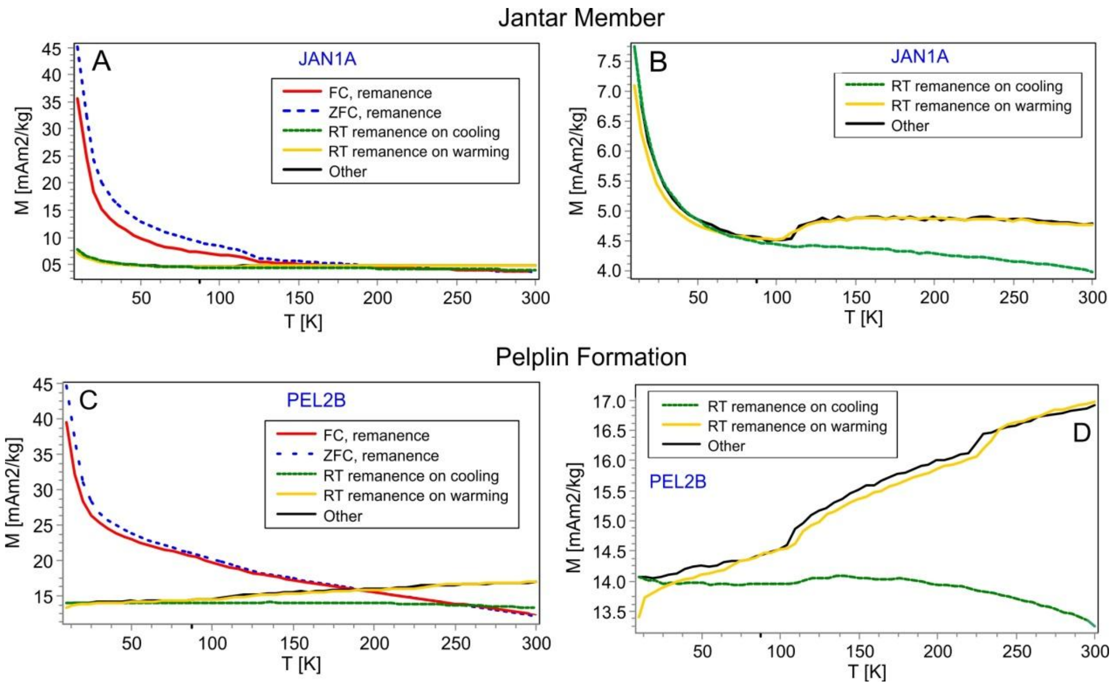

Fig. 1. Results of MPMS measurements of remanence in low temperature range (10–300 K) for selected samples from Pelplin Formation and Jantar Member. Note, typical for magnetite, the Vervey transition in all samples and characteristic for hematite – the Morin transition, which occurs only in Pelplin Formation. Abbreviations: Zero Field Cooled (ZFC), Field Cooled (FC), Room Temperature SIRM, the 'other' curves are results of the RT-SIRM, which was performed in small (+5 μT) induced magnetic field.

of organic matter in shales. However, further investigation is necessary to fully recognize this complex problem.

Keywords: magnetic mineral assemblage, LT measurements, organic-rich shales, depositional system of Baltic Basin.

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HystLab: New Software for Processing and Analyzing Hysteresis Data

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Abstract

Magnetic hysteresis loops are an important tool in theoretical and applied rock magnetism with applications to paleointensities, paleoenvironmental analysis, and tectonic studies, among many others. Hence, information derived from these data is amongst the most ubiquitous rock magnetic data used in the Earth science community. Despite their prevalence, there are no general guidelines to aid scientists in obtaining the best possible data and no widely available software to allow the efficient analysis of hysteresis loop data using the most advanced and appropriate methods. Here we provide a brief outline of detrimental factors and simple approaches to measuring better hysteresis loops as well as introducing a new MATLAB software package called *Hysteresis Loop analysis box* (*HystLab*) for processing and analyzing loop data. This graphical user interface software is capable of reading the wide range of data formats that are generated by the multiple types of equipment typically used to measure hysteresis loops. *HystLab* provides an easy-to-use interface allowing users to visualize their data and perform advance processing, including loop centering, drift correction, linear and approach to saturation high-field slope corrections, as well as loop fitting to improve the results from noisy specimens. A large number of hysteresis loop properties and statistics are calculated by *HystLab* and can be exported to text file for further analysis or can be explored using the in-built bi-plot functionality of *HystLab*. All plots generated by *HystLab* are customizable and user preferences can be saved for future use. In addition, all plots can be exported to encapsulated postscript files that are publication ready with little or no adjustment, greatly enhancing the workflow productivity when processing and analyzing large data sets.

Keywords: rock magnetism, hysteresis, software.

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Magnetic Mapping of Distribution of Wood Ash used for Fertilization of Forest Soil

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Abstract

The effect of wood-ash fertilization on forest soils has been assessed mainly through geochemical methods (e.g., content of soil organic matter or nutrients). However, a simple and fast method of determining the distribution of the ash and the extent of affected soil is missing. In this study we present the use of magnetic susceptibility, which is controlled by Fe-oxides, in comparing the fertilized soil in the forest plantation of pine and oak with intact forest soil. Spatial and vertical distribution of magnetic susceptibility was measured in an oak and pine plantation next to stems of young plants, where wood-ash was applied as fertilizer. Pattern of the susceptibility distribution was compared with that in non-fertilized part of the plantation as well as with a spot of intact natural forest soil nearby. Our results show that the wood-ash samples contain significant amount of ferrimagnetic magnetite and has susceptibility higher than that of typical forest soil. Clear differences were observed between magnetic susceptibility of furrows and ridges. Moreover, the dispersed ash remains practically on the surface, does not penetrate to deeper layers. Finally, our data suggest significant differences in surface values between the pine and oak plants. Based on this study we may conclude that magnetic susceptibility may represent a simple and approximate method of assessing the extent of soil affected by wood-ash.

Keywords: forest soil, wood ash, fertilizing, tree plants, iron oxides.

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Magnetic Response of Airborne Metal Contaminants Captured by Spider Webs

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Abstract

Airborne particulate matter (PM) that originates from the combustion of fossil fuels is of concern due to adverse effects on the environment and human health (Rogula-Kozłowska 2015). Classic monitoring methods based on PM collectors and subsequent chemical analyses are expensive and time consuming. As a result, time- and cost-effective methods were in demand. Results from several studies have identified spider webs as an excellent source of biomonitors (Flanders 1994, Rybak 2015). Spider webs accumulate pollutants to which humans are exposed; thus, they are a reliable source of information about the quality of the environment in a way that is similar to other bioindicators. Compared to conventional atmospheric pollution monitoring, the assessment of air quality with the use of spider webs is cheap, non-invasive and easy as webs are abundant and they are woven in secluded locations, which prevents them from exposure to rain and wind. The basis of the present study was an assumption that because spider webs are diamagnetic (with negative magnetic susceptibility), the increased value of their magnetic susceptibility that results from exposure to the polluted atmosphere may be a sign of contamination by particulates (of which some are metallic). Therefore, the proposed hypothesis is that magnetic susceptibility of spider webs reflects the level of ambient air pollution.

The study involved the investigation of indoor and outdoor webs made by six types of spiders. Additionally, street dust was the subject of study. Volumetric magnetic susceptibility (κ) of dried and weighted samples was measured using an MFK1 Kappabridge device (Agico Advanced Geoscience Instruments Co., Brno) and afterwards, recalculated into mass-specific magnetic susceptibility (χ).

The χ values varied from -1.7×10^{-8} $m^3 kg^{-1}$ (obtained for samples of clean spider webs treated as reference diamagnetic samples) to above 400×10^{-8} $m^3 kg^{-1}$ obtained for samples collected in very busy district of Grunwaldzki Square in Wrocław, which is a large,

congested traffic circle with bus stops and tramways. Similarly, the χ of street dust collected from the same location was the highest as well. When comparing the outdoor and indoor data, outdoor samples of spider webs exhibited higher values of magnetic susceptibility. Therefore, the magnetic susceptibility of webs was directly related to the presumption that webs—with the exception of fine particles that originate from anthropogenic emission—are able to trap particles greater than 10 μm, which are characteristic of road or street dust and soil dust (or a mixture of both), and they generally do not occur in an indoor atmosphere (Rogula-Kozłowska 2015). Moreover, the magnetic susceptibility values differed depending on the species of the spider as well as on the exposure period. Results obtained for the outdoor samples seem to be influenced mainly by the road traffic and industrial emissions, while the results observed from the indoor samples seem to be related to some internal sources of PM, such as combustion of various fuels in domestic furnaces, dust from vacuum cleaners, printers, cooking and smoking (Rachwał *et al*. 2018).

The results support the statement that magnetic biomonitoring with spider webs is an useful approach to delineate airborne PM pollution that originates from sources such as traffic emissions, industrial activity, and emissions from domestic heating systems. Such a tool is needed because we currently rely mainly on time-consuming analyses when assessing air quality. With the use of magnetic biomonitoring, we are able to generate quick and reliable information about the quality of the air both outdoors and indoors.

Keywords: spider webs, magnetic susceptibility, airborne particulate matter, indoor air, outdoor air.

