MISCELLANEA GEOGRAPHICA – REGIONAL STUDIES ON DEVELOPMENT
Vol. 28 • No. 2 • 2024 • ISSN: 2084-6118 • 87-99 • DOI: 10.2478/mgrsd-2023-0034

Wartanian glacial sediments: insights into deglaciation of Polish Lowlands and Highlands border for geotourism

Abstract
This paper presents five sites located in the marginal zone of the Wartanian stadial within the Odranian Glaciation (MIS6a) on the border of the Central Polish Uplands and Lowlands, representing different glacial forms and geological structures: terminal moraine hill, undulating moraine hill, sedimentary margin of the ice sheet, kame hill, and outwash plain. This differentiation is also reflected in the petrographic composition of the gravels and the interesting surface microstructures of the Scandinavian erratic boulders. This small study area, with its high geodiversity, which we have identified and investigated, has considerable potential for sustainable development. Geotourism is a tool for this development in a peripheral tourist region, providing both economic benefits for the local population and conservation services for the geoecosystem.

Keywords
Glacial sediments • marginal zone • deglaciation • geoecosystem services • geotourism • sustainable development • Wartanian stadial • MIS6a • Central Poland

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Received: 18 December 2023
Accepted: 30 April 2024

Introduction

The transition zone between the Polish Uplands and the North European Lowland Plain in Central Poland represents the marginal area of the Wartanian stadial of the Odranian glaciation (Turkowska 2006; Wachecka-Kotkowska 2015a, 2015b; Fig. 1). Moraines, kames, and outwash plains in the region offer valuable palaeogeographical insights into the last ice sheet's transgression and recession dynamics. In the western study area, glacial lobes (Widawka and Rawka, Pilica and Luciąża) intersect, receiving material from NW and NE directions (Turkowska 2006; Wachecka-Kotkowska et al. 2012; Barczuk & Wachecka-Kotkowska 2015; Czubla 2015; Górska-Zabielska & Wachecka-Kotkowska 2015; Król & Wachecka-Kotkowska 2015; Wachecka-Kotkowska 2015a, 2015b). Petrographic analysis of Scandinavian gravels and erratic boulders in glacial and fluvioglacial deposits reflects transgression processes from source areas in Fennoscandia and glacial deposition in the study region. Sedimentological and petrographical studies, with distinct objectives, collectively contribute detailed knowledge of the study area.

The quantitative petrographic study of gravel fraction, crucial for understanding the dynamics of the percentage of petrographic groups in glacial and glaciofluvial deposits, has been extensively explored (e.g. Górska-Zabielska 2008; Górska-Zabielska et al. 2021). While commonly employed for lithostratigraphic correlation in comparable strata (e.g. Lüttig 1991; Böse & Górska 1995; Woźniak et al. 2009, 2018; Czubla et al. 2019; Górska-Zabielska et al. 2021), petrographic analyses also contribute to regional lithostratigraphic correlation within a chronozone (e.g. Böse & Górska 1995; Zabielski 2006; Kucharska & Pochocka-Szwarc 2012).

Petrographic analysis, coupled with the recognition of Scandinavian indicator erratics, helps identify feeding areas and suggests possible routes during the Wartanian stadial of the Odranian glaciations on the border of the Central Polish Plain and Uplands. These analyses extend lithofacial studies, confirming diversification of lithostratigraphic levels known from the literature (e.g. Kozarski 1995; Czubla 2001; Pettersson 2002; Wysota 2002; Kasprzak 2003; Woźniak et al. 2009, 2018; Wachecka-Kotkowska 2015a, 2015b; Czubla et al. 2019; Górska-Zabielska et al. 2021).

In the study of erratic boulders, their various applications, geological heritage, and contribution to geodiversity are recognised (e.g. Alahuta et al. 2018; Moliner & Mampel 2019; Elmi et al. 2020; Meyer 1981, 2006, 2008; Cai 2021; Górska-Zabielska 2021, 2023). As evidence of geological processes during ground structure formation and glacial transport, erratic boulders archive ongoing geomorphological processes, forming a crucial part of the region's geoheritage. Many other important benefits/services provided by erratic boulders – educational, ecological, geoconservational, pro-environmental, cultural, aesthetic, signposting, recreational – support the sustainable development of peripheral tourist areas, with geotourism being used as a tool. All these values justify the protection of this unique geological heritage (Motta & Motta 2007).

Considering the societal role of science, we highlight selected erratic rocks with significant geotouristic appeal that are used to target geotourists and nature enthusiasts familiar with geoconservation. Our study delves into the analysis of medium-grained (4–10 mm) gravels and erratic boulders in the five sites, which are located within the geomorphologic border zones of Central Poland, in the SE Łódź region. Various authors (e.g. Wentworth 1922; Schulz 2003; Górska-Zabielska 2010; Vinx 2015; Górska-Zabielska et al. 2020, 2022) suggest that the shortest axis of an erratic boulder should lie between 25 and 50 cm. These deposits, from the Wartanian stadial of the Odranian glaciations (MIS6a – Marine Isotope Stage), are situated along the Central Polish Lowlands and Uplands border, spanning from Radomsko (in the west) to Przedbórz (in the east), including a portion within the interlobal zone (Fig. 1B).

Our study of the geomorphological heritage enhances the dissemination of earth and environmental sciences, improves and

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stimulates environmental education, and provides geoecosystem services (e.g. Gordon & Barron 2013; Alahuta et al. 2018; Finzi et al. 2021; de Paula Silva et al. 2021; Wolniewicz 2021) for the sustainable economic development of the study area. This, in turn, serves to create a new tourism offer, which is linked to an improvement in the quality of life of local communities (Frey 2021; Drinia et al. 2022).

Study Area and Objectives

The present surface of the study region reflects the morphological processes of the last 24 million years. Elevated summits, including Chełmo Hill (323 m a.s.l.) to the south, and Bąkowa Hill (287 m a.s.l.) and Czartoryja (266 m a.s.l.) to the south-east, are intricately connected to the ancient substratum, with visible Paleogene–Neogene erosional history. These structures are situated on the Kodrąb Elevation, enclosing the Łódź Cretaceous Syncline to the south, and lie on the border of the Przedbórz-Małogoszcz Range, Radomsko Hills, and Piotrków Plain.

The current geomorphological landscape results from Odranian glaciation, detailed in studies by Wachecka-Kotkowska (2015a) and Szmidt & Wachecka-Kotkowska (2019). The developmental history unfolded in six stages, encompassing pre-Odranian, Odranian, and Wartanian periods. These stages included the ice sheet's advance, stagnation, and retreat during the Wartanian stadial. Noteworthy events included the merging of the Widawka Lobe with the Rawka, Pilica, and Luciąża Lobe (Fig. 1A), followed by the ice sheet's retreat and stagnation. Deglaciation concluded with the retreat of the Pilica and Luciąża eastern lobe, leading to postglacial and post-Wartanian phases. The final stage involved ongoing relief transformation during the Vistulian and Holocene periods.

The diverse lithological and petrographic characteristics of the studied sediments can be attributed to the testing of a multitude of different landforms that occur at the edge of the last ice sheet in the study area (Fig. 1B). Landforms include a terminal moraine hill in Masłowice, an undulating till plateau in Ochotnik, a sedimentary marginal ice-sheet zone in Stobiecko Szlacheckie, a kame hill in Miejskie Pola, and an outwash plain in Rzejowice (Fig. 1B).

The geological and geomorphological diversity categorises the study area as geodiverse (e.g. Gray 2013, 2018, 2019; Kubalíková et al. 2021; de Paula Silva et al. 2021), with significant potential for geotourism development in peripheral or indifferent areas (Smoleński 2012) as a tool for sustainable development (Chrobak et al. 2021; Frey 2021; Drinia et al. 2022). The article aligns with the geoconservation trend in local development strategy by integrating various methods (e.g. Gray 2013, 2018, 2019; Anderson et al. 2015), a crucial factor in preserving geodiversity.

The study focuses on the petrographic composition of Scandinavian glacial and fluvioglacial deposits, particularly medium-sized gravel fractions. These analyses, alongside structural and textural assessments, offer a detailed morphogenesis description of the study area. Tentative assumptions suggest potential differences in petrographic percentages within the marginal forms of the Widawka Lobe and the Rawka, Pilica and Luciąża Lobe (Fig. 1B), based on distinct geomorphological settings. The purpose of these analyses is to confirm or reject this initial hypothesis.

Comparing evidence for the Scandinavian origin of glacial deposits with fluvioglacial deposits from the Wartanian stadial is essential. The authors' previous research discusses the significance of various lithological deposits for petrographic content (Górska-Zabielska & Wachecka-Kotkowska 2014, 2015).

The vicinity of Przedbórz (SE part of the study area) features numerous outcrops of Cretaceous, Jurassic, and a small Triassic formation (Fig. 1 in Górska-Zabielska et al. 2022). Some morphologically defined outcrops, influenced by lithological formation and structural conditions, contribute to cuesta or resistive relief (see Sala 2011). Petrographic research results are expected to help determine the ice sheet advance direction(s) (Fig. 1B), considering the importance of the bedrock's configuration.

