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GRAPTOLITE-BEARING SITES IN POLAND – CONCEPT OF PROTECTION. IN MEMORY OF PROFESSOR ROMAN KOZŁOWSKI.

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Abstract: More than half a century ago, Roman Kozłowski, a Polish paleontologist, demonstrated similarities between the extinct group of organisms called Graptolithina and contemporary representatives of hemichordates called pterobranchiates. This important finding had an impact on the opinions pertaining to the evolutionary roots of the most complex organisms of the contemporary biosphere; namely the vertebrates. In Poland, graptolite-bearing sites are very rare. They occur in Ordovician and Silurian deposits. This paper pertains to one of the regions where these fossils occur, i.e. the Kielce zone of the Świętokrzyskie Mts., an area directly connected with R. Kozłowski's research. The characteristics are provided for 10 sites listed in classic papers on the geology of the Świętokrzyskie Mts., together with the proposals to secure and rationally utilise these sites. The present state of these excavations, so important to science, justifies the need for their protection, because of the threat of excessive exploration. A suggestion has been made to declare a natural monument at Wysoczki, named after R. Kozłowski, two nature reserves ("Prągowiec" and "Chojnów Dół") covering non-animate natural landmarks, and documentation sites in the Widełki and Międzygórz localities.

Key words: Graptolithina, fossil-site protection, Świętokrzyskie Mts., Poland.

GRAPTOLITES AND THE PHYLOGENESIS OF CHORDATES

Chordates, the group of organisms which include most of the commonly known members of the animal kingdom (e.g. fishes, amphibians, reptiles, birds and mammals) have their evolutionary roots in Hemichordata (hemichordates). In the contemporary world, the role of this group is less than marginal. It consists of small number of dissipated populations of ca. one hundred species of two systematic groups: Enteropneusta (enteropneusts) and Pterobranchia (pterobranchiates). The individuals in these groups live in the muddy bottoms of sea basins. The enteropneusts are mud-eaters whereas pterobranchiates are sedentary filtrators. The phylogenetic connection of Hemichordata with lower chordates (Tunicata and Acrania) has been derived on the basis of comparative anatomy and embryology. However, paleontological records of this relationship are little known. It is not known, how far back this relationship dates, because all the aforementioned groups phylogenetically linked with chordates (Hemichordata, Tunicata, Acrania) do not have mineralised skeletal parts, thus examples of their fossilization are very rare. No fossils of tunicates are known to date. A possible Cambrian representative of Acrania is *Pikaia* – an organism found in the fauna of Burgess shales (Briggs *et al.* 1994). The casts of feeding canals are regarded as fossilized traces of enteropneusts, because they are similar to the appearance of the canals left in deposits by contemporarily living members of this group. These traces occur in deposits from the Triassic Period. Only a few examples of paleontological records of skin-like capsules of the pterobranchiates are known throughout the entire world. These groups probably emerged independently from a common ancestor, and – in the course of evolution – have reached their present state of development, specific to them. Although their affinity is not questioned, opinions are diverse as to what systematic status should be accorded to them. Hemichordata are commonly ranked as a separate type (Lehmann and Hilmer 1987; Dzik 1992; Jura 1996), or they are treated as one of the subtypes of Chordata, along Tunicata and Acrania (Simpson 1999).

The phylogenesis of chordates is also associated with another group of animals occurring in great numbers in paleontological records, called Graptolithina, which became extinct in a geological epoch a long time ago. The name, introduced by Bronn in 1849 (*vide* Mierzejewski 2001), reflects the appearance of these fossils which look like "writing on rocks" (Fig. 1). The classic research into these fossils were carried out by a British paleontologist Charles Lapworth (1842-1920), who used these fossils as a base for biostratigraphic division of early Paleozoic formations in Scotland. In geographical terms, the distribution of graptolites is enormously wide (they occur in all existing continents) whilst at the same time it is extremely limited in chronostratygraphic terms (they are limited to sea

Fig. 1. Accumulation of rhabdosomes (skeletons of graptolite colonies) on the surface of shales in Prągowiec layers (lower Ludlowian). The outcrop in the Prągowiec gorge. Photo by M. Gonera.

deposits from the lower portions of Paleozoic. These are fossils of colonies (rhabdosomes) which consist of microscopic (up to one millimetre in length) thecae of funnel or cup-like shapes (Fig. 2). The most numerous accumulations of graptolites occur in Ordovician and Silurian deposits. Only the representatives of one of the orders (Dendroidea) have a somewhat wider stratigraphic range of distribution as they occur in deposits ranging from the Cambrian to Carbonaceous deposits. The graptolites displayed very fast evolutionary changes and for this reason they are currently used as indicators in ortho-biostratigraphic divisions of Ordovician and Silurian deposits. Preserved as fossils they are mainly the outer skeletons (thecae) of these organisms, and only exceptionally other elements of rhabdosomes: stolons, cysts, graptoblasts or even fragments of soft parts. The morphologically differentiated parts of the thecae performed various life functions for individuals as well as for the whole colony. The colonies were of very diverse shapes (Bulman 1955; Urbanek 1958). Initially, it was not clear to which systematic group the residents of this "writing on rock" belonged. It was supposed that they could be either bryozoans (Bryozoa phylum) or hydrozoans (Hydrozoa class).

