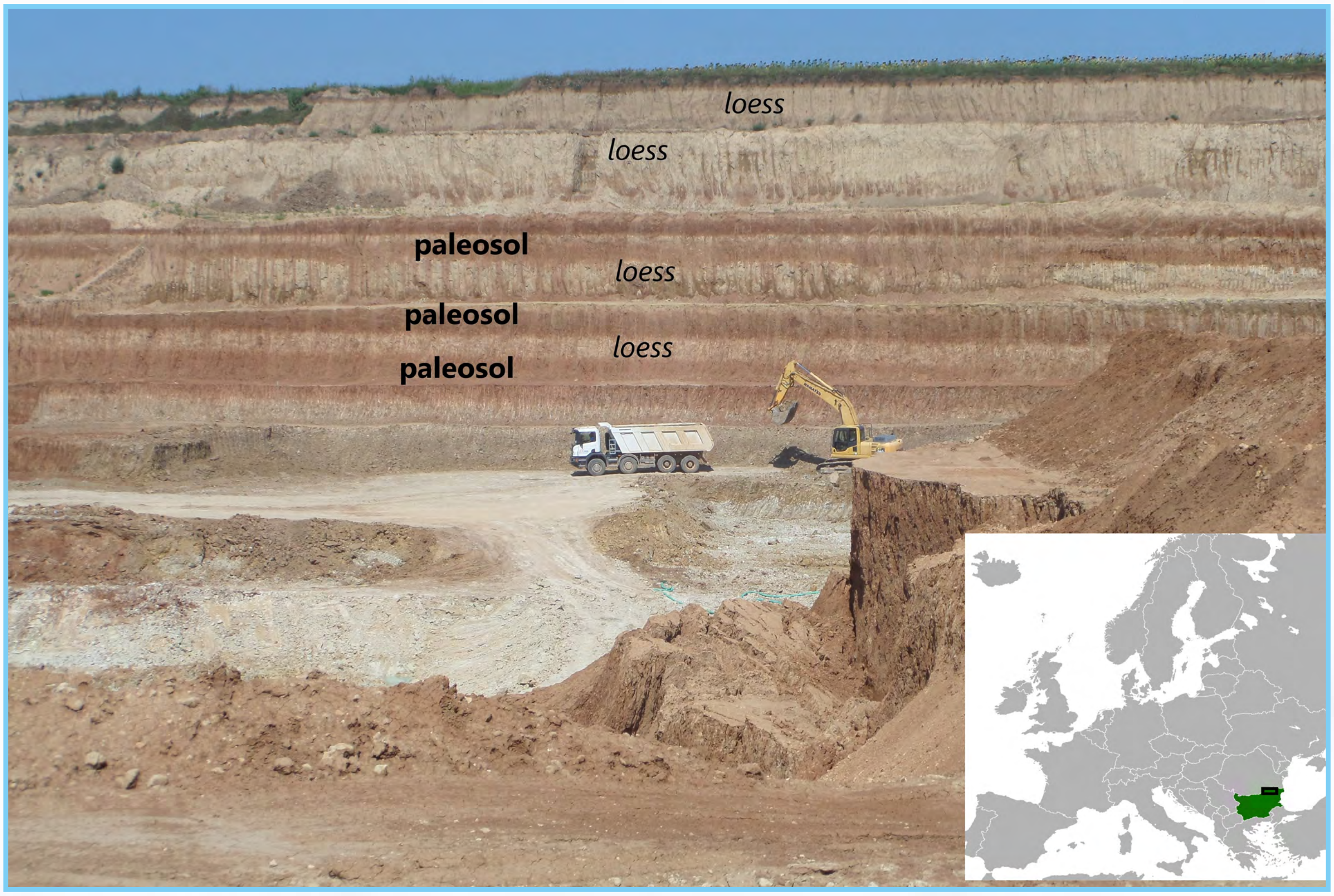
How Scientists Use Ancient Soils to Predict the Future

Written by Josh Gross

The Earth's climate is changing, and fast. We have droughts in Europe, catastrophic wildfires in the United States, and glaciers are receding worldwide. But, how do we predict what future conditions will be like, and how people will respond to them?

