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Morphology, properties and classification of folisols in the Stołowe Mountains and Karkonosze Mountains, SW Poland

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Abstract

The aim of this study was to present the diversity of litter soils (folisols) in the Stołowe Mountains and the Karkonosze Mountains, focusing on their morphology, selected properties, classification and plant communities. A total of 19 soil profiles were studied—10 from the Stołowe Mountains and 9 from the Karkonosze Mountains—based on the analysis of 78 samples. Folic Histosols were found at various altitudes: 681–905 m above sea level in the Stołowe Mountains and 839–1408 m above sea level in the Karkonosze Mountains. These soils were associated with specific landscape features: rock outcrops composed of highly weather-resistant granitoids and sandstones, where rocky folisols developed (Leptic, Folic, Rockic, Histosol – WRB 2022), rocky debris and slope covers consisting of large fragments (stones, blocks, boulders), where rocky covered folisols formed (Skeletic, Folic, Mawic, Histosol – WRB 2022). The thickness of these soils was generally less than 30 cm. However, in areas with rock crevices, large boulders, and "ruins form" relief, soil development was more pronounced, now and again exceeding 60 cm. These deeper profiles were classified as typical folisols (Leptic, Folic, Rockic, Histosol – WRB 2022). In many profiles, particularly in the Stołowe Mountains, lignic material was present. The studied folisols were acidic to very acidic. Interestingly, plant communities probably had a great influence on soil properties.

1. Introduction

Folisols are organic soils containing more than 20% total carbon and are typically well-drained, remaining saturated with water for fewer than 30 consecutive days following rainfall or snowmelt (Kabała et al., 2019). The degree of organic matter decomposition in these soils varies with depth (Telega, 2022), root content (Dijkstra et al., 2021), and altitude (Scherr et al., 2011). Their genesis is primarily associated with the translocation of organic material and the composition of the forest canopy (Bochter and Zech, 1985). The high wood content characteristic of folic horizons contributes to the formation of cool, moist habitats (Achuff and Coen, 1980). Furthermore, root systems penetrating rock crevices play a vital role in soil development (Perret et al., 2016; Gregory, 2022).

Despite their ecological significance, folisols are rarely discussed in the soil science literature. As of 1 June 2025, the Web of Science database listed only 12 records referencing the term folisols. These soils have been reported from various global regions, with the majority of studies conducted in Canada. In British Columbia, folisols form extensive complexes on rocky terrain at elevations ranging from 285 to 850 m a.s.l. (Lewis and Lavkulich, 1972). On Vancouver Island, they occur on both upper slopes and depressions, often forming associations with Ferro-Humic Podzols and Humic Gleysols, reaching thicknesses of up to 40 cm (Jungen and Lewis, 1978). Outside Canada, Vaughan and McDaniel (2009) described shallow soils developing on lava beds in Idaho, USA, under cold, arid conditions at elevations of 1500–1800 m a.s.l. In the alpine zone of the Wetterstein Mountains in Germany (2000–2600 m a.s.l.), folisols are partly buried by eolian loess deposits (Scherr et al., 2011a). In Argentina, Kufman (2003) reported their presence in alpine meadow ecosystems of the Sierra de Iruya. Folisols also develop in tropical regions, such as the lower slopes of the Mauna Loa and Kilauea volcanoes in Hawaii, where organic horizons are 25–40 cm thick (Deenik and McClellan, 2007).

In Poland, folisols are limited to small mountainous areas, typically forming complexes with mineral initial soils in forested habitats (Skiba et al., 2009), and more rarely in meadows (Piekoś-Mirkowa and Mirek, 1996). Compared to other soil types, they remain understudied (Łachacz et al., 2024). Polish research on folisols has focused mainly on the Tatra Mountains, the Eastern Carpathians (Skiba, 1998; Drewnik, 2006; Skiba et al., 1998, 2014; Stolarczyk et al., 2024), and the Sudetes (Skiba et al., 2011). These soils have developed on a variety of parent materials, including granite, sandstone, limestone, dolomite, and Carpathian flysch. Researchers emphasize their ecological and hydrological importance.

Some organic horizons reach thicknesses of up to 120 cm, with skeletal content ranging from 50 to 90% of the soil volume. The degree of organic matter decomposition varies widely, with some soils containing up to 80% organic material. In the Sudetes, folisols commonly form on Pleistocene block weathering surfaces or result from recent mass movement processes (Kacprzak et al., 2006; Skiba, 2006). Musielok et al. (2013) studied folisols in the Kamienne Mountains (Sudetes), identifying soils at approximately 900 m a.s.l. on rhyolites, with folic horizons 60–65 cm thick and organic matter contents ranging from 37 to 55%. The accumulation of organic material in these soils may also be driven by biochemical weathering processes (Hackman et al., 2009).

In carbonate-rich environments, folisols often acquire mineral subsoil characteristics (Miechowka and Drewnik, 2018). Organic matter and mineral particles fill voids within slope deposits (Kacprzak et al., 2006), enabling vegetation establishment on coarse, unstable substrates. Kabała et al. (2013) briefly characterized folisols in the Karkonosze Mountains, particularly in the Czarna Kopa and Wysoki Grzbiet regions. They reported frequent soil formation in rock crevices and among boulders, where humified material gradually transforms into a mursh-like structure. These debris–mursh formations, observed on the upper ridges of the Karkonosze, are classified in the Polish Soil Classification System (Kabała et al., 2019) as organic mursh soils.

The aim of this study is to present the diversity of folisols in the Polish sections of the Stołowe and Karkonosze Mountains, focusing on their morphology, basic properties, and associated plant communities. The study also provides insights into their classification according to PTG 2019 and WRB 2022.

2. Study area

The research was conducted in the Polish sections of the Stołowe Mountains and the Karkonosze Mountains (southwestern Poland), which include the region's highest peaks: Skalnik (915 m a.s.l.) in the Stołowe Mountains and Śnieżka (1602 m a.s.l.) in the Karkonosze Mountains. Areas with folic soils in the Stołowe Mountains are composed primarily of sandstone and marl (Wojewoda, 2011), while the Karkonosze Mountains are dominated by granite formations. In their highest parts, granite is accompanied by hornfels containing quartzite admixtures (Klimaszewski, 1988). The Stołowe Mountains are known for their characteristic "ruin-form" landforms (Duszyński and Migoń, 2015), which resulted from vertical seabed movements leading to the deposition of sandstone sequences. In contrast, the relief of the Karkonosze Mountains features a series of ridges, with the highest summits forming prominent peaks. The landscape in this area is strongly shaped by geological structure and exhibits a distinctly alpine character, particularly at higher elevations, where it has been significantly modified by Pleistocene glacial activity (Czerwiński, 1985).

The climate of the Stołowe Mountains is primarily influenced by polar-maritime air masses (Dubicki and Głowacki, 2008). The average annual air temperature ranges from 5.3°C at the highest elevations to 8.4°C in the valleys. In contrast, the climate of the Karkonosze Mountains is harsher and more variable, shaped by geographic location and atmospheric circulation patterns (Kwiatkowski and Hołdys, 1985). Mean annual temperatures range from 7.9°C at 350–450 m a.s.l. to only 0.7°C at the summit of Śnieżka (Sobik et al., 2013). Annual precipitation in the Stołowe Mountains ranges from 650 to 833 mm, which is 5–30% lower than at similar elevations elsewhere in the Sudetes (Dubicki and Głowacki, 2008). In the Karkonosze Mountains, precipitation varies from 700–750 mm at around 400 m a.s.l. to 1400–1500 mm at higher elevations along the ridges (Kwiatkowski, 1982).

The soil cover of the Stołowe and Karkonosze Mountains is highly heterogeneous due to differences in geological history, topography, hydrological conditions, and vegetation. In the Karkonosze, climatic variability further enhances soil diversity (Kwiatkowski and Hołdys, 1985). In the granite-dominated areas of the Stołowe Mountains, Cambisols predominate, while marl areas feature both Cambisols and Histosols. In sandstone regions, Podzols and Histosols are dominant. In the Karkonosze Mountains, Cambisols are common at lower elevations, whereas Podzols prevail at higher altitudes. Organic soils, primarily Histosols, occur across various elevation zones (Bogacz, 2005; Kabała and Gałka, 2019).

Vegetation in the Stołowe and Karkonosze Mountains reflects the diversity of habitat conditions (Żołnierz and Wojtuń, 2013). In the Stołowe Mountains, notable forest communities include spruce and larch forests, Betula pubescens woodlands, acid mountain beech forests (Luzulo luzuloides–Fagetum), montane ash forests (Carici remotae–Fraxinetum), and rocky Scots pine and Carpathian birch forests. Meadow and pasture communities are classified within the Molinio-Arrhenatheretea, Calluno-Ulicetea, and Festuco-Brometea classes.

In the Karkonosze Mountains, representative forest communities include upper Sudetic spruce forest (Calamagrostio villosae–Picetum), lower Sudetic spruce–fir forest (Abieti–Picetum), and poor mountain beech forests (Luzulo luzuloides–Fagetum). High-elevation grasslands comprise alpine swards (Solidagini–Nardetum), upper montane grasslands (Poo–Deschampsietum), and subalpine grasslands with Juncus trifidus. In both mountain ranges, folic soils are frequently associated with lichen-dominated communities on rock outcrops (Kącki et al., 2018).