Petrographic research will also attempt to determine the age of the transgression, the subsequent stages of recession, and the time of development of the individual formations.

In this paper we would like to point out some unique erratic boulders that have the potential to promote geotourism in this peripheral tourist area (Smoleński 2012). By providing expert knowledge on some significant erratic boulders, which are not generally known, we demonstrate the importance of the geoheritage of the study area, and how this can drive the sustainable development of the region (e.g. Frey 2021).

Material and Methods

The research was carried out at five study sites (Stobiecko Szlacheckie, Rzejowice, Ochotnik, Masłowice and Miejskie Pola; Fig. 1B), located in exploited gravel pits, sand pits, and old closed outcrops. In the context of the regionalisation of the study area, the locations of the sites and the number and type of samples are presented in Table 1.

A sedimentology analysis, according to Zieliński and Pisarska-Jamroży (2012), was made in the study area. The description of individual actions related to sampling and methods of separation and the petrographic identification of the medium-grain (4–10 mm) fraction has been presented in detail in numerous works (e.g. Górska 2000a, 2000b, 2006; Górska-Zabielska 2007, 2008, 2010; Górska-Zabielska & Zabielski 2010, 2011). The consequent laboratory analyses follow the principles of Cepek (1969), Rutkowski (1995) and Górska (2000a; Table 2.4, p. 31).

In the case of erratic boulders, information was collected in the field on their dimensions, petrographic type, source area, indicative value, and characteristic features. Detailed methodological descriptions are given in other papers (e.g. Lüttig 1991; Meyer & Lüttig 2007; Górska-Zabielska et al. 2020, 2022). The estimated volume and weight (Table 2) were calculated according to the formula proposed by Schulz (1964): 0.523 × length × width × height, assuming 1 m^3 = 2.75 t.

Boulders were also examined in the field for the presence of microforms, which are characteristic of the subglacial environment, in which erratics at the base of ice sheets are transported and rubbed against harder material. The rounded edges of a boulder, which indicate transport in high-energy subglacial and inglacial conditions, and surface features typical of the periglacial environment (e.g. aeolian erosion, corrasion, and ridge lines) were documented. Field analysis also included contemporary processes affecting the boulder surface (e.g. exfoliation, corrasion, and colonisation by epilithic flora (e.g. Górska-Zabielska 2020; Górska-Zabielska et al. 2020).

The location of the erratic boulders analysed, as well as their basic characteristics, are given in Table 2. The Scandinavian source areas of the indicator erratics are shown in Figure 3. Photographs were taken by M. Górska-Zabielska in 2021.

Results

Lithology and sedimentological structures

In **Stobiecko Szlacheckie** (Fig. 2), below the erosional horizon, at a depth of 8–16 m, different-grained sands with horizontal Sh/SG beds occur, in which large clasts of gravel and layers of silt several centimetres thick can be found. Although the sediment has a tafloid habit, there are small-scale deformation structures (up to 10 cm) of gravitational disturbance.

At a depth of 10–11 m, a distinct and continuous package of massive or horizontally laminated Gm/GSm (SGh/GSh) gravels is observed. Coarser and finer sediments, in addition to

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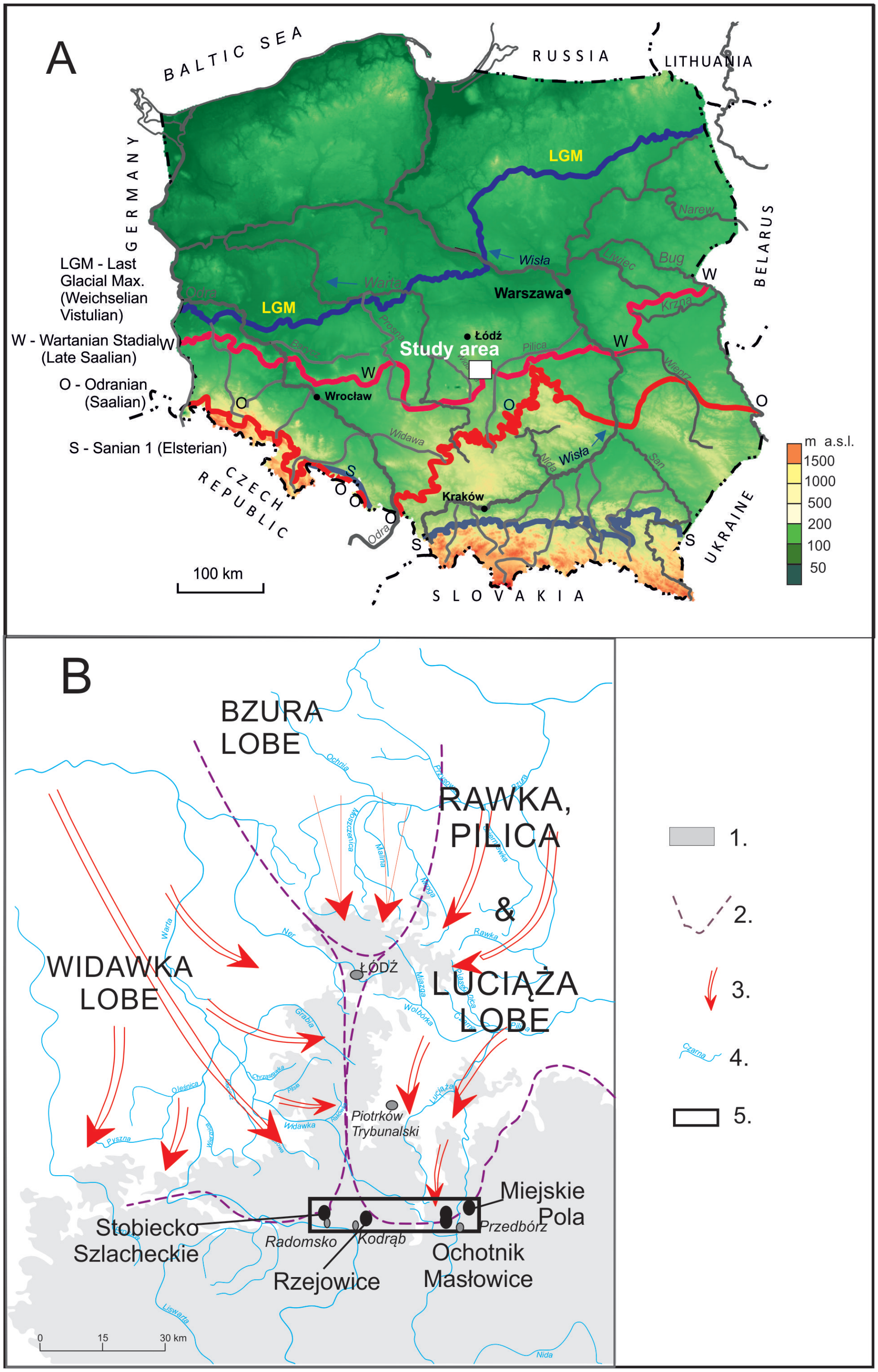

Figure 1. Location of study sites within the transition zone between the Polish Uplands and the European Plain in the central part of Poland. A: The sites belonging to the marginal zone of the Wartanian stadial of the Odranian glaciation (MIS6a). B: 1 – area above 200 m a.s.l.; 2 – lobes of the Wartanian ice sheet acc. to Turkowska (2006), changed; 3 – direction of the ice movement (acc. to Wachecka-Kotkowska 2015b); 4 – rivers; 5 – study area with investigated sites
Source: own elaboration

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the developed cycles, form individual horizons up to 30 cm thick (depths of 8 m, 8.2 m, 9.4 m). Studies of the dip of the lamina packages indicate that the flow was in a southerly direction [240°/4° (depth of 13 m); 189–198°N/7° (depth of 8–9 m)].

The erosional gravels are overlain by a DGm/GDm gravelly diamicton with a massive structure and a thickness of 2 m. The clay matrix contains cobbles. Large clasts have a chaotic arrangement, but most of their longer axes are highly tilted, which may indicate sediment liquefaction and slope flow. At a depth of 0–6 m, without disturbance or deformation structures, fine and coarse-grained sands are bedded horizontally Sh and dip slightly to the south-west (230°/6° [depth of 5 m]). The total thickness of 2.5 m of gravelly sand and sand are covered by the sandy diamicton DS with a fluid structure.

Within the **Masłowice** hill, there is a field of boulders of mainly Scandinavian rocks. Two clay horizons are involved in the structure of the form: the upper one, 1.5–3 m thick, has been petrographically studied and described as Wartanian (Czubla 2015; Górska-Zabielska & Wachecka-Kotkowska 2015), and the lower one, drilled at 8.8 m below the surface, probably originates from the beginning of the Odranian glacial episode. In the 6.5 m deep exposure, three lithofacies complexes were distinguished: the upper one, consisting of brown, light sandy till Dmm/Ds, underlain by moraine gravels GSm/Gm, the middle one SGh/GSh/Gm and the lower one with lithofacies Sh, Sr, SFh, and GSh. The contact between the lithofacies is sedimentary.