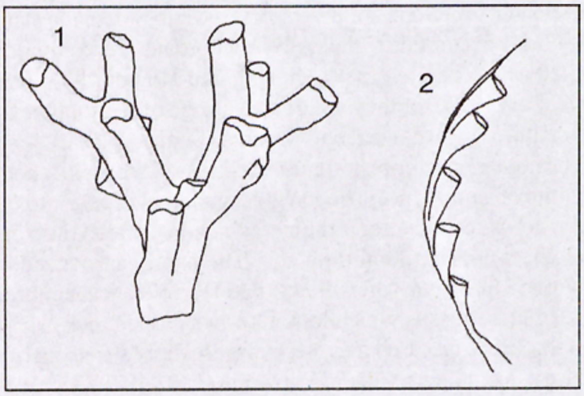

Fig. 2. Examples of differentiated shapes of graptolite thecas.
1 - *Dictyonema wysoczkianum* Kozłowski, 1948 (sessile form of the Dendroidea); 2 - *Pristiograptus bohemicus* (Barrande) 1850 (planctonic form or epiplanctonic of the Graptoloidea).

A key role in identifying the systematic position of graptolites was played by the research conducted by the Polish paleontologist, Roman Kozłowski[1)]. He studied organic remnants preserved in chalcedonies and carbonate formations of older Paleozoic. The method he used, was to dissolve rocks in acids (*inter alia* hydrofluoric acid). This process removed mineral components from the studied samples. The obtained residuum was made of organic remnants insoluble in acids. The graptolites predominated in the residuum (Kozłowski 1938, 1947, 1948, 1962, 1963a, 1966, 1971). There were also algae present (Kozłowski and Kaźmierczak 1968), cyanophytes (Starmach 1963), radiolarians (collection housed in the Institute of Paleobiology PAS), scolecodonts (Kozłowski 1956) and hydrozoans of the Hydroida group (Kozłowski 1959a). Other organisms of unknown or uncertain systematic positions were also represented: problematica (Kozłowski 1959b, 1967), conulariids (Kozłowski 1968) and Chitinozoa (Kozłowski 1963b), as well as remnants of Ordovician terrestrial plants (Kozłowski, Greguss 1959); perhaps older than Psilophyta[2)]. The main achievement of Kozłowski's research was to show the similarity in the structure of the thecae of graptolites and pterobranchiates of the genus *Rhabdopleura*. The opinion of the relationship between graptolites and pterobranchiates had been voiced earlier by Schepotieff (1905), although the manner in which he presented the proof had various shortcomings. Kozłowski discovered that in both these groups, the theca is made of semi-circles (fuselli) connected along a zigzag suture (Fig. 3). The nature of this suture was the main argument, indicated by Kozłowski as proving the relationship between these animals. Organic sheaths of the pterobranchiates occurred in the residuum separated by Kozłowski (1948, 1961, 1967, 1970).

1) Kozłowski Roman (1889-1977). Paleozoologis and geologist, founder of Warsaw school of paleontology. In 1913-1922, Professor and Director of the Mining Engineeers' School in Oruro (Bolivia). Since 1927, Professor of Warsaw University, organizer (1952) and Head (since 1961) of the Department of Paleobiology PAS. Author of papers on paleontology and geology of Bolivia, many classical research papers in paleozoology – particularly classical research papers on Paleozoic graptolites and brachiopods – of great importance to the development of research on fossil invertebrates. Awarded British Wollaston Medal (1961). Awarded the 1st Class State Award (1949). In recognition of the scientific achievements of Professor Roman Kozłowski in the field of paleontological research, the Institute of Paleobiology PAS, a leading Polish scientific research institution conducting the research into the history of life on Earth, bears the name of Professor Roman Kozłowski.

2) In the light of the latest discoveries regarding the oldest terrestrial plants (D. S. Heckman *et al*, 2001), this finding may turn out to be an essential proof that there were plants on Earth older than Psilophyta.

In contrast to the recent *Rhabdopleura* (Fig. 3c), fusellar structures of their Ordovician ancestors were of less regular shape (Fig. 3a).