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An Integrated Enviromagnetic and Lithogenetic Study in the Lakes of the Southern Danube Delta Wing. Evidences from Surficial Sediments and Short Cores

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Abstract

The studies that we have achieved in the last 40 years in the Danube – Danube Delta – Black Sea hydrosedimentary system have revealed strong connections between the characteristics of sedimentary environment, sediment quality and their magnetic properties. The paper analyses a large magnetic susceptibility (**MS**; **k**) database resulting from *ca.* 20 expeditions carried out during 1981–2015 time period in the lakes of two aquatic units of the Danube Delta (DD), i.e., Gorgova – Uzlina and Lumina – Roşu Depressions. These are placed in the DD southern wing, westwards and respectively, eastwards of the Caraorman Sand Ridge (Fig. 1). For the **MS** characterisation of the recent sediments, an original **k** scale with 5 classes (**I** to **V**, from **k** values lower than 10 × 10E-06 SI to **k** values higher than 1000 × 10E-06 SI) is used. The lithological (**LITHO**) support related to the magnetic susceptibility calibration of the lake sediments is equally analysed, and it is defined by three main **LITHO** components: **SIL**iciclastic/minerogenic fraction (**SIL**), **T**otal **O**rganic **M**atter (**TOM**), and **CAR**bonates (**CAR**). The **LITHO** classification of the lake sediments is illustrated by using ternary diagrams, and a **LITHO** scale (with 5 classes), based on **SIL** contents, is applied for the lithological characterisation, as well. To assess the relationship between the magnetic and the lithological parameters, a scale with 6 ranges spanning the interval from (-1) to (+1) systematizes the calculated correlations coefficients (**r**). In the first part, the results concerning the enviromagnetic characteristics and the lithological composition of the lake sediments (surficial and cores) of the Gorgova – Uzlina Depression (**I**, in Fig. 1), placed in the Fluvial Delta Plain, are discussed. The latest **MS** results are compared with the magnetic susceptibility data achieved in the first sampling campaign in the Gorgova, Uzlina and Isacova Lakes, in 1979, relatively close of the beginning times of such types of researches in the world (e.g., Thompson *et al*. 1975). In the second part of the article, the data obtained by applying of this methodological version of environmental magnetism for a series of lakes and swamps belonging to the Lumina – Roşu Depression (**II**, in Fig. 1) are discussed. This area situated eastward of the previously approached deltaic unit is

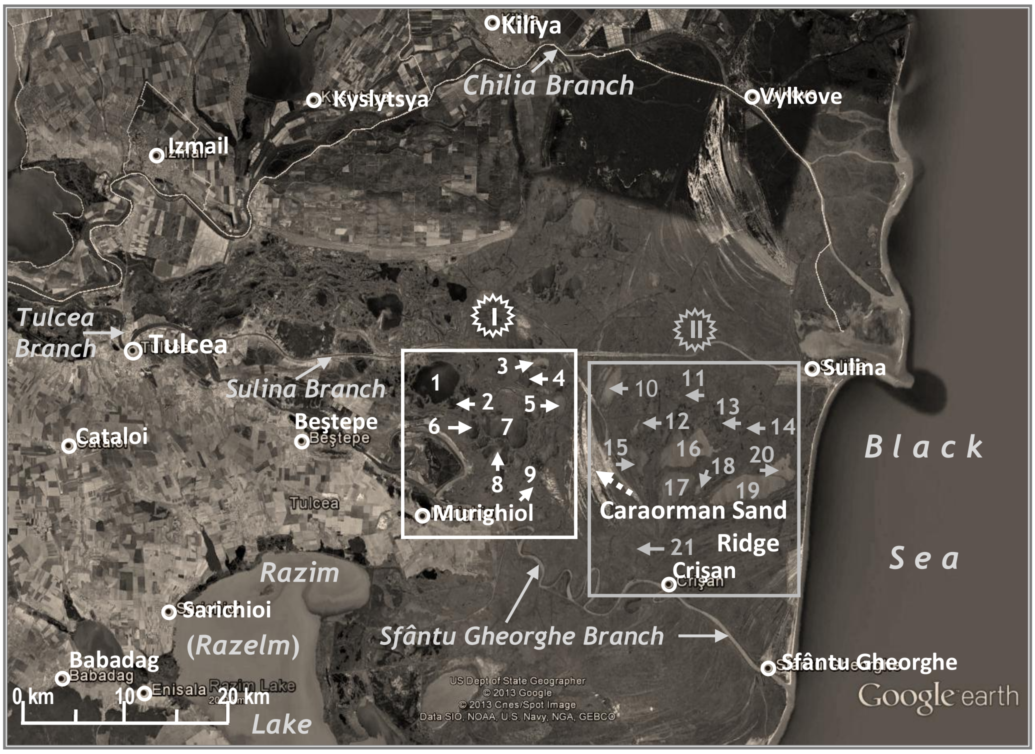

Fig. 1. Location of the two interdistributary depressions in the Danube Delta and position of the water bodies under attention in the paper. I. Gorgova – Uzlina Depression: 1 – Gorgova Lake, 2 – Gorgovăț Lake, 3 – Obretinu Mic Lake, 4 – Obretinciuc Lake, 5 – Cuibeda Lake, 6 – Isăcel Lake, 7 – Isacova Lake, 8 – Uzlina Lake, 9 – Gorgoştel Lake. II. Lumina – Roşu Depression: 10 – Iacub Lake, 11 – Lungu lake, 12 – Vătafu Lake, 13 – Lunguleț Lake, 14 – Porcu Lake, 15 – Puiuleț Lake, 16 – Lumina Lake, 17 – Puiu Lake, 18 – Potcoava Lake, 19 – Roşu Lake, 20 – Roşuleț Lake, 21 – Erenciuc Lake. Note: The figure support – Google Earth image.

particularly located in the Marine Delta Plain. The **LITHO** classification of the lake sediments is illustrated by using ternary diagrams, while the variability of the magneto-susceptibility régimes is exemplified by a series of **MS** maps. The **k** anomalies generated by the deposits from the channel entry mouths into the lakes are revieled inside of such maps. The effects of silting up or of polution are decreasing as much as the transport distance is increasing. The presented data prove the magnetic susceptibility as a sensitive marker for monitoring the natural environmental changes or the anthropic impacts taking place in the lakes. Moreover, the capability to detect and to define – magneto-lithologically – some marine deposits, located very close of the water/sediment interface, is exemplified. The magneto-litho archive constituted for surficial sediments and cores sampled from this lacustrine area (i.e., southern Danube Delta wing) is very important in the context of deciphering of the spatial and temporal evolution of the deltaic geosystem.

Keywords: magnetic susceptibility, lithology, surficial lake sediments, short cores, Danube Delta (Romania).

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A Mid-Paleoproterozoic Apparent Polar Wander Track for the Piedra Alta Terrane (Río de la Plata Craton): Paleogeographic and Geomagnetic Implications

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Abstract

The Paleoproterozoic is a fascinating period of Earth history. Inception of plate tectonics, first supercontinents, inner core nucleation, eukaryote appearance, atmospheric great oxigenation event and other first order global processes likely ocurred during this period. Reliable and well-dated paleomagnetic data from the Paleoproterozoic is scarce, which hampers global paleogeographic and geodynamic models. The characteristics of the Earth Magnetic field in such old times are also known very schematically due to data paucity. In order to contribute to a better understanding of the Paleoproterozoic paleogeographic, geodynamic and geomagnetic evolution, a systematic paleomagnetic study is being carried out on a series of numerous late to post-tectonic igneous bodies of mid-Paleoproterozoic age exposed in the Piedra Alta terrane of Uruguay, which is considered as the core of the Rio de la Plata craton (e.g., Oyhantçabal *et al*. 2018 and references therein). First results from this research were published by Rapalini *et al*. (2015) who presented a schematic apparent polar wander path for this craton for the late Rhyacian to the early Orosirian, based on three paleomagnetic poles obtained from three of these plutons. They also suggested that when compared with coeval data from the Sao-Francisco, Guyana and West Africa cratons it supported an unorthodox configuration of the hypothetical Atlantica continent. Available U-Pb (both SHRIMP and LA-ICPMS) from several of these igneous bodies strongly suggest that they were intruded in a relatively short period between ca. 2.1 and 2.05 Ga. Further paleomagnetic results on several other plutons are presented. After stepwise AF and/or thermal demagnetization, consistent characteristic magnetic components were isolated from the Cufré-Cerro Albornoz granites (2.086 Ga), Carreta Quemada Gabbro (2.086 Ga), Arroyo Marincho Granite (2.081 Ga) and the yet undated Tía Josefa Tonalite, Arroyo Grande Granite and GM4 pluton. Our results permit to compute individual paleomagnetic poles from each body that together with those already published from Mahoma (2.1 Ga), Isla Mala (2.076 Ga) and Soca (2.056 Ga) plutons are distributed along a simple track composed of eight poles. It suggests that the Río de la Plata craton was at polar latitudes during the mid-Paleoproterozoic but experiencing a fast displacement and rotation. Only the Tia Josefa pole seems to be an outlier of this single track. Most bodies show a unique polarity, either normal or reverse, which, according to their position along the track, suggest at least five reversals of the Earth Magnetic Field during that time span and a dominant dipolar field. Since all reliable radiometric datings are U-Pb, precise magnetization ages depend on the cooling rates of these bodies. Few thermo-barometric determinations suggesting shallow intrusive levels and old Rb-Sr ages on these igneous bodies falling in the range 1.95–2.1 (with large uncertainties between 50 and 75 Ma) point to a relatively fast cooling. Comparison with coeval poles from other blocks in South America and Africa support the unorthodox Atlantica reconstruction and point to magnetizations ages somewhat 20 to 30 Ma younger than U-Pb ages. Ar-Ar datings on amphibole are under way to better constrain the magnetization ages of these plutons.

Keywords: Paleoproterozoic, Río de la Plata craton, Piedra Alta terrane, Atlantica, paleogeography.

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Delayed Acquisition of Remanence in Deep Marine Sediments of the Galicia Bank Slope, Eastern North Atlantic

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Abstract

Palaeomagnetic studies of deep marine sediments have made a significant contribution to the development of secular variation and relative paleointensity records which are useful to both understand the behaviour of the geomagnetic field and to date marine sediments at very different time scales. However, the complex mechanisms of remanence acquisition in sediments, involving complex sequences of interactions between Depositional Remanent Magnetisation (DRM), Post-Depositional Remanent Magnetisation (PDRM) and early Chemical Remanent Magnetization (CRM) commonly results in inclination errors and in a time discrepancy between the magnetic and stratigraphic ages. Subsequently, the validation of individual records requires the acquisition of detailed palaeomagnetic, rock-magnetic and geochemical data to detect the occurrence of different magnetic phases and their lock-in ages.

The sedimentary sequence deposited over the last 80 kyr in the Galicia Bank slope (Eastern North Atlantic) provides an interesting case in this regard. These sediment are the result of local turbiditic/contouritic processes, the regional pelagic and hemipelagic sedimentation, the deposition of exotic IRD layers, and redoxomorphic diagenesis, which are all unsteady as a result of climate-driven forcings. This also leads to variable contributions from magnetic sources as well as spatial and temporal changes in depositional rates in the region. This sedimentary complexity, however, seems not to have compromised the preservation of a detailed secular variation record. This record can be correlated over hundreds of km to the distal slope and abyssal-plain sequences of very different sedimentary rates. These correlations lead, however, to age discrepancies of several thousand years when compared with the 14C-based age models of the cores.

