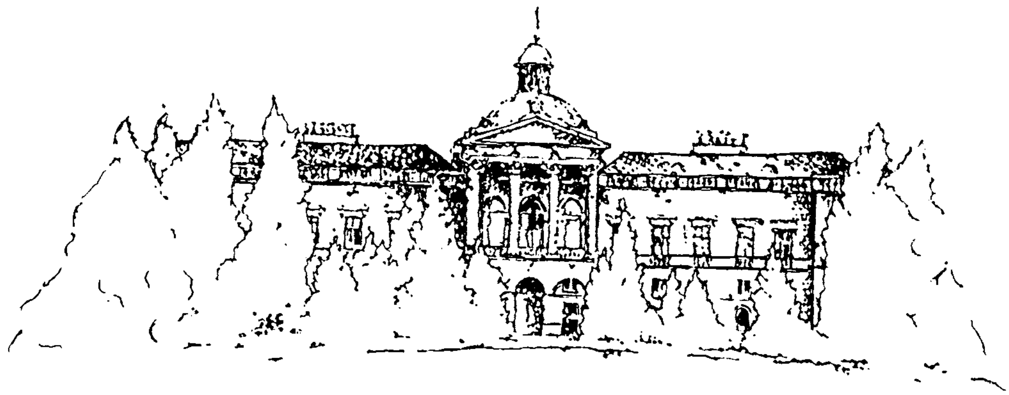
GEOLOGICA CARPATHICA, 47, 3, BRATISLAVA, JUNE 1996
153–212

NEW TRENDS IN GEOMAGNETISM
5th BIENNIAL MEETING
August 19-24, 1996, Castle of Topoľčianky, Slovak Republic



FOREWORD

The forthcoming meeting **"New Trends in Geomagnetism"** follows the previous four meetings, focused on the recent progress in rock magnetism and palaeomagnetism, held in 1988 at Liblice, in 1990 at Bechyně, in 1992 at Smolenice and in 1994 at Třešť. This scientific conference is organized under the patronage of the Ministry of Environment of the Slovak Republic and under the sponsorship of the Slovak Geological Survey - Bratislava, Slovak Mining Society - Banská Bystrica, Geocomplex copm.- Bratislava, Geophysica comp.- Brno, AGICO Brno the Agricultural and Trade Cooperative - Sant Peter as well as Brewery Golden Pheasant - Hurbanovo. The meeting is hosted by the Geophysical Institute of the Slovak Academy of Sciences in Bratislava. It is focused on new methods in Palaeomagnetism and Tectonics, Archaeomagnetism, Assessment of Quality of the Palaeomagnetic and Rock-Magnetic Data, Status of Palaeomagnetic and Rock-Magnetic Databases, General Rock Magnetism and Magnetostratigraphy and their Physical Background, Synthetic and Natural Magnetic Minerals, Environmental Magnetism and New Techniques and Approaches.

The suitable location for the meeting in Central Europe creates an opportunity for informal discussions and information exchange among the scientists from the various countries and also makes it attractive to young scientists from the world around.

More than 70 participants from some 20 countries registered for this meeting. Therefore, the Local Organizing Committee have greatly appreciated the offer of the *GEOLOGICA CARPATHICA* Editorial Board to publish the abstracts of the meeting in this journal. We belive that this is an excellent opportunity to extend the scope of the rock-magnetic and palaeomagnetic research to the scientific community engaged in geological research. On the other hand, the participants of the meeting can learn more on the geological studies (more or less related to the Carpathian region) and find it useful to publish some of their own results with geologically oriented outputs in this journal. Hence, the organizers would like to express their thanks to *Eduard Köhler,* Chief Editor and *Eva Chorvátová*, Managing Editor, for their helpful activity.

Without any preference, the abstracts are published in the special space within *GEOLOGICA CARPATHICA*.

Note: All abstracts are divided into two groups: Oral Presentations and Posters and they are ordered according to the topics.

I. Túnyi, O. Orlický and E. Petrovský in the name of the LOC

Oral Presentations:

EUROPEAN POLAR WANDERING PATH DURING THE HERCYNIAN EPISODE

MIROSLAV KRS*, OTAKAR MAN
and PETR PRUNER

*Geological Institute, Academy of Sciences of the Czech Republic, Rozvojová 135, 165 02 Praha 6 — Lysolaje, Czech Republic

European paleomagnetic data accumulated over the last 30 years were statistically evaluated and a number of results concerning paleogeography and paleotectonic deformations of rocks from the Hercynian orogenic belt were obtained. The territories under consideration are located north of the Alpine tectonic belt and west of the Ural Mts. up to Great Britain. The Trans-European Suture Zone (TESZ) played a significant role in the distribution of the paleotectonic deformations. The Permian period is characterized by a homogeneous grouping of paleomagnetic pole positions in the territories north of the Alpine tectonic belt covering the East-European Platform, Fennoscandia, the Central and West-European Hercynian belt. In the Early Permian, the European lithospheric plate consolidated without major paleotectonic rotation deformations of its segments during later geological history. From the Early Permian to recent times, a continuous movement of the plate occurred as a consequence of the continental drift from its paleogeographical position.

In the western part of the Bohemian Massif (Birkenmajer et al. 1968) and in the West-European Hercynides (Edel 1987), Carboniferous rocks show paleotectonic rotation deformations. If the Early Permian paleogeographic coordinate net is taken as a reference net, then, in the West-European Hercynides, the mean rotations reach values of about 50° clockwise for the Middle Carboniferous and 120° clockwise for the Early Carboniferous rocks. Similar clockwise paleotectonic rotations have recently been derived for the Middle to Late Devonian limestone formations from the Moravian Zone, the eastern part of the Bohemian Massif.

Paleotectonic rotations of the above magnitudes are quite common in the Alpine tectonic belt (cf. Morris & Tarling 1996) and they, undoubtedly, represent characteristic features not only in the Alpine tectonic belt but generally in the tectonic collision zones, as was shown on models simulating translation and rotation movements (Krs et al. 1996).

The TESZ represents a plate boundary between the East-European Platform (cratonic Europe) on the NE, and the Hercynian mobile belt on the SW. The pre-Variscan formations so far studied from the Hercynian mobile belt show different degrees of paleotectonic rotation deformations, predominantly of clockwise sense. The changes in paleomagnetic pole positions due to continental drift of the whole lithospheric plate are small in comparison to changes in pole positions caused by paleotectonic rotations. E.g., if paleomagnetic data derived from Devonian (Eifelian-Early Givetian, Givetian and Late Famennian) limestone formations in the Moravian Zone (the eastern part of the Bohemian Massif) are related to the paleogeographic net corresponding to the stable Europe, the paleotectonic rotations reach high clockwise values of 65°, 71° and 94°, respectively. Consequently, paleomagnetic data derived from pre-Variscan formations SW of the TESZ and influenced by paleotectonic rotations cannot be used for derivation of polar wandering path. Fig. 1 demonstrates the European polar wandering path for the Hercynian Episode; statistically evaluated mean pole positions were derived from rock formations not influenced by paleotectonic rotation deformations. The path constructed with respect to the above phenomena is relatively smooth, without pronounced loops (cf. Butler 1992, page 258).

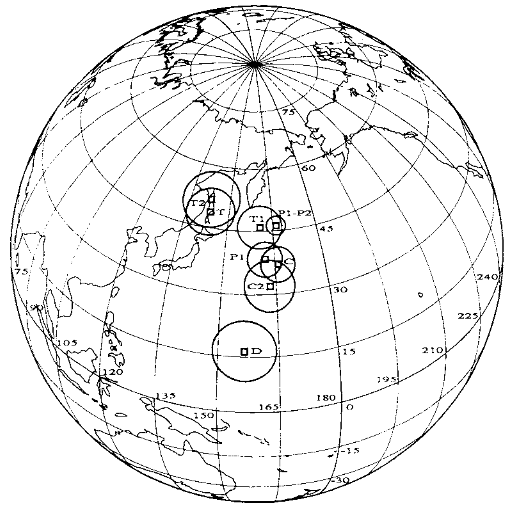


Fig. 1. Triassic to Devonian pole positions derived statistically for stable (cratonic) Europe: T1, T2, P1-P2, C2 — Russian Platform; T — England, Ireland, France and Germany; P1 — Bohemian Massif; C, D — Fennoscandia. The mean pole positions were derived by means of R. Fisher's (1953) statistics at the 95 % probability level from data listed in Krs & Pruner (1995).

References

Birkenmajer K., Krs M. & Nairn A.E.M., 1968: A paleomagnetic study of Upper Carboniferous rocks from the Inner Sudetic Basin and the Bohemian Massif. *Geol. Soc. Amer. Bull.*, 79, 589-608.

Butler R.F., 1992: Paleomagnetism: Magnetic Domains to Geologic Terranes. *Blackwell*, Oxford, 1-319.

Edel J.B., 1987: Paleopositions of the western Europe Hercynides during the Late Carboniferous deduced from paleomagnetic data: consequences for "stable Europe". In: D.V. Kent & M. Krs (Eds.): Laurasian Paleomagnetism and Tectonics, *Tectonophysics*, 139, 31-41.

Fisher R., 1953: Dispersion on a sphere. *Proc. Roy. Soc.*, A 217, 295-305.

Krs M., Krsová M. & Pruner P., 1996: Paleomagnetism and paleogeography of the Western Carpathians from the Neogene to the Permian. In: A. Morris & D.H. Tarling (Eds.): Paleomagnetism and Tectonics of the Mediterranean region. *Spec. Publ. (Geol. Soc. London)*, 105, 175-184.

Krs M. & Pruner P., 1995: Paleomagnetism and paleogeography of the Variscan formations of the Bohemian Massif, comparison with other European regions. *Journal of the Czech Geological Society*, 40, 1-2, 3-46.

Morris A. & Tarling D.H., 1996: Paleomagnetism and Tectonics of the Mediterranean Region. *Spec. Publ. (Geol. Soc. London)*, No. 105.

THE BENDING MODEL OF THE TRANSDANUBIAN CENTRAL RANGE IN THE LIGHT OF PALEOMAGNETIC DATA

EMÖ MÁRTON

Eötvös Loránd Geophysical Institute, Columbus út 17-23, 1145 Budapest, Hungary

It has been known for some time that the orientation of the Mesozoic structures of the Transdanubian Central Range is not uniform: the strike is NE-SW oriented in the Bakony, E-W oriented in the Gerecse and NW-SE oriented in the Pilis and Buda Hills. Balla & Dudko (1989) suggested that the above picture reflects the bending of the Transdanubian Range. They also claimed that paleomagnetic data obtained by Márton & Márton (1983) support their bending model. Balla (1988) even found that a bent Transdanubian Range may be pushed back to the west to match the paleomagnetic rotation pattern of the Northern Calcareous Alps.

More than 500 oriented cores were collected from the late Triassic Platform carbonates, the most wide-spread formation of the Transdanubian Central Range in order to test the bending model. The more than 270 successful samples distributed between 12 localities along the Range allow us to conclude that there is a "break" in the Transdanubian Central Range between Labatlan and Dorog. In the west the counter-clockwise rotation is 38° less than in the east, while the inclinations are consistent and so are the declinations on either side of the break. These observations are clearly incompatible with the bending model.

References

Balla Z., 1988: Clockwise paleomagnetic rotations in Alps in the light of the structural pattern of the Transdanubian Range (Hungary). *Tectonophysics*, 145, 277-292.

Balla Z. & Dudko A., 1989: Large-scale Tertiary strike-slip displacements recorded in the structure of the Transdanubian Range. *Geophysical Transactions*, 35, 1-2, 3-63.

Márton E. & Márton P., 1983: A refined polar wander curve for the Transdanubian Central Mountains and its bearing on the Mediterranean history. *Tectonophysics*, 98, 1-2, 43-57.

GEOMAGNETIC FIELD IN THE VENDIAN PERIOD FROM INVESTIGATIONS OF THE VOLIN-PODOLIAN (UKRAINE) TRAP FORMATION

ALLA GLEVASSKAYA*, SVETLANA KRAVCHENKO and NINEL MIKHAILOVA

*Institute of Geophysics, National Academy of Sciences, Palladin av. 32 , 252680 Kiev 142, Ukraine

The Upper Precambrian sequence of the Volin-Podolian region situated in the SW margin of the East-European Platform is well known as a Vendian system stratotype of global level.

As to the construction of the Precambrian part of APWP, it extends the Early Precambrian sections of the Ukrainian shield and is overlain by Cambrian and Ordovician deposits of its sedimentary cover.

The section investigated (16 boreholes with 690 cores oriented in bottom-up system, 11 outcrops, 540 oriented samples), belonging to the sedimentary Gorbashov suite and volcanic Berestovets series, represents the oldest part of the Vendian sequence (610-560 Ma).

Paleomagnetic data for the basic Gorbashov Formation were obtained from only one borehole. Grey sandstones have normal magnetization. The same magnetization with up to 40° inclination was found in the two lower basaltic flows of the Zabolotie suite (the oldest one in the Berestovets series).

As a predominant ancient NRM direction, it was probably reversed during the period of the tuff accumulation and lava effusions of the middle Babin and late Ratno time. The Ratno suite consists of up to 8 basalt lava flows, differing from each other by their own paleomagnetic inclinations and magnetic parameters (especially Qn, connected with a value of paleointensity on the whole).

The lava flows with R-magnetization are more common, but there are two lava flows with N-magnetization and four with anomalous ones. So, the geomagnetic field interval may be described as an unstable one with mixed polarity.

The virtual pole positions were calculated for the different outcroping basaltic bodies belonging to the Ratno suite: F = 25°-48° S, L = 104°-145° E.

So, the geomagnetic field in the Early Vendian appears to be reversed, but unstable, with some normal and intermediate polarity intervals. The upper part of the volcanic formation has been fixed in an interval of mixed polarity.

According to predominant R-magnetization of the Mogilev-Podolsky, Kanilovka and Baltic (basin belts) series sedimentary rocks, outcropping in the Podolian Middle Dniester area, the Middle and Late Vendian should be identified as a period of stable reversed polarity.

At last we have a rare possibility to obtain a verifiable Precambrian geomagnetic polarity from such a long magnetostratigraphic sequence in a single region.

ANDEAN TECTONICS AND CHANGES IN THE DEPOCENTRE OF THE FORELAND BASIN (27°-33° S); MAGNETOSTRATIGRAPHIC CORRELATIONS

GUILLERMO H. RE and JUAN F. VILAS

Laboratory of Paleomagnetism "Daniel A. Valencio", Department of Geology, Pab. 2, Ciudad Universitaria, 1428 Nunez - Bs. As., Argentina

The Andean range system lies parallel to the Peruvian-Chilean Trench, which marks the zone of contact between the subducted ocean plate (Nazca Plate) and the continental plate (South American Plate). The geometry and position of the subducted plate are known from studies about the position of the seismic hypocenters, showing a tectonic segmentation of the Andean system in correlation with the segmentation present in the Nazca Plate.

The study area, between 27° and 31° S, is situated on a zone of low subduction angle. From a geotectonic point of view, the area can be divided into sectors: the West, which forms part of the backarcs and the East which characterizes the foreland zone. The backarcs region comprises the geological provinces of Cordillera Principal and the Cordillera Frontal, whereas the foreland region is formed by the Precordillera, the valley of the Bermejo River (which separetes the Precordillera from the Sierras Pampeanas), the Sierra de Famatina, and the Pampean Plain.

In the present work, a magnetic age was assigned to twenty sections of Miocene-Pliocene age, outcropping in the surroudings of the Sierras Pampeanas and the Precordillera, by using magnetostratigraphy obtained, together with other achieved by other authors, and from available geological and geochronological information. These sections, with widths ranging between 500 and 6500 m, and which form part of the Andean foreland basin, were correlated with the geomagnetic time scale, calculating in this way their chronological age thoroughly. Afterwards, the sedimentation rate for each section as well as the lithostratigraphic relations existing among the studies units were determined. The lithofacies variations and the widths deposited according to the time were analyzed. Finally, the paleogeographic evolution of the area was interpreted. To do this, a series of maps were drawn, showing the widths of the sediments deposited every 3 Ma (between 18 and 3 Ma). The magnetostratigraphic correlation enable us to see the presence of a strong diachronism in the spatial and temporal distribution of the lithofacies; this is connected with changes in the geographical position of the depocenter of the basin, and with the development of new basins formed by the outcrop of mountain barriers that fragmented the main basins.

From the analysis of the above mentioned maps, it is inferred that: **a**) the position of the main depocenter of the basin migrated from North to South, and back to North (between the towns of Las Juntas-Vinchina and Mogna-Huaco); and **b**) the sections of Rio Guanchin, La Troya and Corral Quemado would have behaved as an independent basin since the uplift of the Sierra de Famatina (12 Ma), remaining isolated from the rest of the Bermejo Basin from the moment that the Sierra de Toro Negro (approximately 5 Ma) ascended and the height of the Sierra de Famatina increased isolating the area from the rest of the sector of the basin and developing a depocenter, independent from the main basin.

PALEOMAGNETIC RECONSTRUCTION OF ANCIENT FLUID PATHWAYS IN PALEOZOIC PLATFORM CARBONATES (ARBUCKLE GROUP, SLICK HILLS, OKLAHOMA, USA)

HERBERT HAUBOLT

Paläomagnetiklabor Gams, Montanuniversität Leoben, Gams 45, A-8130 Frohnleiten, Austria

Owing to several phases of fluid/rock interaction, lapetan platform carbonates from the Cambro-Ordovician Arbuckle Group of the Slick Hills in SW Oklahoma carry a multiple component magnetization. Besides a Cambrian/Lower Ordovician depositional signal, Pennsylvanian, Permian, and Lower Jurassic magnetization components could be isolated.

Merely fine-grained lithofacies types (such as thin-bedded mudstones) partly preserved the depositional magnetization residing in detrital magnetite. However, coarse-grained lithofacies types (such as laminated grainstones) and also early-diagenetic dolomites were pervasively remagnetized during Pennsylvanian tectonic activity in the SW Oklahoma Aulacogen. Apparently, the magnetization of the sampled strata correlates with the ability of the rock bodies to transmit fluids. Some dolomite samples show bright orange luminescence that indicates Pennsylvanian late-stage dolomite recrystallization. During Pennsylvanian tectonism, reactive fluids that were expelled the rock sedimentary basins penetrated the rock bodies and caused magnetic mineral authigenesis.

This interpretation is supported by vertical NRM intensity trends with peak values within coarse grained or dolomitized strata. Thus, the NRM intensity of the Pennsylvanian magnetization covaries with fluid/rock ratios. These trends provide a semi-quantitative indicator of ancient fluid pathways.

Lower Arbuckle Group rocks (Fort Sill Formation, Bally Dolomite) carry a Pennsylvanian signal residing in authigenic magnetite, whereas upper Arbuckle Group rocks (Kinblade Formation), almost 1 km higher in the section, carry a Pennsylvanian overprint residing in authigenic hematite. Possibly, this difference reflects interaction of higher strata with more oxidizing fluids during uplift.

Lower Permian magnetization components do not correlate with particular lithofacies types or with carbonate mineralogy, yet they are absent from coarse-grained strata. Karst features suggest that these signals are the result of meteoric influence and tilt and before post-Permian burial.

Although during the Pennsylvanian time, the massive Bally Dolomite was an inportant fluid pathway, a pervasive Lower Jurassic magnetization resides in associated coarse-grained limestone beds (such as fossiliferous packstones). This magnetization is carried by authigenic magnetite and was acquired during burial diagenesis. Importantly, Pennsylvanian dolomite recrystallization and also compaction during post-Permian burial diagenesis had reduced the porosity of the massive dolomite. Therefore, other strata became preffered fluid pathways.

These findings indicate that paleomagnetic investigations can provide a tool to reconstruct the ability of rock bodies to transmit fluids and also their porosity development. Since many carbonate rocks (including the Arbuckle Group) contain hydrocarbons, paleomagnetic research can, thus, contribute to the assessment of reservoir quality.

PALEOMAGNETISM OF THE ARCTIC URALS: EVIDENCE FOR OROCLINAL BENDING

ALEXANDER G. IOSIFIDI, ALEXEI N. KHRAMOV and SERGEI A. PISAREVSKY

All-Russian Petroleum Scientific Research Geological Exploration Institute, 39 Liteiny ave., St. Petersburg 191104, Russia

The problem of arcuate structure's creation is one of the most importance for the study of fold belt evolution. It is most significant during the recover of the foredeep depression's history. The outer (with respect to platform) parts of these depressions are usually overlapped by overthrust folding structures. The foredeep depression of the Urals mainly hidden under Paleozoic and Precambrian allochthonous sheets is a good example. It is very important to understand to predict the mode and the size of the overthrusting in this region that shielded possible oil and gas bearing autochthonous strata on the eastern margin of the Foredeep. On the boundary between the Northern and Polar Urals we have an interesting feature: a bending of the general strike of the tectonic lines, such as fold axis and thrust fronts. Obvious questions arise here:

— is this bending primary or secondary;

— if it is secondary, is it a result of deformation of the thrust front or is it an intrinsic feature of the Urals' inner structure;

— is the bending related to the formation of the Pechora Basin;

— when did the bending occur?

The general strike of Uralian structures changes from south to north from a meridional direction to a south-western one at 64° N latitude. A paleomagnetic study of Permian and Triassic sediments of Arctic Urals was carried out to clarify the original position and shape of these structures. A total of 83 oriented hand samples were collected from classic sections of Permian and Triassic deposits along the Bolshaya Synya and Kozhim rivers. The collection from Bolshaya Synya has been kindly given to us by V.V. Kochegura (VSEGEI). The samples from the Kozhim River were sampled in 1993.

New paleomagnetic data for Permian and Lower Triassic rocks of Arctic Urals are obtained (Iosifidi & Khramov 1995). The analysis of all available data from this area and their comparison with paleomagnetic data from Russian Platform and Barentz-Pechora Area is carried out. New paleomagnetic pole positions for Lower Pean (31° N, 137° E, $\delta m = 7.9$, $\delta p = 5.4$), Upper Permian-Induan (15° N, 125° E, $\delta m = 17.5$, $\delta p = 10.6$) and Induan-Olenekian (21° N, 131° E, $\delta m = 6.6$, $\delta p = 4.1$) for studied area are presented. A conclusion about a clockwise rotation of the Arctic Urals since Early Triassic time by 28-45 degrees is made. These values are close to the angles of bending of tectonic axis in this area. The paleomagnetic pole positions suggest a 9-degree eastward shift (in recent coordinates) of the studied territory since Early Triassic with respect to Russian Platform.

A long time ago Rotay (1947) during his study of the Kozhim coal field investigated wave-cut signs and reached a conclusion that the structures of this territory in Permian times were parallel to the present Urals.

Indeed, the small circle intersecting the paleomagnetic poles is only 9 degrees apart (southward) from the mean Permian-Triassic pole of the Russian Platform calculated by Khramov (1991). This witnesses that the studied territory was situated to its present position with respect to the Russian Platform. It is possible that the whole lithospheric block including Timan-Pechora area and Polar Urals appeared as an indentor caused from one side by the secondary flexure of the fronts of the Uralian thrusts near the southern edge of this block with rotation of tectonic structures of this territory at 28°-45° with respect to the Russian Platform, and from other side by the dextral shift along the south-western edge of the Barentz-Pechora Plate and to secondary clockwise rotations of the Timan structures.

However the small value of displacement (9) as well as the almost insignificant difference of paleomagnetic pole calculated by Balabanov (Paleomagnetic derections and pole positions, 1971-1989) for rocks of the Tatarian stage, Permian in the Chernyshov Range (41° N, 163° E, $\delta m = 2.7$, $\delta p = 1.8$) from mean the Permian-Triassic pole for the Russian Platform 46° N, 162° E, $\delta m = 2.8$, $\delta p = 2$ (Khramov 1991), shows the necessity of new paleomagnetic investigations for checking of the proposed model.

References

Iosifidi A.G. & Khramov A.N., 1995: On Hercynian deformations in the Arctic Urals region from paleomagnetic data. *Fizika Zemli. Nauka*, 11, 48-54 (in Russian).

Rotay A.P., 1947: New data on coal-bearing strata of the southern part of Pechora basin. *Trudy GIN AN SSSR, Ugol. Ser.*, vip. 20, N2, 111-113 (in Russian).

Khramov A.N., 1991: Standard ranges of paleomagnetic poles for Northern Eurasian plates: connection with problems of paleogeodynamics on USSR territory. In: *Paleomagnetism and paleogeodynamics of USSR territory. L., VNIGRI*, 154-176 (in Russian).

Paleomagnetic directions and paleomagnetic poles (reference book for the USSR). Materials of WDC-B. Issue 1 - 1971, issue 2 - 1973, issue 3 - 1975, issue 4 - 1979, issue 5 - 1982, issue 6 - 1986, issue 7 - 1989 (in Russian).

PALEOMAGNETISM OF THE MONGOLIA - OKHOTSK BELT: KINEMATIC ASPECTS

VECHSLAV A. STARUNOV, ALEXANDER G. IOSIFIDI * and LOLIY E. SHOLPO

Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation, 2 Muchnoj per., St. Petersburg 191023, Russia

*All-Russian Petroleum Scientific Research Geological Exploration Institute, 39 Liteiny ave., St. Petersburg 191104, Russia

Paleogeodynamic investigations are particularly essential for the study of folding belts. At the present time many aspects of the development history of the Mongolia-Okhotsk fold belt situated in the conjugate zone of the East-Siberian and North-China lithospheric plates are discussed. This is connected first of all with the lack of knowledge of this region and the few data for paleogeodynamic reconstructions. One of the methods which allows us to produce quantitative estimates of horizontal movements of the lithospheric plates and blocks proved to be paleomagnetic one. New paleomagnetic data have been obtained for Silurian-Devonian (Starunov et al. 1996), Early Jurassic and Early Cretaceous rocks of South Mongolia.

New paleomagnetic pole position: Section one (lat. 43.7°, long. 103°) – S – D: 42.5° N, 308° E, A = 4.4 and 46.1° N, 267.6° E, A = 5.9; D ?: 14.1° N, 345.6° E, A = 7.4 and 36.8° N, 255.5° E, A = 7.8; D : 54.7° N, 267° E, A = 5.7. Section two (lat. 44.8°, long. 101°) – K: 62.8° N, 179.8° E, A = 2.6.

The analysis of all available determinations for Mongolia (Mc Elhinny M.W. & Jo Lock 1990) and their comparison with nearby tectonic units has been carried out. The studied area in Silurian and Early Devonian was situated in the subequatorial zone. Beginning from the Middle Devonian its progressive motion toward the north with simultaneous rotation counter-clockwise by 30-50 degrees are noticed. Paleolatitude movements of this area in respect to the nearest tectonic units (North-China Plate, Siberian Platform, Tarim Block and northern blocks of Mongolia-Okhotsk Belt) had the similar character. The minimum and maximum differences in paleolatitude position for the studied area were found in comparison with North-China Plate and Siberian Plate respectively. The relative paleolatitude displacements between those tectonic units were minimal on the Paleozoic and Mesozoic boundary. In that period, the connection between South Mongolia and North-China Plate happened. The further progressive motion of all the enumerated litospheric blocks toward the north caused gradual closing of the Asia paleoocean. Its complete closure took place during the Cretaceous.

Determinations of paleointensity were carried out on the basalts and samples from baked contacts. The method of Sholpo -Luzjanina make it possible to say that the studied minerals were created in the high temperature conditions. The method of Van Zijl-Kono and Wilson was used. The mean equatorial value for Devonian is 0.02 Oe.

References

Starunov V.A., Iosifidi A.G. & Sholpo L.E., 1996: Paleomagnetic Study of Paleozoic Ophiolites of South Mongolia. *Fizika Zemli. Nauka*, 1, 30-40 (in Russian).

Mc Elhinny M.W. & Jo Lock, 1990: Global paleomagnetic database project. *Physics of the Earth and Planetary Interiors*, 3, 1-6.

MAGNETIZATION PROCESSES OF PALEOZOIC ROCKS FROM THE NIEMCZA SHEAR ZONE AND GÓRY BARDZKIE (SUDETES, POLAND): PRELIMINARY RESULTS

MARIA JELENSKA[1],
MAGDALENA KADZIALKO-HOFMOKL[1],
TAHAR AIFA[2], JEAN-BERNARD EDEL[3]
and ANDRZEJ ZELAZNIEWICZ[4]

[1]Institute of Geophysics, Polish Academy of Sciences, Ks. Janusza 64, 01-452 Warsaw, Poland

[2]Géosciences-Rennes, Université de Rennes 1, Bt 15, Campus de Beaulieu, 35 042 Rennes cedex, France

[3]Institut de Physique du Globe, 5 rue Descartes, 67 084 Strasbourg cedex, France

[4]Institute of Geological Sciences, Polish Academy of Sciences, ul. Podwale 75, 50-449 Wroclaw, Poland

A suite of igneous, sedimentary and metamorphic rocks was sampled in the Niemcza shear zone, ductile sinistral fault which bounds the Polish Sudetes from the East, and from the South-Eastern part of the Góry Bardzkie where shales and greywackes of the Mlynów-Bardo assemblage outcrop.

The collection consists of granites and granodiorites radiometrically dated to 330-295 Ma, Upper Devonian sandstones and greywackes, Carboniferous schists, Lower Paleozoic schists and amphibolites, sampled at 28 sites.

Examination of polished sections under the microscope did not reveal any magnetic minerals in the metamorphic and sedimentary rocks. Some amount of pyrite and hydroxides were observed.

Thermal demagnetization of saturation IRM showed the presence of magnetite and hematite. In amphibolites, besides magnetite, the magnetic phase with an unblocking temperature of about 320 °C is seen, indicating the occurrence of pyrrhotite. Granites contain magnetite and hydroxides, seen under the microscope and confirmed by thermomagnetic analysis.

The routine paleomagnetic measurements were performed. Several components of magnetization were separated. Paleomagnetic poles calculated from these directions are shown in the figure (Fig. 1). Magnetization or remagnetization occurred in the Jurassic, Carboniferous and Devonian periods. Carboniferous poles show a hair-pin displaced to the East with regard to the APWP of Baltica, probably characteristic of the Sudetes. Besides two Devonian overprints of Lower Paleozoic rocks, two poles were found in Devonian sediments which fit the APWP. The other pole, with a positive fold test, also from Devonian sediments fit with APWP, after clockwise rotation of 125°.

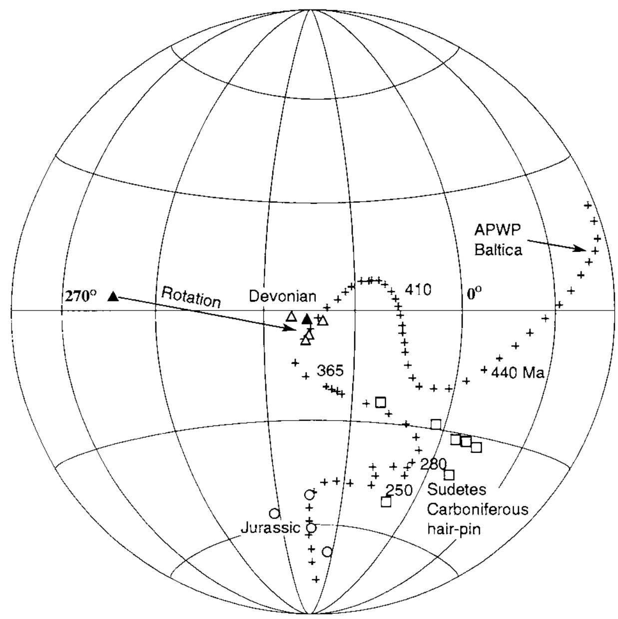


Fig. 1. Apparent polar Wander Path (APWP) for Baltica and positions of paleomagnetic poles found in investigated rocks.

Spatial distribution of these magnetization processes can be seen. They reflect a complex magnetic and deformation history of the Eastern Sudetes supported by magnetic anisotropy study as well.

EVOLUTION OF THE MONGOL-OKHOTSK OCEAN WITH NEW PALEOMAGNETIC DATA FROM THE GEOSUTURE ZONE

VADIM A. KRAVCHINSKY[1],
MIKHAIL I. KUZMIN[2], ANDREY A. SOROKIN[3]
and NINA A. TRUSTCHEVA[4]

[1]VSNIIGGIMS Geological Commity of Russia and Institute of Geochemistry SB RAS, 664033 Irkuts, Russia

[2]Institute of Geochemistry SB RAS, 664033 Irkuts, Russia

[3]International Geological Laboratory, 675006 Blagovestzhenk, Russia

[4]GGP Chita-geologia, 672090 Chita, Russia

The Mongol-Okhotsk geosuture stretches over 3000 km along the south-western boundary of the Siberian Platform from the Udsky Gulf of the Okhotsk Sea through Eastern Trans-Baikalia up to Central Mongolia. The Mongol-Okhotsk fold belt was formed during the closure of the Paleo-Tethys ocean and collision and suturing of a number of blocks and

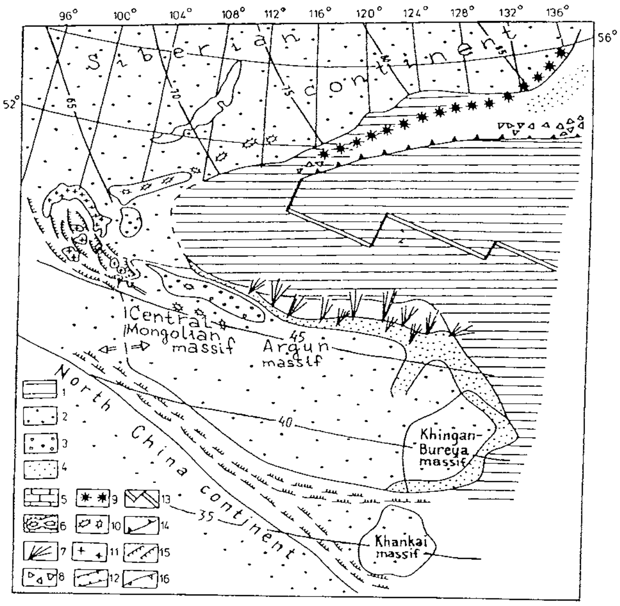


Fig. 1. Palinspastic of the Mongol-Okhotsk belt for the Late Triassic. Modified after Zonenshain et al. (1990). **1** — oceanic floor; **2** — dry land; **3** — continental depression; **4** — shallow water sediments; **5** — limestone; **6** — barrier reef; **7** — fan deposite; **8** — chaotic rocks; **9** — calc-alkaline volcanics; **10** — intraplate volcanics; **11** — granite batholith; **12** — graben; **13** — spreading axis; **14** — subduction zone; **15** — collision zone; **16** — main thrust.

microplates to Eurasia. Bordering the geosuture, to the southeast is the North-China Block, Khingano-Burein, Central-Mongolian and Argun blocks, to the soutwest the Tarim and Jungar blocks, and to the north the Siberian Platform with the Tuva-Mongolian Block, Saian-Baikal fold belt, Western Trans-Baikalia and Stanovy Ridge. The relative position of some of these blocks during the Paleozoic-Mesozoic and their accretion and collision ages has been constrained using paleomagnetism and geology (Parfenov 1984; Zonenshain et al. 1990; Enkin et al. 1990; Zhao et al. 1990; Pruner 1992 and others). Some of us have published results of paleomagnetic study within the junction zone, which before have never been analysed (Kravchinsky 1990; Kravchinsky 1995; Kuzmin & Kravchinsky 1996). We chose for this study well dated paleontological suites from Early Carboniferous to Late Jurassic. Suites of the same age were sampled toward north and south of Mongol-Okhotsk fold belt. The suites' localities are Western and Eastern Trans-Baikalia and the Amur province of the Far East region (2000 km segment of Mongol-Okhotsk geosuture).

The available data permit paleomagnetic reconstructions of the Trans-Baikalian and Argun blocks of the complex Mongol-Okhotsk folded area. We also used available geological data. During the beginning of Carboniferous the Argun microblock was separated from Inner Mongolia and the North-China Block (paleolatitude I = 21°). In the Late Carboniferous-Early Permian, the Argun and Central Mongolian blocks (Amuria) were amalgamated with Inner Mongolia (I = 20°). The studied area migrated nortwards with the composite China Block. Western Trans-Baikalia belonged to the Siberia continent at leats from the Late Permian (Kravchinsky 1990). The Mongol-Okhotsk ocean was closed gradually from the west to the east. This happened at the end of the Late Jurassic in the Eastern Trans-Baikalia, and at the beginning of the Early Cretaceous in Amur province (Far East region).

Reference

Enkin R.J., Yang Z., Chen Y. & Courtillot V., 1992: Paleomagnetic constraints on the geodynamic history of the major blocks of China from the Permian to the Present. *J. Geophys. Res.*, 97, 13953-13989.

Kravchinsky V.A., 1990: Horizontal movements of tectonic blocks of the Mongol-Okhotsk geosuture. In: *Present geophysical investigations of the Eastern Siberia. Publ. House "Eastern Siberian Pravda"*, Irkutsk, 102-105 (in Russian).

Kravchinsky V.A., 1990: Paleomagnetism of rocks of Mongol-Okhotsk geosuture. In: *Publications of the IGCP projects. Nos. 224 (report N6) and 283 (report N1).* Novosibirsk, 146-148.

Kravchinsky V.A., 1995: Paleomagnetism of rocks of Mongol-Okhotsk fold belt. *PhD dissertation, Irkutsk State Technical University*, 1-181.

Kuzmin M.I. & Kravchinsky V.A., 1996: First paleomagnetic data for Mongol-Okhotsk fold belt. *Russian Journal of Geology and Geophysics*, 1, in press.

Parfenov L.M., 1984: Continental borders and island arcs of Mesozoid of the North-East Asia. *Nauka*, Novosibirsk, 1-182 (in Russian).

Pruner P., 1992: Paleomagnetism and paleogeography of Mongoli in the Cretaceous, Permian and Carboniferous — final report. Physics of the Earth and Planetary Interiors. *Elsevier*, Amsterdam, 70, 169-177.

Zonenshain L.P., M.I. Kuzmin M.I. & Natapov L.M., 1990: Tectonics of lithospheric plates of the territory of the USSR. Part 1. *Nedra*, Moscow, 1-328 (in Russian).

PALEOMAGNETISM OF TRIASSIC LIMESTONES FROM THE SILICA NAPPE, SLOVAK KARST — TECTONIC IMPLICATIONS

JADWIGA KRUCZYK[1], MAGDALENA KADZIALKO-HOFMOKL[1], IGOR TÚNYI[2], PAVOL PAGÁČ[2] and JÁN MELLO[3]

[1]Institute of Geophysics, Polish Academy of Sciences, Ks. Janusza 64, 01-452 Warszaw, Poland

[2]Institute of Geophysics, Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic

[3]Slovak Geological Survey, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic

The present study is a continuation of our investigations performed on the Middle-Upper Jurassic rocks from the inversion periods exposed in various regions of the stable and orogenic Europe, including Slovakia. The published results of Márton et al. (1991) and private information from Mock and Channel (1993), concerning Triassic sediments from the Slovak Karst show that in these rocks a reversed component of remanence appears along with the normal one. Therefore we decided to investigate these rocks in order to see whether this reversed component represents a Triassic field reversal (or reversals) and may be applied to the magnetostratigraphic study and tectonic reconstructions of the region. Speciments were sampled in the six limestone outcrops situated within the Silica Nappe (Norther part of the Pelso Unit) on two sides of the Plešivec-Scytnik fault trending NNW-SSE: Silicka Brezowa

SB (Norian), Čoltovo C (Upper Anisian-Lower Ladinian) and Silica S (Lower Ladinian) — on the eastern side of the fault, Hrušovo H (Ladinian), Drienčany D (Upper Ladinian) and Budikovany B (Ladinian) — on its western side. The SB exposure was sampled for the purpose of magnetostratigraphic research. The sampled profile corresponded to the lowest (about 10 m) of the profile sampled by Mock and Channel where two reversed and two normal zones seemed to appear (private communication). Our results obtained after thorough analysis of demagnetization experiments do not support this idea. All specimens along the whole sampled profile reveal the same demagnetization pattern: a strong normal component with the in situ NW declination isolated in the temperature range of 150-400 °C and a weak reversed component with E declination isolated in the temperature range of 450-600 °C are present in all specimens. This pattern was observed only in the SB. In four other exposures only normal components of remanence were obtained, one exposure (B) did not give any results. The incremental fold test applied to the mean normal components from the five exposures revealed their best grouping for the 25 % unfolding. The mean normal direction (see Tab. 1) agrees well with the data in Márton et al. (1991). The results obtained here were compared with directions expected in the sampled area under the assumption of its African affinity. Comparison of our N result with the expected "African" data (the expected "African" direction for the Lower Cretaceous: D = 357, I = 52; for the Lower Tertiary: D = 0, I = 54) shows agreement of its inclination with the "African" one for the Upper Cretaceous-Lower Tertiary. Declinations differ by about 30° implying post-Cretaceous CCW rotation of the Silica Nappe. The inclination of the reversed component after full bedding correction is close to the "African" one for the Upper Triassic-Lower Jurassic (the expected "African" direction for the Upper Triassic: D = 343, I = 45; for the Lower Jurassic: D = 339, I = 51). Declinations differ by about 70° implying CCW rotation of the Silica Nappe after the period of magnetization. Summarizing, the results presented here suggest that the Silica Nappe underwent two CCW rotation episodes: post-Lower Jurassic by about 40° and post-Lower Tertiary by about 30°. This pattern is indicated in Márton & Fodor (1995) and Márton et al. (1995). Magnetic susceptibility of the studied limestones is very weak due mainly to paramagnetic and diamagnetic minerals. Nevertheless directions of maximum axes for the SB anisotropy ellipsoid (D = 313, I = 25, in situ) seem to reflect a tensional regime with the tension direction trending SW, as shown in Márton & Fodor (1995).

Table 1: Paleomagnetic directions for the Triassic limestones from the Silica Nappe.

Loc/age	n	Dbbc	Ibbc	α	k	Dbc 25%	Ibc 25%	α	k	Dabc	Iabc	α	k	Pol
SB Norian	101	311	61	2	37	307	59	3	37	293	50	2	37	N
SB Norian	69	98	-69	5	12					**89**	**-54**	5	12	R
S l.Lad.	23	329	63	6	30	320	51	6	31	332	17	8	14	N
C u.Anis. -l.Lad.	17	303	58	11	12	327	55	11	12	1	22	11	12	N
H Ladin.	18	323	25	4	80	326	36	4	80	358	65	4	80	N
D Ladin.	19	322	42	9	14	315	42	9	14	293	37	9	14	N
Mean Normal	5	318	50	16	22	**319**	**49**	**10**	**56**	322	42	33	6	N

Loc/age — Locality/age of the rocks; l.Lad — Lower Ladinian; u.Anis. — Upper Anisian; Ladin. — Ladinian; n — number of entries; Dbbc, Ibbc — declination and inclination before bedding correction; Dbc 25 %, Ibc 25 % — bedding correction with 25 % untilting; Dabc, Iabc — after bedding correction; α, k — Fisher parameters; Pol — polarity. Final data in bold.

References

Márton P., Rozložník L. & Sasvári T., 1991: Implications of a paleomagnetic study of the Silica Nappe, Slovakia. *Geophys. J. Int.*, 107, 67-75.

Márton E., Vass D. & Túnyi I., 1995: Upper Tertiary rotations of Pelso Unit and adjacent Central Western Carpathians. *Knihovnička ZPN*, 16, 97-108 (in Slovak).

Márton E. & Fodor L., 1995: Combination of paleomagnetic and stress data — a case study from North Hungary. *Tectonophysics*, 242, 99-114.

