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Geoheritage in a Forest: Traces of Ice Sheets in Pałuki, Western Poland

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Abstract: In this paper, we present nine large glacial erratic boulders laying in situ in the forested areas of Pałuki in the north-eastern Wielkopolska (Western Poland). They are discussed against the background of the rich geodiversity of the area, which owes its main features to the last ice sheet (Weichselian, MIS2), the front of which, after a momentary oscillation on the line of the Ryszewo moraines, began to recede and retreated northwards. Our field work consisted of collecting information on the dimensions, petrographic type, and type of eratics as well as specific features of the rock morphology. Attention was paid to the records of sub/inglacial processes, as well as periglacial processes affecting the foreland of the melting ice sheet and contemporary morphogenetic processes. In the detailed description of the boulders, attention is drawn to their scientific, cognitive, educational, cultural, conservational, pro-environmental and recreational importance. The recipient/beneficiary of such information can be anyone who is sensitive to the beauty of inanimate nature, who feels like an inheritance of the geological past of their region, or who wants to broaden their horizons with knowledge from the glacial era. Recognized and disseminated heritage of inanimate objects in nature through the transfer of expert knowledge has a great potential to become an effective generator of sustainable development of peripheral tourist areas such as Pałuki. Geotourism, which can be successfully developed in forests, is a tool for increasing the quality of life of inhabitants. Nowadays, social expectations regarding the functions of a forest are evolving in favour of social, educational (ecological education), tourist, and recreational functions.

Keywords: erratic boulders; Scandinavian ice sheet; Weichselian (Vistula) glaciation; geotourism; forest functions; sustainable development; Pałuki; Western Poland

Citation: Górska-Zabielska, M. Geoheritage in a Forest: Traces of Ice Sheets in Pałuki, Western Poland. *Sustainability* **2022**, *14*, 7190. https://doi.org/10.3390/su14127190

Academic Editors: Marek Sławski and Emilia Janeczko

Received: 22 April 2022
Accepted: 29 May 2022
Published: 12 June 2022

1. Introduction

Geoheritage (geological heritage) comprises those elements and features of the Earth's geodiversity which deserve protection due to their scientific, educational, cultural, spiritual, aesthetic, ecological, or ecosystem values [1]. According to Urban et al. [2], geoheritage includes abiotic natural elements, such as fragments of Earth's crust, landforms, and processes forming terrain, enabling scientific reconstruction of the geological past and an understanding of contemporary processes.

Erratic boulders, according to the abovementioned definitions, are the elements of geological heritage [3–5]. Erratics are rock fragments detached from bedrock in a source area (e.g., Scandinavia) and transported via icesheet in Pleistocene. The name can be derived from the Latin word *errare* (to wander). The erratics that exceed the length of 50 cm along the shortest axis are called erratic boulders [6]. From a petrographic point of view, igneous and metamorphic rocks are the most common among erratic boulders.

These silent witnesses of the ice age have multiple functions. If a boulder stayed where it was deposited, unmoved by anthropogenic factors (occurring in situ), it has a significant scientific value. It can be used in statistical analyses of the main direction of icesheet transportation as well as in dating the beginning of deglaciation in a given area with cosmogenic isotopes, such as ^{10}Be (e.g., [7–11]).

Erratics taken under legal protection serve a conservation function. Large and well-exposed boulders have aesthetic [12–14] and historic values [15]. Erratics on tourist paths and green ways serve recreational purposes [16,17], and if there are additional information boards, they have educational value (e.g., [18]).

The educational function of an erratic boulder can be enhanced by the transfer of knowledge between an expert, geointerpreter, tour guide, and tourists (e.g., [19,20]). The conveyed information may include the petrographic type of a rock, past geological processes in its source area (e.g., weathering or subglacial erosional activity: exaration [glacial erosion], detersion [polishing], and detraction [scouring]), and processes occurring during icesheet movement to the deposition site (e.g., rounding edges or detersion of bedrock on which the ice sheet moved). Microforms resulting from processes operating in periglacial (on the margins of the ice sheet) or extraglacial (outside of it) zones can be shown if they are only present on the boulder's surface. The expert will also indicate present morphogenetic processes shaping the surface of the erratic boulder.

Such a role should not be underestimated in the case of erratics, which, in order to protect them, were moved from deposition sites and collected in stone gardens (e.g., [5,21,22]). There they play additional social, educational, and conservational roles, as visitors become aware of how the protection of all the elements in nature is crucial for its functioning [2].

Erratic boulders have considerable potential for the development of geotourism (e.g., [4,5,23–29]). This branch of tourism is still underdeveloped in Poland. It is committed to maintaining geological and geomorphological heritage through effective conservation of geosites, with their educational and touristic values, and promotion of geological sciences. Without generating conflicts, geotourism uses local natural assets in sustainable social and economic development (e.g., [30]). Therefore, it becomes a driving force for local governments' politics, aimed at improving the quality of life in regions with valuable geological heritage.