The material discussed comprises three gravity cores with lengths of 67, 286, and 274 from the south-western flank of the Galicia Bank, extracted at water depths of 3363 to 4171 m. Standard cylindrical boxes were taken continuously for the uppermost 50 cm and each 10 cm throughout the remaining core. A full array of magnetic susceptibility, hysteresis, remanence, thermomagnetic measurements and geochemical analyses are used to magnetically characterise each sedimentary environment, their associated depositional rates and depth of redox boundaries.

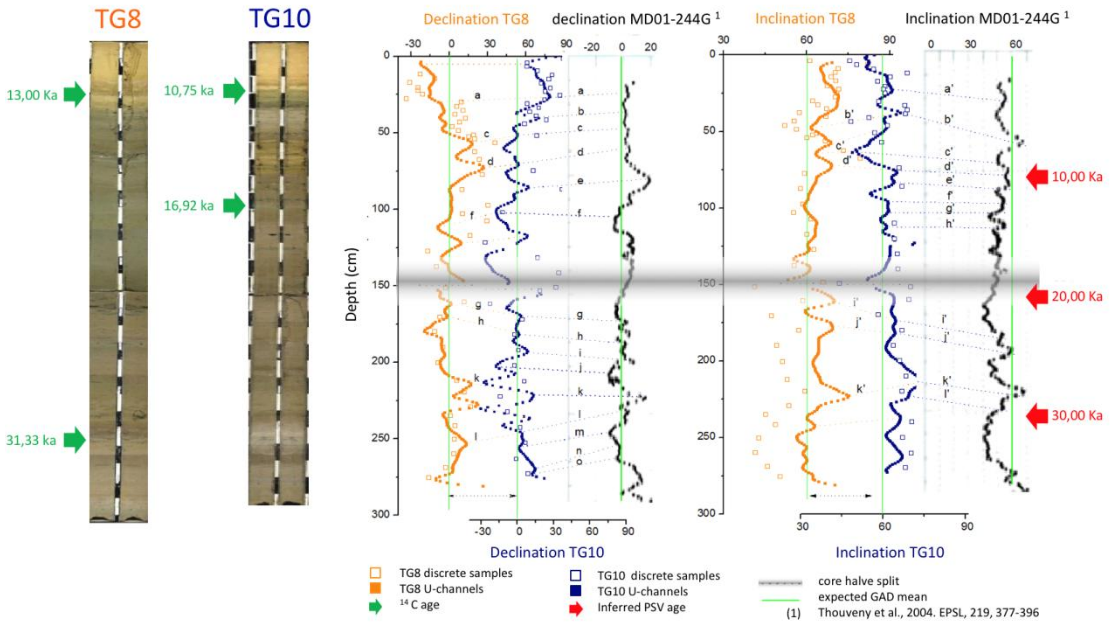

Fig. 1. Remanence record of cores TG8 and TG10 showing the discrepancy the discrepancy between PSV inferred and ^{14}C ages (after Rey *et al*. 2008, Coimbra 2007).

The results show a delayed acquisition processes which depends on the sedimentary redoxomorphic diagenesis rates which are specific of each coring site. Subsequently, and at least for marine sediments, detailed palaeomagnetic, rock-magnetic and geochemical studies are necessary to judge the validity of secular variation records to date sedimentary sequences, even when a recognisable secular variation pattern is present

Keywords: environmental magnetism, delayed remanence acquisition, North East Atlantic.

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Comprehensive Paleomagnetic Study of Chichinautzin Volcanic Field, Central Mexico

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Abstract

The Chichinautzin Volcanic Field (ChVF) is located at the southern boundary of the Trans-Mexican Volcanic Belt (TMVB), in central Mexico. It shows an E–W trend, c.a. 1000 km long volcanic arc, from the Pacific Ocean to the Gulf of México (Gómez-Tuena *et al.* 2007). The ChVF volcanism is related to the subduction of Cocos under North American plate. Their ages range from 1.25 Ma to < 05 Ka (Arce *et al.* 2013). Paleomagnetic cores were collected from 22 sites through the entire volcanic field. Rock magnetic experiments, such as susceptibility vs. temperature, hysteresis curves and FORC were done to identify the magnetic carriers of magnetization and the thermal stability during a heating-cooling processes. AF and termal demagnetization processes were conducted to investigate the mean paleomagnetic direction: Declination = 356.4°, Inclination = 49.7°, α_{95} = 5.2 and *Kappa* = 49.6. The paleointensity process was conducted using the Thellier-Thellier method (Thellier 1959). Results will contribute to develop a secular variation curve for Central Mexico, mainly the results of the youngest lavas (< 5 Ka).

Keywords: paleointensity, paleomagnetism, Mexico, Chichinautzin.

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On the Recurrence of the South Atlantic Geomagnetic Anomaly: Paleomagnetic Evidence from Late Pleistocene and Holocene Chilean Volcanic Rocks

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Abstract

The growth of the South Atlantic Magnetic Anomaly (SAMA) during the last 2 centuries has generated very large geomagnetic secular variation in Chile (Roperch *et al*. 2015). Most global geomagnetic models suggest very low secular variation in southern South America during most of the Holocene but this result may simply be due to the lack of data to constrain the models. In order to better describe the poorly known secular variation during the late Pleistocene-Holocene, we sampled 21 dated lava flows or pyroclastic flows from several Chilean volcanoes (Lonquimay, Llaima, Solipulli, Villarrica, Mocho-Choshuenco, Osorno, Calbuco) located in the southern volcanic zone (~39°S–41°S). We also sampled 56 sites in Holocene lava flows with only relative ages with respect of the dated units. The paleomagnetic results obtained in the present study indicate little geomagnetic secular variation in direction during the Holocene except near 750–1000 AD. The steepest inclination of the geomagnetic field (-71.6°) and the highest intensity (70μT±5) are recorded in a pyroclastic flow from the Osorno volcano (calibrated age range of 782–966 AD) (Roperch *et al.* 2014). A dated lava flow (720–980 AD) to the north of the Llaima volcano records also a steep inclination. The corresponding VGPs are not much different from the VGP recorded at European sites suggesting a significant dipole wobble at that time.

High paleointensities in the range 50–70μT are observed in the time interval 2000 BC–1500 AD in agreement with global models showing geomagnetic moments above 10 10^{-22} Am^2. In contrast, paleointensity results from juvenile clasts of the late Pleistocene Lican ignimbrite at Villarrica (24.7±1.3 mT) and of the Curacautin ignimbrite at Llaima volcano (33±1.9μT) show that the magnetic field strength was low during (14,000 BC–15,000 BC). A geomagnetic configuration (low inclination, low intensity) similar to the present-day field is also observed at the Pleistocene-Holocene boundary in silicate glasses from a site in northern Chile (Roperch *et al*. 2017).

Thus the large and rapid secular variation during the last three centuries palso occurred at the end of the Pleistocene. Thus, the SAMA is probably not the speculated precursor of a geomagnetic reversal.

Keywords: geomagnetism, paleointensity, South Atlantic Magnetic Anomaly.

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Chasing the Jurassic Monster: A New Record from the Northern Apennines (Italy)

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Abstract

A Late Jurassic 30° gap in the Apparent Polar Wandering Path (APWP) of the North American plate has been recently evidenced (Kent and Irving 2010, Kent *et al.* 2015), and is interpreted by these authors in term of plate motion (referred as to the "Jurassic monster shift"). This unusually fast plate motion was previously undetected or only resulted in smooth variations around the Jurassic/Cretaceous boundary in previous composite APWPs, due to the smoothing of data intrinsic to the method of construction, or in the inclusion of lower quality Jurassic paleopoles. The Jurassic shift started between 183 (Pliensbachian-Toarcian boundary) and 160 Ma (Oxfordian) and ended between 151 (early Tithonian) and 145 Ma (Tithonian/Barremian) (Kent and Irving 2010, Muttoni *et al.* 2013).

In this work, we take advantage of the magnetostratigraphic-constrained Salto del Cieco Section (Italy; latitude 42.61°N, longitude 12.86°E) to ascertain and precise the duration and amplitude of the shift. The polarity zone pattern, biostratigraphic and facies analysis from Salto del Cieco section (Satolli *et al.* 2015, Satolli and Turtù 2016) were used to define the age of paleomagnetic directions and paleopoles. The mean directions were computed using the magnetozones, or the stage boundaries when magnetostratigraphy was not defined. Furthermore, we evidence an almost perfect agreement between our new set of data and former discrete paleomagnetic studies from Northern Apennines and Southern Alps (e.g., Satolli *et al.* 2007, Channell *et al.* 2010). We computed from this set of data, a composite paleolatitude curve for Adria which displays first a slow southward motion of some 15° from 190 to 170 Ma, strongly accelerating between 175 to 160 Ma (a minimum paleolatitude of 11.9° is found at 160 Ma), followed by a slower northward motion up to 130 Ma. Despite minor differences, this curve is in global agreement with the expected paleolatitudes from the composite APWP proposed by Kent and Irving (2010), and from the Adria-Africa APWP proposed by Muttoni *et al.* (2013). The changes of direction found in our section are thus not related to some local event, but probably to a global motion of the lithosphere with respect to the earth rotation axis (True Polar Wander). Finally, we derived an APWP from our data, showing first a standstill, followed by a track between 171.8 and 150.4 Ma with a velocity of some 20 cm/yr, followed by other standstill between 142 and 150 Ma and finally a hairpin turn with a rather complex direction pattern. Should these data represent TPW, the velocity would be nearly twice faster than the presently geodetically measured TPW (10 cm/yr) but well below TPW in excess of 40 cm/yr suggested at the end of Precambrian (McCausland *et al*. 2011, Robert *et al*. 2017).

Keywords: paleomagnetism, apparent and true polar wander path, Adria.

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Magnetic Mineralogy of Fluvial Sediments: Challenges and Chances

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Abstract

The complex magnetic mineralogy of fluvial sediments reflects the environmental and climatic evolution of their catchments and is thereby a potential source of information in areas were no other archives are available. However, the analysis of these sediments with rock magnetic methods is a challenging task. The contributions from various sources along the course of the rivers results in a multi-component magnetic mineralogy. Additionally, variable and frequently unsteady redox-conditions during multiple burial-transportation cycles may alter individual grains differently. As a result of these diverse pathways, grain size variations of the bulk sediment material as well as of the magnetic components induce further complications to the analyses. Nevertheless, the identification of the magnetic mineralogy is vital for both, palaeo-magnetic investigations, and enviromagnetic analyses.

