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Original Research

Impact of Former Iron Ore Mining on Soil Cover in the Northern Foreland of Poland's Świętokrzyskie Mountains

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Abstract

The main objectives of this paper are to present the impact of former iron ore mining on the transformation of the soil cover and to demonstrate how these changes have affected plant cover. The research was carried out in 2012-2015 on the remnants of a former iron ore mining (gob piles) located in the northern foreland of the Świętokrzyskie Mountains. On two former post-mining fields eight soil profiles (four on the gob piles and four on untransformed areas) and eight phytosociological relevés were made using the Braun-Blanquet method. Physicochemical analyses were made of all the collected soil samples. The gob piles have favourable physico-chemical properties, differing from the properties of the poorer soils of the untransformed areas. Preferred chemical properties of the gob piles, including increased pH values and increased content of assimilated elements (Ca, Mg, K, Na) also affect the increase in the quality of fossil soil horizons. Former iron ore mining has led to significant, positive changes in the soil cover of the researched areas. The clayey-silty gob piles there have become fertile habitat islands among oligotrophic, sandy, untransformed soils, and the effect of these changes is an increase in the number of plant species.

Keywords: gob piles, soil profiles, vascular plant species, overburden, Poland

Introduction

Soils are a significant element of all ecosystems that are habitats for specific plant and animal species [1-5]. The specificity of soils, their diversity, as well as long-term formation process leads to significant soil-plant relations [6, 7]. Unfortunately, these relations are often uncompromisingly destroyed as a result of many anthropogenic factors [8, 9]. The widest-ranging factors are progressive urbanization and industrialization, including so-called industrial agriculture [10-13].

One of the main global economic sectors putting significant pressure on natural ecosystems is the mining industry [14-16]. Opencast mining is the most common approach, and this results in destruction of the natural environment at all levels. This often irreversible process affects entire biocoenoses, together with their habitats, rocky layers, and parent rocks providing the basis

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for formation of the soil cover. In many cases, the regeneration of natural ecosystems is impeded or even made impossible due to the specificity of the substrate in post-mining areas [17, 18], including but not limited to the area of the spoil heaps. These are areas of waste material that are deprived of soil cover, contain only a small amount of nutrients, and are heavily drained. This makes them unfavourable to the development of most plants, especially more demanding ones (such as forest species requiring level-diversified plant communities and specific soil horizons, for example humus). As a result, the regeneration of ecosystems in post-mining areas must be supported by reclamation processes [19, 20]. These sites also often become habitats for invasive anthropophytes [21, 22]. All these processes lead to a drastic decline in the biodiversity of a given area [23-26].

But there are also events of mining activity which have a completely different effect on the natural environment: former mining activity [27]. This was the main type of mining from around the 15th century to the beginning of the 20th century in the area of southern Poland. In comparison with modern methods, iron ore mines were not very invasive, which led to their excavated, post-mining remnants, commonly known as gob piles, having a very specific character. Gob piles are small heaps of unprocessed material extracted from deeper rock layers and piled up around the heads of old shafts [28]. In this way, the gob piles differ from typical heaps of post-mining waste [29-32].

The remnants of iron-ore mining sites are habitats where mesophilous deciduous forest communities developed [33], and show significantly higher species richness [34]. However, modern forest management techniques in their area can lead to a secondary decline in their floristic diversity [35]. It is also worth noting that these communities are reservoirs for ancient woodland plant species [36].

These sites are unique on the European scale because of the genesis of the gob piles, the specific habitat conditions of the heaps, and the unusual character of the communities formed there. An analysis of the material collected by the authors so far has led them to present the following research hypothesis: former iron ore mining sites have created positive changes in the soil cover in the northern foreland of the Świętokrzyskie Mountains.

The main objectives of this paper are to present the impact of former iron ore mining on the transformation of the soil cover in the researched area, and to demonstrate how the changes found in the substrate have affected the plant cover there.

Material and Methods

Study Area

The research was conducted on the remnants of a former iron ore mining in the area of Suchedniów Plateau and Gielniów Hummock. These two regions are located in the northern Mesozoic fringe of the Palaeozoic core of the Świętokrzyskie Mountains (southern Poland).

The area of the Suchedniów Plateau occupies wide, flat and domed elevations (270-441 m a.s.l.), formed of Triassic sandstones and clays, while the hills of Gielniów Hummock (208-408 m a.s.l.) consist of an alternating series of Jurassic sandstones. Acidic podzolic soils created on a quartz-silicate series dominate in both regions, which is why fertile habitats occur only sporadically and are limited mainly to sites with natural outcrops of the marly-silicate series. The area of Suchedniów Plateau is composed of Triassic sandstones and clays, while Gielniów Hummock consists of an alternating series of Jurassic sandstones. Ore-bearing horizons made of clays and ore-bearing shale clays containing clay siderite and spherosiderites were present in both the Triassic formations (mainly in the Lower Triassic), and in the Jurassic formations (Lower Jurassic), and had been the subject of mining [37].