Geosites are natural sites where the connection between the processes shaping Earth and the resulting forms, functioning in the past and still affecting the present, is evident. Geosites represent those assets of geoheritage which should be examined, protected, and developed in order to guarantee that future generations have the possibility of exploring Earth's geological past, enjoying sites' natural beauty, and enhancing socio-economic development [31]. The significance of geological heritage in the field of science and social education, as well as its immanent values, stimulates its protection [1,30,32]. The list and descriptions of Polish geosites is available in the Central Register of Polish Geosites, maintained by the Polish Geological Institute, National Research Institute [33]. Sites, which are protected as monuments of inanimate nature, are presented in an open-access Central Register of Nature Conservation Forms, provided by the General Directorate for Environmental Protection [34].

The diverse genesis of forms and sediments uncovered in the numerous geosites of a region determines its geodiversity. According to literature [20,32,35–45], geodiversity is a natural assemblage (diversity) of geological elements (rocks, minerals, fossils), geomorphological elements (terrain, physical and chemical processes), and soil features. The term also covers their relations, properties, interpretations, and systems. Pałuki is characterized by considerable geodiversity, which offers enormous potential to be used in the development of the region.

Currently, erratic boulders can be found in situ, mainly on arable fields, where they are often displaced to the nearest field border [6]. Such objects are also present in forests (e.g., [15,46]), where they are legally accessible for tourists (The [Polish] Act on Forests, 1991; [Polish] National Forest Policy, 1997; Decree No. 11A of Director-General of the [Polish] State Forests, 1999).

The shift from having one main function of forests, seen as the production of timber, to multifunctional forestry, in which ecosystems provide numerous social, touristic, and recreational values, has been clearly visible in Poland since 1997 [47]. According to [48], the need to make forests accessible for recreation results from society's growing interest in

recreation in general, including leisure in the forest. Recreational management of forests, including localisation of infrastructure and facilities, should be adjusted to preferences of people vacationing in forests. Society's tourism and leisure preferences, as well as the assessment of forest environments in terms of recreational assets, are the basis for successful adaptation of forests for recreation. As [49] states, recreational preferences and public expectations about social functions of forests are changing. The process is affected mainly by socio-economic factors, such as growing mobility, welfare, increasing amount of free time, etc. Nature-based tourism, including leisure in forests, has expanded outdoor recreation activities to include new forms of activities (e.g., nordic walking, geocaching, orienteering, tree climbing; see also Table 5.1, p. 96 in: [50]), while the development of infrastructure has facilitated recreation (equestrian, biking, cross-country skiing trails, etc.). Changes in the recreational use of forests can be easily noticed, mainly in the woods surrounding large cities (e.g., [46,51]).

Tourism in forests, along with recreation and ecological education, is a separate area of research (e.g., [48,50,52–64]). It is treated as equal to other types of land use in studied areas, and does not determine the aim of research in articles focused on the potential of geotourism development in forests. Therefore, geological assets limited to forest ecosystems, as well as opportunities for development of inanimate nature-based tourism, have rarely been the scope of separate research interest (e.g., [15,46,65–69]).

Polish State Forests maintain a website with updated pages dedicated to tourism and recreation [70]. The institution also encourages visitors to plan recreational activities according to their individual preferences [71].

2. Research Area

Pałuki is a historical and ethnographic micro-region in north-eastern Wielkopolska (Greater Poland; https://encyklopedia.pwn.pl/szukaj/Pa%C5%82uki.html, accessed on 15 April 2022). Its northern and eastern borders are delimited by the Noteć River, while the southern border is delimited by the Wełna River. It is situated on the borderland of Wielkopolskie and Kujawsko-Pomorskie Province, between historical regions of Krajna in the north, Kuyavia in the south-east and east, and Greater Poland in the south and west. According to the recent regionalisation of Poland [72], Pałuki is located in the eastern part of Chodzież Lakeland, northern part of Gniezno Lakeland, and central and northern part of Żnin-Mogilno Lakeland. Major towns of the region are Wągrowiec, Gołańcz, Kcynia, and Żnin (Figure 1A).

Pałuki is connected with the beginning of the Polish State in terms of culture and history. The phrase "it all began here" refers to the results of archaeological excavations on the Piast Trail, which is still subject to detailed research (e.g., [73]). Archaeological sites where the studies were completed are opened for tourists (e.g., Archaeological Museum in Biskupin).

Pałuki hosts significant geodiversity. This can be attributed mainly to the activity of the last Scandinavian Ice Sheet. In the Pleistocene, the geological epoch lasting from ca. 2.6 million to 11.7 thousand years ago, the Scandinavian Ice Sheet entered the present area of Poland several times. The Local LGM in western and central Poland (Leszno Phase of Weichselian/Vistulian glaciation or MIS 2 [MIS = marine isotope stadium]) is dated at 25–21 ka BP [11]. Due to climate change, the ice sheet started to recede northwards. Its movement was not constant; the ice sheet margin stopped/oscillated near the northern Poznań, and then near Brzeźno, leaving behind a hilly terrain. According to [77], the glacial phases might have been preceded by an ice sheet retreat.