3. Materials and methods

The presented material was collected during a soil survey conducted in forested research areas within the Stołowe Mountains National Park and the Karkonosze Mountains National Park (Telega, 2022). In total, 19 folisols were identified, and 78 soil samples were collected (Fig. 1 and Fig. 2). Representative pedons were selected for detailed analysis (Tables 1–2; Figs 3–6). Soils were classified according to the Polish Soil Classification (SGP, 2019) and the World Reference Base for Soil Resources (WRB, 2022).

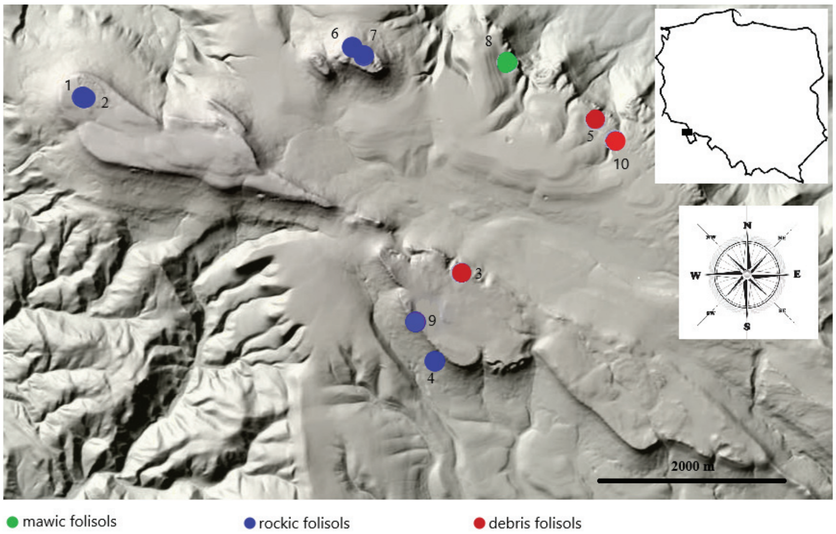

Fig. 1. Location of soils classified as folisols in Stołowe Mountains National Park. Profiles included in this paper are marked with profile numbers (according to Tables 1)

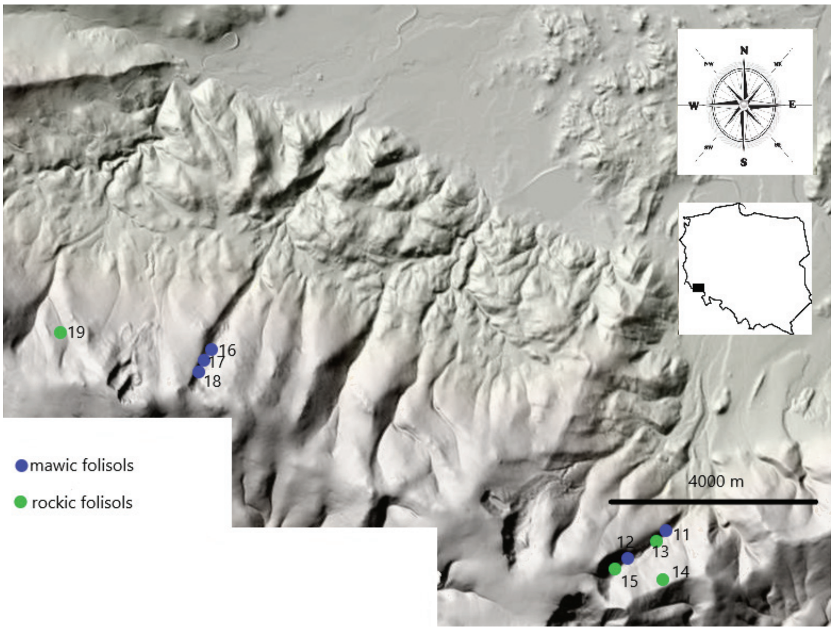

Fig. 2. Location of soils classified as folisols in Karkonosze Mountains National Park. Profiles included in this paper are marked with profile numbers (according to Tables 2)

Soil samples were collected from various genetic horizons. In the laboratory, samples were air-dried at room temperature (~20°C). After manually removing living roots, the samples were gently crushed using a wooden roller and ground in a mechanical mill. The material was then passed through a 2 mm sieve. Based on field observations and prepared samples, the presence and proportion of the skeletal fraction were determined.

Soil pH was measured potentiometrically in deionized water using a 1:2.5 soil-to-water ratio. Total nitrogen (TN) content was determined using a Vario Micro Cube elemental analyser, and total organic carbon (TOC) was measured by combustion at 950°C with thermal conductivity detection using a Vario Macro analyser. The carbon-to-nitrogen ratio (C/N) was calculated as TOC/TN.

Exchangeable Ca^{2+}, Mg^{2+}, K+, and Na+ (collectively denoted as S) were extracted using 1 M NH_4OAc (buffered at pH 7). Exchangeable acidity (EA) was determined using the Sokolow method. The effective cation exchange capacity (CEC) was calculated as the sum of base cations (S) and exchangeable acidity (EA). Base saturation (BS) was then calculated based on CEC and EA values.

Table 1
Selected properties of folisols in the Stołowe Mountains

Horizon	Depth (cm)	Coarse fragments >2 mm (% vol.)	Soil structure	pHw	BS (%)	TOC	TN	TOC/TN
Profile 1; WRB2022: Folic Rockic Histosol (Dystric, Lignic) PTG2019: Gleba ściółkowa skalista; 845 m a.s.l.; bedrock: sandstone (single stone); vegetation: *Vaccinio-Picetea*								
Oi	0–1	0	tw	4.6	74.2	49.4	1.54	32
Oe1	1–3	0	tw	3.9	33.0	44.0	1.21	36
Oe2	3–7	0	tw	3.2	18.0	44.5	1.59	28
Oe3	7–14	0	oa	3.2	34.9	49.7	1.61	31
R	14+	–	–	–	–	–	–	–
Profile 2; WRB2022: Folic Rockic Histosol (Dystric) PTG2019: Gleba ściółkowa skalista; 844 m a.s.l.; bedrock: sandstone (single stone); vegetation: *Vaccinio-Picetea*								
Oi	0–5	0	tw	4.2	57.6	44.8	1.60	28
Oe1	5–15	0	tw	3.7	42.5	47.5	1.76	27
Oe2	15–20	0	tw	3.5	32.2	48.7	2.00	24
Oa	20–25	0	zn	3.4	24.6	37.0	1.76	21
R	25+	–	–	–	–	–	–	–
Profile 3; WRB2022: Folic Rockic Histosol (Dystric), PTG2019: Gleba ściółkowa typowa; 733 m a.s.l.; bedrock: sandstone (single stone); vegetation: *Molinio caeruleae-Pinetum*								
Oi	0–7	0	tw	4.3	83.9	49.8	1.82	27
Oe1	7–15	0	tw	3.4	31.0	47.8	1.58	30
Oe2	15–25	0	tw	3.6	23.5	44.7	1.23	36
Oe3	25–33	0	tw	3.5	18.9	45.1	1.82	25
Oa	33–42	0	zn	3.4	28.0	42.9	1.42	30
C	42–50	0	d	4.5	71.8	4.36	0.24	18
R	50+	–	–	–	–	–	–	–
Profile 4; WRB2022: Folic Rockic Histosol (Dystric), PTG2019: Gleba ściółkowa skalista; 701 m a.s.l.; bedrock: sandstone–sand; vegetation: *Albieti-Picetum* (montanum)								
Oi	0–2	0	tw	4.5	76.6	48.9	1.91	26
Oe1	2–10	0	tw	3.5	39.6	43,9	1.26	35
Oe2	10–15	0	tw	3.6	50.6	44.7	1.27	35
Oa	15–22	0	zn	3.2	30.8	43.0	1.55	28
R	22+	–	–	–	–	–	–	–
Profile 5; WRB2022: Folic Rockic Histosol (Dystric) PTG2019: Gleba ściółkowa typowa; 704 m a.s.l.; bedrock: sandstone-sand (a crack between stones); vegetation: *Tilio platyphyllis-Acerion pseudoplatani*								
Oi	0–4	0	tw	5.1	85.8	51.3	1.65	31
Oe	4–14	0	tw	4.1	47.2	50.6	1.63	31
Oa1	14–30	0	tw	3.4	31.4	38.8	1.32	29
Oa2	30–36	0	zn	3.4	34.6	39.3	1.26	31
Oa3	36–45	0	zn	3.1	30.6	29.9	0.90	33
C	45–55	0	d	3.8	42.0	1.88	0.17	11
R	55+	–	–	–	–	–	–	–