The landscape of this area is dominated by natural vegetation, with a majority of acidic beech communities (*Luzulo-Fagetum*) and pine forests (*Leucobryo-Pinetum*, *Molinio-Pinetum* and *Calamagrostio villosae-Pinetum*). In addition, there are also multi-species mixed forests with a large percentage of *Abies alba* and *Fagus sylvatica*, with *Acer pseudoplatanus* and *Larix decidua s.l.*) [38].

The most intensive iron ore mining occurred in the northern foreland of the Świętokrzyskie Mountains [27]. The first mines there date back to the 12th-15th centuries, with ore mining flourishing in the 17th century following development of the blast furnace. The last mines ceased operation there in the middle of the 20th century [39]. The mining fields were established in dense forest complexes, and the iron ore was mined by hand using a deep-shaft method. The ore was picked out from the material excavated to the surface, and the unnecessary material was left piled around the shaft heads [37]. As a result, these remnants (gob piles), are now scattered throughout the forest communities of the entire northern foreland of the Świętokrzyskie Mountains. They look like small heaps of earth, from 1-3 m in height, dug-up and left behind by the miners from the mine shaft in the middle of the heap [28, 34].

Our research covered the two selected iron ore mining fields (first – 51°06’06”N, 20°29’22”E – on the Suchedniów Plateau, second – 51°10’13”N, 20°43’31”E – on the Gielniów Hummock), which were active from the 18th to the 19th centuries. Each of the fields consists of gob piles and untransformed land surrounding the individual heaps. In the 1950s, two tree species were introduced to the forest stands on both post-mining fields: *Pinus sylvestris* (across almost all of the first mining field), and both *Fagus sylvatica* and *Pinus sylvestris* (across almost all of the second mining field). The trees were planted both on gob piles as well as on untransformed land within the post-mining fields.

Data Set

The research was carried out in 2012-2015. Eight soil profiles were made in the area of the fields. Four were made of the gob piles (with two for each field). For comparison, the other four were made of untransformed areas (also two for each field) at a distance of 5 m from the boundary of each heap. Soil samples were taken from each soil horizon for analysis.

In addition, in close proximity to each soil pit (on the gob piles and in their surroundings), 8 phytosociological relevés were made using the Braun-Blanquet method [40] to determine the floristic composition of the plant communities growing there. Each relevé covered an area of 100 m^2.

Data Analysis

Physicochemical analyses were made of all the collected soil samples using methods generally accepted in the field of soil science. The following variables were determined: the pH H_2O of soil suspension in distilled water (potentiometric method); carbonates, using the Scheibler method; the total exchangeable alkalis using the Kappen method; exchangeable acidity using the Sokołów method; hydrolytic acidity with the Kappen method; Ca, K, Na, Mg availability content, and granulometric composition using the Casagrande sedimentation method, as modified by Prószyński. Additionally, humus content was determined using the Tiurin method for the samples collected from the top levels of the gob piles and the untransformed areas (these levels have a direct impact on plant cover).

In terms of the selected variables, the differences between the analyzed gob piles and the untransformed areas were determined using the Mann-Whitney U test ($P \leq 0.05$). The following variables were taken into account: chemical soil properties (pH, carbonate content, available Ca, K, Na Mg content, humus content); physical soil properties (content of clayey particles); total number of vascular plant species; number of species characteristic of *Querco-Fagetea* and *Vaccinio-Piceetea* class, and the number of ecological indicator values of vascular plants (i.e., the acidity value) [41]. Correlations were made to demonstrate the relationship between the individual chemical and physical properties of the top layers of the soils (pH, Ca, K, Na Mg content, total exchangeable alkalis, exchangeable acidity, hydrolytic acidity, clayey particles), and the number of identified groups of species. The correlation strength was measured using the Spearman correlation coefficient (r_s).

The nomenclature of soil horizons and soil layers was used according to Kowalkowski et al. [42], the nomenclature of species according to Mirek et al. [43], and syntaxon names according to Matuszkiewicz [44]. The analyses were carried out using Statistica 6.1 [45].