A NEW DEVONIAN PALEOMAGNETIC POLE FOR THE SOUTHERN PART OF THE RUSSIAN PLATFORM AND ITS GEODYNAMICAL IMPLICATION

NINEL MIKHAILOVA and MARINA ORLOVA*

*Institute of Geophysics of National Academy of Sciences, Palladin av. 32, 252680 Kiev 142, Ukraine

The Donets Basin Devonian consists of the Middle and Upper division deposits subdivided into the suites (upwards): Nikolaevian (Middle Devonian), Antonovkian (Middle-Upper Devonian), Dolgian, Razdolnian (Upper Devonian) (Aizenverg & Lagutin 1974).

Lithologically, the Devonian stratigraphic sections consist of sandstones, limestones, mudstones, conglomerates, tuffs and volcanic rocks of various compositions laying almost horizontally with a small incination (10-20°) northward.

The sedimentary and the majority of volcanics rocks were oriented in the bedding plane (step 1-10 m). Two sections (the first near village Razdolnoe, the total thickness 232 m and the second near village Nikolaevka, 384 m) were investigated.

The specimens were treated thermally (up to 600-700 °C with steps 50-100 °C), by alternating field (up to 150 mT with steps 5-10 mT) or by acid leaching (HCl, up to 1032 h with steps 24 h); combinations of the tecniques (AF + T, HCl + T) were also tried.

The NRM directions remaining after each demagnetization step were analyzed using the Zijderveld orthogonal vector projections. The magnetic minerals were identified by the rock magnetic and microscopic methods.

The main characteristic components of the magnetization are as follows:

1. The soft component **C** is directed along the present geomagnetic field.

2. The hard (AF, 70 mT + T °C, 500-600 °C; volcanic rocks) and soft (AF, 0-20 mT; T °C, 20-300 °C; sedimentary rocks) component **B** (R-polarity). After the tilt correction the **B** components in the both sections are similar. The statistical tests as well as magneto-mineralogical analysis demonstrate the secondary origin of this component. The mean directions and the paleomagnetic pole (southern) (D = 222°, J = −22°, Lat. = −39.6°, Long. = 339°, Θ_1 = 3.30°, Θ_2 = 1.74°) agree well with the mean directions of other Permian Units of the Donets Basin.

3. The hard components **A1** and **A2** (N and R-polarity) (T °C, 20–500° or 350-600°; sedimentary rocks and 20-450° or 20-700°; volcanic rocks) is interpreted as having been ac-

quired during deposition. The mean directions and the paleomagnetic pole for **A1** and **A2** components are as follows:
(Eifel-Givetian **A1**: (D = 290°, J = 1°, Lat. = 13.7°, Long. = 293°, $\theta_1 = 4.64°$, $\theta_2 = 2.32°$).
Famenian **A2**: (D = 211°, J = -5°, Lat. = -37.6°, Long. = 357,° $\theta_1 = 2.96°$, $\theta_2 = 1.48°$).

The paleomagnetic poles **B** and **A2** roughly coincide with the apparent polar wander path for Baltica (Lewandowski 1993) though the age of 315 Ma for the pole **A2** on the APWP does not match the Famenian age of the investigated rocks and their stratigraphical position.

The significant north-westwards departure of the paleopole **A1** from the Eifel-Givetian APWP may be attributed to the 65° anticlockwise rotation around the Eulerian pole located at the point (50° N/39° E). Such a rotation places the **A1** pole at the Eifel-Vizean part (point 360 MA) of the APWP. This interpretation does not contradict the geological insight into the Dnieper-Donets paleorift formation (Chekunov 1994).

References

Aizenverg D.E & Lagutin P.K., 1974: The Donets Basin. *Stratigraphy of the Ukrainian SSR*, Kiev, 4, 2 (in Rusian, English summary).

Chekunob A.V., 1994: On geodynamics of Dnieper-Donets rift-syneclise. *Geophysical Journal.Publ. of the Inst. of Geophys.* UAS. (in Russian, English summary).

Lewandowski M., 1993: Paleomagnetism of the Paleozoic rocs of the Holy Cross MTS (central Poland) and the origin of the Variscan orogen. *Publications of the Institute of Geophysics Polish Academy of Sciences*, A-23, 1-265.

PALEOMAGNETIC STUDY OF THE TUNAS FORMATION IN SIERRA DE LA VENTANA, ARGENTINE

RENATA N. TOMEZZOLI and JUAN F. VILAS

Laboratory of Paleomagnetism "Daniel Valencio",
Department of Geological Sciences, University of Buenos Aires,
Consejo Nacional de Investigaciones Científicas y Técnicas.

The Sierras Australes de la Provincia de Buenos Aires (Sierra de la Ventana) are located between 37-39° S and 61-63° W and constitute a northwest trending orogen more than 180 km long and approximately 60 km wide. This system was traditionally considered as the prolongation of the Cape System in South Africa.

Several hypothesis about the age of the Sierras Australes deformation have been proposed. Some authors date it in the Triassic, others in the Upper Permian, and some in the Lower Permian.

The paleomagnetic study of this region may contribute to definining more accurately the APWP (apparent polar wandering path) of South America during Paleozoic time. This will have very important implications for understanding the paleogeographic and geodynamic evolution of this orogen, and will clarify the tectonic relations with other continental blocks.

The Tunas Formation consists of gray to greenish sandstones, claystones, and red and violet shales which become more abundant to the top. They were deposited in a shallow shelf to littoral and eolian environment during the Permian-Triassic.

We present results from 12 sites of the Estancia San Carlos locality. Four hand samples or six drilled cores were collected at each site.

In order to determine the stability of the NRM (Natural Remanant Magnetization), the samples were demagnetized with AF and thermal processes. Only the second method was effective. It was applied with 50 to 100 °C intervals until 750 °C when the NRM was virtually destroyed or the sample was chemically altered.

The magnetic behaviour of the specimens was uniform. Components with low unblocking temperatures (less than 500 °C) and negative inclinations possibly correspond to secondary remanent magnetizations. They have a random distribution. Another component, very stable, with positive inclinations directed to the SE (azimuth 110-155°, in situ), was defined between 550 and 750 °C. The high temperatures of this component indicate that the main carrier of the magnetization is hematite.

The mean site directions of the high temperature component show a very good within-site consistency (<15 %).

Application of the stepwise fold test show a better agreement of directions 15 % of structural correction. This implies that the magnetization is either late tectonic or postectonic. The exclusive reversed polarity suggests that the age of the remanence corresponds to the reverse Kiaman Superchron.

The paleomagnetic pole (lat: -59.5, long: 12.5. N = 12. α_{95} = 10) is consistent with the Early Permian mean pole for the western Gondwana.

According to the paleomagnetic data deformation of the Sierras Australes must have occurred in the upper part of the Lower Permian.

ROCK MAGNETIC INVESTIGATIONS IN THE ST-MALO DYKE SWARM (BRITTANY, FRANCE): THE EMPLACEMENT MECHANISM OF DOLERITE INTRUSIONS

TAHAR AIFA and JEAN-PIERRE LEFORT

Géosciences-Rennes, Université de Rennes 1, Bt 15,
Campus de Beaulieu, 35042 Rennes cedex, France

A high quality aeromagnetic survey has recently been completed in northern Brittany. Because of the narrow line spacing and shallow flight elevation, it has been possible to apply the shaded relief technique. On this document, one can see that the whole dyke swarm is fanning at its northern and southern ends. The dyke swarm itself is also affected by N50 sinistral transcurrent faults. After restoration of these offsets, the full structure trends in a N-S direction. The magnetic mapping does not show isolated dykes but rather groups of closely spaced intrusions. Only one third of the known dykes are evidenced by magnetism. Gravity and magnetic modelling shows that this swarm rests over a magmatic chamber. In section, anisotropy of the magnetic susceptibility (AMS) suggests that the dykes display a fanning magmatic flow. This study has been conducted over 308 specimens randomly distributed (figure). The Kamb's equal-area contouring projections

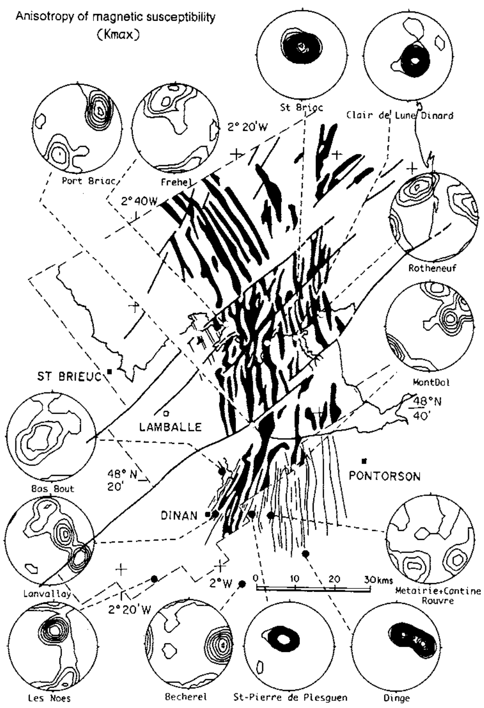


Fig. 1. St-Malo dyke swarm using shaded relief technique after restauration of N50 sinistral transcurrent faults.

method has been used to plot the minimum and maximum axes of the triaxial ellipsoid of magnetic susceptibility magnitude. One can observe three different directions for maximum AMS contouring: (1) a vertical direction related to the magma flow, (2) a N50 direction and (3) an E-W direction close to an E-W mylonitic zone.

Far from the sinistral strike-slip faulting, the flow seems to be vertical as supported by the K_{max}, while it seems to be related to the regional stress component when it is close to the faults. In this case, it is mainly parallel to the faults direction (N50 or E-W). We can also observe that, when K_{max} is vertical it is located just above the magmatic chamber. However, we do not know if we are dealing here with a single N-S elongated magmatic chamber or with two small ones.

A detailed transverse study of the St-Briac dyke reveals that the main carrier of magnetization is magnetite, but some maghemite is sometimes present. The different size of magnetite may be recognized in thin sections. They are between 80-650 μm and 45-80 μm in size, respectively in the center and the borders, 15-50 μm in the borders. This is in agreement with: (1) the high remanent magnetizations and the high susceptibilities in the center, while they are weak in the rims and (2) thermomagnetic curves.

The emplacement of this Lower Carboniferous dyke swarm could have been contemporaneous with the N50 shears which displaced its central part by 20 km. The E-W oriented fault probably acted during Late Carboniferous times.

GEOPHYSICAL EVIDENCE FOR THE EXISTENCE OF A MAGMATIC CHAMBER BENEATH THE ST-MALO DYKE SWARM (BRITTANY, FRANCE). IS THERE A RING DYKE COMPLEX ON TOP OF IT?

JEAN-PIERRE LEFORT and TAHAR AIFA

Géosciences-Rennes, Université de Rennes 1, Bt 15,
Campus de Beaulieu, 35042 Rennes cedex, France

A circular magnetic structure, using the shadow relief technique, has been evidenced beneath the western part of Dol marsh (Northern Brittany, France). This image is based on the processing of the data collected during the aeromagnetic survey of the British island gulf (elevation: 150 m; spacing of the lines: 250 m). This structure is superimposed and apparently associated with the Lower Carboniferous dyke swarm known in the area. It is also responsible for a weak gravity high. Potential field studies of the high frequencies related to the circular body, suggest that it may represent a ring-dyke structure. Geochemical and petrographic studies show that the dykes are free of crustal contamination and suggest that a magmatic chamber should exist at depth. Gravity and magnetic modelling clearly demonstrate that the total volume of the dykes is not enough to create the anomalies recorded at the surface. A 15 × 12 km body with a density contrast of 0.015 g/cm^3 and a magnetic susceptibility contrast of 0.004 SI, topping at 2 km depth, is necessary to create these anomalies. This burried body is considered to represent the magmatic chamber. Measurements of the anisotropy of the magnetic susceptibility over the whole dyke swarm, in 13 sites (308 samples) demonstrate that 4 of them are characterized by a vertical K_{max} (Maximum anisotropy). These four samples are located at the center of the dyke swarm and in the middle of the magmatic chamber when seen in plan view. The K_{max} values are interpreted as associated with a steep magmatic flow. The close spatial relationship which exists between the possible ring-dyke complex, the dolerite dyke swarm and the calculated magmatic chamber suggest that the annular structure is the result of a collapse of the upper crust in the magmatic chamber. Calderas which may have existed at the surface are now eroded since the top of the neighbouring Variscan granites which intruded later is now at the surface.

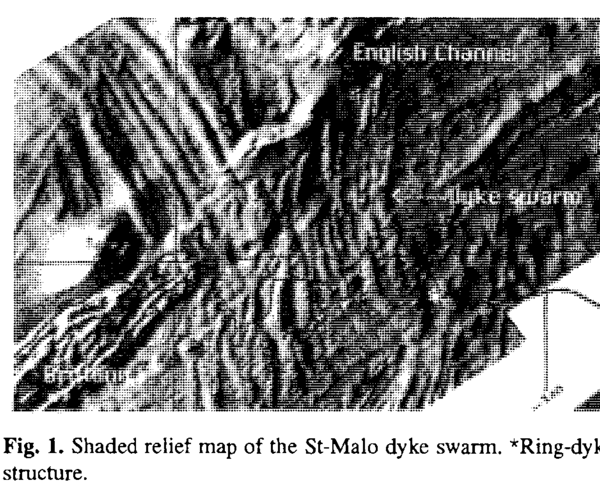


Fig. 1. Shaded relief map of the St-Malo dyke swarm. *Ring-dyke structure.

MAGNETIC ANISOTROPY AND MEAN SUSCEPTIBILITY OF ROCKS FROM THE MAIN KTB BOREHOLE UNDER INHOMOGENEOUS PRESSURE CONDITIONS

ALEŠ KAPIČKA[1], EDUARD PETROVSKÝ[1], FRANTIŠEK HROUDA[2] and JEAN POHL[3]

[1]Geophysical Institute, Academy of Sciences, Boční II/1401, 14131 Praha 4, Czech Republic
[2]AGICO Ltd., Ječná 29a, Brno, Czech Republic
[3]Institute of Geophysics, University of München, Theresienstr. 41a, 80333 München, Germany

Investigation of the magnetic parameters of rocks from deeper layers of the Earth's crust was one of the aims of the Continental Deep Drilling Project (KTB). Magnetic properties are influenced by various physical factors, among which temperature is the most significant in depths corresponding to the Curie temperature of the mineral in concern. In the case of shallower strata (6-7 km in the KTB borehole), stress field plays the most important role. Laboratory investigations of pressure-induced changes of the magnetic parameters of the KTB samples are therefore necessary in order to constitute an actual image of the depth profile of these parameters. Moreover, results of such studies can be helpful in for example interpreting changes of geomagnetic field measured along the borehole (Fiedberg & Kuhnke 1994).

Experimental results retrieved till now suggest the crucial effect of external deviatoric stress on magnetic parameters and their anisotropy. On the other hand, magnetic parameters proved to be comparatively stable upon the action of hydrostatic pressures (Kapička 1990).

This study investigated a set of samples collected from the following KTB main borecores: H001-H007, H010, H012-H014, H016, H019, H023-H025 and H034. The samples represent the main lithological units of the KTB borehole (gneiss, metabasites) and with the exception of a few samples, in which magnetite is the main remanence carrier, the dominant magnetic phase is pyrrhotite (Schuman et al. 1993). Pyrrhotite is primarily present in its monoclinic (ferrimagnetic) phase. However, rarely (sample H034) a hexagonal (antiferromagnetic) phase of pyrrhotite alone was identified and some samples contained a mixture of the above two phases (deWall et al. 1995).

Pressure-induced changes of low-field (300 A/m) magnetic susceptibility due to uniaxial pressure were measured using a special pressure chamber in pressures up to 60 MPa. The measurements were carried out on a KLY-2 Kappabridge, equipped with special large pick-up coils. On the basis of values of 15 directional susceptibilities, a susceptibility tensor was calculated, corresponding to the pressure applied. In order to evaluate the pressure-stability of magnetic susceptibility and its anisotropy, coefficients of stress sensitivity β_{par} and β_{per} were calculated, being associated with the susceptibility parallel or perpendicular to the pressure direction, respectively. In addition, depth profiles of changes of anisotropy parameters (anisotropy degree dP, lineation dL and foliation dF) and mean susceptibility dκ caused by constant pressure of 60 MPa were constructed.

Our measurements revealed significant pressure-unstable behaviour of metabasites from a depth of 4686 m ($\beta_{par} = 1.36 \times 10^{-3}$ MPa^{-1}). Changes in the anisotropy degree P induced by 60 MPa pressure are significant (dP = 9 % of the initial value). This unstable behaviour is due to the presence of pressure-unstable magnetite, which was found to be the dominant magnetic mineral in these depths. Magnetite-bearing rocks show typically high values of β_{par}, while those of β_{per} are consider-

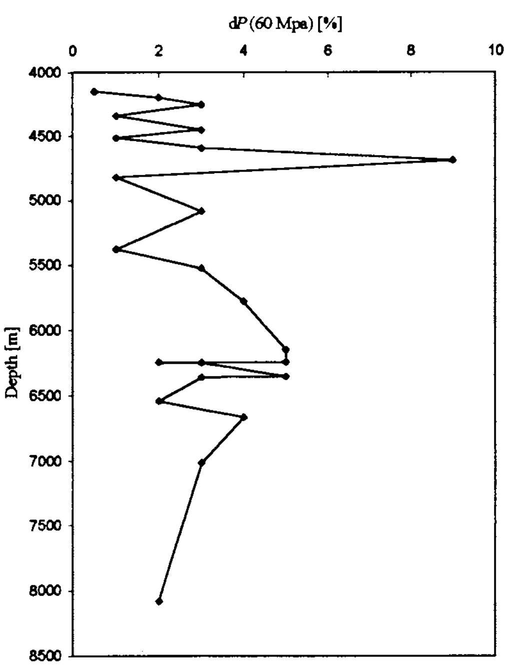


Fig. 1. Depth profile of pressure-induced changes in the anisotropy degree P. The pressure applied was 60 MPa.

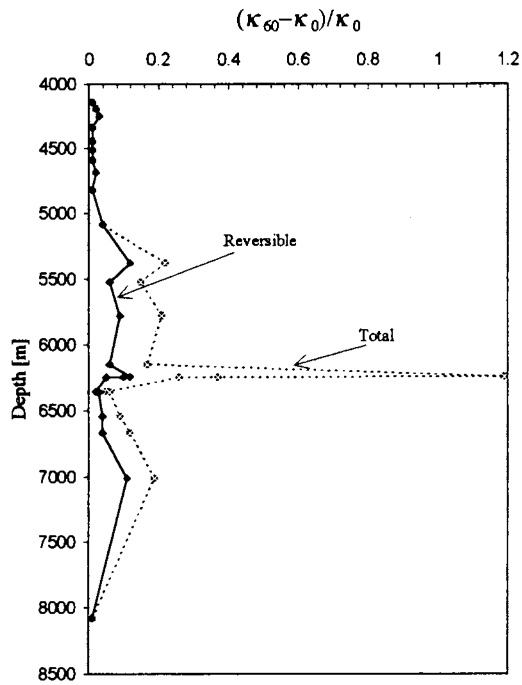


Fig. 2. Depth profile of changes in mean magnetic susceptibility κ_{mean} induced by uniaxial pressure of 60 MPa.

ably smaller. On the contrary, rocks containing only, or predominantly (monoclinic) pyrrhotite (depths from 4149 down to 5083 m) show very stable behaviour under inhomogeneous pressure conditions, with $\beta_{par} = 0.10\text{-}0.5 \times 10^{-3}\,MPa^{-1}$. Changes in the anisotropy degree vary within 0-3 % of the initial value (Fig. 1).

Both gneisses and metabasites from the deepest (5200 down to 6245 m) strata showed completely unusual pressure behaviour. Measurements of temperature dependence of magnetic susceptibility proved that the unstable samples from the above mentioned depths contain both ferrimagnetic (monoclinic) and antiferromagnetic (hexagonal) phases of pyrrhotite. Despite the fact that these samples contain predominantly pyrrhotite, they show very unstable behaviour, the stress sensitivity coefficients reaching values even higher than those for magnetite-bearing rocks. Moreover, the β_{par} coefficient showed negative values, i.e. deviatoric pressure brings about significant increase (both reversible and irreversible) of all the directional susceptibilities. As a result, increase in the mean susceptibility was observed. The depth profile of mean susceptibility κ_{mean} corresponding to uniaxial pressure of 60 MPa is depicted in Fig. 2. Samples from depths down to about 5200 m, as well as those from the deepest layers show stable behaviour of mean susceptibility. On the other hand, samples from depths between 5200 and 6245 m show very unusual behaviour, with significant pressure-induced increase in κ_{mean}. This increase of 20-120 % of the original value is to a great extent of an irreversible nature; however, a small reversible contribution was observed as well.

It was found that pressure-induced increase of κ_{mean} is most significant at pressures up to 20 MPa, while the higher pressure values yielded significantly smaller increases with magnitude corresponding to the reversible contribution of the mean susceptibility changes.

Systematic studies of rock samples from the main KTB borecores suggest that magnetic anisotropy is pressure-unstable in rocks containing magnetite and in rocks from depths between 5200 and 6245 m, containing pyrrhotite. In the latter case, significantly unstable behaviour of mean susceptibility was observed, the phenomenon being unknown in the samples from the pilot KTB borehole (Kapička et al. 1996).

It is evident that the observed behaviour cannot be interpreted in terms of magnetomechanical effect only. Magnetomechanical effect, upon action of uniaxial pressure, yields systematic changes in magnetic susceptibility, the changes being different in different directions. As a result, anisotropy of susceptibility changes, but mean susceptibility remains practically constant, or can slightly decrease, as shown in samples containing (titano)magnetites (Kapička 1990). The behaviour reported in this study can be caused by the ferrimagnetic phase of pyrrhotite itself, or can reflect a pressure-induced local transformation of antiferromagnetic pyrrhotite to the ferrimagnetic one. Further experiments are in progress in order to highlight this phenomenon.

References

deWall H., Friedrich G. & Kontny A., 1995: Magnetomineralogische untersuchungen an naturlichen Pyrrhotinen. *Report DFG Wa 1010/1/1. KTB Feldlabor* (in German).

Fiedberg F. & Kuhnke F., 1994: The increase in the total magnetic field in the KTB pilot and main drillhole. *Scientific Drilling,* 4, 139-145.

Kapička A., 1990: Variations of the mean susceptibility of rocks under hydrostatic and non-hydrostatic pressure. *Phys. Earth Planet. Inter.,* 63, 78-84.

Kapička A., Petrovský E. & Pohl J., 1996: Magnetic anisotropy of the KTB pilot borehole rocks under in situ stress conditions. *Scientific Drilling* (in print).

Schumann R., Pohl J. & Soffel H.C., 1993: A preliminary rock magnetic log of cuttings from the KTB Hauptbohrung (0-7200 m). *KTB Report, Hannover,* 93, 2, 335-336.

REGIONAL REMAGNETIZATION AND ORE DEPOSITS IN THE SOUTHERN BORDER OF THE FRENCH MASSIF CENTRAL

HENRI ROUVIER[1], BERNARD HENRY[2] and MAXIME LE GOFF[3]

GDR "Magnétisme des Roches" of the CNRS, 4 avenue de Neptune, 94107 Saint-Maur cedex, France

[1]Laboratoire de Géologie Appliquée of the PARIS VI University

[2]Institut de Physique du Globe de Paris

[3]Ecole Normale Supérieure

Paleomagnetic studies have been carried out in the ardéchoise area, in the southern border of the French Massif Central. The samples have been taken in different sites, mainly in Triassic to Liasic formations more or less close to ore deposits of Mississippi Valley Type (MVT), and from two deep holes (Balazuc and Morte-Meyrie) of the "Géologie de la France profonde" program (from Permo-Carboniferous to Liasic levels).

A magnetic overprint has been observed in all the samples, except those from argilitic fine grained rocks. This indicates that the overprint is of chemical origin, therefore related to fluid migration. Ore deposits of MVT type are also related to fluid migration, and the remagnetization is very likely connected with the ore deposition (only for a part of this ore if several phases of deposition occurred).

The overprint is always of normal polarity. This suggests either an acquisition age during a long period of normal polarity like the Aptian-Santonian, or a relatively short duration of acquisition, though the regional importance of this event.

The scattering of the paleomagnetic directions of this magnetic overprint is relatively important, before and after tilt correction. However, the part of these directions which have been obtained in sites from horizontal formations are well grouped. A progressive unfolding applied to the other sites clearly shows a good coherence for intermediate tilt correction. The mean direction associated with this intermediate untilting is in very good agreement with the mean direction from horizontal levels. It is well known that different phases of tilting occurred in this area, and this "syntectonic" remagnetization probably corresponds to a period between two tectonic events. Therefore determination of the age of the magnetization yields the percentage of tilting which occurred before this age. The structural interest of such a determination is important in this tectonically complicated zone.

The comparison of the paleomagnetic pole associated with this remagnetization with the APWP for stable Europe shows a nice coincidence for an Eocene-Oligocene age.

THE PLIOCENE TRUBI MARLS AT PUNTA DI MAIATA (SOUTHERN SICILY): A SECONDARY MAGNETIZATION CARRIED BY IRON SULPHIDES?

JAUME DINARÈS-TURELL,
MARK J. DEKKERS, COR G. LANGEREIS
and A.A.M. VAN HOOF

Paleomagnetic Laboratory 'Fort Hoofddijk',
Faculty of Earth Sciences, University of Utrecht, Budapestlaan 17,
3584 CD Utrecht, Netherlands

The Punta di Maiata cliff on the southern coast of Sicily forms, in conjunction with other exposures along the coast (Eraclea Minoa, Capo Rossello, Lido Rossello, Punta Grande and Punta Piccola), the so called Rossello composite stratigraphic section (Hilgen 1987; Langereis & Hilgen 1991) which has become a key reference section for the Mediterranean Early to early Late Pliocene. It ranges from below the Thvera Subchron into the Matuyama Chron (4.86-2.45 Ma), including the Zanclean neostratotype and the Miocene-Pliocene boundary, (Hilgen & Langereis 1988; Langereis & Hilgen 1991). All these exposures belong to the piggyback and thrusted Caltanissetta Basin located on the external side of the Calabro-Sicilian arc.

Original high-resolution magnetostratigraphy coupled with biostratigraphy (planktonic foraminifera) and cyclostratigraphy at Punta di Maiata (Langereis & Hilgen 1991; Hilgen 1991) was carried out on the western side of the cape following a trajectory from the beach up to the cliff. That study revealed a characteristic remanent magnetization (ChRM) residing in single domain (SD) magnetite (van Velzen & Zijderveld 1990) although at the lowermost 4-5 m of the section, unblocking temperatures were lower, around 350 °C or somewhat higher. In the Punta di Maiata section the Trubi marls display a characteristic quadripartite rhythmic bedding of grey-hite-beige-white (G-W1-B-W2) coloured layers in which the grey and beige marls represent the less indurated $CaCO_3$ poor beds. In the numbering scheme of the Rossello composite the Punta di Maiata section comprises the cycles 22 to 71 and ranges from the upper part of the Sidufjall Subchron to the lowermost part of the Gauss Chron.

The ChRM directions showed a consistent clockwise rotation of approximately 35°. This fact was taken as an argument to support a primary nature for this component since this rotation appears to be widespread within the Caltanissetta Basin and related to a two-phase Pliocene rotation in the Tyrrhenian arc (Scheepers & Langereis 1993; Scheepers 1994).

The present work reports on a detailed paleomagnetic and geochemical study of a 3 m interval from W1 of cycle 43 (W1-43) to G-46 in which the lower Cochiti reversal was expected to occur (van Hoof 1993). The actual section is located on the beach at the eastern side of the cape. In this part, magnetic properties diverge from the usual magnetic characteristics of the Trubi marls in several respects. Low-field bulk susceptibility is somewhat lower ranging 25-110 μSI. It depicts a lithologically controlled cyclic pattern with maxima at the beige and grey layers and minima at the white layers, which is different from the general pattern of maxima at the beige layers only and minima at the white and grey layers. Natural Remanent Magnetization (NRM) has a wide range of intensities from about 0.1 mA/m to about 35 mA/m. The highest values are from the uppermost grey layer (G-46) but in general appear to be lower than the usual intensities for the Trubi marls. NRM intensity correlates directly with the Saturation Isothermal Remanent Magnetization (SIRM). IRM acquisition curves up to 2 T reveal that all samples reach 90 % saturation below 300 mT. Subsequent alternating field (AF) and thermal demagnetization of the 2 T SIRM denotes a low-coercivity (Median Destructive Fields ranging from 10 to 45 mT) and intermediate unblocking temperature (around 330 °C) which indicates the presence of magnetic iron sulphides. This has been confirmed by reversible stepwise thermomagnetic runs up to 350 °C and by a typical Curie temperature for pyrrhotite at 325 °C prior to formation of magnetite typically occurring around 400-420 °C. This newly formed phase was also reflected in a subtle increase of susceptibility upon heating at that temperature during stepwise thermal demagnetization of the NRM. This is the first time that the presence of magnetic iron sulphides has been well characterized in the Trubi marls although it was already suspected to occur (Linssen 1991).

In addition to a small viscous component removed below 150 °C, the NRM usually consists of a low temperature component of probably recent origin removed below 250 °C, and a characteristic high temperature component removed below 360-420 °C. There are also cases where interpretation of the demagnetization paths is almost impossible due to erratic behaviour and other cases with apparent single component behaviour. Along the studied interval the direction of the ChRM component is mostly south and reverse, suggesting that the Cochity reversal might be recorded at a higher level in the section, assuming that the present iron sulphides actually record a primary signal. Paradoxically, the mean direction of the computed ChRM does not show the expected 35° clockwise rotation suggesting that the iron sulphides record a secondary magnetization. The arguments for and against this secondary nature and its implications will be evaluated in the light of available rock magnetic, geochemical and petrographical observations.

References

Hilgen F.J., 1987: Sedimentary rhythms and high-resolution chronostratigraphic correlation in the mediterranean Pliocene. *Newslett. Stratigr.*, 17, 109-127.

Hilgen F.J., 1991: Extension of the astronomically calibrated (polarity) time scale to the Miocene/Pliocene boundary. *Earth Planet. Sci. Lett.*, 107, 349-368.

Hilgen F.J. & Langereis C.G., 1988: The age of the Miocene-Pliocene boundary in the Capo Rossello area (Sicily). *Earth Planet. Sci. Lett.*, 91, 214-222.

Langereis C.G. & Hilgen F.J., 1991: The Rossello composite: a Mediterranean and global reference section for the Early to early Late Pliocene. *Earth Planet. Sci. Lett.*, 104, 211-225.

Linssen J.M., 1991: Properties of Pliocene sedimentary geomagnetic reversals recors from the Mediterranean. *PhD Thesis, Univ. of Utrecht, Geologica Ultraiectina*, 80, 1-231.

Scheepers P.J.J. & Langereis C.G., 1993: Analysis of NRM directions from the Rossello composite: implications for tectonic rotations of the Caltanissetta basin, Sicily. *Earth Planet. Sci. Lett.*, 119, 243-258.

Scheepers P.J.J., 1994: Tectonic rotations in the Tyrrenian arc system during the Quaternary and late Tertiary. *PhD Thesis, Univ. of Utrecht, Geologica Ultraiectina*, 112, 1-352.

Van Hoof A.A.M., 1993: Geomagnetic polarity transitions on the Gilbert and Gauss Chrons recorded in marine marls from Sicily. *PhD Thesis, Univ. of Utrecht. Geologica Ultraiectina*, 100, 1-123.

Van Velzen A.J. & Zijderveld J.D.A., 1990: Rock magnetism of the early Pliocene Trubi Formation at Eraclea Minoa (Sicily). *Geophys. Res. Lett.*, 17, 791-794.

NATURAL REMANENT MAGNETIZATION OF DIRT-ICE COLLECTED FROM ANTARCTICA

MINORU FUNAKI

National Institute of Polar Research, 9-10 Kaga 1, Itabashi Tokyo 173, Japan

The natural remanent magnetization (NRM) of colored ice (dirt-ice) layers including tephra or glacial deposit from the Allan Hills in Southern Victoria Land, the Yamato Mountains and the Sor Rondane Mountains, Eastern Queen Maud Land, East Antarctica, was investigated. The ice block samples were collected with in situ orientation, and were refrigerated at -20 °C in transit to Tokyo. Cubic samples cut from top to bottom in the blocks, were subsequently washed with water at 0 °C. The NRM was measured quickly by SQUID magnetometer (within 10 second) in order to avoid melting.

In general, the dirt-ice layers have hard and soft NRM components. These components were discriminated during AF demagnetization. The clear-ice showed only insignificant magnetization due to very weak intensity. Uniform NRM directions reflected by hard NRM components, appeared in the dirt-ice although the intensities varied with the layers and the samples. Two samples from the Allan Hills and the Sor Rondane Mountains showed NRM directions almost parallel to the present geomagnetic field direction. The NRM of a sample from the Yamato Mountains appeared to have a soft viscous component magnetized toward the present geomagnetic field direction. This sample from Yamato Mountains is being investigated at present.

From our research results, we believe that it is plausible that rearrangement of magnetic grains might occur by the interaction between the grains and the geomagnetic field. This can be accelerated by higher temperature due to solar radiation affecting the surface samples. Probably, the ice layers are unreliable paleomagnetic investigation compared to terrestrial rocks, but the magnetic study of ice is useful in identification of the contamination in Antarctic ice by volcanic ash, glacial deposit and cosmic dust.

PRELIMINARY RESULTS FROM PALEOMAGNETIC RECORDS IN LAKE SEDIMENTS FROM SOUTH AMERICA

CLAUDIO S.G. GOGORZA[1], INES DI TOMMASO[2], ANA MARIA SINITO[1], BRUCE JACKSON[3], HECTOR NUÑEZ[4], KEN CREER[5] and JUAN F. VILAS[2]

[1] UNICEN, CONICET, Argentina
[2] UBA, Argentina
[3] Wisconsin University, USA
[4] IAA, Argentina
[5] University of Edinburgh, UK

Introduction

This paper describes the preliminary results of a collaborative, multidisciplinary investigation of Late Pleistocene-Holocene sediments from two lakes of south-western Argentina (Escondido and Moreno).

Geology

These lakes are located in the Llao Llao area (about 41° S, 71°30' W). The Nahuel Huapi Group of Early Cenozoic age, exposed in this area, has been subdivided into the mainly igneous Ventana Formation of Eocene age and the mainly sedimentary Nirihuau Formation of Eocene-Oligocene age, with the former predominating. Granites and tonalites which have been assigned to the Lower Paleozoic are also exposed (Gonzalez-Bonorino 1973).

Field work and sampling

In order to avoid the effects of turbidity currents and other sources of potential post-depositional disturbance of sediments, small lakes were deliberately chosen. Short cores up to 1.5 m, and longer cores up to 6 m long were taken with pneumatically operated corers (Mackereth 1958, 1969). Two short cores and 7 long cores were collected from Escondido and 4 long cores were obtained from Moreno. All the cores were cut into sections 1 m long, and were split open.

The sections were subsampled with plastic cubic boxes of 8 cm^3, sealed and weighted for paleomagnetic studies.

Subsampling for ^{14}C analyses was carried out on pieces of wood, leaves and sediments. Subsampling for palynology analyses was also carried out in several cores.

Macroscopic sedimentological description

The sedimentological description is the macroscopic one done in the field, except some "smear slides" analysis looked through a petrographic microscope.

The sediments in both lakes are granulometrically poorly sorted, clayey-sand and sandy-clay layers are frequently found.

Clay and silt are present in nearly all the column, some thin layers (5 to 10 cm) associated with coarse and very coarse sand or gravel, allow a correlation between cores taking into account the colour and composition of the coarse components. Fine and medium sand well sorted is found in thin layers (1 to 5 cm) and noticeable by their colour and pyroclastic composition.

The sediments have a net predominance of pyroclastic origin, the epiclastic material is less abundant. Volcanic glass, ash, tuff and pumices in dark and light colour are the main component of the gravel, sand and silt fraction; badly rounded quartz and plagioclase are scarce.

The most frequent colours in wet sediments are very dark brown (10YR 2/2, the coding used is from the MUNSELL SOIL COLOUR CHART) in silty-clay layers. Black (10YR 2/1) at the top of many cores in clays rich in organic matter. Very dark grey (10YR 3/1) in sandy-silt layers abundant in basic volcanic ash, light grey (10YR 7/1) in coarse sand and gravel pumice fragments.

Diatoms and sponge spicules are abundant in both lakes, in fine layers diatoms make up more than 10 % of the sediment.

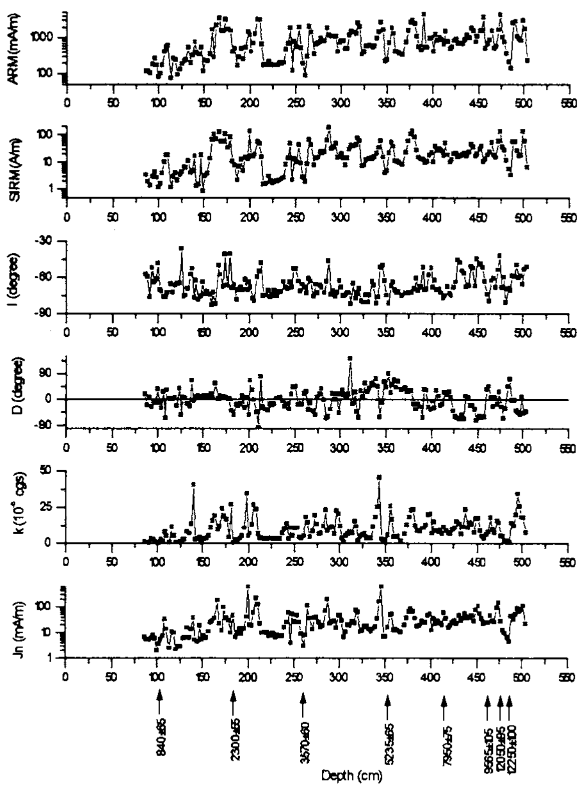


Fig. 1

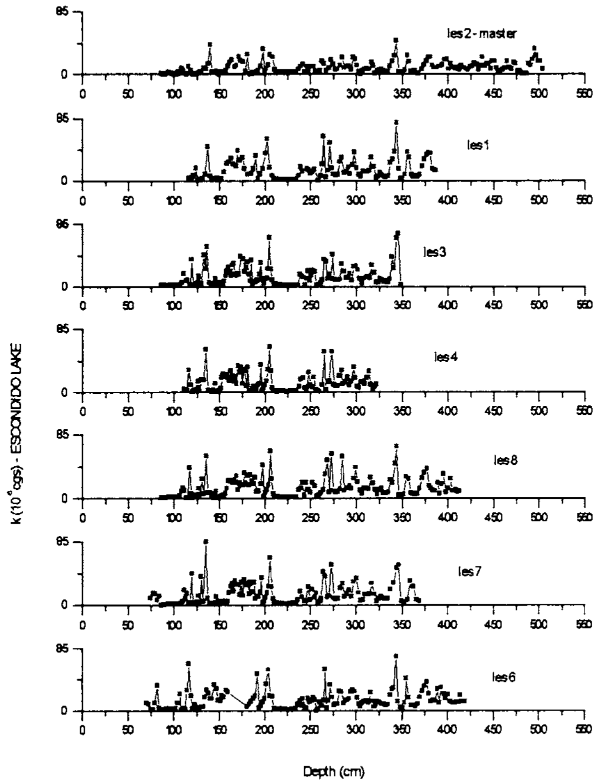


Fig. 2

Lake Escondido has abundant wood fragments and carbon specially between 2 m and 3 m of depth.

Magnetic measurements

The intensity (Jn) and directions (Declination, D and Inclination, I) of the natural remanent magnetization (NRM) were measured using a Digico, a Molspin and a 2-G cryogenic magnetometer.

The stability of the NRM is being investigated by alternating field demagnetization. So far NRM directions typically showed no systematic change during demagnetization.

Magnetic susceptibility measurements (κ) were made using a Bartington susceptibilimeter.

Saturation isothermal remanent magnetization (SIRM) and anhysteric remanent magnetization (ARM) were measured with a Molspin instrument.

SIRM were obtained using an electromagnet with 9000 Oe. ARM was measured using the Earth's vertical field as bias direct field and running the alternate field demagnetizer down from maximum (1000 Oersted). SIRM and ARM were measured for one core of each lake.

Results

Jn, κ, D, I, SIRM and ARM logs were made. Fig. 1 shows the log corresponding to one core from Escondido. The results of the radiocarbon dating, carried out in the NSF Accelerator Facility for Radioisotope Analysis (University of Arizona), are indicated in the figure.

The Jn and κ logs show the same trend; this leads to the conclusion that variations in the magnetic mineral content must dominate the intensity of remanence. Therefore both, Jn and κ logs can be used to define tie-lines to describe the lithostratigraphic correlation of cores of the same lake. These tie-lines were consistent with the lithology.

One core from each lake was chosen as "master" core. The depth scales of all the cores from each lake were adjusted to the depth scale of the respective master core using Jn and κ tie-lines for correlation. Fig. 2 show the alignment of the major peaks and troughs along the Jn logs for Escondido following the adjustment to a common depth scale. Similar alignments were obtained for lake Moreno.

The results of this lake are consistent with those obtained in previous studies (Creer et al. 1983; Valencio et al. 1985).

D and I logs may be used to infer chronostratigraphy within lake correlation and between lake correlation of the sedimentary sequences, but this is not easy because noise of different origins can affect these values.

However, when I logs for El Escondido are made adjusting the depth scale for each individual core to the "master" core, low values of I recorded in different cores appear at the same depth. The D values for the same depth are also lower than the average D.

Conclusions

— The attitude of the lithological layering within each lake can be clearly defined by correlation of Jn and κ logs.

—The D and I logs show consistent results when the depths are adjusted according to the Jn and κ correlation tie-lines.

—The radiocarbon dating is evidence of either a sudden change of the rate of accumulation or a hiatus due to erosion or lack of deposition. The age of the sediment for the depth where the change would occur agree with the suggested age of the deglaciation (about 10,000 years b.p.)

—This work will be completed with palynological studies.

References

Creer K.M., Valencio D.A., Sinito A.M., Tucholka P. & Vilas J.F., 1983: Geomagnetic secular variations 0-14000 yr BP as recorded by lake sediments from Argentina. *Geophys. J. Roy. astr. Soc.*, 74, 1, 109-222.

Gonzalez Bonorino F., 1973: Geología del área entre San Carlos de Bariloche y Llao-Llao. *Departamento Recursos Naturales y Energía, Fundación Bariloche, Public.*, 16.

Mackereth F.J.H., 1958: A portable core sampler for lake deposits. *Limnol. Oceanogr.*, 3, 181-191.

Mackereth F.J.H., 1969: A short core sampler for sub- aqueous deposits. *Limnol. Oceanogr.*, 14, 145-151.

Valencio D.A., Sinito A.M., Creer K.M., Mazzoni M., Alonso M.S. & Markgraf V., 1985: Paleomagentism, sedimentology, radiocarbon age determinations and palynology of the Llao-Llao area, southwestern Argentina (lat. 41 S, long. 71 30' W): Paleolimnological aspects. *Quaternary of South America and Antarctic Peninsula*, 3, 109-147.

CHARACTERISTIC PALEOMAGNETIC DIRECTIONS FROM THE SEDIMENTARY MESOZOIC AND PALEOGENE ROCKS IN THE TATRA MTS, POLAND

JACEK GRABOWSKI

Polish Geological Institute, Rakowiecka 4, 00-975 Warszawa, Poland

Middle Jurassic-Eocene sedimentary rocks were sampled in four tectonic units of the Tatra Mts.: paraautochthonous Mesozoic cover, overthrusted Czerwone Wierchy and Križna Units, and autochthonous Eocene cover. A total number of 195 hand samples was taken from 27 sites. At 14 sites a recent viscous magnetization (component R) was revealed, which is carried by magnetite. Its age was confirmed by conglomerate test. In the Middle Jurassic-Lower Cretaceous limestones (11 sites) pre-folding components were isolated. The pole of the most common componenet A (D = 28°, I = 51°, α_{95} = 6.4, k = 89, N = 7 sites) is situated in the vicinity of the Late Jurassic poles of the European Platform (Besse & Courtillot 1991). Because this component occurs in the rocks of variegated age and it is always of normal polarity, it is tentatively suggested that it represents a pre-Senonian remagnetization. The component A is significantly different than the Late Jurassic-Early Cretaceous paleomagnetic directions from the Apulian realm (Márton & Márton 1983). These data, together with results of Kruczyk et al. (1992) imply that the Central Western Carpathians area was separated from the Apulian microplate at least in the Early Cretaceous and, like as the Northern Calcareous Alps, it did not participate in the counter-clockwise rotation of Apulia.