Here, we present an outline of the course of action used to analyse drill cores from three sites (Viernheim, 350 m; Heidelberg, 500 m; Ludwigshafen, 300 m) within the Heidelberg Basin (Scheidt *et al*. 2015, 2017). The Heidelberg Basin is a large subsiding structure in the northern part of the Upper Rhine Graben (URG) in Germany and hosts a quasi-continuous sedimentary sequence of > 2000 m thickness (Buness *et al.* 2008). The sediments are delivered from the River Rhine and the Palaeo-Rhine, respectively, and their tributaries. The site Heidelberg is additionally heavily influenced by Triassic red clastics of the River Neckar alluvial fan.

Since no template for mineral magnetic analyses of fluvial clastics was available, our approach was not straight forward at all. At the beginning, the measurement routine scheduled the following procedure: determination of the NRM and the susceptibility, AF-demagnetisation for palaeomagnetic analysis (for results see Scheidt *et al.* 2015), ARM acquisition measurement with subsequent AF-demagnetisation and IRM acquisition measurement with subsequent back curve determination. Finally, the hysteresis loop was observed before thermal experiments ($I_S(T)$ and $\kappa(T)$) were started. These first analyses indicated that

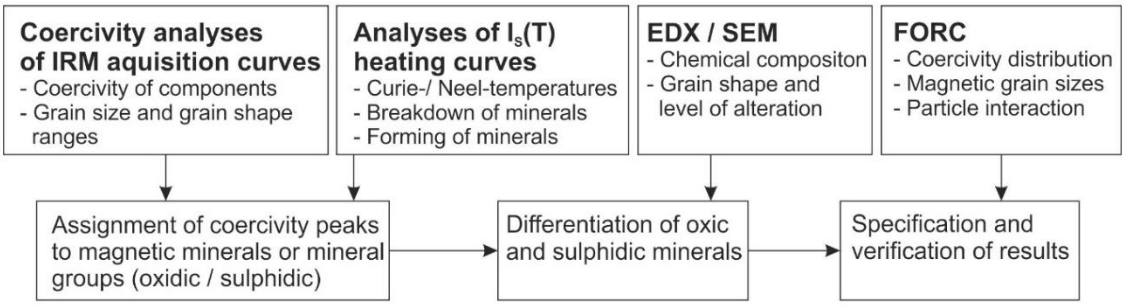

Fig. 1. Illustration of the analytic procedure applied to unravel the multi-component magnetic mineralogy of fluvial sediments. The main objectives of the individual methods are shortly mentioned with bullet points.

the distribution of antiferromagnetic and ferromagnetic minerals cause the Pliocene sediments to be magnetically much weaker than the Pleistocene sediments. However, due to natural variances in grain size, content, and composition of the magnetic components, classical rock magnetic proxies were not able to provide detailed information on magnetic grain sizes or magnetic mineralogy. Only a combination of alternative approaches led to unravelling of the multicomponent systems and identification of involved magnetic minerals. In the first instance, the coercivity analyses of the IRM acquisition curves indicated the simultaneous presence of up to five magnetic components. The identification of these components succeeded by linking the data with the results of the evaluation of their I_S(T) heating curves. SEM/EDX analysis of magnetically extracted minerals gave additional hints on the interpretation of the measured data. FORC analyses of selected samples were finally applied to confirm the finding and specify the magnetic grain size ranges.

In this study, the applied combination of data allowed for unravelling of the multicomponent magnetic mineralogy, and for reconstructions of palaeo-environmental processes and settings (for details see Scheidt *et al.* (2017)). The combination of magnetic polarity stratigraphy and detailed magnetic mineralogy provided thus, new insights into the development of the climatic conditions of continental Western Europe (Scheidt *et al*., in prep.). Despite the challenges fluvial sediments reveal for rock magnetic methods, we therefore propose the systematic environmental magnetic analysis of geologically young fluvial sequences throughout Europe in order to enhance our understanding of the palaeoenvironmental evolution of the recent past.

Keywords: magnetic mineralogy, fluvial sediments, palaeoclimate, palaeoenvironment.

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Possible Correlation of the Burdigalian Strata in Sokolov and Most Basins (ECRIS, Czech Republic)

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Abstract

Several drill cores were studied in order to correlate Sokolov and Most basins.

Both magnetostratigraphy and cyclostratigraphic investigation was conducted on the drill core JP585. The new drill core from of opencast coal mine Jiří in the Sokolov Basin. Both basins are parts of eastern segment of the European Cenozoic Rift System (ECRIS). The sediments in both basins are of Burdigalian age (lower Miocene). Their lithology mainly comprises fossil-free clays/silts above the main coal seam, with three phosphatic horizons with mineral crandallite in the Most Basin and several greigite layers in the Sokolov Basin.

The sedimentation rate was computed by multivariate spectral analysis on data acquired by X-ray fluorescence (Fig. 1). The spectral analysis was performed with our original software solution for identification of typical frequencies and their assignement to Milanković cycles. The sedimentation rates (after compaction) were around 12.6 cm/ky for the upper 25 m of the drill core JP585 and around 27 cm/ky for lower part.

The most important methods were: alternate field demagnetization, anisotropy of magnetic susceptibility (AMS), measured in all sediment samples. Unusually behaving samples with extremely high magnetic susceptibility and inverse AMS structure (siderite) were omitted from further evaluation. Samples with the angle of the main AMS axis exceeding 20 degrees were excluded from further evaluation. The multicomponent analysis was performed after alternate field demagneization.

The drill core JP585 begins with 14 m of magnetically disturbed zone (94–80 m), then continues by ca. 12 m of normal polarity (69–80 m). Above that, after a small gap of magnetically disturbed sediments, there are 60 m of sediments with reverse polarity (62–2 m) with short residue of normal geopolarity zone at the upper half (24–17 m).

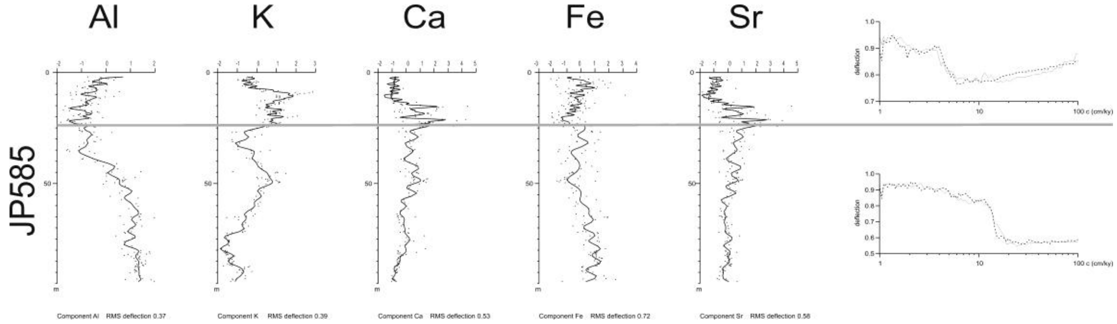

Fig. 1. The figure on the left shows X-ray fluorescence data and fitting curves calculated from the eccentricity signal defined by sedimentation rate found by multivariate spectral analysis (right). The grey line represents the main hiatus and sedimentation rate boundary. The dashed line was calculated as a mean data deflection for different sedimentation rates. The thin black lines represent fit of artificial data defined by sedimentation rate, noise and changes in the sedimentation rate.

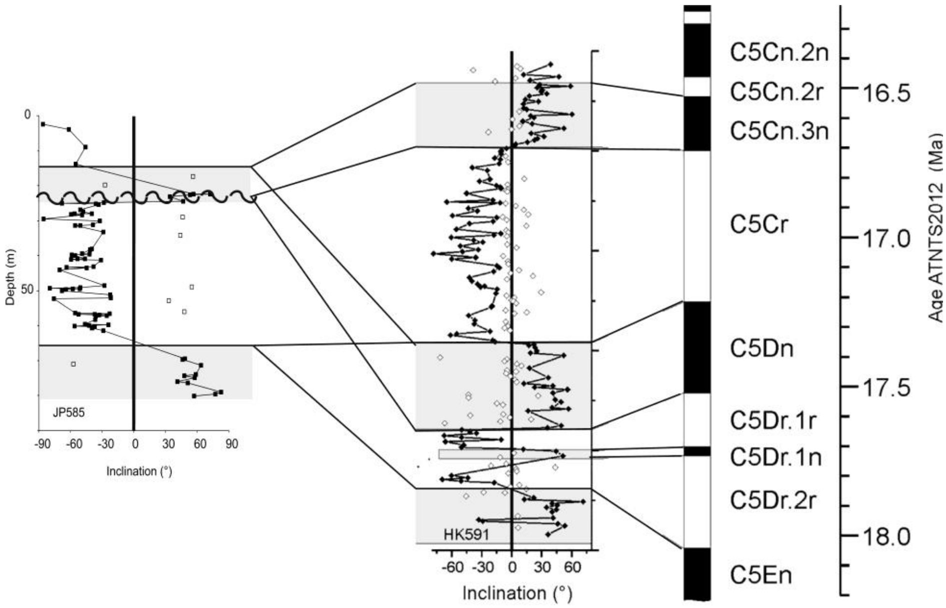

Fig. 2. Paleomagnetic inclination at the upper 80 meters of the JP585 drill core and its correlation to HK591 drill core.

According to comparison with detailed analysis of drill core HK591 (Matys Grygar *et al.* 2014), we suppose, that the most probable succession in JP585 begins in C5En, and ends in the zone C5Cr. The time span in the studied core for JP585 should be approximately 17.1 to 18.2. The second possibility dates the sedimentary infill between C5Dn and C5Cn.2r while the time span is 16.5–17.3 (Fig. 2). The marked hiatus around 25-meter depth represents time gap between 400 and 700 thousand years.

Keywords: magnetostratigraphy, cyclostratigraphy, Holešice and Libkovice Mb., Cypris Mb., Miocene.

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Magnetostratigraphic Correlation around the Jurassic-Cretaceous Boundary in the Vocontian Basin, France

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Abstract

Five sections in the Vocontian basin have been studied for magnetostratigraphy and biostratigraphy (Le Chouet, Charens, Tre Maroua, Haute Beaume (Belvedere), and St Bertrand's Spring). The profiles together provide a robustly connected composite sequence across the J/K boundary.