Table 1 – continue

Horizon	Depth (cm)	Coarse fragments >2 mm (% vol.)	Soil structure	pHw	BS (%)	TOC	TN	TOC/TN
Profile 6; WRB2022: Skeletic Folic Rockic Hi stosol (Dystric) PTG2019: Gleba ściółkowa skalista; 905 m a.s.l.; bedrock: sandstone (single stone) (rock debris); vegetation: *Vaccinio–Piceetea*								
Oi	0–1	10	tw	4.0	51.9	52.9	2.34	23
Oe	1–6	10	tw	3.7	35.6	40.6	2.37	17
Oa	6–12	10	zn	3.5	29.5	36.5	1.35	27
R	12+	0	–	–				
Profile 7; WRB2022: Folic Rockic Histosol (Dystric), PTG2019: Gleba ściółkowa skalista; 901 m a.s.l.; bedrock: sandstone (single stone); vegetation: *Vaccinio-Piceetea*								
Oi	0–2	0	tw	5.1	70.4	52.3	1.69	31
Oe	2–4	0	tw	3.6	40.8	47.9	1.55	31
Oa1	4–14	0	zn	3.5	24.2	36.0	1.18	30
Oa2	14–30	0	zn	3.1	29.0	36.4	1.19	31
R	30+	–	–	–	–	–	–	–
Profile 8; WRB2022: Skeletic Folic Mawic Histosol (Dystric), PTG2019: Gleba ściółkowa rumoszowa; 685 m a.s.l.; bedrock: sandstone (a crack between stones); vegetation: *Luzulo luzuloidis-Fagetum*								
Oi1	0–7	0	tw	4.7	87.0	49.0	1.47	33
Oi2	7–18	50	tw	3.8	54.9	47.2	1.64	29
Oe	18–27	0	tw	3.6	38.4	43.2	1.39	31
Oa	27–37	0	zn	3.3	32.9	28.6	1.60	18
R	37+	–	–	–	–	–	–	–
Profile 9; WRB2022: Folic Rockic Histosol (Dystric, Lignic), PTG2019: Gleba ściółkowa typowa; 684 m a.s.l.; bedrock sandstone–sand (surface between "ruin formation"); vegetation: *Carici remotae-Fraxinetum*								
Oi	0–3	0	tw	4.5	71.3	49.1	3.27	15
Oe1	3–9	0	tw	3.2	32.8	46.9	2.33	20
Oe2	9–19	0	os	3.4	40.8	57.3	2.29	25
Oe3	19–43	0	os	3.4	40.6	53.9	1.47	37
Oe4	43–67	0	os	3.2	42.5	46.8	1.73	27
C	67–75	0	d	3.8	49.2	1.33	0,07	19
R	75+	–	–	–	–	–	–	–
Profile 10; WRB2022: Folic Rockic Histosol (Dystric), PTG2019: Gleba ściółkowa skalista; 1340 m a.s.l.; bedrock: sandstone (single stone); vegetation: *Abieti-Picetum (montanum)*								
Oi	0–4	0	tw	4.7	59.5	53.0	2.28	23
Oe1	4–10	0	tw	4.2	61.9	49.4	1.46	34
Oe2	10–22	0	tg, tw	3.1	50.2	49.2	1.49	33
Oa	22–26	0	zn	3.3	24.3	45.4	1.74	26
R	26+	–	–	–	–	–	–	–

Abbreviations: tw – fibrous, tg – spongy, zn – granular, oa – angular blocky, os – subangular blocky, gr – crumby, d – disintegrated,
* not detected

Table 2
Selected properties of folisols in the Karkonosze Mountains

Horizon	Depth (cm)	Coarse fragments >2 mm (% vol.)	Soil structure	pHw	BS (%)	TOC	TN	TOC/TN
Profile 11; WRB2022: Folic Mawic Histosol (Dystric), PTG2019: Gleba ściółkowa skalista; 839 m a.s.l.; bedrock: granitoide (slope cover); vegetation: *Luzulo luzuloidis–Fagetum*								
Oi1	0–2	0	tw	5.9	91.5	51.0	1.76	29
Oi2	2–8	0	tw	5.5	67.9	51.5	1.96	26
Oe	8–13	0	tw	4.2	48.5	50.3	1.70	30
Oa	13–15	0	zn	3.7	23.4	35.6	1.93	18
R	15+	–	–	–	–	–	–	–
Profile 12; WRB2022: Folic Rockic Histosol (Dystric), PTG2019: Gleba ściółkowa skalista; 1060 m a.s.l.; granitoide (single stone); vegetation: *Calamagrostio villosae–Piceetum* + *Vaccinium Myrtillus*								
Oi	0–4	0	tw	4.5	92.4	51.5	1.65	31
Oe1	4–7	0	tw	4.5	73.1	47.2	1.95	24
Oe2	7–13	0	tw	4.0	33.6	45.6	1.83	25
Oa	13–25	0	zn	3.9	18.2	44.6	1.86	24
R	25+	–	–	–	–	–	–	–
Profile 13; WRB2022: Folic Mawic Histosol (Dystric), PTG2019: Gleba ściółkowa rumoszowa; 880 m a.s.l.; bedrock: granitoide (slope cover); vegetation: *Albieti–Piceetum*								
Oi	0–2	0	tw	5.8	91.0	51.2	1.99	26
Oe1	2–10	0	tw	5.0	72.4	47.5	1.90	25
Oe2	10–25	0	tw	3.8	20.7	21.1	0.56	38
Oa	25–30	0	zn	3.9	25.6	21.3	0.87	24
R	30+	–	–	–	–	–	–	–
Profile 14; WRB2022: Skeletic Folic Mawic Histosol (Dystric), PTG2019: Gleba ściółkowa rumoszowa; 1408 m a.s.l.; bedrock: granitoide + hornfels (slope cover); vegetation: *Pinetum mugo sudeticum* + *Rhizocarpion Alpicolae*								
Oi	0–15	0	tw	4.4	71.5	46.6	1.93	24
Oe	15–30	70	tw	3.6	30.6	24.6	1.02	24
Oa1	30–45	80	zn	3.7	32.6	19.3	0.94	21
A	+45	80	zn	4.1	30.9	11.9	0.46	26
Profile 15; WRB2022: Skeletic Folic Mawic Histosol (Dystric), PTG2019: Gleba ściółkowa rumoszowa; 1120 m a.s.l.; bedrock: granitoide (slope cover); vegetation: *Pinetum mugo sudeticum* +*Pado–Sorbetum* + *Athyrietum distifolii*								
Oi	0–5	0	tw	4.3	45.7	32.9	0.97	34
Oe	5–10	70	tw	4.0	32.0	25.1	0.67	37
Oa1	10–30	80	zn	3.9	34.1	22.8	0.91	25
Oa2	30–40	80	zn	4.0	34.3	21.5	0.80	27
Oa3	40–60	60	os	3.5	26.9	19.9	0.72	28
R	60+	–	–	–	–	–	–	–
Profile 16; WRB2022: Folic Rockic Histosol (Eutric, Lignic), PTG2019: Gleba ściółkowa skalista; 930 m a.s.l.; bedrock: granitoide (simple stone); vegetation: *Albieti–Piceetum* + *Vaccinium Myrtillus*								
Oi	0–3	0	tw	5.2	61.2	49.7	1.99	25
Oe	3–10	0	tw	4.6	9.0	47.2	1.23	38
Oa	10–14	0	zn	4.5	6.8	37.6	1.09	35
R	14+	–	–	–	–	–	–	–

Table 2 – continue

Horizon	Depth (cm)	Coarse fragments >2 mm (% vol.)	Soil structure	pHw	BS (%)	TOC	TN	TOC/TN
Profile 17 WRB 2022: Skeletic Folic Mawic Histosols (Eutric), PTG 2019: Gleba ściółkowa skalista, 1015 m a.s.l.; bedrock: granitoide (simple stone); vegetation: *Albieti–Piceetum*								
Oi	0–2	0	tw	5.1	60.5	41.8	1.76	24
Oe	2–9	0	tw	4.7	14.5	32.4	1.77	18
Oa	10–20	0	zn	4.7	8.8	21.6	1.17	18
R	20+	–	–	–	–	–	–	–
Profile 18 WRB2022: Skeletic Folic Mawic Histosol (Eutric), PTG2019: Gleba ściółkowa skalista; 1010 m a.s.l.; bedrock: granitoide (slope cover); vegetation: *Albieti–Piceetum*								
Oi	0–4	0	tw	4.6	31.4	42.6	1.55	28
Oe	4–16	0	gr, zn	4.4	16.4	41.4	1.76	23
Oa	16–25	0	zn	4.4	9.5	35.5	1.48	24
R	25+	–	–	–	–	–	–	–
Profile 19; WRB2022: Skeletic Folic Mawic Histosol (Eutric), PTG2019: Gleba ściółkowa skalista; 1075 m a.s.l.; bedrock: granitoide (simple stone); vegetation: *Calamagrostio villosae–Piceetum* + *Vaccinium Myrtillus*								
Oi	2–0	0	tw	4.7	24.1	36.2	1.58	23
Oe	0–10	0	zn, os	4.6	13.1	31.2	1.29	24
Oa	10–35	0	ko, gr	4.6	17.5	33.5	1.57	21
R	–	–	–	–	–	–	–	–

Abbreviations: tw – fibrous, tg – spongy, zn – granular, gr – crumby, os – subangular blocky, ko – coprolitic.

* not detected

Particle size distribution was determined for three selected samples using the Bouyoucos hydrometer method. In addition, floristic surveys were carried out at the sampling sites to relate soil characteristics to vegetation patterns.

For all analysed soil properties, mean values and standard deviations were calculated. The Shapiro–Wilk test was used to assess the normality of data distribution. As the data did not follow a normal distribution, the non-parametric Mann–Whitney U test was applied to evaluate differences between groups. Statistical significance was accepted at $p < 0.05$. All statistical analyses were performed using Statistica 13 software (StatSoft, Inc., 2015).

