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Bog iron ore as a resource for prehistoric iron production in Central Europe — A case study of the Widawa catchment area in eastern Silesia, Poland

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ABSTRACT

Spreading from the Near East in the declining Bronze Age from the 2nd millennium BCE onwards, the technique of iron smelting reached Eastern Silesia, Poland, in approximately the 2nd century BCE (pre-Roman Iron Age). At this time the region of the Widawa catchment area was inhabited by the Przeworsk culture. While the older moraine landscape of the study area lacks ores from geological rock formations, bog iron ores were relatively widespread and, due to their comparatively easy accessibility, were commonly exploited for early iron production. This paper investigates the mineralogical and elemental composition of local bog iron ore deposits and iron slag finds, as a by-product of the smelting process, also taking into account the state of the art in research regarding the formation, distribution and utilization of bog iron ores and considering data from comparative studies.

The crystalline mineralogical composition of local bog iron ores is dominated by quartz (SiO_2) and goethite (α-$FeO(OH)$), in contrast to slag samples in which fayalite (Fe_2SiO_4), wüstite (FeO) and quartz, with traces of goethite, represent the main minerals. Ores and slags are both characterized by notable hematite (Fe_2O_3), magnetite (Fe_3O_4) and maghemite (γ-Fe_2O_3) contents. Analyzed bog iron ore samples show iron contents of up to 64.9 mass% Fe_2O_3 (equivalent to 45.4 mass% Fe), whereas the iron contents of bloomery slags vary between 48.7 and 72.0 mass% FeO (equivalent to 37.9 and 56.0 mass% Fe). A principal component analysis of the element contents, which were quantified by portable energy-dispersive X-ray fluorescence spectrometry, indicates local variations in the elemental composition. The results of this study show that bog iron ores are relatively widely distributed with spatially varying iron contents along the Widawa floodplain but present-day formation conditions, such as changed groundwater levels, are negatively affected by modern land-use practices, such as agriculture and melioration measures.

1. Introduction

First iron smelting attempts date back to the 2nd millennium BCE in the Near East (Pleiner, 2000; Yalçin, 2000; Bebermeier et al., accepted). Over the following two millennia this technology was disseminated all over Europe and probably arrived in the study area of Eastern Silesia, Poland, in approximately the 2nd century BCE (Madera, 2002). In the pre-Roman Iron Age the region of the Widawa catchment area (Fig. 1) was inhabited by the Przeworsk culture (3rd century BCE to 5th century CE; Godłowski, 1985; Dąbrowska, 2003). Cultural and technological preconditions as well as requirements in terms of natural resources had to be met for the introduction of the innovative iron smelting. The main resources necessary for local iron production were wood for charcoal production, clay for the construction of bloomery furnaces, water for pre- and post-processing of ores and bloom and, above all, iron ores as a fundamental prerequisite (Koschke, 2002; Pleiner, 2000). For a local and independent iron production only places that united these resources were suitable for early iron smelting (Oberrascher, 1939). During the beginning of iron smelting a local small-scale production of iron was prevailing in the study area and the amounts of wood needed for the production of charcoal were rather negligible due to the occurrence of vast forested areas (Thelemann et al., in press).

While the glacially shaped older moraine landscapes of Northern and Central Europe mostly lack iron gangue minerals from geological rock formations, sedimentary bog iron ores were relatively widespread (Leb, 1983) and, due to its comparatively easy accessibility and reducibility, bog iron ore was commonly exploited for early iron production

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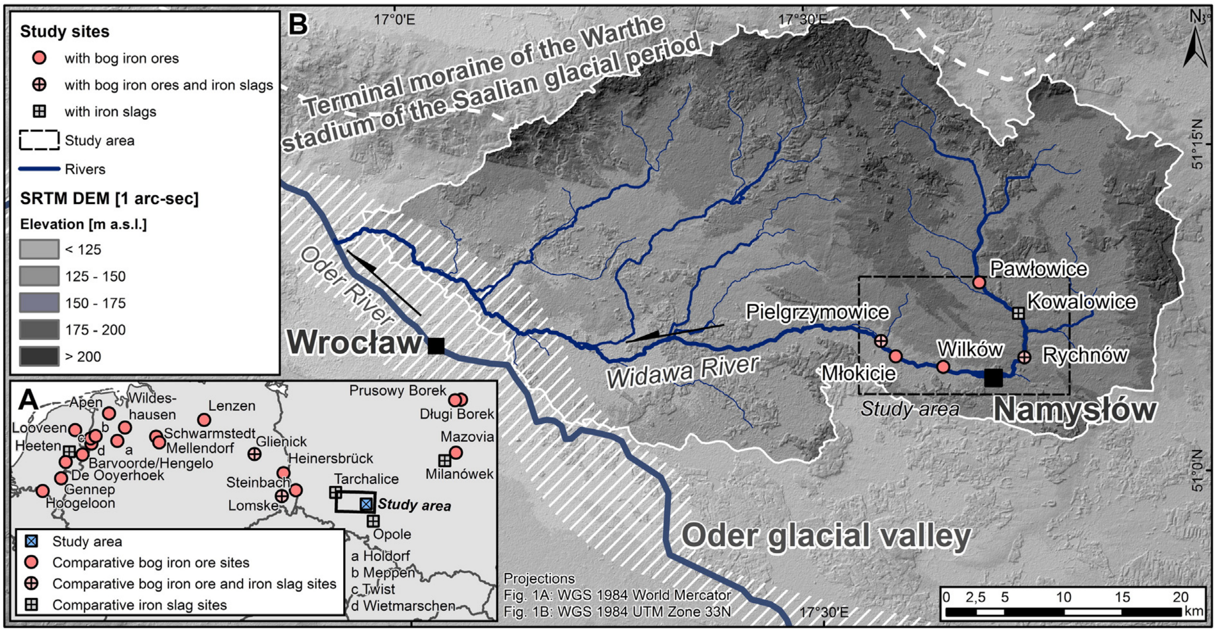