The studied sections consists of well-bedded mostly micritic limestone with minor bioclastic interlayers. In the upper parts of all studied sections there are intercalations of marl (Elbra *et al*. 2017). In the Le Chouet, Charrens and the St Bertrand section there are intrabasinal breccias, which have been omitted from further evaluation. Preliminary results on the distribution of the age-diagnostic ammonite taxa show that Belvedere and St. Bertrand span most of the B. jacobi Zone auctorum, and the Le Chouet and Charens profile starts in the Microcanthum ammonite zone (Wimbledon *et al*. 2013, Frau *et al*. 2016).

All the sections show a sequence of magnetostratigraphic normal and reverse polarity zones. The base of C. alpina zone and the FAD of Nannoconus wintereri fall in a normal polarity zone, which is thus identified as M19n. The span of the studied sections is: i) M19n to M17r (Intermedia to Ferasini Sz.) for Belvedere, ii) M19n to M17n (Intermedia to Elliptica Sz.) for St Bertrand's Spring, and iii) M20n to M19n (Remanei to Alpina Sz.) for Le Chouet. Magnetic susceptibility rises from the negative values in the Tithonian intervals to positive values in the Berriasian, which might be caused by an input of terrigenous material.

Keywords: Vocontian Basin, magnetostratigraphy, Jurassic-Cretaceous boundary.

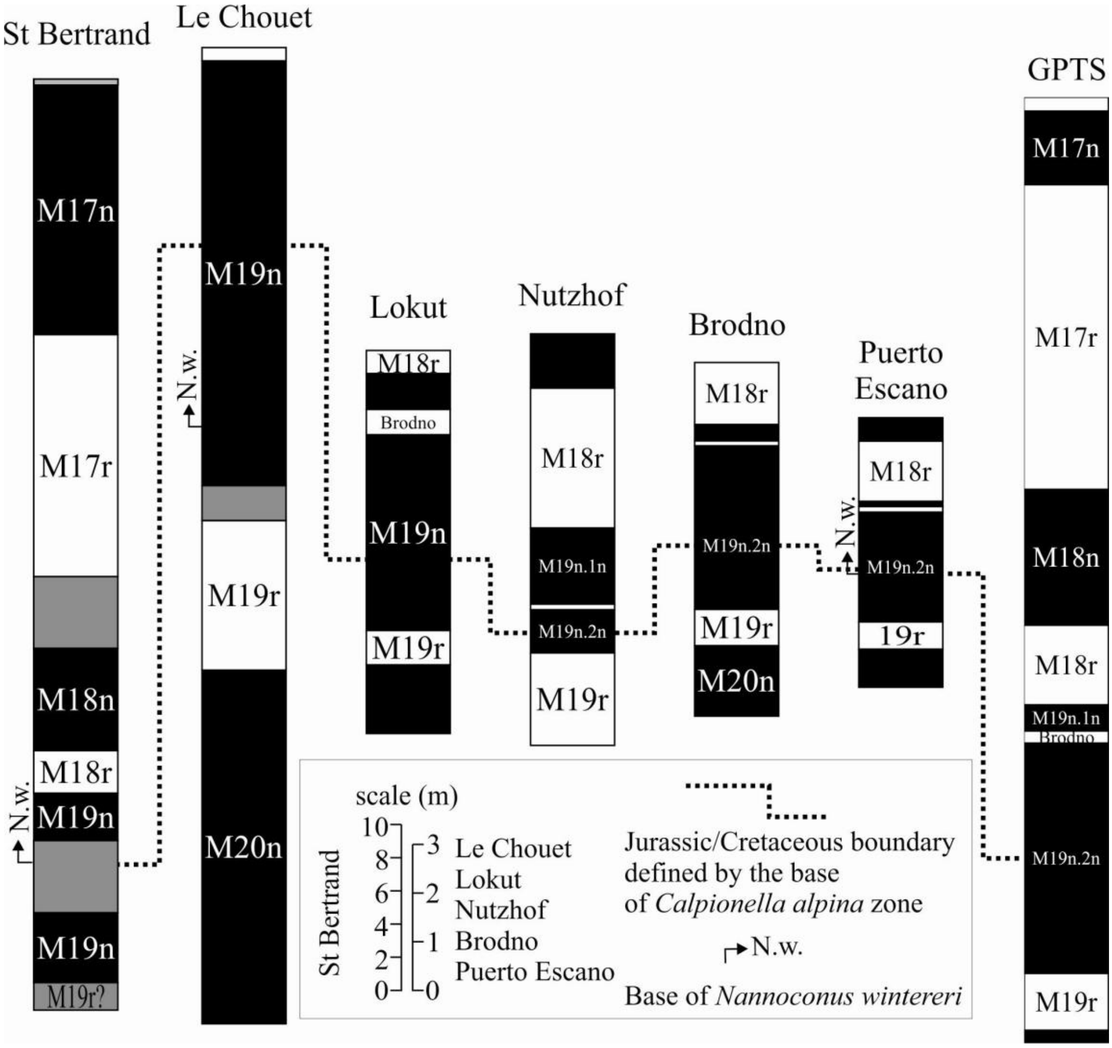

Fig. 1. Correlation of the J/K boundary sections between Vocontian Basin and other parts of the western Tethys and the geopolarity timescale.

Acknowledgements. The research is supported by Czech Science Foundation grant No. GA16-09979S and of research plan of the Institute of Geology of the Czech Academy of Sciences, No. RVO67985831. D. Reháková was funded by APVV-14-0118.

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Recovering Magnetostratigraphy from Drill Cores Despite Low Latitudes

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A b s t r a c t

Magnetostratigraphy is an important building block for age-models of scientific cores. Due to the rotational movement of the coring process the azimuthal orientations of the cores is lost hindering the construction of magnetostratigraphy based of correctly orientated paleomagnetic samples. For high latitudes a high quality magnetostratigraphy can still be reconstructed on the basis of the inclination of the paleomagnetic direction alone. For example in northern latitudes a downward inclination is interpreted as normal and an upwards inclination as reversed paleomagnetic directions of the core samples.

However, at low latitudes near the equator the inclination of the (paleo) magnetic field are near zero. As a result a magnetostratigraphy on the basis of inclination alone cannot be made.

Here we present two methods that can be used to build a core based magnetostratigraphy at low latitudes. First, the anisotropy of the magnetic susceptibility (AMS) can be used in certain cases to reorientate the paleomagnetic samples by identifying the bedding of the sediments throughout the core.

Second, the present/recent low temperatures –low coercivity overprint can be used to reorientate the ChRM directions by orientating these LT/LC components towards the north and recalculate the ChRM directions.

Both methods have been used on the ICDP Hominin Sites Paleolakes Drilling Project (HSPDP) cores taken in Ethiopia and Kenia. Here we will present data of four HSPDP cores as case study to help illustrate the effectiveness of these two methods for building a magnetostratigraphy for low latitude cores.

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Quaternary Slope Instability and Mass Movement Deposits Characterization (Portimão Bank, SW Iberia)

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A b s t r a c t

Submarine slope failure and associated mass movements are common processes worldwide, some of them with high economic impact and societal consequences. This work represents an approach to the more suitable proxy's in order to identify and characterize mass movement deposits and the respective deformation. As case study was selected the Portimão Bank, a submarine E–W elongated structural high with prominent slide scars, located offshore southern Portugal in the Gulf of Cadiz. The used methodologies enabled a two different scales approach. On a broad scale, we look for the occurrence of mass movements deposits through accurate geomorphological mapping and seismic interpretation. At local and detailed scale we looked for the vertical characterization and development of MMDs along piston core (PC-07, 338 cm long retrieved in the centre of a slide scar) by means of sedimentological, environmental magnetism, paleomagnetism and magnetic fabric studies, complemented by bioturbation analysis and C^{14} dating. Our results show that: i) The Portimão bank is characterized by a series of important on-going landslides; ii) The sedimentary column retrieved from piston core is replicated; iii) Anisotropy of magnetic susceptibility is able to identify a segment with approximately 90 cm that accommodated the deformation associated with the replication of the sedimentary column. Important to emphasize that such deformation goes unnoticed by mesoscopic analysis; iv) in the deformed seg-

ment, the AMS lineation represents an intersection lineation that can not be interpreted as the preferred direction of grain alignment. This work was supported by project FCT UID/GEO/50019/2013 to Instituto Dom Luiz.

Keywords: mass movement deposits, Gulf of Cadiz, magnetic fabric, rock magnetism.

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Magnetic Fabric Study of a Complex Mafic Dyke of Pico Island (Azores Archipelago)

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Abstract

Anisotropy of magnetic susceptibility (AMS) and anisotropy of anhysteretic remanent magnetization (AARM) data have been obtained from a vertical, two meters thick, mafic dyke (intruding volcanic lava flow pile dated between 190 and 125 ka – Costa *et al*. (2015), Silva *et al*. (2018)), located on the southern margin of the Pico Island (Azores Archipelago). Its central part is constituted by different volcanic "facies" characterized by discontinuous cores with concentric rings. Locally, the latter form an almost circular sub-horizontal "structure". This "composite" magmatic "dyke" seems to correspond to a sequence of lateral magma pulses. Comparison between AMS and AARM fabrics indicate that inverse fabric related to single-domain grains has negligible effects on AMS. According to the scale used, different interpretations of the flow regime are possible:

At the dyke scale, AMS fabric is dominated by oblate shape and scattering of the minimum axes K_3 along a vertical plane perpendicular to the dyke plane, suggesting a vertical magma movement according to global foliation imbrication (Geoffroy *et al*. 2002). However, when considered the maximum principal axes K_1 as flow indicator (Knight and Walker 1988), horizontal magma flow is suggested. The same remark can be made on a section across the dyke at the scale of one concentric horizontal magmatic structure. However, when considered distinct domains of the dyke, i.e., looking at a smaller scale, different pat-

terns appear. On a dyke border, K_1 presents various inclinations, suggesting oblique flow. Some samples give vertical magnetic foliation perpendicular to dyke plane and, in another part of the dyke, K_1 presents strong plunge in a direction oblique to the dyke plane.