The soil beneath our feet holds vital clues. Dr. Diana Jordanova, a geophysicist with the National Institute of Geophysics, Geodesy and Geography at the Bulgarian Academy of Sciences, explains how she and her colleagues can use the magnetic properties of ancient soils (paleosols) to determine past climates. They can then sync this data with archaeological findings to see how people behaved during different climate periods. This information, in turn, can give us a better idea of what the future holds.

Continue reading to learn more about how ancient soils communicate with us via magnetism.



Above: Figure 1 – Open pit quarry in north Bulgaria, where 27m thick loess-paleosol sedimentary sequence (Pleven profile) is exposed and sampled. Dark layers are the ancient soils formed during past interglacials. They are intercalated with pale loess layers, formed by aeolian dust sedimentation during cold glacial stages of the Pleistocene. Inset figure shows the geographic location of the study area. © Diana Jordanova. All rights reserved.

Q & A: Diana Jordanova (Bulgarian Academy of Sciences)

Please tell us about your yourself and your research at National Institute of Geophysics, Geodesy and Geography (BAS).

I am a professor at the National Institute of Geophysics, Geodesy and Geography at the Bulgarian Academy of Sciences. Our Institute is the national organization for operating and maintaining solid Earth monitoring systems in Bulgaria, and especially seismological, geodetic and mareographic observational networks. My narrow professional experience, however, is related to the studies of the deep past history of our planet by studying the magnetic signals captured in natural archives (soils, sediments, burnt archeological remains).

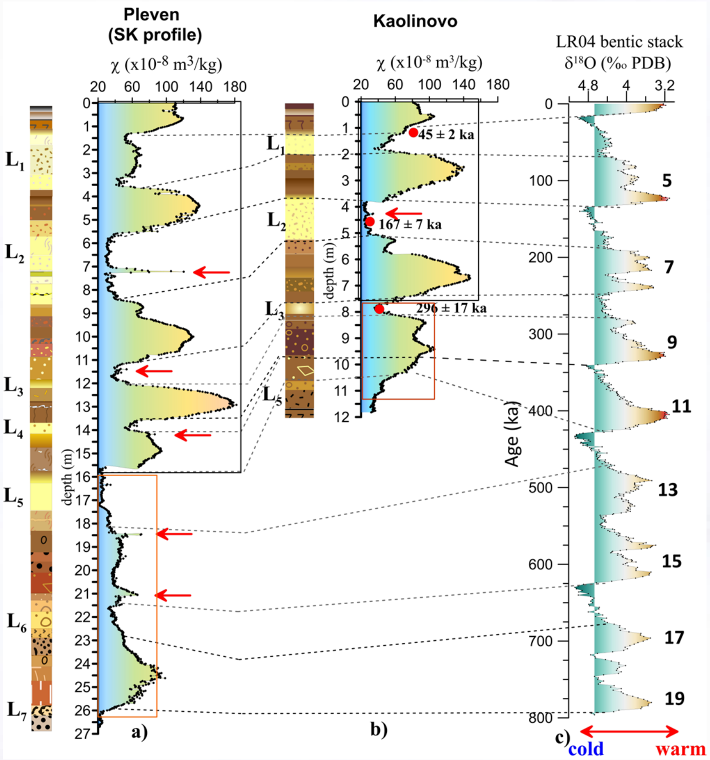
These studies are carried out at the Paleomagnetic laboratory, equipped with specialized instruments unique to Bulgaria that are capable of measuring the weak magnetic signals of natural materials. Research directions in which people from our lab are actively involved are:

1. Studies of the magnetic signals, carried by sediments and soils, which are utilized as proxies to decipher past environments, the climate's history and its role in human migrations in the geologic past;
2. Reconstruction of the history of Earth's magnetic field using archaeomagnetic studies of burnt remains from archeological sites;
3. Estimation of the degree of anthropogenic pollution of soils, sediments and urban areas using magnetic methods;
4. Utilization of magnetic measurements in estimates of past firing temperatures of ancient ceramics and natural fires.

In your recent 2022 study published in Quaternary Science Reviews, why did you focus on a loess-paleosol profile from Kaolinovo, NE Bulgaria. Also, what did the sediments reveal about environmental change in South East Europe in the last 540 thousand years?