In the course of further studies, certain differences (Bates and Kirk 1986) and similarities in the internal structure of the thecae were found in the representatives of both groups (Urbanek and Dilly 2000). The early development stages of the *Rhabdopleura* larvae are similar to graptoblasts (*Graptoblastus* and *Graptoblastoides*) resting stages of crustoidal graptolites (Crustoidea) described by Kozłowski (1948), in the Ordovician formations of the Wysoczki site (Mierzejewski 2000). The pterobranchiates and graptolites also have a similar chemical composition of the material of which the thecae is built. The graptolites built their skeletons of collagen, whereas the recent Rhabdopleuridae and Cephalodiscidea – of a similar protein substance; even though the proportions of particular amino acids therein is different (Towe and Urbanek 1972; Armstrong *et al.* 1984; Dilly 1986). The analogies pertain also to the organisation of individuals in a colony. The differences between these two groups with regard to the habitat: some of the graptolites were planctonic organisms while the recent pterobranchiates are exclusively benthonic. It should be noted with regret, that the achievements of Professor Roman Kozłowski in his studies on the morphology and phylogenetic relationships of graptolites are sometimes passed over without mention. For example, they have not been noted by Fortey (1999) in his account of the history of graptolite research.

Thus, in the fossil records only the graptolites are numerous and abundantly represented group of organisms phylogenetically linked with chordates. For this reason, they are the fossils occupying a very particular place in paleobiological research, because they pertain to the origin of the most complex organisms of the present biosphere – the vertebrates. Are the graptolites the fourth, extinct, branch of a pre-ancestor, common to the systematic groups of chordates (Hemichordata, Tunicata, Acrania) referred to above? We generally agree that these organisms which created "writing on rocks" were, evolutionally, the initial form for the aforementioned subphyla of chordates - but the consensus has not yet been reached; the studies and discussions continue (Urbanek 1986, 1998).

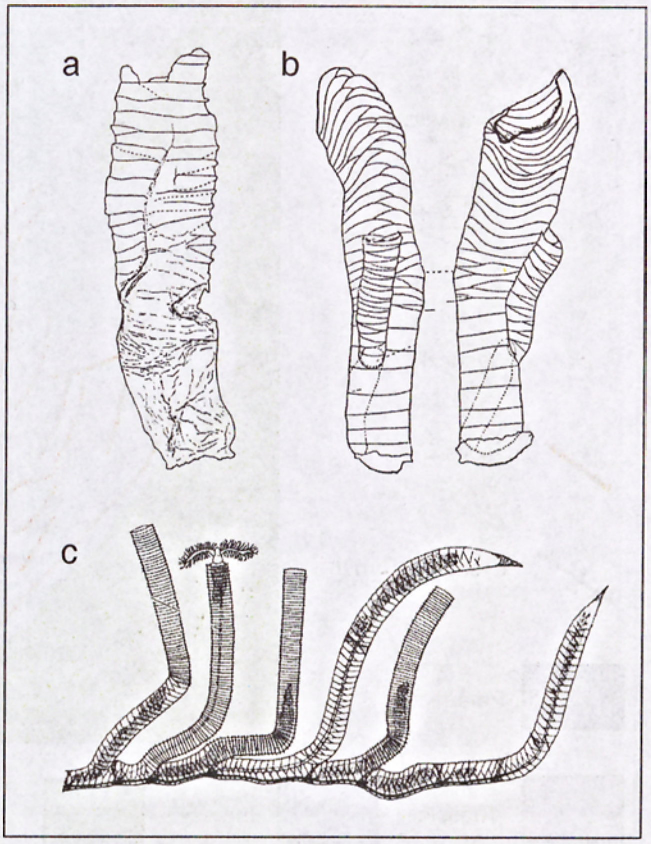

Fig. 3. Analogies in the structure of graptolites and pterobranchiates prove consanguinity between these two groups (Kozłowski 1948). a - Ordovician representative of Pterobranchia (*Rhabdopleurites primaevus* Kozłowski 1967, magnification ca. 80); b - Ordovician representative of graptolites (*Dictyonema wysoczkianum* Kozłowski 1948, magnification ca. 70); c - contemporary Pterobranchia (*Rhabdopleura normanii* Allman 1872, magnification ca. 30). After: Kozłowski 1967 (a) and 1948 (b), and Schepotieff 1905 (c).