Further to the north, in the area of Pałuki, deglaciation took place between 18.8 ka BP (Poznań Sub-phase) and 17.8 ka BP (Chodzież Phase; Figure 1B) [78]. Receding ice sheets left numerous diversified landforms and deposits. This young glacial landscape is dominated by flat plains and flat moraine plateaus [79]. It is more varied in the area of the Wełna River valley (ice marginal valley), with the system of deep glacial channels filled with the water of present lakes: Tonowskie, Wolskie, Rogowskie, Sobiejuskie, and Small

Żnin Lake. Greater denivelations are connected with the zone of moraine hummocks of the Ryszewo oscillation [74] in the southern part of the research area (south from Rogów and Gąsawa) and Chodzież Phase (17.7 ka BP [79]) in the north of the region. The area abounds with fluvioglacial landforms, produced by deposition (outwash plains, kames) and erosion (subglacial channels, now valleys of streams, spring thaw, and kettle holes). Apart from the evidence of glacial and fluvioglacial processes, the terrain of Pałuki also provides fluvial, aeolian, and wetland accumulation landforms [79].

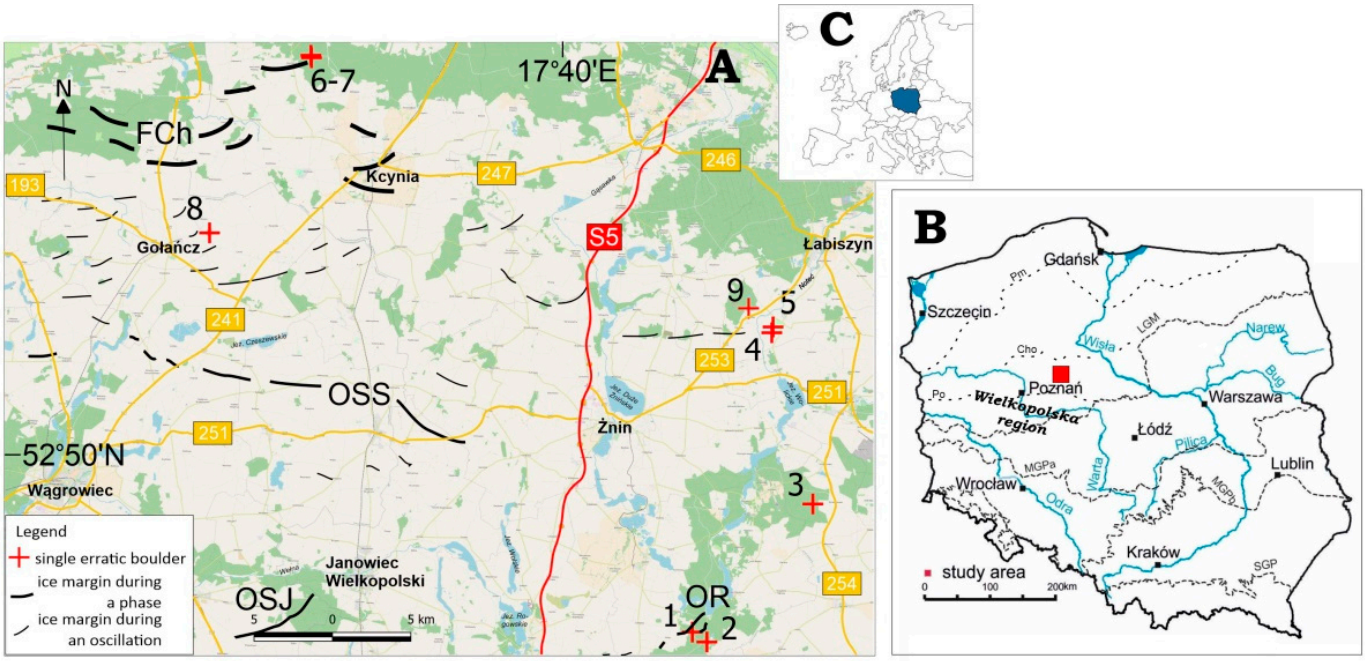

Figure 1. (**A**) Distribution of erratic boulders in Pałuki, presented in the article, against the extent of oscillations (upon [74]): OSJ—Skoki-Janowiec, OR—Ryszewo, OSS—Sypniewo-Sielec, and FCh—Chodzież (Kolmar) Phase of the Vistulian glaciation. (**B**) Location of study area in the north-eastern part of the Wielkopolska region. Limits of Pleistocene ice sheet (upon [11,75,76]) are given: SGP—South Polish Complex, Sanian, MGPb—Middle Polish Complex, Saalian, Odranian Stadial, MGPa—Middle Polish Complex, Saalian, Wartanian Stadial, LGM—Last Glacial Maximum, North Polish Complex, Weichselian, Po—Poznań Subphase, Cho—Chodziż Phase, Pm—Pomeranian Phase. (**C**) Poland on a map of Europe. Source of Figure 1A: OpenStreetMap, modified.

The region of Pałuki hosts numerous forms of nature protection [80]. They include protected landscape areas of Żnin Lakes and Rogowo Lakes, nature and landscape complexes of lakes in Rogowo Commune, "Gniezno Lakeland" and "Ostoja Barcińsko-Gąsawska" Natura 2000 sites, the "Długi Bród" ecological site, and many monuments of animate and inanimate nature (erratic boulders). Three protected erratics in the western and south-western part of Pałuki were described by the author (2010) and included in the Central Register of Polish Geosites. A significant portion of the abovementioned forms of nature protection is located in forests.