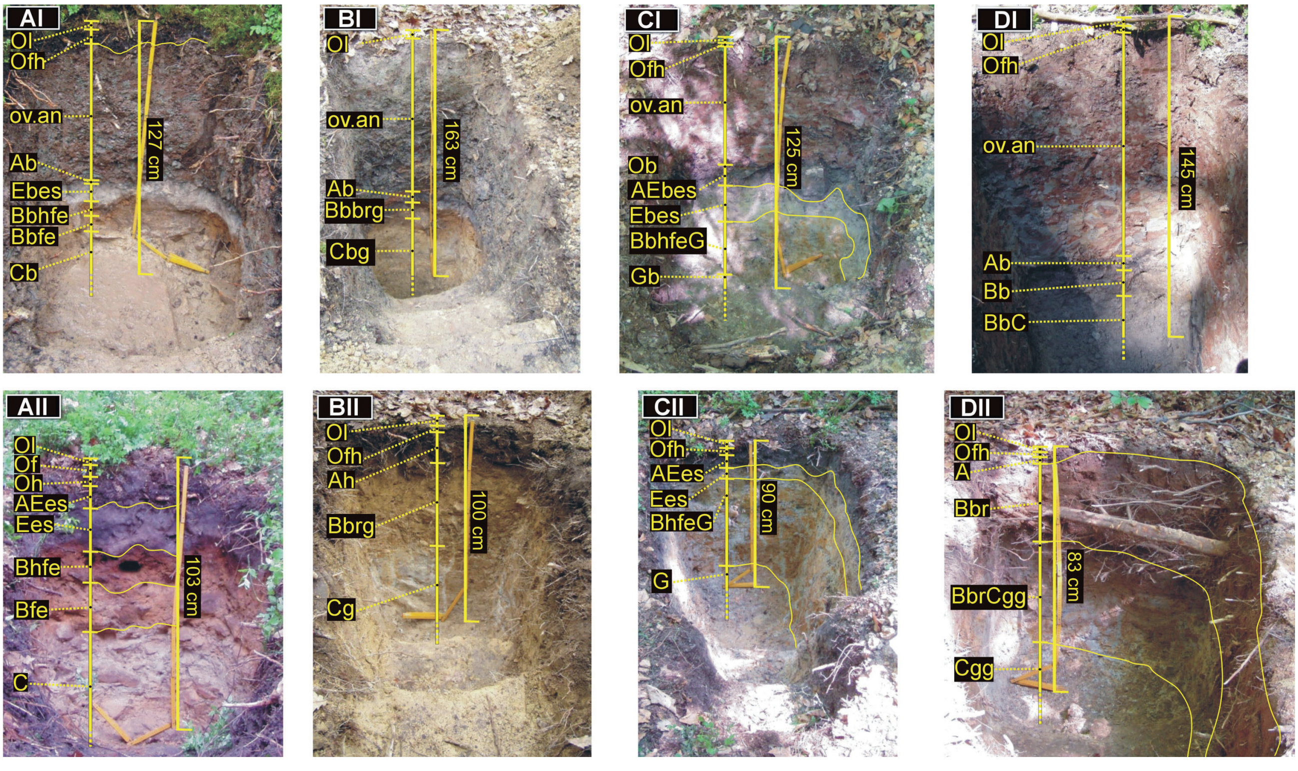

Fig. 1. Soil profiles of the gob piles (AI-DI) and in their surroundings (AII–DII); ov.an – overburden.

Results and Discussion

Characteristics of Soil Profiles within Gob Piles and Their Surroundings

First Post-Mining Field

Soil pit No. 1 was made in a gob pile (Fig. 1, AI), from which 5 soil horizons were distinguished. The 9 cm thick organic horizon (O) contained two Ol and Ofh sub-horizons. A *moder* humus type was distinguished. The next horizon was a 62 cm thick overburden, created as a result of the mining activity, and consisted of compact, clayey-silty material. Fossil soil was found underneath in a clearly developed, 1 cm-thick humus horizon (Ab), a 7 cm-thick light-grey eluvial horizon (Ebes), and an 18 cm-thick accumulation horizon (Bb), at which point two Bbhfe and Bbfe sub-horizons were distinguished. The parent rock (Cb) horizon was found at a depth of 97 cm. The depth of the entire soil pit was 127 cm.

The presence of 6 soil horizons was found in the profile taken from soil pit No. 2 (Fig. 1, AII) made in an untransformed area 3 m from soil pit No. 1. These were: a 9 cm-thick organic horizon (O) with three sub-horizons (Ol, Of, Oh – *mor* humus); an 8 cm dark-grey transitional horizon (AEes); and a 13 cm-thick eluvial horizon (Ees). Two Bhfe and Bfe sub-horizons were distinguished in the 33 cm thick accumulation horizon (B). The parent rock (C) started at a depth of 63 cm. The depth of the entire soil pit was 103 cm.

Both of the profiles were made in the part of the first mining field, where *Pinus sylvestris* dominated the forest stand.

In the second part of first post-mining field, with less share of the *Pinus sylvestris* in the forest stand, two other soil pits were also made. Soil pit No. 3 (Fig. 1, BI) was made on the slopes of a gob pile. In a 5 cm-thick organic horizon (O) only Ol sub-horizon was distinguished, consisting mainly of fallout from deciduous trees. Under the organic horizon, a 98 cm-thick overburden was found, which consisted of a dark grey material with reddish-brown iron, containing strands compounds. It also contained fragments of preserved silty siderites. In the upper part, at a depth of 6-7 cm, the overburden was fragmented. Fossil soil was present at a depth of 98 cm under the overburden with a clearly developed 8 cm thick, dark-grey fossil humus horizon (Ab). A 12 cm-thick accumulated fossil horizon was present at a depth of 106 cm, which exhibited the properties of a reddish-brown gley (Bbbrg). Light-coloured parent rock with a marked gleysol top (Cbg horizon) began at 118 cm. The depth of the entire soil pit was 163 cm.