4. Results

4.1. Occurrence, morphology and classification

The studied folisols in the Stołowe Mountains were found at various altitudes, ranging from approximately 684 m a.s.l. (profile 10) to over 900 m a.s.l. (profiles 6 and 7). These soils were covered with different types of vegetation, including *Vaccinio-Picetea* (Fig. 3: profiles 1, 2, sites A and B; Fig. 4: profiles 6, 7, sites F and G), *Molinio-caerulea-Pinetum* (Fig. 3: profile 3, site C), *Albieti-Picetum* (Fig. 3: profile 4, site D; Fig. 4: profile 10, sites J), *Tilio platyphyllis-Acerion pseudoplatani* (Fig. 3: Profile 5, site E), *Luzulo-luzuloides-Fagetum* (Fig. 4: profile 8, site H), and *Carici remotae-Fraxinetum* (Fig. 4: profile 9, site I). The occurrence of these soils was associated with very specific locations: 1) outcrops of various single rock types – for example, sandstones in the Stołowe Mountains (Fig. 3: profiles 1, 2, 3; Fig. 4: profiles 6, 7 and 10). In such places, rocky folisols (Rockic Folic Histosols according to WRB 2022) were formed. 2) rock debris and slope covers consisting of large rock fragments (Fig. 3: profile 4). These conditions favoured the formation of debris folisols (Skeletic Folic Mawic Histosols according to WRB 2022) 3) rock pockets (Fig. 3: profile 5; Fig. 4: profile 8), where Leptic Folic Mawic Histosols developed. 4) surfaces between stones in the “ruin system” (Fig. 4: profile 9), where Folic Mawic Histosols were formed (WRB 2022)

In the Karkonosze Mountains, the described folisols occurred at higher elevations, ranging from 839 m a.s.l. (profile 11) to 1408 m a.s.l. (profile 14). These soils were covered with different vegetation types, including *Luzulo-luzuloides-Fagetum* (Fig. 5: profiles 11, 13, sites K and Ł), *Calamagrostio villosae-Picetum* (Fig. 5: profile 12, site L; Fig. 6: profile 19, site S), *Albieti-Picetum* (Fig. 6: profiles 16, 17, 18, sites O, P, R), and *Pinetum mugo sudeticum* (Fig. 5: profile 14, 15, sites M, N). The occurrence of these soils was associated with specific locations: 1) rock block outcrops (profiles 13, 14, 15, 17, 18), where Leptic Folic Mawic Histosols developed (WRB 2022) 2) individual rock blocks (profiles 11, 12, 16, 19), where Folic Mawic Histosols were formed (WRB 2022) Folisols were characterized by thick organic ho-

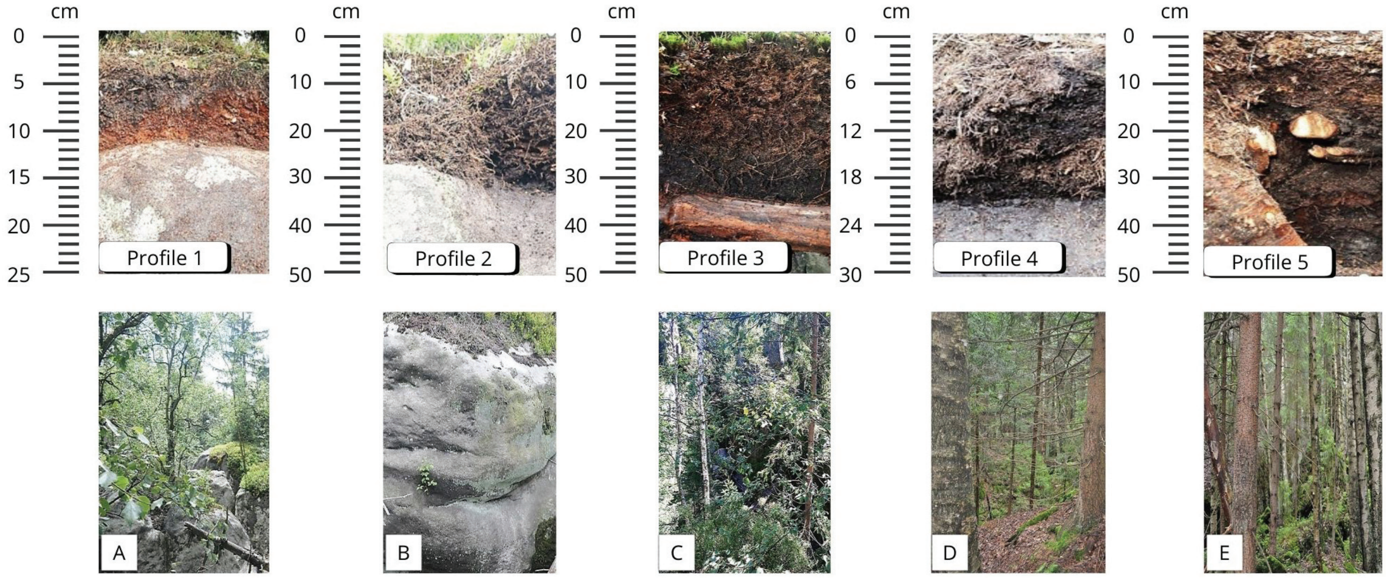

Fig. 3. Profiles of the studied rocky and typical subtype folisols in the Stołowe Mountains and their locations: A – surroundings of profile 1, B – surroundings of profile 2, C – surroundings of profile 3, D – surroundings of profile 4, E – surroundings of profile 5

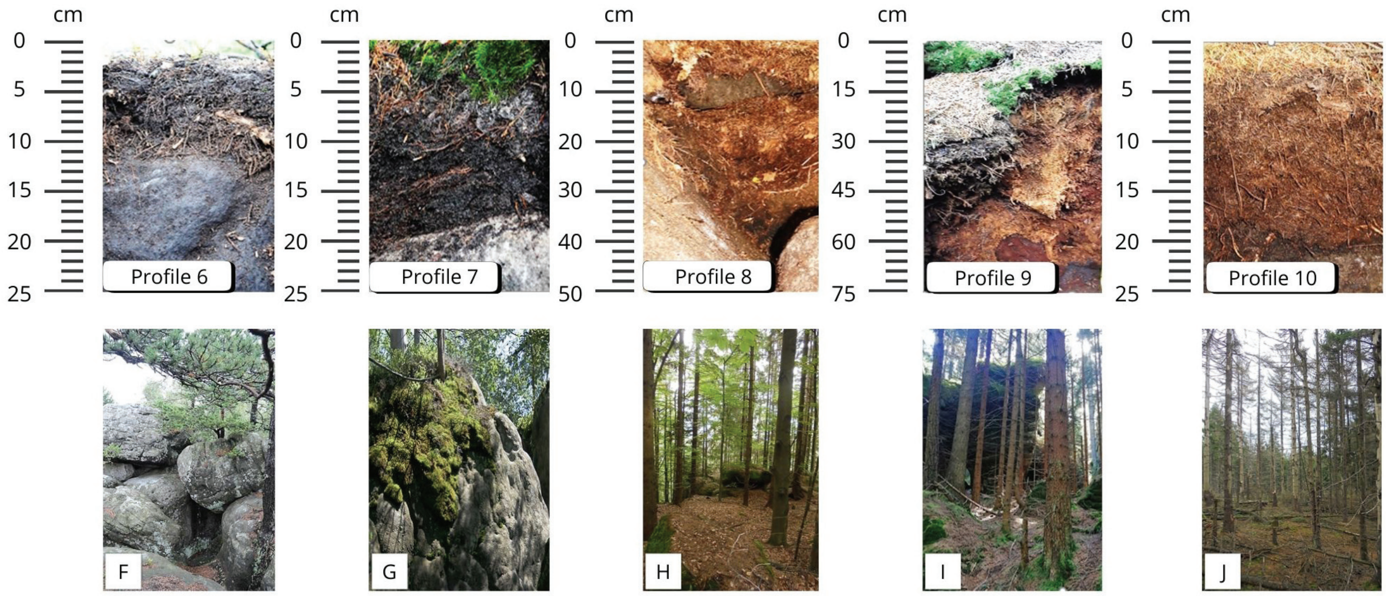

Fig. 4. Profiles of the studied rocky and debris subtype folisols in the Stołowe Mountains and their locations: F – surroundings of profile 6, G – surroundings of profile 7, H – surroundings of profile 8, I – surroundings of profile 9, J – surroundings of profile 10

rizons formed from litter at various stages of transformation, ranging from the Oi horizon through the Oe horizon to the Oa horizon. Notably, folic horizons were absent in soils covered with grass vegetation.

The uppermost part of these soils consisted of the Oe horizon (Tables 1–4). These layers, especially Oe and Oa, were often enriched with lignic material (Tables 1–4; Fig. 3, 4, 6). The total thickness of the litter horizons reached up to 30 cm in rocky folisols (Tables 1–4) and at least 70 cm in debris-folisols, where organic material accumulated between stones and boulders (both in open-work and non-open-work slope covers) (Tables 1–3). The organic material showed no signs of peat formation, as indicated by the absence of peat material in the studied folisols. The moss *Sphagnum* sp. was observed only in one case – at the soil surface in profile 14 in the Karkonosze Mountains.