References

Besse J. & Courtillot V., 1991: Revised and synthetic apparent polar wander paths of the African, Eurasian, North American and Indian plates and true polar wander since 200 Ma. *J. Geoph. Res.*, 96, 4029-4050.

Kruczyk J., Kadzialko-Hofmokl M., Lefeld J., Pagáč P. & Túnyi I., 1992: Paleomagnetism of Jurassic sediments as evidence for oroclinal bending of the Inner West Carpathians. *Tectonophysics*, 206, 315-324.

Márton E. & Márton P., 1983: A refined apparent polar wander curve for the Transdanubian Central Mountains and its bearing on the Mediterranean tectonic history. *Tectonophysics*, 98, 43-57.

PALEOMAGNETIC STUDY OF PLIO-PLEISTOCENE VOLCANITES OF NEUQUEN (38°–40° S) ARGENTINA

GUILLERMO H. RE and JUAN F. VILAS

Laboratory of Paleomagnetism "Daniel A. Valencio", Department of Geology, Pab. 2, Ciudad Universitaria, 1 428 Nunez - Bs. As., Argentina.

Important outcrops of basaltic sequences from the Cenozoic age can be observed in the area located between 38° and 40° S. These outcrops are situated in the East of the volcanic front, and bear features of intra-arc and back-arc volcanism. In the first case, the volcanic centers are placed between the pre-Cordilleran blocks, which are separated by graben type structures. The presence of this kind of structure points out the existence of a period of intra-arc extension during the Plio-cene-Quaternary. The back-arc volcanism appears in the form of extensive basaltic layers, with volcanic cones that can be aligned along the fractures, as they usually appear, scattered without apparent structural pattern. Generally, they are alkaline basalts, with a low degree of differentiation and a marked compositional homogeneity.

Eight volcanic events took place during the Cenozoic. These events were informally Basalt 0 to Basalt VII, and comprise the period between the Oligocene (Basalt 0) and Holocene (Basalt VII). These series of volcanic events can be grouped into two great magmatic periods: one of them prior to the Miocene and the other to the Pliocene-Holocene.

The present work shows the result of a paleomagnetic study carried out on samples of the so called Basalt II and Basalt III, obtained in six locations. Out of these six locations, samples from 22 sites were taken, and from each site, an average of 5 oriented hand samples and two specimens from each sample were obtained.

These specimens were demagnetized by exposure to high temperature, up to 700 °C, and by application of AF, up to 900 mT. After demagnetization, the studied specimens showed a simple magnetic behaviour, which is generally a mono-component or in some cases bicomponent type behaviour. In the last case, the specimens show the presence of a secondary component that can be assigned to the present field. From studies of isothermal remanent magnetization (IRM), it can be inferred that magnetization is carried mainly by magnetite and quantities subordinated to hematite. From the directions of the characteristic remanent magnetism isolated in each of the specimens and following the usual procedures, the magnetic polarity for each of the locations sampled was obtained. From each polarity obtained, from geochronological data and geological information available in literature, each location was correlated with the geomagnetic time scale for the last 10 million years. From such correlation, it can be inferred that the magnetostratigraphic correlation implied that some analysed sequences were not well dated. Previous works have assigned the same geological age to sequences with different magnetic polarities. This magnetostratigraphic study suggests that the volcanism was continuous and involved more volcanic events than were previously considered. A revision of the geological and geochronological correlation of the volcanism should be carried out according to the magnetostratigraphic analysis.

THE STATIONARY MAGNETIC FIELD OF THE MATUYAMA AND JARAMILLO CHRONS CLOSE TO THE LOWER JARAMILLO REVERSAL

GARRY Z. GURARY and V. M. TRUBIHIN

Geological Institute, Russian Academy of Sciences, Pyzhevsky 7, 109017 Moscow, Russia

We are sure that an analysis of the transitional geomagnetic field should be combined with detailed studies of the stationary field. The latter studies should establish the following: *1* — Secular variaton (SV) spectrum for periods longer than 10 ky before and after transition; *2* — SV spectrum for periods shorter than 10 ky far off, immediately before and after transition; *3* — Presence of "triggering" phenomena; *4* — Existence of systematic deviations of virtual geomagnetic poles (VGP) from the geographical pole before and/or after transition.

From the Adji-dere locality in the West Kopet-Dagh (Turkmenistan), we sampled a sedimentary section covering a part of the Matuyama Chron for about 200 ky and the entire Jaramillo Subchron. Each of 170 stratigraphic level studies corresponds approximately to a time interval of 1.0-2.5 ky. Also, we used a sample-to-sample scheme at two intervals about six meters thick within each chron to study a medium-wave part of the SV spectrum; these two intervals cover about 9 and 20 ky. Finally, the sample-to-sample scheme was applied to a 17-meter thick section (about 50-60 ky) to study the Lower Jaramillo transition and SV spectra immediately before and after it. By now, we have finished stepwise thermal demagnetization of four to five specimens per stratigraphic level and component analysis of data the stationary field intervals (Fig. 1).

The data received allow us to do the following preliminary conclusions:

1 — The SV periods 10 ky in the Matuyama Chron and 3.8, 6.0 and 9.7 ky in the Jaramillo Subchron are recorded in the set of directions of the field.

2 — It is not possible to define the anomalous period longer that 2.5 ky and 1.0 ky in the Matuyama Chron and Jaramillo Subchron accordingly at this stage of research in the time interval studied.

3 — The mean direction of the field for the studied part of the Matuyama Chron is D = 189°, I = -49°, k = 40.5, α_{95} = 2.8; Jaramillo Subchron — D = 345°, I = 58°, k = 41.7, α_{95} = 2.6. Thus the difference between the directions is 165° i.e. they are not fully antipodal. The mean directions are obviously shifted to the west and the Matuyama field inclination is too shallow.

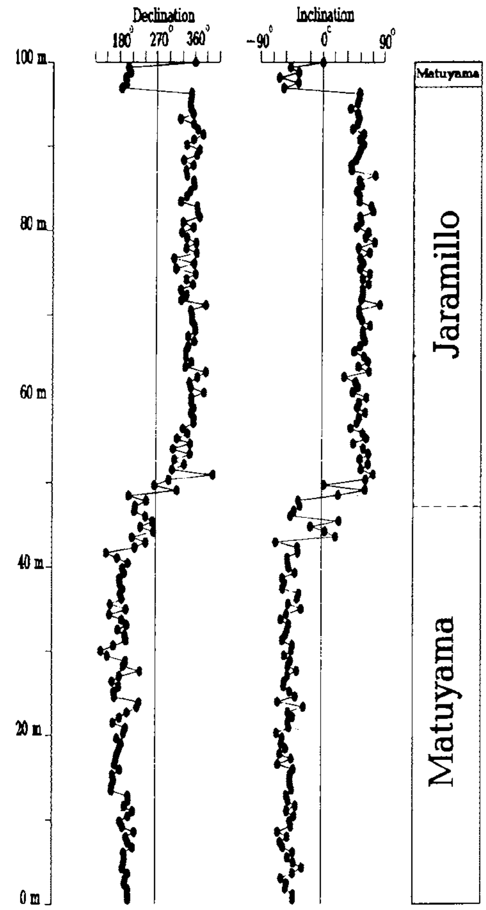


Fig. 1. Records of the declination and inclination obtained after thermal demagnetization and component analysis of the Matuyama and Jaramillo Chrons near the lower Jaramillo transition.

ANOMALOUS DIRECTION OF THE NATURAL REMANENT MAGNETIZATION IN QUATERNARY MARINE SEDIMENTS

MAJA HAAG* and CATHERINE KISSEL

*Centre des Faibles Radioactivites, Laboratoire mixte CNRS/CEA, Avenue de la Terrasse, F-91198 Gif-sur-Yvette, France

In the last approximately 700 ky, i.e. in the Brunhes Chron, the Earth's magnetic field had with a few exceptions a normal polarity. Geomagnetic excursions as short-time partial reversals of the Earth's magnetic field were observed for different periods (for a compilation see e.g. Jacobs 1994). However, a specific excursion had rarely been observed worldwide in rocks of similar age and contradictory results on sediments and volcanic rocks of the same age led to doubts about the reliability that such excursions actually monitor the behavior of the Earth's magnetic field. This was believed to be the cause of uncertainties in the age determination of the rocks. In the last 150 ky various excursions have previously been reported: the Gothenburg flip, 24-29 ky for the Mono Lake excursion, 25-30 ky for the Lake Mungo excursion, 25-50 ky for the New Zealand event, 34-43 ky for the Laschamp event, 72-86 ky for the Norwegian-Greenland Sea event, 95-104 ky for the Fram Strait event and 118-128 ky for the Blake event. It has been shown that an excursion has only a duration of approximately 0.5-1 ky in contrast to a polarity reversal of 5-10 ky.

The cause of these excursions is still unclear. To find a trigger mechanism it is crucial to know if they are not fully recorded field reversals or big excursions of the field which are connected to local non-dipolar components of the Earth field. The latter could then explain why they might be found only in a restricted region and do not represent a global effect. A third mechanism can be attributed to rockmagnetic phenomena: a chemical remagnetization or a partial or full self-reversal mechanism.

The marine core "SEDORQUA 20bK" have been obtained during the ocean drilling campain SEDORQUA1 (SEDimentation ORganique marine et changement globaux au cours du QUAternaire) and is situated at 25° N, south of the Canary Islands. It consists of pelagic, mostly anoxic sediments of the last 150 ky (glacial-interglacial stages 1-6). As the sedimentation rate deduced from the d018 profiles lies between 3 cm/ky (glacial stage 3) and 14.5 cm/ky (glacial stage 5e) most of the above excursions and events are expected to be found in these marine deposits.

The variations of the natural and anhysteretic remanent magnetization (NRM and ARM) and the low field magnetic susceptibility were measured on u-channels taken from the half-cores of the Kullenberg cores which allow a continuous high resolution record to be obtained. The remanences were measured with a pass-through cryogen magnetometer, the susceptibility with a Bartington susceptometer. The alternating field (AF) demagnetization of the remanences up to 90 mT was carried out in a coil system which is integrated in the magnetometer. The ARM was given in a pass-through electromagnet in a peak alternating field of 60 mT and an applied direct field of 0.04 mT. The rockmagnetic properties were examined on single samples by the acquisition, the thermal and the AF demagnetization of the isothermal remanent magnetization, by Curie temperature determination and by the investigation of the frequency dependence of the low field susceptibility. Mineral observations were carried out by reflection and transmission microscopy.

Slight differences in inclination over the whole core are most probably due to differences in the DRM or PDRM alignment owing to the presence of different minerals with their different shapes. A distinct deviation of the NRM direction is observed at 12.5 ky. In this timespan, however, no excursions are reported. The sediments come from the zone of prominent color change from brown/beige to olive green which is the limit of the iron reduction zone. This change in the chemical environment is also reflected in the rockmagnetic measurements which show that the coercivity and the mean destructive field of these particular sediments are strongly increased. Microscopy shows that the sediments are more oxidized.

There is no reason why the sediments deposited at times of variations of the Earth's magnetic field should result in a changed ferromagnetic mineral content. We therefore attribute the change in the remanence direction within these marine sediments at the boundary of the iron reducing zone to a chemical remagnetization and not to an excursion of the Earth's magnetic field.

The observed change of the remanence direction could be the result magnetic interactions of these altered minerals and the magnetization of the original ferromagnetic minerals. In the most extreme case this could lead to a self-reversal of the magnetization. Such examples of magnetite/maghemite-hematite intergrowth show that post-depositional processes can systematically produce a high-coercive remanent direction which deviates or is even antiparallel to the geomagnetic field.

Reference

Jacobs J.A., 1994: Reversals of the Earth's Magnetic Field. *Cambridge, New York*, 1-346.

BRIEF MIXED POLARITY INTERVALS FROM A HIGH RESOLUTION LATE MIOCENE RECORD

MIKLÓS LANTOS[1] and DONALD P. ELSTON[2]

[1]Geological Institute of Hungary, Stefánia út 14, H-1143 Budapest, Hungary

[2]U.S. Geological Survey, Flagstaff, Arizona 86001, U.S.A.

The Pannonian Basin subsided rapidly during the Late Miocene and Pliocene, and received thick, predominantly clastic sediments consisting of sand, sandstone, silt, clay and marl. Geological and paleomagnetic studies indicate that the unreworked sediments accumulated rapidly, were promptly buried and have never been exposed to weathering. A 1.8 km-thick Late Miocene section was continuously cored near Szombathely, NW Hungary. Rock magnetic, micromineralogical studies and demagnetizations indicated a stable magnetization residing in detrital magnetite in the sediments (Lantos & Elston 1995).

On paleontological and seismostratigraphic grounds, the polarity zones of the Szombathely section correlate with chrons C5n.2n to 4Ar.1n of the geomagnetic polarity time scale of Cande & Kent (1992). An extremely high resolution record had been obtained, the samples, collected at 0.5 m intervals, provided an ~250 year sampling of the geomagnetic field.

Many intervals of mixed polarity were recognized across the section. Correlations with other Hungarian deep records indicate that the mixed polarity intervals are not the result of incomplete demagnetization. Two narrow intervals of mixed polarity at Szombathely correlate with the upper two reversals of chron C5n (Fig. 1) in the polarity zonations of Blakely (1974), Ness et al. (1980) and Cande & Kent (1992). From basalt flows of Iceland, McDougall et al. (1984) have reported a brief reversal that appears to correlate with cryptochron C5n.2n-1. Because "events" having similar positions in chron C5n have been identified by different methods (marine magnetic measurements and paleomagnetic studies), and because the paleomagnetic records were obtained from different geological environments (sedimentary and volcanic rocks), the events can be considered real.

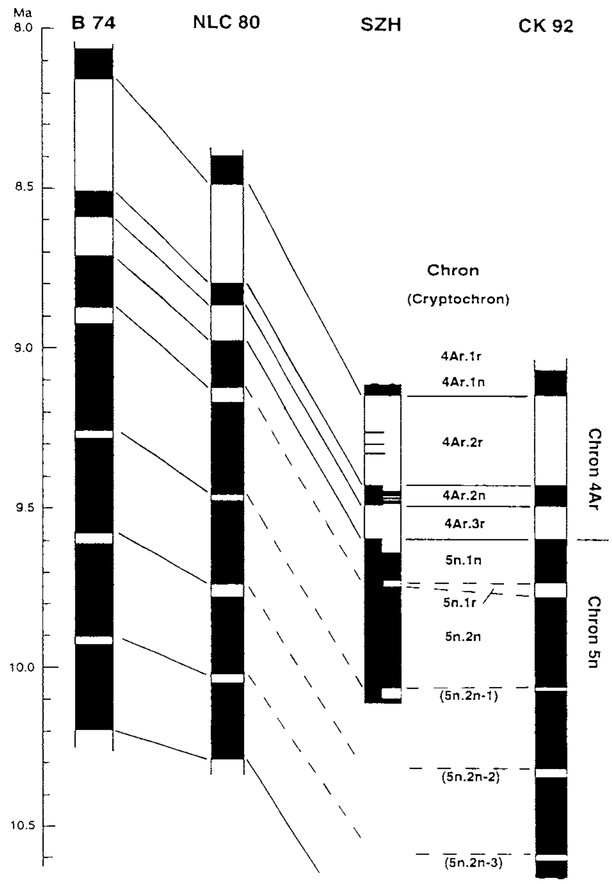


Fig. 1. Correlation of the Szombathely polarity zonation (SZH) with parts of the polarity time scales of Blakely (1974 - B 74), Ness et al. (1980 - NLC 80) and Cande & Kent (1992 - CK 92). Black — normal polarity; white — reversed polarity; black and white — mixed polarity.

Nearly all brief polarity events in the Szombathely record display intervals of mixed polarity. Additionally, the brief reversed interval of McDougall et al. (1984) is also an interval of mixed polarity.

Oscillating mixed polarity transitions bound the major polarity intervals at Szombathely. Oscillating transitions have also been reported in other paleomagnetic studies from strata of greatly different ages. These observations suggest that oscillations typically mark the boundaries that separate major (> ~10^5 years) polarity zones.

Correspondences of the fine-scale features in the Szombathely and the marine records indicate that 'tiny wiggles' in the ocean floor record generally reflect mixed polarity intervals rather than changes in intensity of the ambient field (suggested by Cande & LaBrecque 1974).

References

Blakely R.J., 1974: Geomagnetic reversals and crustal spreading rates during the Miocene. *J. Geophys. Res.*, 79, 2979-2985.

Cande S.C. & LaBrecque J.L., 1974: Behavior of the Earth's paleomagnetic field from small scale marine magnetic anomalies. *Nature,* 247, 26-28.

Cande S.C. & Kent D.V., 1992: A new geomagnetic polarity time scale for the Late Cretaceous and Cenozoic. *J. Geophys. Res.*, 97, 13917-13951.

Lantos M. & Elston D.P., 1995: Low- to high-amplitude oscillations and secular variation in a 1.2 km late Miocene inclination record. *Phys. Earth Planet. Int.*, 90, 37-53.

McDougall I., Krisjansson L. & Saemundsson K., 1984: Magnetostratigraphy and geochronology of Northwest Iceland. *J. Geophys. Res.*, 89, 7029-7060.

Ness G., Levi S. & Couch R., 1980: Marine magnetic anomaly timescales for the Cenozoic and Late Cretaceous: A précis, critique, and synthesis. *Rev. Geophys. and Space Phys.*, 18, 753-770.

THE GENERAL DESCRIPTION OF THE COURSE OF THE INVERSION PHENOMENON, IN THE TERMS OF A LARGE SCALE GEOMETRIC ELEMENTS OF THE MAGNETIC FIELD SHAPE ON THE EARTH'S CORE SURFACE

LECH KRYSINKI

Institute of Geophysics, University of Warsaw, Pasteura 7, 02-093 Warsaw, Poland

The Earth's magnetic field shape representation by the radial component B_r map on the core surface is the main one in the field nature studies, because of the magnetohydrodynamic context of the field evolution. The language of a large scale geometric elements in such a map allows us to describe commonly the properties of the field inversion phenomenon. The remark of the core convection thermal conditioning upon the mantle, gives suppositions concerning some regularities of the course of the inversion phenomenon, which can be tested in its rock record.

— The direction of quadrupolar momentum $G_{2,0}$ is correlated with the direction of dipolar momentum change $\Delta G_{1,0}$, if the quadrupolar part dominates in the field shape (the simpliest case).

— The areas of the VGP attraction during its movement, are situated near the regions of amplified core magnetic flux, lying closely to the place of sampling.

These properties are stable at least over a time-scale of tens of milions of years.

I am going to focus on the description of the method of the practical interpretation of the inversions rock record:

— The supposition of the typical direction of local field rotation in the initial and final phase of the inversion.

— The concept of the VGP attraction regions in the middle phase and the influence of these regions upon the initial and final phase of the inversion.

MAGNETIC FABRIC OF THE UPPER PALEOZOIC PILLAHUINCO GROUP (SIERRAS AUSTRALES CURVED OROGENIC BELT, BUENOS AIRES, ARGENTINA)

JOSE SELLES-MARTINEZ[1], JOSEP PARES[2] and JUAN F. VILAS[1]

[1]Department of Geological Sciences, University of Buenos Aires, Buenos Aires, Argentina

[2]"Tierra Jaume Almera" Institute of the Earth Sciences (CSIC), Barcelona, Spain

Measurements of the AMS of 121 specimens from 28 sampling sites representing the Sauce Grande, Piedra Azul, Bonete and Tunas Formations (Pillahuinco Group, Upper Paleozoic, Sierras Australes de Beuenos Aires, Argentina) have been carried out using a Kappabridge susceptibilimeter at the Laboratorio de Paleomagnetismo del Instituto de Ciencias de la Tierra Jaume Almera (CSIC), Barcelona (Spain).

The siliciclastic sequence was deformed during Permo-Triassic times — along with the older Ventana (Devonian) and Curamalal (Ordovician-Silurian?) Groups -- into a sigmoidal fold belt. The Pillahuinco Group crops out in the easternmost area of the Belt and is characterized by open folds, with axis trending Az 145 and plunging a few degrees to the SE. Axial planes are almost vertical. There is a strong lithological control on the development of axial plane cleavage which is not homogeneously developed. Main deformation mechanisms active in the area during deformation have been identified as rigid body rotation, grain sliding and pressure solution, allowing mass transfer and recrystallization of quartz and sericite. The metamorphic grade has been established on the bases of illite crystallinity to be in the lowermost part of greenschist facies or even remain in anchizonal conditions.

Preliminary ASM results show high coherence not only within specimens from the same hand sample, but also within sampling sites, Formations or structural position, depending on the case. No traces of random depositional magnetic fabrics, or even of flow related ones, have been found although delicate primary depositional features are preserved throughout the sampled units. This enables the following interpretations to be attempted. Major axis of ASM ellipsoids parallel with the fold axis mostly everywhere, displaying an horizontal trend in the Az 145-Az 325 direction. Only a few exceptions have been found that will be discussed afterwards.

The intermediate and minor axes are distributed on an Az 55-Az 235 trending girdle which is normal to fold axis direction. Minor axes are never found outside this plane and they are mostly concentrated in the NE sector of the stereoplots.

Oblate and prolate fabrics have been found. Drolate chapes are always correlated with fold axis lineation, but two main geometric relationships are found for oblate shapes. The first one displays minor axis in a normal-to-bedding position and it is attributed to early compaction by overload. The second is related to layer-parallel shortening in early stages of tectonic compression. In these cases major axes appear normal to bedding. It must be pointed out that even in the former cases, in which the oblate ellipsoid reflects vertical compaction, the major axes are mostly subhorizontal and parallel to fold axes reflecting probably a synchronous process of compaction and tectonic deformation. Magnetic foliation has been found to rotate from these two earlier positions (with minor and intermediate axes following the normal-to-fold-axis girdle) in the way to the normal-to-cleavage position.

Several cases have been found in which a strong magnetic foliation is associated with a vertical orientation of the major axis of the ellipsoid. These cases — which cannot be explained by layer parallel compaction because bedding is not horizontal for those samples — are interpreted to be associated with a strong layer parallel shears, which is intrinsic to flexural-slip folding mechanisms.

The magnetic information correlates very well with other strain markers and structural observations in the area but a detailed discussion falls outside the possibilities of this contribution.

This survey has been performed with the aid of a grant from the Buenos Aires (UBACYT EX071/93) and a Cooperative Research Project from the Instituto de Cooperacion Iberoamericana. Lic. R. Tomezzoli is greatly acknowledged for her help in field work and preparing the samples.

A CHRONOLOGIC REVIEW OF THE STUDIES OF THE HOLOCENE PALEOMAGNETIC RECORD FOR CANADA

JOHN MOTHERSILL

Royal Roads University, Victoria, B. C., Canada, V9B 5Y2

The first studies of the Holocene paleomagnetic record were published two decades ago based on records compiled from the stratigraphic sequences of Lake Erie (Creer et al. 1976a) and Lake Michigan (Creer et al. 1976b). Since then a number of records have been published from other lakes in east central Canada including Lake Superior (Mothersill 1979), Lake Huron (Mothersill & Brown 1982) and Lake Ontario (Carmichael et al. 1990). The work of Banerjee et al. (1979) and Sprowl & Banerjee (1995) in lakes just south of the Canadian border provided important additional information on the regional paleomagnetic record. Based, in part, on this information Creer & Tucholka (1982) and Thomson (1985) compiled type paleomagnetic records for east central North America.

The chronologic paleomagnetic record for eastern Canada, particularly for the Great Lakes area has been fairly well defined for the Holocene and the Late Pleistocene. The 'type' declination and inclination logs can be use for chronostratigraphic correlation and dating of Holocene stratigraphic sections for the limited geographic area around the Great Lakes. It may well be possible and practical to establish 'subtype' declination and inclination longs within this general area.

Studies of the paleomagnetic record for western Canada have been published by Latham et al. (1982), Turner (1987) and Mothersill (1991a and 1991b) and for the eastern Arctic by Andrews et al. (1986). However the paleomagnetic record for the Holocene Epoch for western Canada and the Arctic is not nearly as well defined as for east central North America.

References

Andrews J.T., Mothersill J.S. & Tabrez A.R., 1986: Paleomagnetic record, texture and mineralogy of late Quatemary sediments, Baffin Island Fiords, N. W. T., Canada. *Arctic and Alpine Res.*, 18, 361-376.

Banerjee S.K., Lund S.P. & Levi S., 1979: Geomagnetic record in Minnesota lake sediments-absence of the Geothenburg and Erieau excursions. *Geology*, 7, 588-591.

Carmichael C.M., Mothersill J.S. & Morris W.A., 1990: Paleomagnetic and pollen chronostratigraphic correlations of the late glacial and postglacial sediments in Lake Ontario. *Can. J. Earth Sci.*, 27, 131-147.

Creer K.M., Anderson T.W. & Lewis C.F.M., 1976a: Late Quarternary geomagnetic stratigraphy recorded in Lake Erie sediments. *Earth and Plan. Lett.*, 37-47.

Creer K.M., Gross D.L. & Lineback J.A., 1976b: Origin of regional geomagnetic variations recorded by Wisconsinan and Holocene sediments from Lake Michigen, U. S. A. and Lake Windermere, England. *Geol. Soc. Am. Bull.*, 87, 531-540.

Creer K.M. & Tucholka P., 1982: Construction of type curves of geomagnetic secular variation for dating lake sediments from east central North America. *Can. J. Earth Sci.*, 19, 1106-1115.

Latham A., Schwarz H.P., Ford D.C. & Pearce G.W., 1982: The paleomagnetism of U-Th dating of three Canadian speleothems: evidence for the western drift, 5.4-2.1 ka BP. *Can. J. Earth Sci.*, 19, 1985-1995.

Mothersill J.S., 1979: The paleomagnetic record of the late Quatemary sediments of Thunder Bay. *Can. J. Earth Sci.*, 16, 1016-1023.

Mothersill J.S. & Brown H., 1982: Late Quaternary stratigraphic sequence of the Goderich Basin: Texture, mineralogy and paleomagnetic record. *J. Great Lakes Res.*, 8, 578-586.

Mothersill J.S., 1991a: Dating of paleomagnetic logs by tephra layers, Mara Lake, Canada. *Studio geoph. et geod.*, 35, 302-313.

Mothersill J.S., 1991b: Utilization of magnetic susceptibility and intensity of remnant magnetization for chronostratigraphic correlation of lake sediments. *Studio geoph. et geod.*, 35, 314-324.

Sprowl D.R. & Banerjee S.K., 1985: High resolution paleomagnetic record of geomagnetic field fluctuations from the varved sediments of Elk Lake, Minnesota. *Geology*, 13, 531-533.

Thompson R., 1985: A global review of paleomagnetic results from wet lake sediments. In: Hayworth E.Y. & Lund J.W.G. (Eds.): *Lake sediments and environmental history. Univ. of Minnesosta Press*, 144-164.

Turner G.T., 1987: A 5000 year geomagnetic secular variation record from western Canada. *Geophys. J. R. Astron. Soc.*, 91, 103-121.

LATE PLEISTOCENE PALEOMAGNETIC RESULTS FROM CENTRAL AFRICA

JOHN MOTHERSILL

Royal Roads University, Victoria, B. C., Canada V9B 5Y2

The first paleomagnetic study of lake sediments from Central Africa was published by Barton & Torgersen (1988) on soft sediment cores taken from Lake Turkana. Since then additional studies have been carried out on Lake Tanganyika by Williamson et al. (1991), on Lake Barombi Mbo by Maley et al. (1990) and on Lakes Victoria and Albert by Mothersill (1996). The Lake Tanganyika work encountered an upper Holocene sedimentary sequence (0-5,000 years B.P.) of only about 0.8 m thickness which was too thin to determine the paleomagnetic oscillations for that time period. However the paleodeclination and paleoinclination logs compiled by Maley et al. (1990) from cores taken from Lake Barombi Mbo in the Cameroons showed fairly well defined and controled oscillation swings dating back to 25,000 years B.P. with gaps from about 0 to 1,500 and 10,000 to 12,000 years B.P. The paleodeclination and paleoinclination logs from Lake Victoria shows a continuous record from 0-6,500 years B.P. and the combined information provides the first complete record for the Holocene Epoch from Central Africa.

New paleomagnetic data is presented from Lake Edward which correlates with this complete though combined record.

References

Barton C.E. & Torgersen T., 1988: Paleomagnetic and 210 Pb estimates of sedimentation in Lake Turkana, East Africa. *Paleogeogr., Paleoclimatol., Paleoecol.*, 68, 53-60.

Maley J., Livingstone D.A., Diresse P., Thouveny N., Brenac P., Kelts K., Kling G., Stager C., Haag M., Fournier M., Bandet Y., Williamson D. & Zogning A., 1990: Lithostratigraphy, volcanism lacustrine deposits from Barombi Mbo (West Cameroon): preliminary results. *J. Volcanol. Geotherm. Res.*, 42, 319-335.

Mothersill J. S., 1996: Paleomagnetic results from Lakes Victoria and Albert, Uganda. *Studia geoph. et geod.*, 40, 1-11.

Williamson D., Thouveny N., Hillaire-Marcel C., Mondeguer A., Taieb M., Tiercelin J.-J. & Vincens A., 1991: Chronological potential od paleomagnetic oscillations located in late Quaternary sediments from Lake Tanganyika. *Quat. Sci. Rev.*, 10, 351-361.

RECORDS OF BRUNHES CHRON POLARITY EVENTS AND PALEOINTENSITY VARIATIONS AS DERIVED FROM NORTHERN HIGH LATITUDES

NORBERT R. NOWACZYK[1] and THOMAS W. FREDERICHS[2]

[1]GeoForschungsZentrum Potsdam, Projektbereich 3.3 — Sedimente und Beckenbildung,Telegrafenberg A26, D-14473 Potsdam, Germany

[2]Fachbereich Geowissenschaften, Universität Bremen, Postfach 330 400, D-28334 Bremen, Germany

High resolution magnetostratigraphic as well as rock magnetic analysis of sediments recovered from numerous sites in the Norwegian-Greenland Sea and the Arctic Ocean between 69° N and 90° N consistently revealed records of several geomagnetic polarity events throughout the Brunhes Chron. The lithogenic sediments from these sites turned out to be the ideal material to investigate such high-frequency field behavior of the Earth's magnetic field. Detailed rock magnetic analysis such as measurements of magnetic susceptibility as well as ARM and IRM acquisition/demagnetization experiments could prove that fine-grained magnetite is the dominant magnetic carrier mineral. No significant changes of mineral magnetic parameters could be observed across polarity transitions, which therefore are interpreted as true recordings of geomagnetic field variations.

Intra-basin correlation of the core profiles was achieved by using distinctive variations in magnetic susceptibility and other physical properties of the sediments. Increasing numbers of AMS ^{14}C ages, oxygen isotope records, ^{230}Th and

^{10}Be data as well as calcareous nannofossil biostratigraphies result in a more and more consistent data base of the geomagnetic field behavior in course of the Brunhes Chron which has been interupted by several events with a duration of up to 10 ka at the sites investigated: 26-28 ka — Mono Lake excursion, 33-40 ka — Laschamp event, 72-86 ka — Norwegian-Greenland Sea event, 118-128 ka — Blake event, and 179-189 ka — Biwa I/Jamaica event. The data suggest that the transition process of the Earth's magnetic field during such polarity events requires only about 1 ky. In at least one of the cores each event exhibits a full reversal of the local geomagnetic field vector.

Sediments recovered from several sites are characterized by only moderate fluctuations in concentration as well as grain size related rock magnetic parameters. They therefore provided ideal conditions for the reconstruction of the relative paleointensity of the geomagnetic field approximated by three different methods. The NRM-intensities and residual remanences after treatment with increasing alternating field peak amplitudes (B) were divided:

a) by the ARM-intensities of the corresponding demagnetization levels: $J_{NRM}(B)/J_{ARM}(B)$,

b) by the SIRM: $J_{NRM}(B)/SIRM$, and

c) by the low field magnetic susceptibility: $J_{NRM}(B)/\kappa_{LF}$.

In most cases the results of all three approximation methods do not deviate significantly from each other. Thus, the recorded geomagnetic events are clearly linked to drastic reduction in the relative paleointensity of the field. The lowermost values were derived for the time of the polarity reversal with a trend to higher relative intensities in the course of the polarity events. Ages of the events and the relative paleointensity variations based on different methods derived from the Greenland Sea sediments investigated are in good agreement with the data published in literature.

PALAEOMAGNETISM OF PERMIAN REDBEDS OF THE ABADLA BASIN

NACER MERABET[1], BERNAD HENRY[2] and HAMZA BOUABDALLAH[1]

[1]Centre de Recherche en Astronomie, Astrophysique et Géophysique (CRAAG), BP 63, 16340, Bouzaréah, Algiers, Algeria
[2]GDR Magnetisme des roches du CNRS, IPGP, 4 Avenue de Neptune, 94107, Saint-Maur cedex, France

A paleomagnetic study was performed by Morel et al. (1981) in the Abadla redbeds formation, but unfortunately in the undated levels. In spite of this lack of dating, this result is often considered as a reference direction for the African APWP.

Doubinger & Fabre (1983) carried out a palynological investigation in the Abadla redbeds formation. Microflora found in the lower levels gives an Autunian age, but the upper part remains undetermined. Thus, the aim of this study is to obtain dated paleomagnetic pole in the lower part of the Abadla redbeds formation. The comparison of this new pole with the Morel et al.'s one can yield an indication of the age of the upper part of these redbeds.

Paleomagnetic measurements pointed out the presence, in some samples, of a remanent magnetization component which corresponds to a recent partial or total overprint or to superimposed components with the same overlapped unblocking temperature spectra. Besides, a Characteristic Remanent Magnetization (ChRM) was found, in most specimens after elimination of a first (<300 °C) spectrum. The direction of this component is close to that of the Earth's present magnetic field and then is probably of a viscous nature. The mean direction of the ChRM, after dip correction, of 11 sites (96 samples and 20 great circles) is D = 130.1° I = 13.0° α_{95} = 3.6° by giving unit weight to each site. This direction orientation leads to the following Virtual Geomagnetic pole 29.1° S, 57.8° E.

The comparison of this pole with that (29° S, 60° E) determined by Morel et al. (1981), and the Moscovian one (28.7° S, 55.9° E) of the Illizi Basin, and those given by Upper Permian overprints of others Saharan areas (Daly & Irving 1983; Aifa 1987; Henry et al. 1992), show that our pole, obtained from well dated levels of the Abadla redbeds formation, is of Autunian age and cannot be the results of an Upper Permian remagnetization.

This study also showed that the previously undated upper levels of this redbeds series are likely to have an Autunian age.

References

Doubinger J. & Fabre J., 1983: Mise en évindence d'un Autunien a "Flore Mixte" dans le bassin de Béchar Abadla (Sahara Occidental Algérien). *Pollen et Spores,* XXIV, 1, 91-116.

Morel P., Irving E., Daly L. & Moussine-Pouchkine A., 1981: Paleomagnetic results from Permian rock of the northern Saharan craton and motions of the Moroccan; Meseta and Pangea. *Earth Planet. Sci. Lett.*, 55, 65-74.

Aifa T., 1987: Paléomagnétisme en zones de collison: déformations récentes dans l'arc Tyrrhénien et raccourcissement crustal hercynien en Afrique. *Thesis,* Paris.

Daly L. & Irving E., 1983: Paléomagnétisme des roches carboniféres du Sahara central; analyse des aimantations juxtaposées; configuration de la Pangée. *Ann. Geophys.*, 1, 207-216.

Henry B., Merabet N., Yelles A., Derder Mem. & Daly L., 1992: Geodynamical implicaations of a Moscovian paleomagnetic pole from the stable Saharan cration (Illizi basin, Algeria). *Tectonophysics,* 201, 83-96.

MAGNETOSTRATIGRAPHY AS A TECHNIQUE OF NOMINATION AND CORRELATION OF COAL BEDS: TWO EXAMPLES FROM THE WESTERN DACIC BASIN (RUMANIA)

SORIN C. RĂDAN and MARIA RĂDAN

Geological Institute of Rumania, 1 Caransebes Str., 79678 Bucharest, Rumania

The present paleomagnetic study is based in large collection of oriented cubic clay samples originating in Pliocene lignite quarries. "Up/down" oriented cores from two exploration bereholes were also used. The distance between the sampling levels was chosen so that we could obtain a good enough resolution for determining the length of magnetic polarity zones and so that we would not miss (short) paleomagnetic events. This has not been entirely the case of Husnicioara quarry (Mehedinti zone), where large sand deposits are developed and an important sedimentary gap has been remarked (Andreescu 1995).

To remove secondary magnetizations the stepwise thermal demagnetization method was applied. In some intervals small temperature increments have been used: 20°, 30°, 40°, 50 °C. Magnetic susceptibility monitoring and, in some cases, clay mineralogy study (Rădan et al. 1994) have been used to control changes in the behaviour of magnetic parameters during thermal demagnetization. As a result of alterations which occur during the consecutive heating steps to increasingly higher temperatures, new magnetic minerals are formed from magnetic precursors and non-magnetic matrix minerals as well (van Velzen & Zijderved 1992). The thermal decay curves of NRM must be carefully interpreted.

Magnetostratigraphic data obtained on Pliocene lignite-clay sequences investigated in 8 quarries from the Western Dacic Basin (Carpathian Foredeep) have resulted in a better temporal and spatial correlation of coal beds. Chronostratigraphic consequences including a higher resolution of the Dacian/Rumanian boundary (coincident with the Cochity Subchron) have already been pointed out (Rădan et al. 1992, 1995a, 1995b; Rădan & Rădan 1995).

In this paper two examples of the use of magnetostratigraphic technique to correct the nomination of lignite beds or to nominate unnumbered ones are discussed.

The first case is chosen from Montru-Jilt area. Magnetic polarities recorded in clays sampled from four districts of South Jilt quarry related to the successive coal exploitation steps led to the polarity sequence of the entire section. Normal polarities have been identified for the samples taken between coal bed **VII** and the last layer of the coal seam **VIII.** This interval represents the Cochity Subchron (4.18-4.29 Ma) and continues with a prolonged reversed polarity zone extended from the coal bed **VIII** up to below coal bed **XIII** which is assigned to the Upper Gilberet Chron (C2Ar). In the terminal part of the South Jilt section a mixed polarity zone has been found.

The numbering of the lignite layers existing between coal bed **VII** and coal seam **X** according to the local quarry geological documentation has been invalidated by our paleomagnetic arguments. The new coal nomenclature is consistent with the synonymous interval clearly numbered in Lupoaia quarry (also paleomagnetically investigated) and confirms the coal bed numbering proposed by Nica (pers. com.) for geological-mining reasons.

The second example chosen in the paper has been provided by Husnicioara section, a lignite quarry situated in the western extremity of the Dacic Basin.

The composite Husniciora section has been constructed on the basis of five subsections (related to the exploitation steps in quarry). The magnetic polarity zones identified for subsections have confirmed their positions established on the basis of four coal beds nominated **IV**, **x**, **y**, **z** and three lithological marker levels informally numbered **1**, **2**, **3**.

The resultant polarity sequence reveals normal magnetic polarity interrupted by two reversed polarity zones.

Excepting the coal seam **IV** (situated at the base of the quarry), the numbering of the three lignite beds, related to synonymous coal beds from other quarries is not known (consequently named **x**, **y**, **z**). As a result of the paleomagnetic investigation of the Husnicioara quarry a solution has been found.

The calibration to the GPTS (Cand & Kent 1992, 1995, Berggren et al. 1995a, 1995b) of the entire polarity sequence recorded in the composite section has revealed:

— the Nunivak Subchron (the lower and the upper boundaries have not been located), associated to the coal seam **IV** and the clays overlying it (up to an unconformous boundary between these clays and some thick sand deposits),

— the C2An.3n Chron (the lower boundary has not been located) which continues with the Mammoth Subchron, the

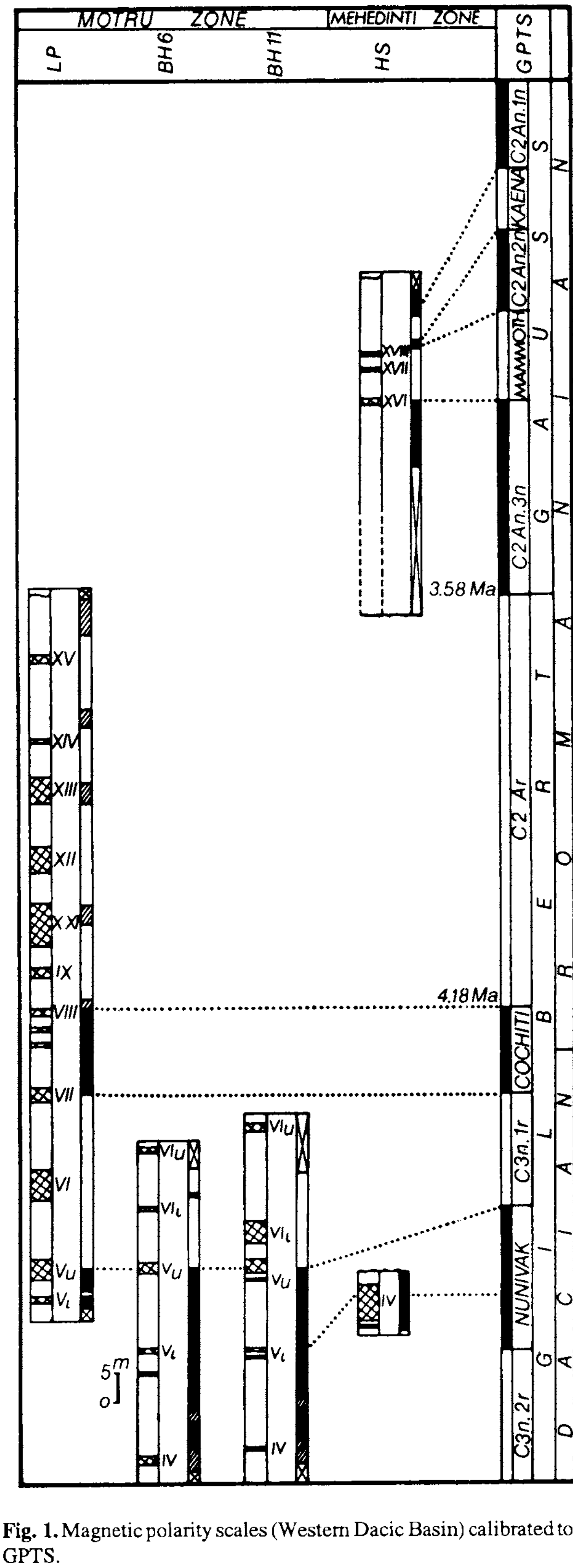


Fig. 1. Magnetic polarity scales (Western Dacic Basin) calibrated to the GPTS.

C2An.2n Chron, the Kaena Subchron and the lower part of C2An.1n Chron (in the terminal part of the section), all belonging to the Gauss Chron.

The C3n.1r Chron, the Cochity Subchron and the Upper Gilbert Chron (C2Ar) have not been identified, this paleomagnetic result being in agreement with the litostratigraphic and sedimentogenetic arguments (according to Andrescu 1995).