At a distance of 3 m from the gob pile, in an area not covered by overburden, soil pit No. 4 was made (Fig. 1, BII). In this soil pit, the organic horizon had a thickness of 5 cm. A 2 cm-thick detritus sub-horizon Ofh (*moder* humus) was present under a 3 cm-thick fresh forest litter sub-horizon (Ol). Underneath this, at a depth of 5-17 cm, a humus horizon (Ah) was found with marked quantities of organic matter. At a depth of 17-60 cm, a 43 cm-thick accumulated horizon with visible light brown gley (Bbrg) was found. The light-coloured parent rock (Cg horizon), with a markedly gley top (whitish bleeds visible), began at a depth of 60 cm. The entire soil pit had a depth of 100 cm.

Second Post-Mining Field

Soil pit No. 5 (Fig. 1, CI) was made in a complex of shallow gob piles. In this soil pit, the 3 cm organic horizon consisted of a 2 cm fresh forest litter sub-horizon (Ol), composed of fallout from deciduous trees and *Pinus sylvestris* needles, as well as the 1 cm detritus sub-horizon (Ofh) *(moder* humus). At a depth of 3-60 cm, a compact, reddish-grey overburden was found. At a depth of 3-10 cm, the overburden was mostly fragmented. Beneath the overburden was fossil soil with a thin organic horizon (Ob); an 8 cm-thick dark-grey fossil horizon (AEbes); a 21 cm-thick eluvial horizon (Ebes); an accumulation horizon (Bb) with a noticeable eluvial accumulation of iron; and a gley horizon (BbhfeG). A steel-grey gley horizon with spotted colouration (Gb) then began at a depth of 118 cm. The depth of the entire soil pit was 125 cm.

Soil pit No. 6 (Fig. 1, CII) was made on untransformed ground 5 m from the gob pile used for soil pit No. 5. The presence of a 6 cm-thick organic horizon (O) with Ol sub-horizon was found in this profile, which consisted mainly of pine needles and Ofh sub-horizon (*moder* humus). At a depth of 6 cm, a 7 cm-thick, dark-grey, compact AEes horizon was found. A 6 cm-thick lightish-grey eluvial horizon (Ees) was then seen at a depth of 13 cm. The transition between the AEes and Ees horizons was clearly wavy. At a depth of 19-75 cm, the accumulation horizon was found with a noticeable eluvial accumulation of iron and a marked gley horizon (BhfeG), which transitioned into a barely visible gley horizon (G) at a depth of 75 cm. The depth of the entire soil pit was 90 cm.

Soil pit No. 7 (Fig. 1, DI) was made in the slopes of a high gob pile within the same field. In this pit, the organic horizon (O) consisted of a 3 cm-thick fresh forest litter sub-horizon Ol (this was mainly composed of *Fagus sylvatica* leaves) and a dark grey detritus sub-horizon (Ofh) at a depth of 3-5 cm (*moder* humus). At a depth of 5 cm, an overburden began which reached a depth of 95 cm. Beneath the overburden was a fossil soil in which an 8 cm humus horizon (Ab) was found, with a 17 cm accumulation horizon (Bb) and a quartzite-bearing transition horizon (BbC). The depth of the entire soil pit was 145 cm.

At a distance of 5 m from the gob pile with soil pit No. 7, an eight soil pit was made in an untransformed area (soil pit No. 8 – Fig. 1, DII). In this pit, a 4 cm thick organic horizon (O) was found, where a fresh forest litter sub-horizon (Ol), distinguished mostly of *Fagus sylvatica* leaves, and a detritus sub-horizon (Ofh) of *moder* humus. Below the organic horizon, a thin humus horizon (A) was found, with a thickness of 3 cm and a compact, reddish-brown accumulation horizon (Bbr) present beneath it. At a depth of 32-75 cm there was a 43 cm-thick transition horizon (BbrCgg). This horizon was compacted and characterized by very small rooting. A compact parent rock horizon (Cgg) with a strong bottom gley started from 75 cm. The depth of the entire soil pit was 83 cm.

Positive Changes in the Soil Cover Caused by Mining

In both post-mining fields, significant differences were found in the physical and chemical properties of the substrate between the gob piles and their surroundings (untransformed areas).