At the **Ochotnik** site, the sediments exposed to a depth of 6 m show a bipartite character, similar to the Masłowice site. In the upper part of the profile, there are glacial till (3.5–0 m) with a Dm/DSm lithofacies complex and sandy grains. Flush boulders can be seen in the bottom layer of the till. In the middle part, a gravelly-sandy sequence (4.03.5 m) is exposed, where the Sh, Sl lithofacies change to SGh/Gm lithofacies and, in the lower part, a sandy sequence (5.4–4.0 m), with a Sh, Sl →GSh lithofacies complex, is exposed.

On the **Miejskie Pola** hill, with a relative height of about 20 m, there is a large sand pit. In its walls, mainly fine sandy sediments are exposed. Till and isolated boulders are only found at the base of the hill. Coarser sediments, GSm/GSh sandy gravel, are deposited in the summit areas within a series of normal faults. In the central part of the hill, there is a sandy core with Sm/SFm lithofacies with post-sedimentary disturbance. The whole form is built up by a huge complex of sandy silty sediments with the character of a local glacideltaic (limnic) cone with a sequence of lithofacies Sl→Sh→Sr→SFr→SFw→FSh→FSr→FSw (with a direction 130º/5º).

At the **Rzejowice** site, a two-part sedimentary complex was investigated consisting of sandy-gravely lithofacies SGm, SGl, and SGh in the bottom. The top layer shows a succession of sandy lithofacies Sh-Sr/Src (out of channel sediments) – St-Sp-Sl (trough and channel sediments and sandy bedforms).

Petrographic Analysis of Medium-Grained Gravel (4–10 mm)

Approximately half of the gravels present in the area, deriving from various lithological deposits – namely from (sand-gravelly) kame (Miejskie Pola), till plateau (Ochotnik), and (till-sand-gravelly) terminal moraine with ice-sheet edge (Stobiecko Szlacheckie, samples 2 & 3) – that were deposited during the Odranian glaciation, were identified as Lower Palaeozoic limestones (Table 1; Fig. 2). The grey Silurian limestones with outcrops at the bottom of the central Baltic Sea are usually accompanied by red Ordovician limestones from the western part of this water area (Fig. 3). The depositional conditions in three of these different environments have not influenced the final petrographic content of these most erosionally sensitive carbonate rocks.

The location of these deposits in two different lobes (Widawka in the west and Pilica and Luciąża in the east – see Fig. 1) does not affect the petrographic percentages. The igneous and metamorphic gravel remains at about 35–37%. Sandstones are the third petrographic group in this fraction in terms of number. They are more or less equally represented (5–12%) in each sample.

Gravels originating from a morainic hill (Masłowice) and a terminoglacial fan (Stobiecko Szlacheckie, sample 1) in two different lobes (Fig. 1B) are characterised by the presence of mainly crystalline rocks (about 60–90%) and sandstones (8–26%; Table 1). The studied gravels, completely devoid of carbonate rocks, were accumulated during the short glacial Wartanian stadial. Also, the Rzejowice sample is devoid of Lower Palaeozoic limestones; here, this is due to their leaching into the outwash plain.

A small percentage of quartz, known for its resistance to destruction, was identified in all samples.

Erratic boulder analysis

Fourteen erratic boulders, found at two geosites and in their immediate vicinity, were examined in detail. Their main characteristics are presented in Table 2.

Only one erratic boulder (no. 11 in Table 2) was found *in situ*. The remaining thirteen remain *ex situ*, most likely moved from their original positions by farmers, often from the field itself to the field boundaries. It is recommended that the boulder be left in the same place (*in situ*) to reconstruct the direction of the advance of the ice sheet. The lithostratigraphic significance of the *ex situ* and *in situ* boulders in question is comparable, as their positions differ by only a few tens/hundreds of metres. The measured dimensions of boulder no. 11 are very small, but this is due to the fact that the top of the boulder is slightly above ground level.

Seven of these are indicator erratics – they originate from the Åland Islands (Åland rapakivi granites, Figs. 4 & 5; Åland quartz granites, Fig. 9) and from the SE part of Sweden (Småland granites, Figs. 6 & 7). The remaining erratics are from unknown specific source regions within the Baltic Shield. According to Schulz (1996) and Górska (2000a), the proportion of limestones decreases with increasing grain size, whereas the proportion of crystalline rocks increases. This typical trend is the result of the physical properties of the rocks. For this reason, no carbonate boulders were identified among the Scandinavian erratics in the study area.

Twelve boulders are heavier than one tonne and three of them are heavier than two tonnes. One of the sides of boulders 2 and 14 forms a glacial polish, which is a record of subglacial processes. Boulders 2 and 12–14 show corrugated relief in the form of micro-ribs and micro-grooves, which is typical evidence of a periglacial climate (frosty and dry conditions), operating in the foreland of the retreating ice sheet. The most mature surface microform of an erratic that has resided in such an environment is a clearly visible corrasive facete. There is such a microform on the upper surface of the rock (Fig. 8). Boulder 9 is colonised by lichens, evidence of a well-functioning ecology of abiotic and biotic life.

Discussion

The research carried out appears to indicate that in the area of the Przedbórz-Radogoszcz Range, on the border between the Łódź Cretaceous Syncline and the Kodrąb Elevation, marginal forms of the Wartanian ice sheet were formed during mixed deglaciation (Fig. 10). The ice sheet flowed in from the north (Ochotnik site; see Wachecka-Kotkowska 2015b). The dynamics of deglaciation varied and depended on the configuration of the Mesozoic bedrock (Szmidt & Wachecka-Kotkowska 2019). During the

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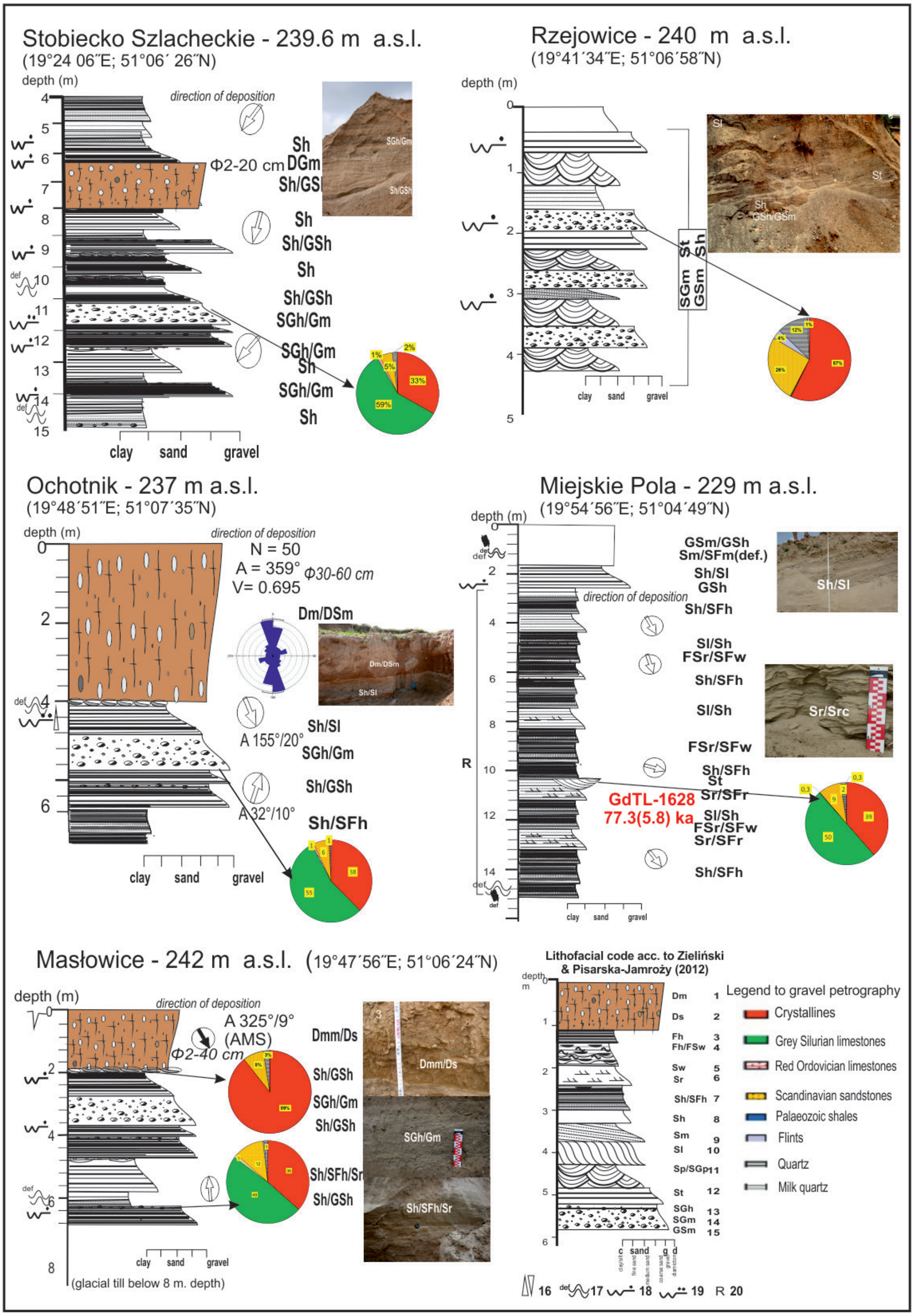