The magnetic polarity scales performed for the Husmicioara composite section (western extremity of the Dacic Basin) and the Lupoaia section completed with two subsections based on two boreholes (north-western Dacic Basin) are together calibrated to the GPTS (Rădan & Rădan 1995). As a result, an attempt to label the coal beds **x**, **y**, **z** located in the first mentioned section has been done, numbering them **XVI**, **XVII** and **XVIII**, respectively (Fig. 1).

Some other consequences of the magnetostratigraphic approach in the area are finally commented (e.g., the absence of the upper part of the Upper Dacian in the westernmost zone of the Dacic Basin).

References

Cande S.C. & Kent D.V., 1995: Revised calibration of the geomagnetic polarity timescale for the Lake Cretaceous and Cenozoic. *J. Geophys. Res.*, 100, B4, 6093-6095.

Rădan S., Rădan S.C., Rădan M. & Vanghelie I., 1994: Mineralogy and magnetic properties of baked clays in Pliocene coal deposits of the Dacic Basin, Romania. *Abstracts, Int. Mineral. Assoc., 167 Gen. Meet., Pisa*, Italy, 344-345.

Rădan S.C. & Rădan M., 1995: Paleomagnetism and Rock Magnetism of Upper Neogene deposits in the stratigraphic and sedimentogenetic context of the western Dacic Basin (Romania). *Abstracts*, 4th Workshop of IGCP-329 ("Paratethys Neogene"), Bucharest, Romania, 22.

Rădan S.C., Rădan M., Andreescu I. & Enciu P., 1995a: Pliocene magnetostratigraphy in the Western Dacic Basin (Romania). *Annales Geophysicae*, Suppl. 1 to Vol. 13, C 73.

Rădan S.C., Rădan M. & Andreescu I., 1995b: Magnetostratigraphy of Pliocene Lignite - Clay sequences in the Western Carpathian Foredeep (Romania). *Program and Abstracts. Vol. I, XXI IUGG Gen. Assem., Boulder*, Colorado, A 144.

Van Velzen A.J. & Žijderveld J.D.A., 1992: A method to study alterations of magnetic minerals during thermal demagnetisation applies to a fine-grained, marine marl (Trubi formation Sicily). *Geophys. J. Inst.*, 110, 79-90.

A STATISTICAL APPROACH TO GEOMAGNETIC POLARITY TIME SCALE OVER 1700 Ma

DIAMAR M. PECHERSKY[1], MAXIM Yu. RESHETNYAK[1] and DMYTRY D. SOKOLOFF[2]

[1]Institute of Physics of the Earth, B. Gruzinskaya 10, 123810 Moscow, Russia

[2]Moscow State University, Department of Physics, 119899 Moscow, Russia

During the Earth's history the direction of the field changed its sign, presented as a geomagnetic polarity time scale. Here we present the summary geomagnetic field combined with the sections:

I. For times less them 170 Ma, the 170-scale is accepted in the form which is performed by Harland et al. (1989).

II. For the Paleozoic and Mezozoic (170-570 Ma) summary magnetostratigraphic scale, which has been constructed for a territory of USSR by Molostovsky & Khramov (1984) is accepted; it is completed by the following regional magnetostratigraphic scales data:

a — Upper Triassic-Lower Jurassic of the Newark Basin by Witte et al. (1991),

b — Lower Carboniferous-Upper Cambrian of Urals by Danukalov et al. (1983),

c — Lower Cambrian of Eastern Siberia by Kirschvink & Rozanov (1984).

III. For the Vendian and Rifey (560-1700 Ma) we used:

a — summary magnetostratigraphic scale of the Vendian-Rifey of Eastern Siberia, Kuznetskiy Alatau by Osipova et al. (1988) and Middle-Proterozoic supergroup of North America (Montana and Idaho) by Elston & Bressler (1980). These scales have the same general shape and approximately the same number of inversions,

b — the magnetostratigraphic section of low metamorphic Lower-Rifeian deposits (about 1600-1700 Ma) for McArthur Basin, Australia by Idnurm (1992).

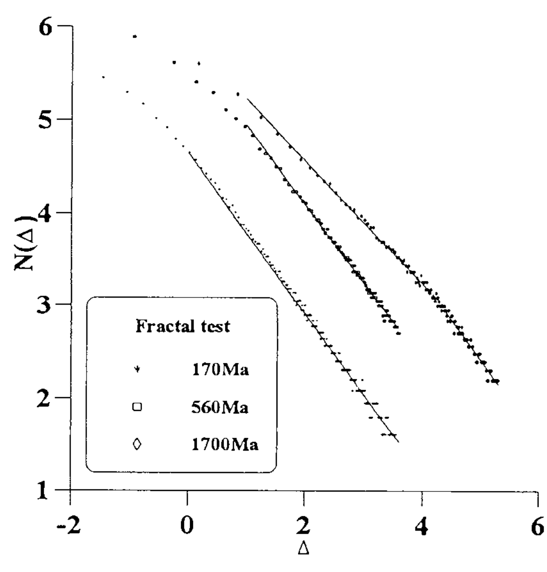
The data series presented only the information about the sign of geomagnetic field and asked for great cannot be used for any stratigraphical purposes.

We propose that this scale is the product of the random process of the geodynamo mechanism generating the magnetic field of the Earth. Thus the statistical approach may be used to study this scale. We present the histogram of the frequency of the scale.

One of the main feature of this scale is the existence of different time regions of the same polarity. It follows that it can be investigated in terms of fractal objects and be characterized in terms of its Hausdorf dimension d and measure M and (Anufriev & Sokoloff 1994):

$$N(\Delta) = M\Delta^{-d}$$

Here $N(\Delta)$ is the number of intervals of length Δ in which at least one inversion is present. The plot of dependence $N(\Delta)$ is presented in the figure:



We observe the same value of Hausdorf dimension d of order 0.8 for the periods less then 560 Ma. We suppose it has the direct connection with geodynamo mechanism. For the period of time 0-1700 Ma we observe the appearance of the new process in terms of fractal analysis with Hausdorf dimension equal to 1. The results obtained considered in terms of geodynamo theory.

Authors are gratefully to financial support of RFFI under Grant N94-06-17628.

References

Anufriev A. & Sokoloff D., 1994: Fractal properties of geodynamo models. *Geophys. Astrophys. Fluid Dynam.*, 1994, 74, 207.

Danukalov N.F., Kondruchina L.S. & Chernikov A.P., 1983: Paleozoic paleomagnetism of the South and Middle Ural. *UFA, BF AN USSR*, 120.

Elston D.P. & Bressler S.L., 1980: Paleomagnetic poles and polarity zonation from the Middle Proterozoic Belt Supergroup, Montana and Idaho. *J. Geophys. Res.*, 85, 339.

Harland W.B., Armstrong R., Cox A., Craig L., Smith A. & Smith D., 1990: A geologic time scale. *Cambridge University Press*, NY, 263.

Idnurm M., 1992: Paleomagnetism delivers a "whopper" on the southeastern McArthur Basin. *AGSO Research Newsletters*, 17, 132-138.

Kirschvink J.L. & Rozanov F.Yu., 1984: Magnetostratigraphy of Lower Cambrian strata from the Siberian platform: a palaeomagnetic pole and a preliminary polarity time-scale. *Geol. Mag.*, 121, 189.

Molostovsky E.A. & Khramov A.N., 1984: Paleomagnetic scale for the Phanerozoic and magnetostratigraphic problems. *Proceeding of 27 Internat. Geol. Congress, v. 1, Moscow, Nauka*, 31.

Osipova E.P., Rodionov V.P. & Khramov A.N., 1988: Paleomagnetic stratigraphy of Precambrian. Geomagnetism. *Theoretical and practical aspects. Naukova Dumka*, Kiev, 126, (in Russian).

Witte W.K., Kent D.V. & Olsen P.E., 1991: Magnetostratigraphy and paleomagnetic poles from Late Triassic-Earliest Jurassic strata of the Newark basin. *Geol. Soc. Amer. Bull.*, 103, 1648.

MAGNETIC PROPERTIES OF DIFFERENT GRAIN SIZE FRACTIONS IN LOESS SEDIMENTS FROM PAKS (HUNGARY)

MAURIZIO SARTORI[1], THOMAS FORSTER[1], FRIEDRICH HELLER[1], MICHAL BORKOVEC[2] and JEAN M. HAMMANN[3]

[1]Institut für Geophysik, ETH-Zürich, CH-8093 Zürich, Swirzerland
[2]Institute für Terrestrische Oekologie, ETH-Zürich, CH-8952 Schlieren, Switzerland
[3]SPEC, Centre d'Etudes de Saclay, F-91191 Gif-sur-Yvette, France

The loess sequence exposed in the brickyard of Paks (Hungary, ca. 100 km south of Budapest) reaches a thickness of about 49 meters, and contains nine paleosols and two embryonic soils. The sequence consists of the so-called young loess unit representing the upper 28.9 meters and of the underlying old loess-paleosol sequence. A detailed magnetostratigraphical analysis located the Matuyama/Brunhes boundary at a depth of 43.8 m in the old loess layer L5 between the paleosols PD1 and PD2 (lithology designation after Pécsi 1979). The magnetic susceptibility has been measured in 10 cm intervals along the section. The magnetic signal is enhanced in all paleosols with susceptibility values which are up to ten times higher than the signal in the loesses.

In order to investigate the magnetic properties of different grain size fraction, a few samples from this loess section have

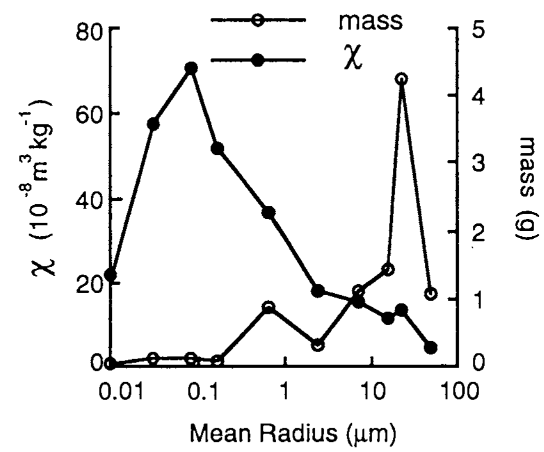


Fig. 1. Specific susceptibility χ and mass as a function of grain size in a paleosol sample (profile depth: 23 m).

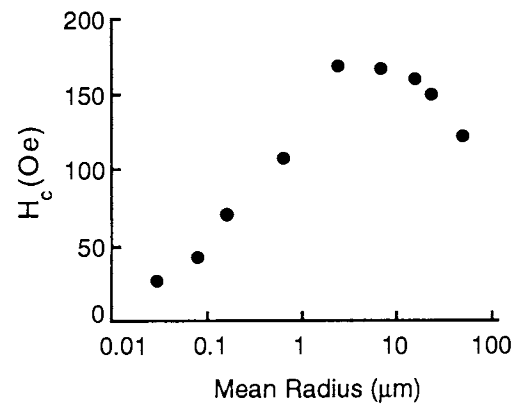


Fig. 2. Coercivity distribution in an altered loess sample (profile depth: 23.2 m).

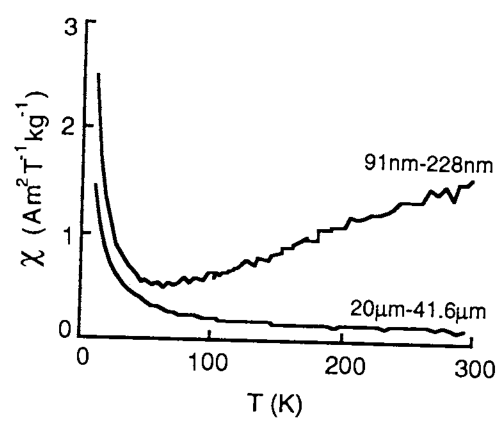


Fig. 3. Specific susceptibility χ in two grain size fraction of an altered loess sample (profile depth: 23.2 m).

been separated into ten fractions between 11 nm and more than 50 μm using sedimentation and centrifugation methods. The grain size distribution depends on the lithology, having a maximum at ca. 1 μm in the paleosols and at ca. 20 μm in loess samples. Hysteresis curves have been measured on an alternating gradient magnetometer (MICROMAG) and low field susceptibility and its frequency on a Bartington susceptibility bridge using a dual frequency sensor. A cryogenic SQUID-magnetometer S-600 has been used in different characteristic modes for zero field cooling (ZFC), field cooling and hysteresis loops.

Maximum specific susceptibility is observed at grain sizes around 0.1 μm in paleosols and sligthly weathered loesses (Fig. 1). A broad coercivity maximum occurs between 0.2 and 2 μm which drops off sharply at the smaller grain sizes (Fig. 2).

The low temperature dependence of susceptibility in the ZFC experiment is predominated by paramagnetic contributions in the coarse grained fractions above 0.3 μm whereas superparamagnetic contributions become significant in the fraction below 0.3 μm (Fig. 3). The onset of the superparamagnetic signal varies between 20 K and 50 K in the fines fractions and allows estimation of the minimum grain size of the ferromagnetic minerals in the paleosols.

References

Pécsi M., 1979: Lithostratigraphic subdivision of the loess profiles at Paks. *Acta Geol. Acad. Sci. Hung.*, 22, 409-419.

RECONCILING ROCK MAGNETIC MEASUREMENTS AND ORE MICROSCOPY OF IGNEOUS ROCKS

GRAHAM SHERWOOD*, SILVIA GONZALEZ, YUQUAN HU, MARÍA JULIA ORGEIRA and HARALD BÖHNEL

*School of Biological & Earth Sciences, Liverpool John Moores University, Byron St., Liverpool, L3 3AF, UK

In our paleointensity studies using igneous rocks we routinely measure a number of rock magnetic properties, and also often observe the grains directly using reflected light microscopy. Whilst measurements of hysteresis parameters and Curie temperatures are widely used, the variation of low-field susceptibility from liquid nitrogen temperature up to room temperature is studied less frequently. The pioneering work by Radhakrishnamurty and Likhite (for summary see Radhakrishnamurty 1993) led to the development of the technique as a method for determining both grainsize and composition of the magnetic minerals present in the sample. Radhakrishnamurty et al. (1977) interpreted variations in low temperature susceptibility behaviour in basalts purely in term of domain state and ignored compositional variations in the titanomagnetites (Senanayake & McElhinny 1981). Whilst the interpretation of most types of behaviour is now certain, with measurements on well characterized artificial samples (Radhakrishnamurty & Likhite 1993), the interpretation of samples which show a decrease in susceptibility on warming is not so well understood. A relative susceptibility (RS) of about 2.5 could be explained by the dominance of paramagnetic susceptibility in the sample, and RS values of 1.1 to 1.5 seem to match experimental observations of TM10. The problems arrive when we observe behaviour which does not conform to these norms.

We will present data from a number of igneous rocks from different parts of the world, which exhibit low temperature susceptibility behaviour which do not fit observations on synthetic samples. In particular, we will show data from basalts from Mexico and Argentina which have susceptibility values at liquid nitrogen which are many times (RS values between 7 and 10) their room temperature levels. Our microscopic observations seem to suggest that basalts which show a decrease in susceptibility with temperature often contain high concentrations of ilmenite, and it is possible that in these samples with extreme RS values we are observing the unblocking of an impure ilmenite.

References

Radhakrishnamurty C., 1993: Magnetism and basalts. *Geol. Soc. India Mem.*, 26, 1-208.

Radhakrishnamurty C. & Likhite S.D., 1993: Frequency dependence of low-temperature susceptibility peak in some titanomagnetites. *Phys. Earth Planet. Int.*, 76, 131-135.

Radhakrishnamurty C., Likhite S.D. & Sahasrabudhe P.W., 1977: Nature of magnetite grains and their effects on the magnetism of basalt. *Phys. Earth Planet. Int.*, 13, 289-300.

Senanayake W.E. & McElhinny M.W., 1981: Hysteresis and susceptibility characteristics of magnetite and titanomagnetites: interpretation of results from basaltic rocks. *Phys. Earth Planet. Int.*, 26, 47-55.

THE DRM DURING REVERSAL

VSEVOLOD VADKOVSKY

Geological Department, Moscow State University Vorobjovy Gory, 119899 Moscow, Russia

The role of the geomagnetic field variations in formation of detrital remanent magnetization (DRM) including the post-sedimental stage is discussed. It has been found that the most likely direction of particle orientation may not coincide with the direction of the permanent geomagnetic field, at certain ratios medium viscosity, own magnetic moment, amplitude and frequency of variations.

The nonlinear equations descriptive of particle dynamic in the magnetic field are considered. The solution of these equations has been performed by numerical methods on computer.

Stable and unstable areas of solutions have been found. The solution analyses have revealed that small energy of variable geomagnetic field is accumulated in system over a long period of time.

The results are compared with the experimental data obtained from the investigations of DRM in the process of reversals.

PALEOMAGNETIC DATA BASE IN WDC B FOR SOLID EARTH PHYSICS

NATALIA SERGREYEVA

Geophysical Center, Russian Academy of Sciences,
Molodezhnaya str. 3, 117296, GSP-1, Moscow, Russia

As a rule analysis of paleomagnetic data involves the complete resources of a great number of other geological-geophysical global or regional data.

The significant part of WDC B for the Solid Earth Physics archive consists of planetary digital data for seismology, gravity, main magnetic field and its variations over time, archeo- and paleomagnetism, heat flow, marine geology and geophysics, recent movements of the Earth's crust, topography, coast lines, volcanoes, linear anomaly axes and transform faults in the World ocean and so on.

The availability of the great diversity of data is favourable for the investigation work. The special software for comprehensive computer analysis of paleomagnetic data together with tectonics, geological, seismological and other data have been developed on GIS technology in WDC B together with Geological Dept. of Moscow State University.

THE SIGNIFICANCE OF STATISTICAL AND EFFECTIVE PRECISION OF PALEOMAGNETIC DATA IN TECTONIC INTERPRETATION

EMÖ MÁRTON

Eötvös Loránd Geophysical Institute,
Columbus út 17-23, 1145 Budapest, Hungary

As is well-known, the statistical precision of paleomagnetic data is expressed by statistical parameters. Relative movements between continents, blocks, nappes etc. are postulated on the basis of statistically significant differences between paleomagnetic directions characterizing each of them.

Most of the paleomagnetists who apply their method to tectonics are aware of the problem, that statistical parameters may be non-comparable, simply because the data combination in paleomagnetism is not standardized. Moreover, hidden errors may influence unfavourably the true precision of data. It is clear, therefore, that a simple procedure of statistical comparison must be replaced by comprehensive analysis of possible sources of "error", i.e. the effective precision of the data must be considered in tectonic interpretation.

The method of data combination, the problem of unremovable (or not removed) overprint, the bias due to local tectonics, the influence of anisotropy on true precision, the time factor will be examined from the viewpoint of true precision.

It will be shown that several conditions must be fulfilled before we can safely use statistical parameters as expressions of effective precision. Finally, a few guidelines will be suggested that may promote fast and effective checks on paleomagnetic data as well as on the reliability of tectonic interpretations based on them.

MAGNETIC PROPERTIES AT LOW TEMPERATURE AND THERMAL ALTERATION OF SYNTHETIC GREIGITE

MARK J. DEKKERS[1] and MARTIN A.A. SCHOONEN[2]

[1]Paleomagnetic Laboratory 'Fort Hoofddijk', Faculty of Earth Sciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands
[2]Department of Earth and Space Sciences, State University of New York at Stony Brook, Stony Brook NY 11794-2100, USA

Recently, paleomagnetic interest in the modes of occurrence of greigite (Fe_3S_4) and the stability of NRMs residing in greigite has increased considerably. Greigite is meanwhile reported in quite a number of cases, in particular in sedimentary rocks (e.g. Roberts 1995). Consequently, there is a real need for diagnostic criteria to be able to detect greigite in low concentrations in various rock types. Rock magnetic parameters are principally suited to satisfy this criterion, because they are sensitive and usually non-destructive. The rock magnetic properties of greigite, however, are not yet well established but considerable research effort is directed toward this issue (e.g. Krs et al. 1990, 1992; Snowball & Thompson 1988, 1990; Hoffmann 1992; Reynolds et al. 1994; Roberts 1995; Dekkers & Schoonen, accepted). Characteristic of greigite are a high M_{rs}/χ_{in} ratio (e.g. Snowball & Thompson 1988, 1990; Roberts 1995) and typical thermomagnetic behaviour when heated in air (Reynolds et al. 1994). Most of the data available to date refer to natural greigite. Dekkers & Schoonen (1994, accepted) designed a hydrothermal synthesis recipe that yields greigite of a reasonable purity which can be handled in laboratory experiments without being oxidized before meaningful experimental parameters have been acquired.

To further complete the chart of rock magnetic properties of greigite, the synthetic material of Dekkers & Schoonen (1994, accepted) was subjected to thermomagnetic experiments using low and high applied magnetic fields. The former set of experiments was carried out with a CS2 heating unit on a KLY-2 susceptibility bridge while for the latter the modified horizontal translation Curie balance (Mullender et al. 1993) was used.

Curie balance measurements in air indicate that the synthetic greigite is oxidized completely to hematite after heating at 350 °C; only occasionally traces of intermediate magnetite are observed. Intermediate magnetite as evidenced by an increase in magnetization between 400 and 450 °C, is more prominent in natural greigite which is presumably slightly coarser grained than the present synthetic greigite (up to 400 nm in size). Heating in air already shows alteration after 250 °C: an irreversible decrease in magnetization occurs. In argon, a minute increase is observed at ~200 °C, a decrease after the 350 °C run, while some pyrrhotite is produced after the 450 °C run (Curie temperature slightly above 300 °C). Heating in an argon atmosphere ultimately yields magnetite and pyrrhotite in varying amounts. This indicates that some sorption of oxygen onto the surface of the particles or minute oxidation of the greigite particles upon storage in dry air (silicagel) must have occurred. Magnetite formation is more prominent in less pure samples.

Obviously, heating curves of χ_{in} are different in air and in an atmosphere. In air, χ_{in} decreases slightly upon heating to 350 °C, upon heating to 450 °C some magnetite is formed which does not oxidize completely to hematite upon heating to 650 °C. Magnetite formation seems to be more prominent in greigite samples with a low saturation magnetization which are less pure. In contrast to Curie balance runs where the magnetite is oxidized, the sample insert of the CS2 heating unit apparently does not contain sufficient amount of air to have the oxidation reaction fully completed. In argon, χ_{in} show a reversible behaviour upon heating to 350 °C. Upon heating to 450 °C, pyrrhotite is formed as indicated by a discontinuity in χ_{in} at 320 °C. The amount, however, cannot be assessed. Magnetite formation hardly occurs upon further heating to 650 °C. After the runs the sample insert is yellow due to evolving elemental sulphur which precipitates when reaching the cooler top part. Staining by elemental sulphur was not observed in the Curie balance runs.

No magnetic transition similar to the Verweij transition is observed upon the cooling to 4 K of a SIRM induced at room temperature. Also observations made on natural greigite show no transition (e.g. Moskowitz et al. 1993; Roberts 1995). This may be related to the suggestion that the [100] direction is the easy axis in greigite at room temperature rather than the [111] direction which is the case for magnetite. Unfortunately, the absence of a magnetic transition during cooling is no positive criterion for the presence of greigite in a rock because other magnetic minerals may not show any transition either. M_{rs} of the synthetic greigite seems to reach maximum values at ~10 K. This property is also measured for natural greigite and may develop into a diagnostic tool for greigite in cases where thermal alteration must be avoided.

References

Dekkers M.J. & Schoonen M.A.A., 1994: An elektrokinetic mobility study of synthetic greigite and pyrrhotite. *Geochim. Cosmochim. Acta*, 58, 4147-4153.

Dekkers M.J. & Schoonen M.A.A., accepted for publication: Magnetic properties of hydrothermally synthesised greigite (Fe_3S_4). 1. Rock magnetic parameters at room temperature. *Geophys. J. Int.*

Hoffmann V., 1992: Greigite (Fe_3S_4): magnetic properties and first domain observations. *Phys. Earth Planet. Inter.*, 70, 288-301.

Krs M., Krsová M., Pruner P., Zeman A., Novák F. & Jansa J., 1990: A petromagnetic study of Miocene rock bearing micro-organic material and the magnetic mineral greigite (Sokolov and Cheb basins, Czechoslovakia). *Phys. Earth Planet. Inter.*, 63, 98-112.

Krs M., Novák F., Krsová M., Pruner P., Kouklíková L. & Jansa J., 1992: Magnetic properties and metastability of greigite-smythite mineralization in brown-coal basins of the Krušné hory Piedmont, Bohemia. *Phys. Earth Planet. Inter.*, 70, 273-287.

Moskowitz B.M., Frankel R.B. & Bazylinski D.A., 1993: Rock magnetic criteria for the detection of biogenic magnetite. *Earth Planet. Sci. Lett.*, 120, 283-300.

Mullender T.A.T, van Velzen A.J. & Dekkers M.J., 1993: Continuous drift correction and separate identification of ferrimagnetic and paramagnetic contributions in thermomagnetic runs. *Geophys. J. Int.*, 114, 663-672.

Reynolds R.L, Tuttle M.L., Rice C.A., Fishman N.S., Karachewski J.A. & Sherman D.M., 1994: Magnetization and geochemistry of greigite-bearing Cretaceous strata, North Slope Basin, Alaska, *Am. J. Sci.*, 294, 485-528.

Roberts A.P., 1995: Magnetic properties of sedimentary greigite (Fe_3S_4). *Earth Planet. Sci. Lett.*, 134, 227-236.

Snowball I. & Thompson R., 1988: The occurrence of greigite in the sediments of Loch Lomond. *J. Quat. Sci.*, 3, 121-125.

Snowball I. & Thompson R., 1990: A stable remanence in Holocene sediments. *J. Geophys. Res.*, 95, 4471-4479.

MAGNETIC STATES OF QUASI-SINGLE-DOMAIN MAGNETITE GRAIN

L.L. AFREMOV, B.E. LAMASH* and A.V. PANOV

*Department of Physics, Far Eastern State University, Vladivostok, 690600, Russia

Paleomagnetic stability of rocks depends on the quality as well as grain-size of their magnetic particles. We prefere an idea to collect rock samples containing magnetic minerals of small-sized particles (with a size close to single-domain one). The remanent magnetization of such rocks has high stability in relation to temperature, chemical and other effects. However, the availability of a metastability of magnetic states of considered particles can essentially affect safety of a remanent magnetization that plays an essential role in diagnostic of its form.

The last time enough works, basically theoretical, on was executed study of particles such size. However, one of these researches cannot apply for completeness of consideration. We attempted analyse of magnetic states in the framework of the following model: two-domain magnetic particle has the shape of rectangular parallelepiped with the square of basis a^2 and height qa (the cubic edges coincide with crystallographic axes), the magnetic moment can change its orientation only in a plane of a parallel one of extended sides.

The modelling of distribution of a magnetic moment of a grain was conducted by minimization of complete energy E, including by exchange energy, magnetostatic energy and energy of a crystallographic anisotropy by four parameters θ_1, θ_2, p_1, p_2. As a result, it has appeared possible to allocate three types of magnetic state:

— state with a uniform magnetization,

— state with small (quasi-single-domain) and

— with a large heterogeneity of a magnetic moment (two-domain).

The state with the uniform vector I_s is main only in a interval of the sizes, limited by the single-domain size a_0, which behaves unmonotonely by a image with growth of a grain (Fig. 1).

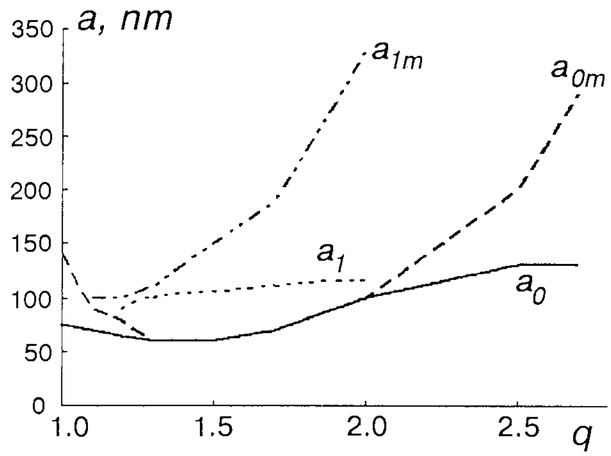


Fig. 1. The dependence of sizes of single-domain state a_0 and quasi-single-domain state a_1, maximum size for existence of single-domain state a_{0m} and maximum size for existence of quasi-single-domain state a_{1m} from the grain elongation q.

At a > a_0 the two-domain state energetically more expediently than quasi-single domain state, but single-domain state, if it will be realized, is metastable up to the limiting size a_{0m}. The dependence a_{0m} from a grain elongation q is submitted on Fig. 1. As we can see, a_{0m} decreases in two times at a increase of a grain elongation from q = 1 up to q = 1.3 and then grows and at q > 2.8 the uniformity of distribution of the magnetic moment can be realized in particles of all sizes.

States with the weak non-uniform distribution I_s are equilibrium only in the area $a_0 < a < a_1$ (Fig. 1), at $a_1 < a < a_{1m}$ they are metastable (here a_1 is a size of quasi-single-domain state, a_{1m} is a maximum size for existence of quasi-single domain state). We shall note also, that at q > 2.5 the quasi-single domain state can be realized in particles of any sizes large a_{0m}.

The transition from a state with uniform distribution I_s in two-domain state can be executed as through quasi-single domain state at 1.1 < q < 2.5 (Fig. 1) as passing it (1.0 < q < 1.1). In the first case the heterogeneity of a magnetic moment is increased with growth of the particle size and a > a_{1m} the grain from quasi-single domain state passes in two-domain state.

Essential feature of obtained results in unmonotone of change of the single-domain size from the grain elongation. Such dependence $a_0 = a_0(q)$ is connected with unmonotone behaviour of an effective constant of an anisotropy, which is result of tensor addition of constants of the crystallographic anisotropy and the anisotropy of the form.

UNUSUAL THERMOMAGNETIC BEHAVIOUR OF SEVERAL NATURAL HEMATITES

COR B. DE BOER[1], MARK J. DEKKERS[1] and EDUARD PETROVSKÝ[2]

[1]Paleomagnetic Laboratory 'Fort Hoofddijk', Faculty of Earth Sciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands
[2]Geophysical Institute, Boční II/1401, 141 31 Praha 4, Czech Republic

A Curie balance is a useful tool in magnetomineralogic research by monitoring the (saturation) magnetization as a function of temperature. Thermomagnetic analysis not only provides mineral specific Curie (or Néel) temperatures (resp. T_C or T_N), but also yields essential information concerning changes in magnetic structure (i.e. crystal structure) and chemical reactions involving ferromagnetic minerals. We recorded thermomagnetic runs for several pure hematites on an ultrasensitive modified horizontal translation type Curie balance (Mullender et al. 1993) to distinguish different 'types' of hematites by their thermomagnetic behaviour and to detect changes in the structure of the hematites during heating.

Hematite shows two common types of thermomagnetic behaviour, mainly depending on the strength of the applied magnetic field. If the applied field is not capable of saturating the hematite sample, the decrease in microcoercivity outweighs the decrease in M_s with increasing temperature, so that a gradual increase in magnetization can be observed up to ~600 °C before the curve starts to decrease more steeply up to the Néel point. The thermomagnetic curves, however, tend to be flatter for higher applied fields (Duff 1979). If the magnetic field is high enough to saturate the hematite, the 'model' M_S-T curve of hematite results, characterized by a typical block-shape (e.g. Pullaiah et al. 1975): hardly any change in M_S until ~500 °C and a steep decrease after ~650 °C to the T_N of ~680 °C. If no textural changes occur as a consequence of the heatings, the described thermomagnetic curves will be reversible on cooling.

Here, we present two natural hematites which show a thermomagnetic behaviour noticeably different from the general trend outlined before. Figure 1 shows the thermomagnetic curves of a platy hematite (LH 4) described by Hartstra (1982). Repeated runs to increasingly higher temperatures (run 1 & 2) up to 700 °C yield curves with an upward convex shape. Differences between the heating and cooling curves are probably explained by textural changes that influence the magnetic structure of hematite. The cooling curve of run 2 and the curves of subsequent runs to 800 °C, however, show the characteristic block-shape of hematite, with magnetization values at 100 °C typically around 0.3 Am^2/kg. Moreover, all

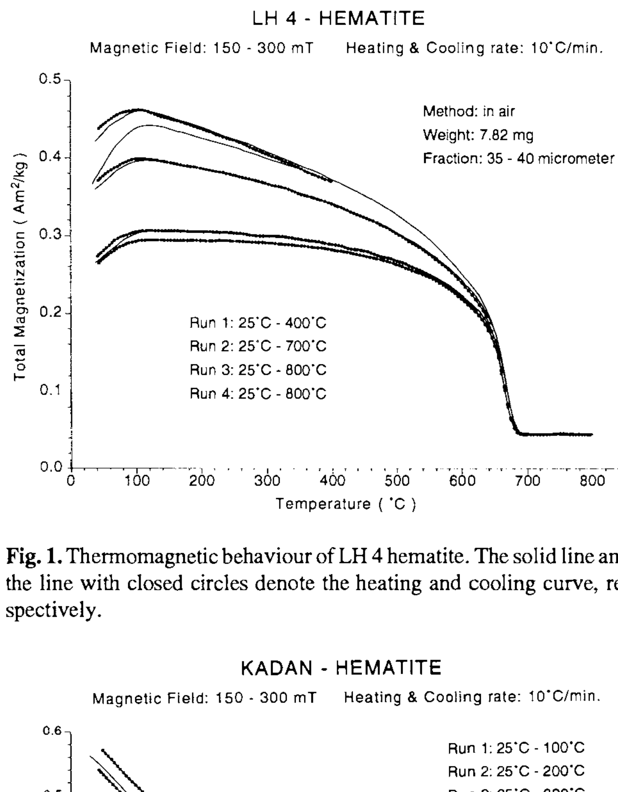


Fig. 1. Thermomagnetic behaviour of LH 4 hematite. The solid line and the line with closed circles denote the heating and cooling curve, respectively.

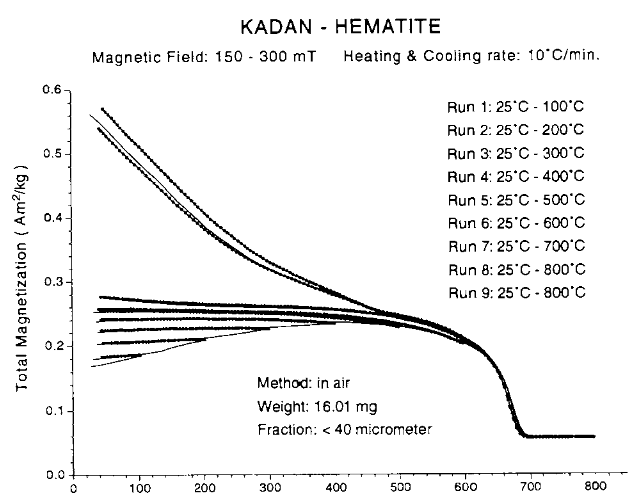


Fig. 2. Thermomagnetic behaviour of Kadaň-hematite. Symbols as in Fig. 1.

curves show a characteristic maximum in magnetization around 100 °C. We interpret the initial increase in magnetization from room temperature (RT) to ~100 °C as the onset of the Morin transition at this temperature, in contrast to commonly reported onsets of the Morin transition below RT. Hartstra (1982) reported that the Morin transition for LH 4 hematite was more an interval (spanning a temperature range -75 °C to +100 °C), rather than a well-defined sharp transition.

In Figure 2, the variation of magnetization with temperature is given for a highly pure natural hematite of hydrothermal origin (Kadaň, Czech Republic). Repeated cycling (run 1-7) up to a maximum of 700 °C show a T_N (680 °C) typical of pure hematite. We attribute the irreversibility of the curves to a recrystallization process which seems to soften the hematite until the specific block-shape is reached, with a magnetization of ~0.3 Am^2/kg at RT. Substantial textural changes can apparently already be induced at relatively low temperature in hematite. The first cycling to 800 °C (run 8), however, shows upon cooling an additional Curie point at ~470 °C, corresponding to a newly formed magnetic phase. No hematite-like phase with a T_C of 470 °C is, to the best of our knowledge, known in literature. The curves now have a downward convex shape indicating ultrafine superparamagnetic grains. Unfortunately, this new magnetic phase could not be detected with X-ray diffraction analysis indicating a weight percentage of <5 %.

We suggest that stress- and defect-'poor' hematites tend to have the characteristic block-shaped thermomagnetic curves (if close to saturation) with a magnetization at RT typically close to 0.3 Am^2/kg (in the applied magnetic field of 450 mT of the Curie balance used). "Stressed" hematites, however, deviate from this specific behavior by not having the block-shape, and magnetization values at RT which are lower or, surprisingly, even higher than 0.3 Am^2/kg (ranging ~0.15-~0.5 Am^2/kg). Additional rock magnetic properties of these hematites and the enigmatic newly formed phase are currently being measured for a detailed characterization.

References

Duff B.A., 1979: Peaked curves for hematite-bearing rocks and concentrates. *Phys. Earth Planet. Inter.*, 19, 1-4.

Hartstra R.L., 1982: Some rockmagnetic parameters for natural iron-titanium oxides. *Ph.D. thesis, Utrecht University*, Utrecht, 1-145.

Mullender T.A.T, van Velzen A.J. & Dekkers M.J., 1993: Continuous drift correction and separate identification of ferrimagnetic and paramagnetic contributions in thermomagnetic runs. *Geophys. J. Int.*, 114, 663-672.

Pullaiah G., Irving E., Buchan K.L. & Dunlop D.J., 1975: Magnetization changes caused by burial and uplift. *Earth Planet. Sci. Lett.*, 28, 133-143.

THE INFLUENCE OF VANADIUM OXIDE ACCESSORIES ON THE CURIE TEMPERATURES OF NATURAL MAGNETITES

ALEXY G. GORCHKOV and V.Yu. SAFROCHKINE

Institute of Oceanology, Russian Academy of Science, Krasikova 23, Moscow, Russia

We developed and promoted the spectral thermomagnetic analysis method that permits us to make the precise measurements of Curie points for the complex phase composition.

In our research we carried out the spectral thermomagnetic investigation of vanadium containing magnetite and correlated these results with the data of detailed micro spectral analyses of these samples. The results are displayed in the Tab. 1. The objects of investigation were the separated ore fractions of Indian granulites (samples 1-2) and titanium-vanadium ores from Iran. The magnetization-temperature relationship I(T) was measured in the constant magnetic field H = 0.12 Tesla by the vibromagnetometer. Under the assumption that the influence of each admixture on the T_c is linear, we form the system of equations that minimizes the mean-square error between calculated and experimentally obtained Curie points. Where the calculated Curie point (T calc) for each sample is computed as 575 °C degrees minus the linear combination of the weight percents of admixtures mentioned in the table with the unknown coefficients "K". These coefficients show the degree of the depression of the Curie points of natural magnetites affected by the admixtures.

The solution of this system revealed that 1 wt. % of the admixture decreases the magnetite Curie point in the following way: V_2O_5 — to 9.1, TiO_2 — to 5.2, Al_2O_3 — to 5.6, Cr_2O_3 — to -1.1 °C; according to our solution the differences between measured and calculated Curie points is less then 2 °C. The accuracy of coefficients "K" definition can be roughly estimated by the disagreement of T_c and T calc from the Tab. 1. Although the theory supposes the depression for TiO_2 to be 25-30 °C, the low values obtained by our work as well as the negative value for Cr_2O_3 suggests that in the investigated rocks the main part of TiO_2 and Cr_2O_3 is not an isomorphic composition of the magnetite structure but is a part of another mineral inclusion such as an ilmenite.

The interpretation of the obtained data allows us to suppose that the influence of the vanadium oxide on Curie points of the natural magnetites exceed the influence of the other admixtures by more than two times. This result allows us to use the thermomagnetic analyses for the quick and cheap estimation of the vanadium contents in ore deposits.

Table 1:

Sample No	T °C exp.	admixture concentration [wt. %]				Analysis No	T °C calc.
		V_2O_5	TiO_2	Al_2O_3	Cr_2O_3		
1	532	2.10	2.10	1.91	0.30	8	534
2	559	1.01	0.32	0.93	0.51	6	559
3	551	1.51	1.12	0.94	0.11	40	550
4	549	2.44	0.47	0.71	0.06	28	546.5
5	541	2.32	1.08	1.01	0.08	22	542.5

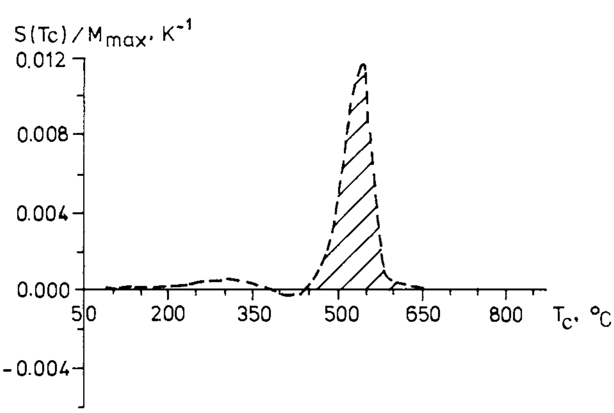


Fig. 1

Reference

Akimoto S., Katsura T. et al., 1957: Magnetic properties of Fe_2TiO_4 -Fe_3O_4 system and their change with oxidation. *Journal of Geomagnetic and Geoelectric,* 9, 4, 165-178.

MAGNETOSPECTRAL INVESTIGATION OF ROCKS AND SEDIMENTS — A RADICALLY NEW TECHNOLOGY OF THE MAGNETOACTIVE MINERALS RESEARCH

ALEXY G. GORCHKOV and V.Yu. SAFROCHKINE

Institute of Oceanology, Russian Academy of Science, Krasikova 23, Moscow, Russia

Up to now there was not an efficient method of investigation of rock magnetic phases, particularly in the event of several magnetoactive minerals present in one sample. We have developed and promoted radically new methods which enables us to obtain the qualitative and quantitative composition of all the ferromagnetic phases of the specimen as well as the dominant type of the domain structure of each ferromagnetic mineral and to compute the input of any phase and mineral generation into the magnetization of the specimen. These methods are spectral thermomagnetic analysis (STMA) and the spectral analysis of coercivity curves (SCA). The central idea of these spectral methods is a representation of the thermomagnetic or coercive curve as a sum of corresponding curves for a great number of pure phases and the identification of the isolated phases. These procedures are based on original theoretical and wide experimental material and are realized as an original software. The sensitivity of STMA is 10^{-6} g/cm^3 for the magnetite, 10^{-5} g/cm^3 for the hemoilmenite, and 10^{-3} g/cm^3 for sulphides. The phase is adequately detected if its magnetization is no less than 5 % of total I_s or total I_{rs} of the specimen.

We conducted studies of different rock types of the oceanic crust. We showed that even the fresh basalts of the axes of the mid-oceanic ridges are affected by the processes of the single-phase oxidation. Besides this, we separated the samples affected by the hydrothermal alteration, and estimated the range of temperature of the hydrothermal fluids. In some cases the presence of the sulfides was located and their mineralogy was investigated.

We studied the Gorringe Ridge (NE Atlantic) serpentinites. Whereas the only magnetoactive mineral of those rocks is magnetite, the SCA techniques application revealed that in many samples there are two generations of magnetite with different domain structure. The subsequent investigation intimated that multidomain magnetite grains are of primary origin, and the pseudosingledommain ones — of secondary origin. The secondary magnetite generation was formed from the primary one under the action of the tectonic stress.

In such a manner magnetospectral mineralogy enables us to reconstruct the tectonic and geological history of the oceanic crust.

