PALEOMAGNETIC LABORATORY

SECTION "EARTH MAGNETISM"

Palaeomagnetic Laboratory at NIGGG is unique for Bulgaria and possesses specialized scientific instrumentation for magnetic and palaeomagnetic studies. It was established in year 1961 by Prof. Dr. Petar Nozharov and remains continuously working since that time. The main research directions developed from classical palaeomagnetic and archaeomagnetic studies at the beginning and continuing now days to incorporation of recently developed magnetic studies on sediments, soils, vegetation, anthropogenic and synthetic materials. It contributes to the establishment of a wide area of expertise of the team members of the research group.

The main research directions are:

- Archaeomagnetism
- Environmental magnetism, including:
  - Paleoclimate reconstructions based on magnetic properties of loess-paleosol sediments
  - Magnetic properties of soils in Bulgaria
  - Application of magnetic methods for fast and efficient mapping of the degree of anthropogenic pollution of soils, sediments and urban areas

Equipment

Paleomagnetic Laboratory posses unique for Bulgaria specialized equipment for studies of magnetic properties of solids. It was recently modernized with new instruments for measurements of magnetic remanence and susceptibility of rocks (JR6A and MFK-1, AGICO, Brno); Franz magnetic barrier separator LB-1 (S.G. Franz Co Inc., USA); laboratory mill and dry/wet sieving machines (Pulverisette 6, Analysette 3 PRO, Fritsch, Germany); Laboratory furnace for stepwise thermal demagnetization and in-field magnetization MMTD (Magnetic Measurements, UK); Bartington dual frequency susceptibility meter and field probe (MS2D and MS2F) (Bartington, UK); Alternating filed demagnetizer with a unit for acquisition of anhysteretic remanence (Molspin, UK); centrifuge Sigma 2-6 (SIGMA Laborzentrifugen GmbH), muffle furnace MF306 (NUVE, Turkey) with maximum temperature of 1200^{o}C; mu-metal shielded boxes.

RESEARCH TOPIC: Archaeomagnetism

Scientists, working on this subject: Assoc. Prof. Dr. Maria Kostadinova-Avramova; Prof. DSc. M. Kovacheva (retired); Assist. Prof. Dr. Deyan Lesigyarski

The residual magnetism of archaeological remains of burned clay is a major source of information for the state of the Earth`s magnetic field in the past. This determines the significance of archaeomagnetism for both – geophysics and archaeology. The recovery of the three main geomagnetic field`s elements (defining its direction and intensity) recorded in well dated archaeological materials, leads to the accumulation of an unique local database that cannot be obtained by other methods. These data are further used for elucidating the geomagnetic field origin and for the elaboration of the so-called archaeomagnetic reference curves that represent local geomagnetic field variations for a certain period. The existence of such a local geomagnetic field model ensures the application of archaeomagnetic dating method. At the same time, based on the available archaeomagnetic determinations only, relative synchronizations of spatially remote archaeological sites from a given territory can be done. Other important applications of archaeomagnetism for archaeology are establishment (without any doubt) whether some structure is discovered in situ (i.e. in the position of its last cooling) or it has been secondary displaced and reliable determination of maximum temperatures of firing/burning of various clay remains.
The Bulgarian archaeomagnetic database can be considered as the longest local dataset in the world, covering almost fully the last 8000 years going back to Neolithic (Kovacheva et al. 2014). The Bulgarian reference curves are calculated based on over 300 reference points, which are included in the GEOMAGIA50.v3 global database (http://geomagia.ucsd.edu) (Figs. 1, 2). Among the other archaeomagnetic laboratories, the Sofia laboratory was the first to be engaged in the simultaneous determination of the full geomagnetic field vector (D, I, F) from one and the same material.

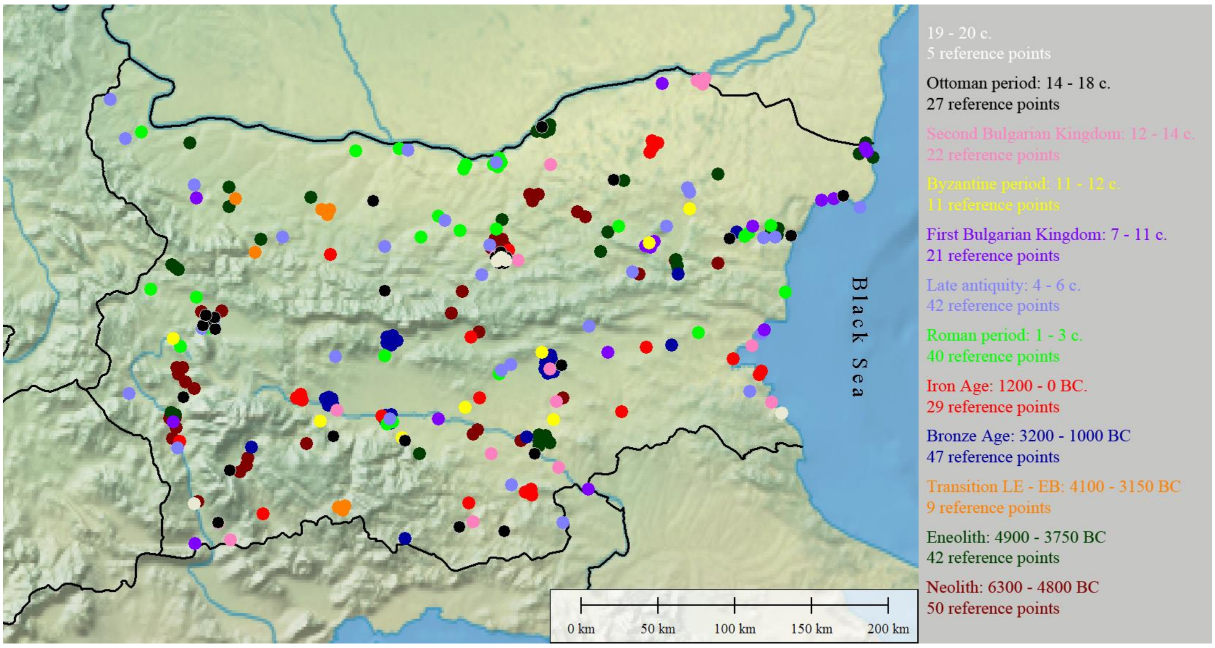


Figure 1

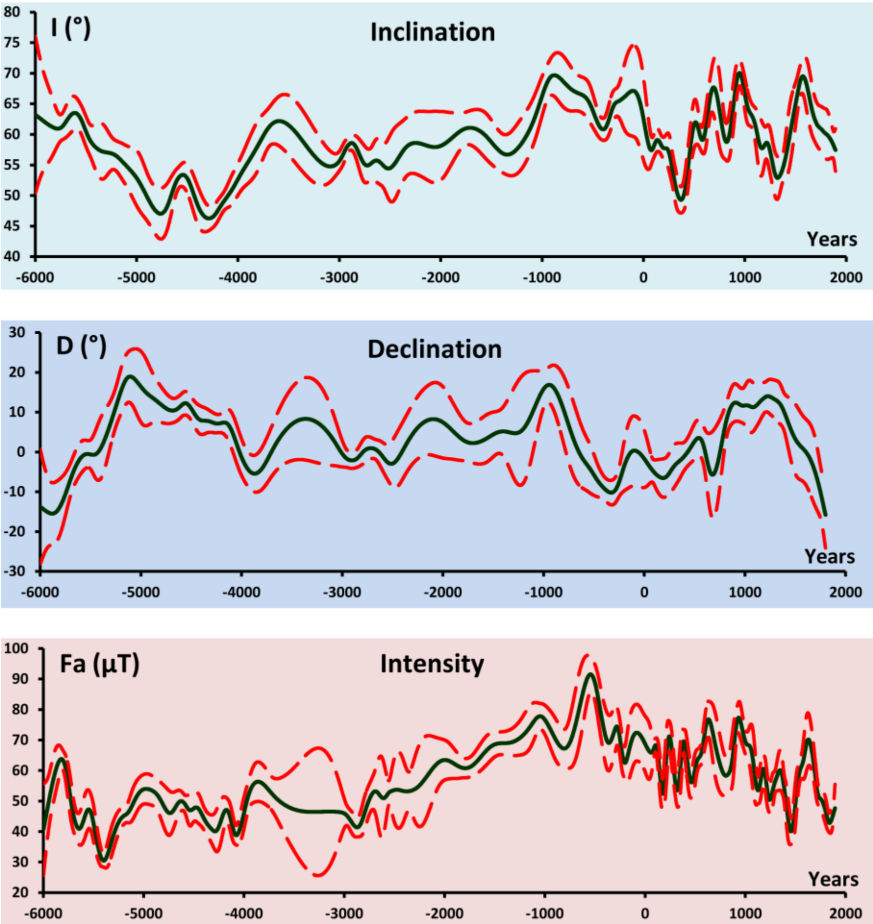


Figure 2

The most valuable materials for archaeomagnetic investigations are various structures of burned clay that are well dated by other methods and are supposed to be discovered *in situ* (i.e. in the position in which they have cooled down in the antiquity).