In the case of the gob piles, the overburden excavated by the miners is a direct habitat for plants, while for the untransformed area it is the humus horizon (A horizon). Overburden pH measured within the soil pits made in the gob piles range from 5.3 to 7.0 (average 6.1). In contrast, the pH of the humus horizon (A) of the surroundings ranged from 4.3 to 4.9 (average 4.6). The difference in pH between the overburden and the humus horizon of the untransformed area is significant ($P = 0.021$, $U = 2.31$). The pH values of the overburden ranged from acidic to neutral. In comparison, the pH of the untransformed soils was strongly acidic (Table 1). Significant differences between the overburden of the gob piles and horizon A of the untransformed areas were also found in the presence of available contents of Ca, K, Mg and Na (Table 1). The greatest difference was found in calcium content: in the overburden calcium content ranged from 117.8 mg/100 g to 167.3 mg/100g (average 144.44 mg/100 g), and in the humus horizon of the untransformed areas, from 8.3 mg/100g to 24.1 mg/100g (average 15.9 mg/100 g) (Table 1).

The overburden, which is a direct substrate for the plants on the gob piles, is characterized by lower humus content (from 1.03% to 1.62%, average 1.37%), compared to horizon A of the untransformed areas (from 2.52% to 4.86%, average 3.72%) ($P = 0.02$; $U = -2.32$), as well as lower values of exchange acidity and hydrolytic acidity (Table 1).

In addition to the differences in the chemical properties of both areas (the overburden on the gob piles and the humus horizon on the untransformed areas), there are also significant differences in their granulometric composition. The overburden is characterized by a high percentage of loamy parts (from 51.8 to 82.7%, averaging 70.2%), resulting in its clayey particles constituting average 70.6% of its content. The humus horizon of the untransformed areas is characterized by a high percentage of sandy parts (from 62.3% to 90.3%, averaging 75.9%), which results in average clayey particles content of only 11.6%. The difference in clayey particle content is statistically significant at $P = 0.02$ ($U = 2.31$) (Table 1). Thus, the researched granulometric composition of the overburden indicates that we are dealing with clayey loam, while the humus horizon is mainly represented by clayey sand.

In comparison to the humus horizon of the untransformed areas, the anthropogenic overburden's

Table 1. Differences between chemical and physical characteristics of overburden of gob piles and A horizon of non-transformed areas – two horizons which are the main habitats for plants; $^{*}0.05 \geq P \geq 0.01$.

Characteristics		Units	Range		Mean values	
			Overburden	A horizon	Overburden	A horizon
Chemical	pH_{H20}	(pH unit)	5.3 – 7.0	4.3 – 4.9	6.1*	4.6
	carbonates	(%)	0.2 – 0.2	0.17 – 0.2	0.2	0.2
	Ca	(mg/100g)	117.8 – 167.3	8.3 – 24.1	144.4*	15.9
	K	(mg/100g)	13.6 – 23.6	2.8 – 5.7	18.4*	4
	Na	(mg/100g)	1.2 – 1.7	0.5 – 0.9	1.4*	0.7
	Mg	(mg/100g)	51.0 – 79.0	0.3 – 0.9	61.9*	0.5
	Total exchangeable alkalis	(me/100g)	7.5 – 14.9	0.3 – 2.9	11.9*	1.5
	Exchangeable acidity	(me/100g)	6.7 – 9.8	6.2 – 16.1	8.1	11.7
	Hydrolytic acidity	(mmol/100g)	1.2 – 3.2	6.6 – 11.3	2.4*	8.5
	Humus content	(%)	1.03 – 1.62	2.52 – 4.86	1.37*	3.72
Physical	Sandy parts	(%)	1.0 – 35.0	62.3 – 90.3	15*	75.9
	Loamy parts	(%)	51.8 – 82.7	9.7 – 34.0	70.6*	22.5
	Clayey particles	(%)	52.5 – 88.2	3.0 – 22.8	70.2*	11.6

Table 2. Some chemical and physical characteristics of main soil horizons found in soil profiles on 4 gob piles (GP) and in 4 their surroundings (S); b - fossil soil horizons.

	Characteristics												
		Chemical									Physical		
	Main soil horizons	pH H_2O (pH unit)	Carbonates (%)	Ca (%)	K (%)	Na (%)	Mg (%)	Total exchangeable alkalis (me/100g)	Exchangeable acidity (me/100g)	Hydrolytic acidity (mmol/100g)	Sandy parts (%)	Loamy parts (%)	Clayey particles (%)
	Mean values												
GP	ov.an	6.1	0.2	144.4	18.4	1.4	61.9	11.9	8.1	2.4	15	85.0	70.2
	Ab	6.3	0.2	81.7	5.7	1.4	30.6	9.2	4.9	3.4	58.8	41.2	24.3
	Bb	6.5	0.2	20.6	2.7	0.8	7.8	2.9	4.7	1.6	76.2	23.7	13.9
	Cb	6.6	0.2	35.9	3.9	0.9	15.2	3.4	2.5	2.1	58.5	41.5	27.1
S	A	4.6	0.2	15.9	4	0.7	0.5	1.5	11.7	8.5	75.9	24.1	11.6
	B	4.7	0.2	8.7	2.1	0.6	0.2	0.7	12.8	6.1	73.2	26.7	15.1
	C	4.7	0.2	14.6	3.7	0.9	1.3	0.8	11.8	4.8	40.6	59.4	38.3

different chemical and physical properties also influenced the change in the chemical properties of the fossil soil horizon beneath it (Table 2). Primarily, the overburden caused an increase in the pH value of the fossil horizon, an increase in the content of researched elements (Ca and Mg in particular), and increased values of total exchangeable alkalis compared to the untransformed soil horizons (Table 2).