SPHEROIDAL VS. TRIAXIAL MAGNETIC PARTICLES IN AMS TO STRAIN RELATIONSHIP MODELS: VIRTUALLY NO DIFFERENCE

FRANTIŠEK HROUDA[1] and J. JEŽEK[2]

[1]AGICO Inc., Box 62, 612 46 Brno, Czech Republic
[2]Institute of Petrology and Structural Geology, Charles University, Albertov 6, 128 43 Praha, Czech Republic

The individual spheroidal particles in the Jeffery model of deformation behave very differently than individual triaxial particles. This may imply different AMS to strain models for spheroidal and triaxial particles, respectively. However, our modelling has shown that in the multi-particle AMS to strain models, the defferences between the above respective models are small. This is explained by some "averaging out" process in the multi-particle system.

BLOCKING TEMPERATURES OF AN ENSEMBLE OF INTERACTING SINGLE-DOMAIN GRAINS BASED ON NUMERICAL MODELLING

BORIS E. LAMASH[1] and V. P. SHCHERBAKOV[2]

[1]Department of Physics, Far Eastern State University, 8 Suhanova str., Vladivostok, 690600, Russia
[2]Geophysical Observatory "Borok", Nekouzskij region, Yaroslavskaja oblast, 152742, Russia

Early (Shcherbakov et al. 1995) we carried out TRM acquisition in an ensemble of magnetostatically interacting SD grains using the Monte-Carlo method. It was shown that blocking temperatures T_b sharply increase with the increase of interactions, i.e. increase of volume concentration c of the magnetic particles. As suggested the increase T_b is connected with the transition of a system in a state of "the frozen disorder" similar to the spin glasses. As is known, the indicator of the transition in the spin glass phase is the occurrence of spontaneous nonzero time averaged magnetic moments m_i of individual particles (so-called "local freezing of the spins"). The temperature at which this phenomenon takes place is refered to as the "temperature of freezing". From formal point of view this transition means that the distribution function $P(m_i)$ of the paramagnetic phase close to the Dirak delta-function but in the phase of spin glass the distribution function is flat and constant in time.

To check whether or not this transformation occurs for interacting SD grains we investigated an ensemble of SD identical randomly oriented in space consisting of 500 particles with size 40 nm. The concentration of particles in the ensemble varied from close to 0 % (absence of the interactions) up to 5 % (strong interactions). The number of the Monte-Carlo steps/grain varied from 1000 up to 50,000 which corresponds to the "time of experiment" ranging from 2 to 100 s. The results confirmed the existence of the transition into "the frozen disorder" phase and demonstrated the strong dependence of the "temperature of freezing" T_f on the concentration of the SD particles: if for the noninteractiong ensemble T_f = 300 °C, for c = 5 % we found T_f being above 500 °C.

References

Shcherbakov V.P., Lamash B.E., Sycheva N.K., 1995: Monte-Carlo modelling of thermoremanence acquisition in interacting single-domain grains. *Phys. Earth Planet. Inter.*, 87, 197-211.

CLASSIFICATION OF THE MAGNETIC MICROSTRUCTURES OF MAGNETO-MINERALS — A REVIEW

VIKTOR HOFFMANN

Institut für Allgemeine und Angewandte Geophysik, Univ. München, Germany

In this paper a systematic overview of the observed magnetic domain patterns of the important magneto-minerals will be given. For the case of magnetic materials of technical relevance various specific criteria were developed in order to describe and distinguish their typical micromagnetic structures. In a similar way, the magnetic domain structures of the magneto-minerals can be classified. However, an important prerequisite for such an intention is sufficient knowledge of the relevant energy-terms, namely of the material constants and parameters of the magneto-minerals, which determine the magnetic microstructures. This would allow not only a classification but, moreover, some theoretical estimations and predictions concerning type and basic properties of the respective microstructure. In rockmagnetism, such efforts are limited mainly by the fact that many (micro-) magnetic properties of the magnetic minerals are not very well determined or even unknown. Nonetheless, a classification of the magnetic domain structures of the important magnetic minerals will be presented in the following which summarizes the "state of the art" by using the following criteria:

1 — Crystal-symmetry, number and type of easy axes/planes (Tab. 1);

2 — Q-parameter: $Q=K/K_d$, $K_d=M_s^2/2\mu_0$; K: effective anisotropy;

3 — Size and dimension: $\Delta = (A/K)^{0.5}$; Bloch-wall width parameter; A: exchange-constant, K: effective anisotropy.

Table 1: Classification of the important magnetic minerals with respect to (*1*).

Code	Class	Easy axes/ planes	Examples	Magnetic minerals
I	Uniaxial	1 easy axis	Hexagonal, orthorhombic, tetragonal crystals with "positive" anisotropy	Ti-magnetite $0.3 \lesssim x \lesssim 0.7$ (!) hemoilmenite $0.5 \lesssim x \lesssim 0.8$
II	Planar	2 or more easy axes in a plane	Hexagonal, orthorhombic, tetragonal crystals with "negative" anisotropy	Hematite hemoilmenite $0 \leq x \lesssim 0.5$ pyrrhotite (?)
III	Multiaxial	3 or more easy axes in space	Cubic, amorphous, polycrystalline crystals with small crystallites	Magnetite ti-magnetite $x \lesssim 0.3$ greigite (?)

Table 2: Overview of the magnetic microstructures of the magneto-minerals. **EA** - easy axis; **EP** - easy plane.

Mineral	Dominating anisotropy	Magnetic microstructure, type	Characteristics
(Titano-) magnetite $x \lesssim 0.3$	E_K, $K_1 < 0$	Cubic EA {111}	Lamellar, 180 °, 71 °, 109 °-walls
Titanomagnetite $0.3 \lesssim x \lesssim 0.7$ (?,!)	E_σ, $\lambda_s > 0$	Uniaxial, stress dominated	Locally varying EA 180 °-walls
Hematite, hemo-ilmenite $x \lesssim 0.5$	E_K, $K_{u1} < 0$ E_σ	"Antiferromagnetic" EP < 0001 >	Irregular shape, 180°-walls, others ?
Hemoilmenite $0.5 \lesssim x \lesssim 0.8$	E_K, $K_{u1} > 0$	Uniaxial EA [0001]	Lamellar, 180°-walls
Pyrrhotite	E_K, $K_{u1} < 0$	"Uniaxial" EP < 0001 > (?)	Lamellar, 180°-walls (?)
Greigite	E_K, $K_1 > 0$ (?) E_σ (?)	Cubic ? EA 100	??, influence of stress (?)
Smythite, Goethite	???	???	???

PROSPECTING FOR AND INVESTIGATION OF IRON AGE SLAGS IN DENMARK

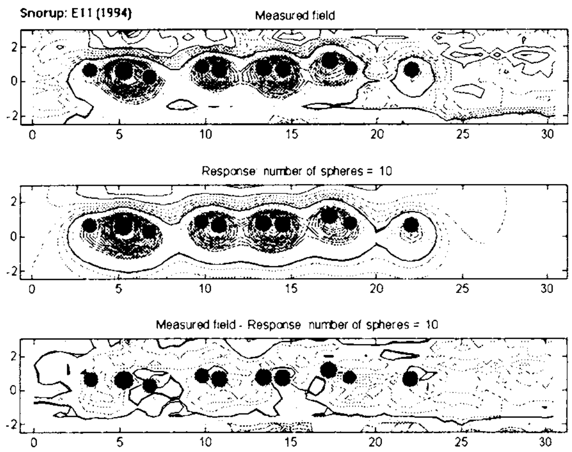
NIELS ABRAHAMSEN[1], BO HOLM JACOBSEN[1], UWE KOPPELT[1], OLFERT VOSS[2] and TATYANA SMEKALOVA[3]

[1]Department of Earth Sciences, Aarhus University, Denmark
[2]National Museum, Copenhagen, Denmark
[3]Physics Institute, St. Petersburg University, Russia

Denmark is poor in natural resources such as coal and iron-ores for industrial production, but metallic iron was locally produced in Denmark between the 2nd century BC and 1300 AD. The production was in periods quite intense, based upon local bog-iron ore and locally produced charcoal. In SW Jutland more than 50 locations with slag-pit furnaces have now been localized, and the total number of furnaces is estimated to around 100,000. With a production of some 40-50 kg of metallic iron from each pit, the estimated total production of metallic iron amounts to some 4-5000 tons in the old times.

Although the kilns were usually destroyed immediately or shortly after the production, the vestiges of the iron production are still often well preserved as slag-pits. Pits, which have not been disturbed or broken up by farmers during ploughing, are situated just below the soil, the slagg surface being typically some 0.3-0.5 meter below the present-day soil surface. The weight of the undisturbed slags are typically 200±100 kg, and as the slags are strongly magnetic due to the high content of iron oxides (which were not succesfully reduced to metallic iron), it is an easy target to locate by means of a detailed magnetic survey. Magnetic surveying, being a standard geophysical tool for mineral prospecting, has also been used in Danish archaeology over the years for mapping of Iron-Age slags, brick-kilns and other old constructions.

In the present communication we describe some detailed magnetic surveys for Iron-Age slags in the Snorup area, present a simple magnetic modelling tool, and compare the magnetic findings with the facts as interpretated by means of archaeological excavations.



PREMINILARY RESULTS ON THE MAGNETIC ANISOTROPY OF BULGARIAN ARCHAEOMAGNETIC SAMPLES

NELI JORDANOVA, VASSIL KORLOUKOVSKI and MARY KOVACHEVA

Geophysical Institute, Acad.G.Bonchev Str., bl.3, 1113 Sofia, Bulgaria

The aim of the present investigation is to study the magnetic fabric of archaeological materials in order to check the reliability of the obtained direction and intensity of the ancient geomagnetic field.

The studied samples are taken from ovens and destroyed remnants after an ancient fire. The first stage of the study includes identification of ferromagnetic carriers and their domain state. The most common minerals are (titano-) magnetites with a broad grain-size distribution.

The shape of the susceptibility ellipsoid for samples, taken from ovens, is oblate with K_{min} axes perpendicular to the oven's floor, while K_{max} axes lay in a near-horizontal plane. In some cases a non-horizontal a slope of the oven is found. Samples from destroyed remnants show random distribution of the principal susceptibility (P') is usually low (less than 5 %). Because of similarity between the TRM and IRM ellipsoids (Stephenson et al. 1986), the anisotropy of isothermal remanence is studied. In general, the principal directions of the two ellipsoids (K and IRM) do not coincide. The reanson for the observed distribution will be discussed.

ARCHAEOMAGNETIC INVESTIGATIONS ON BRONZE AGE SMELTING PLACES

HERMANN J. MAURITSCH* and ROBERT SCHOLGER

*Institute of Geophysics, Montanuniversität Leoben, Franz-Josefstrasse 18, A-8700 Leoben, Austria

During any investigation of Bronze Age smelting places, various problems regarding sample collection have to be taken into consideration. Smelting places usually include the so-called roast bed where the ore was roasted, and, a few meters away, the actual oven. Collecting oriented cores from the ovens is routine work, provided the oven remains in their original position. However, sampling of the typically dark red roast beds can be rather problematic. They consist of roasted ore pieces with a broad range of particle sizes. These pieces are embedded in a backed soil matrix with variable clay content.

While the ovens were still in use, a broad variety of materials was exposed to very different temperature ranges. Accordingly, the oven remains contain different kinds of magnetic carrier minerals. Pilot studies were conducted on samples from these rock, ores, soils, and slags, in order to investigate their magnetic mineral content. Using laboratory techniques such as thermal and AF demagnetization, IRM acquisition, I_s-T plots, Curie point analyses, and also microscopy, iron sulfides, iron hydroxides, and iron oxides (hematite, magnetite) were identified.

Interestingly, iron sulphides, originally contained in the rocks, had remained stable only within the cooler outside parts of the ovens. However, the inner, hotter parts are now dominated by magnetite. This characteristic mineral distribution indicates a strongly reducing environment inside the ovens during the smelting processes.

In most cases, the demagnetization behaviour of the samples provided evidence for a two component-NRM. One of these components typically decayed below 10 mT and is carried by iron hydroxides; the other component resides in magnetite. Additionally, some samples contain a magnetically hard component carried by hematite. Principal component analyses yielded clearly defined vector trajectories for the range of 10 mT to 60 mT or that of 150 °C to 500 °C.

Samples from different smelting places yielded similar magnetic remanence directions, provided that data merely from ovens are compared. However, this is no longer the case if data from roast beds are included as well. A possible explanation for this discrepancy is the fact that after completion of the roasting process, the bottoms of the roast beds were intensively cleaned using iron tools. Most likely, during this procedure, the substance was completely reworked.

A paleointensity study was conducted using the method of Thellier and Thellier. Because the rock types investigated in this study exhibit an extremely heterogeneous magnetic mineralogy, a correction procedure according to J. Shaw and another one according to M. Kono was applied. Both correction procedures are based on the comparison of ARM before and after thermal demagnetization of the samples.

Although the reliability of some of the observed remanence directions may be questionable, the observed paleointensities are apparently reliable. These data suggest that during the Bronze Age, the Earth's magnetic field was roughly 60 % stronger than the present field.

PRELIMINARY ARCHAEOMAGNETIC RESULTS FROM A FLOOR SEQUENCE OF A BREAD KILN IN LÜBECK (GERMANY)

ELISABETH SCHNEPP[1] and RUDOLF PUCHER[2]

[1]NLfB-GGA Hannover, Arbeitsbereich Grubenhagen, OT Rotenkirchen, 37574 Einbeck, Germany
[2]NLfB-GGA Hannover, Stillweg 2, 30655 Hannover, Germany

The building Mühlenstrasse 65 in the old town of Lübeck was first mentioned as a bake-house at the end of the 13th century AD. During a renovation in the late 1980s a series of bread kilns were excavated, which document the tradition of this bake-house from presumably late medieval times until today (Müller 1992). By archaeological means seven periods of rebuilding of the bread kilns can be identified, in which the younger kiln was always mounted on the floor of the older one. In most periods the kilns had a round shape with a minimum diameter of 3.6 m. Each period includes several floor layers made of fresh clay. The result is a 1.3 m pile of 25 floor layers. Each layer shows a reddish colour with a greyish surface obviously due to intense heating which transformed the upper part (about 2 cm) of each clay layer into brick. The oldest parts of the kilns may be dated to between the 13th and 15th century.

For 23 of the kiln floor layers it was possible to take 3 to 17 oriented handsamples with the plaster technique and the upper brick-like part of each hand sample was sawn in cubes of 17 to 25 mm size. These cubes are studied rock magnetically and paleomagnetically in order to obtain the characteristic remanent magnetization (CARM) of each floor layer. The preliminary results are presented here.

Natural remanent magnetization (NRM) and bulk susceptibility have been measured and the Koenigsberger ratio Q has been calculated. Q values lie between 4 and 50 for the small (17 mm) and 1 to 20 for the large (25 mm) cubes. This is interpreted as a decrease of the amount of thermoremanent magnetization (TRM) with depth in each layer.

At least one sample of each layer has been subjected to thermal runs with a horizontal magnetic balance. The thermomagnetic curves are nearly reversible with a more or less well pronounced Curie point between 570 °C and 620 °C indicating (maghemized) magnetite as the main magnetic carrier. Furthermore isothermal remanent magnetization (IRM) curves have been measured using a pulse magnetizer with a maximum field of 3 T. In all experiments more than 90 % of the final IRM were obtained already at a field of 0.3 T showing that no remarcable amount of hematite or other high coercive mineral is present. By combining saturation IRM, remanent coercive force, and bulk susceptibility in the diagram of Bradshaw & Thompson (1985) the grain size of the magnetic fraction lies between multi-domain and pseudo-single-domain magnetite fields.

Up to now from each layer at least one thermal and two alternating field (AF) demagnetization curves have been measured. In general after demagnetization by 20 mT viscous overprints are removed and Zijderveld diagrams show a well-defined stable CARM direction. This is also the fact for the thermal demagnetization runs where overprints are removed above 250 °C. Neither AF demagnetization nor thermal demagnetization show strong or systematic overprints. This may indicate that an older kiln floor has not been reheated by a younger layer.

For each layer mean CARM directions have been calculated using Fisher statistics. In floor layers 25 to 9 inclination increases from 60 to 75° N while declination is always around 10° E. In layers 8 to 1 declination moves from 10° E to 10° W and inclination is about 75° N. Because of the inclination range obtained, inclination shallowing due to magnetic refraction (Soffel & Schurr 1990) seems not likely. Accordingly, the mean CARM directions are interpreted as archaeodirections of the Earth's magnetic field.

In order to date the kiln floor series these very preliminary mean CARM directions have been compared with the archaeomagnetic curve of Paris (Bucur 1994). The oldest floor layer (25) was heated the last time around 1450 AD, floor layer 9 was heated around 1600 AD, and the kiln floor series was finished before 1800 AD. Up to now the accuracy of the CARM mean directions is not always satisfying. Therefore more samples have to be demagnetized and poorly sampled layers should be resampled.

References

Bradshaw R. & Thompson R., 1985: The use of magnetic measurements to investigate the mineralogy of Iceandic lake sediments and to study catchment process. *Boreas*, 14, 203-215.

Bucur I., 1994: The direction of the terrestrial magnetic field in France, during the last 21 centuries. Recent progress. *Phys. Earth Planet. Int.*, 87, 95-109.

Soffel H.C. & Schurr K., 1990: Magnetic refraction studied on two experimental kilns. *Geophys. J. Int.*, 102, 551-562.

Müller U., 1992: Eine gewerbliche Bckerei in Lübeck vom 13. bis zum 20. Jahrhundert. Ergebnisse der Grabung Mühlenstr. 65. *Lübecker Schr. Arch. Kulturgesch*, 22, 123-143.

THE "BLAKE EVENT" RECORDED IN AN EARLY WEICHSELIAN LOESS DEPOSIT AT TÖNCHESBERG IN THE EAST EIFEL VOLCANIC FIELD (GERMANY)?

JOZEF HUS[1] and DIANA JORDANOVA[2]

[1]Centre de Physique du Globe, 5670 Dourbes, Belgium
[2]Bulgarian Academy of Sciences, Geophysical Institute, Acad. G. Bonchev str., block 3, 1113 Sofia, Bulgaria

Previous paleomagnetic investigations of an Early Weichselian loess deposit in a depression of a volcanic crater rim Tönchesberg in the East Eifel volcanic field by Becker et al. (1989) and Reinders & Hambach (1995), revealed short periods of reversed polarity which they identified as the "Blake Event". In a section of about 28 m at Tönchesberg 2 one can recognize from bottom to top a Saalian loess deposit (with basaltic tephra intercalations), in the top of which a Bt horizon of the Eemian last interglacial paleosol is found. Follows reworked soil material, humic colluvium and an Early Weichselian loess deposit which is discordantly overlain by a humic-rich layer. In the latter a thin loess marker horizon with frost wedges occurs. This is overlain by Middle and Late Weichselian loess covered by tephra of the Laacher See eruption. Chronological control is provided by the eruption of the Tönchesberg volcano dated at 200 Kyr (Schmincke 1990), the Laacher See tephra dated at 11.4 Kyr BP (Van den Boogaard & Schminke 1985) and several TL datings (Frechen 1991; Zoller et al. 1991). Becker et al. (1989), who considered the "Blake Event" as a twin event, correlated the short period of reversed polarity discovered in the bottom half of the Early Weichselian loess layer with the upper Blake Event and one of the short zones of reversed polarity revealed in the underlying humic colluvium and reworked soil material with the Lower Blake Event. They did not exclude the possibility that the Blake Event had been entirely recorded in the reworked sediments. On the other hand, Reinders & Hambach (1995), who limited their examination to the Early Weichselian loess and humic colluvium more towards the depression, where the loess unit wedges out, found a triple event of three short intervals of reversed polarity separated by short periods of normal polarity. They identified it as the Blake Event mainly because of its resemblance with other records by Herrero-Bervera & Helsley (1993) in diatomaceous lacustrine sediments from Pringe Falls (Oregon) and by Zhu et al. (1994) in a loess section near Ximing in China. As spatial and time consistency should be fulfilled, with the minimum requirement that the same signature should be found in parallel sections, a new collection of oriented hand samples was investigated on request of N.J. Conard. The Early Weichselian loess unit was sampled in a section located between the previous ones (section 1) and the humic colluvium and reworked soil material more to the SW where these units are thicker (section 2).

Indeed, the "Blake Event" is one of the most serious candidates of short reversed periods in the Brunhes Chron and may indicate a complex behaviour of the geomagnetic field. Moreover, it would be an important stratigraphic marker for paleoclimatic and environmental reconstructions and in particular for the archaeological findings in the Bt horizon of the last interglacial soil in Tönchesberg.

Stepwise thermal demagnetizations revealed, besides a viscous component acquired in the present field, in most cases a two-component remanent magnetization with overlapping blocking temperature spectra.

Several samples of the reworked sediments in section 2 showed anomalous declination values after thermal "cleaning" at 270 °C probably linked to their mode of deposition, sedimentological factors and eventually due to the presence of large pieces of tephra. Besides some anomalous declination values near the top of the Early Weichselian loess unit of section 1, anomalous magnetization directions were found at three different levels in the lower part of it, of which one was reversed. Comparison with the results of Reinders & Hambach is difficult because of poor stratigraphic control and because the entire sequence of triple event is recorded in less then 25 cm of loess/soil reworked material. Hence, further investigations of parallel sections are needed. Anisotropy of magnetic susceptibility of the Early Weichselian loess unit revealed a normal magnetic fabric which can be represented by an oblate ellipsoid, with K_{min} close to the vertical, but slightly titled to the SE, in agreement with the slope of the deposit. The K_{max} defines a NW-SE lineation suggesting a transport direction and supporting the idea of a hill washed loess facies. A magnetic susceptibility profile of the upper 12.5 meters of the section displays low values in the loess but high values in the humic rich colluvium, reworked soil material and levels with volcanic tephra.

References

Becker U., Boenigk W. & Hentzsch B., 1989: Reverse magnetisierung in den frühwürmzeitlichen deckschichten am Tönchesberg/ Osteifel. *Mainzer naturw. Archiv*, 27, 1-22.

Frechen M., 1991: Thermolumineszenz-Datierungen an Lössen des Mittelrheingebietes. *Sonderveröff. des Geologischen Instituts der Universität zu Köln*, Köln, 79.

Herrero-Bervera E. & Helsley C.E., 1993: Global paleomagnetic correlation of the Blake geomagnetic polarity episode. In: Aissaoui D.M., McNeill D.F. & Hurley N.F. (Eds.): *Applications of Paleomagnetism to Sedimentary Geology. SEPM (Soc. Sed. Geol.), Special Publication,* 49, 71-82.

Reinders J. & Hambach U., 1995: A geomagnetic event recorded in loess deposits of the Tönchesberg (Germany): identification of the Blake magnetic polarity episode. *Geophys. J. Int.*, 122, 407-418.

Zhu R.X., Zhou L.P., Laj C., Mazaud A. & Ding Z.L., 1994: The Blake geomagnetic polarity episode in Chinese loess. *Geophys. Res. Lett.*, 21, 697-700.

Zöller L., Conard N.J. & Hahn J., 1991: Thermoluminescence dating of Middle Paleolithic open air sites in the Middle Rhine valley/Germany. *Naturwissenschaften,* 78, 408-410.

BULGARIAN HOLOCENE SOILS AS A CARRIER OF PALEOENVIROMENTAL INFORMATION

DIANA JORDANOVA[1] and JORDAN EVLOGIEV[2]

[1]Geophysical Institute, Acad. G.Bonchev Str., bl. 3, Sofia 1113, Bulgaria
[2]Geological Institute, Acad. G.Bonchev Str., bl. 24, Sofia 1113, Bulgaria

Seven profiles of Holocene soils from North-Eastern Bulgaria have been studied using different rock magnetic methods. A uniform magnetic mineralogy of Bulgarian loess-soil sediments is obtained. Enhanced susceptibility and remanence values in the humic and illuvial horizons are shown to be due to both concentration and grain size changes (from more stable near-SD through highly viscous SP/SD to true SP domain state of the "in situ" formed ferromagnetic grains).

A correlation among the susceptibility variations along the profiles is performed. The main paleoclimatic stages during the Holocene (Atlantic and Subboreal) are identified in κ-variations. Susceptibility behaviour is compared with other paleotemperature curves (pollen and $\delta^{18}O$).

THE USE OF MAGNETIC METHODS TO IDENTIFY ANTHROPOGENIC FERRIMAGNETICS IN SOILS

TADEUS MAGIERA and ZYGMUNT STRZYSZCZ

Institute of Environmental Engineering, Polish Academy of Sciences, M. Curie-Sklodowskiej 34, 41-819 Zabrze, Poland

The effect of increase in the magnetic susceptibility in topsoil was already observed in the 1950s (Le Borgne 1955). The processes causing this effect were described by Mullins (1977), who attributed them only to: *a* — forest and duff fires, *b* — dehydration of lepidocrocite (γ-FeOOH) to maghemite (γ-Fe_2O_3), *c* — formation of microcrystalline maghemite or magnetite from weakly magnetic iron oxides and hydroxides via the reduction-oxidation cycles which occur under normal pedogenic conditions. In the following years some authors noticed, that at sites close to major urban and industrial centres, topsoil may have a higher susceptibility as a result of fallout from the atmosphere of magnetic particles derived from fossil-fuel combustion (Thompson & Oldfield 1986). Recent study carried out in many regions and particularly in Upper Silesia, where topsoil has especially high level of magnetic susceptibility ambiguously proved its origin from industrial immission (Strzyszcz et al. 1988; Strzyszcz 1989a; Strzyszcz et al. 1994).

In industrial areas with the magnetic susceptibility (χ) exceeding 200×10^{-8} m^3/kg, the concentration of ferrimagnetics in topsoil is high enough that in some cases a separation of the magnetic particles for a normal chemico-mineralogical analysis is possible. The increase of χ value in topsoil, however, is olso observed in ares far from industrial and urban centres, where the amount of ferrimagnetics is too low for chemical or X-ray analysis. Since the fly ashes emitted from large power plants containing ferrimagnetics of anthropogenic origin (formed as a result of fossil-fuel combustion) may be transported very large distances the question is whether the increase of χ value in areas far from any large emitters is caused only by the processes described by Mullins or also by the ferrimagnetics of anthropogenic origin.

The identification of anthropogenic ferrimagnetics in soils on the basis of some magnetic parameters, which have been compared with these measured for ferrimagnetics contained in fly ashes has been carried out. For this purpose, samples or fly ashes from several power plants and soil samples from 5 areas of Poland have been collected and analysed in the geomagnetic laboratory. In the case of fly ashes the rather high concentration of ferrimagnetic particles enabled us to separate the proper amount of magnetic material for parallel geochemical and mineralogical study and direct measurements of particle size using electron microprobe. This enabled a verification of conclusions drawn on the basis of the magnetic parameters analysis.

For this study, except fly ashes from several power plants burning both hard and brown coal, samples from soil subhorizons where the χ maximum has been noted were taken up. The soil was sampled from the vicinity of "Jaworzno III" power plant, in the Ojcow National Park — 25 km east from the Upper Silesian Industrial Region, in the same distance west from Upper Silesian Industrial Region (Ortowice), in Wielkopolski NP (Poznan region) as well as in the coastal area, far from any large emitters (Slowinski NP).

The following magnetic methods were used for identification of the anthropogenic ferrimagnetics:

— measurement of low-frequency magnetic susceptibility using the low-field susceptibility bridge KLY-2,

— measurement of frequency-dependent susceptibility (χ_{fd}) taken at two frequencies χ_{LF} = 0.47 kHz and χ_{HF} = 4.7 kHz using the Bartington susceptibility bridge (results were presented as a percentage of χ value change at a higher frequency),

— measurements attempted to determine the basic parameters of hysteresis (SIRM, IRM, $(B_0)_{CR}$, *S*) performed in a magnetic field up to 1 T using the Digico fluxgate spinner magnetometer,

— measurement of temperature dependence of saturation magnetization using a Curie balance whereby the samples were subjected to a heating and cooling cycle in air in a steady magnetic field of 0.1 T in order to establish the Curie point of magnetic minerals.

Results presented in Tab. 1 characterize both mineralogy and grain size of magnetic particles and their concentration in the sample. The concentration of anthropogenic ferrimagnetic minerals in fly ashes is rather large, as is confirmed by the high χ value. The particles are relatively large with diameter >>1 μm which is testified by the low value of $(B_0)_{CR}$. According to Thompson & Oldfield (1986), assuming a spherical form of magnetite (a common form of anthropogenic ferrimagnetics) this corresponds to particle size in the range of 64–256 μm. An absence of superparamagnetic minerals is confirmed by a very low χ_{fd} value. Also the SIRM/χ ratio = 17.2 proves the average grain size over 5 μm.

The mineralogy of anthropogenic ferrimagnetics may be concluded on the basis of the value of the *S* parameter expressing the ferrimagnetics to antiferromagnetics ratio which in the case of fly ashes (0.75) indicates a prevalence of ferrimagnetic minerals. The Curie point is also close to 585 °C, typical for magnetite.

All these observations based on the magnetic parameters were confirmed by the investigations of magnetic concentrate made of fly ashes from "Jaworzno III" and "Siersza" power plants using the electron microprobe. The investigation showed that a majority of the ferrimagnetic particles in fly ashes is in the range 1–20 μm, although larger particles are also observed. The stochiometric chemical analysis of magnetic particles revealed that they are mainly transient phases between magnetite and maghemite, in some cases more similar to Fe_3O_4 and in another to γ-Fe_2O_3.

The search for anthropogenic ferrimagnetics in soil was based on measurements of the same magnetic parameters and comparing them with values obtained for ferrimagnetics contained in fly ashes and with those described in literature as natural ferrimagnetics formed in pedogenic processes in the uppermost layer of soil. The results presented in Tab. 1 enable the assumption that magnetic minerals occurring in the topsoil are similar to those present in fly ashes. The Curie point is close to 585 °C — the value characteristic for magnetite, however, it is in a majority of cases shifted by 10-20 °C to higher temperatures which is probably caused by the fact that anthropogenic magnetite is in most cases nonstoichiometric. The *S* parameter ranges from 0.64 to 0.78 which also testifies to the prevalence of ferrimagnetics and is close to the value found in the fly ashes. Also in all cases a very high level of χ_{fd} indicates a lack of superparamagnetic minerals which are often accompanied by finecrystalline ferrimagnetics being formed in the processes described by Mullins (1974). All these parameters are very similar despite large differences in the χ value, which is related to the proximity of an area to large industrial and urban centres as well as the level of industrial immission over the given area.

A slightly higher difference in values of $(B_0)_{CR}$ and SIRM/χ parameters corresponding to the size of magnetic particles is observed. It is probably due to the differences in magnetic particle size although the range of $(B_0)_{CR}$ values between 20 and 40 mT is still considered to correspond to retalively large magnetite grains, over 1 μm in diameter. Values of these parameters do not indicate the presence of a higher amount of superparamagnetic or fine magnetite and maghemite being formed through natural processes.

The analysis of magnetite parameter values may lead to the conclusion that anthropogenic ferrimagnetics from industrial immissions are primarily responsible for the increase of magnetic susceptibility in topsoil.

Table 1: The magnetic parameters values for fly ashes and soil samples.

Sample	χ $\times 10^{-8} m^3 kg^{-1}$	χ_{fd} (%)	SIRM/χ (kAm^{-1})	$(B_0)_{CR}$ (mT)	S	(T_c) (° C)
Fly ashes from power plant	2586.0	1.65	17.2	27	0.75	595
Soil near power plant	1400.0	1.54	18.7	45	0.64	600
Soil from Ojcow NP	218.5	2.92	12.6	22	0.68	605
Soil from Ortowice	185.4	2.05	12.0	32	0.74	595
Soil from Slowinski NP	31.4	1.35	4.5	21	0.78	595
Soil from Wielkopolski NP	68.4	0.88	16.7	37	0.73	585

References

LeBorgne E., 1955: Susceptibilite magnetique anormale du sol superficiel. *Ann. Geophys.*, 11, 399-419.

Mullins C.E., 1977: Magnetic susceptibility of the soil and its significance in Soil Science: a review. *J. Soil Sci.*, 28, 223-246.

Strzyszcz Z., Tolle R. & Katzur J., 1988: Zur Anwendung eines hochfrequenten Messverfahrens fur den Nachweis von ferromagnetischen Eisen in der Umwelt. *Arch. Ochr. Srod.*, 3-4, 1137-1143.

Strzyszcz Z., 1989: Anwesenheit des ferromagnetischen Eisen in oberschlesischen Waldboden und deren Ursachen. *Mitt. Deut. Boden Ges.*, 59, 1197-1202.

Strzyszcz Z., Magiera T. & Bzowski Z., 1994: Magnetic susceptibility as an indicator of soils contamination in some regions of Poland. *Roczniki Gleboznawce, Warszawa*, Suppl. XLIV, 85-93.

Thompson R. & Oldfield F., 1986: Environmental magnetism. *Allen and Unwin*, London.

ENVIRONMENTAL MAGNETISM IN THE PAMPEAN LOESS (ARGENTINA)

MARÍA J. ORGEIRA[1], ANA M. WALTHER[1], CARLOS A. VASQUES[1,2], JUAN F. VILAS[1,2] and HORACIO LIPPAI[1]

[1]Lab. de Paleomagnetismo "Daniel Valencio". Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina

[2]Universidad de Buenos Aires, Cdad. Universitaria Pab II., 1428 Buenos Aires, Argentina

Introduction

The studies on environmental magnetism carried out on continental sediments of aeolian origin have been in the last decade, an important source of data to determine climatic changes in the Late Cenozoic (Heller et al. 1991; Verosub & Roberts 1995, among others).

The mineralogical transformations caused in situ by different environmental conditions are the signals that the magnetic methodology aims to isolate.

The diagenetic and/or pedogenetic processes bring about formation of ferromagnetic phases and/or dissolution of magnetic minerals. The determination of these magnetic minerals, their grain size and variations along a sedimentary profile allows us to obtain a model of the physico-chemical variations of the sedimentary environment. On the basis of this data, it is possible to determine the climatic changes that took place during the studied period.

So far, there are no records of studies on environmental magnetism in sedimentary sequences in the Chaco-Pampean region (Argentina). A project on this subject, especially focused on the study of the Pampean loess, has been initiated at the Paleomagnetic Laboratory "Daniel Valencio". The first results of this study are presented in this contribution.

Geology of the sequence

The Pampean loess is a silty sediment, of aeolian origin, generally massive and brown or reddish brown, which shows frequent carbonate nodular concretions and plenty of evidence of pedogenesis.

Many lithological differences exist between the Pampean loess and that from other parts of the world (Frenguelli 1955) such as a low content of clastic quartz, higher solubility in an acid environment and a great amount of evenly distributed volcanic shards, among others.

The results were obtained from a profile of typical loess and a secondary profile of a paleosoil, located a distance of 100 m away and stratigraphically correlated with the former. Both profiles, located in the underground of the city of Buenos Aires were found as a results of excavation done at a building site. While the paleomagnetic studies assign a Brunhes magnetic age (< than 0.7 Ma) to these sediments, the fossils found suggest a Lujanense land mammal age (Late Pleistocene) to them.

The profile at Cervino street has a thickness of 7.6 m, and 54 levels of sediment were sampled at it. The associated profile of paleosoil at Oro street has a thickness of 1.8 m and 12 levels were sampled. Besides, the macroscopic field description shows that both profiles are silty brown sediments. Nodular concretions of calcium carbonate of several sizes (<1 cm) and pedotubes of roots, evenly distributed, were observed. The Oro street paleosoil in particular, shows a higher concentration of clay, a brown slightly greenish colour and a prism structure, which is typical of the buried soils in the area.

Studies of rock magnetism

The tests done will be briefly outlined:

— Susceptibility (X): Susceptibility measurements at low (0.47 KHz) and high (4.7 KHz) frequency were done on both profiles and the F factor was calculated.

— Isothermal Remanent Magnetization (IRM) tests: isothermal remanent magnetization up to saturation and field tests were carried out in all samples. The maximum fields applied were 2.4 T and, in some cases, 4 T. Based on the results obtained, the following parameters and ration were determined: Coercivity of the remanence (B_{cr}), remanent acquisition coercive force (H'_{cr}), S-ratio, coercivity spectrum, saturation isothermal remanent magnetization (SIRM), field of saturation and SIRN/X.

— Test of Lowrie (1990): IRM acquisition in successive smaller fields along three orthogonal directions was done. Thermal demagnetization of each orthogonal component of the composite IRM was then plotted.

— Low temperature tests: These tests were at liquid air temperatures (85 K). The variations of the SIRM from 85 K to room temperature were determined. Besides, the variations of thé magnetic susceptibility for the same temperature range were recorded.

— High temperature test: High temperature demagnetization of the natural remanent magnetization (NRM) and SIRM was done in steps of 50°/100 °C up to 700 °C.

— Chemical analysis: to determine the Fe_2O_3, FeO and MnO in the paleosoil, the acid disgregation and atomic absortion technique (Fe^{3+} and Mn) as well as the volumetric technique of the US Geological Survey (Fe^{3+}) were applied.

The variations of the magnetic parameters determined (X, SIRM, B_{cr}, H'_{cr}, SIRM/X, S-ratio, F factor) were plotted on both profiles according to the stratigraphic position of the samples. These profiles were interpreted together with the results obtained from the Lowrie, and high and low temperature tests.

Results

The interpretation of the magnetic results is complex because the presence of more than one magnetic mineral was detected in most of the samples analysed. Besides, each of the minerals have different grain sizes. In spite of this, the fractions of diagenetic origin could be distinguished from those of detritic origin.

Summing up, a lixiviation of magnetic minerals was detected in the levels of paleosoils. This is associated with a decrease in the concentrations of the cations Fe^{2+} Fe^{3+}. A decrease of ferrimagnetic minerals, and an increase of antiferromagnetic ones were observed, as well as variations in the granulometry of the magnetic fraction, at these levels.

Similar fluctuations of less magnitude were detected in the rest of the profile.

The chemical variations of the depositional paleoenvironment were determined on the basis of the variations of the magnetic minerals. Consequently, a scheme of the climatic changes for this period is presented.

References

Lowrie W., 1990: Identification of ferromagnetic minerals in a rock by coercivity and unblocking temperature properties. *Geophys. Res. Let.*, 17, 2, 159-162.

Verosub K.L. & Roberts A.P., 1995. Environmental magnetism: Past, present and future. *J. Geophys. Res.*, 100, 2, 2175-2192.

Heller F., Xiuming Liu, Tungsheng Liu & Tongchun Xu, 1991: Magnetic susceptibility of loess in China. *Earth Planet. Sci. Lett.*, 103, 301-310.

Frenguelli J., 1955: Loess y limos pampeanos. *Serie Técnica y Didáctica No.7, Universidad 778778 National de La Plata*, 1-88.

MAGNETIC SUSCEPTIBILITY MONITORING — RECORDER OF ENVIRONMENTAL CHANGES IN THE DANUBE DELTA

SORIN CORNELIU RĂDAN[1], MARIA RĂDAN[1], SILVIU RĂDAN[2] and NICOLAE MIHĂILESCU[1]

[1]Geological Institute of Rumania, 1 Caransebeş Str., RO-79679 Bucharest, Rumania

[2]Rumanian Center of Marine Geology and Geoecology 23-25, D. Onciu Str., RO-70318 Bucharest, Rumania

Since 1992 in the Danube Delta and Razelm-Sinoe lacustrine complex a geoecological monitoring has been applied. During the research cruises organized in Danube Delta. Consisting of 1-2 legs each year, samples of water, biota, suspended and bottom sediments have been collected.

Among the various tools used to assess the environmental changes and/or to pollution and its sources, the magnetic susceptibility (**MS**) investigation has been introduced.

The **MS** monitoring is carried out on bottom sediments, so that subsamples especially taken for **MS** measurements are provided to the paleomagnetic laboratory. To determine **MS** (κ values) of various types of sediments (muds, sometimes rich in vegetal detritus, silty muds, silty-sandy muds, muddy sands), KLY-1 and/or KLY-2 Kappabridges have been used. Other subsamples of bottom sediments are analysed for grain size, clay mineralogy and geochemistry.

The sampling stations which suport the minitoring network are placed within several interdistributary depressions of the Danube Delta (lakes and channels/canals) and within the Razelm-Sinoe lacustrine complex, as well.

The **MS** data accumulated since 1977, when we performed the first measurements of magnetic susceptibility on bottom sediments, have emphasised the ability of this rock-magnetic parameter as a sedimentological indicator (Rădan et al. 1981, 1985, 1990, 1993-1995; Mihăilescu et al. 1983). The present paper especially deals with the results obtained during the **MS** monitoring (1992-1996).

The lowest κ values have been obtained from bottom sediments sampled from lakes showing (sometimes locally) more confined environments, containing organic mud (e.g., L. Bogdaproste, L. Răducu, L. Trei Ozere, L. Merchei, L. Roşu, L. Băclăneşti, L. Babina). The **MS** measured on muds consisting mainly of very fine vegetal detritus is ussually not higher than 10×10^{-6} SI u., revealing even negative values (e.g. Bogdapostre — 1994 and 1995 cruises, L. Răducu — 1994 cruise). The **MS** of silty muds with subordinate vegetal ditritus (e.g. samples from L. Puiu, L. Cuteţchi, L. Matiţa, L. Isacova) is frequently lower than 75×10^{-6} SI u.

Higher κ values (e. g., 171×10^{-6} SI u.) have been determined in silty muds from L. Dranov (situated in the fluvial delta plain). The samples collected from this lake analysed for other parameters (e.g. Zn, Pb, Cd, Ni, Mn, Fe, Cr, Hg contents) show abnormal values as compared with other lakes within the Danube Delta area. Subsequent phases of the monitoring will be very important to clarify some aspects related to pollution processes and sources.

The highest **MS** values (up to 500×10^{-6} SI u.) have been obtained on silty muds and/or fine sandy muds sampled from some lakes directly influenced by the Danube River supplies (L. Fortuna, L. Uzlina, L. Meşteru and L. Lungu). Sometimes, anomalous values of physical-chemical parameters and heavy metal contents have been recorded, as well. In the case of Fortuna and Uzlina lakes, connected by very short channels to the Sulina distributary and Sf. Gheorghe distributary, respectively, a high level of **MS** has been detected since the first cruises carried out in the area, in 1979-1980. Regarding Lungu and Meşteru lakes, an important increasing of **MS** values — as compared with measurements related to 1980 cruise — has been remarked for the sediments sampled in 1987 an in all legs of the monitoring, since 1992. These results are explained by recent environmental changes taking place due to digging in the area of a new canal of connection with the

Danube River (at M 35). The **MS** parameter reflects the enhancement of the silting process.

Reliable **MS** data have been equally obtained on sediments sampled from some channels/canals within the Danube Delta. Important differences have been remarked for the κ values determined on silty and/or sandy muds collected from Dranov and Dunavăţ canals (up to 773×10^{-6} SI u., in the upper sectors) as compared with **MS** measured on sediments consisting usually of deposits made by shells and vegetal fragments with muddy matrix sampled from channels (e. g. Perivolovca Chn. with κ values of 35×10^{-6} SI u., in 1994 or 19×10^{-6} SI u., in 1995). The first two canals connect the Sf. Gheorghe distributary with the Razelm lake, the influence of detrital material supplied by the Danube River being significantly reflected by the constitution of bottom sediments. As concerns the Perivolovca channel this is characterized now by a stagnant state without an important water circulation, the sediment being represented by a porous mud, very rich in fine vegetal detritus.

