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ROCK- AND ARCHEOMAGNETIC INVESTIGATION OF PREHISTORIC COPPER SLAG FROM THE SE SWISS ALPS

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ABSTRACT

Copper slag is a relatively new and promising material used to recover the ancient geomagnetic field intensity. We investigate copper slag from the Oberhalbstein Valley, located in the Swiss Alps, in order to determine its suitability for archeointensity experiments. During the process of copper production different types of slag accumulate, *e.g.*, plates of tapped slag or slag cakes. We want to shed light on the type of copper slag that is most suitable for this type of experiment. Furthermore, we attempt archeomagnetic dating in order to complement previous contradictive radiocarbon and dendrochronological dating results. The new data will enhance the archeointensity database of Switzerland for data < 0 AD.

Keywords: Archeointensity, copper slag, rock magnetism, Switzerland

RESUMEN

La escoria de cobre es un material relativamente nuevo y prometedor para estimar la intensidad del campo geomagnético antiguo. Con la intención de determinar su utilidad para los experimentos de arqueointensidad, realizamos una investigación de escoria de cobre proveniente del valle de Oberhalbstein, situado en los Alpes suizos. Debido a que durante el proceso de producción del cobre se generan diferentes tipos de escoria (placas de escoria o aglomerado de escoria), estamos interesados en conocer cuál de estos tipos de escoria de cobre es el más adecuado para este tipo de determinaciones. Asimismo, realizamos el fechamiento arqueomagnético de las muestras con el fin de complementar los resultados previos contradictorios entre la datación dendrocronológica y por medio de radiocarbono. Los resultados obtenidos mejorarán la base de datos de arqueointensidad de Suiza para temporalidades < 0 DC.

Palabras Clave: Arquemagnetismo, escoria de cobre, magnetismo de las rocas, Suiza

1. Introduction

In order to reconstruct Earth's magnetic field prior to direct measurements, we rely on different kinds of materials that are able to record the geomagnetic field, e.g., archeological artifacts, volcanic rocks, or sediments. Archeological artifacts such as ceramics, baked bricks or furnaces for, *e.g.*, iron or copper production, have several advantages compared to other recorders. They acquire a thermoremanent magnetization parallel and proportional to the predominant geomagnetic field, they are abundant and cover up to the past 10,000 years. In recent years, copper slag, the waste product that originate during the copper production, has been discovered as new suitable material in archeomagnetic studies. The pioneering study of Ben-Yosef *et al.* (2008a) investigated copper slag from Jordan for the first time and proved it to be suitable for recovering the geomagnetic signal. They found that slag exhibits good experimental behavior and, in many cases, embedded charcoals for radiocarbon dating can be found and related directly to the slags. Several subsequent studies of Jordanian copper slag confirm their suitability (*e.g.*, Ben-Yosef *et al.*, 2008b; 2009; Shaar *et al.*, 2010; 2011a; 2011b). Other studies investigated copper slag from Georgia, Cyprus, Tunisia, Mexico, and Italy (Shaar *et al.*, 2013; 2015; 2017; Fouzai *et al.*, 2013; Morales *et al.*, 2017; Kapper *et al.*, 2015).

During the copper production different types of slag accumulate and not all are equally suitable for obtaining archeointensities, *e.g.*, plates of tapping slag or slag cakes (*e.g.*, Ben-Yosef *et al.*, 2008a). A preselection of suitable slags in the field can tremendously increase the success rate of an archeointensity experiment. Archeomagnetic investigations of this type of material are of benefit for archeologists, not only in the most common application of archeomagnetism, in archeomagnetic dating, but also in the reconstruction of the original position of the slag, determination of ancient heating temperatures, and magnetic mineralogy.

In this study, we aim to investigate slag samples from the Oberhalbstein Valley, Switzerland, with rock magnetic measurements. Dendrochronological dating from charcoal from a slag heap reveals an age in the first half of the 7th century BC, whereas radiocarbon dating from charcoal from inside the furnace reveals an age of about 100-200 years earlier (Turck *et al.*, 2014). We intend to determine the age of the samples through archeomagnetic dating to confine their ages. Furthermore, we demagnetize the samples thermally and with alternating fields (AF) in order to further characterize the samples.

Although Europe has an abundance of archeomagnetic data compared to other parts of the world, *e.g.*, the Southern Hemisphere, there are only two intensity data from before 0 AD from Switzerland in the Geomagia50.v3 database, the largest database for archeomagnetic data (Brown *et al.*, 2015). Some more data are reported in less than a handful other studies (*e.g.*, Kapper *et al.*, 2015; Donadini *et al.*, 2007).

2. Sites, samples and methods

The Oberhalbstein Valley is a large copper production area in the South-Eastern Swiss Alps and has been investigated by R. Turck of University of Zurich, Switzerland (*e.g.*, Turck *et al.*, 2014, and references therein). Radiocarbon ages from settlement find and slag heaps reveal mining and smelting activities from the late Middle Bronze Age to the late Iron Age. We obtained eight slag samples of tapped slag and slag cakes. One sample stems from an excavation close by (Savognin), which is believed to be from a contemporary copper production. This sample is supposed to verify the methodology since it can be compared with direct measurements of the geomagnetic field.

First rock magnetic measurements of four samples include the determination of thermomagnetic, backfield and isothermal remanent magnetization (IRM) curves, and hysteresis loops. AF demagnetization was performed on the same four pilot samples in 16 steps up to 150 mT. It has to be noted that the slag samples are unoriented, but the demagnetization procedure should reveal the demagnetization behavior in terms of single or multiple components and unblocking temperatures. In order to determine archeointensities, a Thellier-Coe experiment was performed on seven samples that were each cut in six specimens (Thellier, Thellier, 1959; Coe *et al.*, 1978). Each of the specimens per sample was oriented along the principal axes +x, -x, +y, -y, +z, -z, in order to take into account a possible influence of magnetic anisotropy. The slag pieces were encapsulated in salt pellets in these specific orientations.

3. Results

Thermomagnetic measurements reveal Curie temperatures ranging between 530-558º C, indicating Ti-magnetite as main magnetic carrier. Heating and cooling curve are nearly reversible. IRM curves saturate at 300 mT, supporting the existence of Ti-magnetite. Hysteresis loops reveal rather large coercivities, B_c, ranging between 9.9-29.1 mT (Median: 21.4 mT), indicating single domain grain sizes. Two of the four loops are slightly wasp-waisted. AF demagnetization reveals univectorial vector diagrams, in general, with a small viscous component. Medium destructive fields range between 20-40 mT. The Thellier-Coe experiment yielded 25 out of 42 successful specimens. The behavior during the experiment was very different for different samples: some revealed linear Arai diagrams, while others exhibit several components.

4. Discussion and ongoing work

Preliminary rock magnetic measurements indicate that the samples are very suitable to perform a Thellier-type archeointensity experiment. The AF demagnetization as well indicates that the samples are promising due to univectorial components. The Thellier-experiment was successful for more than half of the specimens. However, each slag sample shows very different characteristic. A clear strategy for selecting the most suitable samples for the Thellier-experiment, probably by prior thermally demagnetizing them, may yield a high success rate.

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