Transitions between soil horizons were usually smooth or wavy; however, where coarse fragments such as stones and boulders were present, the transitions were irregular or disrupted. In the case of open-work covers, mechanical translocation of soil material was observed (Fig. 5: profiles 13, 14).

The soil structure depended on the degree of litter transformation. In litter horizons (Oi, Oe), the structure was predominantly fibrous. However, in deeper horizons (particularly in the Oa horizons), it became angular, subangular blocky, or granular. In some cases, the granular structure resembled a mursh structure (Tables 1–4; Fig. 5: profiles 3, 14, 15).

Table 3
List of plants on research areas in the Stołowe Mountains

Number of places	1	2	3	4	5	6	7	8	9	10
Vascular plants										
Betula pendula		+	+			+	+			+
Fagus sylvatica				+				+		
Pinus sylvestris			+			+				
Picea abies	+	+	+				+		+	+
Vaccinium myrtillius	+	+	+	+		+	+			+
Vaccinium vitis-idaea			+							
Brachypodium sylvaticum				+						
Lysimachia europaea		+								
Deschampsia flexyosa		+		+						
Calluna vulgaris						+				
Gymnocarpium dryopteris								+		
Mosses and liverworts										
Dicranum polysetum	+	+	+	+	+	+	+	+		
Dicranum scoparium		+								
Dicranodontium denudatum			+				+	+	+	
Hypnum cupressiforme		+								
Leucobryum juniperoideum					+			+		
Mnium hornum								+		
Plogiothecium curvifolium				+				+	+	
Pleurozium schreberi	+		+							+
Sphagnum capillifolium			+							
Tetraphis pellucida							+			
Bazzonia trilobata			+			+				
Calypogeia integristipula									+	
Nardia scalaris			+							
Lichens										
Cladonia chlorophea		+								
Cladonia digitata				+						
Cladonia macilenta	+									
Cladonia polydactyla						+				
Cladonia ramulosa							+			
Cladonia squamosa			+							
Cladonia uncialis						+				
Cetraria islandica						+				
Cladonia pyxidata		+								
Trapeliopsis granulosa	+									
Polycynthiella icmalea	+									
Hypogymnia physodes									+	
Lepra lobificans						+				

Table 4
List of plants on research areas in the Karkonosze Mountains

Number of places	1	2	3	4	5	6	7	8	9
Vasculare plants									
Hypericum sp.					+				
Vacinium vitis-idaea				+	+				
Avenella flexuosa		+		+	+			+	
Pinus mugo				+	+				
Picea abies	+	+	+		+	+	+	+	+
Betula pendula	+		+		+				
Sorbus aucuparia	+	+	+		+	+		+	
Vaccinium myrtillus	+	+	+		+	+		+	+
Fagus sylvatica	+								
Cystopteris fragilis	+	+	+						
Rubus idaeus		+							
Oxalis acetosella			+						
Calamagrostis villosa			+						
Dryopteris carthusiana						+			
Mosses and liverworts									
Polytrichum commune					+				
Dicranum polysetum			+		+				
Racomitrium sudeticum		+			+				
Orthodicranum montanum					+				
Sphagnum girgensohni					+				
Dicranum scoparium				+					
Sphagnum capillifolium				+					
Polytrychum alpinum	+		+	+			+		
Dicronodontium denudatum	+		+			+	+		
Dicranum fuscescens	+						+		
Kiaeria Blyttii		+							
Scapania undulata			+						
Polytrichum formosum						+			
Bazzania trilobata								+	
Plagiothecium curvifolium								+	
Hypnum cupressiforme							+		
Lepidozia reptans							+		
Lichens									
Pseudoevernia furfuracea	+						+	+	
Lepraria lobificans	+								
Trepeliopsis granulosa		+		+					+
Cladonia bellidiflora			+	+	+	+			
Cladonia digitata		+	+						
Cladonia coniocraea		+							
Cladonia polydactyla		+							
Hypogymnia physodes			+	+				+	
Cetraria islandica				+					
Vulpicida pinastri				+					
Cladonia coccifera				+					
Cladonia fimbriata									+

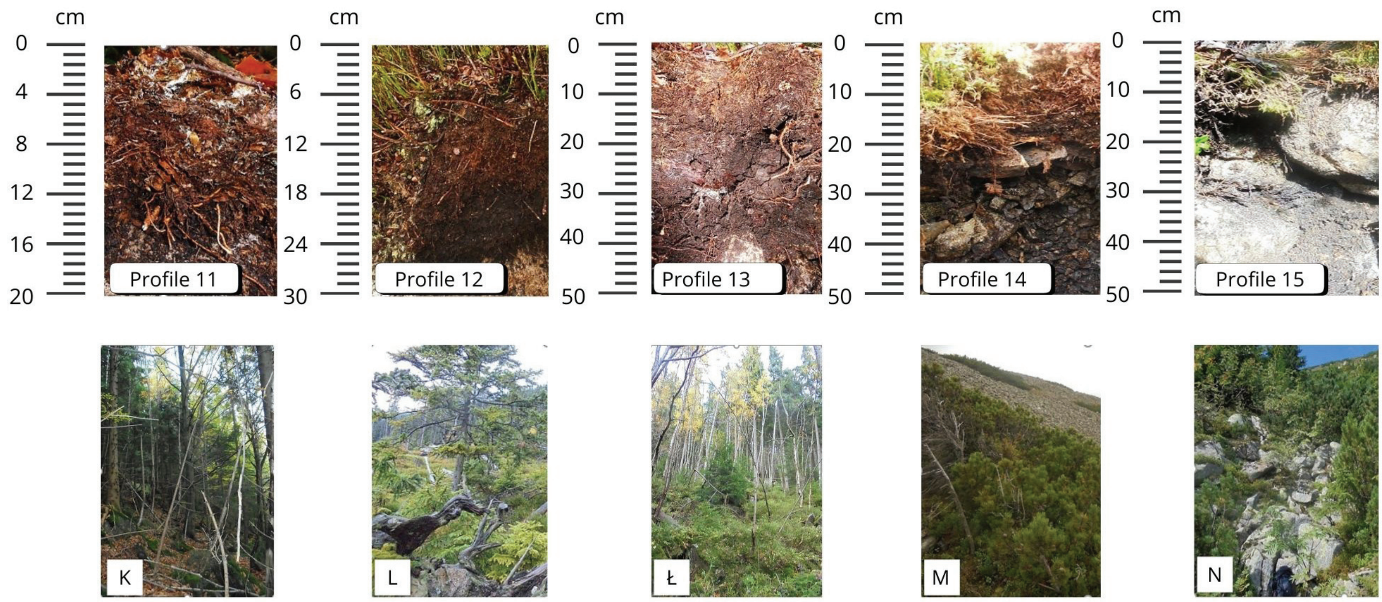

Fig. 5. Profiles of the studied rocky and debris subtype folisols in the Karkonosze Mountains and their locations: K – surroundings of profile 11, L – surroundings of profile 12, M – surroundings of profile 13, N – surroundings of profile 14, O – surroundings of profile 15

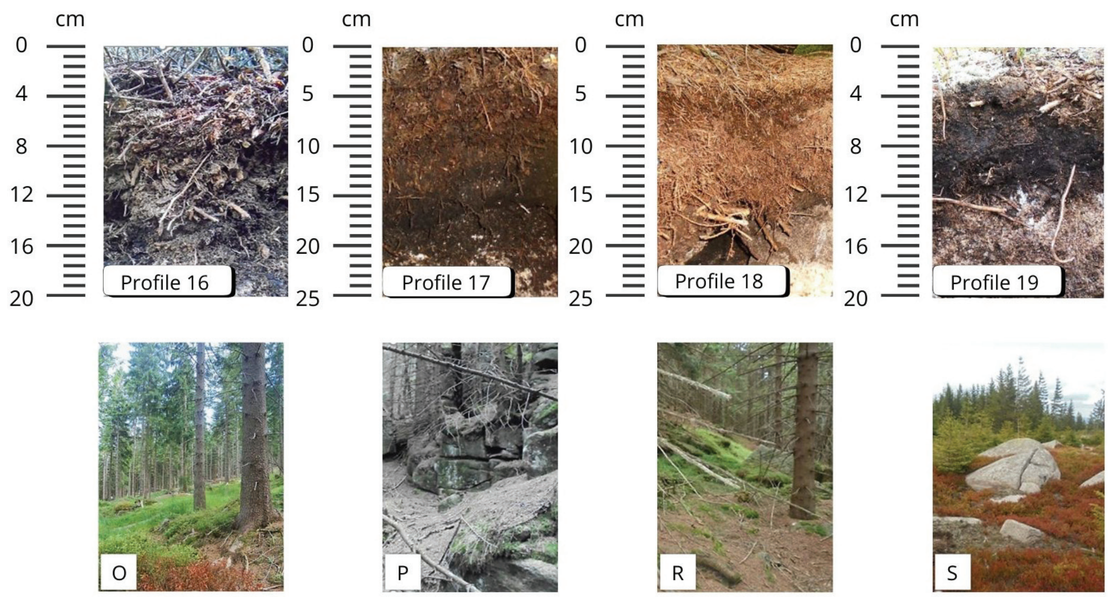

Fig. 6. Profiles of the studied rocky and debris folisols in the Karkonosze Mountains and their locations: P – surroundings of profile 16, R – surroundings of profile 17, S – surroundings of profile 18, T – surroundings of profile 19

4.2. Texture of the folisols coarse rock

In the studied soils, sometimes an medium content of coarse rock fragments was observed, starting from the upper horizons and extending to the deepest layers, particularly on slopes. In folisols developed on slope covers formed from granite, large pores spaces between rock fragments (open-work structure) accounted for up to 20–30% of the soil volume (Fig. 5: profile 14, side site M). In the Karkonosze Mountains region, the folisols profiles did not contain any weathered mineral soil horizons. In contrast, in the Stołowe Mountains, three profiles of folisols included mineral weathered soils formed from Cretaceous sandstones, located beneath the organic horizon and above the bedrock. Granulometric analysis classified these horizons as sands (Tables 1 and 2).