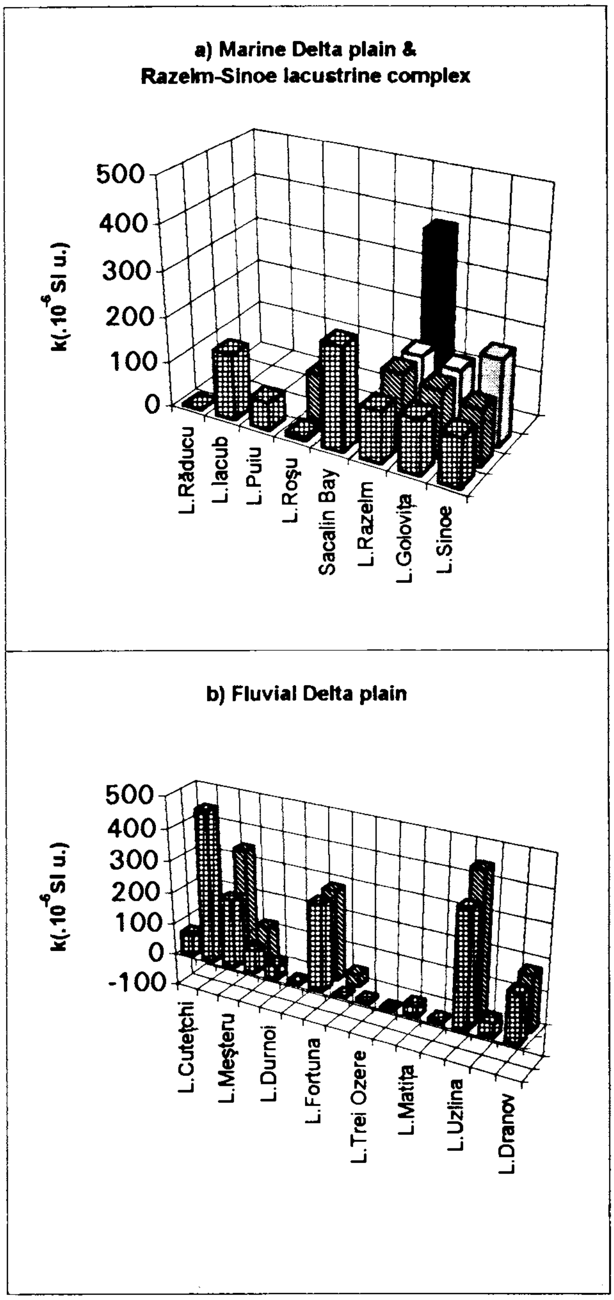


Fig. 1. Magnetic susceptibility of bottom sediments Monitoring - Phase 1995-1996.

The constitution of the sediments (silty-sandy muds, muddy sands) sampled in the monitoring stations close to the entry mouths of the Dranov and Dunavăţ cannals into the Razelm Lake explain the higher κ values (up to 384×10^{-6} SI u.) as compared with the **MS** usually measured on silty muds collected from the Razel-Sinoe lacustrine complex.

Magnetic susceptibility data recorded in the last phase of the monitoring (1995/1996; Fig. 1) are compared with the previous ones (1992-1995), as well as with a series of results obtained in the first cruises (since 1977) performed in Danube Delta and Razelm-Sinoe lacustrine complex. A good resolution of the applied method is pointed out.

As regards the capacity of **MS** to detect pollution processes and sources in the particular environment of an area covered by water and vegetation like the Danube Delta, new results are commented.

Anyway, the data presented in the paper confirm the ability of the magnetic susceptibility monitoring to emphasise some Danube Delta. **MS** is able to provide physical/quantitative elements characterizing different environments or, in other case, reflecting environmental changes recently produced by human interventions within the Danube Delta ecosystem.

References

Mihăilescu N., Rădan S., Artin L., Rădan S.C., Rădan M. & Vanghelie I., 1983: Modern sedimentation in the Razelm-Sinoe lacustrine complex. *An. Inst. Geol. Geofiz.*, LXII, 299-304.

Rădan S.C., Rădan M., Rădan S. & Mihăilescu N., 1993: Magnetic susceptibility of recent sediments: case studies from Danube Delta and Danube (Romania). *Annales Geophysicae,* Suppl. 1, to Vol. 11, C 91.

Rădan S.C., Rădan M., Rădan S., Mihăilescu N., Oaie G. & Szobotka St., 1994: Magnetic susceptibility as geoecological indicator in the environmental context of the Danube - Danube Delta macrosystem. *New Trends in Geomagnetism - IV, Castle of Třešť, Czech Republic,* Abstracts, 16.

Rădan S.C., Rădan M., Rădan S., Ghenea C., Mihăilescu N., Oaie G. & Szobotka St., 1995: Magnetic signature of past and recent environmental changes recorded in Pleistocene deposits and modern sediments. *Abstracts. XIV INQUA Congress, Berlin, Terra Nostra,* 2.

MAGNETIC SUSCEPTIBILITY AND HEAVY METAL CONTAMINATION OF SEDIMENTS IN THE RIVER MUR (STYRIA, AUSTRIA)

ROBERT SCHOLGER

Institut für Geophysic, Montanuniversität,
Franz-Josef-Strasse 18, A-8700, Leoben, Austria

The magnetic properties of recent river sediments are strongly affected by heavy metal input through industrial processes (the iron-freigh annually carried by rivers world-wide, as estimated by the UNESCO, is more than 350×10^9 kg). Sediments of the river Mur were sampled in 73 localities over a

190 km river section between Judenburg and Spielfeld for chemical and magnetic analyses.

The most important aquifers in Styria are in fluvial gravel deposits of Holocene and Pleistocene age within the catchment area of the river Mur. Owing to an extensive river regulation program during tha late 19th century, stream velocity increased, and, thus, the river channel became predominantly erosive. Therefore, ground water pollution through infiltration of river water into surrounding aquifers became more likely. In additional, the impact of polluted river sediment has to be considered where retentive areas are utilised for agricultural production.

The magnetic susceptibility (κ) of samples from areas with moderate industrialisation was typically below 500×10^{-6} SI, which is similar to the local geological background of Tertiary basinal sediments, whereas values of about 5000×10^{-6} SI were obtained in sections with proven heavy metal contamination.

Samples were magnetically fractionated in order to compare the magnitude of κ with the mass content of magnetic components. Analyses of isothermal remanent magnetization and Curie-point determinations (T_c = 530 °C) provided evidence for the presence of a magnetite-like phase. Using electron microscopy, this phase could be identified as scale.

The magnetic susceptibility of the sediments was dominated by scale ("hammer-scale","iron scale"), which is a waste material from metal producing and manufacturing processes. The linear regression of κ versus scale content is significant, with 2500×10^{-6} SI = 1 percent scale (mass content). Chemical analyses of the samples established a strong correlation of heavy metal concentration (especially Zn, Pb, Ni, Cu, Cr) with the scale content.

Therefore, as a measure of the scale content, magnetic susceptibility also provides an indicator of the heavy metal contamination of the sediments.

DO CAVE SEDIMENTS FROM THE SPIRÁLKA CAVE (CZECH REPUBLIC) RECORD ENVIRONMENTAL CHANGE (PART 2)?

PAVEL ŠROUBEK[1], JIMMY F. DIEHL[1] and JAROSLAV KADLEC[2]

[1]Deparment of Geological Engineering and Sciences, Michigan Technological University, Houghton, MI 49931, USA

[2]Czech Geological Survey, Klárov 6, 118 21 Praha 1, Czech Republic

Over the past three years we have been investigating a 4 m high profile in clastic sediments deposited during flooding in the interior of Spirálka Cave (Moravian Karst), Czech Republic. Šroubek et al. (1995) reported a possible correlation between the record of ferromagnetic susceptibility (MSferro) and winter temperature anomalies determined from data collected at the Prague-Klementinum observatory over the past 200 years. Variations in the concentration and grain-size of non-stoichiometric magnetite and/or maghemite are responsible for the observed changes in MSferro.

We revisited the site during the fall of 1995 and sampled the bottom 2 meters of the section. In this part of the profile brown silts and sands typical of the upper part of the profile are interbedded with two layers of gray organic rich material and a thin flowstone bed. The variations in lithology suggests to us that the sediments record periods of significant climatic change. Samples from the same stratigraphic level show similar values of MS while MS varies by up to the magnitude of two throughout the profile. Preliminary measurements of SIRM, MSarm/MS, MSarm/SIRM and IRM acquisition, S-ratio suggest that MS variations in the cave section are responding to variations in the magnetic mineralogy, concentration and grain-size. The correlation between MSferro and a direct temperature measurement is very intriguing and to our knowledge has not been previously reported. In order to confirm this interesting observation we are currently undertaking the following tasks:

1 — Age dating

Currently, 2 radiocarbon dates (one using the AMS technique) on charcoal samples have been obtained for the upper half of the profile. Unfortunately the young age (0-350 years B.P.) of the sediments have resulted in a very large error in the dendrochronologically corrected dates for the charcoals. The topmost part of the profile is currently being dated using the lead-210 technique. This technique allows us to date sediments up to 150 years B.P. In central part of the profile a large wood fragment was found which is being age dated at the Technical University in Zvolen (Slovakia) using the dendrochronological method. Lastly, another charcoal fragment from the base of the profile has been sent off for radiocarbon dating.

2 — Determining the driving mechanism of the change in mineral magnetic properties

We are seeking an explanation for the observed correlation between MSferro and temperature. It is improbable that minor temperature oscillations may be driving changes in concentration and grain-size of magnetic minerals. However climatic change can trigger other processes influencing the catchment area from which the sediments are derived. The change in concentration of magnetic minerals previously observed in lake sediments is known to be a sensitive indicator of changes in the erosional rates and the energy of transport. Therefore we are searching historical records to identify climatic/environmental changes which are tied to temperature and could affect arosional rates. The historical record of rainfall in Moravia shows a good correlation with the MS record, however the rainfall has been recorded only since 1880 A.D. Records of severe floods are being available but only since 1930 A.D. A proposed correlation between these floods and sedimentation episodes in the cave will be discussed. Historical records of forest clearance in the catchment area of the cave are available only in a very limited amount. Records of other human activities such as industrial development and agriculture are being investigated.

3 — Confirmation that MS is truly an erosional indicator

Detrital iron oxides in the sediments have been identified using an optical microscope, authigenic iron oxide overgrowths are also present. Microprobe analysis aided by magnetic force microscopy will serve to determine the elemental composition of the grains present and to estimate their contribution to the mineral magnetic signal. Another method of testing whether MS is truly an erosional indicator is by comparing it which the records of concentration of Ti an Zr, which reflect the heavy mineral influx rate. This is also being currently done and will be reported on.

THE MAGNETIC PROPERTIES OF THE BASZKOWKA L5 CHONDRITE

ELIZABETH KROL[1], BRUNO LANG[2] and JACEK SIEMIATKOWSKI[3]

[1]Institute of Geophysics, Polish Academy of Sciences, Ks. Janusza 64, 01-452 Warsaw, Poland
[2]Department of Chemistry, Warsaw University, al. Zwirki i Wigury 101, 02-089 Warsaw, Poland
[3]State Geological Institute, al. Jaworowa 19, 53-122 Wroclaw, Poland

This meteoritic body fell on August 25, 1994, about 4 p.m. of the local time. The place of the fall — the small settlement of Baszkowka — is situated at the distance of 23 km directly to the South of the center of Warsaw, capital of Poland. The weather was good and the air transparent, while the acoustical effect, relatively small attracted the attention of 4 persons only working in the garden on collection of strawberries. The meteorite body was found buried, and the lack of cratering confirmed the relatively low velocity of fall equivalent to the very low altitude of stagnation of flight of the body nearing the Earth surface.

The mass of the body is 15.83 kg, while its shape is like a fragment of a sphere.

The size of Baszkowka is 25-30 cm in diameter of the circular part, while 18 cm high. The spherical surface of the body is covered by remaglypts produced by the interaction of the molten mass with the shock wave impacting at high velocity.

As a result of the delay of the beginning of meteoritic study of the Baszkowka meteorite, our study of its magnetic properties preceeds the appropriate multidisciplinary study according to the usual routine.

Unfortunately such an advanced position of the magnetic investigation on the exploratory front has its price: we have to wait with our valid conclusions for publication of the results of a more progressed multidisciplinary study being their natural predecessor. The abundances of the main and accessory minerals with their chemical composition, the size distribution of crystal and amourphous grains, accounted magnetic minerals like pure Fe, FeNi alloys, iron oxides, sulphides, phosphides etc. are needed.

The very preliminary data on the Baszkowka meteorite, which has been included in local collection of the State Institute of Geology in Warsaw, were communicated to us by Dr M. Stepniewski. According to them the Baszkowka with its ca. 7 % of Ni was found to be an L5 chondrite.

The observations under the optical microscope in reflected light show kamacite aggregates in Baszkowka, which were found intergrown with troilite, while interstidial to chondrules, their fragments and single silicate crystals. The aggregates of troilite interstidial to chondrules, are xenomorphic, sized up to 1.5 mm, while making 6 % of the total volume. Inside chondrulites kamacite is observed intergrown with crystals of silicates. The aggregates of fine silicate crystals in chondrules are of size of 0.01 mm. In chondrules rich in kamacite and troilite these mineral components together with silicates form assemblages with of sizes 0.1-0.001 mm.

Chromite is also observed in Baszkowka chondrules. The latter make 30 % of the total mass of the chondrite.

On the typical thin section of Baszkowka chondrite grey coloured chondrules and their fragments are seen, white intergrowns expose kamacite and troilite crystals.

The enlarged fragment of thin section (microphotography in refelected light × 100) presents: the kamacite as white, the troilite as yellow-brownish, the chromite spinel — as green, while the matrix being silicate — as green-brownish.

Our attention has been focused on two important topical problems of meteoritic systematics:

1 — the magnetic classification of stony meteorites (Nagata & Sugiura 1976; Nagata 1979) by measuring the major magnetic transition temperature in cooling process (after heating) and plotting them against the saturation magnetization IS;

2 — study of the parameters of the hysteresis loop combined with modelling of percentage composition of different magnetic carriers in relation to these parameters.

Measurements of magnetic properties of Baszkowka have been made in the Paleomagnetic Laboratory (Institute of Geophysics, Warsaw) and thanks to the kindness of Dr O. Orlický a curve of thermal dependence of magnetic susceptibility in the Geophysical Institut of Slovak Academy of Sciences in Bratislava.

The measurement of the intensity of natural remanent magnetization (NRM) and AF demagnetization process was performed on the 2G cryogenic SQUID magnetometer with demagnetization device attached, the mean magnetic susceptibility was measured on the Kappabridge KLY-2, the hysteresis loops were obtain on the Vibrating Sample Magnetometer (Molspin Ltd.) and a thermal dependence of magnetic remanence I_{rs} was traced on a home-made device.

The main magnetic parameters of the Baszkowka chondrite are compiled in Tab. 1.

	NRM [A/mkg]	k [10^{-4} SI/kg]	I_S [A/mkg]	H_{cr} [mT]	H_c [mT]	H_{cr}/H_c	M_r [A/m]	M_s [A/m]
Baszkowka	3.54	106	10.7	14 $^+$ 1	1	15-13	8.81	1779.33

The measured values of magnetic susceptibility and saturation magnetization determine the chondrite to correspond with type L according to the classification of stony meteorites by Nagata & Siugura (1976).

During AF demagnetization the natural remanence falls to 50 % of its initial value in around 6 mT, the whole process of demagnetization closes in 60 mT. This means that magnetic carriers are soft. The kamacite is a dominant magnetic mineral and is represented by relatively big crystal aggregates (visible on microphotographs), composed of large domains.

The parameters of the hysteresis loop, especially M_r/M_S = 0.005 confirms the presence of large, single domains. The high value of the ratio H_{cr}/H_c = 14 suggests reference to the magnetic binary system model of Nagata & Funaki (1988, 1989) involving the role of second high-coercivity component (troilite or tetrataenite) as an important carrier of remanence. The troilite is abundant, easy to be seen in the thin sections, while tetrataenite was not directly observed by us.

The most conclusive thermal curve among three different thermal experiments conducted for the Baszkowka meteorite appeared to be the heating-cooling curve of magnetic susceptibility, measured during constant heating-cooling process in the field on the Kappabridge device in Bratislava, as only during this experiment were we able to reach the temperatre of 770 °C. During heating two different blocking temperature are observed: 565 °C connected with a magnetic spinel (chromite- ?) and 730 °C — for the phase change alfa to gamma of kamacite.

During cooling the reversal change gamma to alfa kamacite takes place in the temperature 630 °C.

The saturation remanence (I_{rs}) was measured without magnetic field during heating (with a constant velocity) twice. As the maximum temperature in our device reaches only 700 °C we could find only the confirmation for the presence of troilite (the blocking temperature 180 °C) and of magnetic spinels (a broad spectrum of blocking temperatures higher than 400 °C), but we did not reach the range of temperature in which kamacite demagnetizes in the course of its alfa to gamma phase change. On the second heating curve the decomposition of troilite to magnetite is visible. A similar situation was found during an experiment conducted on the Curie balance in the Paleomagnetic Laboratory in Rennes, as the maximum temperature of heating in this device is only 680 °C. The only distinct blocking temperature was observed during cooling — it was 575 °C — connected with a fresh magnetite, the product of oxidation of troilite.

The most important feature for the magnetic classification of stony meteorites that is the magnetic transition temperature of gamma to alfa kamacite during cooling, which for the Baszkowka is 630 °C, together with the I_S value of 10.7 [A/ mkg] locates this new Polish meteorite among chondrites of class L (probably L5) according to the data and the diagram after Nagata & Siugura (1976).

The presented preliminary results of magnetic studies for the Baszkowka will be enriched and compared with the data for other chondrites of type H and L in the nearest future and with complementary detailed studies of its mineralogy, absolute age etc.

ANALYSIS OF SELF- AND HETERODIFFUSION DATA IN FERROMAGNETIC AND PARAMAGNETIC α-IRON

FILIPPOS VALLIANATOS

Technological Educational Institute of Crete, Branch of Chania

Recently, several experimental studies show that during the transition from the ferromagnetic to paramagnetic state, the physical quantities of a magnetic mineral do not change suddenly at a given temperature but gradually over a temperature interval called the Curie zone (see Kucera & Stransky 1982).

Self-diffusion experiments shows a strong anomaly in the Arrhenious plot in the Curie zone. This anomaly is the so-called "magnetic diffusion anomaly". Due to the lack of experimental diffusion data in magnetic minerals, we focus our interest in the study of self and heterodiffusion in the paramagnetic and ferromagnetic state of α-Fe. As a consequence of the aforementioned anomaly a large redaction in the value of the self-diffusion coefficient begins already in the paramagnetic region and extends over the paramagnetic-ferromagnetic transition. Furthermore, it is well known that impurity diffusion of Co, Cr, Cu, Zn, V and Ni shows a quite remarkable diffusion anomaly in ferromagnetic α-iron.

The physical basis hidden behind the experimental results indicates that easiest migration occurs in the paramagnetic state and most difficult in the ferromagnetic one. The latter expressed by the enthalpies' relation $h_p^{act} < h_f^{act}$. An explanation for the aforementioned experimental fact is based on the effect of the ferromagnetic spin ordering that reduces the mobility below the Curie temperature T_c. According to this model a ferromagnetic short range order exists already in paramagnetic α-iron at a temperature considerably above T_c. Therefore a smooth decrease of the diffusion coefficient is expected when approaching T_c from the high temperature range.

An equation that gives the temperature dependence of the diffusion coefficient $D_f(T)$ in the ferromagnetic state as a function of the activation enthalpy h_{act} for diffusion in the paramagnetic state is (Geise & Herzing 1987):

$$D_f(T) = D_{op}\exp\left(-\frac{h_{exp}^p(1+\lambda R^2(T))}{k_B T}\right)$$

where D_{op} is the pre-exponential factor in the paramagnetic state. R(T) is a magnetic order parameter which for α-iron is the spontaneous magnetization and λ is a temperature independent quantity related to the exchange integral at the equilibrium point. For low temperatures $R(T) \rightarrow 1$ and the quantity $h_{exp}^p(1+\lambda)$ is the activation enthalpy for diffusion in the fully ordered state (Cermak et al. 1989).

On the other hand Varotsos & Alexopoulos (1986) have proposed the so-called cBΩ model in order to study the curved Arrhenious diffusion plots. They suggested that the Gibbs energy g^i for various processes (i.e., i = activation, migration, formation) is given by the expression $g^i = c^i B\Omega$ where c^i is a dimensionless constant, independent of temperature and pressure. B is the isothermal bulk modulus and Ω the mean atomic volume. According to this model the diffusion coefficient is given:

$$D^i = fa^2 v_m (m_m/m_i)^{1/2} \exp(-c^i B\Omega/k_B T)$$

where f is the correlation factor, a is the edge of the elementary cube, v_m is the attempt frequency of the matrix material; m_m, m_i the masses of matrix and diffusing atoms, respectively.

In the present contribution, we investigate whether the self- and heterodiffusion data in the transition from ferromagnetic to paramagnetic α-iron can be connected to the variation of

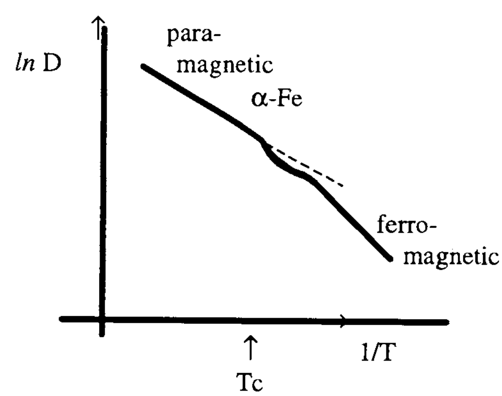


Fig. 1. Qualitative description of the anomaly in the self-diffusion in α-Fe at the Curie point.

elastic constants in the temperature region near to T_c = 1043 K. Using the experimental data from self and heterodiffusion to α-Fe and the elastic data of α-iron, we estimate the constant c_p, in the paramagnetic state from the expression:

$$c_p = -(k_B T/B\Omega)\ln[\frac{Di(m_i/m_m)^{1/2}}{fa^2 v_D}]$$

We point out that in the present calculation we assume that v_m is equal to the Debye frequency v_D. Using the quantity c_p the activation enthalpy can be deduced for any temperature by means of the relation:

$$h_p = c_p(B\Omega - T\, d(B\Omega)/dT)$$

By summarising the results of the present contribution we can state that the diffusion magnetic anomaly could be partly explained by the anharmonic behaviour of bulk elastic and expansivity data.

References

Cermak J., Lubbehusen M. & Mehrer H., 1989: *Z. Metalikde*, 80, 213-219.
Geise J. & Herzing C., 1987: *Z. Metalikde.*, 78, 291-294.
Kucera J. & Stransky K., 1982: *Mater. Sci. Engng.*, 52, 38-47.
Varotsos P. & Alexopoulos K., 1986: In: Thermodynamics of point Defects and their relation with bulk properties, North Holland.

CAPABILITIES OF THE NEW AUTOMATED, LONG-CORE MAGNETOMETER FACILITY AT THE UNIVERSITY OF CALIFORNIA, DAVIS

KENNETH L. VEROSUB and ANDREW P. ROBERTS

Dept. of Geology, University of California, Davis, CA 95616, U.S.A.

The University of California, Davis, now has a 2-G Enterprises Model 755-R cryogenic magnetometer that is specially designed for making high-resolution continuous measurements of long-core samples. The instrument utilizes D.C. SQUID detectors and is capable of making automated measurements of natural remanent magnetism (NRM), anhysteretic remanent magnetism (ARM), isothermal remanent magnetism (IRM) and magnetic susceptibility. It is located in a magnetically-shielded room in the Paleomagnetism Lab. of the Dept. of Geology.

The magnetometer measures sediment samples that have been collected in non-magnetic, plastic u-channels which are 2 cm high, 2 cm wide and up to 1.5 m long. The sample is collected by pushing the u-channel into the split face of a sediment core. In the laboratory, the u-channel is placed on a track that is part of an automated sample handling system. Measurements are typically made at 1 cm intervals, but other values can be used. With the 1 cm measurement interval, magnetic features with spatial resolution as small as 3-5 cm can be detected without deconvolution.

The magnetometer has one axial and two transverse demagnetization coils mounted on the access track. Each coil is capable of applying peak alternating fields of up to 120 mT. A direct bias field as high as 0.2 mT can also be applied to the axial demagnetization coil for ARM studies. The track extends outside the shielded room where another axial coil can impart an IRM in magnetic fields up to 1.0 T. This coil can also be used for backfield demagnetization of the IRM to assess the hardness of the magnetic carriers. A Bartington Instruments magnetic susceptibility meter is mounted in-line with the other equipment for automated measurement of the magnetic susceptibility.

The entire magnetometer system is computer-controlled so that a complete, three-axis, stepwise alternating field demagnetization of the NRM can be done in a fully automated mode. Measurements of magnetic susceptibility and of the acquisition and demagnetization of an ARM and a saturation IRM (SIRM) can also be done in this way. With the appropriate software, it is possible to generate down-core logs of individual and composite magnetic parameters as well as orthogonal vector component plots at any specified interval. A comprehensive paleomagnetic and mineral magnetic characterization can therefore be carried out for each u-channel sample.

The magnetometer also has a much higher throughput than can be achieved with back-to-back discrete samples on a conventional cryogenic magnetometer. Even with a 1 cm measurement interval, a 1.5 m u-channel can be measured about 20 times faster than it would take to measure individual samples extracted at 2.5 cm intervals. Thus, it is now feasible to consider making continuous, high-resolution magnetic measurements on cores that are tens or even hundreds of meters long and to rapidly scan a large number of shorter cores to identify specific magnetic features for more detailed study. Because of these capabilities, the magnetometer represents a major advance in paleomagnetic instrumentation, particularly for studies of environmental magnetism and investigations of the behaviour of Earth's magnetic field.

DETERMINATION OF DIFFERENT TYPES OF FINE DISPERSED Fe-MINERALS OF HYDROTHERMAL ORIGIN. METALLIFEROUS SEDIMENTS OF EPR, JUAN DE FUCA RIDGE AND THE RED SEA

TATYANA S. GENDLER, VALERIY I. BAGIN, ALLA A. NOVAKOVA* and ELENA HALIULINA

*United Institute of the Physics of the Earth,
B. Gruzinskaya 10, 123810 Moscow, Russia

It is well known that Fe is the main hydrothermal element and a very sensitive indicator of hydrothermal activity. The type, structure, oxidizing state, crystallite size, degree of crystallinity and cationic of fine dispersed Fe-minerals in metalliferous sediments (MFS) are of great important because they are intimately related to the evolution of hydrothermal processes and deposit environments. To determine these data correctly comparative analysis using different physical methods is necessary. More reliable determination of Fe-phase composition and state in MFS can be achieved using the Mössbauer spectroscopy on Fe-57 and rock magnetic measurements.

In the present contribution, the Mössbauer spectra (MS), scalar magnetic characteristics, element contents and XRD pictures of MFS from zones of submarine hydrothermal activity with different spreading rates were studied.

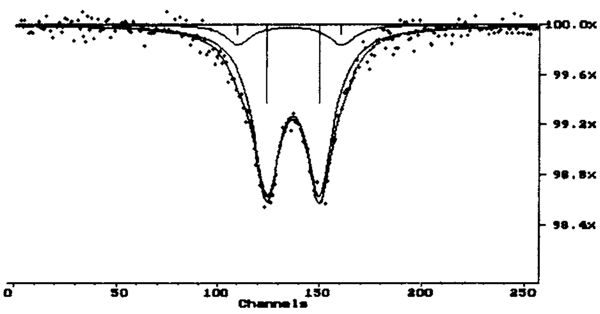


Fig. 1. Typical Mössbauer spectrum of EPR MFS.

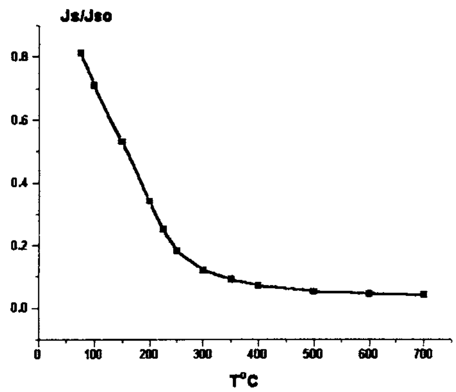


Fig. 2. Typical thermomagnetic curve of EPR MFS.

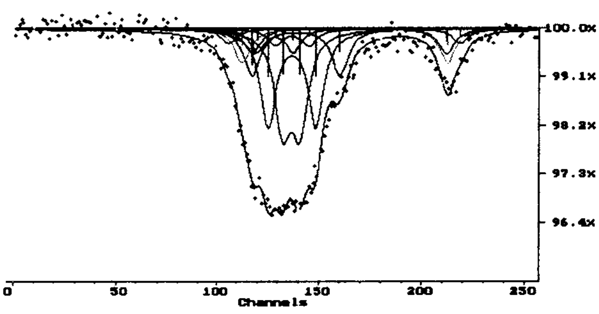


Fig. 3. Typical Mössbauer spectrum of Juan de Fuca MFS.

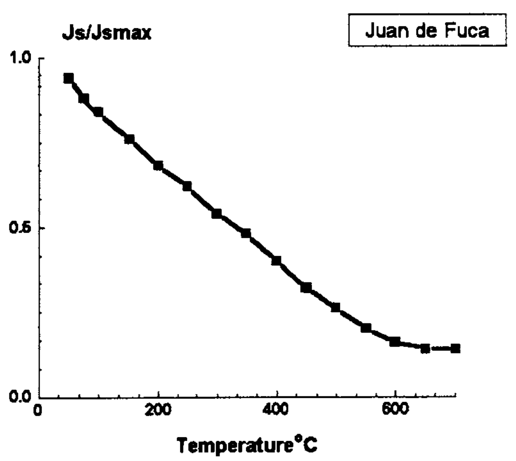


Fig. 4. Typical thermomagnetic curve of Juan de Fuca MFS.

The samples under study were taken from 20 cores of EPR (20°30'-22° S, 14th cruise of RV "Geolog Fersman"), 2 MFS-cores situated at 40 and 50 km distance from Juan de Fuca Ridge (12 cruise of RV "Acad. M. Keldish") and 2 depressions Atlantis and Tethys in Red Sea.

It was shown that all EPR MFS down the length of the cores mainly consist of amorphous and cryptocrystalline Fe^{3+} -Mn hydroxides (goethite and Mn-ferroxygite). Thus the superparamagnetic particles of about 7-10 and <5 nm sizes were formed in pure oxidized conditions. A new tendency was found in surface change in MFS magnetic properties. The MFS magnetization J_0 measured in field about 0.25 T increases from 5 to 20 × 10^{-2} Am^2/kg) away from the spreading axis. The thermomagnetic curve shapes change from pure paramagnetic ($T_{1/2}$ ~ 230-250 °C) for MFS of 10-20 km profiles to strong concave ($T_{1/2}$ ~ 150 °C) for MFS of 40 km profile. Relations J_t/J_0 decrease from 7-8 to ~1. Similar changes are observed after laboratory heating of MFS samples. J_0 values of MFS have a negative correlation with J_t/J_0 relations, Fe and Mn contents, but a positive correlation with the $CaCO_3$ content. These peculiarities were observed only in hydrothermal sources area. They may be explained by recrystallization of initial hydrothermal precipitates and forming a new more strong magnetic phase with Tc ~ 250 °C during plume transportation from the rise crest.

Partly oxidized magnetite (T_C ~ 600 °C) is the magnetic mineral of the basaltic component. Its part in MFS is negligible (J_{rs} ~ 10^{-4} Am^2/kg) and decreases away from the rise crest.

The main Fe-minerals of Juan de Fuca MFS are Fe-montmorrilonite and notronite containing both ferric and ferrous ions. The distribution of the Fe^{3+}/Fe^{2+} ratio, nontronite proportion and common Fe contents in MFS down the length of the cores were estimated by MS computer fitting. The variations of these values reflect the hydrothermal process pulsation and differences in the marine environment (oxic condition, Si/Fe and Mn/Fe ratio in plume). The scalar magnetic parameters are very similar and change with the depth insignificantly.

Complex noticed methods showed that they consist of a whole series of Fe-minerals. Amorphous, fine dispersed superparamagnetic and OD particles of Fe^{3+}-Mn hydroxides and hematite, nontronite well crystallized authigenic magnetite, and some transitional sulfide phases are represented in different layers of the cores in varying relations. J_s and J_{rs} values vary significantly in accordance with different Fe-phase compositon (J_s = 4 × 10^{-2} -64.5, J_{rs} = 2 × 10^{-2} -2.2 Am^2/kg, H_{cr} = 19-60 mT). The thermomagnetic curve shapes are also very different. Pure paramagnetic curves, with sharp peaks at 350-

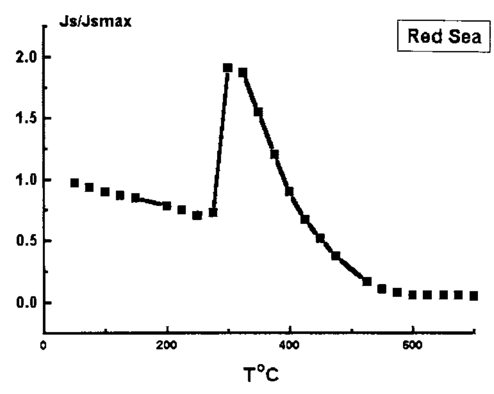


Fig. 5. Typical thermomagnetic curve of Red Sea MFS.

500 °C, curves denoting pyrrhotite or pyrite phase transitions and curves with blocking temperatures of 120, 480, 580 and 675 °C were observed.

All these results show the great environmental differences in the formation of metalliferous sediments in different spreading zones. The environmental history and hydrothermal plume dischange vents are recorded in the Fe-mineral structure and composition.

Posters:

SUPERZONES OF PREVAILING GEOMAGNETIC POLARITY IN THE UKRAINIAN CARPATHIAN TERTIARY VOLCANITES AND SOME TECTONIC IMPLICATIONS OF PALEOMAGNETIC DATA

ALLA GLEVASSKAYA*, NINEL MIKHAILOVA and VSEVOLOD TSYKORA

*Institute of Geophysics, National Academy of Sciences, Palladin av. 32, 252680 Kiev 142, Ukraine

The Ukrainian part of the Vihorlat-Hutin volcanic belt, buried volcanic ridge of the Tchop-Mukachevo Basin and Beregovo hills is a well known region, where large-scale geological mapping has been combined with detailed paleomagnetic mapping. These situation secured construction of paleomagnetic sections for every volcanic massif and separate stratovolcano and regional magnetostratigraphical section of the Ukrainian Transcarpathian region.

According to the regional paleomagnetic section and K-Ar dating of paleomagnetically characterized rocks Uzhgorod (R) and Transcarpathian (N) geomagnetic epochs have been described (Glevasskaya & Mikhailova 1969; Bagdasaryan et al. 1970; Mikhailova et al. 1974; Glevasskaya et al. 1984). Now we suppose, that the range of magnetic superchrons of prevailing polarity is more correct for these magnetoschronological subdivisions. The age limits of the Uzhgorod Superchron should be expansed to 19.2-12.4 Ma, of Transcarpathian superchron — to 12.4-8.0 Ma. The magnetostratigraphic equivalents name as Uzhgorod and Transcarpathian, superzones of prevailing geomagnetic polarity.

The major achievements of paleomagneting mapping are evidence of unhomogeneity and block structure of volcanic belts, time displacevent of active volcanic centers in direction NW-SE along Transcarpathian and Peripannonian faults and S-N along the periphery of Pannonian massif.

Taking into account new paleomagnetic data including analysis of paleomagnetic parameters, paleointencity and paleolatitude variations for stable and intermediate polarity magnetozones some features of postvolcanic block and local tectonics have been recognized.

References

Bagdasaryan G.P., Glevasskaya A.M. & Mikhailova N.P., 1970: On the absolute dating of the paleomagnetic zones in the Vihorlat-Gutin ridge sections. *Materiales of 8 Congress CBGA, part 2*, Kiev, 30-35 (in Russian).

Glevasskaya A.M. & Mikhailova N.P., 1969: Transcarpathian Neogene volcanic rocks stratification in the light of paleomagnetic data. *Abstracts of Paleovolcanological Congress of USSR*, Lvow, 41 (in Russian).

Mikhailova N.P., Glevasskaya A.M. & Tsykora V.N., 1974: Paleomagnetism of the volcanic rocks and Neogene geomagnetic field reconstruction. *Naukova dumka*, Kiev, 1-232.

Glevasskaya A.M., Mikhailova N.P. & Tsykora V.N., 1984: Paleomagnetic geochronological scale for the Central Paratethys. *Acta Geodaet., Geophys. et Montanist. Hung.*, 19, 61-70.

MAGNETIC CHARACTERISTICS OF GNEISSOSE ROCKS FROM EASTERN ANTARCTICA

MINORU FUNAKI[1], OTO ORLICKÝ[2] and IGOR TÚNYI[2]

[1]National Institute of Polar Research, 9-110, Kaga I-chome, Itabashi-ku, Tokyo 173, Japan

[2]Geophysical Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic

A total of 220 oriented samples of gneissose rocks such as pyroxene gneiss and garnet gneiss were collected in two localities of the East Ongul Island in Eastern Antarctica. Pyroxen gneiss is the dominant rock type of intermediate compositions over the Ondul Islands. The main constituents are feldspar, quartz, clinopyroxene, orthopyroxene and hornblende. Magnetite, apatite and zircon were ascertained as accessory minerals. Garnet gneiss is white to gray-coloured, massive, medium-grained rock. The main constituents are garnet, plagioclase, K-feldspar and quartz with mostly graphite impregnation (Ishikawa et al. 1994).

While the pyrrhotite (Fe_7S_8) is the main carrier of magnetism in the pzroxene gneiss, the magnetite (Fe_3O_4) is the dominant magnetic mineral in the garnet gneiss, according to measurements of low-field susceptibility changes induced by temperature (Figs. 1, 3), as well as by study of the Curie points of rock samples using the vibrating sample magnetometer (Figs. 2, 4). The method of low-susceptibility measurements has been described in Orlický (1994). A secondary magnetite was created during laboratory heating of samples in the pyroxene gneiss (Figs. 1, 2).

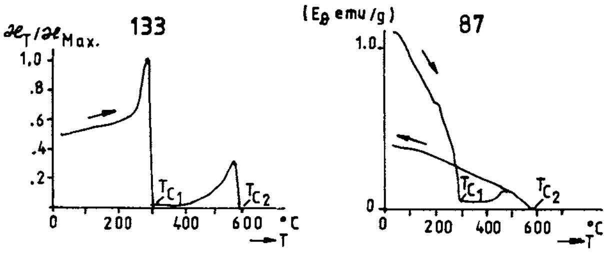
The progressive thermal demagnetization and AC demagnetization were performed on selected samples in order to determine the demagnetization characteristics. The AC demagnetization was carried out, stepwise at 5 mT up to 50 mT and the thermal demagnetization in 50 °C steps up to 650 °C. The optimum AC and temperature demagnetization fields were 25-30 mT and 250-300 °C (for the pyroxene gneiss) and 0-50 mT and 25-500 °C (for garnet gniess), respectively.

The AC demagnetization of samples of both groups gave more or less good convergention of NRM directions. While the thermal demagnetization of samples of pyroxene gneiss indicated the presence of induced-secondary unstable magnetization and very large dispersion of directions of RM, (Fig. 5), samples of garnet gneiss showed conspicuous paleomagnetic stability (Fig. 6).

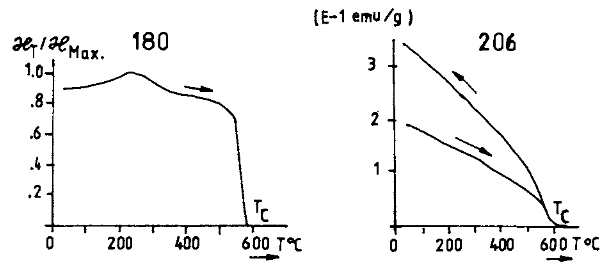
The majority of samples show low magnetic susceptibility anizotropy not similar to this typical gneissose rocks (Hrouda et al. 1978), what can be consequence of the high degree of metamorphism (Fig. 7).

We can conclude, that while pyroxene gneisses under consideration are almost paleomagnetically unstable, investigated garnet gneisses have shown conspicuous paleomagnetic stability.

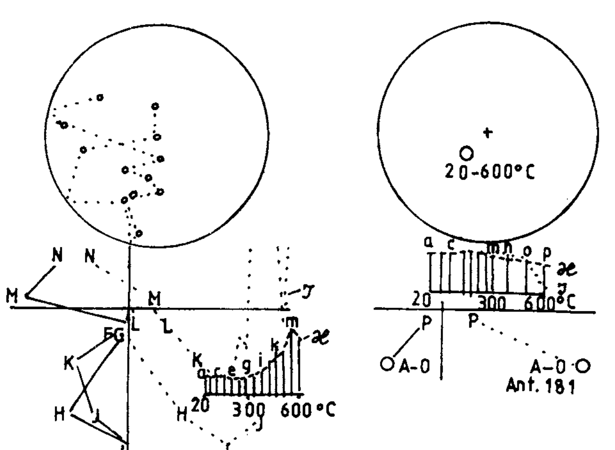
The origin of pyrrhotite is an open question. The presence of this mineral could be caused by hydrothermal alteration in the geological history of the Antarctic gneissose rocks (Nakai et al. 1993).



Figs. 1–2



Figs. 3–4



Figs. 5–6

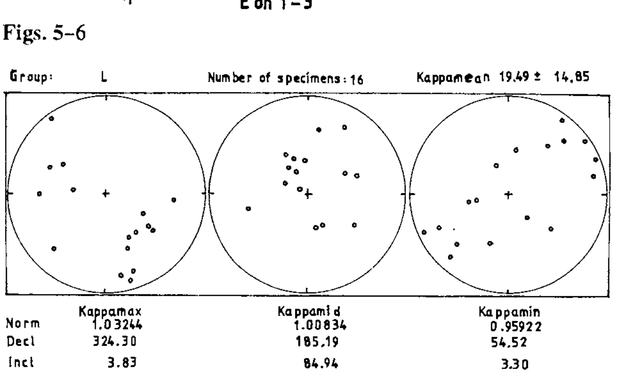


Fig. 7

References

Hrouda F., Janak F. & Rejl L., 1978: Magnetic anizotropy and ductile deformation of rocks in zones of progressive regional metamorphism. *Gerland. Beitr. Geophysik, Leipzig* 87, 2, 126–134.

Ishikawa M., Shiraishi K., Motoyoshi Y., Tsuchiya N., Shimura T. & Yanai K., 1994: Explanatory text of geological map of Ongul Islands, Lutzow Holm Bay, Antarctica. *National Institute of Polar Research*, Tokyo, 3–8.

Nakai M., Funaki M. & Wasilewski P., 1993: The magnetic anizotropy of gneissic rocks from the Skarvsnes Area, East Antarctica. *Proc. NIPR, Symp. Antarct. Geosci.*, 6, 37–46.

Orlický O., 1994: Study and detection of magnetic minerals by means of the measurement of their low-field susceptibility changes induced by temperature. *Geol. Carpathica*, 45, 2, 113–119.

WHAT KIND OF MAGNETIC MINERALS CONTAIN NEOVOLCANICS FROM SLOVAK TERRITORIES; IS THERE SOME RELATION BETWEEN RESPECTIVE TYPE OF MAGNETIC MINERAL AND THAT OF VOLCANIC MAGMA?

OTO ORLICKÝ

Geophysical Institute, Slovak Academy of Sciences,
Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic

Experiences from the study of magnetic Fe-Ti and Fe-S minerals of neovolcanic rocks have confirmed, that composition as well as physical properties are very conspicuously associated with the conditions which affected their origin and successive forming.

According to Lexa et al. (1993) the essential features of space-time composition distribution of the Neogene/Quaternary volcanic rocks in the Carpatho-Pannonian region have been determined by the following phenomena: — Migration of the Carpathian arc and its collision with curved passive margin of European Platform during Miocene-Pliocene time. Advance of the arc was compensated by interarc and backarc extension including diapiric uprise of asthenosphere, and litosphere escape from the collision zone of Alps. — Subduction of oceanic/suboceanic crust of flysch basin. The authors distinguished four essential groupings of neovolcanic rocks. We studied only products of two groupings:

— Alkali olivine basalt/nepheline basanite activity. It took place during the Pannonian to Quaternary. Basalts of this type indicate continuing extension, accompanied by diapiric uprise in mantle, which has not been affected by subduction.