Looking in more detail at the results in different parts of the dyke, magnetic data show a certain coherence. Magnetic foliation in the concentric rings follows the ring shape, explaining the K_3 distribution with a vertical plane. On a dyke border, foliation imbrication clearly points out horizontal flow vector, an interpretation that is reinforced by a well defined sub-vertical magnetic zone axis (Henry 1997); K_1 presents directions scattered between this magnetic zone axis and the horizontal direction obtained in most sites and then appears to be "composite", explaining its oblique orientation in part of the samples. The other plunging K_1 axes also coincide with the corresponding magnetic zone axis. Magnetic foliation perpendicular to flow corresponds to the middle of circular structures and likely to particular flow conditions in restricted "channels", likely with a dominant pure shear stress regime.

All this complexity can be therefore simply explained by horizontal propagation of magma (related to successive magma pulses) towards the South, i.e., from its volcanic center toward its limit. The observed sub-horizontal "tube" then does not represent a "rolling" embedded structure during an upward magma movement, but a kind of horizontal pipe in the core of a partly "cooled" dyke. This particular dyke shows how complex the flow can be and how important is a dense sampling strategy.

Keywords: AMS, Dyke, Flow, Imbrication, Magnetic zone axis.

Acknowledgement. This work was supported by project FCT UID/GEO/50019/2013 to Instituto Dom Luiz.

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Uncertainty Analyses of Static Measurements of Induced Magnetisation

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Abstract

Magnetic nanoparticles (MNP) have a wide range of application. They are used for instance as contrast agent for magnetic resonance imaging, as drug delivery vehicle, for magnetic hyperthermia, for sewage treatment, as ink for bank notes, in high-quality loudspeakers or for research purposes. The demand for custom tailored MNPs fosters the development of new MNPs with specific biological and physical properties. Accurate and precise magnetic property characterisation is thus required for quality control of newly developed MNPs at laboratory scales but also for optimising scale-up production procedures, i.e., the production of MNPs in commercial quantities. International standards for definition and measurement of the magnetic properties of MNPs do not exist. This reduces the trust of magnetic nanoparticle consumers in safety, reliability and functionality of magnetic nanoparticle products and increasingly hampers the market chances of magnetic nanoparticle producers.

Internal and external sources of uncertainty of induced magnetisation curves will be analysed and their consequences on the uncertainty of corresponding parameters discussed, i.e., saturation magnetisation, saturation remanence, coercive force and as well as low and high-field susceptibility. Example measurements performed with a Magnetic Property Measurement System will be presented for the calibration standard, natural samples, artificial MNP powders and MNP suspensions. The example below refers to two different magnetic nanoparticle samples. One consists of $\geq \approx 150$ nm magnetite (Fe_3O_4) particles and the other of maghaemite (γ-Fe_2O_3) particles with a size of 34 nm. In order to detect possible sources of uncertainty, four different sub-samples were made from each of the two samples. Uncertainty analysis reveals that the actual measured values, i.e., the magnetic moments are not affected by large uncertainties. For individual subsamples they range between 0.001 and 0.009%. However, the standard deviation of the mean M_s of the four sub-samples is much larger, i.e., between 2 and 4% for magnetite and maghaemite, respectively. The uncertainty

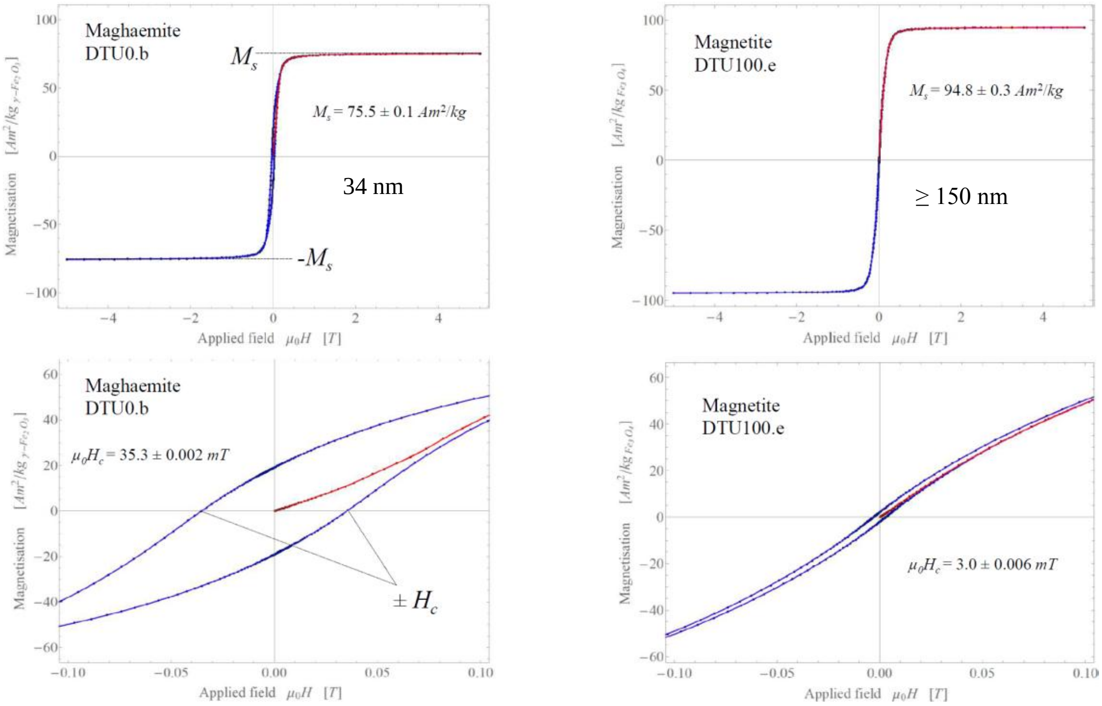

Fig. 1. Magnetic hysteresis measurement of a maghaemite sub-sample (left side) and a magnetite sub-sample (right side). Both lower diagrams are a zoom into the low-field region of the upper diagrams. The measurement cycle starts by increasing the applied field stepwise from 0 to +5 T (red curve). The field is then stepwise decreased from +5 T to -5 T and again increased to +5T (blue curves). At each field step, five individual measurement were recorded. The black points are average measurement values. Both samples differ significantly in grain size, which is reflected by Hc.

of the coercive force, is not affected by the mass and is much smaller, i.e., 0.01 and 0.3% for the maghaemite and the magnetite sample, respectively. Regarding accuracy, the average values obtained differ between 3 and 5% from the reference values published in the scientific literature (e.g., Fock *et al.* 2017), for H_c and M_s respectively; for both samples. Concluding can be said so far that the mass determination of the individual subsamples, which is in the order of a few milligrams, is the largest source of uncertainty.

Keywords: DC-magnetometry, uncertainty budget, magnetic hysteresis, magnetic nanoparticles.

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The Frequency of Geomagnetic Polarity Reversals in the Carboniferous: Insight into Earth's Deep Interior

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Abstract

Long-term variations (> 10 Ma) in Earth's magnetic field have been postulated to reflect the influence of mantle forcing, bound to changes in heat flow at the core mantle boundary. One of the best documented records of long-term changes in Earth's magnetic field is the Geomagnetic Polarity timescale (GPTS). Examination of the GPTS demonstrates that the occurrence of polarity reversals is stochastic, however there is evidence that the frequency of magnetic field reversals varies in a periodic manner. This observation is the foundation for the 200 Ma cyclicity hypothesis, which proposes that periods where the field undergoes rapid transition from a highly unstable state (high reversal frequency) to a more stable state (superchrons) is on a 200 Ma cycle, hypothesized to reflect periodic superplume growth and collapse in Earth's mantle (Amit and Olson 2015, Olson and Amit 2015). Documented transitions from a highly unstable state to a more stable state are observed between the Middle Jurassic (high-reversal frequency) and the Early Cretaceous (Cretaceous Normal Superchron). Other records of extended non-reversal have been recognized in the Phanerozoic, and they appear to follow a ~200 Ma periodicity. However, better records documenting magnetic reversal frequency preceding these intervals, particularly in the Paleozoic, are needed to appropriately test this hypothesis.

Here we present preliminary magnetostratigraphic data collected from Carboniferous age sediments outcropping in the United Kingdom (Cumbria and Scottish Borders), which span the 40 Ma preceding the Permo-Carboniferous Reverse Superchron (PCRS). The PCRS is an extended period of reverse polarity that begins around the Mississippian-Pennsylvanian boundary (~323 Ma) and extends into the Permian, covering an interval of ~50–60 Ma (Davydov *et al*. 2012). Besides the PCRS, there is only one well-constrained period of polarity reversal history in the Carboniferous ~333–327 Ma (Opdyke *et al*. 2014). Records of polarity patterns for other parts of the Carboniferous exist, but many of these records are derived from regional-based studies which lack the means to confidently correlate the records to the global framework (Hounslow *et al*. 2004). Furthermore, there is evidence that many of these records are biased by remagnetization and do not record a Carboniferous signal. Overall, the existing magnetic polarity record for the Carboniferous is not robust

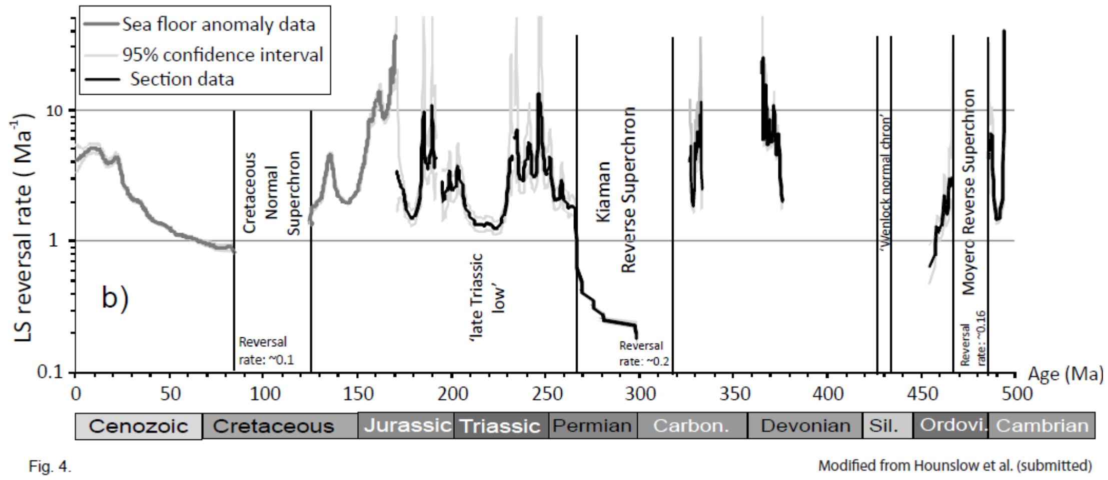

Fig. 1. Reversal rate through the Phanerozoic estimated from existing paleomagnetic data.

enough to test whether there was a period of high reversal frequency before the PCRS. By constraining the polarity reversal history in the Carboniferous between 360–320 Ma, our work will help test the 200 Ma cyclicity hypothesis, in addition to helping establish a reliable global polarity timescale for this time period.