GRAPTOLITE SEDIMENTS IN POLAND: A PALEOGEOGRAPHIC OUTLINE

The optimum of graptolite development falls into two periods in the Earth's history: the Ordovician and Silurian. In Poland the deposits of this age are represented by two types of sedimentary environments: geosyncline and platform. Graptolites occur in both these facies. The two environments are separated by the Teisseyre-Tornquist tectonic zone (Fig. 4). Sediments found to the south-west of this zone were formed in the geosynclinal basin of a deep and unstable-basement Central European ocean rift, a part of the Caledonian system of European geosynclines (Fig. 5). It must be noted that during the lower Paleozoic, the area in question (being a north-European plate of litosphere) was at an entirely different place on the globe, drifting in the southern hemisphere (probably between 30° and 60°), near the Gondwanaland. In the area of geosynclines, mudstones and clay shales facies predominated. Graptolites occur in the area in high numbers in deposits (the so called graptoplite shales). The platform formations occupy the region of Poland situated to the North-east of the Teisseyre-Tornquist line. The epicontinental sediments deposited there, constitute primarily marly-limestone facies with abundant shallow-water fauna. Compared with the geosynclinal areas, the layers are thin (up to 200 m); only along the edge of the platform (along the Teisseyre-Tornquist zone) does the thickness of the local clay and siltstone formations reach 2000 m. Platform and epicontinental formations were successfully correlated (i.e. stratigraphically linked) with the use of a leading graptolite taxa

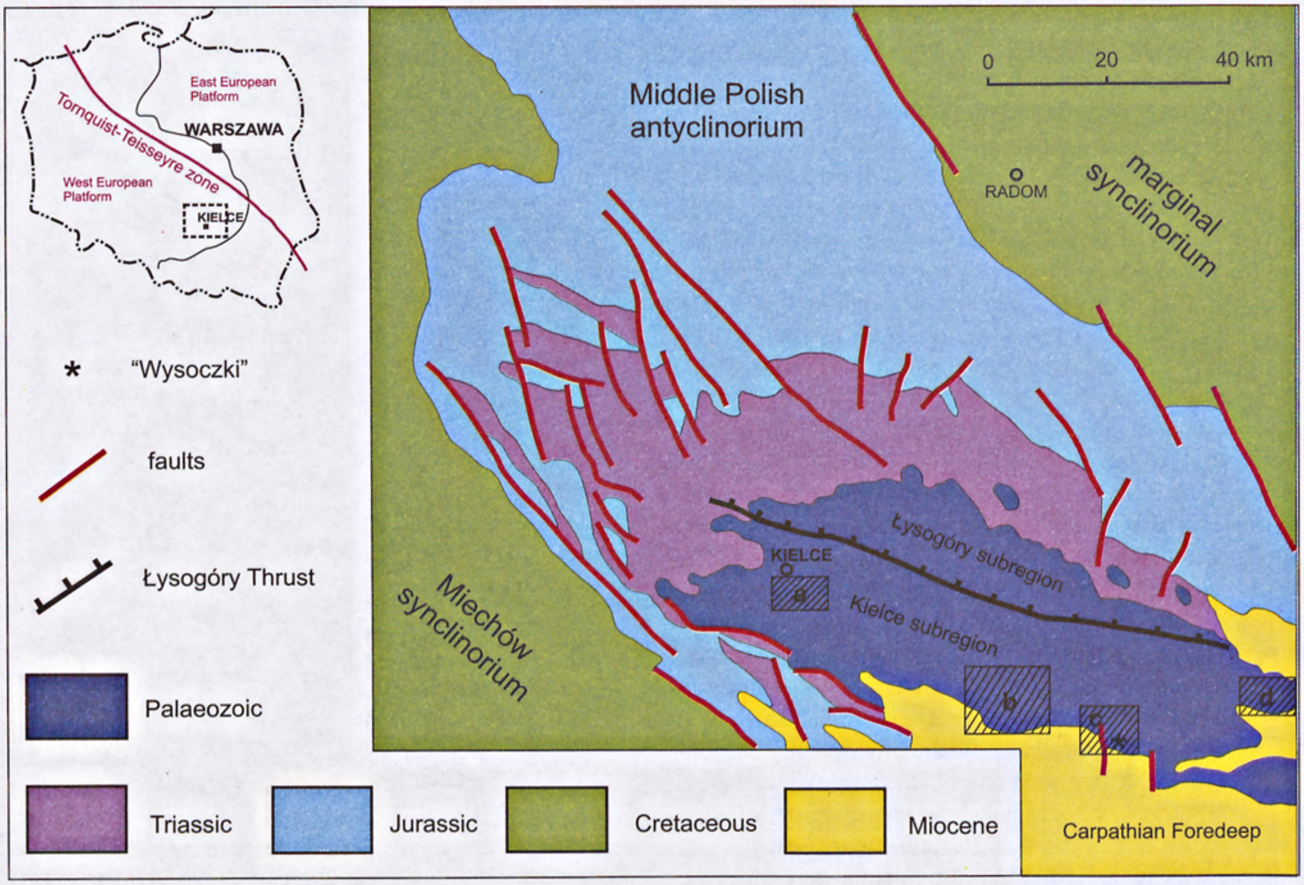

Fig. 4. Geological sketch of the Świętokrzyski region. Hatched fields (a-d) indicate the areas featuring the outcrops mentioned in the text and shown in Fig. 7.

occurring therein. In both these areas the Silurian and Ordovician formations are covered by younger deposits and show on the surface only in the zone of tectonically lifted portions of the substrate; in Poland only in the Świętokrzyskie Mts. and Sudety Mts.