The sampling is a very important stage of any archaeomagnetic study because the accuracy of the determined geomagnetic field direction depends on the precision of the samples' orientation during the fieldwork (Fig. 3).

Figure 3 – Sampling procedure

1. Absolute dating of archaeological structures and comparison of the results with those obtained by other methods

The values obtained for the three geomagnetic field elements (I – inclination, D – declination and Fa – intensity) are compared with the reference curves corresponding to the considered period. As a result, for each geomagnetic field element several archaeomagnetic dating intervals can be determined. After that, the determined dating intervals for each geomagnetic field element are combined and the most probable period of the last burning of the studied structure is established (Fig. 4). Dating by the three geomagnetic elements is a prerequisite for most precise archaeomagnetic dating compared by dating using one or two geomagnetic field' characteristic.

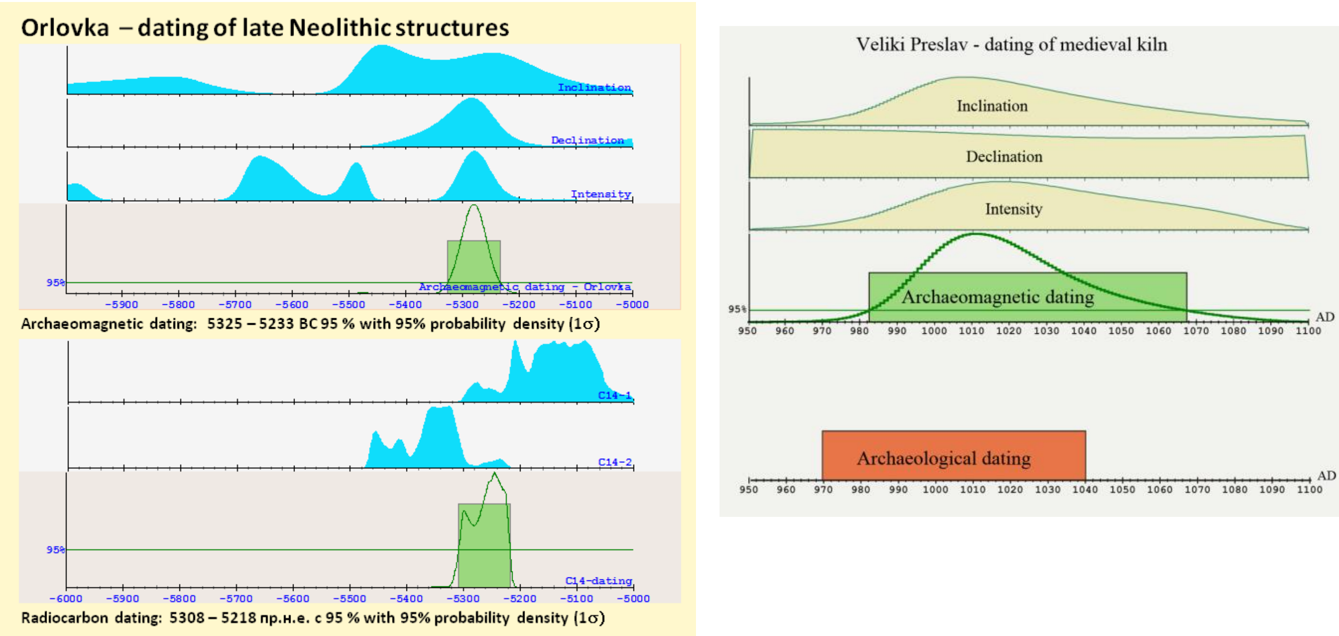


Figure 4 – Examples of archaeomagnetic dating using the three geomagnetic field elements

The precision of the performed archaeomagnetic dating depend on the accuracy of the experimental archaeomagnetic results, the accuracy of the reference curves used and the change (rapid or smooth) of the Earth`s magnetic field elements.

2. Relative dating (synchronization) of archaeological structures from different archaeological sites

The resulting archaeomagnetic determinations for three late Neolithic archaeological sites are compared (Table 1). Obviously, the values determined for the three geomagnetic field elements (I, D and Fa) are very similar for two of the studied sites (Sharkov Chiflik and Chavdarova cheshma – given in the same colour in the table), while these for the third site (site 14, near Mursalevo village) differ significantly. Hence, settlements Sharkov Chiflik and Chavdarova cheshma are very likely synchronous, but not simultaneous with Site 14, near the village of Mursalevo.

Site	I (°)	D (°)	α_{95} (°)	Fa (μT)	σ (μT)
Site 16, Sharkov chiflik	59.7	9.9	2.9	40.89	2.23
Site 14, Mursalevo	49.1	355.6	2.9	30.58	2.73
Chavdarova cheshma	56.4	0.7	2.4	37.94	2.92

Table 1.

3. Resolving the state of an archaeological structure – *in situ* (in the position of its last cooling) or secondary displaced

Archaeomagnetic study of a kiln for pottery production discovered in the Thracian site Halka Bunar indicate that the materials collected have not cooled in the position in which they have been discovered. The directional (I, D) results obtained are highly scattered and in many cases unrealistic. This is evident from the presented stereographic projections (Fig. 5).

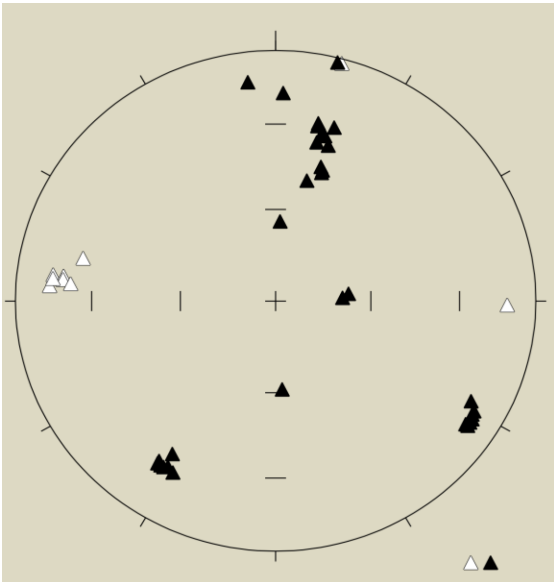
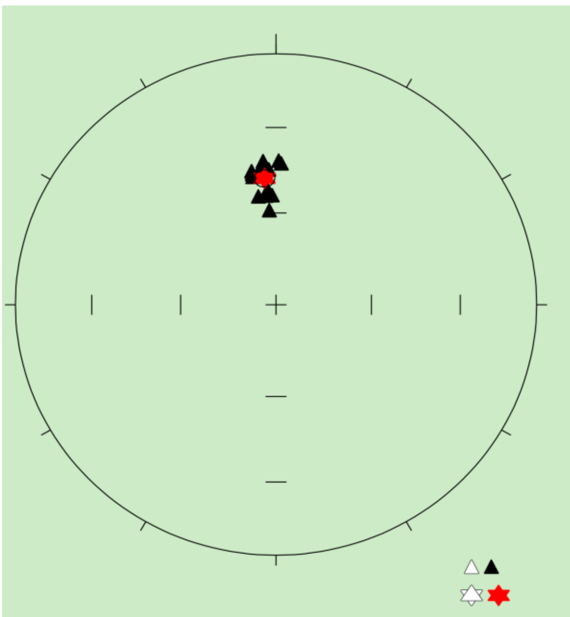


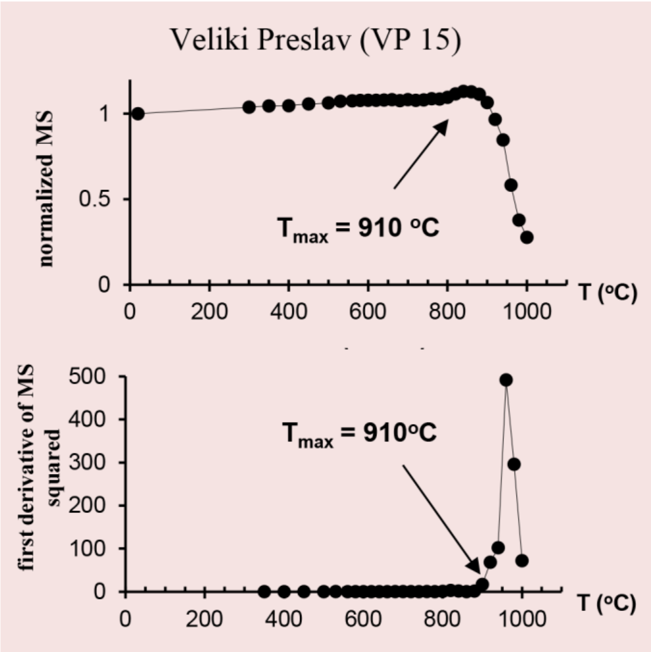
Figure 5

Burned dwelling plasters from Site 14 near the village of Mursalevo discovered in the position of their last cooling. The directions obtained are well grouped around an average value shown in red on the stereo plot (Fig. 6).

Figure 6



4. Determination of maximum temperatures of firing/burning of clay remains



The methodology is based on the magnetic and mineralogical transformations occurring in the burned materials, which affect significantly their magnetic susceptibility (Rasmussen et al., 2012). The maximum firing temperature (T_{max}) is determined by subjecting the analysed samples to step wise laboratory re-heating and measuring their magnetic susceptibility at room temperature after each heating step. The ancient firing temperature (T_{max}) matches the most significant change in magnetic susceptibility (Fig. 7).