Keywords: Paleomagnetism, magnetostratigraphy, reversals, carboniferous.

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Assessment of Heavy Metal Pollution of Vistula River Sediments using Magnetic Method

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Abstract

The river sediments have high cappasity to acumulate heavy metal pollutions originated a.o. from industrial wastewater, fossil fuel combustion and atmospheric deposition. The purpose of this research was to estimate the concentration of magnetic particles to assess the level of heavy metal pollution using magnetic methods.

The research was conducted on Vistula's sediments collected in the Warsaw's areas including the city center (area B, Fig. 1a) and out of the urbanized area (area A and C, Fig. 1a). For individual granulometric fractions of surface (0–2 cm) sediments several magnetic properties such as mass magnetic susceptibility (χ), changes of magnetic susceptibility in low and high temperature ranges and hysteresis loops were analyzed in order to determine the concentration and grain size of magnetic particles and their magnetic mineralogy. To characterize the morphology and chemical composition of magnetic particles the microscopic observations and chemical measurements were carried out.

The results of test study show that magnetic particles are mainly presented in the fine fractions of 100–71 μm and below 71 μm. Therefore, both fine fractions were taken account in the study of pollution level.

Distributions of χ along the Vistula river show the maximum in the very center of the city and relatively low values out of the urbanized area. The increase of χ in the city center and the decrease of χ outside the city center indicates that pollution level is mainly affected by local sources.

Significant correlations between the Pollution Load Index calculated for Pb, Zn, Al, Fe, Cr, Co, Cu, Ni and the magnetic susceptibility showed high heavy metal pollution level in very center. Outside the city heavy metal pollution level were relatively low and close to the background value.

The thermomagnetic analysis revealed magnetite as a primary magnetic phase in the city center (area B) and maghemite or cation deficient magnetite in areas outside of Warsaw (area A and C). The results show that in the area of Warsaw the magnetic extract is enriched in spherical-shaped particles (Fig. 1b). It was observed that fraction below 71 μm contained

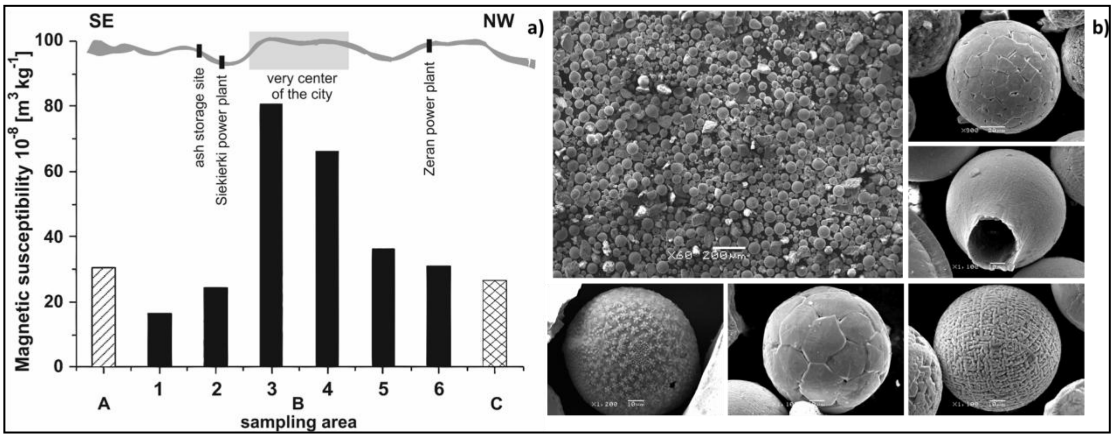

Fig. 1. Distribution of average magnetic susceptibility (χ_{av}) of surface Vistula River sediments for the Warsaw area (B) with corresponding subareas (from 1 to 6) and for two areas outside of Warsaw (A and C) (a). Scanning Electron Microscope images for fraction below 71 μm of surface sediments for area B (b).

more spherules than fraction of 71 μm. In both fractions a few types of surface morphology were observed such as particles with smooth, glossy, matt, orange-peel and druse-like surface.

Our research demonstrate that magnetic methods can be apply for detecting and mapping pollution in sediments around modern industrial cities.

Keywords: magnetic susceptibility, sediments, spherules, heavy metals.

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Impact of a Former Glasswork on Soil Magnetic and Geochemical Signals: A case Study of the Izery Mountains

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Abstract

The aim of this work was to determine impact of a former glasswork using magnetic methods, conductivity and electrical resistivity tomography (ERT) as well as to distinguish between soil pollution from long-range (LRTAPs) and local transport of atmospheric pollutants using soil magnetometry supported by geochemical analyses (i.e., content of the potentially toxic elements – PTEs). The study area was located in the Izery region of Poland – the Izery Mountains (within the “Black Triangle” region, which is the nickname for one of Europe’s most polluted areas, where Germany, Poland, and the Czech Republic meet) and examined soils were developed from the Izera granite. The major site of the study area was situated in the Forest Glade and was exposed to the anthropogenic pressure from a former glasswork that was active here from 1754 until 1891. Whereas, the second site of the study area was located on a neighboring hill (Granicznik), whose western, north-western, and south-western parts of the slope were exposed to the long-range transport of atmospheric pollutants from the Czech Republic and Germany. Our results indicate that the Forest Glade site was characterized by many anthropogenic translocations and confirmed by a relatively high value (0.61) of the Topsoil Transformation Factor – TTF (Łukasik *et al*. 2015). Moreover, TTF and the initial study of ERT revealed existence of anthropogenic layer of wastes, dumping during the glasswork activity. The highest contents of Cu, Ni, Pb, Sn, and Zn in the Forest Glade site correspond to the local sources of pollutants and anthropogenic influence (i.e., former glasswork), whereas, the highest concentration of As, Cd, Hg, In, Mo, Sb, and Se on the Granicznik Hill site are likely a result of long-range transport of atmospheric pollutants. The principal component analyses (PCA) analysis showed that χ value is inversely correlated with the contents of Nb, Th, U, and Zr, indicating a natural origin of these elements.

Keywords: magnetic susceptibility, potentially toxic elements, soil pollution, anthropogenic impact.

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An Updated Catalogue of Italian Palaeomagnetic Data from Volcanic Rocks and Archaeological Artifacts

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A b s t r a c t

An updated catalogue of Italian palaeomagnetic data published in international journals and small archaeological reports or university thesis during the last decades has been compiled. The new dataset includes data from both archaeological artifacts and volcanic rocks and aims to better constrain the full vector geomagnetic field secular variation (SV) in Italy during the last 8000 years. In respect to the previously published Italian directional SV curve, 24 new directional data from archaeological baked clays have been added while the contribution of directions coming from volcanic rocks importantly enrich the dataset mainly for the last millennium. One of the main problems with the Italian volcanic data is their precise dating and for this reason all data coming from lava and pyroclastic flows have been controlled. Only data with undisputable age have been accepted for further considerations. The available intensity dataset from Italy still remains poor, even when the intensities from volcanic rocks are included. The updated dataset shows that reliable considerations about the SV in Italy can be done only for the last three millennia while data from older periods are extremely scarce for any further elaboration. Comparison of the Italian data with the predictions of European and global geomagnetic field models shows a good agreement suggesting the great potential of the Italian SV dataset for reliable dating of archaeological artifacts, and lava flows emplaced during the last 3000 years.

Keywords: geomagnetic field records, volcanic rocks, archaeological artifacts, Italy.

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New Directional Archaeomagnetic Data from Seven Baked Clay Structures Excavated at the Archaeometallurgical Site of Agia Varvara-Almyras, Cyprus

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Abstract

The first directional archaeomagnetic results from Cyprus are presented, based on the study of seven baked clay structures excavated at the copper smelting site of Agia Varvara-Almyras, situated some 20 km south of Nicosia. This ancient copper working site represents a unique example of complete primary production of the copper metal in Cyprus. In total five furnaces, one ore roasting pit and an oven were sampled in situ for an archaeomagnetic investigation. All the studied structures are well dated, based on pottery finds and radiocarbon analyses, with ages ranging from 600 BC to 50 BC. Several rock magnetic experiments were performed to determine the main magnetic carrier and to investigate the thermal stability of the studied material. The direction of the Characteristic Remanent Magnetization (ChRM) for each structure has been determined by demagnetization of 7 to 15 specimens in alternating magnetic fields up to 100–120 mT. Mean directions were calculated assuming a Fisherian distribution and are very well defined for five out of the seven structures studied. The new directions are compared with the few directional data available for the area, mainly coming from Greece, and with the predictions of global geomagnetic field models. They are an important contribution to improving our knowledge of the geomagnetic field variations in the eastern Mediterranean and emphasize the need for more directional data from well dated structures in order to acquire a better understanding of the geomagnetic field's short-term variations in this region.

Keywords: archaeomagnetism, secular variation, Cyprus; Eastern Mediterranean.

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Paleomagnetism of the Cherni Vrah Massif, Balkan-Carpathian Ophiolite: Preliminary Results

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A b s t r a c t

Balkan-Carpathia Ophiolite is the dismembered pieces of ancient oceanic crust cropping out in Romania, Serbia and Bulgaria. Although a pioneering work dated the Bulgarian Cherni Vrah massif as Late Neoproterozoic (von Quadt *et al.* 1998), more recent studies reported Early Devonian ages for multiple massifs in the ophiolite (Zakariadze *et al.* 2012, Balica *et al.* 2014, Plissart *et al.* 2017, Kiselinov *et al.* 2017). Consequently, little is established for the tectonic history of the ophiolite. We investigated the paleomagnetism of the gabbroic rocks and sheeted dykes in the Cherni Vrah massif sampled near the village of Gorni Lom. Both types of rocks exhibit similar characteristic remanence direction with West declination and moderate negative inclination (geographic coordinate). Natural remanent magnetization (NRM) are completely demagnetized by 150 mT of alternating field (AF), indicating that titanomagnetite is the primary remanence carrier. Gabbros are stable against AF demagnetization with median destructive field often exceed 50 mT. Microscopic observations revealed that rare, unaltered plagioclase in gabbros contain fine rods of exsolved magnetite. It is yet to be investigated if these exsolved magnetite are the voluminously important carrier of the stable NRM in gabbros. Anisotropy of magnetic susceptibility of gabbros revealed consistent pattern of magnetic foliation with c. 50° strike and c. 50° dip to the South. Assuming that this AMS fabric approximate the paleohorizontal, the characteristic remanence direction after tilt correction shows inclination of c. -38°.