Fig. 1. Fig. 1 A. Location of the study area in Silesia and comparative case studies taken into account from literature on bog iron ores and iron slags; 1 B. Distribution of investigated bog iron ore deposits and iron slag findings in the catchment area of the Widawa River. Data sources: Fig. 1: A: Bog iron ores sites from Graupner (1982), Hensel (1986), Joosten et al. (1998), Ratajczak and Rzepa (2011), Puttkammer (2012), Brumlich et al. (2012); iron slag sites from Domanski (1972), Piaskowski (1976), Hensel (1986), Joosten et al. (1998), Puttkammer (2012), Brumlich et al. (2012), country borders Natural Earth Data; B: Digital elevation model from USGS (2000) SRTM-data; Widawa catchment area and rivers from KZGW (2015); terminal moraine and Oder glacial valley Liedtke (1981).

(Küster, 1999; Sperling, 2003; Leb, 1983; Brumlich et al., 2012; Sitschick et al., 2005).

This paper summarizes the state of the art of research on bog iron ores as a raw material for early iron smelting in Northern Central Europe. For the catchment area of the Widawa River geochemical and mineralogical data on local bog iron ores and slags are presented. As the chemistry of the bog iron ore – apart from other factors – dominates the chemical composition of the resulting slags, a focus is set on the analyses of the utilized ores.

The paper thus deals with the following research questions regarding the study area of the Widawa catchment area: (i) How can the present distribution and quality of bog iron ore resources be characterized, (ii) how is the mineralogical and elemental composition of iron slags and what conclusions can be drawn regarding the utilized ores and the early iron smelting techniques and (iii) how favorable was the study area for early iron production and are local variations in the quality of ores verifiable?

1.1. State of the art on bog iron ore

Bog iron ore is a subtype of bog ores. Main component of these ores is either iron or manganese. While manganese-rich bog ores are characterized by a gray-blackish color, the color of bog iron ores is brown-reddish (Charlton et al., 2010; Krempler et al., 2004). It is assumed that based on the different colors early iron smelters were able to clearly distinguish between both types.

1.1.1. Morphology, elemental and mineralogical composition of bog iron ores

Bog iron ores are consolidated terrestrial accumulations dominated by iron minerals precipitated in sandy, silty or clayey sediments (Graupner, 1982; Sperling, 2003) with an iron content of >25 mass% Fe_2O_3 (Wünsche, 2007). In this study the term bog iron ore is used as an umbrella term for initial (<25 mass% Fe_2O_3) and developed (>25 mass% Fe_2O_3) bog iron ore samples in order to summarize the different bog iron ore characteristics and development stages.

Bog iron ores are distinguished into three different macro-morphological types, which can be regarded as development stages: (i) a soft unstable form, (ii) randomly spread, nest-like distributed concretions, blocks or nodules and (iii) massive continuous horizons of horizontal, hard layers (Kaczorek and Sommer, 2003; Kaczorek et al., 2005; Landuydt, 1990; Sperling, 2003). Bog iron ore layers often reach a thickness of between several cm and >30 cm (Kaczorek et al., 2004). On the micro-scale the quartz-rich components of the parent sediment are separated from each other by an iron-rich matrix, which often dominates the structure of the ore (Krempler et al., 2004). The microstructure is represented by a relatively high capillarity and porosity and an often cellular fluctuating structure of micropores, which affects stability, weathering resistance and water absorbency (Krempler et al., 2004; Charlton et al., 2010; Lindbo et al., 2010). The stability and resistance depend on solidification and composition of the material and vary between crumbly, disintegrated and very solid fragments (Graupner, 1982; Krempler et al., 2004). Solidification mainly depends on the content of iron minerals and the degree of oxidization: the higher these are, the more cured the material (Graupner, 1982).

Table 1 shows a summary of the major oxide concentrations of bog iron ores based on a literature analysis. The elemental composition of bog iron ores is characterized by often considerable phosphorus and manganese contents of up to 8 mass% P_2O_5 and up to 10 mass% MnO (Wünsche, 2007; Landuydt, 1990; Sperling, 2003). The iron contents in bog iron ores mostly vary between 35 and 50 mass% Fe_2O_3 but can also reach up to 95 mass% Fe_2O_3 (Sitschick et al., 2005; Joosten et al., 1998; Sperling, 2003; Charlton et al., 2010). Silicon-dioxides (SiO_2), manganese-oxides (MnO), phosphorus-pentoxides (P_2O_5), calcium carbonates ($CaCO_3$) and oxides (CaO), nitrogen compounds and water also characterize the composition of bog iron ores (Krempler et al., 2004; Graupner, 1982; Puttkammer, 2012; Zwahr et al., 2000). Aluminium- (Al_2O_3), potassium- (K_2O), barium- (BaO), magnesium- (MgO), sodium-oxides (Na_2O), titanium-dioxides (TiO_2), total organic carbon (TOC) and total inorganic carbon (TIC) are also present in minor concentrations (Table 1; Krempler et al., 2004; Graupner, 1982; Puttkammer, 2012; Zwahr et al., 2000).