Figure 7

4.1. Investigation of household ceramic fragments, representative for some of the basic ceramic groups of the site "Ruler's Church" in Veliki Preslav – Byzantine period (10-11 c.) and the period of Second Bulgarian Kingdom (12-13 c.). There is no significant difference in the range of the maximum firing temperatures obtained (Fig. 8). This suggests that probably similar kilns have been used for the ceramic production in both periods (Kostadinova-Avramova et al., 2018).

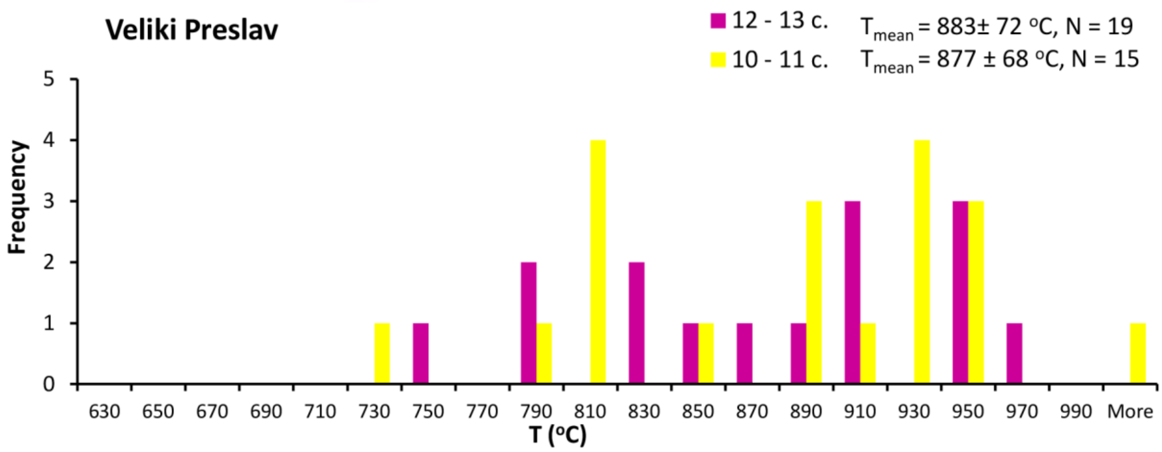


Figure 8

4.2. Magnetic study of burnt destructions from dwellings of the Neolithic site Mursalevo Deveboaz

Magnetic study of a large collection of burnt clay materials from dwellings of the Neolithic settlement Mursalevo – Deveboaz gives an independent analytical prove for the maximum burning temperatures and the firing conditions, as well as allows to suggest a hypothesis for the mechanism of the observed burnings at extremely high temperatures. Magnetic diagnostic experiments revealed the presence of strongly magnetic iron oxides – magnetite and maghemite, as well as hematite, all being of very fine nanometer grain sizes. Determined maximum firing temperatures range from 680ºC up to 1140ºC, suggesting the presence of extreme temperatures in most of the burnt houses (Fig. 9). Comparing the color, magnetic and spectroscopic characteristics of the studied Neolithic burnt clay destructions with published studies in the field of pigments' synthesis through solution combustion, a new hypothesis is proposed, suggesting that iron oxides in the Neolithic burnt clay destructions originate from such a process. The results are published in Journal of Geophysical Research – Solid Earth (Jordanova et al., 2018).

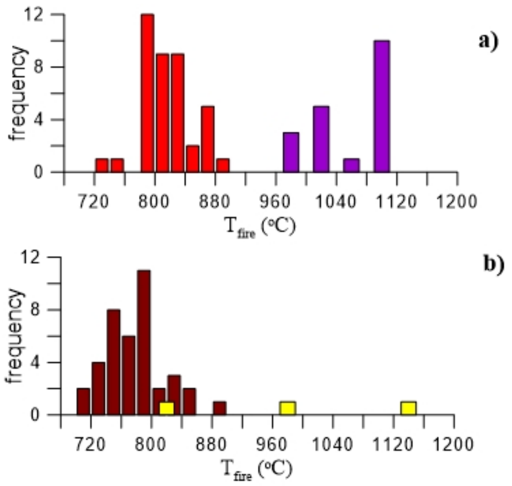


Figure 9 – histograms of the distribution of maximum firing temperatures of the burnt clay destructions from Mursalevo Deveboaz shown separately for samples with different colors – a) orange-red and purple; b) brown and yellow.

Major publications on the subject:

Kostadinova-Avramova, M., Jordanova, N., Jordanova, D., Grigorov, V., Lesigyarski, D., Dimitrov, P., & Bozhinova, E., 2018. Firing temperatures of ceramics from Bulgaria determined by rock-magnetic studies. J. Archaeol. Sci.: Reports 17, 617–633.

Jordanova, N., Jordanova, D., Kostadinova-Avramova, M., Lesigyarski, D., Nikolov, V., Katsarov, G., & Bacvarov, K. , 2018. A mineral magnetic approach to determine paleo-firing temperatures in the Neolithic settlement site of Mursalevo- Deveboaz (SW Bulgaria). Journal of Geophysical Research: Solid Earth, 123. https://doi.org/10.1002/ 2017JB01519.

Kostadinova-Avramova, M., Kovacheva, M., & Jordanova, N., 2016. Early Neolithic Settlement Yabalkovo (Maritsa valley, Bulgaria) in the context of archaeomagnetic studies. Bulgarian e-Journal of Archaeology, 6, 277-294.

Kostadinova-Avramova, M. & Kovacheva, M., 2015. Further studies on the problems of geomagnetic field intensity determination from archaeological baked clay materials. Geophys. J. Int. 203, 588–604.

Kovacheva, M., Kostadinova-Avramova, M., Jordanova N., Lanos, Ph. and Boyadzhiev, Y., 2014. Extended and Revised Archaeomagnetic Database and Secular Variation Curves from Bulgaria for the Last Eight Millennia. Phys. Earth Planet. Inter. Vol. 23, 79-94.

Kostadinova_Avramova, M., Kovacheva, M. and Boyadzhiev, Y., 2014. Contribution of stratigraphic constraints of Bulgarian multilevel tells in the prehistory and comparison with archaeomagnetic observations. J. Archaeol. Sci., 43, 227-238.

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Donadini, F., Kovacheva, M., Kostadinova-Avramova, M., 2010. Archaeomagnetic Study of Roman Lime Kilns (1 c. AD) and One Pottery Kiln (1st c. BC – 1st c. AD) at Krivina, Bulgaria, as a Contribution to Archaeomagnetic Dating. Archaeologia Bulgarica, XIV, 2, 23-38. ISSN 1310-9537

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Kovacheva, M., Boyadziev, Y., Kostadinova-Avramova, M., Jordanova, N. and Donadini, F., 2009. Updated archaeomagnetic data set of the past 8 millennia from the Sofia laboratory, Bulgaria, Geochem. Geophys. Geosyst., 10, Q05002, doi:10.1029/2008GC002347, ISSN: 1525-2027

RESEARCH TOPIC: Paleoclimate reconstructions based on magnetic properties of loess-paleosol sediments from north Bulgaria

Team members working on this subject: prof. Dr. D. Jordanova, Prof. DSc. N. Jordanova, Assistant Prof. Dr. P. Petrov

European loess cover, including that on the Bulgarian territory, had formed during the glacial Pleistocene. Sedimentary sequences, consisting of alternating loess and paleosol horizons reflect the cyclic changes of cold (glacial) and warm (interglacial) conditions. Loess horizons formed during the glacial times as a results of intense dust sedimentation, arid conditions and poor vegetation cover. During the warm interglacial epochs, paleosols developed on loess, reflecting the effects of improved climate conditions (temperature and precipitation), rich vegetation and soil fauna. The magnetic properties of the loess/paleosol profiles provide sensitive records of paleoclimate due to the high sensitivity of the concentration, type and properties of the iron oxides along the sequence to environmental change.
On the other hand, chronostratigraphy of the loess/paleosol sequences is complicated because of lack of strict biostratigraphic markers and inherent methodological problems with the use of common dating techniques such as OSL, radiocarbon, Ar-Ar dating, etc. in this time interval. Thus, paleomagnetic dating and magnetostratigraphy using correlation of loess/paleosol magnetic properties with the global oxygen isotope records are good available methods for dating and correlation of terrestrial sedimentary sequences.

Detailed investigations of a number loess-paleosol profiles from north Bulgaria have been carried out during the last 15 years (Fig. 10). A correlation of the obtained magnetic susceptibility variations along the profiles with stacked global oxygen isotope record from the Atlantic has been done, revealing the dynamics of environmental change at the Bulgarian territory (Fig. 11).