To conclude, the diversity of landforms and legally protected areas, described and easily found on the Internet, along with the roots of the Polish State and rich archaeological resources, which are available in Pałuki, can be used for education and tourism in this valuable area [81–83]. Geotourism, understood as a tool of sustainable development, should involve the enumerated assets in the diversification of its (geo)touristic portfolio. This would undoubtedly be conducive to improving the quality of life of the region's inhabitants.

3. Objectives

The aim of this article is to promote geotourism by providing expert knowledge on nine erratic boulders, which are not commonly known, but constitute significant geoheritage of forests in Pałuki. They have not been described in scientific publications so far, and general awareness of their presence in the research area is rather low. All objects described in the paper occur in situ, within forests or in their close vicinity. The article answers the appeal issued by [84,85], which argued for new discoveries in forest science in its broad sense, as the present state of forest science is insufficient. The author hopes that the paper will inspire readers interested in geology and geomorphology, geography teachers, geointerpreters, and tourists, who would perceive, maybe for the first time, erratic boulders as valuable inanimate natural elements of a forest ecosystem (comp. [2]).

4. Methods

Field studies were conducted in the summer and winter of 2021. Information about the erratic's dimensions, petrographic type, source area, indicative value, and characteristic features was gathered. Detailed methodology descriptions are given in other papers (e.g., [6,28,86,87]). Each boulder's localisation in situ was confirmed. Estimated volume (Table 1) was calculated according to the formula proposed in [88]: 0.523 × length × width × height, assuming that 1 m^3 = 2.75 t.

Boulders were examined for the presence of microforms, e.g., crescent chatter marks or glacial polish, characteristic for the subglacial environment, where erratics are transported at the bottom of ice sheets and scoured against harder material. The shape of the boulder edges was also analysed; rounded edges indicate transport in high-energy sub- and inglacial tunnels. Forms on the erratic's surface (e.g., marks of aeolian erosion, corrasion, crest lines), typical for the periglacial environment, were documented. Field analysis also included contemporary processes affecting the boulder's surface (e.g., exfoliation, corrasion, and colonisation by epilithic flora (e.g., [3,28])).

Localisation of the analysed erratic boulders is presented in Figure 1A, showing the extent of some Vistulian (Weichselian) glaciation oscillations in the north-eastern part of the Wielkopolska region. Basic features of the described boulders are given in Table 1. Scandinavian source areas of indicator erratics are presented in Figure 2. Photographs were taken in 2021 by M. Górska-Zabielska.

Table 1. Basic information about the erratic boulders presented in the article.

Boulder's Name or location	Coordinates	Length [m]	Width [m]	Height [m]	Volume [m^3]	Weight [t]	Perimeter [m]	Source Region and Petrographic /Indicator Type	Protection *
1. Boulder by Oćwieka forester's house	17°48′07″ E 52°43′43″ N	3.0	2.7	1.4	5.93	16.31	9.35	Metamorphic rock	1985-04-10
2. Boulder by a fishing farm in Bełki	17°48′57″ E 52°43′23″ N	2.6	2.0	1.0	2.72	7.48	9.1	Småland granite	1985-04-10
3. Stone House (*Kamienny Dom*) near Szczepankowo	17°54′50″ E 52°48′12″ N	4.2	3.4	2.5	18.67	51.35	13.1	Småland granite	1955-04-01
4. Lubostroń, close to a former forester's house	17°52′21″ E 52°54′05″ N	3.2	1.6	0.7	1.87	5.15	9.0	Uppsala granite	1955-06-01
5. God's Passion (*Boża Męka*) or Big Boulder in Lubostroń	17°52′25″ E 52°54′17″ N	4.2	3.5	0.8	6.15	16.91	12.0	-	1955-06-01
6. Boulder in Dębogóra Forest Subdistrict	17°25′50″ E 53°03′16″ N	3.6	3.6	0.35	2.37	6.52	11.5	Småland granite	1990-02-10
7. Big Boulder in Gromadno	17°25′48″ E 53°03′21″ N	4.5	3.5	1.7	14	38.51	14.9	Småland granite	1970-07-31
8. Boulder in Borek Oleski	17°20′15″ E 52°57′09″ N	5.25	3.7	1.3	13.21	36.32	14.3	Blekinge granite	1957-06-01
9. Boulder in a forest buffer zone by Załachowo	17°51′01″ E 52°54′52″ N	3.0	2.31	1.53	5.55	15.25	10.56	Åland rapakivi granite	-

* Date of taking under protection as a monument of inanimate nature according to Central Register of Nature Conservation Forms [34].