— Areal type andesite volcanic activity which includes also short episode of acidic rhyolite activity. It started during the Lower Badenian time and continued until the Lower Pannonian time. Its spatial distribution is influenced strongly by backarc extension tectonics assotiating with diapiric uprise of mantle. Mantle magmas were influenced by the previous subduction. They were variable contaminated by the crust material (Lexa et al. 1993).

Presented results are based on the study of magnetic minerals of neovolcanics from about 680 individual outcrops from central, southern and eastern areas of Slovakia. Microprobe analyses, Mössbauer spectroscopy, Curie temperature measurements, Verwey temperature detection (if any) were used to study magnetic minerals and their properties.

Olivine basalts and nepheline basanites. They were collected from 31 localities. Thermomagnetic curves show that natural Fe-Ti oxides of basalts mostly contain two magnetic phases of different Curie temperatures (T_C). The first magnetic phase attains $T_C \approx 120-280$ °C, the second one $T_C \approx 490-580$ °C (exclusively $T_C \approx 610$ °C). Quite commonly were revealed titanomagnetites (TMs) with an inversion temperatures around of 300-380 °C. Samples of basalts from several localities contain only one magnetic phase with high T_C ($T_C \approx 560-600$ °C). While TMs of low T_C were revealed within the smaller individual lava flows and basaltic diatremes, oxidized TMs of high T_C were found mostly in basalts of different shapes (lava flows, volcanic cones and aglomerates together). Such combined volcanic bodies at one place are mostly emplaced at eastern part of the Cerová vrchovina Upland. The ratio of Ti/Fe (detected by electron microprobe analysis) has been used to derive the compositional parameter x of TMs ($Fe_{3-x}Ti_xO_4$). It is in the range x = 0.528-0.720. Study of TMs in vacuum (10^{-5} Torr) and that realized on air verified, that both — composition and T_C of TMs depend very extremely on the presence/absence of oxygen, during their heating and successive cooling. We can suggest that the TMs have very specific property — they are able to change their previous composition very easily, depending on oxygen fugacity.

Our results have approved an idea that TMs are the main magnetic minerals in basaltic rocks. The composition of the TMs is extremely dependent on the temperature and oxygen fugacity. But there are also other media — water and volatile oxidants which can influence the composition of the TMs of basalts.

The basalts and the nepheline-rich rocks contain xenolits which indicate that their source lies within the mantle (40-100 km below the surface), according to Ehlers & Blatt 1980. Basaltic magma probably arose from very hot peridotites due to their decompression, according to Bonatti (1994). We can presume that TMs of basalts arose from minerals (clinopyroxene and spinel) which were originally in the peridotites. The TMs have a source within the Earth's Mantle.

Andesite rocks — Kremnické vrchy Mts. Oxidized TMs were detected in the aphanitic basaltic andesites of the Šibeničný vrch complex, in the andesite basaltic bodies from Vtačnik mountain range. These TMs contain mostly magnetic phase of low T_C, of composition x = 0.7-0.5, as well as the phase with high $T_C \approx 580$ °C, very near to that of magnetite. Similar type of oxidized TMs were detected in some volcanic bodies of basaltic and pyroxene andesites of Turčok, Flochová and Zlatá Studňa formations, as well as in glassy pyroxene andesites of Baďan Formation from Štiavnické vrchy Mts. Oxidized TMs with only one phase of high T_C ($T_C \approx 420-580$ °C) were detected in the porphyri basaltic andesites of the Vlčí vrch Formation, in several bodies of augite-hyperstene-pyroxene andesite of respective Remata, Flochová, Zlatá Studňa formations, in the hornblende-pyroxene andesites of the Turček and Kremnický štít formations, as well as in the basaltic andesites of the Blýskavica Formation and the Javorie Formation (in Javorie mountain range) and in several volcanic bodies of the pyroxe biotite andesite and pyroxene augite andesite of respective Veľká Detva and Abčina Formations (in Detva mountain range). Above described volcanic rocks contain Fe-Ti oxides which originated probably in the mantle.

Pyroxene and pyroxene-hornblende andesites (mostly propylitized) of the I (first) stage contain dominantly magnetic minerals of $T_C \approx 580$ °C with very sharp Verwey temperature around $T_V \approx -150$ °C. Presence of Fe_3O_4 and high content of FeO were confirmed by Mössbauer spectroscopy and Microprobe analyses, respectively. There are commonly present TiO_2 (rutile or anatase) in these rocks. Intrusive diorite and diorite porphyri of the Hodrušsko-Štiavnický complex, Banisko complex (Štiavnické vrchy Mts.) and diorite to monzonodiorite of the Kalinka complex (Javorie mountain range) contain dominantly Fe_3O_4, which has been verified by their T_C, T_V, by the results of the Mössbauer spectroscopy and Microprobe analyses. Measurements of T_C and T_V of many other intrusive rocks from Zlatno and Šementlovo areas have verified that main magnetic minerals are there in these rocks either magnetites (Fe_3O_4) or pyrrhotites (Fe_7S_8).

Hornblende-pyroxene andesites, biotite-hornblende andesites, biotite-hornblende-pyroxene andesites and hyperstene-hornblende andesites of respective 32 volcanic formations from all volcanic areas under study contain mostly haematite-ilmenites as the main magnetic minerals. They show Curie temperatures mostly $T_C \approx 600$ °C; they mostly do not show presence of the Verwey temperatures. Such behaviour of magnetic minerals influenced by temperature is characteristic for biotite-hornblende andesites of the Studenec Formation. They mostly contain high content of hematite. The T_C of some samples attains $T_C \approx 640$ °C. The hornblende and biotite are hydrous minerals. It suggests that creation and forming of magnetic minerals took place in the highly oxidative conditions. Rhyolites and rhyodacites contain exclusively either magnetites or haematite-ilmenites. The Curie temperatures of these minerals are in the range $T_C \approx 580-630$ °C. They do not contain TMs, or oxidized TMs.

We can suggest that the studied magnetic minerals were created in both basically different types of magmas. Titanomagnetites and oxidized titanomagnetites arose in mantle magmas, while magnetites, and hematite-ilmenites originated in the crustal magmas. There are present both — oxidized TMs and hematite-ilmenites in some neovolcanics. These types of magnetic minerals correspod to mixed magmas-mantle magmas contaminated by crustal material.

References

Bonatti E., 1994: The Earth's Mantle below the Oceans. *Scientific American,* March 1994, 44-51.

Ehlers E.G. & Blatt H., 1980: Petrology, Igneous, Sedimentary and Metamorphic. *W.H. Freeman and Company*, San Francisco.

Lexa J., Konečný V., Kaličiak M. & Hojstričová V. 1993: A Space-Time Distribution of Volcanics in the Carpatho-Pannonian Region. Geodynamic Model and Deep-Seated Pattern of the West Carpathians. *GÚDŠ,* Bratislava, 57-69 (in Slovak).

HIGH-FIDELITY MAGNETOSTRATIGRAPHY OF JURASSIC/CRETACEOUS BOUNDARY LIMESTONES AT BRODNO NEAR ŽILINA, WESTERN CARPATHIANS

VÁCLAV HOUŠA, MIROSLAV KRS, MARTA KRSOVÁ, PETR PRUNER and DANIELA VENHODOVÁ

*Geological Institute, Academy of Sciences of the Czech Republic, Rozvojová 135, 165 02 Praha 6-Lysolaje, Czech Republic

In 1992, the Paleontological and Paleomagnetic Departments of the Geological Institute of the Czech Academy of

Sciences started a joint project of magnetostratigraphic investigations of the Tithonian-Berriasian boundary strata at two localities in the Western Carpathians, Brodno near Žilina, W. Slovakia, and Štramberk, N. Moravia. The above studies were preceded by petromagnetic and paleomagnetic investigations of the pilot samples collected from five localities in the Western Carpathians. All the five localities were found suitable for magnetostratigraphic investigations, but the Brodno locality was given preference due to its suitable geological and paleontological conditions (Houša et al. 1996). The aim was to determine the principal biostratigraphic boundaries in reference to magnetostratigraphic scales and to prepare data for the next correlations between biostratigraphic zonations in the Tethyan and Boreal realms.

Magnetostratigraphic and biostratigraphic investigations carried out at the Brodno locality fully confirmed the geological assumption that sedimentation in a quiet basin is fundamental for preservation of a continuous fossil record of accurately defined geomagnetic polarity zones. Samples for micropaleontological and magnetostratigraphic analyses were collected independently, but in reference to the same strata labelled with numbers. Boundary positions of biozones and magnetozones were interpreted more accurately during additional and repeated collection of samples. Ammonites are missing at the Brodno locality, consequently, only associations of calpionellids were used for correlation.

Selected pilot samples were subjected to magnetic mineralogy studies. The unblocking temperatures of between 540 to 560 °C suggest the presence of magnetite. The magnetite as the principal carrier of magnetization was confirmed by magnetic measurements (unblocking temperatures determined on natural samples and pilot samples subjected to saturation magnetization) as well as by X-ray diffraction studies. A few samples also exhibited a small fraction of a mineral with an unblocking temperature below 680 °C, evidently due to a small admixture of hematite.

The measured remanence data were subjected to the multicomponent analysis (Kirschvink 1980). All samples exhibit high proportions of secondary magnetization (viscous magnetization and chemo-remanent magnetization conditioned by weathering). The laboratory measurements indicated that the paleomagnetization carrier is magnetite, evidently fine-grained magnetite which is in accordance with results from other localities in the Tethyan realm and generally with results obtained from samples of marine shallow-water carbonates.

The interpreted magnetozones were published in the paper by Houša et al. (1996). The pattern of normal and reverse polarity magnetozones from M17 to M21 correlates well with magnetozones derived in the regions of Foza (north Italy), Bosso Valley (Umbria, central Italy) and with marine M (Mesozoic) anomalies. It is of significance, that a very narrow sub-zone was detected in the younger part of the magnetozone M19n well correlating with a similar sub-zone in the marine magnetic M anomalies. The base of the standard Calpionella Zone, i.e. the Jurassic/Cretaceous boundary, was placed in the younger part of the older half of the magnetozone M19n.

The next narrow reverse sub-zone of marine origin was reported from the younger part of the M20n, cf. Butler (1992, page 225). Consequently, additional very detailed (condensed) sampling was carried out in the Brodno locality in the beds potential for occurrence of this sub-zone. The sub-zone was safely delineated in the younger part of the magnetozone M20n, see Fig.1. Progressive thermal demagnetization of samples by means of the MAVACS apparatus (Příhoda et al. 1989) yield dependable data for multi-component analysis; Fig. 2 exemplifies results of a sample with normal paleomagnetic direction. The sample No. 7550A located at the transition zone between the N and R polarity zones is carrier of two fossil components of remanence with normal and reverse polarities. The transition of the paleomagnetic field was fossilized in a layer whose thickness is less than 2 cm. Detection of two narrow reverse sub-zones in magnetozones M19 and M20, as well as precise detection of magnetozones M17 to M21 place the Tithonian-Berriasian magnetostratigraphic profile at Brodno among the high-fidelity profiles suitable for accurate correlation with biostratigraphic zones.

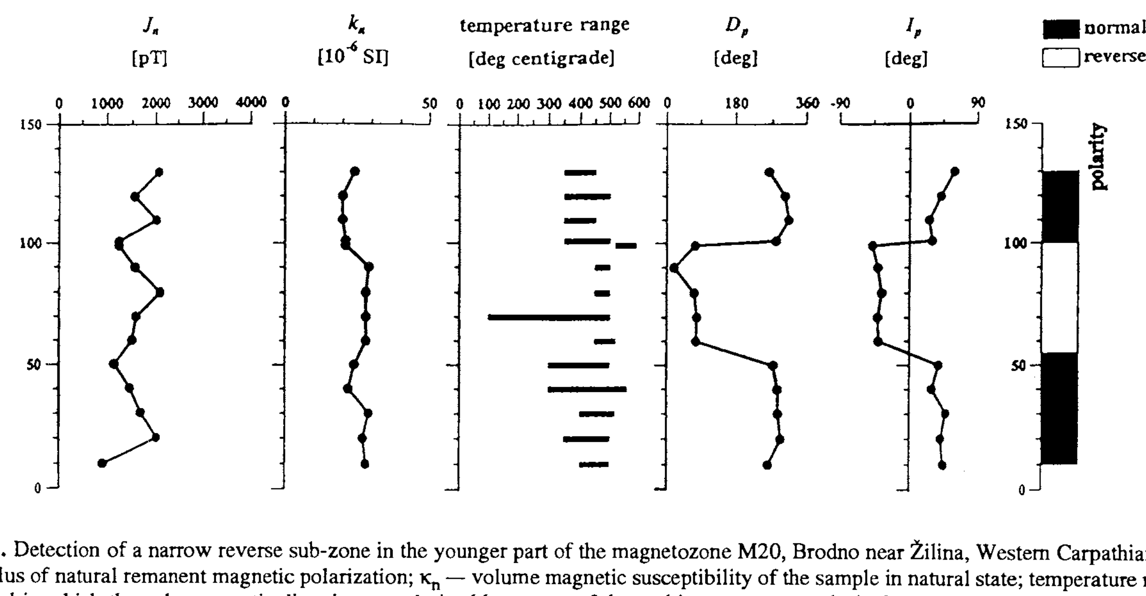


Fig. 1. Detection of a narrow reverse sub-zone in the younger part of the magnetozone M20, Brodno near Žilina, Western Carpathians. J_n — modulus of natural remanent magnetic polarization; κ_n — volume magnetic susceptibility of the sample in natural state; temperature range — interval in which the paleomagnetic direction was derived by means of the multi-component analysis; D_p, I_p — declination, inclination of paleomagnetic direction.

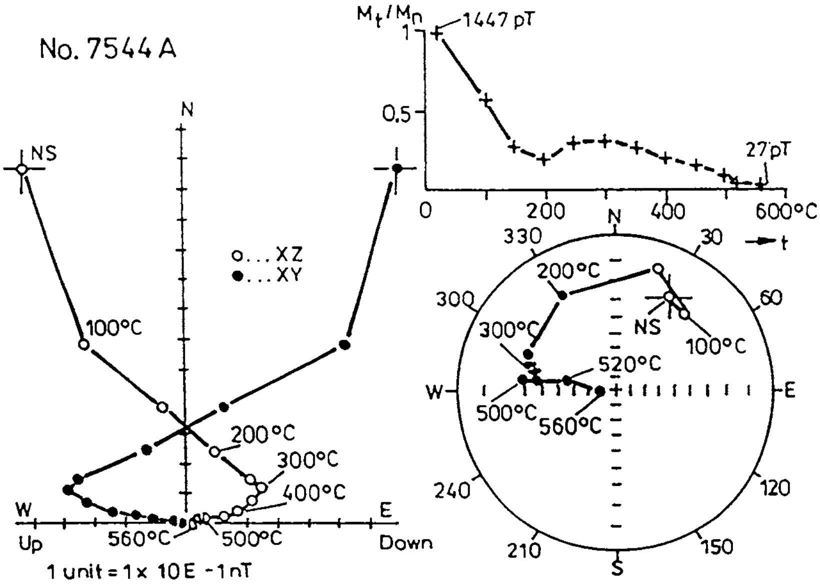


Fig. 2. Results of progressive thermal demagnetization of the limestone sample No. 7544A by means of the MAVACS apparatus, Brodno near Žilina, Western Carpathians. Left-hand side of the Fig.: Zijderveld's diagram. Right-hand side of the Fig.: graphs of standardized values of remanent magnetic moments plotted against the temperature t (°C) and stereographic projection of directions of remanent magnetization of sample in natural state (NS) and after thermal treatment at temperatures t (°C). M_t — remanent magnetic moment of the sample demagnetized at temperature t (°C), M_n — remanent magnetic moment of the sample in its natural state.

References

Butler R.F., 1992: Paleomagnetism: Magnetic Domains to Geologic Terranes. *Blackwell*, Oxford, 1-319.

Houša V., Krs M., Krsová M. & Pruner P., 1996: Magnetostratigraphy of Jurassic-Cretaceous limestones in the Western Carpathians. In: A. Morris & D. H. Tarling (Eds.): Palaeomagnetism and Tectonics of the Mediterranean Region. *Spec. Publ. (Geol. Soc. London)*, 105, 185-194.

Kirschvink J.L., 1980: The least-squares line and plane and the analysis of palaeomagnetic data. *Geophysical Journal of the Royal Astronomical Society*, 62, 699-718.

Příhoda K., Krs M., Pešina B. & Bláha J., 1989: MAVACS — a new system of creating a non-magnetic environment for palaeomagnetic studies. *Cuad. Geol. Ibérica*, 12, 223-250.

PETROMAGNETIC AND PALEOMAGNETIC INVESTIGATIONS OF THE EARLY CRETACEOUS LIMESTONE BEDS FROM THE RÍO ARGOS AREA, SE SPAIN

MIROSLAV KRS, OTAKAR MAN, PETR PRUNER and DANIELA VENHODOVÁ

Geological Institute, Academy of Sciences of the Czech Republic, Rozvojová 135, 165 02 Prague 6-Lysolaje, Czech Republic

Magnetostratigraphic results so far obtained along the Jurassic/Cretaceous boundary strata at several localities in the Tethyan realm were the basis for extending magnetostratigraphic investigations to further key localities. Especially the results from the Brodno locality, near Žilina, W. Slovakia, where the magnetozones M17, M18, M19, M20, M21 and two narrow reverse sub-zones in normal zones M19 and M20 were precisely detected, enable correlation with global events with high resolution (Houša et al. 1996). Magnetostratigraphic dating offers an alternative method of identifying sections in distant regions and can potentially be used to correlate globally biostratigraphic zonations. At both the IGCP/UNESCO Meetings of the Project 362 in Coimbra (Portugal) in 1993 and in Smolenice (W. Slovakia) in 1994, the next profile selected for a detailed magnetostratigraphic investigation was the Early Cretaceous section at the Río Argos, Provincia Murcia, SE Spain. The larger area of the Río Argos is characterized by well exposed outcrops of individual beds of alternating limestone, marlstone, marly limestone and sandstone turbidites (Hoedemaeker & Leereveld 1995). The oriented samples were collected from limestone strata covering the epochs of the Berriasian, Valanginian, Hauterivian, Barremian and the Earliest Aptian.

Altogether 361 oriented hand samples were collected, from which laboratory specimens were prepared. Laboratory procedures were combined in a way that enabled the derivation of respective magnetic remanence components in different temperature intervals (during progressive thermal demagnetization using the MAVACS apparatus, Příhoda et al. 1989), the determination of moduli and directions of remanent magnetization, of volume magnetic susceptibility and determination of the minerals — carriers of respective remanence components. The aim was to establish a geological-historical succession for the generation of remanence components and to derive data suitable for testing those samples which are potential carriers of paleomagnetic directions.

According to the values of moduli of J_n (natural remanent magnetic polarization) and of κ_n (volume magnetic susceptibility), the samples may be divided into three categories: *i)* The extremely low magnetic samples show mean values of $J_n = 33 \pm 11$ [pT], $\kappa_n = 24 \pm 5 \times 10^{-6}$ [SI]. Low unblocking

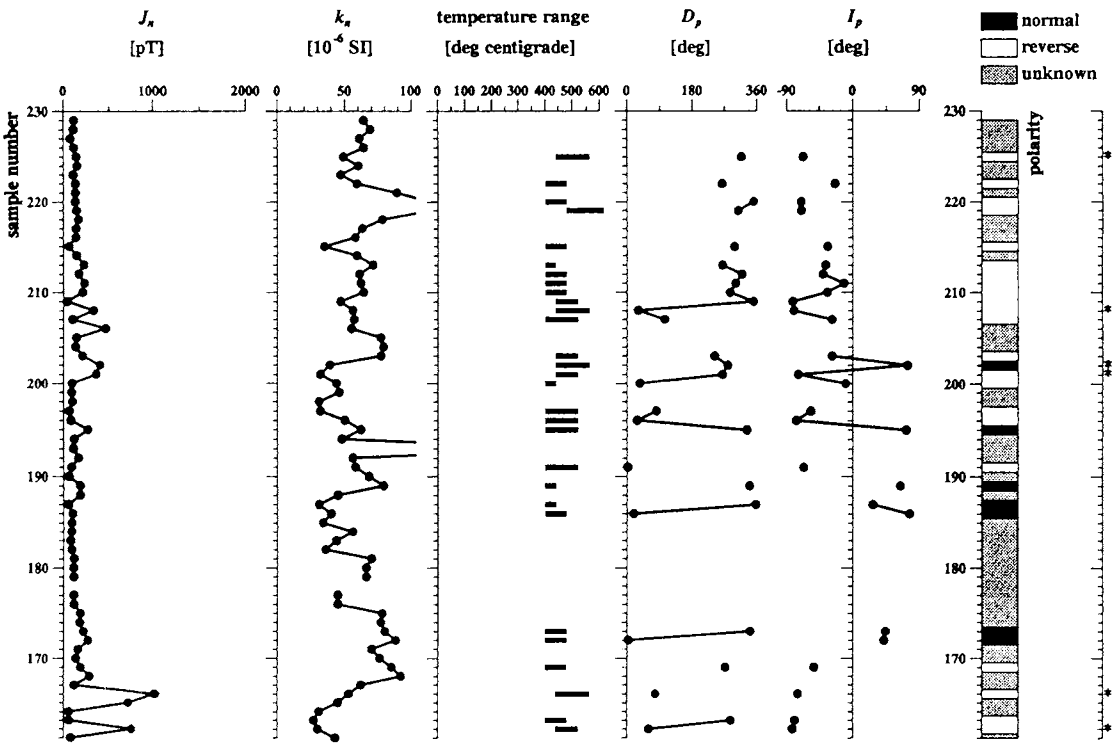


Fig. 1. Plot of basic petromagnetic data and of directions of C-components for the boundary section of the Valanginian/Hauterivian. The Río Argos area, Provincia Murcia, SE Spain.

temperatures (due to goethite) and low values of J_n exclude these samples from paleomagnetic investigations. *ii)* The second category of samples is characterized by considerably increased values of J_n. The mean values of $J_n = 770 \pm 799$ [pT], $\kappa_n = 55 \pm 12 \times 10^{-6}$ [SI]. These samples show signs of total remagnetization or Miocene and/or later overprint, they are denoted by asterisks in Fig. 1. *iii)* The third category comprises low magnetic samples, their values of κ_n are similar to those sub ii), but the moduli of J_n are considerably lower. The mean values of $J_n = 205 \pm 214$ [pT] and $\kappa_n = 53 \pm 29 \times 10^{-6}$ [SI]. By application of the multi-component analysis of remanence (Kirschvink 1980) it was revealed that the samples under ii) are carriers of prevailingly two-component remanence: the A-components are small and evidently of viscous origin, the B-components are pronounced and are characterized by the Miocene and/or later overprint. The samples under iii) represent partially remagnetized limestones and they carry three-component remanence: the A-components are small and evidently of viscous origin, the B-components were separated within the temperature interval of approx. 100 to 400 °C. The C-components were separated in temperature intervals of approx. 400 to 500 up to 540 °C, they evidently carry the fossil record of the paleomagnetic field and should be used for derivation of magnetostratigraphic scales. The carrier of magnetization of the samples under ii) and iii) is magnetite, either totally or partially remagnetized.

Fig. 1 exemplifies values of J_n, κ_n, temperature intervals in which the C-components of remanence were derived, the declination D_p, inclination I_p and polarities of C-components plotted along the axis indicating the Nos. of samples. The remanence directions of totally remagnetized samples are denoted by asterisks. The unknown polarities (due to low unblocking temperatures or incomplete Zijderveld's diagrams) are denoted by grey field, the normal and reverse polarities of C-components are denoted by black and blank fields. The normal zone of the sample Nos. of 172 to 189 may be tentatively correlated with the normal part of the magnetozone M11A (?) and the reverse zone of the sample Nos 191 to 222 with the reverse part of the magnetozone M11 (?). According to data of Hoedemaeker & Leereveld (1995), the sample No. 205 corresponds to the top bed of the Valanginian. Petromagnetic data are fundamental for distinguishing those samples which may be suitable for derivation of paleomagnetic directions. However, construction of continuous magnetostratigraphic profiles would need additional and detailed sampling.

References

Hoedemaeker Ph.J. & Leereveld H., 1995: Biostratigraphy and sequence stratigraphy of the Berriasian - lowest Aptian (Lower Cretaceous) of the Río Argos succession, Caravaca, SE Spain. *Cretaceous Research*, 16, 195-230.

Houša V., Krs M., Krsová M. & Pruner P., 1996: Magnetostratigraphy of Jurassic-Cretaceous limestones in the Western Carpathians. In: A. Morris & D.H. Tarling (Eds.): Palaeomagnetism and Tectonics of the Mediterranean Region. *Spec. Publ. (Geol. Soc. London)*, 105, 185-194.

Kirschvink J.L., 1980: The least-squares line and plane and the analysis of palaeomagnetic data. *Geophysical Journal of the Royal Astronomical Society*, 62, 699-718.

Příhoda K., Krs M., Pešina B. & Bláha J., 1989: MAVACS — a new system of creating a non-magnetic environment for palaeomagnetic studies. *Cuad. Geol. Ibérica*, 12, 223-250.

MAGNETOSTRATIGRAPHIC TIME FRAME OF THE LACUSTRINE PTOLEMAIS BASIN (NW GREECE): A PRECESSIONAL ORIGIN OF LIGNITE-MARL COUPLETS

NICOLE VAN VUGT, JORIS STEENBRINK, MARK J. DEKKERS and COR G. LANGEREIS

Paleomagnetic laboratory 'Fort Hoofddijk', Faculty of Earth Sciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands

The intra-montane Florina-Ptolemais-Kozani Basin (NW Greece) contains a rhythmic sequence of alternating lacustrine marls and lignites which is mined by the national power company in open pits. Earlier studies assigned a Lower Pliocene age to the basin infillings. The present contribution forms part of a multi-disciplinary program aimed at unravelling the underlying mechanism for the very distinct cyclicity observed in these sediments. A link to regional paleoclimate is likely. A first step toward resolving this problem is to establish a detailed time frame that will allow bed-to-bed correlations between the sections and various subbasins.

The Ptolemais stratigraphy is divided into three formations. The lowermost formation, conveniently termed Lower Formation, consists of marly limestones, with several hardgrounds nine metres below the top, whereas in the uppermost formation (Upper Formation) clays are by far predominant, with occasional intercalations of pebble-sized conglomerates and sandy layers. The Middle Formation contains the rhythmic lignite-marl alternations which are the prime focus of our study. This formation comprises four units; the lower lignite, with a predominantly lignitic lithology and dark grey marl beds; the lake marl unit, dominated by light marls; the rhythmite unit, with very distinct cyclic lignite-marl couplets; and the upper lignite unit, laterally varying in thickness, and consisting of xylite as well as lignite. This unit shows no cyclicity.

Approximately twenty volcanic ashlayers were found throughout the whole stratigraphy. Most of them can be correlated between different sections, because they appear at typical levels in corresponding cycles. The R3-ashlayer, located in the third cycle of the rhythmite unit, has an $^{40}Ar/^{39}Ar$ sanidine age of 4.19 Ma. Other ashes are still to be analysed.

The paleomagnetic properties are highly variable. Almost all lignitic samples are diamagnetic; they must be demagnetized by alternating fields. Only a few lignite samples yielded meaningful results. White limestones are also diamagnetic, with NRM intensities below the noise level of the DC-SQUID magnetometer. Mixed lithologies (marls and lignitic clays) give better results, although they still have a low susceptibility ($<120 \times 10^{-6}$ SI units) and NRM intensity (200-1000 $\mu A\ m^{-1}$, with several exceptions of up to 15 $mA\ m^{-1}$).

Both thermal and AF demagnetization show a randomly oriented overprint, that is removed at circa 200 °C or 10 mT. The majority of the samples that were classified in the field as 'marly mixtures' show a major NRM-intensity drop between 150 and 230 °C, followed by a more gradual decrease. The NRM of the 'clayey mixtures' decreases gradually throughout the heating process.

NRM intensities increase at 400 °C, because of chemical alterations, precluding determination of the maximum unblocking temperature in approximately 50 % of the samples. The ChRM direction, however, could still be reliably determined in these samples. In the remainder of the samples no alteration occurred and thermal demagnetization revealed maximum unblocking temperatures close to 580 °C. IRM experiments reveal maximum unblocking temperatures of 580 °C for all samples indicating magnetite as the carrier of the characteristic component.

The magnetostratigraphic data reveal four normal and five reversed polarity zones (Fig. 1). The R3-ashlayer is situated in the upper normal interval, indicating that this interval represents the Cochiti Subchron. The other normal intervals therefore can be interpreted as the Nunivak, Sidufjall and Thvera Subchrons (from top to bottom). The hardgrounds found in the Lower Formation might then correspond to the Miocene-Pliocene boundary. The Ptolemais section correlates well with the marine Rosello composite section from Sicily (Langereis & Hilgen 1991). The number of lignite-marl couplets in the Nunivak to Cochiti and in the Thvera Subchrons agrees well with the number of precession related $CaCO_3$ cycles in the Rosello composite. These observations confirm a precessional original for the lignite-marl alternations. The exact phase relations of the lacustrine cycles, however, are still to be determined (do lignites correspond to precession minima or maxima?).

The Sidufjall and overlying reversed subchron, however, have far less cycles in the Ptolemais section (between 3 and 6)

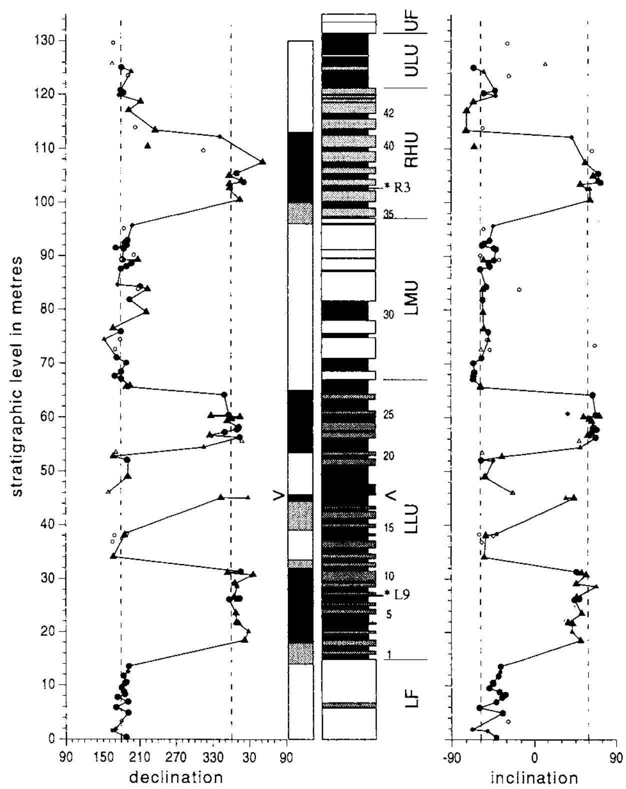


Fig. 1. Ptolemais section; stratigraphic column: black = lignite, grey (white) = dark (light) marl; LF/UF = Lower/Upper Fm, LLU = Lower lignite unit, LMU = Lake marl unit, RHU = Rhythmite unit, ULU = Upper lignite unit, cycles are numbered, ><= hiatus, * = ashlayers; characteristic remanent magnetization directions: closed [open] circles (triangles) are reliable [less reliable] data from thermal (AF) demagnetizations; polarity column: black/white = normal/reversed polarity, grey = uncertain polarity.

than in the Rosello composite section (nearly 13). This suggests a hiatus. Indeed, exactly at the upper Sidufjall polarity reversal a brown, slightly indurated marl bed occurs with an irregular lower boundary, caliches and small channel fills.

Reference

Langereis C.G. & F.J. Hilgen, 1991: The Rosello composite: a Mediterranean and global reference section for the Early to early Late Pliocene. *Earth Planet. Sci. Lett.*, 104, 211-225.

ANISOTROPY OF THE MAGNETIC SUSCEPTIBILITY AS A 'CORRECTION TOOL' IN PALEOMAGNETIC STUDIES OF TECTONIC ROTATIONS: A CASE HISTORY

CHARON E. DUERMEIJER, NICOLE VAN VUGT, COR G. LANGEREIS, FREDERIK J. HILGEN and JAN W. ZACHARIASSE

Paleomagnetic laboratory 'Fort Hoofddijk', Faculty of Earth Sciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands

The Central Mediterranean area plays a key role in the geodynamics of the convergence zone between Africa and Eurasia. The African Plate with a northwest-ward dipping slab is subducting underneath the European Plate. The vertical sinking and detachment of the dipping lithosphere fragment results in the southeastward movements of continental blocks, thereby creating the Tyrrhenian arc system (Wortel & Spakman 1992). The Tyrrhenian arc comprises Sicily and the southern part of peninsular Italy (Calabria, Campania, Basilicata and Apulia). The detachment process started in Late Miocene times and caused the opening of the Tyrrhenian Basin.

This paleomagnetic investigation aims to determine age estimates (timing and duration) of rotations caused by the detachment process and concentrates on the Calabrian block, which forms the central part of the Tyrrhenian arc. The Calabrian block constitutes a complex pile of thrust sheets comprising a Paleozoic basement and a Mesozoic to Miocene cover, intersected by numerous oblique transcurrent fault systems. The Late Miocene to Early Pleistocene cover of the Calabrian block generally shows a 15° clockwise rotation (Scheepers & Langereis 1994a,b). Older rotations are usually counter-clockwise (30°) and similar to those from the Late Cretaceous for this area.

The Basilicoi section (Crotone Basin, northern Calabria) revealed paleomagnetic evidence for a major (nearly 100°) counter-clockwise (CCW) rotation in the middle Miocene (Scheepers 1994). Since this major rotation is not in agreement with the general trend in Calabria (Scheepers & Langereis 1994a,b) we resampled the Basilicoi section in detail. In addition, we sampled another and apparently parallel section, the Lese section, for comparison. Both sections mainly consist of marls with occasional intervals of sandy layers. In the Basilicoi section several small intervals with sheared sediment are found.

In the middle part of the Basilicoi section, the bedding plane could not be measured, so the well-determined bedding plane from the bottom part was used for the entire stratigraphic interval. Paleomagnetic directions resulted in different polarity patterns for the Basilicoi and Lese section. We determined the low-field magnetic susceptibility (range: 100-350 μSI-units) as well as the anisotropy of the magnetic susceptibility (AMS) for all levels in both sections. The magnetic lineation, foliation and AMS ellipsoid are constant in the top and bottom part of the Basilicoi section (L = 1 %, F = 5 %) and in the entire Lese section (L = 1 %, F = 4 %). The (sub)vertical K_{min} axis with respect to the bedding plane denotes a sedimentary fabric in those parts (Figs. 1, 2). In the middle part of the Basilicoi section, the fabric strongly deviates with nearly horizontal K_{min} axes.

In this part an increased lineation (L = 3 %) and decreased foliation (F = 1 %) is found. The large counter-clockwise rotations (Scheepers 1994) are derived from this middle part. Biostratigraphy reveals several hiatusses (Fig. 1) and indicates that the Basilicoi section is partly older than the Lese section. Assuming a sedimentary fabric, we can use the K_{min} axis as pole of the bedding plane for this middle part. The major apparent counter-clockwise rotation (~100°) is then reduced to approximately 30° CCW. This is in good agreement with the generally observed trend. The Lese section shows a 13° clockwise rotation, which concurs with the general (Late Miocene to Early Pleistocene) rotations in Calabria. A biostratigraphic

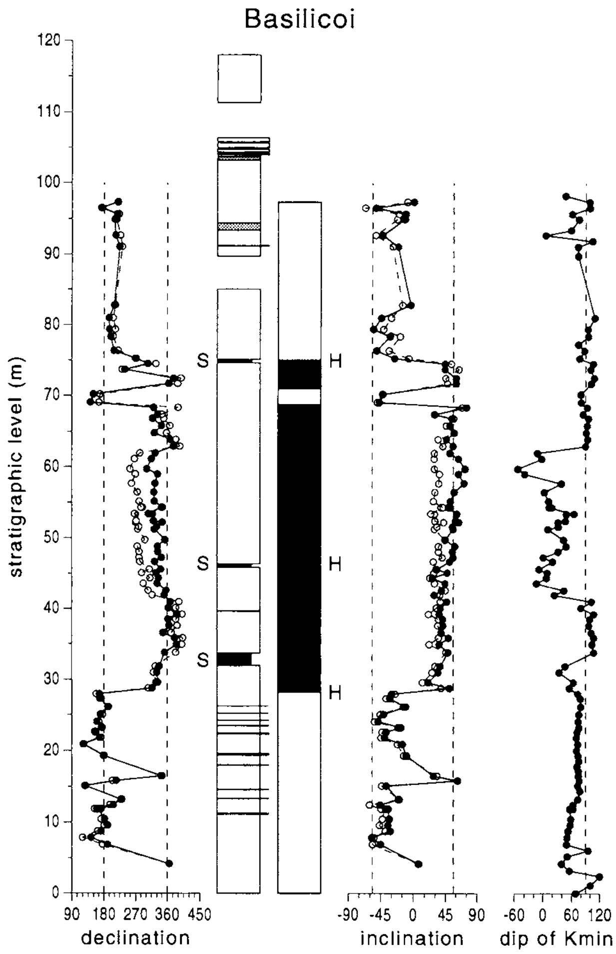


Fig. 1. Basilicoi: ChRM directions and dip of K_{min} axis in geographical coordinates (open circles) and tectonic coordinates (closed circles). In the polarity column black/white denotes normal/reversed polarity zones. The lithology column displays variations of clays (white) and prominent sandlayers (grey/black). S/H indicates a shearzone/hiatus.

analysis is currently being carried out to provide additional age constraints for both sections.

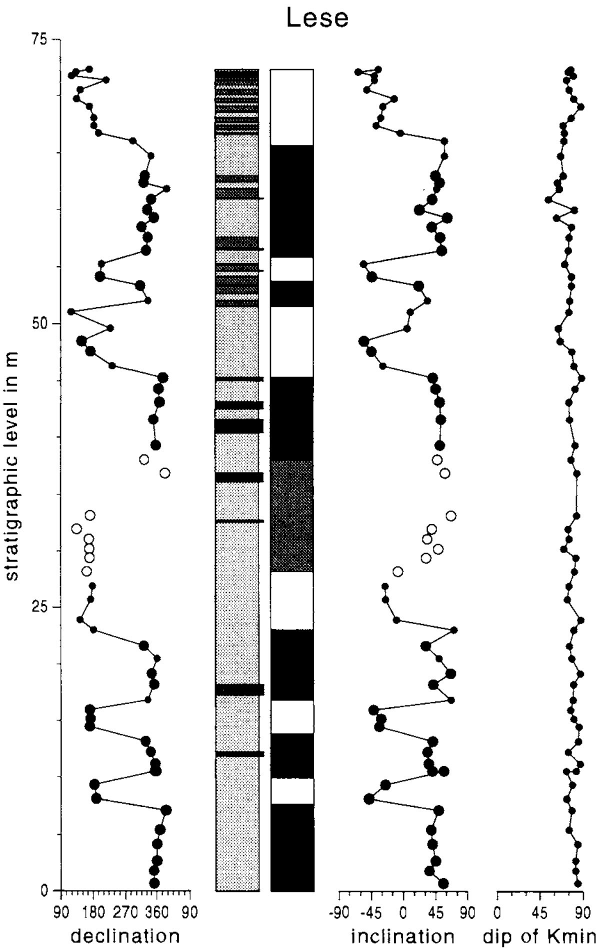


Fig. 2. Lese: ChRM directions and dip of K_{min} axis in tectonic coordinates. Closed circles represent reliable directions, small closed circles have low-intensities but reliable polarities, open circles represent low-intensity samples which are more difficult to interpret. In the polarity column black/white denotes normal/reversed polarity zones; shaded interval indicates a zone of uncertain polarity. The lithology column displays variations of clays (light grey) and sands (dark grey).

References

Scheepers P.J.J., 1994: Tectonic rotations in the Tyrrhenian arc system during the Quaternary and Late Tertiary. *Geol. Ultraiectina*, 112, 1-352.

Scheepers P.J.J. & Langereis C.G., 1994a: Paleomagnetic evidence for counter-clockwise rotations in the southern Apenninic fold-and-thrust belt during the late Pliocene and middle Pleistocene. *Tectonophysics*, 239, 43-59.

Scheepers P.J.J. & Langereis C.G., 1994b: Magnetic fabric of Pleistocene clays from the Tyrrhenian arc: a magnetic lineation induced in the final stage of the middle Pleistocene compressive event. *Tectonics*, 13, 1190-1200.

Wortel M.J.R. & Spakman W., 1992: Structure and dynamics of subducted lithosphere in the Mediterranean region. *Proc. Kon. Ned. Akad. v. Wetensch. B*, 95, 325-347.

EARLY DIAGENESIS IN PERU BASIN SEDIMENTS: AN INTEGRATED GEOCHEMICAL, MÖSSBAUER AND ROCK MAGNETIC APPROACH

IRIS KÖNIG[1], MARK J. DEKKERS[2], MARTIN DRODT[3], ERVIN SUESS[1] and ALFRED X. TRAUTWEIN[3]

[1]GEOMAR Research Center for Marine Geosciences, Wischhofstrasse 1-3, 24148 Kiel, Germany

[2]Paleomagnetic Laboratory 'Fort Hoofddijk', Faculty of Earth Sciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands

[3]Institute of Physics, Medical University of Lübeck, Ratzeburger Allee 160, 23538 Lübeck, Germany

To extract the geomagnetic field behaviour from the NRM as recorded in sediments, its depositional and subsequent diagenetic history must be understood. As part of a larger scientific program aiming at unraveling the geochemical environment of Peru Basin sediments (Pacific Ocean) box core and multicore sediments were analysed with geochemical, Mössbauer and rock magnetic techniques. The sediments (05° 30.06' S, 85°22.36' W, waterdepth 4080 m; 05°30.48' S, 85° 22.48' W, waterdepth 4069 m) exhibit the brown-tan-green colour zonation commonly observed in abyssal plane sediments. The brown-tan colour transition marks the current position of the Mn-reduction front and the tan-green colour transition the current position of the Fe-reduction front. $\delta^{18}O$ values indicate that the latter transition approximately coincides with the base of the Holocene, implying a sedimentation rate of ~2 cm/kyr. The organic carbon content of glacial sediments is higher than that of the Holocene sediments. Within the sampled sediments, an overall decrease of Fe and Al is observed related to increasing contents of biogenic opal and carbonate. The Fe/Al ratio indicates Fe enrichment in the lower part of the tan zone.

Rock magnetic parameters indicate that magnetite is the dominant NRM carrier. Alternating field demagnetization shows a soft NRM behaviour with (virtually) complete demagnetization at 100 mT. IRM acquisition also indicates a fairly soft behaviour. Thermomagnetic analysis of dried samples hints at magnetite. Within the tan zone, ARM (30 μT DC bias field, 100 mT peak AC field) and IRM (2 T) intensities start to decrease to a 'base level' which is more or less reached at the tan-green transition (1 cm deeper). The NRM intensity continues to decrease to slightly deeper levels (5 cm below the tan-green transition). In the green zone increasing hardness is deduced from the S-ratio (0.3 T/2 T) and the modified Lowrie-Fuller test. The remanent coercive force and the median destructive field of the ARM and IRM hardly increase.