For the Ordovician and Silurian, Wales and Scotland are the stratotypical areas with deposits of these systems formed in the geosynclinal facies. The biostratigraphic zones identified in the stratotypic area (15 graptolite biozones in the Ordovician and 24 in the Silurian) have been confirmed, even in very distant sites throughout the world. In epicontinental zones and at the fringes of geosynclines, i.e. where graptolites occur more rarely, the biostratigraphy of these periods is based on trylobites and brachiopods. The regression of graptolites began in the upper Silurian. They disappear from many areas, including the stratotypic region of the Caledonian geosyncline. The graptolites survived however, in the Polish lowlands (part of the Central European geosyncline) where many new taxa evolved, thus providing a basis to distinguish a time period called Postludlowian (Teller 1969). Graptolites have made it possible to distinguish several dozen biozones within this stage and the Silurian in the Polish Lowlands now provides the most complete picture worldwide of graptolite fauna of this system. Unfortunately, the Postludlow sediments are only accessible by drilling methods as they are covered by younger formations, including those left in the area by Quaternary glaciers.

In the Świętokrzyskie Mts. – i.e. in the area from where the graptolite fauna of the classic research by R. Kozłowski was obtained – the Ordovician and Silurian deposits are represented within two main structural units of this orogeny (named Łysa Góra and Kielce), separated by the Świętokrzyskie overthrust (Fig. 4). Although the facies in these two regions differ, their precise stratygraphic dating and correlation were made possible thanks to the "biological clock" provided by evolutionary changes in the graptolite fauna. In chronostratigraphic terms, the Ordovician profile is more complete in the Kielce unit, whereas that of the Silurian – in the Łysa Góra unit of orogeny.

In the Kielce unit, the Ordovician deposits began with a transgressive conglomerate (Fig. 6). In younger layers there is a transition into glauconitic sandstones with chalcedonies containing a rich graptolite fauna (upper Tremadocian). Above them still there are sandstones (Arenigian – lower Llanvirn), carbonate rocks (upper Llanvirn) marl and clay faciae (upper

Ashgillian). In the western part of the Kielce region, there is a lack of of upper Ashgillian formations; in the uppermost part of the Ordovician of this area, there is a stratigraphic gap. These sediments are, however, represented locally in the eastern part (Zalesie layers) and a continuous transition occurs there into the shale formations of the Silurian Period. The Ordovician system of the Łysa Góra unit shows a higher proportion of deep-water sediments than the Kielce region – although it lacks the lowest links (Tremadocian-Llanvirn). The profile begins here with calcareous deposits (Llandeil), and then continues transition into shales interbedded by marls (Llandeil-Caradok) and siltstones (Ashgillian).

Lithofacial similarity between the Łysa Góra and Kielce is far greater within the Silurian system than in the Ordovician one. Even though the formation of sediments is somewhat different in these two areas, two general lithological complexes could be distinguished. The lower complex (Llandower – lower Ludlowian) is of strictly geosynclinal character with predominant clay sedimients featuring abundant graptolite fauna; whilst in the lowest part of the Silurian, black silica shales thinly interbedded by lyddites are found throughout the Świętokrzyskie Mts. All these formations bear radiolarians. The upper part of the Silurian (upper Ludlowian) consists of mudstones and greywackes containing shallow-water benthonic fauna, such as molluscs, brachiopods, and trylobites. Extrusive rocks (i.e. diabase), are found locally in the Kielce zone (Bardo syncline) at the border of the clay and greywacke complexes. The presence of greywacke in the upper Ludlowian stage is a result of activated diastrofic processes during the younger Caledonian orogenic phases. As a result, the Kielce region was folded and lifted while the basin of the Łysa Góra region was still connected with geosyncline and in the uppermost Ludlowian was still a deep-water mudstone sedimentary area.

The tectonic formation of the Świętokrzyskie Mts. Paleozoic massif occurred as a result of the Variscian *vel* Hercynian orogenesis, i.e some 160 million years after the Silurian Period. The Paleozoic sediments were then folded into three structural parts of this mountain system, i.e. the Łysa Góra fold, the Central Synclinorium and the Klimontowskie Antyclinorium, as well as the Świętokrzyskie overthrust, the largest dislocation in the area (Fig. 4), a separated fold from the latter two structures (Czarnocki 1957; Tomczyk 1964).