In our recent article, together with colleagues from the soil research group at CEREGE (Aix-Marseille University) we show how information stored in minerals from a sedimentary succession can be utilized to reconstruct past environments.

Loess – paleosol profiles are terrestrial archives, formed by aeolian (meaning wind-blown) dust sedimentation during the Pleistocene (Figure 1). Soil formation happened during warm inter-glacials, accompanied by “in situ” production of new strongly magnetic minerals. The amount of this pedogenic (soil-based) magnetic fraction depends on climate (temperature, precipitation). Because loess sediments have low magnetic susceptibility, while soils show high susceptibility originating from pedogenic strongly



Right: Figure 2 – Correlation of magnetic susceptibility records along depth of Kaolinovo and Pleven loess – paleosol profiles (North Bulgaria) with global paleotemperature record from oceanic deep sea cores represented by LR-04 stack of Lisiecki and Raymo, 2005 (Paleoceanography, 20, PA1003, doi:10.1029/2004PA001071). Marked by red arrows depths represent sharp peaks of (crypto) tephra (volcanic ash) layers.

Original research is published in Jordanova et al., 2022, QSR, 292, 107671. © Diana Jordanova. All rights reserved.

magnetic minerals, this cyclic pattern represents a detailed paleoclimate proxy record. Figure 2 demonstrates how this magnetic signal at Kaolinovo site matches the global climate record for the last 800 ky (ky meaning thousand years). Statistical analysis revealed that significant change in magnetic minerals occurred 300 ky ago. This indicates changes in dust source and related paleo-wind directions, governed by the atmospheric circulation during glacial periods. Weaker magnetism and increased hematite content in older deposits signifies that past warm periods were much warmer than the present day climate at the study area. Magnetic records at Kaolinovo and another nearby quarry (Pleven profile) also reveal several sharp peaks representing the signal of external additions of strongly magnetic volcanic ashes, spread by volcanic clouds of past eruptions from Mediterranean volcanic provinces.

As seen in your paper in Quaternary International, what did your analysis of mineral magnetic and paleomagnetic records in alluvial soil (in NE Bulgaria) reveal about climate in the Holocene?

In addition to going deep in time, the magnetism of soils, formed during the contemporary Holocene period, is a source of valuable information about the effects of climate fluctuations on human societies. Our study, published in QI, presents how ancient people reacted to climate change. Soil profile, dated at about 6000 y BP, was sampled near the oldest Neolithic site in Bulgaria. Two ratios of magnetic parameters show variations which closely match paleotemperature records from Greenland ice cores and records of flood intensities of the Alps' rivers (Figure 3). This provides new data on the main climate variability in the area and shows the suitability of magnetic studies for paleoenvironmental reconstructions. Figure 3 suggests that the hottest period covered by the

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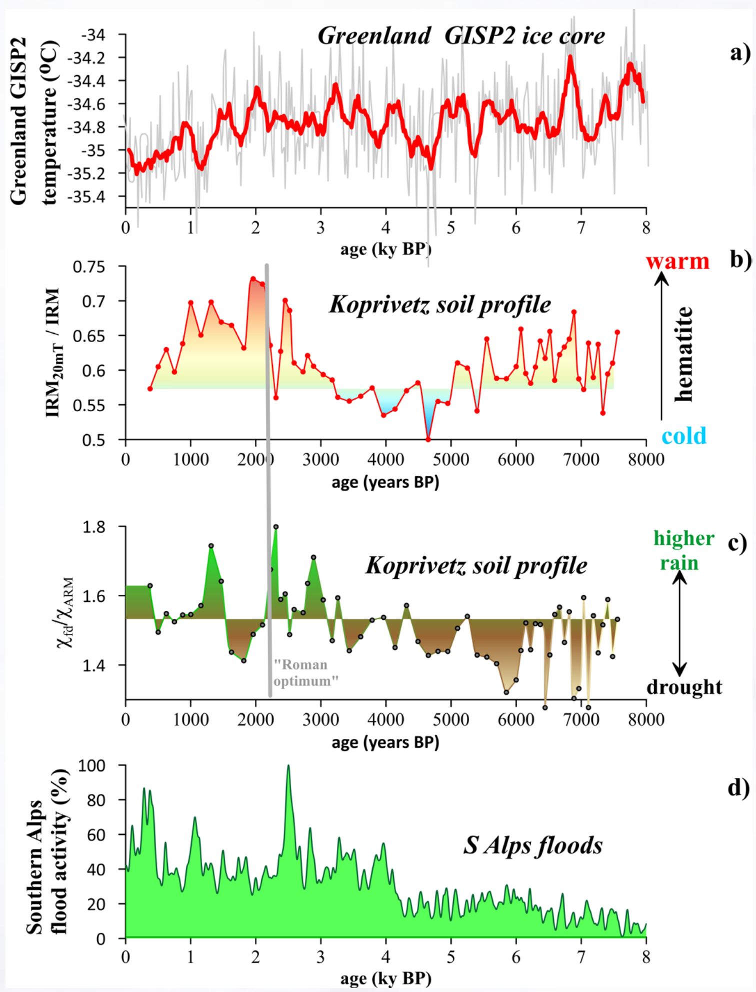