Fig. 10

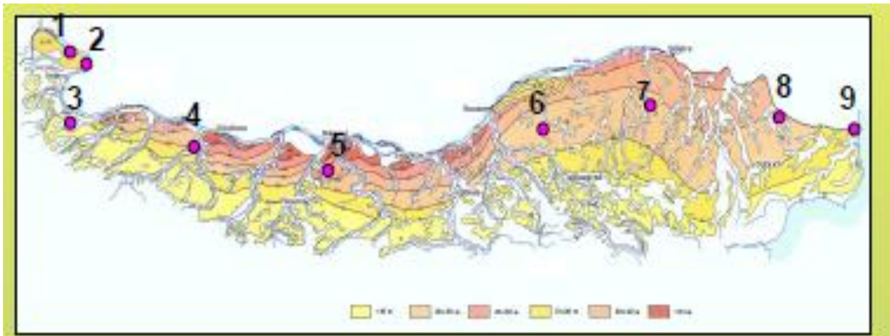


Fig. 2 Loess thickness (Evlogiev, 2006). Studied loess-palaeosol sections: 1 – Gomotartzi; 2 – Koshava; 3 – Orsoja; 4 – Harletz, 5 – Lubenovo; 6 – Viatovo, 7 – Kaolinovo; 8-Koriten, 9 - Durankulak

Viatovo quarry (No6) Durankulak outcrop (No9)

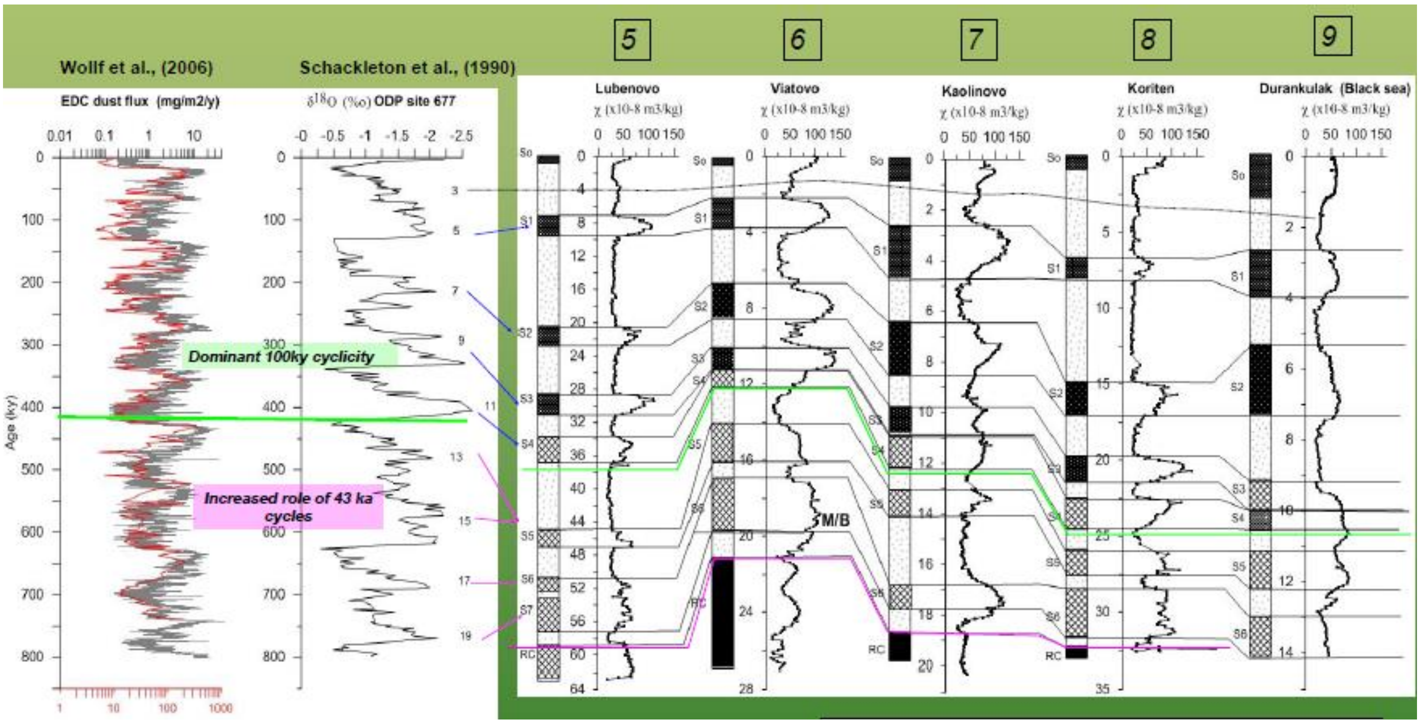


Figure 11

Valuable stratigraphic marker is obtained through identification of the Brunhes – Matuyama paleomagnetic reversal at the bottom part of the sixth paleosol and upper part of the lower seventh loess horizon in Viatovo section (Jordanova et al., 2008).

Major publications on the subject:

Jordanova, D. and N. Petersen, 1999. Palaeoclimatic record from loess-soil section in NE Bulgaria. Part I: rock-magnetic properties. *Geophys. J. Int*., 138, 520-532.

Jordanova, D. and N. Petersen, 1999. Palaeoclimatic record from loess-soil section in NE Bulgaria. Part II: correlation with the global climatic events during the Pleistocene. *Geophys. J. Int*., 138, 533-540.

Avramov, V., Jordanova, D., Hoffmann, V., Roesler, W., 2006. The role of dust source area and pedogenesis in three loess-palaeosol sections from North Bulgaria: a mineral magnetic study. *Studia Geoph. Geodaetica*, **50,** 259-282

Jordanova, D., Hus, J., Geeraerts, R., 2007. Palaeoclimatic implications of the magnetic record from loess/palaeosol sequence Viatovo (NE Bulgaria). *Geophysical Journal International*, **171**, 1036-1047; Doi: 10.1111/j.1365-246X.2007.03576.

Jordanova, D**.**, Hus, J., Evlogiev, J., Geeraerts, R., 2008. Palaeomagnetism of the loess/palaeosol sequence in Viatovo (NE Bulgaria) in the Danube basin. *Phys. Earth Planet. Inter.* , 167, 71-83.

Jordanova, D., Jordanova, N., Grygar, T., 2011. Rock magnetic and DRS characteristics of loess palaeosol sediments from Bulgaria and their link to palaeo-environmental conditions. *In: The Earth's Magnetic Interior. IAGA Special Sopron Book Series***,** Volume 1. Petrovsky, E., Herrero-Bervera, E., Harinarayana, T., Ivers, t. (Eds.). 1st Edition, 2011, XVIII, Springer Science+Buisness Media B.V., 399-412.

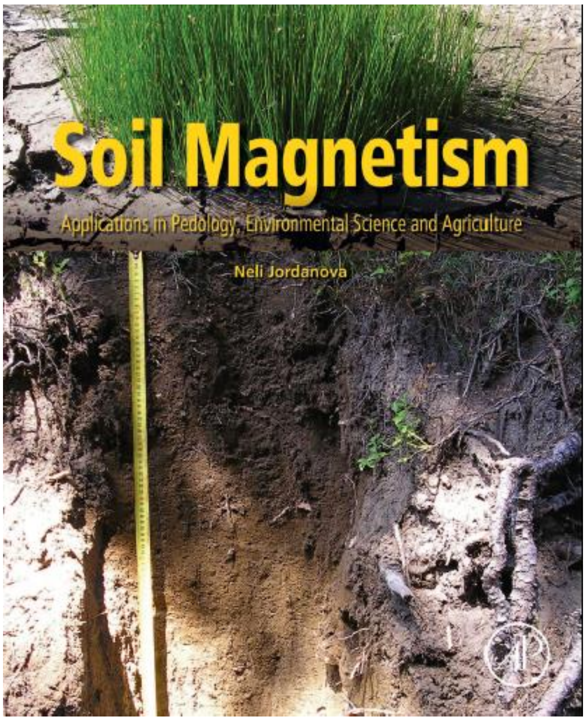
Lomax, J., Fuhs, M., Antoine, P., Rousseau, D.-D., Lagroix, F., Hatte, C., Taylor, S., Till, J., Debret, M., Moine, O., Jordanova, D., 2018. Aluminescence-based chronology for the Harletz loess sequence, Bulgaria. John Willey & Sons Ltd., in press, DOI:10.1111/bor.12348

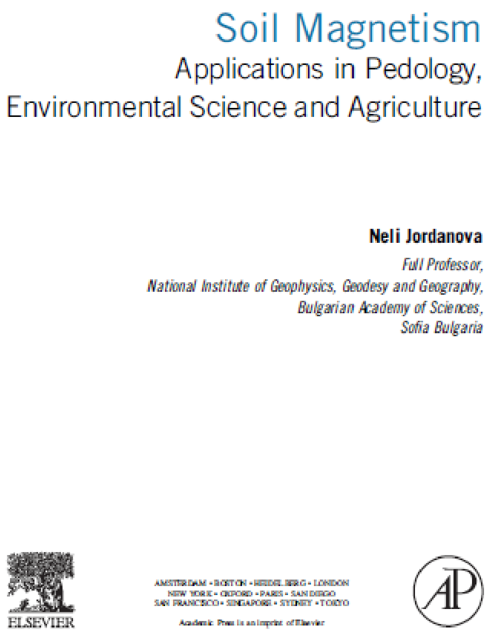
Antoine, P., Gauthier, C., Hatte, C., Rousseau, D.-D., Jordanova, D., Lagroix, F., Till, J., Lomax, J., Fuchs, M., Debret, M., Jordanova, N., Moine, O., Taylor, S., Coutard, S., in press. A remarkable Late Saalian (MIS 6) loess (dust) accumulation in the Lower Danube at Harletz (Bulgaria). Quaternary Science Reviews.