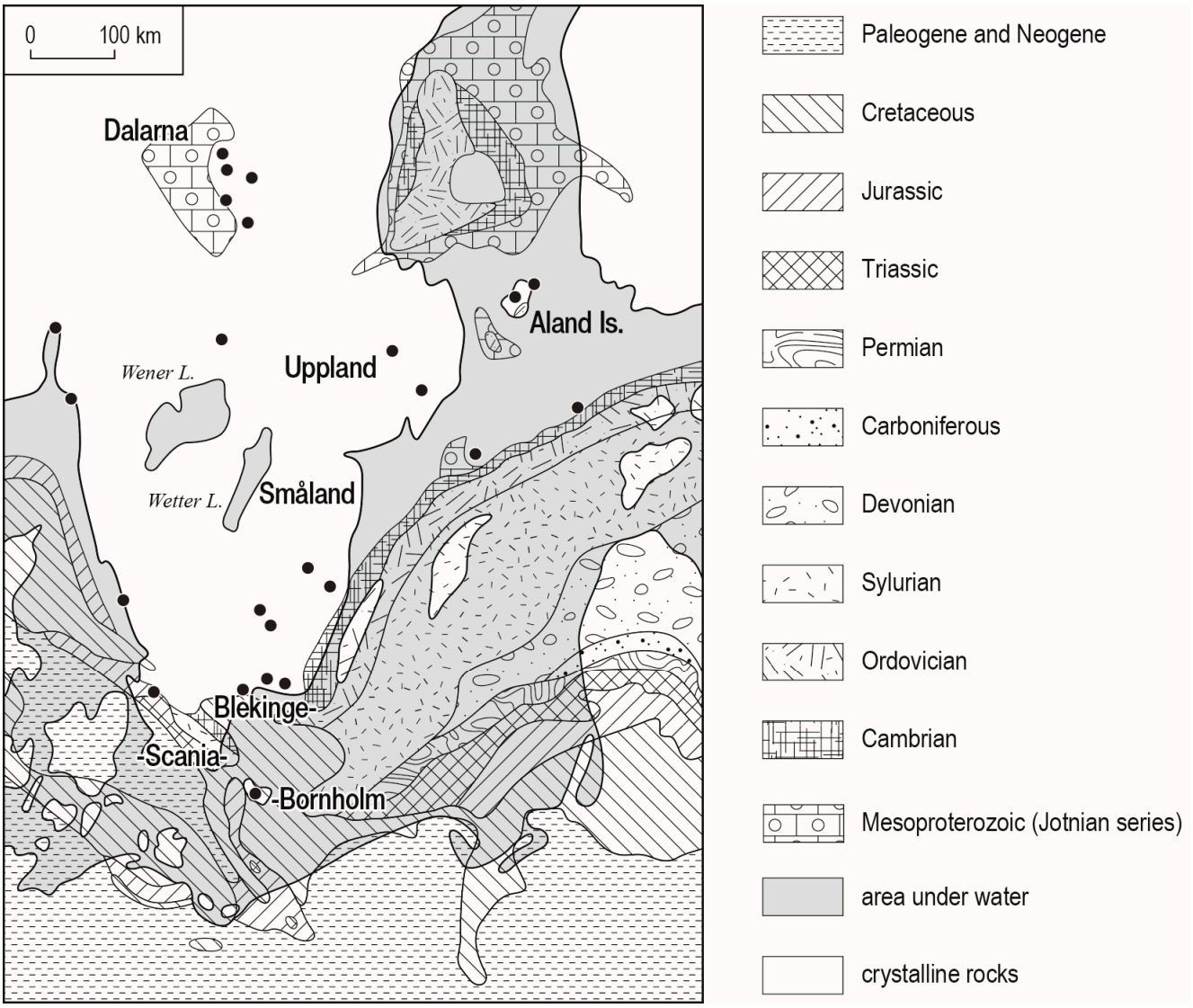

Figure 2. Main source regions of erratics from the southern part of the Baltic Shield, exposed in the glacial depositional area. The dots correspond to the main rock outcrops that fed the Scandinavian ice sheet—for more information, see [87,89,90].

5. Review of Erratic Boulders in Pałuki

5.1. Boulder by Oćwieka Forester's House

This boulder (No. 1 in Figure 1) is a migmatite (metamorphic rock) with clearly visible disharmonic folds of leucosome (Figure 3) and a pale magmatic structure rich in quartz and alkali or plagioclase feldspars. The presence of such structure indicates that it crystallised when the remaining magma was still plastic. The fragment of erratic boulder visible over surrounding terrain has rounded edges, due to glacial erosion. It is not an indicator erratic. It has been probably partially unearthed, as there is a fringe of sediments around it. The top part of the boulder is colonised by epilithic flora.

The erratic is located in the vicinity of Oćwieka forester's house. Its distance to the nearest paved road is about 200 m in a straight line. It is situated within the Żnin Lakes Protected Landscape Area and Natura 2000 habitat site, about 1 km from the blue biking trail of Pałuki Lakes. The boulder was taken under legal protection as a monument of inanimate nature (Table 1).

Figure 3. Erratic boulder near Oćwieka forester's house—migmatite with clearly visible disharmonic folds of leucosome.

5.2. Boulder by a Fishing Farm in Bełki

This boulder (No. 2 in Figure 1) is an indicator erratic Småland granite, transported by the Scandinavian Ice Sheet from south-eastern Sweden (Figure 2). It is partially exposed due to contemporary morphogenetic processes on the slope of a deep subglacial channel,

where the upper course of Gąsawka River is located. All the edges of the boulder are rounded. The erratic is additionally rounded by exfoliation of its surface. The process is driven by temperature changes and movement of water and solutions in microspaces between minerals of the weathered surface. They lead to disintegration of the rock.