4.3. Plant species composition in the research areas

Eleven species of vascular plants, 13 species of mosses and liverworts, and 13 species of lichens were identified at the soil sampling sites in the Stołowe Mountains, giving a total of 37 plant species. The most frequently occurring vascular plant among the tree layer was *Picea excelsa.* Among the heath and herbaceous plants, *Vaccinium myrtillus* was the most common. Mosses and liverworts were most frequently represented by *Dicranum polysetum.* Lichens were found in almost every research plot (Table 3).

In the research areas in the Karkonosze Mountains, 14 species of vascular plants, 17 species of mosses and liverworts, and 12 species of lichens were recorded, totalling 43 species. As in the Stołowe Mountains, *Picea excelsa* was the most widespread tree species. Among heath and herbaceous plants, *Vaccinium myrtillus* was again dominant. *Polytrichum alpinum* was the most common species among mosses and liverworts. Lichens were mainly represented by *Cladonia bellidiflora* and *Cladonia digitate* (Table 4).

4.4. Chemical properties

The studied soils exhibited pHw values ranging from 3.1 to 5.1. No major differences in pHw values were observed between rocky folisols and debris folisols (PTG 2019). Regardless of vegetation type, the soils generally had a very strongly acidic reaction (pH < 4.0) or an acidic reaction (pH ≥ 4.0 and < 5.0) (Tables 1, 2). In folisols from the Karkonosze Mountains, pHw values ranged from 3.5 to 5.9, with most horizons showing an acidic reaction. A pHw ≥ 5.0 was generally found in the upper horizons. Notably, in both the Stołowe and Karkonosze Mountains, all folisols were covered with forest vegetation.

The total organic carbon (TOC) content in folisols from the Stołowe Mountains was very high and decreased with soil depth, ranging from 53.0–40.6% in the uppermost part of the soil (Oi, Oe, Oa horizons) to 45.4–28.6% in the O horizons (Table 1). In the horizons with lignic material, TOC content ranged from 46.8% to 57.3%. The total nitrogen (TN) content in organic horizons was also high, varying from 0.90% to 3.27%. The TOC/TN ratio in the Stołowe Mountains was relatively stable, ranging from 36:1 to 15:1.

Similarly, in the Karkonosze Mountains, TOC content was very high but decreased with depth, from 51.5–24.6% in the Oi and Oe horizons to 44.6–21.3% in the Oa horizon (Tables 1, 2). However, TN content in the Karkonosze folisols was slightly lower, ranging from 0.56% to 1.99%.

5. Discussion

The diversity of the studied folisols can be explained by the heterogeneity of soil-forming factors. One of the key factors differentiating them was the type of bedrock. In this study, folisols developed on granite, sandstone, and hornfels – rocks that are generally resistant to weathering, especially hornfels. In several soil profiles, the presence of voids not filled with soil material was observed. This arrangement facilitates the movement of surface material deeper into the soil profile. One consequence of this process is the downward translocation of humus compounds onto the underlying rock. Similar subsurface movements were described by Skiba and Komornicki (1983) and Stolarczyk et al. (2024) in isolated patches of washed granitoid moraine soils in the Polish Tatra Mountains. In our study, such folisols occurred across extensive slope areas, often inconspicuous in the field (Fig. 5: profiles 13, 14, 15). The influence of lithology on folisol diversity is not clearly reflected in the mineral composition of the bedrock, which does not mitigate soil acidity.

Folisol diversity was more strongly influenced by vegetation type (Olleck et al., 2020). This was evident in the absence of O horizons under diverse forest vegetation. Vegetation, especially in coniferous forests and tundra, produces large amounts of organic litter, including leaves, needles, bark, and pedicels (Leal et al., 2023), which often accumulates to form thick organic horizons (Luttmerding, 1981). Due to the cool, humid climate and typically acidic conditions, microbial decomposition of organic matter is slow (Kondratova et al., 2023), leading to the build-up of undecomposed or partially decomposed material (Matteoda et al., 2018). The nature of plant litter strongly influences soil chemistry (Durai et al., 2023). In boreal coniferous forests, needle litter contributes to acidification (Ste-Marie and Paré, 1999), whereas grasses and mosses typical of tundra produce organic horizons that are less acidic and lower in lignin content (Glime, 2024). Folisols are further stabilized by tree and shrub roots that help prevent erosion of the organic layer (Godey-Fernandes et al., 2021). Thus, vegetation not only initiates folisol formation but also maintains and shapes it (Goetz, 2012). Without continuous organic input from plant cover, folisols would neither form nor persist (Samborn et al., 2021).

In the folisols of the Stołowe Mountains, Oa horizons were absent in two profiles, but Oe horizons or horizons with wood were observed in profiles 1 and 9 (Tables 1–2). In profile 4 (Table 1), an Oi horizon was overlain by an Oe horizon. These morphological differences may result from erosion processes typical of slope environments, as noted by Kabała et al. (2013).

The folisol profiles presented from the Stołowe and Karkonosze Mountains offer insights relevant to the SGP 2019 soil classification. In the Stołowe Mountains, folisols can be classified into the following subtypes: typical folisols (3 profiles), rocky folisols (6 profiles), and debris folisols (1 profile) (PTG 2019). In contrast, no typical folisols have yet been identified in the Karkonosze Mountains.

Based on these data, a preliminary conclusion is that typical folisols occur in microhabitats that favor local litter accumulation – specifically, in traps between boulders and rocks where there is limited downward or lateral translocation. This pattern is characteristic of the unique rock relief of the Stołowe Mountains. In the Karkonosze Mountains, rocky folisols dominate at lower elevations (6 profiles), while debris folisols are more common at higher elevations, as also noted by Telega (2022). The occurrence of folisols in the Karkonosze and Tatra Mountains (Stolarczyk et al., 2024) differs from that in the Stołowe Mountains.

In the SGP 2019 system, the significance of lignic material may be underestimated (Fox et al., 1993), even though it alone can lead to folisol formation, as demonstrated in profile 9 from the Stołowe Mountains (Table 1, Fig. 2).

According to WRB 2022, debris folisols were not identified in the Karkonosze Mountains. Most folisols in the Stołowe Mountains were classified as Rockic Folic Histosols (Table 1) and Mavic Folic Histosols (Table 2). This is likely related to the properties of granite and sandstone, which differ significantly from carbonate rocks (Stolarczyk et al., 2024).

Table 5
Mean soil pHw, content of TOC and TN as well as TOC/TN ratio in folisols developed on granite and sandstone rocks

Bedrock/Region	Horizon	n	pHw x(SD)	TOC (% w.) x(SD)	TN (% w.) x(SD)	TOC/TN x(SD)
sandstone	Oi	12	4.4(0.47)	49.4(2.68)	1.87(0.51)	28(5.26)
Stolowe	Oe	15	3.6(0.29)	46.3(2.70)	1.64(0.35)	29(5.53)
Mountains	Oa	11	3.3(0.14)	37.6(4.94)	1.39(0.25)	28(4.31)
granite	Oi	10	5.0(0.59)	45.5(6.49)	1.71(0.29)	27(3.32)
Karkonosze	Oe	11	4.3(0.42)	37.6(10.39)	1.42(0.23)	28(6.57)
Mountains	Oa	10	4.1(0.38)	29.3(8.51)	1.26(0.40)	21(4.69)

Explanation: n - number of, x – mean value, (SD) - standard deviation

Table 6
Differences at p based coefficient on non-parametric Mann-Whitney U test.

Value	Horizon	p	Value	Horizon	p	Value	Horizon	p	Value	Horizon	p
pH	Oi	0.044*	TOC	Oi	0.275	TN	Oi	1.000	TOC/TN	Oi	0.500
	Oe	0.001*		Oe	0.066		Oe	0.603		Oe	0.503
	Oa	0.001*		Oa	0.022*		Oa	0.342		Oa	0.500

Explanation: p - coefficient, * - significant at p<0.05, statistically significant differences are marked in bold

Climate and vegetation, which vary with elevation, influence the pH of folisols formed on sandstone and granite. In humid climates, organic matter tends to retain its acidic nature (Conteaux and Bottner, 1995). The acidity of organic material – especially in the presence of granite and sandstone – has been highlighted by Bojko and Kabała (2017), Szopka et al. (2016), Gałka et al. (2013), and Łabaz et al. (2014).