RESEARCH TOPIC: Magnetic properties of soils in Bulgaria

Team members working on this subject: Prof. DSc. N. Jordanova; Prof. Dr. D. Jordanova, Assistant Prof. Dr. P. Petrov

Iron and its particular phase composition and partitioning existing in natural soils, is one of the link elements among the two of the major Earths' cycles – carbon cycle and dust cycle. As a part of the mineral soils' composition, pedogenic iron oxides play important role in regulation of the interaction processes between terrestrial and water ecosystems, as well as their interaction with the atmosphere. One of the main advantages of the magnetic methods applied in the studies of soil iron oxides, is their high sensitivity in identification of even minor amounts of iron oxides (less than 1wt%), which cannot be identified by other mineralogical methods such as XRD or Moessbauer spectroscopy. Depth variations of different magnetic parameters are utilized for obtaining a precise reconstruction of the particular micro-environmental conditions in different genetic soil horizons.
Major part of the carried out soil magnetic studies are summarized in a scientific monograph **„Soil Magnetism. Applications in Pedology, Environmental Science and Agriculture" by Neli Jordanova**, **Academic Press (Elsevier publisher),** 2016, ISBN:9780128092392




Soil Magnetism
Applications in Pedology,
Environmental Science and Agriculture

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The main results obtained can be summarized in the following:

1) Detailed characterization of the type, concentration, grain sizes, mineralogical transformations and stabilities of the magnetic fraction in the natural soils from major soil groups on Bulgarian territory is carried out.
2) Using high-resolution 2cm sampling interval, detailed behavior of the magnetic parameters along depth of various soil types allows for precise monitoring of the changes in physical soil properties (Fig. 12).

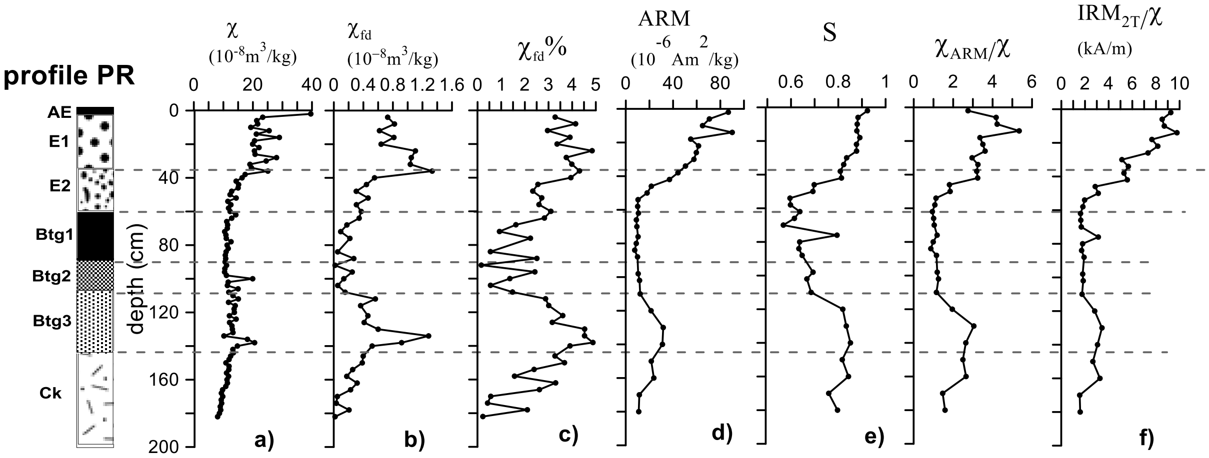

Figure 12. Depth variations of a set of magnetic parameters along Planosol profile from the region of Primorsko. The following magnetic parameters are plotted: magnetic susceptibility (χ), frequency dependent magnetic susceptibility (χ_{fd}), percent frequency dependent susceptibility (χ_{fd}%), anhysteretic remanent magnetization (ARM), ratio of anhysteretic magnetization to magnetic susceptibility (χ_{ARM}/χ) and the ratio of isothermal remanent magnetization to magnetic susceptibility (IRM_{2T}/χ)

3) The link between magnetic characteristics and various geochemical parameters is revealed for representative samples from different soil horizons.
4) Magnetic data base on topsoil (0 – 20cm depth) magnetic properties from the Bulgarian non-agricultural land is compiled and geospatial maps of different magnetic characteristics are prepared.
5) Soil magnetic properties are applied as classification criteria in genetic soil classification system and are utilized for evaluation of the ecological status of different soil types from Bulgaria.
6) Magnetic parameters "frequency dependent magnetic susceptibility (χ_{fd})" and "percent frequency dependent magnetic susceptibility (χ_{fd}%)" reflect the absolute and the relative amount of strongly magnetic pedogenic iron oxides and that's why they are among the most informative on the direction and intensity of different soil processes.

Figure 13 gives an overview of the range of variations of different magnetic parameters for the topsoils from various soil groups from Bulgaria. Median values along with the statistical estimates (range, quartile, outliers) are plotted. The most significant variations are observed for magnetic susceptibility of soil groups, which are not primarily affected by climate – Leptosols, Fluvisols, Vertisols.

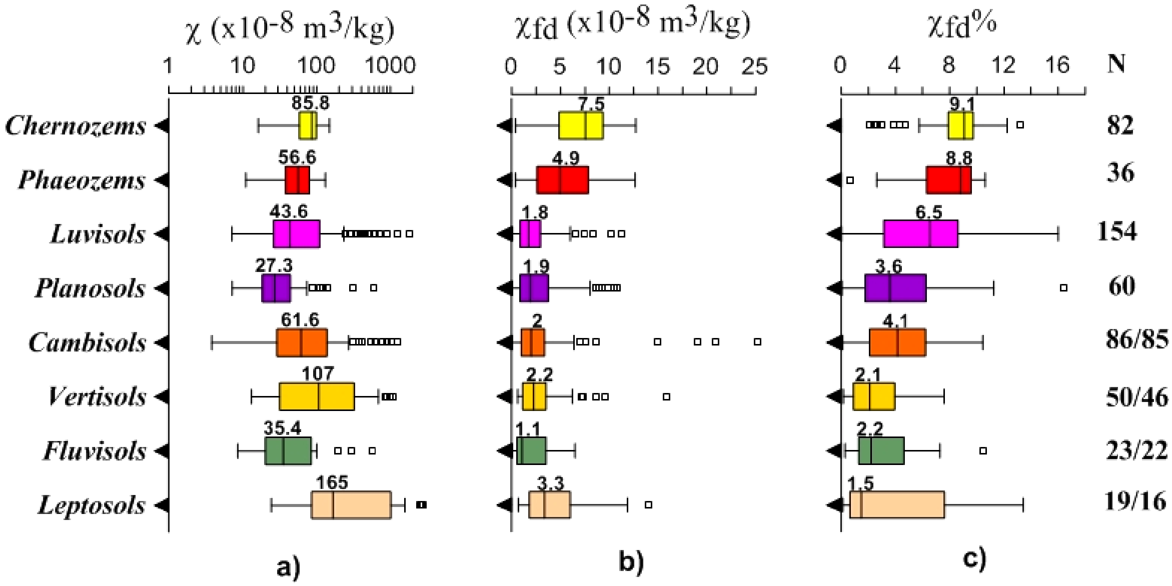

Figure 13. Magnetic parameters for the major soil types in Bulgaria, represented as box-and-whisker plots – magnetic susceptibility (χ), frequency dependent magnetic susceptibility (χ_{fd}), percent frequency dependent magnetic susceptibility (χ_{fd}%). Column N gives the number of samples in each soil group.