Figure 2. Schematic profile of the lithology in five outcrops with sedimentary structures according to own elaboration (LWK) based on Wachecka-Kotkowska (2015a) and marked sampling sites for analysis of erratic gravels and erratic boulders. 1 – massive diamicton; stratified diamicton (Dm); 2 – matrix supported and clast poor (Ds); 3 – horizontally laminated fines (Fh); 4 – wavy laminated sand with fines (SFw); 5 – wavy laminated sand (Sw); 6 – ribbon cross-laminated sand (Sr); 7 – horizontally stratified sand/laminated fines (Sh/SFh); 8 – horizontally stratified sand (Sh); 9 – massive sand (Sm); 10 – sand low-angle (<15°) cross-stratification (Sl); 11 – planar cross-stratified gravelly sand/gravelly sand (Sp/SGp); 12 – trough cross-stratified sand (St); 13 – horizontally stratified sandy gravel (SGh); 14 – massive gravelly sand (GSm); 15 – massive sandy gravel (SGm); 16 – normal/inverted sequence fractional grain size; 17 – continuous deformations of various types; 18 – local erosion surface; 19 – regional erosion surface; 20 – rhythmite

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Table 1. Percentage of petrographic types of 4–10 mm gravel in the study area

	Rzejowice	Ochotnik 1	Ochotnik 2	Masłowice	Miejskie Pola 1	Miejskie Pola 2	Stobiecko Szlacheckie 1	Stobiecko Szlacheckie 2	Stobiecko Szlacheckie 3
	Outwash plain	Till plateau		Morainic hill	Kame		Terminoglacial fan, sedimentological edge of ice-sheet		
	%								
Kr	57.4	37.2	37.5	89.3	38.6	34.8	86.0	36.9	33.2
Wp1	0.0	51.4	54.7	0.0	49.7	51.4	0.0	52.5	58.5
Wp2	0.0	0.3	0.9	0.0	0.4	0.6	0.0	2.7	1.2
Wk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pp	25.9	5.1	6.0	8.2	8.9	11.9	12.9	4.8	5.0
Łp	0.0	0.6	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Krz	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Qp	12.0	1.1	0.9	2.5	2.1	0.9	1.1	2.9	1.7
Qml	0.7	0.0	0.0	0.0	0.3	0.2	0.0	0.2	0.4
in.	0.4	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Legend: Kr – crystalline rocks, Wp1 – grey Silurian limestones, Wp2 – red Ordovician limestones, Wk – Cretaceous limestones, Dp – Devonian dolomites, Pp – sandstones, Łp – Palaeozoic shales, Krz – flints, L – lydites, Qp – quartz, Qml – milk quartz, in. – other; analysed by M. Górska-Zabielska

Table 2. The main characteristics of the erratic boulders, found in the study sites and their immediate vicinity

No.	Length [m]	Width [m]	Height [m]	Circuit [m]	Volume [m³]*	Weight [t]*	Petrographic type and kind of erratic; Fig. no.	Specific morphological characteristics; other information
1	1.65	1.0	0.8	4.6	0.69	1.90	Åland rapakivi; Figs. 5–6	near Masłowice
2	1.7	1.05	0.9	4.75	0.84	2.31	Småland granite; Figs. 7–8	glacial polish, spur outline, corrasive microrelief, eolian cut, Ochotnik
3	1.3	1.1	0.5	4.1	0.37	1.03	granite-gneiss; Fig. 9	Ochotnik – Kalinki
4	1.35	1.2	1.1	3.75	0.93	2.56	red granite with pegmatite vein	Kraszewice (4 km to the S of Masłowice), a boulder cracked on the surface of the vein, weathered
5	0.95	0.75	0.48	3.2	0.18	0.49	granite	Wierzchlas (14 km to the E of Masłowice)
6	1.4	1.1	0.75	4.05	0.60	1.66	fine crystalline granite	
7	1.4	1.4	0.4	4.5	0.41	1.13	fine crystalline granite with pegmatite vein	
8	1.35	0.95	0.75	4.2	0.50	1.38	Småland granite, gneissed	
9	1.15	1.1	0.75	3.75	0.50	1.36	Åland rapakivi	mossy, covered with lichen, Wierzchlas (location as above)
10	1.7	0.75	0.7	4.05	0.47	1.28	granite with pegmatite veins	Sokola Góra (8 km to the SSE of Masłowice)
11	1.2	0.85	0.55	3.4	0.29	0.81	Åland granite with pegmatite vein	**the only boulder *in situ!*** measurements of the part of the boulder above the ground, Sokola Góra (location as above)
12	1.4	1.3	0.7	4.75	0.67	1.83	fine crystalline granite, Åland rapakivi	corrasive microrelief, Sokola Góra (location as above)
13	1.38	0.95	0.55	3.75	0.38	1.04	red coarse crystalline granite with pegmatite vein	
14	1.85	1.6	0.55	5.3	0.85	2.34	coarse crystalline Åland quartz granite	corrasive microrelief, glacial polish, Pratkowice (8 km to the SSE of Masłowice)

**The volume of the boulders was calculated using the formula 0.523 × length × width × height; weight calculation assumes that 1 m³ = 2.75 t (Schulz 1964)*

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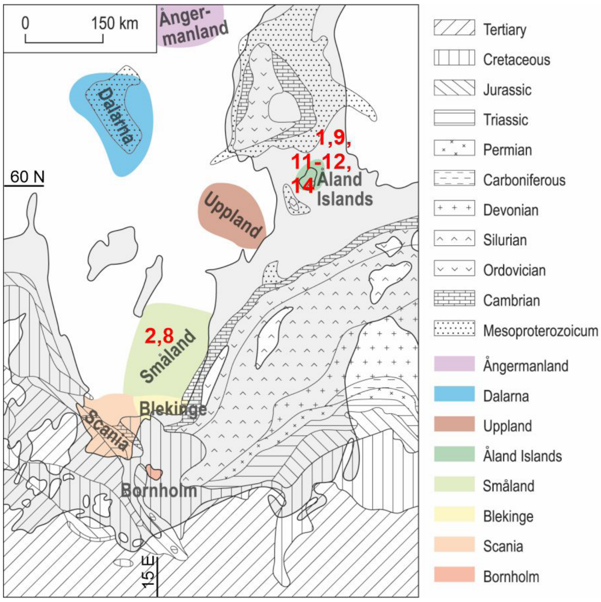

Figure 3. Parent locations of seven indicator erratic boulders presented in this paper, against other primary Scandinavian feeding areas. The relevant numbers are listed in Table 2
Source: drawn by Małgorzata Gościńska-Kolanko

Figure 4. Masłowice, well-reworked rapakivi Åland granite; erratic boulder 1 in Table 2.
Source: photograph by Maria Górska-Zabielska

Figure 5. Masłowice, close-up of the rapakivi structure in Åland granite
Source: photograph by Maria Górska-Zabielska

Figure 6. Ochotnik, close-up of the Småland granite.
Source: photograph by Maria Górska-Zabielska

transgression, some peaks of the Mesozoic remnant hills above 250 m a.s.l. were nunataks (Wachecka-Kotkowska 2015a; Fig. 10). In the depressions of the Mesozoic subsurface, or between the remnant hills (Miejskie Pola), dead-ice patches were deposited for longer periods, resulting in the formation of kames-like forms. On the other hand, the elevations of the Mesozoic substrate forced the glacier masses to flow uphill, sometimes causing a local standstill of the ice sheet and rapid melting, as in the case of Stobiecko Szlacheckie, which shows a tafloid glacimarginal cone (in the sedimentary margin ice-sheet edge), built of gravelly-sandy sediments (Wachecka-Kotkowska 2015a).

The large but varied dynamics of deglaciation is recorded in the structural features of the sediments. Glacimarginal forms are characterised by lithofacies and lithogenetic differentiation. The presence of DSm, Dm diamictons and boulder beds indicates direct contact with the ice sheet during deglaciation. A meltwater diamicton is present in Masłowice, and the basal part of the ice sheet has been documented in Ochotnik. Lithofacies representing St, Sp trough sediments are almost absent at the studied sites, with the exception of sand deposits at Rzejowice. The dominant lithofacies are SGh, Sh, and Sr, indicating glacial sedimentation (Miejskie Pola). The SGh, Sh and Sr lithofacies point to weak flow or its expiration (Miejskie Pola). Most sediments were deposited out of channel and on the floodplain of the terminoglacial cone (Masłowice & Stobiecko Szlacheckie) or in shallow braided troughs on the proximal terminoglacial cone (Ochotnik). The presence of different types of sediment deformation confirms the deglaciation of the ice sheet, which varied in time and space (Wachecka-Kotkowska 2015a).