Right: Figure 3. Magnetic paleoclimate proxy ratios for Koprivetz soil profile compared with Greenland temperature record from GISP2 ice core (a) (data from Grootes and Stuiver, 1999 (PANGAEA Database, doi:10.1594/ PANGAEA.56094, with 10-points running average) and Southern Alps flood activities (d) from Wirth et al., 2013 (PANGAEA Database, doi: 10.1594/ PANGAEA.823415a).

The magnetic ratio of isothermal remanences (IRM20mT/ IRM) (shown in Fig. 3b) is sensitive to the relative amount of the weakly magnetic iron oxide hematite. The ratio of frequency dependent to anhysteretic magnetic susceptibilities (Fig. 3c) has higher values when flooding brought eroded soil material from upslope to the alluvial plane and this material was incorporated into the sampled soil profile. Original research published in Jordanova et al., 2022, Quaternary International, 631, pp. 47–58.

record occurred at about 2.2 ky BP, coinciding with a period of the highest flood intensity. Such conditions are favourable for the development of ancient societies, and this was the period when the Roman empire rose in Europe.

The general intensification of flood activities after 3000 y BP probably is partly caused by anthropogenic influence through forest clearance.

Conversely, a relatively cold period of one millennia during 4.5 – 3.5 y BP was the timing of intense use of fire in the technological chain at the oldest open pit gold mine in Europe, studied by us (Figure 4).

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How do your studies of the Holocene paleoenvironment assist with our understanding of climate change patterns now and in the future?