The boulder can be found easily; it is visible from a forest path, about 100 m from Leszek Biały yellow hiking trail and 150 m from blue biking trail of Pałuki Lakes. It was taken under legal protection as a monument of inanimate nature. As is the boulder described above, it is located within the Żnin Lakes Protected Landscape Area and Natura 2000 habitat site. Nature Reserve "Gąsawka River Source" and educational path "Gąsawka River Valley" are situated about 1 km from the erratic.

5.3. Stone House (Kamienny Dom) near Szczepankowo

The largest boulder of Pałuki (No. 3 in Figure 1) is Småland granite from SE Sweden (Figure 2). Its rounded edges (Figure 4) are the evidence of destructive processes in the past glacial environment. Traces of contemporary processes shaping the erratic's surface, including exfoliation (physical weathering), are visible on its top part. On one of its sides, there is a slickenside, a smoothly polished surface with parallel corrugations along the direction of frictional movement between two rocks. This structure may be a record either of rejuvenation of pre-existing tectonic discontinuities or a small tectonic fault along which the fragments of crushed rock moved. The erratic is partially colonised by epilithic flora. Unfortunately, the boulder is irretrievably damaged due to human pressure.

Figure 4. Stone House near Szczepankowo—the biggest erratic boulder within the study area.

The boulder's size, shape and a legend connected with it were probably the decisive factors in taking it under legal protection as early as in 1955. It is situated by a forest path, ca. 1.3 km west from Szczepankowo and 2 km east from an airport in Annowo. A commemorative information board in Polish and English is located by the erratic (Figure 5). It informs about the legend, the boulder's size, and its location in the SE part of Pałuki.

Figure 5. Information board (in Polish and English) with basic data about the boulder.

According to a folk tale, in the place of the Stone House, there was a castle inhabited by a lonely, evil wizard. When he was bored, he lured children lost in the forest. They underwent difficult trials, and if they failed, the wizard turned them into stone statures. One day, when a son and a daughter of a poor blacksmith from Annowo, ignoring father's ban, went to the forest and did not come back before night, their youngest brother set out to find them. Though the boy was young, he was very smart, brave, and kind-hearted. He reached the castle and passed the wizard's tests, recognized his siblings, removed the spell, and set all the children free. When they were going back home, they heard a boom; the castle and its evil owner disappeared. The large boulder that lays there to this day warns children to obey their parents.

The boulder is located within the Żnin Lakes Protected Landscape Area, and it is protected as an inanimate nature monument. The surroundings of the Stone House, compared with other studied erratics, are relatively well-developed and may serve as a good local model. However, it should be underlined that they are far from fulfilling geotourists' needs. Better examples can be found, e.g., in Kotarwice (Kotarwice Stone) south from Radom, and were described in literature (e.g., [15]).

5.4. Boulder in Lubostroń, Close to a Former Forester's House

The boulder (No. 4 in Figure 1) is an indicator erratic made of Uppsala granite with outcrops, occurring in eastern Sweden (Figure 2). Due to the small size of the aboveground part, colonised by epilithic flora, and the surrounding thicket, the boulder is not visible; however, it can be easily reached, as it is located on the side of a forest road leading to the buildings of a former forester's house. The place is situated ca. 800 m east from the Noteć River and in the same distance towards the south-west from a 19th century Lubostroń Palace [91] outside of the surrounding park. The boulder is protected as a monument of inanimate nature.

5.5. God's Passion (Boża Męka) or Big Boulder in Lubostroń

This boulder (No. 5 in Figure 1) is a granite with well-exposed pegmatite vein. It is located 300 m towards NNE from the previous erratic. The boulder is not an indicator

erratic, and its source area cannot be located accurately within the Baltic Shield. It has rounded edges and its surface is colonised by epilithic flora.

Access to the boulder is difficult during the vegetation period, as it is hidden in dense nettles. The only sign, a characteristic plate indicating a nature monument, is located 5 m away from the erratic. It is situated in the park surrounding Lubostroń Palace, near an old, legally protected linden alley, without direct access from a forest path.

The boulders no. 4 and 5 (Figure 1) are located near the blue Pałuki Hiking Trail, running along an asphalt road between Pturek and Lubostroń.

5.6. Boulder in Dębogóra Forest Subdistrict

This boulder (No. 6 in Figure 1) is located in the Dębogóra Forest Subdistrict, Kcynia Commune, in the northern part of Pałuki. It is a Småland granite with a source area in SE Sweden (Figure 2). It has been partially unearthed (with the top surface about 35 cm above the terrain). The fringe of sediments surrounding the boulder hinders one's ability to find it, even from a short distance. The aboveground part is colonised by epilithic flora.

Traces of damage and remaining fragments of chipped rock around the boulder are the evidence of human pressure.

The boulder can be easily reached, as it is located on the side of a forest road, ca. 1300 m towards the east from Gromadno village. It is legally protected as a monument of inanimate nature.

5.7. Big Boulder in Gromadno

Another inanimate nature monument (No. 7 in Figure 1) is located about 200 m from the object described above. It is known as the Big Boulder, and is an indicator erratic, Småland granite from south-eastern Sweden (Figure 2). Its visible part has rounded edges, and one of the surfaces (with the table indicating its status as nature monument), bears the signs of glacial polish (Figure 6). The distal side has been colonised by epilithic flora.