Mössbauer experiments were carried out at 77 K on wet sediment which was sealed and kept deep frozen until measurement to avoid distinctly changed Fe(II)/Fe(III) ratios by exposure to atmospheric oxygen. This precludes a geochemically meaningful interpretation. Measurement at 77 K is needed to obtain well resolved Mössbauer spectra. The S content of these sediments is very low so that pyrite is absent. Also, thermomagnetic analysis did not indicate pyrite. Under this condition Fe(II) and Fe(III) phases are easily distinguished by their different isomer shifts. Lorentzian line fitting indicated that in the brown and tan zones the percentage Fe(II) is always ~11 % whereas in the top 2-3 cm of the green zone the relative Fe(II) content rapidly increases to ~37 % where after it remains unchanged. At 77 K, there are no indications of magnetic phases in the Mössbauer spectra. The Mössbauer line width Γ is larger for Fe(III) than for Fe(II) indicating that more mineral phases or lattice sites are available for Fe(III) than for Fe(II). The isomer shift δ remains uniform throughout the whole interval and is indicative of hexacoordinated Fe, probably by O. The quadrupole splitting Δ of Fe(II) remains constant in the brown and tan zones whereas it increases in the green zone. In the brown and tan zones, Δ of Fe(III) decreases with increasing depth indicating that the Fe(III) partitioning is continuously changing concurring with the Fe-enrichment in the lower part of the tan zone as inferred from increased Fe/Al ratios.

In the Mössbauer spectra recorded at 4.2 K there is a six-line pattern visible pointing to the presence of a magnetic phase. On basis of Mössbauer parameters this phase is goethite (α-FeOOH) which must be extremely fine-grained because it is superparamagnetic at 77 K, hence, not detectable. Within the tan zone its concentration regularly decreases from ~25 % of the total iron to below the limit of detection (~3 %). The trace amount of magnetite behaves similar to goethite for reasons that are not clear at present. This indicates that the use of rock magnetic parameters as proxy parameters is warranted in this and similar settings.

THE MODIFIED HORIZONTAL TRANSLATION CURIE BALANCE

TOM A.T. MULLENDER, COR B. DE BOER and MARK J. DEKKERS

Paleomagnetic Laboratory 'Fort Hoofddijk', Faculty of Earth Sciences, Utrecht University, Budapestlaan 17, 3584 CD Utrecht, Netherlands

The measuring principle of a horizontal translation type Curie balance has been changed by the application of a sinusoidally cycling magnetic field rather than a steady magnetic field. By cycling between a minimum and maximum field value (respectively B_{min} and B_{max}), a time-dependent magnetization signal is generated which is amenable to Fourier analysis. Partial Fourier analysis during the acquisition of thermomagnetic data yields the fundamental (SIG1) and the second harmonic (SIG2). By using Fourier transformed data the undesired noise is substantially reduced while instrumental drift is insignificant. Provided true saturation is reached at the B_{min} value, SIG1 and SIG2 are related to the saturation magnetization M_S and χ_{par} (A″ is an instrumental calibration constant) by:

$$M_S = \{2\ SIG1 - 8\ SIG2[(B_{max} + B_{min})/(B_{max} - B_{min})]\}/[A''(B_{max} - B_{min})]$$

and

$$\chi_{par} = 8\ SIG2/[A''(B_{max} - B_{min})^2]$$

This allows simultaneous evaluation of the saturation magnetization and paramagnetic susceptibility as a function of temperature. SIG1 and SIG2 (or M_S and χ_{par}) can also be combined to the signal which would have been obtained by a classical Curie balance using a steady applied magnetic field.

The cycling frequency is the modified Curie balance 0.83 Hz. SIG1 data can often already be "visually interpolated" to a smooth curve. Unfortunately, SIG2 is noisier (partly because it is inherently close to zero; partly because the SIG2 frequency appeared to be fairly close to a vibration frequency of the building). A transversal filtering program was developed to smooth SIG2 data to an interpretable curve. The principles described so far were reported in Mullender et al. (1993). A new development meanwhile has been to make the cycling field behaviour field-controlled rather than current-controlled. In the time-domain, the field now follows a true sine function rather than a slightly distorted one, so one source of (small) error (the necessity to correct for deviations from the true sine function) has been removed.

The extremely low drift and noise evidently results in a high sensitivity making the instrument very suitable for thermomagnetic analysis of weakly magnetized material without tedious preconcentration procedures. Examples of thermomagnetic analysis of a sulphide-bearing clay, a diamagnetic sandstone and a high blast furnace slack will be shown.

Reference

Mullender T.A.T, van Velzen A.J. & Dekkers M.J., 1993: Continuous drift correction and separate identification of ferrimagnetic and paramagnetic contributions in thermomagnetic runs. *Geophys. J. Int.*, 114, 663-672.

THE MODELLING OF THE FERROMAGNETIC CRYSTALLIZATION PROCESS UNDER DIFFERENT PARTIAL OXYGEN PRESSURE

VLADIMIR TSELMOVITCH, YURIJ GENSHAFT and ANATOLIJ GAPEYEV

Geophysical Observatory "Borok", Nekouzskij region, Yaroslavskaja oblast 152742, Russia

In the igneous rocks ilmenite is one of the main rock-forming ferro-titanium minerals. Its structure is a sensitive indicator of the initial composition of magma, temperature, oxidation-reduction condition and some other factors of formation of magma and minerals. However, the main appropriatenesses of the variability of the ilmenite structure and its microstructure are unstudied.

To reveal the influence of T-pO_2 conditions upon the recrystalization of ilmenite, the authors did experimental research on the ilmenite conduct under the thermal treatment in the open air, in the CO_2 current, in the current of 95 % Ar - 5 % CH_4 mixture and in the atmospheres given by the buffers IM and MH.

It is determined that the annealing of ilmenite in the open air and in the CO_2 current under the temperature of 1000-1150 °C leads to the appearance of the ferromagnetic phase magnohemoilmenite of variable composition with the Tc = 200-400 °C, which excretes on the surface of the samples and in its cracks; as well as the dissociation structures of ilmenite-pseudobrookite and solid solution of (Mg, Fe)TiO_3–TiO_2.

The oxidation of ilmenite under 1150 °C during the period of 4-6 hours leads to the appearance of antiferromagnetic phases, which by its structure is close to ulvospinel and the rombohedric ilmenite phase with a high concentration of TiO_2 (possibly, a solid solution of ilmenite — TiO_2).

The annealing in the MH buffer during 30 minutes did not cause any changes. The annealing in the 95 % Ar - 5 % CH_4 mixture led to the formation of Fe, FeO, TiO_2 and the appearance of the dissociation structures of ilmenite, analogous to those which were observed with the annealing in the IM buffer.

The obtained results can be used for the study of the thermal history of the life of minerals and for understanding of the condition of antiferromagnetic phase formation.

ELECTROMAGNETIC VARIATIONS ASSOCIATED WITH THE SEISMICITY OF THE FRONTAL HELLENIC ARC

KONSTANTINOS NOMIKOS[1]
and FILIPPOS VALLIANATOS[2]

[1]Technological Educational Institute of Athens, Greece
[2]Technological Educational Institute of Crete, Chania, Crete, Greece

A number of electromagnetic phenomena associated with earthquakes have been reported in recent time in different frequency ranges. There are slow magnetic field variations which are claimed to be a useful tool for earthquake prediction (Shapiro et al. 1994). Also ultra low frequency (ULF) electromagnetic emissions (0.01-10 Hz) (Fraser-Smith et al. 1990), ELF-VLF electromagnetic radiation (0.1-100 kHz), (Gokhberg et al. 1982; Nomikos et al. 1994) and HF emission (f > 1 MHz) (Nomikos et al. 1995) are associated with earthquakes.

In order to study the aforementioned preseismic electromagnetic phenomena, a telemetric system has been installed on Crete Island, (South Aegean, Greece). Structurally, our test area is linked with the frontal part of the central segment of the Hellenic arc. The South Aegean is an appropriate place for our experimentation, because in this area the existence of shallow and intermediate depth seismicity has long been recognised (Hatzfeld & Martin 1992).

The latter multipoint network records the Earth's electromagnetic field variations in four field stations installed along Crete Island. In each field station, we measure, using tuned loop antennas, the two horizontal components of the electromagnetic field variations, in low frequencies (LF), i.e in 3 and 10 kHz. Using $\lambda/2$ dipoles we measure high frequencies (HF), i.e in 41 and 53 MHz. The central station communicates with a datalogger in the field station and collects the data through a standard telephone line.

For the observation of electromagnetic variation in each field station, the following instruments are used:

a) our receivers appropriate for measuring the electromagnetic field variations at 3 and 10 kHz in EW and NS directions. These receivers are constructed using wide band and low noise amplifiers and switching band-pass filters that are tuned by crystal oscillators. The final stage of the receiver is an RMS to DC converter. Thus, the output V_{out} of the receiver is a DC voltage that is proportional to the power spectrum density Φ_H of the magnetic field that excites the antenna and is given from the expression:

$$V_{out} = \omega \, \mu N \alpha^2 \, Q_A G(\Phi_H \, \Delta f_F)^{1/2}$$

where N, α and Q_A are the number of turns, the radius and the quality factor of the antenna, respectively. Δf_F is the bandwidth of the filter and G is the total gain of the system;

b) two receivers for measuring the electric field variations at 41 MHz and 53 MHz. The receivers are constructed using double supper heterodyne technology and the output in each of them is a DC voltage which is proportional to the electric field which appears on the antenna;

c) datalogger that is the main instrument for reading the analog information from the electromagnetic receivers. The sampling rate was taken on a channel basis every second, and the average value of 60 samples for each channel saved in the final memory. Then the signal from the field station was transmitted through a telephone line to the Central one.

One of the most important point in our experiment was how to determine the observation frequencies. A number of transmitting stations radiate electromagnetic signals at almost all frequencies over and around the island of Crete. To make sure that the observation frequencies were silent, they were checked using a radio receiver, for a long period of time. The only criterion for a preseismic electro-magnetic signal should be its existence in both components simultaneously, otherwise they could be artificial interference. Any interference from mobile transmitters at these two frequencies will obviously

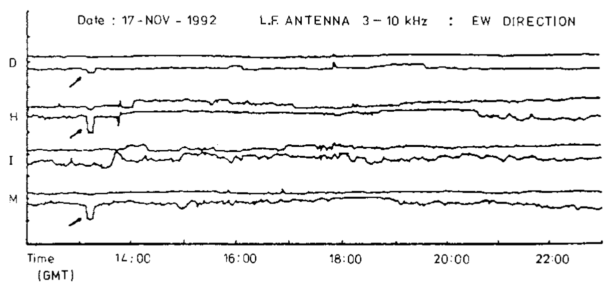


Fig. 1. Electromagnetic variation at 3 and 10 kHz, recorded at three stations, prior to November 21, 1992 earthquake of magnitude Ms = 6.0.

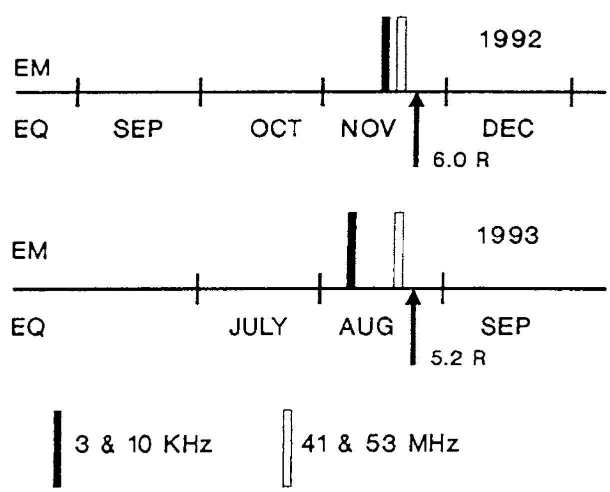


Fig. 2. Time charts shows the sequence of preseismic electromagnetic variations before : a) The isolated in time and space earthquake of November 21, 1992 and b) the earthquake of August 1993.

produce spikes on the recordings for at most a few minutes and in the specific frequency of the transmitter and not simultaneously in both of them.

In the present contribution recordings of the electromagnetic anomalies that preceded earth-quakes in the time window October 1992 - December 1995 are presented.

The experimental results indicate the presence of electromagnetic variations in the frequencies of 3 and 10 kHz , 41 and 53 MHz, associated with shallow and intermediate depth earthquakes in the vicinity of Crete Island (South Aegean-Greece).

In order to study the time sequence of seismo-electromagnetic events time charts are constructed. The time charts shows the sequence of electromagnetic events that precede the earthquakes in the time window under investigation. It is concluded that the electromagnetic variations appears to follow an invariant time pattern (i.e. LF variations-HF variations-Earthquake event).

Furthermore, a possible explanation of the origin of the preseismic electromagnetic anomalies is given. It is based on the stochastic microcurrent activity due to the opening of charged cracks.

References

Fraser-Smith A.C., Bernardi P.R., McGill P.R., Ladd M.E., Halliwell B.A. & Villard O.G., 1990: Low-frequency magnetic field measurements near the epicenter of the 7.1 Loma Prieta earthquake. *Geophys. Res. Lett.*, 17, 1465-1467.

Gokhberg M.B., Morgounov V.A., Yoshino, T. & Tomozawa I., 1982: Experimental measurement of electromagnetic emissions possibly related to earthquakes in Japan. *Journal of Geophysical Research*, 87, B9, 7824-7828.

Hatzfeld D. & Martin C., 1992: The Aegean intermediate depth seismicity defined by ISC data. *Earth Planet. Sci. Lett.*, 113, 267-275.

Nomikos K., Bakatsakis M., Paterakis D., Kogionis T., Sideris S., Zaxaropoulos B., Cristou C., Kaliakatsos J. & Vallianatos F., 1994: Development of a telemetric system for observation of radioemission associated with earthquakes in Crete Island. *Proceedings of the XXIV General Assembly, European Seismological Commission, Athens*, vol. II, 1112-1120.

Nomikos K., Vallianatos F., Kaliakatsos J., Sideris S. & Bakatsakis M., 1995: Latest aspects of telluric and electromagnetic variations associated with shallow and intermediate depth earthquakes in South Aegean. *International Workshop: electric, magnetic and electromagnetic methods in Seismology and Volcanology*, Positano.

Shapiro V.A., Muminov V. & Abtullabecov K.N., 1994: High precision magnetometry for earthquake prediction in Uzbekistan: Ninetyone forecasts between 1982 and 1982. In: *Electromagnetic Phenomena related to Earthquake prediction. Terra Pub.*, Tokyo.

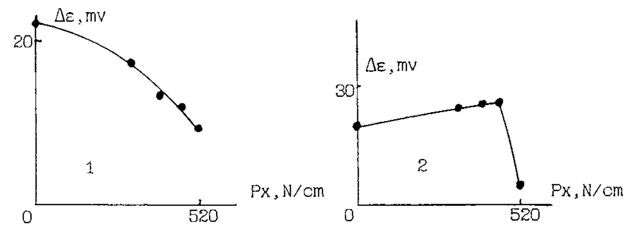
THE INFLUENCE OF MECHANICAL PRESSURE ON THE INDUCED MAGNETIC ANISOTROPY OF ROCKS

VLADIMIR S. VETCHFINSKI, ANDREY N. ERSHOV and DMITRY A. LARIONOV

Rybinsk Aviation Technology Academy, 152934 Rybinsk, Russia

When rocks containing magnetic minerals cool in a magnetic field H_t from temperature $T_x \le T_c$ (T_c — Curie temperature) the rocks may be remember about H_t and T_x. The minor hysteresis loops of rocks can acquire constriction which may be observed in the region of field H_t in intensity. This memory is connected with induced magnetic anisotropy (IMA). IMA depends on mechanical external pressure (P_x) which affects the rocks. In this work the influence P_x on IMA has been investigated. There were investigated the rocks containing magnetite and titanomagnetite. The investigation showed that the value of IMA depends on the temperature of the rock, value pressure and defects in the structure of magnetic minerals (microcracks, nonmagnetic inclusion, etc. When pressure affects on rock IMA may be decreased at low temperature and increased when rock get cool from T_x. Physical processes causing affect pressure on IMA of rocks has been explained.

The figures show the dependence constriction of minor hysteresis loops (ε) of basaltic lava on mechanical pressure: 1 — at room temperature, 2 — after cooling from 150 °C under affect pressure.



PALEOENVIRONMENTAL CHANGE DOCUMENTED BY MAGNETIC INVESTIGATIONS AT ROXOLANY, A LOESS TYPE SECTION NEAR ODESSA (UKRAINE)

FRIEDRICH HELLER[1], MAURIZIO SARTORI[1], JOZEF HUS[2], RAOUL GEERAERTS[2], ERNIE A. HAILWOOD[3], PAUL MONTGOMERY[2], TANYA GENDLER[4], VALERY I. BAGIN[4], ELENA VIRINA[5] and ALEXANDER TSATSKIN[6]

[1]ETH-Zürich, CH-8093, Zürich, Switzerland
[2]Centre de Physique du Globe, B-5670 Dourbes, Belgium
[3]Southampton University, Southampton SO9 5NH, England
[4]Russian Academy of Sciences, Moscow 123810, Russia
[5]Moscow State University, Moscow 119899, Russia
[6]University of Haifa, Haifa 31905, Israel

The ca. 46 m thick loess section at Roxolany near Odessa (Ukraine) is one of the best developed loess profiles in the Black Sea region. Nine major pedocomplexes which alternate with silty to sandy loess layers, show enhancement of magnetic properties such as low field susceptibility or natural remanent magnetization like similar sediments in Central Asia or China (Fig. 1). Several thousand in situ susceptibility measurements haave been calibrated by comparison with a large number of samples (several hundreds) collected along the profile. The paleosol susceptibilities approach maximum values of nearly 100×10^{-8} m^3/kg whereas the pristine, often very sandy loess averages values around 10×10^{-8} m^3/kg.

The lower part of the section (below 33.5 m) is mainly reversely magnetized suggesting a pre-Brunhes age. The part of the section which corresponds to the Brunhes epoch shows in contrast to earlier findings only very few excursion-type directions. Extremely strong viscosity (up to 95 % of the initial signal) of the natural remanent magnetization is typical for most of the samples.

Mineralogical studies focus at this stage on XRD and Mössbauer analysis and thermal analysis of low field susceptibility and saturation remanence. The XRD data of the Roxolani soils (clay fraction < 0.025 mm) indicate very similar general composition: quartz, calcite, chlorite, kaolinite, illite and mixed layer illite/smectite. The Mössbauer spectra are dominated by paramagnetic clays which contain variable contributions from Fe and Fe^{2+} depending on depth and climatic conditions. The thermal susceptibility data are often characterized by superparamagnetic behaviour at temperatures below 30 °C on the one hand and irreversible peaks around 300 °C on the other hand which suggest the presence of Fe-carbonates (siderite) whereas the main Curie temperatures lie generally around 560-570 °C (indicative of magnetite?).

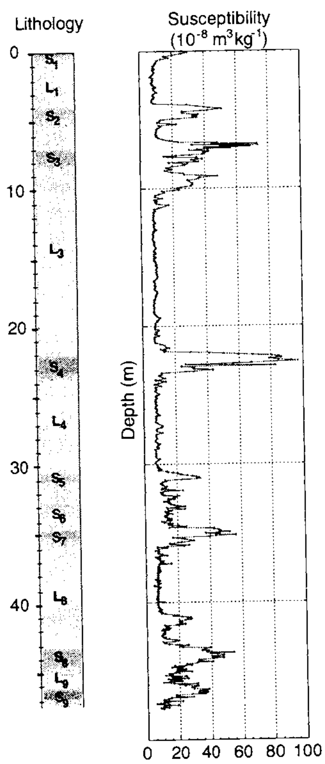


Fig. 1. Lithology and low field susceptibility at Roxolani.

A NUMERICAL SOLUTION FOR ELECTROMAGNETIC SCATTERING BY A PLATE IN CONDUCTIVE MEDIA

VLADIMÍR SEDLÁK

Technical University of Košice, Department of Geodesy and Geophysics, Park Komenského 19, 042 00 Košice, Slovak Republic

As much of the Earth is inaccessible to direct observation, its composition and structure must be inferred from remote measurements of its physical properties. Lithological and structural variations may be detected electromagnetically because they are often associated with changes in electric conductivity and magnetic permeability. Local variation in conductivity can be diagnostic of structures such as faults, fractures and shear zones which are of interest in geological mapping, or of mineral deposits and aquifers which are of direct economic interest. Regional variation in conductivity may be used to delineate formations having different porosity and fluid permeability. Although the electromagnetic method has also been used to map formations based on their magnetic permeability, its major role is to detect conductivity variation.

As the Earth is opaque to fields at high frequency, conductivity variations must normally be detected with audio or sub-audio frequency fields. These fields are typically sensed with induction coils, magnetometers, or from the potential difference between pairs of grounded electrodes. Data collected in this manner has been understood through the use of theory, computer and scale modelling, and through laboratory measurement of conductivity. Theory and laboratory measurement are useful for understanding the mechanism through which fields interact with the earth while scale and computer modelling are used to understand macroscopic electromagnetic scattering from inductive structures in the earth. Scale modelling is most useful when the structures being modelled are complicated, but the technique suffers from a lack of available material with suitable electric properties. Moreover, scale model experiments are difficult and time consuming to undertake.

Much emphasis has recently been placed on computer modelling, as this method allows the interaction of electromagnetic fields with complex geological structures to be examined with relative ease and certainty. A major impediment to numerical modelling is that it has required large computing resources and has therefore been quite costly. Consequently, the scope of numerical modelling has been limited to computing a few type examples and the method has had little direct application to data interpretation.

Computer models are by nature more widely usable than are scale models as suitable computer facilities are wide spread whereas modelling facilities are relatively specialized and rare. One natural application of computer modelling is in the development of inversion and imaging algorithms. Although inversion algorithms could be extremely useful for data interpretation, they require very fast forward models to be practical. Currently these only exist for simple geological structures such as a plane layered earth. There is a need for faster computer algorithms capable of handling more complex geological structures.

In this paper, the electromagnetic response of a thin conducting plate in a stratified conducting medium is modelled. The plate is a gross simplification of geological structure, but in many cases it is a sufficient one. It is useful both for representing planar geological structures and as a conceptual model when current flow in a three-dimensional structure is predominantly two-dimensional (Best et al. 1985; Newman et al. 1986; Goldman et al. 1986). Although the problem has been successfully tackled by others, their solutions have been less than satisfactory in some respects. The presented solution is more stable than existing solutions and is faster to calculate. The model is demonstrated to be valuable by comparison to other model results and by checks on its internal consistency. Sets of estimators are also presented which can be used to predict which of many response domains a given model is in. These estimators were initially developed to validate model results. However they have another use: they identify cases where complicated full electromagnetic solutions such as the one developed in this paper may be safely replaced by simpler algorithms.

A new integral solution formulated with the Galerkin method is derived and applied to model the electromagnetic response of a thin conducting plate in a stratified medium. The solution is expressed as two coupled integral equations, one for the scalar potential of the equivalent current density and the other for the corresponding magnetic field. The solution adopts the form of a single equation plus a constraint on the current density in two limiting cases. Where the host medium is resistive, the scalar potential equation forces the current to be divergence free. For static field excitation, the magnetic field equation forces the current to be curl free. This property of the solution is responsible for the robustness of the method for a wide range of model parameters.

The Galerkin method requires multiple integration which can be extremely time-consuming when the required Green function is not analytical. To overcome this problem, new integration techniques are introduced in which the Green function is represented as a product of geometrical and electric factors. The geometrical factors are time-consuming to calculate but can be precalculated and used in many model evaluations. The electric factor can be computed relatively easily, but cannot be saved. This separation permits the response of the plate in a layered environment to be calculated extremely efficiently.

Parametric scalling arguments are used to determine when it is necessary to compute the electromagnetic response with a solution accounting for both galvanic and inductive effects. Estimators are developed and tested which allow one to predict if the complete solution to be replaced by a simpler solution such as those which treat the inductive and galvanic components separately. These estimators may be used to predict the mode of current excitation itself, or the mode of current excitation which dominates the sensed fields.

The developed method with a numerical solution for electromagnetic scattering by a plate in conductive media has been tested against alternative integral equation algorithms VH for the galvanic (V) and inductive (H) limit cases, and against Hanneson's electric field integral equation algorithm which includes both inductive and galvanic effects. Agreement is particularly good for unsaturated current responses and saturated ones, too. Test models in which parameters were varied continuously to generate responses moving from the inductive limit to the galvanic limit have further verified that the model is robust. The employed numerical models for a comparison use basic functions which extend over the entire body, so that the presence of current in one part of the conductor necessarily implies current over all of it: too few basis functions are used to ensure that sufficient destructive interference is present to eliminate all spurious currents. Similarly, orthogonalizing functions should be selected so that they control the error in the equations (fields) where the fields are the strongest: not over the entirety of the body where in many cases the fields are small and where therefore, the resulting error is small. The optimum way to create a numerical solution may therefore be not to use the Galerkin method, but to use different sets of global functions in the source and orthogonalizing bases. Thus, one avenue for future research may be to concentrate on finding an improved basis for the plate. Efforts should also be made to relate errors in the integral equation solution to errors in the calculated secondary fields.

The modelling algorithm was used to verify the usefulness of inductive and galvanic estimators for current excitation and the associated scattered fields. The estimators were developed using a simple parametric theory to define the inductive and galvanic limits formally, and show that the definition of these limits must differ depending on whether received signals or currents are being considered. There are two characteristics of the algorithm which affect the accuracy of the computed response. One is that the integrals of the Green functions with the primary field are approximated by representing the primary field with a set of basis functions. This means components of the field external to the basis cannot contribute to the computed response, and thus the response to source fields containing large high order spatial derivatives cannot be accurately calculated. One way to improve this aspect of the algorithm may be to first compute these integrals in the spatial wavenumber domain and then to transform them. Doing this would replace the transformation of the source field itself in layered earth environments and should not add much to the calculation. For uniformly conducting host media, it should be possible to compute these terms accurately by representing the source field in a Taylor series expansion. The second characteristic of the algorithm which affects the accuracy of the computed response is that it consists of two steps. Thus errors in the secondary magnetic field and the scalar potential will propagate into the current density calculation. One way to eliminate this problem would be to compute the received fields directly after the first step of the calculation is completed. If this could be done, and if the primary field integrals could be accurently found, the VH algorithm could be substantially simplified and its accuracy improved.

References

Best M.E., Duncan P, Jacobs F.J. & Scheen W.L., 1985: Numerical modelling of the electromagnetic response of three-dimensional conductors in a layered earth. *Geophysics,* 50, 665-676.

Goldman Y., Hubans C., Nicoletis S. & Spitz S., 1986: A finite-element solution for the transient electromagnetic response of an arabitrary two-dimensional resistivity distribution. *Geophysics,* 51, 1450-1461.

Newman G.A, Hohmann G.W. & Anderson W.L., 1986: Transient electromagnetic response of a three-dimensional body in a layered earth. *Geophysics,* 51, 1608-1627.

MAGNETIC OBSERVATORIES: PAST AND PRESENT

JULIO C. GIANIBELLI, JEAN RASSON, IRIS R. CABASSI* and OSCAR SIDOTI

*Department of Geomagnetism, Faculty of Astronomical and Geophysical Sciences, La Plata National University, Paseo del Bosque s/n—1900, La Plata, Argentina

The present problems of magnetic observatories include their past. We observed that there are few observatories in the Southern Hemisphere. Modern technology requires digital outlets and the modernization of instruments (variometers, QHM's and BMZ magnetometers). But lack of money and personnel is the principal problem. Trelaw observatory initiated its activities in 1957, and Las Acacias in 1962. Trelaw was modernized in 1993 by means of agreements with Dr. J. Rasson of Belgium, and our Faculty. This paper presents the task required by this objective. In the future, Las Acacias will also be modernized.

MAGNETIC PROPERTIES AND SELF-REVERSED MAGNETIZATION OF DACITIC PUMICES FROM THE 1991 PINATUBO ERUPTION (PHILIPPINES)

BINA[1], E.L. LISTANCO[4], J.C. TANGUY[1], M. PREVOT[2], V. HOFFMANN[3], R. KELLER[3], A. GOGUITCHAICHIVILI[2] and R.S. PUNONGBAYAN[4]

[1]Laboratoire de Géomagnétisme, Univ. Paris 6, CNRS, 94107 St. Maur, France
[2]Laboratoire de Géophysique et Tectonique, Univ. Montpellier II, France
[3]Institut für Allgemeine und Angewandte Geophysik, Univ. München, Germany
[4]Philippine Institute of Vulcanology and Seismology, Quezon City, Philippines

The NRM of about 40 samples collected from several sites on the Pinatubo ignimbrite field shows self-reversed magnetization. A few samples of pumice or lithic rocks present scattered directions, but from their thermal demagnetization behaviour we concluded that their orientations were changed after emplacement. Such orientation change is probably caused by phreatic explosions or collapse and topple over of large blocks by lahars and torrents, very common after eruption. The emplacement temperature found from lithic samples is higher than 460 °C at the studied site. By means of microprobe analyses two minerals were found to dominate the magnetic properties of these rocks: iron-rich Al and Mg substituted titanomagnetite ($\chi \approx 0.1$) and hematite-ilmenite with little Al and Mg substitution ($\chi \approx 0.5$). High and low field induced magnetization are dominated by TM ($T_c \approx 480$ °C) but TRM is almost completely dominated by hem-ilm ($T_c \approx 280$ °C). Field variation of TRM shows a maximum reversed at $H_{TRM} = 0.5$ mT. AF demagnetization of TRM acquired in different fields shows the existence of low coercivity normal components which were removed in AF < 40 mT. The reversed components were also demagnetized to about 80 % of initial values by AF of 40–120 mT intensities. The remaining reversed remanences could not be removed even by AF more than 200 mT. Hysteresis parameters (at T_0 or $T > T_0$) are similar to those of mixtures of SD and MD (and/or PSD) particles with very high H_{cr}/H_c (10-20) and low J_{rs}/J_s (about 0.01). PTRM and thermal demagnetization of TRM measured at T_0 or $T > T_0$ shows blocking temperatures ranging from 250 °C to 350 °C which can increase if the sample was already heated. Micromagnetic experiments revealed the presence of Ti-poor titanomagnetite and of 2 different hem-ilm phases, partially intergrown in a very specific manner: (i) a hematite-rich rim showing the typical micromagnetic structures of a weak ferromagnet (spin-canting antiferromagnet like hematite), therefore being disordered, and (ii) an ilmenite-rich ferrimagnetic core with the typical domain patterns of an uniaxial ferromagnet (like cobalt or magnetoplumbite), therefore being ordered. From these results and also from rotational hysteresis measurements one can suggest that in SR-TRM, carried by large 2-phased MD size hem-ilm grains, both mechanisms of exchange and magnetostatic interactions may be involved.

INTERPRETATION OF THE EXTENSOMETRIC MEASUREMENTS AND PALEOMAGNETIC DATA FROM THE WESTERN CARPATHIANS

VIERA DUDÁŠOVÁ

Geophysical Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic

In the Carpatho-Pannonian region a network of extensometric stations was built which consists of the stations Vyhne (Slovakia), Budapest and Sopron (Hungary), Beregovo (Ukraine). This region is one of the most active tectonic parts of Europe which is characterized by recent movements of the Earth's crust, high activity of the tectonic movements, anomalously high heat flow and high seismicity. For these reasons the research of this region is interesting not only from the point of view of solving the scientific tasks but also for the applied geophysics.

The purpose of the extensometric measurements in the Carpatho-Pannonian region is the study of the regional tectonic processes. At the tidal station of the Geophysical Institute of the Slovak Academy of Sciences in Vyhne, irreversible deformation (rate 5.5×10^{-7} per year) was registered. This corresponds to the dilatation of the rock massif surrounding the station (Brimich & Latynina 1989).

In this poster we shall study the problem of the relation between the deformation processes registered at the Vyhne tidal station and the regional tectonics. This region was formed in Neogene; in the younger tectonic epoch, i.e. the activation of the tectonic processes in this region in the last 10 million years was observed. The mountains surrounding the Pannonian Basin were developed in the condition of the tangential compression. Pannonian Basin was shaped in the conditions of dilatation or warp. The character of the Earth's crust in the Pannonian Basin is similar to the oceanic type of the crust.

At present there are still various hypotheses on the character of the processes which determine the development of the Carpatho-Pannonian region. The Hungarian geologist Balla (1984) expressed a hypothesis which is based on the theory of the lithospheric plates. In accordance with this hypothesis the existence of the regular circular structure of this region requires the activity of the axial symmetric tectonic sources. Such source could be the convective flow coming out from the Pannonian Basin whose horizontal compensating branches are spreading and reducing the Eart's crust in the Pannonian region. The hypothesis of taphrogenesis (remaking of the continental type of the crust into the oceanic type in the upper mantle) also requires expansion of the tectonic process from the centre of the Carpatho-Pannonian region to its borders. Conforming with this hypothesis the Pannonian Basin was formed in conditions of the warp.

From the interpretation of the paleomagnetic data from the western part of the Central Western Carpathians a hypothesis of counter-clockwise rotation of this region was expressed. This rotation, which took place at the end of the Early Miocene, is subtracted from the whole estimated rotation, evaluated in the Eocene sediments. The origin of this rotation can be explained only by means of the overall rotation of the territory which was located in the dextral wrench zone during that time, when the opposite rotation blocks took place (Kováč &

Túnyi 1995). Paleomagnetic investigation of neovolcanics of the East-Slovak lowlands have detected the counter-clockwise rotation of the volcanic bodies of all stratigraphic horizonts, including the youngest Late Sarmatian basaltic andesites (Orlický 1996).

The paleomagnetic results are in agreement with the extensometric measurements at the Vyhne tidal station. Provided that the irreversible monotone increasing deformation of the rocks observed in Vyhne has tectonic origin, the results of the extensometric measurements confirm the ideas about the dilatation of the Earth's crust in the Pannonian basin. The rate of the dilatation at the Vyhne station is not large. We can explain this fact by position of this station which is on the boundary of the Panonian Basin (Brimich & Latynina 1988). The dilatation in the central parts of the Pannonian Basin is more intensive (Varga & Varga 1995) which is in accordance with Balla's hypothesis.

References

Balla Z., 1984: The Carpathian loop and the Pannonian basin. *Geoph. Trans.*, 30, 313-353.

Brimich L. & Latynina L.A., 1988: Results of the extensometric measurements in Slovakia. *Physics of the Earth,* 12, 3-10 (in Russian).

Brimich L. & Latynina L.A. 1989: The results of the extensometric observations in Vyhne. In: *Geodesy and Physics od the Earth,* ZIPE, Potsdam, 239-253.

Kováč M. & Túnyi I., 1995: Interpretation of the paleomagnetic data from western part of the Central Western Carpathians. *Miner. slovaca,* 27, 213-220.

Orlický O., 1996: Paleomagnetism of neovolcanics of the East-Slovak Lowlands and Zemplínske vrchy Mts.: A study of the tectonics applying the paleomagnetic data (Western Carpathians). *Geol. Carpathica,* 47, 13-20.

Varga P. & Varga T., 1995: Horizontal recorded with the extensometers. *BIM,* 122, 927-9276.

TIME OF FORMATION OF THE GENERAL STRUCTURES OF BAIKAL FOLDED AREA

A.N. ZHITKOV, K.M. KONSTANTINOV and V.V. BULDYGEROV

East Siberian Research Institute of Geology, Geophysics and Mineral Resources, 664007, Irkutsk, Russia

The results of paleomagnetic investigations in Baikal folded area illustrate an example of use of paleomagnetism for regional geological problems. Available paleomagnetic data for Vendian (600 Ma) are presented in outer (near Siberian Platform) and inner (central) segments of folded area. Extension of the main structures changes in north-east direction from 30 to 180°. The same pattern is observed in orientation of inner zone structures. 10 available paleomagnetic poles for synchronic Vendian age geological complexes are in good concordance due to their paleolatitudes. The paleolatitudes are disposed in a narrow interval of values from 20° of southern hemisphere to 8° of the northern hemisphere. This interval is around the coincidence cone of each value. This result suggests a hypotheses that in Vendian time there was unite plate complex for South of Siberia. Orientation of peleolongitudes are in great discordance (from 60° to 215°) between each other but in good concordance with general structures. Reconstruction of paleolongitudes, when their orientations became subparallel, suggests an idea that Proto-Baikal-Patom line structure of sublatitudional orientation existed in Vendian. A further consequence of this study supports formating of main geological structures due to collision of Angarian, Aldan and Barguzin lithospheric blocks in post-Vendian time. Formating of geological structures are linked with this collision (as was showed before by Kravchinsky 1990) as well as the whole folded area, inc!·ıding inner geological zone. The highest time limit of these geological events is not estimated so definitely. Paleozoic collision complexes are present in inner zone on the basis of geological data. The ages of the complexes are estimated from isotope dating in interval 490-230 Ma. Paleomagnetic data obtained for Kadaly-Butuin lamprophire complex (Late Devonian - Early Carboniferous), matachrone magnetization of Kholodninskaia and Padrokan suites (Late Devonian - Early Carboniferous), gold deposit age (Late Triassic - Early Jurrasic) are in good correlation with this geological data. The listed paleomagnetic poles are concordant with the apparent polar wander path of the Siberian Platform. We estimate possible time range of the formation of the general structure of Baikal folded area from post-Vendian up to post-Devonian.

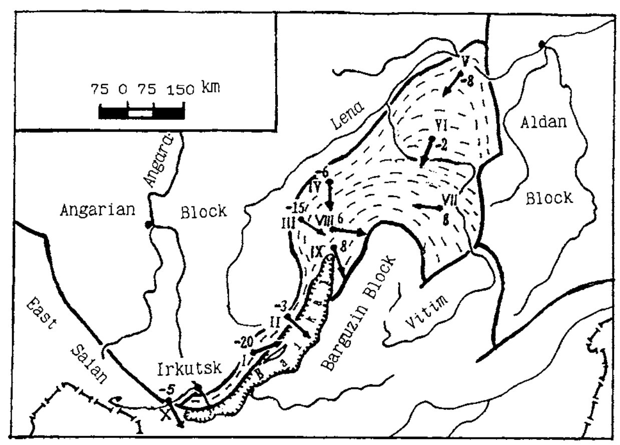


Fig. 1. Paleomagnetic directions of Vendian geological formations of Baikal folded area. Paleomagnetic directions: **I** - Ushakov suite, r. Sarma (Komissarova, Pisarevsky, 1981); **II** - Ushakov suite, source of r. Lena Komissarova, Pisarevsky, 1981); **III** - Ushakov suite, r. Minya (Rodionov, Osipova, 1981); **IV** - Zherbin suite, r. Chaya (Rodionov, Osipova, 1981); **V** - Nokhtuy suite, r. B. Patom (Zhitkov, Konstantinov, 1994); **VI** - Dogaldyn suite, r. Bodaibo (Zhitkov, 1984); **VII** - Mamakan & Zolotovskaia suites, r. Kilyana (Konstantinov, Mazukabzev, 1994); **VIII** - Avgol suite & Inyapkuk volcanic complex, Olokit depression (Kravchinsky, Zhitkov, 1984); **IX** - Kholodninskaia & Tukolomiyskaia suites, r. Verhnyaya Angara (Konstantinov, Zhitkov, Buldygerov, 1994); Khuzhir suite, r. Irkut (Zhitkov, Konstantinov, Krabchinsky, 1996). Arabic number near arrow - paleolatitude of site.

Instructions to Authors

GEOLOGICA CARPATHICA publishes original research papers, review articles and news across of the geosciences. The journal publishes occasional thematic or conference special issues.

Only the high quality, concise, clear papers presenting new important information, arranged in a logical succesion will be accepted.

General

Manuscripts (three copies) and initial correspondence should be addressed to the Chief Editor or the Managing Editor. The papers are acceptable only in English.

Authors of submitted papers will receive a form assigning the copyright of the article to this journal.

The Editor retains the right to modify the style and length of the paper (major changes being agreed with the author) and to decide the time of its publication. Each contribution will be reviewed by at least two referees.

Manuscripts

Manuscripts are limited to a maximum typed length of 25 pages including figures and tables, except special agreement from the Editorial Board (1 typewritten page = max. 30 lines at 60 types in a line). Authors are asked to submit papers in electronic form (but also in printed version), processed by means of *IBM compatible computers*. Both 3.5″ and 5.25″ diskettes are acceptable. The preferred formats are: Wordperfect, Wordstar, MS Word, Text 602 and DOS or ASCII files. The name and version of the program, name of the files and format of the text should be clearly indicated.

Consult a recent issue of *GEOLOGICA CARPATHICA* for the style to be adopted.

Papers usually consist of the title page, text, references, tables, figures, captions and sometimes an appendix.

The title page — comprises the title of the paper, unabbreviated first names and surnames of the authors and their institutional address.

Abstract — not exceeding 15 lines, should be informative and it should not contain references.

Key words — (max. 7 items) should be in succession from general to specific ones, e.g.:

Western Carpathians, Nízke Tatry Mts., granitoids, geochemistry, REE.

The text — consists of introduction, methods of study, experimental data, results, discussion, conclusion, and an acknowledgement (e.g. Grant Agency, sponsors, etc.). The main body of the text should be arranged under two or three levels of headings. Their hierarchy should be indicated in the manuscript in descending order. The text that is to appear in small print should be marked by a vertical line at the margin of the manuscript. Words to be emphasized, physical symbols and Greek letters to be set in other type (e.g. italics) should be marked. Greek letters has to be written in the margin in full (e.g. sigma). Hyphen should be carefully distinguished from dash. SI units are preferred.

The author should mark in the margin of the manuscript where tables and figures may be inserted.

References — should be listed in alphabetical order and consists of all literature cited in the text. The author(s) is (are) cited in the text without first name(s) and its (their) abbreviation(s). Standard form is as follows:

Lucido G., 1993: A new theory of the Earth' s continental crust: the colloidal origin. *Geol. Carpathica*, 44, 2, 67-74.

Cambel B., Kráľ J. & Burchart J., 1990: Isotopic geochronology of the Western Carpathian crystalline complex. *VEDA*, Bratislava, 1-184 (in Slovak, English summary).

Ratsbacher L. & Frisch W., 1993: Palinspatic reconstruction of the Pre-Triassic basement units in the Alps: The Eastern Alps. In: Von Raumer J.F. & Neubauer F. (Eds.): *Pre-Mesozoic geology in the Alps. Springer-Verlag*, Berlin-Heidelberg etc., 41-51.

Quotations of papers published in languages other than English ought to be translated into English with the indication of the original language in parentheses, e.g. (in Slovak). References of archival works must be limited to minimum.

Tables — should be on separate sheets, they can not be included in the text. Titles of the tables must be short, clear and intelligible. Number of tables must be limited to an inevitable amount. If the tables cannot be set up (because of combination of the text and graphic figures), they must be reproducible (adequate height of letters and graphic signs, well-contrasted). Table not fulfilling these criteria will be returned to authors.

Figures — all figures should be drawn in India ink only in a form suitable for reproduction. The author's name and figure number should be indicated at the foot of the illustration. The maximum printed size of illustration is 172 × 235 mm (two columns) or 82 × 235 mm (one column). Authors are encouraged to send the figures already reduced to the size desired for publishing. Enlargement is given in graphic scale. Letters and numerals should not be less than 1 mm in height after reproduction. All figures and tables should be cited in the text in correct numerical order. Figure captions should be listed on a separate sheets.

Supporting material (appendix) — it will be set up in smaller type (petite) at the end of the paper.

General comments

Since the papers are acceptable only in English language, the Editorial Office reserves the right to make language correction in that papers which have not sufficient accuracy in language level.

Galley proofs should be corrected and returned within two days of receipt. Authors are asked that no new material may be inserted in the text at the time of proofreading. Whenever possible proof corrections should be returned by the Fax. If the author does not return the galley proofs in due time, the Editorial Office reserves the right to make corrections of the text in accordance with manuscript. Every contribution is supplied by 20 free of charge reprints. Extra reprints should be paid by authors.

Further information can be provided by the Chief Editor or the Managing Editor.

MIČ 49 202

ISSN 1335-0552

Contents

Indexed/Abstracted in: *Current Contents, BIOSIS, Chemical Abstracts, GeoAbstracts, GeoArchive, Mineralogical Abstracts, PASCAL Database, Ulrich's International Periodicals*