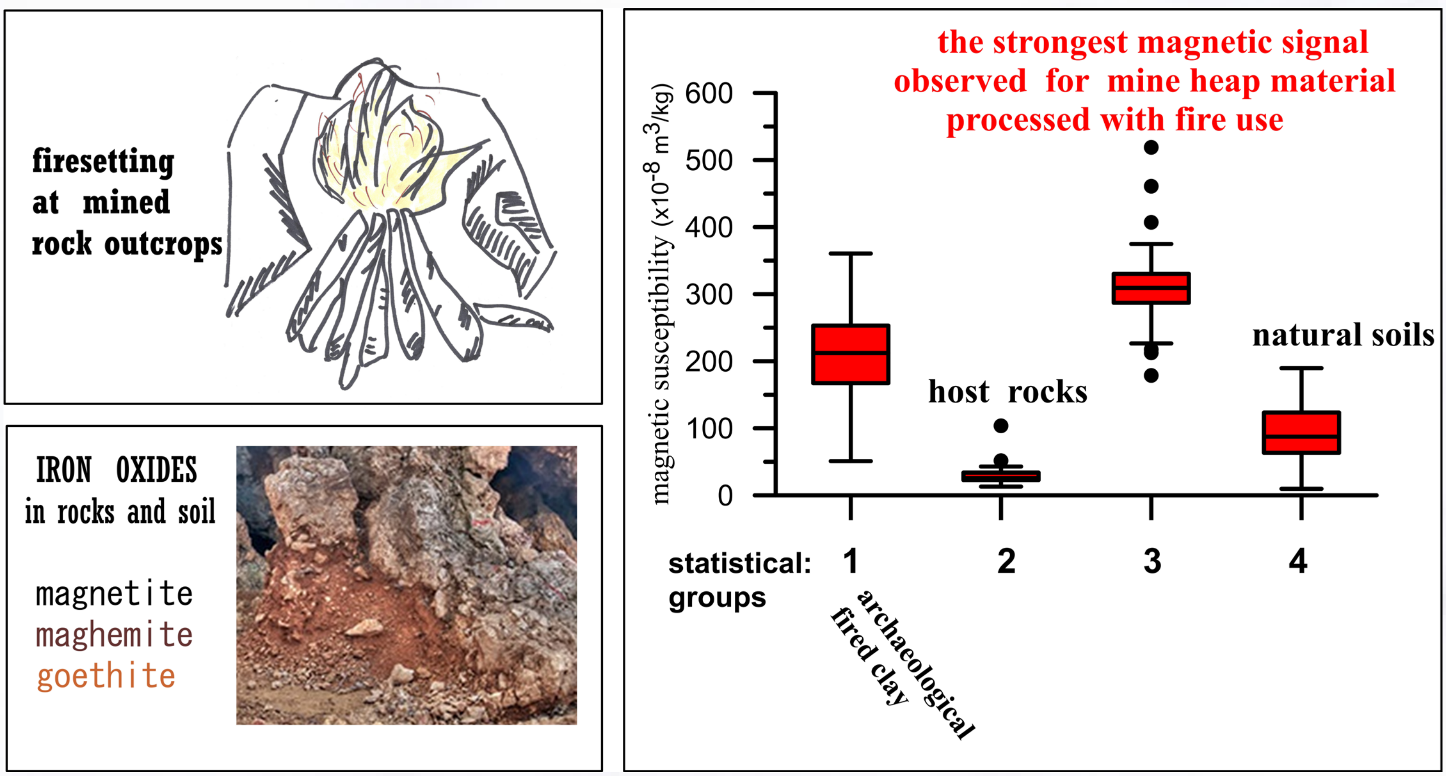
Mineral magnetic and Interdisciplinary studies on natural archives, revealing records of past climate during the present Holocene era, as well as in deeper geologic time of glacial Pleistocene have great importance.

They are the only way to learn what would be the future state of the soil cover on the Earth with the changing climate. This has important implications for securing humanity's food production.

Obtaining more records of local and regional climate change during the Holocene and its link to the archeological findings about ancient technologies and social behaviour is also of prime importance in planning measures for the sustainable use of resources and restricting human impacts on climate warming.

Below: Figure 4 – Mineral magnetic measurements on a collection of materials from the Europe's oldest Bronze Age open-pit gold mine Ada Tepe (Bulgaria) were successfully applied for characterization and discrimination of ancient technological mining processes. Iron oxides in host rocks and gold mineralization are genetically linked, which predetermined suitability of rock magnetic measurements.

Fire setting caused thermal changes in natural iron oxides, which are readily detected and characterized by the magnetic parameters measured. The original study is published in: Geochemistry, Geophysics, Geosystems, 21, e2020GC009374. DOI: 10.1029/2020GC009374.



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Final thoughts

It is fascinating to know that different materials in the soil produce varying levels of magnetic signals, and that scientists can use those signals to determine what sorts of conditions existed when those soils were formed. This information, then, helps scientists like Prof. Jordanova to “read” past climates.

Even more remarkable is that human behavior reflected those climactic conditions, and even interacted with them in ways that affected the landscape. For instance, the Roman empire grew in Europe during a warm period, which correlated with deforestation and subsequent flooding.

Prof. Jordanova’s research provides clues as to what sorts of resource use patterns we might see in coming years, which helps us plan for an uncertain future.

Who would have thought that ancient dirt, when combined with magnetism, could tell us so much?

Bio

Diana Jordanova graduated as a Geophysicist at Dept. of Physics, Sofia University in 1992, with a PhD obtained at Geophysical Institute (Bulgarian Academy of Sciences) with the subject “Magnetism of Holocene soils from north Bulgaria”.

Prof. Jordanova won an Individual Marie Curie fellowship (6th EU FP) at Tuebingen University (2001- 2002), and was Lecturer at Sofia University, Dept. of Physics (2007 – 2012 years).

A Full Professorship was obtained in 2012 at NIGGG – BAS. Working in mutual cooperation, Diana shares ideas and inspirations with her twin sister Prof. Neli Jordanova.

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