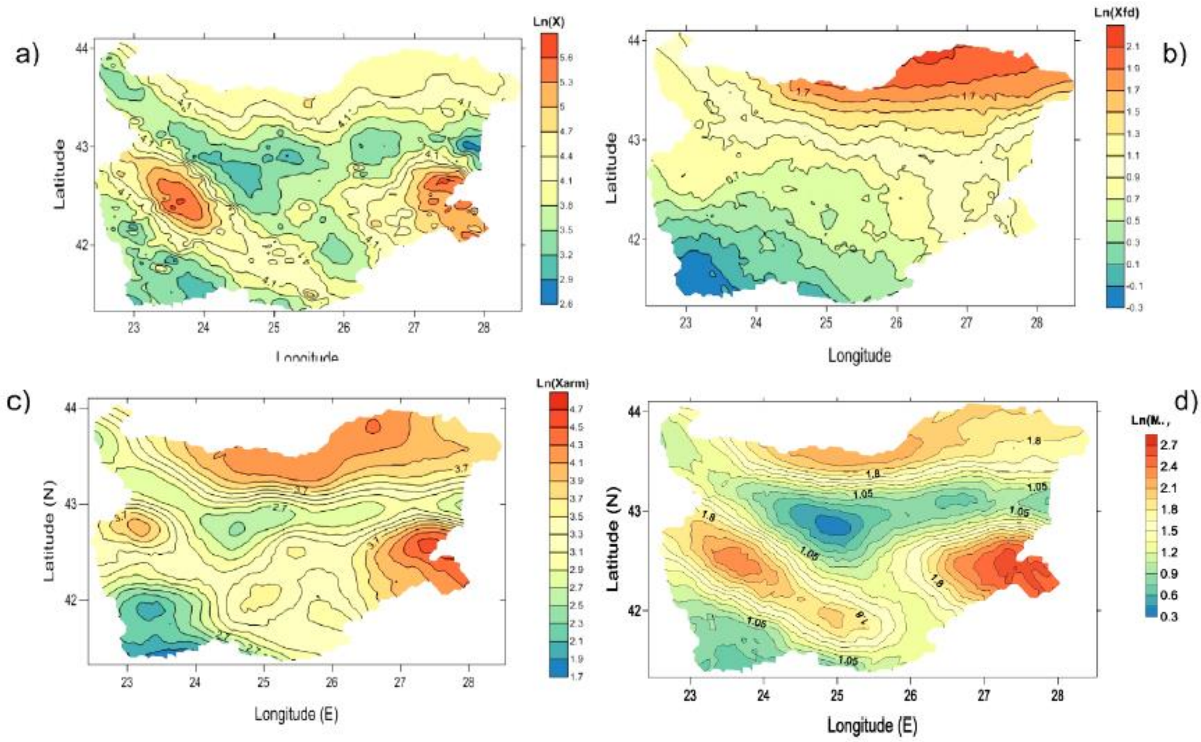

Figure 14. Interpolated maps of the lateral distribution of different magnetic parameters of the topsoils from Bulgaria: a) magnetic susceptibility; b) frequency dependent magnetic susceptibility; c) anhysteretic remanent magnetization; d) isothermal remanent magnetization (Mrs)

The map of magnetic susceptibility of the topsoils (Fig. 14a) reflects mainly the changes in parent rock lithology and the concentration of strongly magnetic iron oxides in the parent rock. Magnetic characteristics, influenced mainly by the presence of fine grained pedogenic iron oxides (Fig. 14b – d) show different lateral patterns, which depends on the changing climate conditions.

Sub-topic: Evaluation of the erosion and soil redistribution on agricultural land using magnetic methods

Magnetic mapping of an agricultural experimental plot near the village of Trastenik (Rousse district) had been carried out on a regular grid 10x10m. The obtained map of magnetic susceptibility distribution shows well expressed features related to the local peculiarities of the field (vegetation remains, soil compaction, rows, etc.) except the main effect of the removed various parts of the uppermost soil layers due to erosion. Maps of cumulative soil loss are prepared, using two different magnetic characteristics (Fig. 15). It is shown that in the uppermost parts of the plot, showing shallow slope (1-5°), tillage operations are the major factor, influencing the soil redistribution. For locations downslope, characterized by steeper slopes (11-15°), water erosion dominates and causes significant wash-out of the upper soil horizons. The mean estimated erosion rate is 8 - 6.8 t/ha/y, supposing a period of 50 years of agriculture using conventional tillage. This result corresponds very well with the erosion estimates for this particular region, using standard pedological methods.

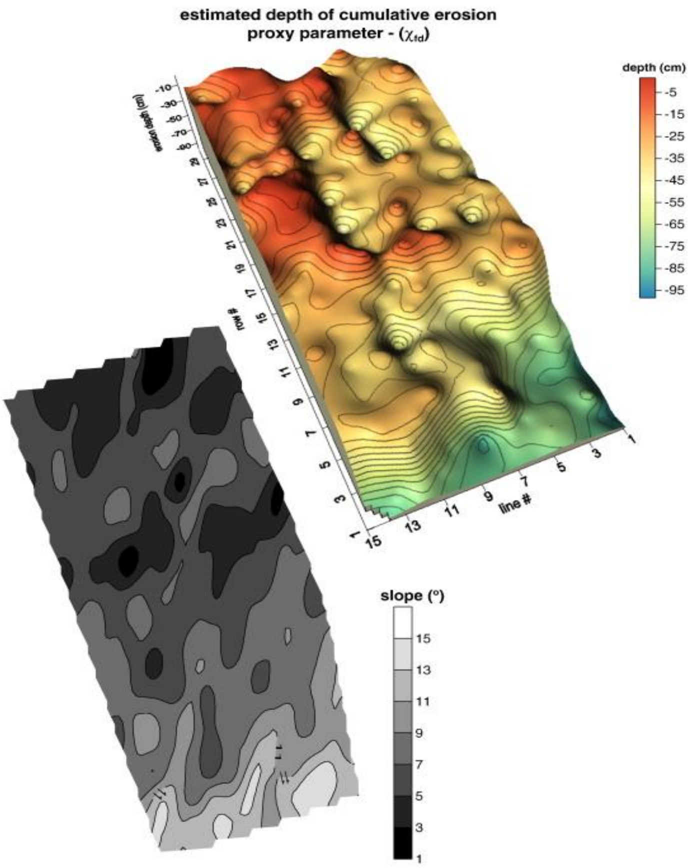

Figure 15. Estimates of soil erosion (in cm) using the parameter “frequency dependent magnetic susceptibility” (Jordanova D., Jordanova N., Petrov P., 2014. Pattern of cumulative soil erosion and redistribution pinpointed through magnetic signature of Chernozem soils. Catena, 120, 46-56)

Major publications on the subject:

Jordanova D., Jordanova N., Petrov P.,Tsacheva, T., 2010. Soil development of three Chernozem-like profiles from North Bulgaria revealed by magnetic studies. Catena, 83, 158-169.

Jordanova N., Jordanova, D., Petrov, P. , 2011. Magnetic imprints of pedogenesis in Planosols and Stagnic Alisol from Bulgaria. Geoderma, 160, 477-489.

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Jordanova, N., Jordanova, D. 2016. Rock-magnetic and geochemical characteristics of relict Vertisols—signs of past climate and recent pedogenic development. Geophysical Journal International, 205, 1437-1454.

Jordanova, N. “Soil Magnetism. Applications in Pedology, Environmental Science and Agriculture”. 1st Edition, Academic Press (Elsevier), 2016, ISBN:9780128092392, 466

RESEARCH TOPIC: Application of magnetic methods for fast and efficient mapping of the degree of anthropogenic pollution of soils, sediments and urban areas

Team members working on this subject: Prof. DSc. N. Jordanova; Prof. Dr. D. Jordanova, Assistant Prof. Dr. P. Petrov

Environmental pollution originating from the emissions of various industrial activities causes significant damages to soils, air, water, and the human health. The magnetic methodology for detection of the degree of pollution of the environment has been successfully applied during the last 15 years in Europe, as well as in Bulgaria for screening and monitoring of soils and sediments. The main parameter utilized is magnetic susceptibility. It reflects the concentration of the strongly magnetic iron oxides in a given material. The application of the magnetic method for detection of anthropogenic pollution is based on the well known fact, that different waste products and emissions from industrial processes contain certain fraction of strongly magnetic minerals (generally magnetite, maghemite or native iron) along with the toxic heavy metals. Thus, this anthropogenic magnetic fraction causes magnetic enrichment of the polluted matter as compared to the natural non-polluted counterpart. Using fast field measurements of magnetic susceptibility, large areas can be screened for initial evaluation of the lateral distribution of the pollutants.

Thus, identification of anomalous high magnetic susceptibility values of natural materials, exposed to anthropogenic influences can be used for:

- application of the magnetic method for initial fast and cost-effective estimate of the ecological situation of a certain area.

- long time monitoring of the state of environment after pollution accident or remediation action

- utilization of vegetation as a passive samplers of atmospheric pollutants and use of their magnetic signal for estimation of the degree of anthropogenic pollution.

Examples:

1. **Identification of the degree of anthropogenic pollution of the Danube floodplain sediments along the Bulgarian part of the river (Fig. 16).**