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Figure 7. Ochotnik, Småland granite with well-rounded edges, glacial polish in places, corrosion microrelief; erratic boulder 2 in Table 2.
Source: photograph by Maria Górska-Zabielska

Fig. 8. Ochotnik, granite-gneiss is a ventifact with a clearly visible corroded facete on the upper surface of the rock; erratic boulder 3 in Table 2.
Source: photograph by Maria Górska-Zabielska

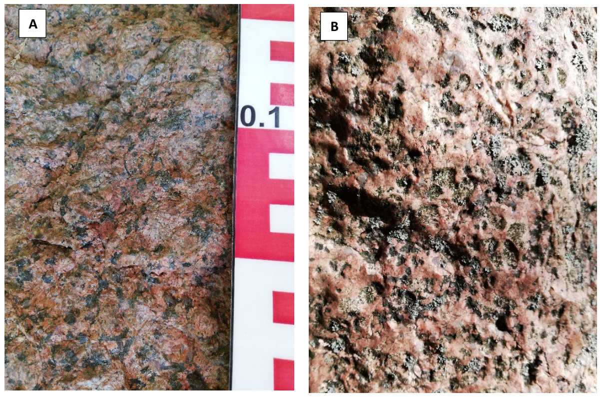

Figure 9. Example of the same Åland granite with surfaces representing different states of preservation: A – fresh surface, B – eolised surface; the scale is the same for both figures.
Source: photographs by Maria Górska-Zabielska

The studies carried out showed variability in the petrographic composition of medium-grained fluvioglacial and glacial gravels from the area of retreat of the Central Polish glaciations. The main petrographic types are crystalline rocks and limestones of the Lower Palaeozoic. Neither the geomorphological position of the sampled deposits, which is obviously related to the different lithology, nor the location in two different glacial lobes influenced the percentage content of petrographic type in the analysed gravels. The main factor that differentiates the petrographic composition of the sediments must be associated with separate advances of the ice sheet. Therefore, the thesis about the influence of weathering on the petrographic composition, which is often mentioned in the literature (e.g. Lisicki 1998, 2000, 2003; Czubla 2001; Woźniak 2004), must be rejected in the case of the analysed material. No such regularity was observed.

Due to the small number of petrographic samples (4–10 mm) analysed in this study, it is not possible to determine the direction in which the ice sheet moved. However, our previous studies (Górska-Zabielska & Wachecka-Kotkowska 2014, 2015) in medium and coarse gravel fractions confirmed the initial hypothesis that this is the zone where two ice-sheet lobes came into contact – namely Widawka Lobe and Rawka, Pilica and Luciąża Lobe. Thanks to the results of complex petrographic analysis, it is possible to determine the directions of advance of the ice masses from NE, NNW (the Widawka Lobe) and NE, NEE (the Rawka, Pilica and Luciąża Lobe).

Evidence of periglacial and contemporary morphogenetic processes is visible on the surface of some of the erratics. All these elements constitute the scientific values of erratic boulders; therefore, they should be considered as geosites (Reynard 2004; Migoń 2012).

Erratic boulders have cultural value; boulders 3, 5 and 7 have their own names, and boulders 3 and 8 have additional legends. Due to their size, the erratic boulders have an aesthetic value. With the exception of boulder 9, all are protected as monuments of inanimate nature. Only one boulder (no. 3) is registered as a geosite in the Central Register of Polish Geosites (https://cbdgportal.pgi.gov.pl/geostanowiska/).

The erratic boulders described above already provide geoecosystem services such as: cognitive, educational, pro-environmental, cultural, conservational, recreational, signposting, and aesthetic (see Finzi et al. 2021; da Silva et al. 2022; Lima & Pereira 2023). There seem to be no contraindications to continuing to perform these functions in the future. Above all, these important geosites should be protected – their *in situ* conservation is an

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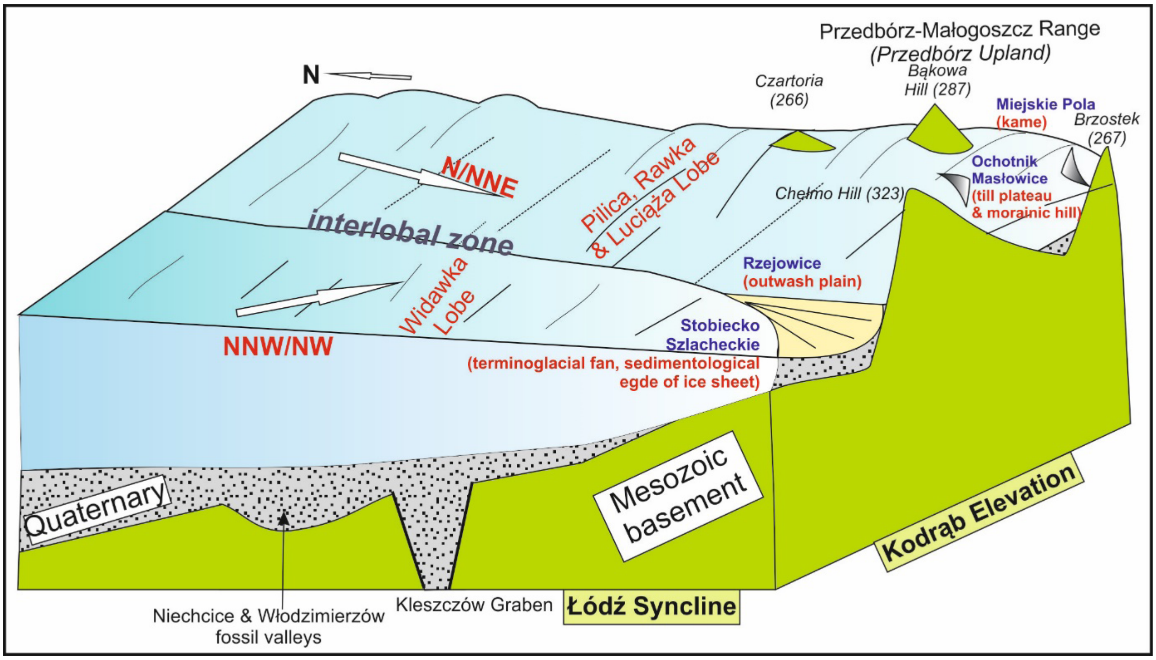

Figure 10. Model of transgression of the Wartanian ice sheet in Central Poland and stagnation on the northern slopes of the highlands
Source: own elaboration

important task, as it provides present and future generations of researchers with the opportunity to understand the Earth's history, past environmental changes, and geological phenomena (e.g. Urban et al. 2022; Rodrigues et al. 2023).

Erratic boulders (even monuments of abiotic nature) are being lost for different reasons from the environment due to a lack of knowledge in the community (e.g. Piotrowski 2008; Chrząszczewski 2009). Therefore, there is a need for continuous education to raise the awareness of the local population who have inherited the geological assets of the region (e.g. Urban et al. 2022; Rodrigues et al. 2023). The importance of geoeducation in the promotion of the local geological heritage is highlighted in a recent article published by Górska-Zabielska (2023). Landscapes deprived of erratic rocks lose their geodiversity.

Our ability to apply this knowledge of erratic rocks in the environment is important for the sustainable development of the region. Erratic boulders and, more generally, rock specimens that are typical of the immediate environment have considerable potential for the development of local geotourism. In the literature, there are numerous examples of the use of such objects in educational, sightseeing, and nature tourism (e.g. Górska-Zabielska & Dobracki 2015; Moliner & Mampel 2019; Elmi et al. 2020; Cai 2021; Górska-Zabielska 2021). Erratic boulders may also be used in geowatching (Garofano 2015). Knowledge transfer raises the awareness of the recipients (e.g. tourists, visitors, holidaymakers, Green Schools), so that familiar erratics speak to recipients who are already able to appreciate the geological heritage of their own country. As communication is a tool for protection (Garofano 2015; Urban et al. 2022; Rodrigues et al. 2023), it is only a small step to care for the protection of an erratic – a witness of the glacial age.

In this way, boulders can be a driving force for the sustainable development of local communities. They bring economic benefits to all those involved in the exhibition and geo-interpretation of erratic rocks, including the initiators of the idea, landscape architects, transport and crane operators, designers and producers of information boards and labels, as well as geo-interpreters, maintenance service workers, who take care of the objects' protection (volunteer eco-patrol, cleaning the surface of the rock from graffiti and lichen), and ensure the safety of geotourists. It should not be forgotten that an effective geo-interpreter and/or a clear set of information panels are needed to share the knowledge.

Conclusions

Key findings are detailed in this chapter. The focus is on the diversity of glacial sediments in different geomorphological settings and their geoecosystem services. Special attention is paid to geotourism. This is a successful driver for sustainable development in a peripheral region.

