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Technogenic magnetic particles in soils as evidence of historical mining and smelting activity: A case of the Brynica River Valley, Poland

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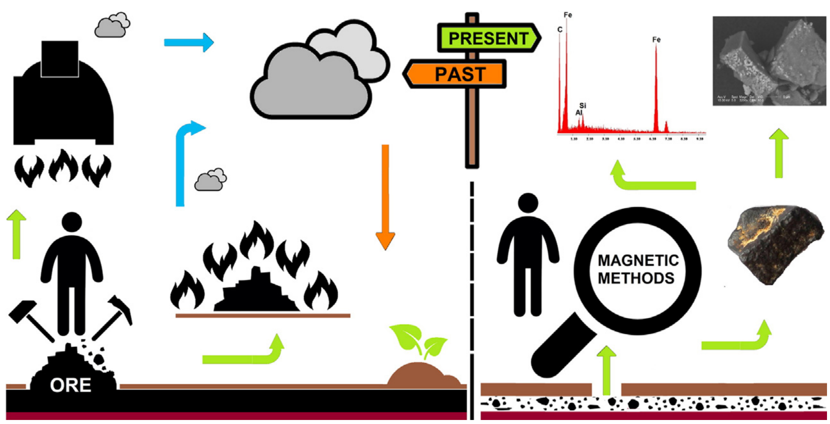
HIGHLIGHTS

- Due to ferrimagnetic properties of historical slags magnetic prospection is an efficient tool for they localization.
- C^{14} dating indicates Pb contamination from about the year 1000 BC
- Ore mining and smelting in Upper Silesia was older than previously estimated

GRAPHICAL ABSTRACT



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ABSTRACT

In the area of Brynica River basin (Upper Silesia, southern Poland) the exploitation and smelting of iron, silver and lead ores was historically documented since early Middle Ages. First investigations showed that metallurgy industry had a large impact from 9th century (AD) until the Second World War. The aim of the study was to use magnetic prospection to detect traces of past mining and ore smelting in Brynica River Valley located in Upper Silesia (southern Poland). The field screening was performed by measurement magnetic susceptibility (κ) on surface and in vertical profiles and was supported locally by gradiometric measurements. Vertical distribution of magnetic susceptibility values was closely associated with the type of soil use. Historical technogenic magnetic particles resulting from exploitation, processing, and smelting of iron, silver, and lead ores were accumulated in the soil layer at the depth 10 to 25 cm. They were represented by sharp-edged particles of slag, coke, as well as various mineralogical forms of iron minerals and aggregates composed of carbon particles, aluminosilicate glass, and single particles of metallic iron. The additional geochemical study in adjacent peat bog supported by radiocarbon dating was also performed. The application of integrated geochemical-magnetic methods to reconstruct the historical accumulation of pollutants in the studied peat bog was effective. The magnetic peak, which was pointed out by magnetic analyses, is consistent with the presence of charcoal and pollution from heavy metals, such as Ag, Cd, Cu, Fe, Pb, or Sn. The results of this work will be helpful for the further study of human's

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impact on the environment related to the historical and even pre-historical ore exploitation and smelting and also used for better targeting the archeological excavations on such areas.

1. Introduction

Increased values of magnetic susceptibility of soils exposed to long-term accumulation of pollutants resulting from industrial activity were measured in many areas of the world (Strzyszcz et al., 1996; Spiteri et al., 2005; Magiera et al., 2006; Chaparro et al., 2008; Jordanova et al., 2008; Sarris et al., 2009; Xia et al., 2014). Soil magnetometry, as a screening method to detect sites of magnetic and geochemical anomalies of anthropogenic origin, was applied in many cases (Magiera et al., 2007; Blaha et al., 2008; Magiera et al., 2015). Most of the abovementioned studies were mainly concerned with current pollution, emitted nowadays or during the last decades of the 20th century. However, in many European and non-European regions, the industrial era started in the middle of the 18th century, when hard coal was first used on a massive scale, initiating intensive development of the heavy and steel industry. This development is associated with emissions of considerable amounts of heavy metals into the atmosphere which ended up in the soil (Magiera et al., 2007). The main carriers of these metals, contained in dust emitted into the atmosphere, were technogenic magnetic particles present in industrial and urban dust (Strzyszcz et al., 1996; Sagnotti et al., 2006; Magiera et al., 2011a, 2013; Jordanova et al., 2013; Catinon et al., 2014). Technogenic magnetic particles (TMPs) are iron minerals of ferro- or ferrimagnetic properties arising from the high temperatures associated with the smelting of ores or combustion of solid fuels (Magiera et al., 2011a).