As a result of the mining works carried out in the researched area, the originally acidic sandy soil deposits were covered with unprocessed material extracted from deeper rock layers (Fig. 1, AI-DI). The research showed that the overburden has a number of chemical and physical properties (including increased pH, or Ca, K, Na, Mg content – Tables 1 and 2), which help create habitats for more demanding plant species. The material forming the gob piles originated from the ore horizon (from the marly-silicate series), which contains marls. This can affect an increase in pH compared to the surroundings of the untransformed areas with poor and acidic soils formed from the quartz-silicate series [46].

Additionally, in the areas of the former iron ore mining, the excavated overburden could become a new 'parent rock' for the soils formed upon it. Creation of the first 'new soil' horizons on the overburden, being an advantageous soil-forming substrate, was first observed on the gob piles in one of the oldest post-mining fields (formed before the 15th century) by Adamczyk [47]. In contrast, on the oldest gob piles in the currently researched area – soil pit No. 5 (Fig. 1, CI), strong fragmentation of the overburden was observed in its upper part, which suggests the beginning of the formation of the next soil horizon under the organic horizon.

The physical and chemical properties of fossil soils are mainly related to their parent rock [48, 49]. In the case of the researched gob piles, significant differences between the chemical properties of the fossil soils and the untransformed soils were found, despite the fact that they developed in close proximity to each other, on the same parent rock, and have the same soil horizons (Fig. 1). Changes in the chemical properties of these fossil soils are clearly influenced by the overburden, leading to increased pH value and the amounts of certain elements (mainly Ca and Mg), in comparison the soils which are not covered with overburden (Table 2). This phenomenon is unusual because of the specific, advantageous properties of the overburden (Table 1). In other post-mining areas, the phenomenon of fossil soils being enriched by their overburden's properties does not occur, because this is most often a highly processed material of poorer quality than the fossil soils it is covering [50, 51].

The Positive Effect of Former ore Mining Activities on Plant Cover

Gob piles formed of overburden excavated during mining activities are a more fertile habitat for plants, compared to habitats in untransformed areas. Phytosociological relevés of the gob piles show a higher number of plant species (60 species) compared to the number of species growing in areas not transformed by mining (21 species) ($P = 0.02$, $U = 2.32$). In individual phytosociological relevés of the heaps, the number of species ranges from 19 to 39, while in untransformed areas these numbers are just 5 to 12 species (Table 3).

When analysing the percentage of species in both types of habitats, based on acidity values it was found that there was a significant increase in the number of alkaline species (15) in the former iron ore mining

Table 3. A synoptic table of floristic composition of communities developed on gob piles (GP) and in their surroundings (S) in two mining fields.
I-V – constancy: II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%; +-5 – abundance: +<5%, 1 = 5%, 2 = 5-25%, 3 = 25-50%, 4 = 50-75%, 5 = 75-100% (Braun-Blanquet 1964); R – acidity value: alk: alkaline species, neut: neutrophyte, acid: moderately acidophyte, acid+: strong acidophyte, acid-: light acidophyte (Zarzycki et al. 2002).

Type of habitat			GP	S
Average cover of tree layer	a [%]		56	46
Average cover of shrub layer	b [%]		32	22
Average cover of herb layer	c [%]		70	40
Average cover of moss layer	d [%]		1	0
Average number of species			27	9
Number of relevés in table			4	4
Characteristics	Layer	R	Constancy and abundance	Constancy and abundance
Trees and shrubs:				
ChCl. Querco-Fagetea				
Fagus sylvatica (planted)	a, b, c	alk	III^{2-4}	III^{+-2}
Carpinus betulus	a, b, c	neut	IV^{+-3}	II^{+-2}
Corylus avellana	b	neut	III^{+-2}	II^{+}
Cerasus avium	b, c	neut	II^{+-1}	.
Daphne mezereum	b, c	alk	II^{+}	.
Padus avium	b	alk	II^{+}	.
ChCl. Vaccinio-Piceetea				
Pinus sylvestris (planted)	a	acid	III^{2-3}	IV^{3}
Abies alba	a, b, c	acid^{-}	III^{+-2}	III^{+-2}
Picea abies	a, b, c	acid+	IV^{+}	III^{+-3}
Others:				
Quercus robur	a, b, c	neut	III^{+-3}	III^{+-2}
Quercus petraea	a, b, c	neut	II^{+}	III^{+-2}
Populus tremula	a, b, c	acid^{-}	III^{+-3}	.
Larix decidua	a	acid^{-}	III^{+-3}	III^{+-2}
Betula pendula	a, c	neut	II^{+}	.
Pyrus communis	b	alk	II^{+-2}	.
Rubus hirtus	b, c	neut	V^{+-3}	IV^{+-3}
Frangula alnus	b, c	acid^{-}	III^{+-2}	IV^{+-1}
Sorbus aucuparia	b, c	acid^{-}	IV^{+}	II^{+-1}
Viburnum opulus	b, c	neut	IV^{+-1}	.
Prunus spinosa	b	alk	III^{+-2}	.
Rhamnus cathartica	b	alk	II^{+}	.