1. High geodiversity, due to the peripheral location of tectonic units (Łódź Syncline/Kodrąb Elevation/Przedbórz-Małogoszcz Range) on the border between the Polish highlands and lowlands, caused the transgression of the Wartanian ice sheet of the Odranian glaciation – in the form of two glacial lobes, Widawka and Rawka, Pilica and Luciaża – onto the increasingly higher Mesozoic substrate. This, in turn, influenced deglaciation and the formation of various shapes, which are located close to each other on the same parallel.
2. Glacial and fluvioglacial landforms were formed in different sedimentary environments of mixed deglaciation. They formed a series of moraine hills, an undulating plateau behind the glaciomarginal zone, kames between clumps of dead ice, and elevations of Mesozoic hilltops or outwash plains. The large boulders indicate the extreme strength of the ice sheet, which deposited sediments on the northern slopes of the uplands of the Przedbórz-Małogoszcz Range. There is no shortage of records of glacial sedimentation episodes – lodgement till and melt-out till (Masłowice, Ochotnik). The sedimentological record shows high-energy structures of glacial sedimentation with glacial floods (Stobiecko Szlacheckie), typical structures of proglacial braided rivers (Rzejowice). There is also an abundance of low-energy structures, up to the disappearance of a stream, typical of glaciofluvial environments (Miejskie Pola).
3. The percentages of petrographic types distinguished in the medium-coarse fraction of glacial and fluvioglacial deposits

are independent of lithology and the geomorphological setting. One of the drivers for percentage anomalies is the post-depositional weathering process.

4. Fourteen erratic boulders are evident traces of the glaciation that occurred in this area between Radomsko in the west and Przedbórz in the east. Unfortunately, there is only one boulder *in situ* that can provide services for terrestrial cosmogenic nuclide exposure dating.
5. The described Scandinavian erratic boulders are characterised by scientific and cognitive values, and their educational value is not insignificant. In general, locals know little about their presence, and have no idea of the genesis of their vicinity. Therefore, all activities aimed at promoting services in relation to geological objects and processes (geodiversity) are important for geoheritage dissemination.
6. The activities listed above can lead to a better acceptance of the proposed action in the field of territorial and general protection of nature and landscapes, including the protection of geological elements and phenomena. As a result, greater public awareness of the need for geoconservation will translate into more effective planning and adequate provisions in strategic documents of local self-government.
7. A number of additional erratic rocks from the region require examination to ascertain their potential value for geotourism implementation. The development of such a tourism initiative is a pressing matter, as this type of nature-based tourism is a highly effective tool for the sustainable development of peripheral tourist areas.
8. All values and the main results derived from the sedimentological analyses of the erratic rocks in the study region are ready to be used in geotourism. Together with other elements of geodiversity, they increase the attractiveness of the region. A new tourist offer in the context of sustainable development could be a driving force in improving the quality of life of local communities. The welfare of the inhabitants and the economic situation of the Przedbórz-Małogoszcz Range can be positively influenced by the presence of erratic rocks, if their values of scientific, educational, and aesthetic services (large dimensions) are used effectively and promptly in geotourism.

Authors' Contributions

Maria Górska-Zabielska and Lucyna Wachecka-Kotkowska - conceptualisation, methodology, fieldwork, writing – original draft preparation, writing – review and editing, supervision. Both authors have read and agreed on the published version of the manuscript.

Funding

The research of Maria Górska-Zabielska received funding from Jan Kochanowski University in Kielce, Poland, project no. SUPB. RN.21.256.

Acknowledgements

We thank anonymous reviewers, whose insightful comments and suggestions significantly helped us to improve our work. We also thank Dariusz Wieczorek from the Polish Geological Institute – National Research Institute for field assistance and Małgorzata Gościńska for drawing Figure 3. The language editor owes our gratitude.

Conflicts of Interest

The authors declare no conflict of interest.

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References

Alahuta, J, Ala-Hulkko, T, Tukiainen, H, Purola, L, Akujärvi, A, Lampinen, R & Hjort, J 2018, 'The role of geodiversity in providing ecosystem services at broad scales', *Ecological Indicators*, vol. 91, pp. 47–56.

Anderson, MG, Comer, PJ, Beier, P, Lawler, JJ, Schloss, CA, Buttick, S, Albano CM & Faith DP 2015, 'Case studies of conservation plans that incorporate geodiversity'. *Conservation Biology*, vol. 29(3), pp. 680–691.

Barczuk, A. & Wachecka-Kotkowska, L. 2015, 'Analiza minerałów ciężkich jako metoda określania źródła osadów wodnolodowcowych w obszarze między Piotrkowem Trybunalskim, Radomskiem a Przedborzem' ['Analysis of heavy minerals as a method for determining the source of the glaciofluvial sedments in the Piotrków Trybunalski, Radomsko and Przedbórz area']. *Acta Geographica Lodziensia,* vol. 103, pp. 9–24.

Böse, M & Górska, M 1995, 'Lithostratigraphical Studies in the Outcrop at Ujście, Toruń-Eberswalde Pradolina, Western Poland', *Eiszeitalter und Gegenwart*, vol. 45, pp. 1–14.

Cai, G 2021, 'The Changing Landscape: A Study of Natural Transformation on Ryoan-Ji Rock Garden', *ACADEMIA Letters*, 2098.

Cepek, AG 1969, 'Zur Bestimmung und stratigraphischen Bedeutung der Dolomitgeschiebe in den Grundmoränen im Nordteil der DDR', *Geologie*, vol. 18, pp. 657–673.

Chrobak, A, Novotný, J & Struś, P 2021, 'Geodiversity Assessment as a First Step in Designating Areas of Geotourism Potential. Case Study: Western Carpathians', Front. Earth Sci., vol. 9: 752669.

Chrząszczewski, W 2009, 'Stoneman spod Konina' [Stoneman from Konin], *Nowy Kamieniarz*, vol. 43, pp. 40–44.

Czubla, P 2001, 'Eratyki fennoskandzkie w Polsce Środkowej i ich znaczenie stratygraficzne' ['Fennoscandian erratics in the Middle Poland and their stratigraphic significance'], *Acta Geographica Lodziensia*, vol. 80.

Czubla, P 2015, 'Analiza zespołów eratyków w glinach lodowcowych i ich znaczenie w rekonstrukcji zasięgu lądolodu warciańskiego w obszarze między Piotrkowem Trybunalskim, Radomskiem a Przedborzem' [summary: 'Indicator erratics analyses in glacial tills and their significance for the reconstruction of icesheet dynamics of the area between Piotrków Trybunalski, Radomsko, and Przedbórz)', *Acta Geographica Lodziensia*, vol. 103, pp. 25–44.

Czubla, P, Terpiłowski, S, Orłowska, A, Zieliński, T & Pidek, IA 2019, 'Petrographic Features of Tills as a Tool in Solving Stratigraphical and Palaeogeographical Problems—A Case Study from Central-Eastern Poland', *Quaternary International*, vol. 501, pp. 45–58.

da Silva, MLN, Mansur, KL & Nascimento, MAL 2022, 'Ecosystem services assessment of geosites in the Seridó Aspiring UNESCO Geopark Area, Northeast Brazil', *Geoconservation Research*, vol. 5, no. 1, pp. 29–46.

de Paula Silva, J, Alves, GB, Ross, JLS, de Olivera, FS, do Nascimento, MAL, Grochoski Flini, M, Manosso, FC &

Vol. 28 • No. 2 • 2024 • ISSN: 2084-6118 • 87-99 • DOI: 10.2478/mgrsd-2023-0034

Pereira, DI 2021, 'The Geodiversity of Brazil: Quantification, Distribution, and Implications for Conservation Areas', *Geoheritage* , vol. 13, no. 75.

Drinia, H, Voudouris, P & Antonarakou, A 2022, 'Editorial of Special Issue—"Geoheritage and Geotourism Resources: Education, Recreation, Sustainability"', *Geosciences*, vol. 12, 251.

Elmi, C, Simal, AG & Winchester, GP 2020, 'Developing a Rock Garden at Edith J. Carrier Arboretum, Harrisonburg VA (U.S.A.) as a Resource for Promoting Geotourism', *Geosciences*, vol. 10, 415.

Finzi, Y, Avni, S, Ganz, N & Limon, Y 2021, Geosystem services and nature conservation in geoparks – geoethical dilemmas from the Negev Craterland, Israel', *Academia Letters, Article* 225.

Frey, ML 2021, 'Geotourism - examining tools for sustainable development', Geosciences, vol. 11, 30, pp. 1-28.

Frey, ML 2021, 'Geotourism—Examining Tools for Sustainable Development', *Geosciences*, vol. 11, 30.

Garofano, M 2015, 'Geowatching, a Term for the Popularisation of Geological Heritage', *Geoheritage*, vol. 7, pp. 25–32.

Gordon, JE & Barron, HF 2013, 'The role of geodiversity in delivering ecosystem services and benefits in Scotland', *Scottish Journal of Geology*, vol. 49, no. 1, pp. 41–58.