TMPs arise contemporarily, but were also produced in historic and prehistoric times since people have mastered the art of smelting metals from ores. Soil magnetometry can be helpful to find artefacts related to the metal smelting therefore soil studies based on combination geochemical and geophysical techniques can reveal archeological sites of primitive metallurgy (Marwick, 2005; Walkington, 2010). The tracers of the past ironworking or other smelting activities can remain in peat bogs (Mighall et al., 2009).

A characteristic feature of TMPs is the co-occurrence of anthropogenic forms of iron oxides and heavy metals, which - adsorbed on their surface - are transferred to the soil environment (Hulett et al., 1980; Hansen et al., 1981). The nature of these particles and their magnetic properties depends on the type of the emission source (Szuszkiewicz et al., 2015). During high temperature technological processes, the iron occurring in various forms in raw materials, fuels, and additives, is transformed into oxide forms, which exhibit elevated values of magnetic susceptibility. As a result of industrial emissions, fly ash and dust containing TMPs escapes into the atmosphere, and consequently end up in soils and sediments (Strzyszcz et al., 1996; Petrovský et al., 2000; Lu and Bai, 2006; Schmidt et al., 2000; Magiera et al., 2006, 2008, 2015).

There are several sites of early medieval mining and metallurgy activities in Central Europe. One of the oldest sites is situated in the area of Tarnowskie Góry town (Upper Silesia, southern Poland), where traces of this type of activity date back to the 12th century, however, a recent study has indicated even earlier activities in this region (Chróst, 2013). Pollutants were stored in soil and peat bogs, the latter occurred in Europe much more numerously in ancient times than today. Previous studies conducted in the Brynica River basin showed that these particles are quite common in peat deposits, soils, and abandoned dumps, which are currently covered with a layer of soil and do not stand out from the surrounding area geomorphologically (Cabała et al., 2013).

Previous research conducted in this area gives information about the significant amount of charcoal particles coexisting with other anthropogenic particles and - in terms of age - corresponding with layers of elevated content of chemical contaminants (heavy metals) (Tudyka and Pazdur, 2010). At the turn of the 21st century, German researchers examined the content of different forms of organic carbon in the soils of the Ruhr region and Saxony and suggested an increased value of magnetic susceptibility of soils containing particles of soot and charcoal (Rumpel et al., 1998; Schmidt et al., 2000).

In this study, we used magnetic prospection to detect traces of past mining and early metallurgical activity in the Brynica River Valley, Miasteczko Śląskie, in the area of Upper Silesia (southern Poland). We also used magnetic separation to characterise historical magnetic particles resulting from exploitation, processing, and smelting of iron, silver and lead ores.

2. Materials and methods

2.1. The study site

This study was conducted north of the town of Żyglin (district of Miasteczko Śląskie, Upper Silesia, southern Poland) (Fig. 1), whose historical name derives from the word "*żglić*", which means "to smelt". The study area was located between the top of the hill (now there is a church and cemetery), where the first settlement was founded before year 1065 (first written document), and the margin of the peat-bog (now covered with alluvial sediments), where previous studies have reported that a large amount of charcoal and metals typical for early metallurgy (Tudyka and Pazdur, 2010; Chróst, 2013). Hints of iron, lead and silver ore smelting in this area can be dated back to the Early Middle Ages, but primitive exploitation of these raw materials probably took place much earlier. The study area is partly level ground and partly slight grade, sloping towards the Brynica valley (3–5% grade in a north and north-easterly direction). Measurements were carried out on arable soils, wastelands, in the area of the former peat bog and partly on forest soils (Fig. 1).

2.2. Field measurements

In the area of Żyglin, preliminary field measurements of magnetic susceptibility (κ) were performed using a MS2 Bartington meter equipped with the field sensor MS2D in an area of about 120 ha in a regular grid of 50 × 50 m (Fig. 1). The sensor had a penetration range of a maximum of 10 cm in depth; however, most signals were received from the upper 3 cm of the soil (Lecoanet et al., 1999). The measured κ-value was directly proportional to the amount of ferrimagnetic particles located within the penetration range of the sensor. The κ-value of a single point was an average of nine measurements performed in a circle with a radius of 2 m, according to the procedure defined by Schibler et al. (2002).

For the correctness of field measurements, the sensor was located directly on the surface. Prior to measurements, branches, stones, and pieces of wood were removed and high grass was turned aside similarly to a previous study (Zawadzki et al., 2010). For each point, geographic coordinates were determined using a GPS Garmin. Based on the results of these measurements, a map of the magnetic susceptibility distribution was drawn (Fig. 2).

For more detailed magnetic measurements, we selected three areas (Figs. 1 and 2). The first area of detailed studies was located in the north western part of the research area, situated on the slope of a grade of about 5%, falling to the Brynica valley (A in Figs. 1 and 2). Measurements