Significant differences in pH were observed across all litter subhorizons (Oi, Oe, Oa) between folisols from the Stołowe and Karkonosze Mountains (Tables 5–6). The higher pH values in the Karkonosze folisols are likely due to a greater proportion of deciduous vegetation, which produces less acidic organic layers compared to coniferous species (Berg and Laskowski, 2006). Moreover, the Oa horizons in the Karkonosze folisols had lower TOC content than those in the Stołowe Mountains (Tables 5–6), possibly due to the Oa layers being more strongly enriched with mineral components (Tables 3–4). A similar phenomenon was previously observed in the folic horizons of Podzols in the Karkonosze Mountains (Kabała et al., 2012).

6. Conclusions

The Histosols in the Stołowe Mountains are classified according to WRB 2022 as Rockic Histosols, while Mavic Histosols predominate in the Karkonosze Mountains. This is likely due to the frequent presence of rock blocks in the higher parts of the Karkonosze Mountains.

The properties of folisols in the Stołowe and Karkonosze Mountains likely depend on plant communities. In general, vegetation influences the morphology of these soils and also significantly effects certain chemical properties, such as pH and total carbon (TOC), in all or some horizons.

In the specific humid and cool climate, folisols formed on granite, sandstone and hornfels rocks are acidic and strongly acidic. The folisols in the Stołowe Mountains are more acidic than those in the Karkonosze Mountains. This difference can probably likely by influenced by variation in plant species within the studied plant communities.

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Conflict of interests

The authors declare no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research did not involve human or animal subjects.

Author Contributions

Paweł Telega: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Supervision, Validation. **Adam Bogacz**: Conceptualization, Investigation, Methodology, Supervision, Visualization, Writing - Review and editing. All authors read and approved the final manuscript.

References

Achuff, P.L., Coen, G.M., 1980. Subalpine cryosolic soils in Banff and Jasper National Parks. Canadian Journal of Soil Science 60(3), 579–581.

Berg, B., Laskowski, R., 2006. Relationship between haloketone and lignin during decomposition. [In:] B. Berg and R. Laskowski (Eds.), Litter decomposition: A guide to carbon and nutrient turnover (pp. 114–118). Elsevier.

Bochter, R., Zech, W., 1985. Organic compounds in cryofolists developed on limestone under subalpine coniferous forest, Bavaria. Geoderma 36(2), 145–157.

Bogacz, A., 2005. Właściwości i stan przeobrażenia wybranych gleb organicznych Sudetów, Rozprawy CCXXVI, Zeszyty Naukowe Akademii Rolniczej we Wrocławiu.

Bojko, O., Kabała, C., 2017. Organic carbon pools in mountain soils: Sources of variability and predicted changes in relation to climate and land use. Catena 149, 209–220. https://doi.org/10.1016/j.catena.2016.09.022

Conteaux, M.M., Bottner, P., 1995. Litter decomposition, climate and litter quality. Trends in Ecology and Evolution 10(2), 63–66. https://doi.org/10.1016/S0169-5347(00)88978-8

Czerwiński, J., 1985. Główne rysy rzeźby i rozwoju geomorfologicznego. [In:] A. John (Ed.), Karkonosze Polskie (pp. 53–76). Polska Akademia Nauk, Oddział we Wrocławiu; Karkonoskie Towarzystwo Naukowe w Jeleniej Górze. (in Polish with English abstract)

Deenik, J., McClellan, A.T., 2007. Soil in Hawaii. Soil and Crop Management, SCM-20, 1–12.

Dijkstra, F.A., Zhu, B., Cheng, W., 2021. Root effects on soil organic carbon: A double-edged sword. New Phytologist 230(1), 60–65. https://doi.org/10.1111/nph.17082

Dutai, M.V., Godzina, A., Ravi, N., Vapulhulla A., Kartik, A.G. 2023. Chemical properties of soil in forest and non-forest land use in Bangalore rural forest division, Karnataka. Annual Plant and Soil Research 25(1), 110–119. https://doi.org/10.47815/apsr.2023.10243

Drewnik, M., 2006. Effect of environmental conditions on the decomposition rate of cellulose in mountain soils. Geoderma 132, 116–130. https://doi.org/10.1016/j.geoderma.2005.04.023

Dubicki, A., Głowacki, B., 2008. Klimat. [In:] A. Witkowski, B.M. Pokryszko, W. Ciężkowski (Eds.), Przyroda Parku Narodowego Gór Stołowych (pp.101–113). Wydawnictwo PNGS. (in Polish with English abstract)

Duszyński, F., Migoń, P., 2015. Boulder aprons indicate long-term gradual and non-catastrophic evolution of clefted escarpments, Stołowe Mountains, Poland. Geomorphology 250, 63–77. https://doi.org/10.1016/j.geomorph.2015.08.007

Fox, C.A., Preston, C.M., Fyfe, C.A., 1994. Micromorphological and 13C NMR characterization of a humic, lignic, and histic Folisol from British Columbia. Canadian Journal of Soil Science 74, 1–15.

Gałka, B., Podlaska, M., Kabała, C., 2013. Forest habitats on dystric Cambisols developed from granite in the Stołowe Mountains. Sylwan 157(5), 385–394. https://doi.org/10.26202/sylwan.2012084

Glime, J.M., 2024. Roles of bryophytes in forest sustainability – Positive or negative? Sustainability 16(6), 2359. https://doi.org/10.3390/su16062359

Goday-Fernandes, P.H., Souza, A.L.T., Tonaka, M.O., Sebastiani, R., 2021. Decomposition and stabilization of organic matter in an old-growth tropical riparian forest: Effect of soil properties and vegetation structure. Forest Ecosystems 8, 13. https://doi.org/10.1186/s40663-021-00340-w

Goetz, J., 2012. Natural and anthropogenic controls of landslides on Vancouver Island [Master's thesis]. Waterloo, Ontario, Canada.

Gregory, P.J., 2022. Are plant roots only "in" soil or are they "of" it? Roots, soil formation and function. European Journal of Soil Science 73(1), 1–25. https://doi.org/10.1111/ejss.13219

Hackman, K., Welty-Bernard, A., Rasmussen, C., Schwartz, E., 2009. Geologic control of soil carbon cycling and microbial dynamics in temperate conifer forest. Chemical Geology 267, 12–23. https://doi.org/10.1016/j.chemgeo.2009.01.004

IUSS Working Group WRB, 2022. World Reference Base for Soil Resources: International soil classification system for naming soils and creating legends for soil maps (4th ed.). International Union of Soil Sciences, Vienna, Austria.

Jungen, J.R., Lewis, T., 1978. The Coastal Mountain Island. [In:] K. W. G. Valentine, P. N. Sprout, T. E. Baker, L. M. Lavkulich (Eds.), The Soil Landscape of British Columbia (pp. 101–121). BC Ministry of Environment, Resource Analysis Branch.

Kabała, C., Bogacz, A., Łabaz, B., Szopka, K., Waroszewski, J., 2013. Różnorodność, dynamika i zagrożenie gleb. [In:] R. Knapik and A. Raj (Eds.), Przyroda Karkonoskiego Parku Narodowego (pp. 91–126). Wydawnictwo Karkonoskiego Parku Narodowego. (in Polish with English abstract)

Kabała, C., Charzyński, P., Chodorowski, J., Drewnik, M., Glina, B., Greinert, A., ... and Waroszewski, J., 2019. Polish soil classification: Principles, classification scheme and correlations. Soil Science Annual 70(2), 71–97. https://doi.org/10.2478/ssa-2019-0009

Kabała, C., Gałka, B., 2019. Estimation of bulk density of the mountain soils from the organic carbon content. Sylwan 163(4), 320–327. https://doi.org/10.26202/sylwan.2018125

Kabała, C., Waroszewski, J., Bogacz, A., Łabaz, B., 2012. O specyfice bielic górskich. Soil Science Annual 63(2), 55–64. (in Polish with English abstract)

Kącki, Z., Szymura, M., Świerkosz, K., Swacka, G., Pender, K., 2018. Roślinność Parku Narodowego Gór Stołowych. [In:] C. Kabała (Ed.), Góry Stołowe – przyroda i ludzie (pp. 311–326). (in Polish with English abstract)

Kacprzak, A., Drewnik, M., Uzarowicz, Ł., 2006. Rozwój i kierunki przemian węglanowych gleb rumoszowych na terenie Pienińskiego Parku Narodowego. Pieniny – Przyroda i Człowiek 9, 41–50. (in Polish with English abstract)

Klimaszewski, M., 1998. Geomorfologia. Wydawnictwo PWN, Warszawa.

Kufmann, C., 2003. Soil types and aeolian dust in high-mountainous karst of the Northern Calcareous Alps (Zugspitzplatt, Wetterstein Mountains, Germany). Catena 53(3), 211–227. https://doi.org/10.1016/S0341-8162(03)00075-4

Kwiatkowski, J., 1982. Skuteczne sraczki v Krkonosich. Actual rainfall in the Krkonose Mountains. Opera Corcontica 19, 45–64.