Górska, M 2000a, 'Wybrane właściwości petrograficzne vistuliańskich moren dennych środkowej i zachodniej Wielkopolski oraz ich znaczenia dla oceny dynamiki ostatniego lądolodu' ['Some petrographical features of the Vistulian lodgement till in the Central and Western Wielkopolska and their significance towards estimating the dynamics of the last ice sheet'], Poznańskie Towarzystwo Przyjaciół Nauk, *Prace Komisji Geograficzno-Geologicznej*, vol. 28, Poznań.

Górska, M 2000b, 'Narzutniaki skandynawskie - metodyka badań i interpretacja. Analiza eratyków ze stanowiska w Koczerach koło Drohiczyna' ['Scandinavian erratics - research methodology and interpretation. Analysis of erratics from the Koczery site near Drohiczyn'], *Warsztaty terenowe „Osady, struktury deformacyjne i formy warciańskiej strefy glacjomarginalnej na Nizinie Podlaskiej"'* [Field workshop 'Sediments, deformational structures and forms of the Wartanian glaciarginal zone in the Podlasie Lowlands'], Lublin - Mielnik, 25-29.09.2000, pp. 67–72.

Górska, M 2006, 'Fennoscandian erratics in glacial deposits of the Polish Lowland—methodical aspects', *Studia Quaternaria*, vol. 23, pp. 11–15.

Górska-Zabielska, M 2007, 'Eratyki skandynawskie – metodyka i interpretacja' ['Scandinavian erratics – metods and interpretation'] in *Badania cech teksturalnych osadów czwartorzędowych i wybrane metody oznaczania ich wieku* [Textural characteristics of Quaternary sediments and selected methods of their age determination], eds E Mycielska-Dowgiałło & J Rutkowski, Wydawnictwo Szkoły Wyższej Przymierza Rodzin, Warszawa, pp. 75–82.

Górska-Zabielska, M 2008, *'Fennoskandzkie obszary alimentacyjne osadów akumulacji glacjalnej i glacjofluwialnej lobu Odry'* ['Fennoscandian mother areas of glacial and glaciofluvial deposits of the Oder lobe'], Wydawnictwo Naukowe Uniwersytetu im. Adama Mickiewicza w Poznaniu, Poznań, vol. 78.

Górska-Zabielska, M 2010, 'Głazy narzutowe w Wielkopolsce' ['Erratic boulders in Wielkopolska, western Poland'], *Prace i Studia z Geografii i Geologii*, vol. 18, Bogucki Wyd. Naukowe, Poznań.

Górska-Zabielska, M 2020, 'The most valuable erratic boulders in the Wielkopolska region of western Poland and their potential to promote geotourism', *GeoJournal of Tourism and Geosites*, vol. 29, no. 2, pp. 694–714.

Górska-Zabielska, M 2021, 'The Rock Garden of the Institute of Geography and Environmental Sciences, Jan Kochanowski University—A New Geo-site in Kielce, Central Poland', *Geosciences*, vol. 11(3), no. 113.

Górska-Zabielska, M 2023, 'A New Geosite as a Contribution to the Sustainable Development of Urban Geotourism in a Tourist Peripheral Region—Central Poland', *Resources*, vol. 12, Iss. 6, 71.

Górska-Zabielska, M & Dobracki, R 2015, 'Petrographic Garden in Moryń–A New Geotouristic Attraction inWestern Poland', *Landform Analalysis*, vol. 29, pp. 73–80.

Górska-Zabielska, M & Wachecka-Kotkowska, L 2014, 'Petrographical analysis of Warthian fluvioglacial gravels as a tool to trace the source area – a case study from central Poland', *Geologos*, vol. 20, no. 3, pp. 183–199.

Górska-Zabielska, M & Wachecka-Kotkowska, L 2015, 'Petrografia żwirów i eratyki przewodnie w osadach wodnolodowcowych jako przesłanki wnioskowania na temat źródeł i kierunków transportu materiału w obszarze między Piotrkowem Trybunalskim, Radomskiem a Przedborzem' ['Gravel petrography and erratics of the glaciofluvial sediments as base of characteristics of the source and transport direction in the Piotrków Trybunalski, Radomsko and Przedbórz area'], *Acta Geographica Lodziensia,* vol. 103, pp. 57–78.

Górska-Zabielska, M, Wieczorek, D, Zabielski, R & Stoiński, A 2022, 'Głazy narzutowe z regionu Przedborza jako obiekty geodziedzictwa oraz ich znaczenie dla geologii czwartorzędu i geoturystyki' ['Erratic boulders from the Przedbórz Region as objects important for Quaternary geology and geoheritage'], *Przegląd Geologiczny*, vol. 70, no. 1, pp. 34–49.

Górska-Zabielska, M, Witkowska, K, Pisarska, M, Musiał, R & Jońca, B 2020, 'The Selected Erratic Boulders in the Świętokrzyskie Province (Central Poland) and Their Potential to Promote Geotourism', *Geoheritage*, vol. 12, no. 30, pp. 1–14.

Górska-Zabielska, M & Zabielski, R 2010, 'Petrographic analysis and indicator erratics of gravels of the Odra Lobe', *Studia Quaternaria*, vol. 27, pp. 17–25.

Górska-Zabielska, M & Zabielski, R 2011, 'Kleinkieszählung und Leitgeschiebe des Oder Lobus' ['Counting of medium grained gravel and indicator erratics of the Oder Lobe'], *Zeitschrift für Geomorphologie*, vol. 55, no. 4, pp 493–513.

Gray, M 2013, '*Geodiversity: Valuing and Conserving Abiotic Nature*', Wiley Blackwell, Chichester.

Gray, M 2018, 'Geodiversity: The Backbone of Geoheritage and Geoconservation', in *Geoheritage: Assessment, Protection, and Management*, eds E. Reynard & J. Brilha, Elsevier, Amsterdam, pp. 13–25.

Gray, M 2019, 'Geodiversity, geoheritage and geoconservation for society', *International Journal of Geoheritage and Parks*, vol. 7, Iss. 4, pp. 226–236.

Kasprzak, L 2003, *'Model sedymentacji lądolodu vistuliańskiego na Nizinie Wielkopolskiej'*['Model of Vistulian ice sheet sedimentation in the Wielkopolska Lowlands'], Wydawnictwo Naukowe Uniwersytetu im. A. Mickiewicza, Poznań.

Kozarski, S 1995, '*Deglacjacja północno-zachodniej Polski: warunki i transformacja geosystemu (~20 ka → 10 ka BP)*' ['Deglaciation of northwestern Poland: conditions and geosystem transformation (~20 ka → 10 ka BP)'], Dokumentacja Geograficzna, vol. 1, Wrocław.

Król, E & Wachecka-Kotkowska, L 2015, 'Anizotropia podatności magnetycznej jako potencjalne narzędzie wyznaczania

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kierunków paleoprądów w osadach glacigenicznych w obszarze między Piotrkowem Trybunalskim, Radomskiem a Przedborzem' ['Anisotropy of magnetic susceptibility as a potential tool of palaeocurrent directions of the glacial sediments in the Piotrków Trybunalski, Radomsko and Przedbórz area'], *Acta Geographica Lodziensia,* vol. 103, pp. 79–98.

Kubalíková, L, Bajer, A & Balková, M 2021, 'Brief Notes on Geodiversity and Geoheritage Perception by Lay Public', *Geosciences*, vol. 11(2), no. 54.

Kucharska, M & Pochocka-Szwarc, K 2012, '*Objaśnienia do Szczegółowej mapy geologicznej Polski'*, Ark. Wyszków (451) ['Explanations to the Detailed geological map of Poland'], Archiwum Państwowego Instytutu Geologicznego–Państwowego Instytutu Badawczego, Warszawa.

Lima, NP & Pereira, DI 2023, 'Living and Dying on Planet Earth: an Approach to the Values of Geodiversity', *Geoheritage,* vol. 15, no. 4.

Lisicki, S 1998, 'Interpretacja wyników analizy petrograficznej frakcji żwirowej glin zwałowych w nawiązaniu do ich genezy' ['Interpretation of results of the petrographic analysis of till derived gravels according to their genesis'], *Przegląd Geologiczny*, vol. 46, pp. 410–416.

Lisicki, S 2000, 'Kryteria stosowania litotypów stratygraficznych glin lodowcowych w badaniach czwartorzędu' ['Criteria for the use of till stratigraphic lithotypes in Quaternary research'], *Przegląd Geologiczny*, vol. 48, pp. 368–370.

Lisicki, S 2003, 'Litotypy i litostratygrafia glin lodowcowych plejstocenu dorzecza Wisły' ['Lithotypes and lithostratigraphy of Pleistocene till within the Wisła catchment'], *Prace Państwowego Instytutu Geologicznego*, vol. 177, pp. 105.

Lüttig, G 1958, '*Methodische Fragen der Geschiebeforschung*' ['Methodological questions of medium grained gravel petrographic research'], *Geologisches Jahrbuch*, vol. 75, pp. 361–418.