MANAGEMENT OF THE GRAPTOLITE-BEARING SITES IN POLAND – CASE STUDY OF THE ŚWIĘTOKRZYSKIE MTS.

The classic studies by R. Kozłowski on graptolites were based on the material obtained from Ordovician silicate rocks (chalcedonies), extracted from a quarry at Wysoczki (Samsonowicz 1948) in the Świętokrzyskie Mts. (Fig. 4). This site, nowadays an abandoned quarry in the Kolonia Wysoki Małe locality, grown over with grass and shrubs, also yielded material for the study of other organisms, documenting the early Phanerozoic life forms (Kozłowski 1938, 1947, 1948; Mierzejewski 2000; Starmach 1963). It is situated among

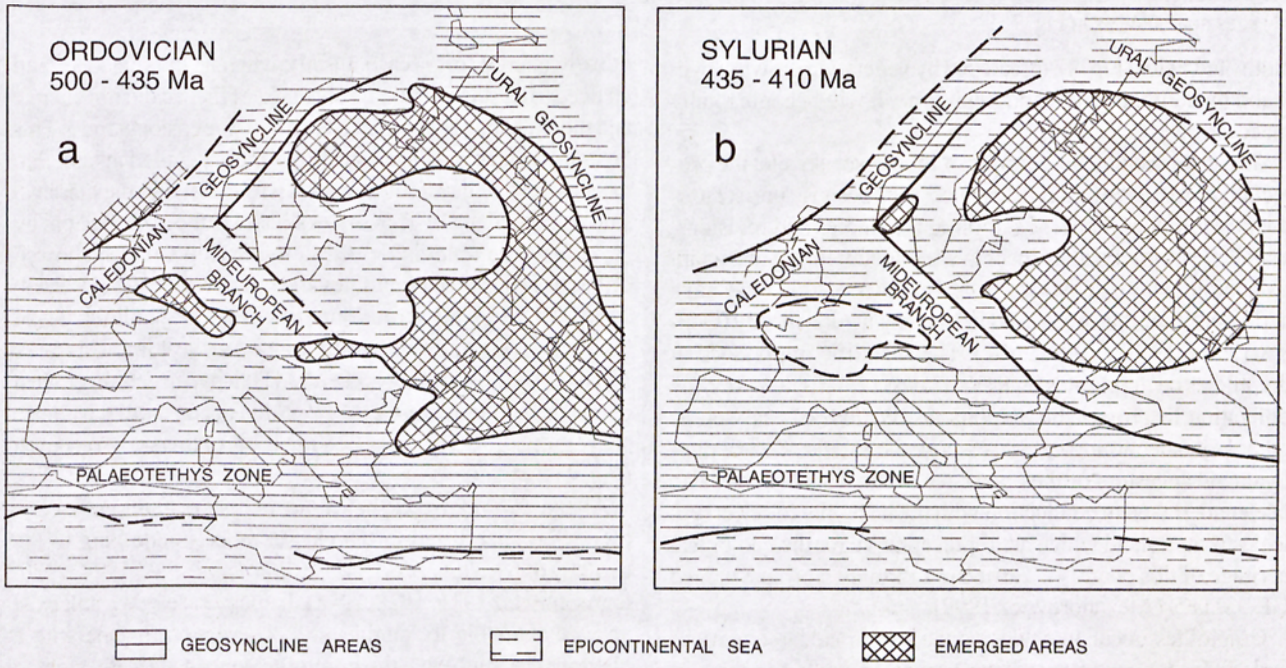

Fig. 5. Paleographic sketch of Europe in the Ordovician (a) and Silurian (b). After Orłowski and Szulczewski (1990).