Table 3. Continued.

Type of habitat			GP	S
Characteristics	Layer	R	Constancy and abundance	Constancy and abundance
Forest floor vegetation:				
ChCl. Querco-Fagetea				
Sanicula europaea	c	alk	V^{+-3}	.
Actea spicata	c	neut	V^{+-1}	.
Viola reichenbachiana	c	neut	IV^{+-1}	.
Anemone nemorosa	c	neut	III^{+-1}	II^{+}
Hepatica nobilis	c	alk	II^{1}	.
Poa nemoralis	c	alk	III^{+}	.
Epipactis helleborine	c	alk	II^{+}	.
ChCl. Vaccinio-Piceetea				
Vaccinium myrtillus	c	acid^{-}	IV^{+-5}	III$^{2-4}$
Vaccinium vitis-idaea	c	acid	II^{+}	II^{2}
Orthilia secunda	c	acid^{-}	II^{+}	.
Dryopteris dilatata	c	acid^{-}	II^{+}	.
Trientalis europaea	c	acid	III^{+}	.
Pleurozium schreberi	d	-	II^{+}	II^{+}
Others:				
Oxalis acetosella	c	neut	IV^{+-2}	IV^{+-2}
Majanthemum bifolium	c	acid^{-}	V^{+-2}	III^{1}
Ajuga reptans	c	neut	IV^{+-2}	.
Mycelis muralis	c	neut	IV^{+-1}	II^{1}
Luzula pilosa	c	neut	V^{+-1}	.
Fragaria vesca	c	neut	III$^{1-2}$	.
Pteridium aquilinum	c	acid	.	II^{3}
Athyrium filix-femina	c	acid^{-}	II^{1}	.
Hieracium murorum	c	neut	III^{+-1}	.
Lysimachia nummularia	c	neut	II^{2}	.
Viola riviniana	c	alk	II^{2}	.
Hieracium lachenali	c	acid^{-}	II^{1}	.
Deschampsia caespitosa	c	neut	II^{1}	.
Genista tinctoria	c	neut	II^{1}	.
Moehringia trinervia	c	alk	II^{+}	.
Veronica chamaedrys	c	neut	II^{+}	.
Agrostis capillaris	c	neut	II^{+}	.
Vicia sepium	c	alk	II^{+}	.
Veronica officinalis	c	acid^{-}	II^{+}	.
Hypericum maculatum	c	neut	II^{+}	.
Geranium robertianum	c	neut	II^{+}	.

Table 3. Continued.

Epilobium montanum	c	neut	II$^+$	.
Calamagrostis epigejos	c	acid$^-$	II$^+$	.
Knautia arvensis	c	alk	II$^+$	.
Pimpinella saxifraga	c	alk	II$^+$	.
Carex pallescens	c	acid	.	II$^+$
Poa pratensis	c	neut	II$^+$	.
Plagiomnium affine	d	-		.

area, compared to the untransformed area (1 species) (P = 0.02, U = 2.34). A similar situation was found for neutrophytes which favour neutral soils – 25 neutrophytes were found on the gob piles, and 8 in the untransformed areas (P = 0.01, U = 2.42). These clear differences in the number of species favouring richer habitats correlate with the substrate properties (Table 4). The number of alkaline species positively correlates with the substrate pH (r_s = 0.79, P = 0.02, t = 3.21), the total of exchangeable alkalis (r_s = 0.87, P = 0.005, t = 4.27) and Ca, K, Na and Mg content. But the strongest correlations were found with the Ca and K contents (r_s = 0.92, P = 0.001, t = 5.58). A similar correlation was found for the analysis of the neutrophytes. However, for the species preferring acidic and very acidic substrates, the correlations were not statistically significant (Table 4).

When analysing the percentage of species in both habitat groups (gob piles and untransformed areas) in terms of syntaxa, it was found that species of mesophilous deciduous forests, characteristic of the *Querco-Fagetea* class (13 species), formed a significant percentage in the gob pile communities (both qualitatively and quantitatively). In contrast, there were only 4 species found in the untransformed areas (Table 3). The difference in the percentage of these species is significant (P = 0.02, U = 2.34). The percentage of species characteristic of the *Querco-Fagetea* class positively correlates with the substrate pH (r_s = 0.81, P = 0.01, t = 3.35); the total of exchangeable alkalis (r_s = 0.83, P = 0.01, t = 3.66), and Ca, K, Na and Mg content. The strongest correlation (r_s = 0.93, P = 0.0009; t = 6.09) was found between the number of these species and the Na content (Table 4). However, the differences in the percentage of species characteristic of *Vaccinio-Piceetea* between the two types of habitats are not statistically significant (P > 0.05). Here, 9 species were recorded on the gob piles and 6 species in the untransformed areas (Table 3).