Keywords: ophiolite, gabbro, Balkan, AMS, exsolved magnetite.

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Thermomagnetic and Mineralogical Analyses of Industrial Dust and Fly Ashes Originating from Different Kinds of Industrial Processes

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Abstract

Industrial emissions are very important source of technogenic magnetic particles (TMPs) – mainly, oxides and hydroxides of Fe. TMPs introduced by Magiera *et al.* (2011, 2013), thanks their specific mineral and magnetic properties, and well developed specific surface area, are characterized by an affinity for some elements like heavy metals. They are generated in a wide variety of high temperature industrial processes where different iron minerals, present in raw materials, fuels and additives are transformed to highly magnetic iron oxides. TMPs are emitted to the atmosphere and then deposited on the soil, plant, and building surfaces.

The main objective of the research was identification of iron and manganese minerals (mainly oxides and hydroxides) occurring in TMPs. For the purpose of this study fly ashes from two power plants, dusts from non-ferrous metal smelting and two steelworks were collected and subjected to magnetic (bulk magnetic susceptibility and temperature dependence of magnetic susceptibility) and mineralogical (Mössbauer spectroscopy and scanning electron microscopy with energy dispersive spectroscopy – SEM/EDS) analyses.

The χ of fly ashes was at the level of 1000–1300 × 10^{-8} m^3kg^{-1}. Dusts originated from electrofilters were characterized by very diversified values of magnetic susceptibility. The highest values were obtained for furnace bottom ashes from coal-fired power plant (above 10000 × 10^{-8} m^3kg^{-1}) and the lowest – for dusts from non-ferrous metal smelting (below 1000 × 10^{-8} m^3kg^{-1}). Thermomagnetic analyses revealed differences between samples from particular industries. Inflection at 580 °C of the curve of TMPs emitted by power plants indicated that magnetite was the main magnetic phase. In case of non-ferrous metal smelting

additional curve deflection at 130 and 210 °C occurred relating to intermediate titanomagnetite (Vahle and Kontny 2005).

Mössbauer spectra showed that the magnetic phase accounted for 50–70% of fly ashes samples (mainly ferrihydrite and hematite), for 47–57% of bottom ashes (mainly ferrihydrite, magnetite and magnesioferrite), and for more than 90% dusts from electrofilters (mainly magnetite and maghemite). The smallest content of magnetic phase was characterized by steel dust from non-ferrous metal smelting: 11–30%. The main compound present in these dusts were franklinite, γ-FeZn and goethite.

SEM analysis revealed that the main components of fly ashes were glaze (mullite and quartz), quick cokes, calcium sulfates and spherical aluminosilicates with inclusions of Fe and Mg oxides. Iron and manganese were the main elements in almost all dust samples, however, the zinc and lead, as well as cadmium and copper prevailed in samples of dusts coming from Zn and Pb works.

Keywords: magnetic susceptibility, SEM, Mössbauer spectroscopy, TMPs, dusts.

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First Paleomagnetic Constraints on the Latitudinal Displacement of the West Burma Block

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Abstract

Cenozoic collision between India and Eurasia produced the Himalayan-Tibetan orogen, which is commonly considered as the archetypical orogen for continent-continent collision systems. However, there is still no consensus on the amount and mechanism of post-collisional convergence, as well as on the roles of the numerous tectonic terranes comprising the orogen (Jagoutz *et al*. 2015, 2016; Replumaz *et al.* 2013, Royden *et al*. 2008, van Hinsbergen *et al.* 2011). The West Burma block exhibits a unique geodynamic evolution within this system, influenced by oblique subduction of the Indian plate and significant strike-slip motions along the dextral Sagaing Fault. Furthermore, it is at a key location for paleoenvironmental reconstructions (Cai *et al.* 2016, Licht *et al.* 2013). Despite this, robust paleomagnetic data from the West Burma block is largely absent.

Here we report new paleomagnetic, petrological and U-Pb age data to constrain the latitudinal displacement of West Burma. To this end, 45 sites were drilled in the intrusives, extrusives and sediments of the Wuntho arc, Myanmar. Paleomagnetic results were obtained at 30 sites. In addition, 135 paleomagnetic results were obtained from a Late-Eocene monoclinic sedimentary section in the Chindwin basin, Myanmar.

Wuntho arc U-Pb ages cluster in the range 110–90 Ma, indicating a Late-Cretaceous age. Paleomagnetic results from this area show declination values of around 50°–100°, implying clockwise rotation of the overall arc dispersed by local-block rotations related to faulting, and inclination values close to zero, corresponding to near-equatorial paleolatitude. Tilt corrections are not available for sites in intrusive rocks. However, the sampling is distributed over a large area (1000 km^2) and the results are found inconsistent with regional tilting of the arc. The occurrence of remagnetization after tilting of the country rocks in several sites by the intrusive batholith also support the clockwise rotations and the low paleolatitude. In the Late-Eocene sediments, normal and reverse polarity magnetizations, alongside the occurrence of numerous ~10 cm thick siderite-rich layers with stable magnetizations, indicate a primary detrital or a very early diagenetic origin for the acquisition of the magnetization. The sediments constrain a low inclination after tilt correction, which is coherent with the inferred near-equatorial position from the older Wuntho arc rocks. Based on these results, we suggest that accretion of the West Burma block occurred at near-equatorial latitude, and that it subsequently underwent significant clockwise rotation and northward translation during the Cenozoic.

Keywords: paleomagnetism, plate tectonics, Wuntho arc, West Burma block, Himalayan-Tibetan orogen.

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Thermal Analysis of the Kerogen Rich Black Shales from the Upper Devonian in Kowala Quarry, the Holy Cross Mountains, Poland

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Abstract

In-situ conversion process for recovery of hydrocarbons from shales requires heating the rock formation to 320°C in order to break down kerogen polymer into fragments small enough to permeate toward collection facility. Thermal analysis is essential for understanding the properties of shales as they change during heating to the target temperature (Grębowicz 2014). The study involved kerogen rich samples derived from the Late Famennian rocks representing global anoxic events: Annulata and Hangenberg. The Upper Famennian Annulata (ABS) and Hangenberg (HBS) Black Shales are exposed in the successions of the Kowala Quarry in the Holy Cross Mountains. The twin Annulata anoxic events are manifest as two organic-rich (TOC up to 23 wt.%), finely laminated black shales, each up to 0.6 m thick, separated by marl or nodular limestone layers (Racka *et al*. 2010). The sampled HBS succession (TOC c.a. 10 wt.%), is divided into seven layers, each being around ten to fifteen centimeters thick (Marynowski *et al*. 2012). For this study a thermomechanical analysis (TMA) and an analysis of anisotropy of magnetic susceptibility (AMS) vs temperature was used. Thermal expansion measurements were conducted in two different directions: perpendicular (vertical) and parallel (horizontal) to the layers from room temperature to 800°C at a rate of 10°C a minute. In AMS analysis samples was measured from room temperature to 600°C, taking measurements every 25°C. The expansion pattern (Fig. 1A) could be divided into three main temperature ranges: (1) low temperature: between 25 and 340–360°C (pre-pyrolysis), (2) transition range: 350–500°C, with the peak around 415–430°C (pyrolysis), and (3) high temperature: above 500°C (post-pyrolysis). Those three ranges are best seen in vertical measurements. At 450°C, overall increase of sample size has reached more than 30%. After passing the peak expansion, the samples quickly shrinks by about 10% at 500°C, followed by slow decrease in size until 800°C. AMS fabrics show typical sedimentary pattern with K_1 and K_2 axes in a bedding plane and a vertical K_3 (Fig. 1B). Magnetic susceptibi-

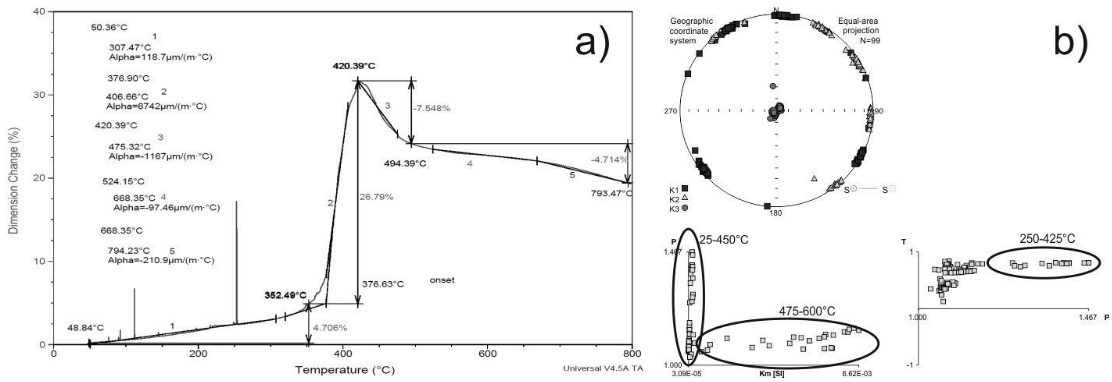

Fig. 1. (a) Thermal expansion results for the Annulata Black Shale sample (vertical), (b) AMS fabrics, P/K, and P/T diagrams for Annulata and Hangenberg Black Shale samples.

lity values at a room temperature ranges from 36 to 50 × 10^{-6} [SI] and the anisotropy degree (P) ranges from 1.05 to 1.09. After heating the anisotropy degree (P) rapidly rises between 250–425°C reaching the peak value (1.47) at 300–325 °C. During further heating (450–600°C) the anisotropy degree (P) falls to the previous values but magnetic susceptibility strongly increases up to 6.60 × 10^{-3} [SI]. This suggests the presence of iron sulphides and, after pyrolysis, the formation of superparamagnetic magnetite grains.

Keywords: oil shales, in-situ conversion process, thermomechanical analysis, anisotropy of magnetic susceptibility.

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CONTENTS