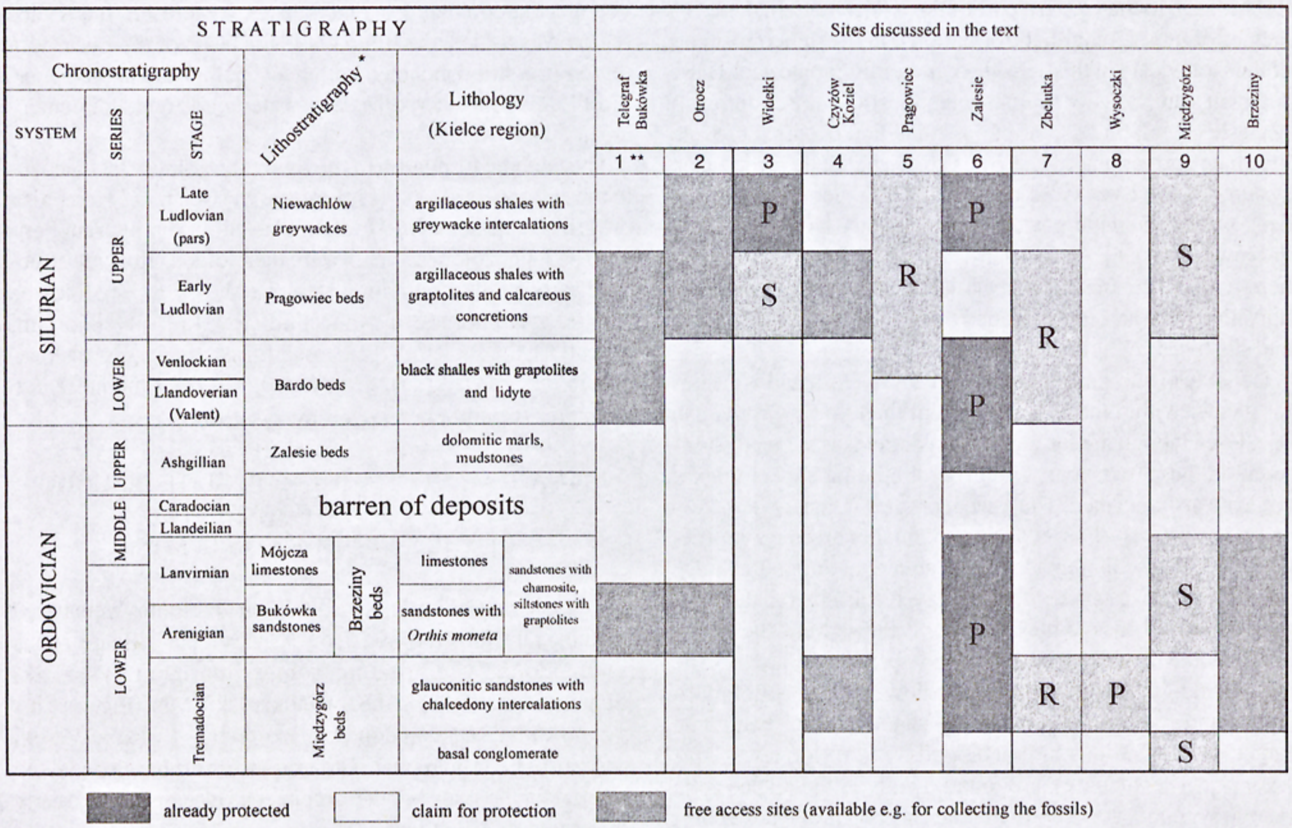

Fig. 6. Graptolite-bearing sites in the Świętokrzyskie Mts. – concept of protection. Conservation management of the graptolite-bearing sites: R – nature reserve, P – natural monument, S – documentation site.
*) lithostratigraphy after: Tomczykowa, Tomczyk 1968; Tomczyk 1968
**) sites numbered as in Fig. 7.

cultivated fields (Fig. 8), threatened by vegetation growing over it and by dumped refuse and, with time, it will become totally inaccessible.

As can be seen in the example of the Wysoczki site, the protection of fossils *in situ* is often necessary because this secures the possibility of renewed sampling for studies and revisions, which is essential with respect to sites documenting important paleontological discoveries. The findings of this type have additional importance as an aid in teaching natural history (Gonera 1997a, 1997b, 1999, 2001). The scientific importance of the studies on graptolites by R. Kozłowski entails, in a way, the obligation to protect the exhibits at "Wysoczki", as well as other key paleontological sites where the fossils of these phylogenetic ancestors of the chordates occur. This task has also been undertaken in connection with the necessity to select typical sites in Poland which are representative for the geological heritage of this country – carried out through a project named GEOSITES (Alexandrowicz 1999).

Graptolites occur in shales as well as in calcareous rocks and chalcedonies. In these two groups of rocks the form of fossilisation was different. In shales thecae are on the surfaces of layers, are deformed (flattened) and preserved in a chemically altered form (carbonised), whereas in limestones and chalcedonies, the chemical substance of thecae did not change and the skeletons are preserved in three-dimensional form. This latter process of fossilisation allows more detailed insight into the structure of graptolites, which was utilised in the classical studies carried out by R. Kozłowski and in those carried out by A. Urbanek, employing electron microscopy, which showed differences between graptolites and pterobranchiates (Urbanek 1986). There are numerous outcrops of the graptolite shales or the Ordovician and Silurian lithofacies richest in this type of fossils, in the Świętokrzyskie Mts. This paper pertains to just one of the geological areas of graptolite occurrence: the Kielce subregion, directly linked with R. Kozłowski's research (Fig. 4).