Correlations between the chemical properties of the substrate and the increase in species richness occur in many different areas [52-56]. In those researched for the present paper, the main factors influencing the increase in the number of species are the specific chemical and physical properties of the material previously mined and left piled around the shaft heads. The increase in species richness is correlated with the properties of the substrate such as pH, the total exchangeable alkalis and Ca, K, Na, and Mg contents (Table 4).

The pH range of a given habitat can also affect its species richness. Schuster and Diekmann [57] stated that a pH of about 5.0 to about 6.0 is the most favourable for species diversity, because both acidophytes and alkaline species can coexist on this type of substrate. Only in the case of lower or much higher pH will the number of species in a given habitat decrease (either only acidophytes or only alkaline species), due to the limited ecological tolerance of plants. This phenomenon was confirmed in the areas currently researched, which showed the pH range of the gob piles as being very favourable, ranging from 5.3 to 7.0 (Table 1). This allows for the occurrence of both acidophytes and alkaline species (Table 3), and influences the increase in the total number of species of the former mining areas [34].

It is also interesting that in the researched areas the increase in species richness does not result from the domination of random species (e.g., anthropophytes), as frequently seen in post-mining areas [58-60], but from an increased percentage of native species (mainly forest species – Table 3). This is an extremely rare phenomenon in post-mining areas and can be explained by two factors: the nature of the overburden (the unprocessed material resembling natural substrate); and age [36], as heaps are sometimes older than 200 years and already demonstrate very advanced succession. These species form specific forest phytocoenosis of a mesophilic deciduous character, in contrast to untransformed areas surrounding the heaps where acidophilic communities occur [33, 35].

A similar influence of anthropogenic transformation on soil properties and vegetation has been described by, for example, Janqueira et al. [61] for the Amazon area. On anthropogenic soils formed as a result of human activity in the Amazon Rainforest, forest communities with different floral compositions have developed from the primary communities of the area, growing on untransformed soil. This phenomenon is caused by the increased pH values of the secondary soils, which generate a different direction of succession

Table 4. Spearman's rank correlation coefficients (r_s) for some chemical characteristics of soils (units are contained in Tables 1 and 2) and distinguished groups of species found in the gob piles and in their surroundings in the northern foreland of the Świętokrzyskie Mountains (SE Poland); Q-F – *Querco-Fagetea* class, V-P – *Vaccinio-Piceetea* class; others abbreviations – see Table 3. *0.05≥P ≥0.01; **0.01>P ≥0.001; ***0.001>P≥0.0001.

Variables	Total number of species	alk	neut	acid-	acid	acid+	Q-F	V-P
pH	0.78*	0.79*	0.80*	0.58	-0.01	0.11	0.81*	0.23
Total exchangeable alkalis	0.84**	0.87**	0.85**	0.71*	-0.06	0.33	0.83*	0.23
Exchangeable acidity	-0.37	-0.36	-0.35	-0.30	0.38	-0.65	-0.49	-0.03
Hydrolytic acidity	-0.68	-0.72*	-0.80*	-0.47	0.35	-0.22	-0.77*	0.01
Ca content	0.89**	0.92**	0.90**	0.80*	0.00	0.44	0.83*	0.33
K content	0.89**	0.92**	0.90**	0.80*	0.00	0.44	0.83*	0.33
Na content	0.79*	0.82*	0.90**	0.61	-0.36	0.44	0.93***	0.05
Mg content	0.83*	0.82*	0.80*	0.76*	-0.06	0.65	0.75*	0.36

and increase the floral richness of the Amazonian Rainforest. Janquiera et al. [61] emphasize that the floral composition is different in both types of forests, developing on various types of soils (anthropogenic and primary), even if they are adjacent to each other. A similar situation is observable in former areas of iron ore mining (Tables 1 and 3).

Conclusions

1) As a result of the former iron ore mining material originating from deeper rock layers was extracted to the surface (now overburden). This material has favourable physico-chemical properties, differing from the properties of the poorer soils of the untransformed areas.

2) Preferred chemical properties of the overburden, including increased pH values, increased content of assimilated elements (Ca, Mg, K, Na) also affect the increase in the quality of fossil soil horizons.

3) The mining of iron ore in the past has led to significant, positive changes in the soil cover of the researched areas.

4) The clayey-silty gob piles made of overburden there have become fertile habitat islands among oligotrophic, sandy, untransformed soils, and the effect of these changes is an increase in the number of plant species.

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Conflict of Interest

The authors declare no conflict of interest.

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