Lüttig, G 1991, 'Erratic Boulder Statistics as a Stratigraphic Aid—Examples from Schleswig-Holstein', *Newsl. Stratigr.*, vol. 25, pp. 61–74.

Meyer, K-D 1981,'Der Findlingsgarten von Hagenburg am Steinhuder Meer' ['The boulder garden in Hagenburg at Steinhuder Meer'], *Ur-Und Frühzeit*, vol. 2, pp. 4–13.

Meyer, K-D 2006, 'Der Findlingsgärten in Niedersachsen'['The boulder gardens in Lower Saxony'], *Archiv für Geschiebekunde*, vol. 5, pp. 323–338.

Meyer, K-D 2008, 'Die Findlinge und Findlingsgärten in Niedersachsen' ['Erratic boulders and erratic boulder gardens in Lower Saxony'], *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, vol. 56, pp. 117–122.

Meyer, K-D & Lüttig, G 2007, 'Was meinen wir mit Leitgeschiebe?' [‚What do we mean by an indicator erratic?'], *Geschiebekunde Aktuell*, vol. 23, pp. 106–121.

Migoń, P 2012, '*Geoturystyka*' ['Geotourism'], Wydawnictwo Naukowe PWN, Warszawa.

Moliner, L & Mampel, L 2019, 'The Rock Garden 'Geologist Juan Paricio" (Alcorisa, Maestrazgo Geopark, Spain): An Effective Example of Geosciences Popularization', *Geoheritage*, vol. 11, pp. 1869–1878.

Motta, L & Motta, M 2007, 'Erratic blocks: From protector beings to geosites to be protected. *Geological Society London Special Publications*, vol. 273, no. 1, pp. 315–327.

Pettersson, G 2002, 'Weichselian glaciation in the middle Noteć River region, northwest Poland *LUNDQUA Thesis*, 47, pp. 1-19.

Piotrowski, K 2008, 'Dobry pomysł na biznes. Kamieniarstwo "głazowe" '[Good business idea. „Boulder" masonry], *Nowy Kamieniarz*, vol. 34, pp. 58–62.

Reynard, E 2004, 'Protecting Stones: Conservation of Erratic Blocks in Switzerland', in *Dimension Stone. New Perspectives for a Traditional Building Material*, ed R. Pikryl, Balkema, Leiden, The Netherlands, pp. 3–7.

Rodrigues, J, Costa e Silva, E & Pereira, DI 2023, 'How Can Geoscience Communication Foster Public Engagement with Geoconservation?', *Geoheritage*, vol.15, no. 32.

Rutkowski, J 1995, 'Badania uziarnienia osadów bardzo gruboziarnistych' ['Investigation of grain size composition of very coarse-grained sediments'] in *Badania osadów czwartorzędowych. Wybrane metody i interpretacja wyników* ['Investigations of Quaternary sediments. Selected methods and interpretation of results'], eds E Mycielska-Dowgiałło & J Rutkowski, Faculty of Geography and Regional Studies, Warsaw, pp. 106–114.

Sala, S 2011, 'Rzeźba krawędziowa północno-zachodniej części Pasma Przedborsko-Małogoskiego' ['Edge relief of the north-western part of the Przedbórz-Małogoszcz Range'], in *Znane fakty – nowe interpretacje w geologii i geomorfologii* [Known facts - new interpretations in geology and geomorphology] ed A Zieliński, Instytut Geografii Uniwersytetu Jana Kochanowskiego, Kielce, pp. 65–77.

Schulz, W 1964, 'Die Findlinge Mecklenburgs als Naturdenkmäler' ['The erratic boulders of Mecklenburg as natural monuments'], *Archiv für Naturschutz und Landschaftsforschung*, vol. 4, no. 3, pp. 99–130.

Schulz, W 1996, 'Zur Bedeutung der Korngröße bei Geschiebezählungen' ['The importance of grain size in petrographic analysis of gravel fraction'], *Der Geschiebesammler*, vol. 29, no. 3, pp. 91–102.

Schulz, W 2003, *'Geologischer Führer für den norddeutschen Geschiebesammler'* ['Geological guide for collectors of the North German erratic boulders'], CW Verlagsgruppe Schwerin, Schwerin.

Smoleński, M 2012, **'**Modelowanie przestrzeni turystycznej peryferyjnych regionów turystycznych' ['Modelling the tourism space of peripheral tourist regions'], *Ekonomia i Zarządzanie*, vol. 4, pp. 64–91.

Szmidt, A & Wachecka-Kotkowska, L 2019, 'Relations between present relief on the border of lowlands and highlands and geological structures of the Palaeozoic Platform – a case study from central Poland', *Geology, Geophysics and Environment*, vol. 45, no. 1, pp. 57–70.

Turkowska, K 2006, '*Geomorfologia regionu łódzkiego*' ['Geomorphology of the Łódź Region'], Wydawnictwo Uniwersytetu Łódzkiego, Łódź.

Urban, J, Radwanek-Bąk, B & Margielewski W 2022, 'Geoheritage Concept in a Context of Abiotic Ecosystem Services (Geosystem Services) — How to Argue the Geoconservation Better?', *Geoheritage*, vol. 14, no. 54.

Vinx, R 2015, 'Gesteinsbestimmung im Gelände' ['Rock identification in the field'], Springer, Berlin, Heidelberg.

Wachecka-Kotkowska, L 2015a, '*Rozwój rzeźby obszaru między Piotrkowem Trybunalskim, Radomskiem a Przedborzem w czwartorzędzie*' ['Relief development of the area between Piotrków Trybunalski, Radomsko and Przedbórz in the Quaternary'], Wydawnictwo Uniwersytetu Łódzkiego, Łódź.

Wachecka-Kotkowska, L 2015b, 'Badania ułożenia klastów w glinach morenowych jako element rekonstrukcji kierunków transportu lodowego w obszarze między Piotrkowem Trybunalskim, Radomskiem a Przedborzem' ['Measurements of till fabric orientation in the morainic tills for reconstruction of the ice flow direction in the Piotrków Trybunalski, Radomsko and Przedbórz area'], *Acta Geographica Lodziensia,* vol. 103, pp. 99–111.

Vol. 28 • No. 2 • 2024 • ISSN: 2084-6118 • 87-99 • DOI: 10.2478/mgrsd-2023-0034

Wachecka-Kotkowska, L, Czubla, P, Górska-Zabielska, M & Król, E 2012, 'Poligeneza pagóra w okolicach Mąkolic na wododziale Wisły i Odry na Wysoczyźnie Bełchatowskiej, region łódzki' ['Polygenesis of the Mąkolice Hill on the Vistula and Odra Watershed on the Bełchatów Plateau, Łódź Region'], *Acta Geographica Lodziensia*, vol. 100, pp. 161–178.

Wentworth, CKA 1922, 'A scale of grade and class terms for clastic sediments', *Journal of Geology*, vol. 30, pp. 377–392.

Wolniewicz, P 2021, 'Beyond Geodiversity Sites: Exploring the Educational Potential of Widespread Geological Features (Rocks, Minerals and Fossils)', *Geoheritage*, vol. 13(2), no. 34.

Woźniak, PP 2004, 'Przydatność analizy litologicznej glin morenowych w badaniach geomorfologicznych stref marginalnych ostatniego zlodowacenia' ['The usefulness of the lithological analysis of moraine tills in the geomorphological study of the marginal zones of the last glaciation'], *Przegląd Geologiczny*, vol. 52, no. 4, pp. 336–339.

Woźniak, PP, Czubla, P, Wysiecka, G & Drapella, M 2009, 'Petrographic Composition and Directional Properties of Tills on the NW Surroundings of the Gdańsk Bay, Northern Po-Land', *Geologija*, vol. 51, pp. 59–67,

Woźniak, PP, Sokołowski, RJ, Czubla, P & Fedorowicz, S 2018, 'Stratigraphic Position of Tills in the Orłowo Cliff Section (Northern Poland): A New Approach', *Studia Quaternaria,* vol. 35, no. 1, pp. 25–40.

Wysota, W 2002, *'Stratygrafia i środowiska sedymentacji zlodowacenia Wisły w południowej części dolnego Powiśla'* ['Stratigraphy and Sedimentary Environments of the Weichselian Glaciation in the Southern Part of the Lower Vistula Region'], Wydawnictwo Uniwersytetu Mikołaja Kopernika, Toruń.

Zabielski, R 2006, 'Badania litologiczno-petrograficzne osadów plejstoceńskich' [,Lithological and petrographic studies of Pleistocene sediments'] in *Szczegółowa Mapa Geologiczna Polski w skali 1:50,000* ['Detailed Geological Map of Poland in the scale 1:50.000'], *Ark. Wyszków*, Państwowy Instytut Geologiczny—Państwowy Instytut Badawczy, Warszawa.

Zieliński, T & Pisarska_Jamroży, M 2012, 'Which features of deposits should be included in a code?' *Przegląd Geologiczny*, vol. 60, no. 7, pp. 387–397.