Kwiatkowski, J., Hołdys, T., 1985. Klimat. [In:] A. John (Ed.), Karkonosze Polskie (pp. 117–144). Ossolineum. (in Polish with English abstract)

Leal, F., Aburto, F., Agnilera, N., Echeverría, C., Gatica-Saavedra, P., 2023. Forest degradation modifies litter production, quality and decomposition dynamics in Southern temperate forest. Frontiers in Soil Science 3, 1111694. https://doi.org/10.3389/fsoil.2023.1111694

Lewis, T., Lavkulich, L.M., 1972. Some folisols in the Vancouver area, British Columbia. Canadian Journal of Soil Science 52(1), 91–98.

Luttmerding, H.A., 1981. Soil of the Langley–Vancouver Map Area. RAB Bulletin 18, Report No. 15(3), 66–67.

Łabaz, B., Gałka, B., Bogacz, A., Waroszewski, J., Kabała, C., 2014. Factors influencing humus forms and forest litter properties in the mid-mountains under the temperate climate of southwestern Poland. Geoderma 230-231, 265–273. https://doi.org/10.1016/j.geoderma.2014.04.021

Łachacz, A., Bogacz, A., Glina, B., Kalisz, B., Mendyk, Ł., Orzechowski, M., Smólczyński, S., Sowiński, P., 2024. Origin, transformation, and classification of organic soils in Poland. Soil Science Annual 75(4), 195241. https://doi.org/10.37501/soilsa/195241

Matteoda, M., Grand, S., Verrecchia, E.P., 2018. Decoupling of topsoil and subsoil controls on organic matter dynamics in the Swiss Alps. Geoderma 330, 41–51. https://doi.org/10.1016/j.geoderma.2018.05.011

Miechówka, A., Drewnik, M., 2018. Rendzina soils in the Tatra Mountains, Central Europe: A review. Soil Science Annual 69(2), 88–100. https://doi.org/10.2478/ssa-2018-0009

Musielok, Ł., Kacprzak, A., Opyrchał, J., 2013. Właściwości i pozycja systematyczna gleb wytworzonych na ryolitach w Górach Kamiennych. Prace Geograficzne 135, 21–39. (in Polish with English abstract)

Olleck, M., Reger, B., Ewald, J., 2020. Plant indicators for Folic Histosols in mountain forests of the Calcareous Alps. Applied Vegetation Science 23(2), 285–296. https://doi.org/10.1111/avsc.12470

Piękoś-Mirkowa, H., Mirek, Z., 1996. Zbiorowiska roślinne. [In:] Z. Mirek (Ed.), Przyroda Tatrzańskiego Parku Narodowego (pp. 237–274). Wydawnictwo Tatrzańskiego Parku Narodowego. (in Polish with English abstract)

Pierret, A., Maeght, J.L., Clément, C., Montoroi, J.P., Hartmann, C., Gonkhamdee, S., 2016. Understanding deep roots and their functions in ecosystems: An advocacy for more unconventional research. Annals of Botany 118(4), 621–635. https://doi.org/10.1093/aob/mcw130

Sanborn, P., Bulmer, C., Geertsema, M., Smith, S., 2022. A proposed Folic subgroup for the Organic Cryosols. Canadian Journal of Soil Science 102, 811–816. https://doi.org/10.1139/GJSS-2021-0182

Scheer, M.B., Curico, G.R., Roderjan, C.V., 2011. Environmental functionalities of upper montane soils in Serra da Ingria, Southern Brazil. Revista Brasileira de Cięncia do Solo 35, 1013–1026. https://doi.org/10.1590/S0100-06832011000400005

Skiba, S., Drewnik, M., Smuc, R., Prędki, R., 1998. Gleby Bieszczadzkiego Parku Narodowego. Monografie Bieszczadzkie, 2, 80 + mapa. (in Polish with English abstract)

Skiba, S., 1998. Gleby górskie w Systematyce Gleb Polski. Zeszyty Problemowe Postępów Nauk Rolniczych 464, 5–35. (in Polish with English abstract)

Skiba, S., 2006. Pokrywa glebowa strefy wysokogórskiej Karpat i jej zagrożenia. Roczniki Bieszczadzkie 14, 201–214. (in Polish with English abstract)

Skiba, S., Komornicki, T., 1983. Gleby organiczno-sufozyjne w Tatrach Polskich. Roczniki Gleboznawcze – Soil Science Annual 34, 8–16. (in Polish with English abstract)

Skiba, S., Szymański, W., Nędzka, M., Prędki, R., 2009. Inicjalne gleby (Lithic Leptosols) piętra połonin w Bieszczadach i Czarnohorze (Karpaty Wschodnie). Roczniki Bieszczadzkie 17, 357–366. (in Polish with English abstract)

Skiba, S., Kacprzak, A., Szymański, W., Musielok, Ł., 2011. Walory przyrodnicze górskich gleb rumoszowych. Roczniki Bieszczadzkie 19, 335–348. (in Polish with English abstract)

Skiba, S., Szymański, W., Prędki, R., 2014. Badania gleboznawcze w Karpatach Wschodnich i ich znaczenie w ochronie gleb Bieszczadzkiego Parku Narodowego. Roczniki Bieszczadzkie 22, 129–140. (in Polish with English abstract)

Sobik, M., Błaś, M., Migała, K., Godek, M., Nasiókowski, L., 2013. The Nature of the Karkonosze National Park. In: R. Knapik A. Raj (Eds.), Karkonoski Park Narodowy (pp. 147–186). Jelenia Góra.

StatSoft, Inc. 2015. Statistica (version 13) [Software].

Ste-Marie, C., Paré, D., 1999. Soil pH and N availability effects on net nitrification in the forest floors of a range of boreal forest stands. Soil Biology and Biochemistry 31(11), 1579–1589.

Stolarczyk, M., Musielok, Ł., Szymański, W., Drewnik, M., 2024. Morphology, properties, and classification of folisols in the Tatra Mountains. Soil Science Annual 75(4), 195239. https://doi.org/10.37501/soilsa/195239

Szopka, K., Kabała, C., Karczewska, A., Jezierski, P., Bogacz, A., Waroszewski, J., 2016. The pools of soil organic carbon accumulated in the surface layers of forest soils in the Karkonosze Mountains, SW Poland. Soil Science Annual 67(2), 46–56. https://doi.org/10.1515/ssa-2016-0007

Telega, P., 2022. Gleby organiczne ściółkowe – geneza, właściwości i rola ekologiczna w ekosystemach górskich [Doctoral dissertation, Uniwersytet Przyrodniczy we Wrocławiu]. (Manuscript in Polish with English abstract)

Vaughan, K., McDaniel, P.A., 2009. Organic soils on basaltic lava flows in a cool, arid environment. Soil Science Society of America Journal 73(5), 1510–1518. https://doi.org/10.2136/sssaj2008.0257

Wojewoda, J., Białek, D., Bucha, M., Głuszyński, A., Gotowała, R., Krawczewski, J., Schutty, B., 2011. Geologiczne warunki środowiska przyrodniczego Parku Narodowego Gór Stołowych. [In:] T. Chodak, C. Kabała, J. Kaszubkiewicz, P. Migoń, J. Wojewoda (Eds.), Geologiczne warunki środowiska przyrodniczego Parku Narodowego Gór Stołowych (pp. 53–96). WIND. (in Polish with English abstract)

Żołnierz, L., Wojtuń, B., 2013. Roślinność alpejska i subalpejska. [In:] R. Knapik and A. Raj (Eds.), Przyroda Karkonoskiego Parku Narodowego (pp. 241–278). Karkonoski Park Narodowy. (in Polish with English abstract)

Morfologia, właściwości i klasyfikacja gleb ściółkowych w Górach Stołowych i Karkonoszach

Słowa kluczowe

Gleby ściółkowe
Ściółkowe gleby organiczne
Klasyfikacja gleb
Glebowy węgiel organiczny
Góry

Streszczenie

Celem pracy było przedstawienie zróżnicowania gleb ściółkowych (folisols) w Górach Stołowych i Karkonoszach, ze szczególnym uwzględnieniem ich morfologii, wybranych właściwości oraz klasyfikacji zbiorowisk roślinnych. Przebadano łącznie 19 profili glebowych – 10 z Gór Stołowych i 9 z Karkonoszy. Łączna liczba przebadanych próbek wyniosła 78. Folic Histosols stwierdzono na różnych wysokościach – w Górach Stołowych (681–905 m n.p.m.) i w Karkonoszach (839–1408 m n.p.m.). Gleby te były związane ze specyficznymi typami krajobrazu: odsłonięciami skalnymi, zbudowanymi z wysoce odpornych na wietrzenie granitoidów, piaskowców i hornfelsów, gdzie rozwinęły się skaliste folisole (Skeletic Folic Mawic Histosol wg WRB 2022). Grubość tych gleb była na ogół mniejsza niż 30 cm. Na obszarach ze szczelinami skalnymi, dużymi głazami i rzeźbą typu „ruin form" rozwój gleb był znacznie wyraźniejszy – czasami przekraczający 60 cm. Te głębsze profile sklasyfikowano jako typowe folisole (Leptic Folic Rockic Histosol wg WRB 2022). W wielu profilach, szczególnie w Górach Stołowych, obecny był materiał ligninowy. Badane folisole cechowały się kwaśnym i bardzo kwaśnym odczynem. Zbiorowiska roślinne prawdopodobnie miały istotny wpływ na właściwości tych gleb.