Figure 6. Big Boulder in Gromadno with a glacial polish visible on the right side of the boulder. There is a sign in front of the boulder denoting an inanimate nature monument.

The boulder is located close to a forest path used by mushroom pickers. It had been known much earlier and is larger than the erratic no. 6; therefore, it was taken under protection in the beginning of the 1970s.

5.8. Boulder in Borek Oleski

This boulder (No. 8 in Figure 1) is a Blekinge granite originating in southern Sweden (Figure 2). It has rounded edges and, unfortunately, significant traces of anthropogenic pressure. Its surface is partially colonised by epilithic flora.

The boulder can be easily reached, even by car. It is located about 600 m towards the east from the red hiking trail Gołańcz-Kcynia and 800 m south from the houses of Oleszno village, within the rural park near the Gołańcz Stream. It is marked with a large board, informing about its legal protection (Figure 7).

Figure 7. Boulder in Borek Oleski on a red hiking trail.

According to one of the Wągrowiec legends, the boulder covers a collapsed inn. In its glory days, the inn hosted numerous revelries with alcoholic beverages. During the last one, one of the feasters was stabbed, yet it did not stop the party. When the feasters were admonished for the third time and did not leave the inn, a mysterious figure cast a spell on it. The inn suddenly collapsed under the ground, and a giant boulder appeared in its place. It is said that even today, if the boulder is hit with a metal knife, blood can be seen seeping out from it.

5.9. Boulder in a forest buffer zone by Załachowo

The erratic (No. 9 in Figure 1) is an Åland rapakivi granite, with a source area in the Åland Islands in the Baltic Sea (Figure 2). The unearthed part exposes rounded edges and glacial polish on one of its surfaces.

As the boulder is situated on arable field (Figure 8), it is difficult to reach it in the vegetation season. It has been dug up only partially, and its top surface is even with the terrain. Although it is located only 20 m away from the forest edge, on the southern slopes of Jabłowska Hill (152 m asl), it is not visible in the vegetation season.

Figure 8. The boulder in the forest buffer zone near Załachów is visible only outside the growing season.

It is the only erratic boulder in the research area not taken under legal protection, which may suggest that it has been dug up recently. However, its surface is already partially colonised by epilithic flora.

6. Discussion

Pałuki, located in north-eastern Wielkopolska, hosts significant geodiversity. Erratic boulders are among the elements creating its geoheritage. Geological diversity of the region grows with the petrographic diversity of boulders and the number of indicator erratics from known Scandinavian areas. The nine erratic boulders described in the article were deposited by the last ice sheet that reached the area, probably during the Ryszewo Phase [74] of the Vistulian (Weichselian) glaciation (MIS 2), between 18.8 ka BP and 17.7 ka BP [78]. They have stayed in the same localisation (in situ) since then; therefore, their positions aid in the reconstruction of the direction of the ice sheet advance.

It is worth noting the convergence of the location of the large erratic boulders studied with the extent of subsequent oscillations during the recession from the Poznań sub-phase line. A similar tendency in other parts of Poland was noticed in [29,92–97]. Additionally, the recent research by [6] in the Przedbórz Upland in central Poland documents regions of increased presence of erratic boulders on the hills of terminal moraine from the period of maximum extent of the Saalian glaciation during MIS 6.

There is another regularity which is worth noting. Apart from the Stone House near Szczepankowo (boulder No. 3), no erratic boulders of similar size have been found so far in the areas located between the marginal glacial zones of the Pałuki research area. Similar findings were made by Zabielski in the hinterland (not publicised research for the Detailed Geological Map of Poland, 2021) and by the author in the foreground of the MIS 6 marginal

glacial zone in the western part of the Małopolska Upland, who did not observe a clearly increased number of erratic boulders there.

Evidence of periglacial and contemporary morphogenetic processes is visible on the surface of some of the erratics. All the above mentioned elements constitute scientific values of erratic boulders; therefore, they should be considered as geosites [98,99].

Erratic boulders have cultural values; no. 3, 5, and 7 have their proper names, and boulders no. 3 and 8 are additionally shrouded in legend. Due to their large size, the erratics have aesthetic value. Apart from boulder no. 9, all are protected as monuments of inanimate nature. Only one erratic (no. 3) is registered as a geosite in the Central Register of Polish Geosites [33].

The described erratic boulders already have multiple functions (scientific, aesthetic, cultural, conservation, and signpost). It seems that there are no contraindications for the objects to continue to fulfill these functions in the future. Above all, these important in situ geosites [100] need to be protected. Their in situ conservation is an important task, as it provides present and future generations of researchers the opportunity of understanding the Earth's history, past environmental changes, and geological phenomena [101]. In situ erratic boulders are appropriate elements for the dating of cosmogenic nuclides, a modern technique for establishing the local maximum of the last Scandinavian glacial maximum in its southern ice margin (e.g., [11]). Field studies conducted by the author in Middle Pomerania (N Poland) indicate that protecting an erratic boulder as a monument of inanimate nature is not a sufficient measure. There is a need for constant education, increasing the awareness of local inhabitants who inherited the region's geological assets. Moreover, there are documented cases of irretrievable destruction of erratic boulders by stone craft [102,103]. Landscape stripped of erratic boulders loses its geodiversity.