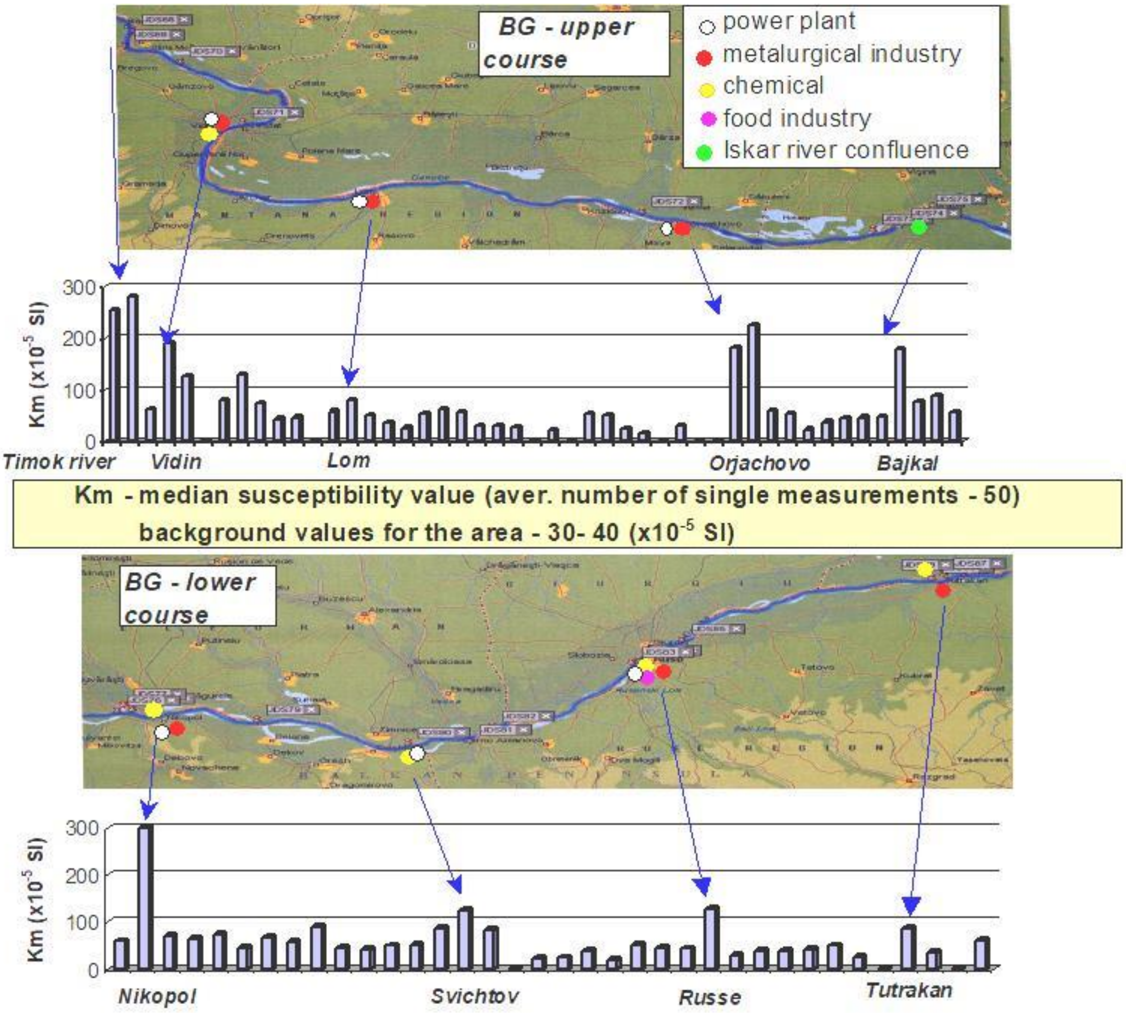

Figure 16.

Magnetic susceptibility is a highly sensitive parameter, reflecting the cumulative anthropogenic load in the river sediments.

2. **High-resolution study of the anthropogenic pollution of soils around Varna – Devnja industrial complex**

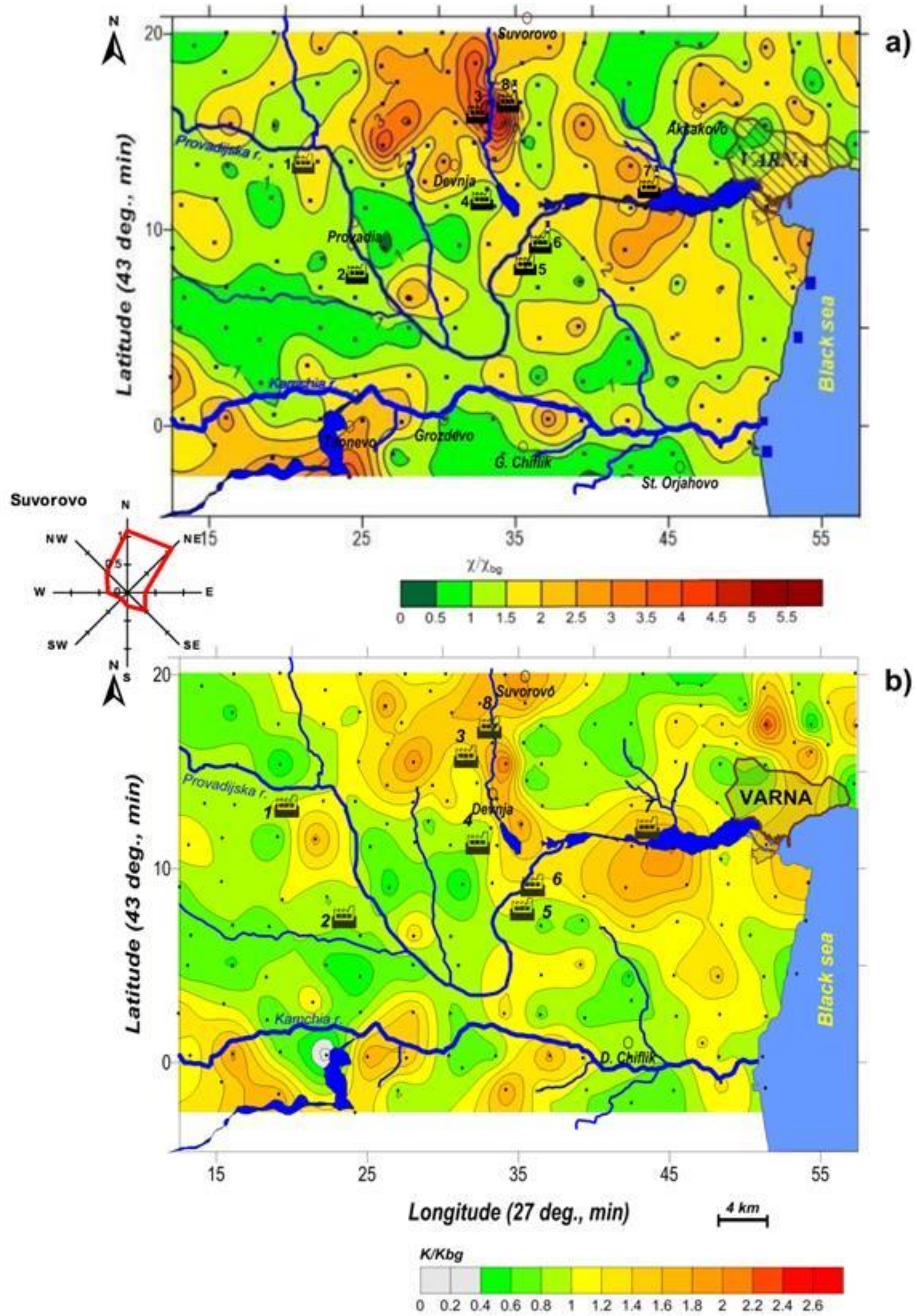

Figure 17. Evaluation of the degree of anthropogenic pollution of soils using: a) laboratory magnetic measurements of mass-specific magnetic susceptibility and b) field measurements of volume magnetic susceptibility (Jordanova et al., 2008).

3. Magnetic studies of the degree of urban environmental pollution using settled dust

Magnetic studies in urban areas utilize settled dust from roads, outer surfaces with accumulation of dust, and indoor settled dust. The mineral magnetic fraction in the urban dust samples originates mainly from traffic-related emissions (exhaust and non-exhaust), industrial emissions and natural dust. The amounts of the traffic-related emissions depend on the number of vehicles as well (e.g. from the population size).

- Magnetic study of settled road dusts from 26 urban areas in Bulgaria

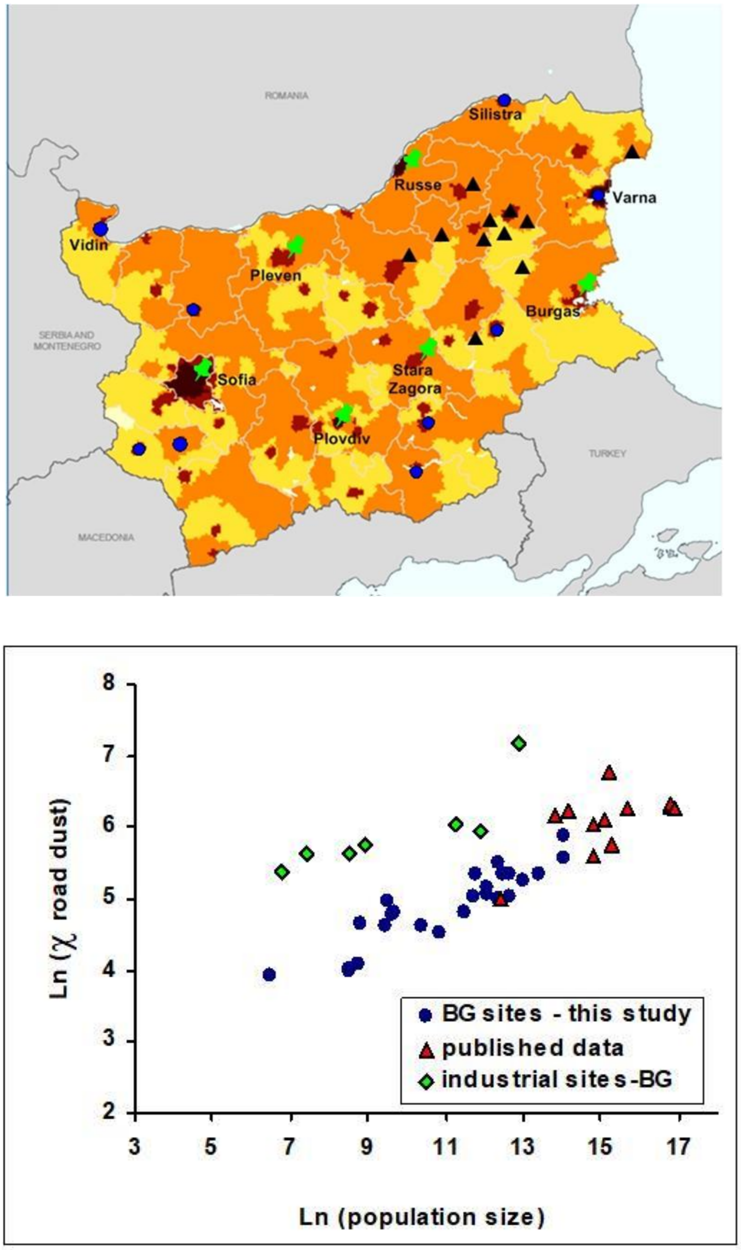

Figure 18. Magnetic susceptibility of settled road dust shows linear relationship to the population size of the corresponding urban area. The results for urban sites with heavy industries follow separate tendency. Results are published in Jordanova et al. (2014)