The application dimension of the presence of erratic boulders in the environment is important in the sustainable development of the region. Erratic boulders, and more broadly, rock specimens, typical of the immediate vicinity, have considerable potential for the development of local geotourism. Literature gives numerous examples of using such objects in educational, sightseeing, and nature tourism (e.g., [4,5,26,104–113]). First of all, erratic boulders should be used in geocaching, an activity which popularises geological heritage [114], and parallelly in education. Due to the transfer of knowledge, its recipients' (e.g., tourists, visitors, vacationers, participants of green schools) awareness of the value of geoheritage, including erratic boulders, to reconstruct the geological past of the region, grows. Familiar erratics speak to local inhabitants, who are already able to appreciate geological heritage of their own homeland. Since communication is a tool for protection [114], there is only a small step to care for the protection of an erratic, a witness of glacial age.

In this way, boulders can be a driving force for sustainable development of local communities. They bring economic benefits to all people engaged in exposition and geointerpretation of erratic boulders, including idea initiators, landscape architects, transport and crane operators, and designers and producers of information boards and labels, as well as geointerpreters, maintenance service workers taking care of the objects' protection (volunteer eco patrol, cleaning the surface of the rock block from graffiti and lichen), and the safety of geotourists.

While the majority of enumerated services are available in the area where erratics are located, the problem lies in the lack of local geointerpreters, who could show the values of geoheritage and the beauty of inanimate nature in a professional and attractive manner. Attempts were undertaken in Poland to overcome the shortage of qualified guides, by introducing geotourism, a new area of studies in universities. However, popularity of the programme is rather low, and it will probably take some time to fulfil the potential of erratic boulders for the development of geotourism. Nevertheless, there are some positive examples of grassroots movements in this respect, initiated by local authorities, nature enthusiasts, and committed inhabitants [5,26,115,116].

All of the above mentioned features of the analysed erratic boulders add to the educational value, which can be used by geotourism. However, in order to use it efficiently,

the objects should be accessible and prepared for the reception of tourists. It is necessary to supply geosites at least with information boards and, if possible, the opportunity to gain knowledge from local geointerpreters. Tourists would also appreciate additional facilities, such as hiking trails, parking space, benches, roofed tables, and toilets. Local geoheritage can also be successfully promoted by organised guided tours and events, including TRInO [117], geocaching, quest, orienteering, Earth Day, Erratics Day, and others (e.g., [5,115,116,118]). Unfortunately, the erratic boulders of Pałuki have not been considered as interesting by the regional authorities yet. However, there is an initiative proposed by a local tour guide from Żnin to place the analysed boulders on a list of tourist spots worth visiting in NE Wielkopolska. Geosites could be then visited by tourists exploring the archaeological and historic Piast Trail or the objects of cultural heritage, such as the Lubostroń Palace. The boulders could be also visited by ecotourists, exploring valuable natural sites in forests located far from cities. However, research devoted to this form of tourism [57] indicates that ecotourists prefer woods without tourist facilities.

7. Conclusions

Nine erratic boulders in North-east Wielkopolska are silent witnesses of the glacial era, which functioned in this region between 18.8 and 17.7 ka BP. They contribute to the geological heritage of the region. The most important scientific value of the examined boulders is the fact that they have been found since the times of glacial deposition in situ. This position allows these boulders to be used in terrestrial cosmogenic nuclide exposure dating (e.g., [10,11]).

The described geological objects are also characterized by aesthetic, cultural, and conservation values. The educational value of erratic boulders is not without significance, and so far, they have not been used in the school practice of local geography and earth science teachers. Local residents know little about their presence in the area. Hence, all activities aimed at promotion of geological objects and processes (geodiversity) are important parts of dissemination of geoheritage (e.g., [18]). According to [20], these activities may lead to better acceptance of the proposed action in the field of territorial and general protection of nature and landscape, including the protection of geological elements and phenomena. As a consequence, greater public awareness of the need for geo-conservation will be transferred into more effective planning and adequate provisions in strategic documents of the local self-government.

In the future, it is planned to evaluate and valorize the above-mentioned erratic boulders and other objects of Pałuki geological heritage for the needs of the development of tourism in the region. Good and proven categories and evaluation criteria known from the literature will be used; however, they will be adapted to the specificity of the region and the purpose of the research.

All values of the erratic boulders of Pałuki described in the article are ready to be used in geotourism. Together with other elements of the region's geodiversity, they enhance its attractiveness. A new offer made to tourists, in the light of sustainable development, could be a driving force for improving the quality of life in local communities. Inhabitants' welfare and the economic situation of Pałuki may be positively affected by the presence of erratic boulders if their scientific, cultural, and aesthetic values are effectively and promptly utilised in geotourism.

Funding: Financing of field research was secured by the Jan Kochanowski University research project No. SUPB.RN.21.256.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Izabela Nowak, a licensed leader of PTTK in the Kuyavian-Pomeranian Voivodeship, is thanked for inspiration for research and accompaniment in the field. In relation to her, the author expresses her hope for the continuation of their joint journeys in the footsteps of the last ice sheet. Joanna Przybylska has translated the text.

Conflicts of Interest: The authors declare no conflict of interest.

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