The observed relationship between magnetic susceptibility of the settled road dusts and the population size of the urban area, from which dust is gathered, shows that the main source of pollution is transport.

4. Relationship between magnetic properties of urban dusts and health indicators

We have studied the magnetic properties of settled indoor and outdoor dusts from several Bulgarian cities and explored the relationship of magnetic properties with the health indicators, such as mortality caused by different medical factors. Figure 20 presents the relationship obtained between the ratio of magnetic susceptibility of indoor dust to magnetic susceptibility of outdoor dust, and the mortality caused by cardiovascular diseases.
The results are published in: ***Jordanova, D., Jordanova N., Lanos, Ph., Petrov P. Tsacheva Ts. 2012. Magnetism of outdoor and indoor settled dust and its utilization as a tool for revealing the effect of elevated particulate air pollution on cardiovascular mortality. Geochemistry, Geophysics, Geosystems (AGU journals), 13 (8), article Q08Z49, doi:10.1029/2012GC004160***

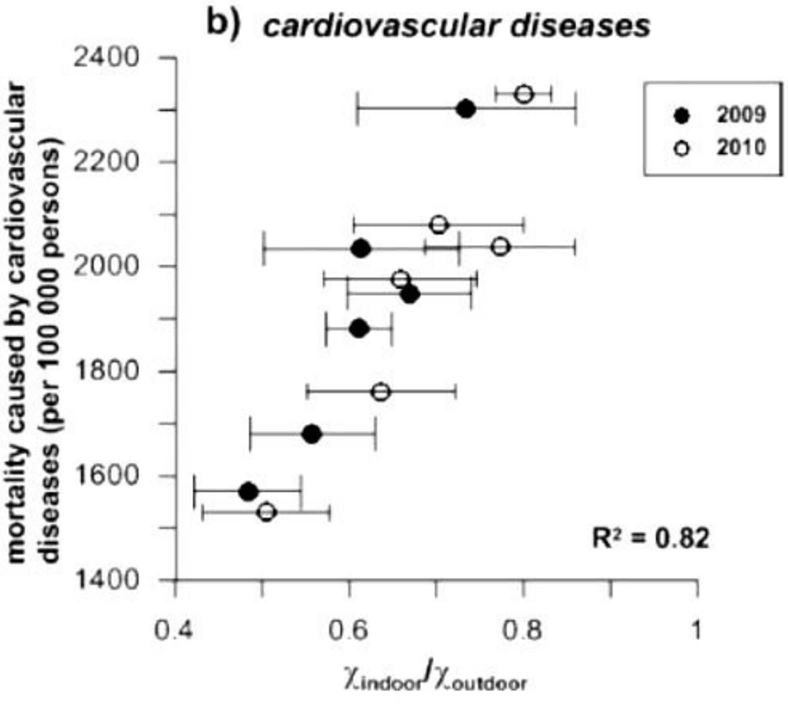

Figure 19.

Main publications on the subject

Jordanova, N., Jordanova, D., Veneva, L., Yorova, K., Petrovsky, E., 2003. Magnetic response of soils and vegetation to heavy metal pollution – a case study. Environmental Science and Technology, 37, 4417-4424.

Jordanova, D., Jordanova, N., Hoffmann, V., 2006. Magnetic mineralogy and grain-size dependence of hysteresis parameters of single spherules from industrial waste products. Phys. Earth Planet. Inter. , 154, 255-265.

Jordanova, N., Jordanova D., Tsacheva Ts., 2008. Application of magnetometry for delineation of an thropogenic pollution in areas covered by various soil types. Geoderma, 144(3-4),557-571

Jordanova, D., Jordanova N., Lanos, Ph., Petrov P. Tsacheva Ts. 2012. Magnetism of outdoor and indoor settled dust and its utilization as a tool for revealing the effect of elevated particulate air pollution on cardiovascular mortality. Geochemistry, Geophysics, Geosystems (AGU journals), 13 (8), article Q08Z49, doi:10.1029/2012GC004160

Jordanova D., Goddu S.R., Kotsev T., Jordanova N.,2013.Industrial contamination of alluvial soils near Fe-Pb mining site revealed by magnetic and geochemical studies. Geoderma 192,237-248.

Jordanova, D. , Jordanova, N., Petrov, P., 2014. Magnetic susceptibility of road deposited sediments at a national scale - Relation to population size and urban pollution. Environmental Pollution 189, 239-251.

Jordanova, N., Petrovský, E., Kapicka, A., Jordanova, D., Petrov, P., 2017. Application of magnetic methods for assessment of soil restoration in the vicinity of metallurgical copper-processing plant in Bulgaria. Environmental Monitoring and Assessment, 189, Article number 158

International projects:

2009 - 2010 "Collision Europe-Dinarides: Maritza shear zone in Central Bulgaria" proj. RILA 4/405 EGIDE Programme PHC-Rila

2008 - 2011 "Interactions between soil related sciences – Linking geophysics, soil science and digital soil mapping", EU-7FP of, Cooperation Project (iSOIL), Contract 211386

2005 - 2008 "Environmental applications of soil magnetism for sustainable land use", SCOPES 2005 - 2008 JRP - cooperation between ETH-Zurich and Geophysical Institute, Proj. No IB7320-110723/1

2006 - 2008 "Integrated environmental screening by bioindicators and magnetic proxies", NATO Collaborative Linkage Grant grant No ESP.EAP.CLG. 982060

2004 - 2005 "Magnetic proxies for evaluation of "hot spot" industrial pollution in East Bulgaria", 6th FP Marie Curie European Reintegration Grant MAPHOPE: MERG-CT-2004-508786

2002 - 2005 "Improving the Human Research Potential and the Socio-economic knowledge base", Training Network AARCH, "Archaeomagnetic Applications for the Rescue of Cultural Heritage", EU- 5FP, No HPRN-CT-2002-00219

2002 - 2004 "Rock magnetic proxies for palaeoclimatic changes in the Carpatho-Danubian area", NATO Linkage Grant No EST.CLG.978564

2001 - 2003 "Magnetic proxy mapping of anthropogenic impacts on low Danube sediments", 5th FP Marie Curie Fellowship of Dr. Diana Jordanova, contract No HPMF-CT-2000-01084 hosted by the University of Tuebingen

2000 - 2003 "New aspects of archaeomagnetic studies involving rock magnetism", SCOPES, Project No JRP 7BUPJ062179

1999 - 2000 "Shear sense in the granitoids from southeastern Bulgaria by petrostructural and AMS methods", NATO Linkage Grant No CRG.LG973943

Projects funded by National Science Fund:

2011 - 2013 "Archaeomagnetism – a key for resolving the fundamental problems in geophysics and archaeology", Project ДМЧ 03/42

2008 - 2012 "Geophysical studies on the degree of anthropogenic environmental pollution and its effect on the human health in urban areas." Project ДО02-193/2008.

2005 - 2008 “Soil magnetic properties as reflection of their ecological status. Project H31510/05

Bilateral cooperation projects

2012 – 2014 “Soils and palaeosols as an archive of (palaeo)climates”, Bilateral cooperation project BAS - Chinese Academy of Sciences

2011 – 2013 “Ecological state of soils evaluated through magnetic methods”, Bilateral cooperation project BAS - Academy of Sciences of Czech Republic (Institute of Geophysics)

2006 – 2007 “Magnetic fabric of Strandja and Central Srednogorie plutons (Bulgaria) and structural implications”, Bilateral cooperation project between BAS (Geophysical Institute) and IPGP (Paris, France)

2004 – 2006 “Comparative palaeointensity study on archaeological specimens from Bulgaria, Finland and Switzerland”, Bilateral cooperation between BAS (Geophysical Institute) and University of Helsinki, Finland

2004 – 2005 “Paleomagnetism and magnetic fabric in the Srednogorie zone’, Bilateral cooperation project between BAS (Geophysical Institute) and IPGP (Paris, France)