All the sites referred to below are of historical importance as they were once listed in the classic reports pertaining to the geology of Świętokrzyskie Mts. (Czarnocki 1919, 1928, 1950; Samsonowicz 1916, 1928, 1948). In many cases, they still exist and are available for studies and observation. In line with a historical terminology, the graptolite deposit sites are situated within "the Dymińska, Chęcińska and Bardziańska folds" (Czarnocki 1919). These geological structures are currently known as the Dymińska and Chęcińska Anticlines and the Deleszczycko-Bardziańska Syncline, all part of the Klimontowskie Anticlinorium (Fig. 4, 7a-c). Only one of the sites is situated in the area of the Central Synclinorium (Fig. 4, 7d). Geographically, these sites are located within the Dymińskie, Cisowskie and Orłowińskie mountain ranges and in the Sandomierska Upland, with the largest concentration in the eastern part of the Orłowińskie range, along the margin of the Bardziańska Syncline.

The sites with Ordovician and Silurian deposits are known from the area of the Telegraf Mt. (Fig. 4, 7a). Along the northern slope of the Dymińskie range, outcrops of Ordovician sandstones occur with *Orthis* brachiopods (Fig. 6). Their biostratigraphy was determined as early as in the 19th century (*see:* Tomczykowa and Tomczyk 1968). East of Telegraf Mt., at Bukówka, there is a stratotype section profile of these layers, while some outcrops of these sediments can be found in an abandoned and largely overgrown quarry, at the northern foot of the mountain. However, graptolites are very rare in these rocks and thus they do not constitute a particular attraction as a site bearing these fossils. Outcrops of graptolite-bearing shales are known from the same part of the foothill (Czarnocki 1919; Kotański 1959). They represent the lower Ludlowian stage. Graptolites are rare (*Gothograptus nassa, Pristiograptus pseudodubius*). However, there are numerous fossils of brachiopods (*Chonetes, Leptaena*), molluscs (*Cardiola, Dualia, Antipleura*), trylobites (*Odontopleura, Raphiophorus, Proëtus*) and cephalopods (*Dawsonoceras, Kionoceras*). Outcrops of these formations are rare because the Silurian shales form flat or concave terrain forms. Any exposed sites are not durable and are easily covered by decomposed rocks and vegetation. As witnessed by numerous pits left by generations of exposure, this outcrop has been intensively explored by geologists.

In Bukówka (Fig. 4, 7a), an outcrop of graptolite-bearing shales of the Wenlockian stage was documented (Kotański 1968). It was a small site on an escarpment at a side of the Kielce-Deleszyce road. At present, it has been completely covered by decomposed rocks.

The outcrops of the lower Ordovician (sandstones of Bukówka) and Silurian (Czarnocki 1919) are on the southern

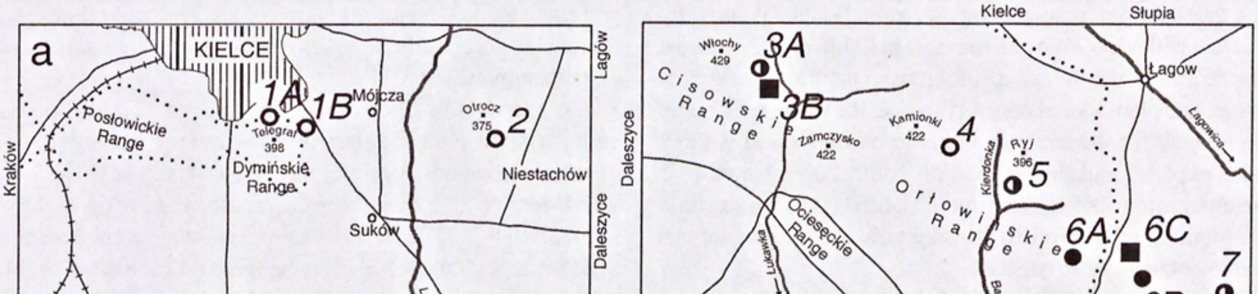

Fig. 7. Location of geological sites referred to in the text. (1A – foothill of Telegraf Mt., 1B –Bukówka, 2 – Otrocz Mt., 3 (A-B) – Widełki, 4 – Czyżów, 5 – Prągowiec gorge, 6 (A-C) – Zalesie, 7 – gorge in Zbelutka, 8 – Kolonia Wysoki Małe ("Wysoczki"), 9 – Miedzygórz, 10 – Brzeziny).

slope of Otrocz Mt. (Fig. 4, 7a) (its top is made of Devonian sandstones). Here occur both the graptolite shale (lower Ludlowian) and greywacke facies (upper Ludlowian). A well exposed outcrop of the Silurian facies was found at Młynarskie Doły. At present, access to the Silurian rocks is very difficult. The old excavation no longer exists, and the whole area is covered by a forest stand.

In a dell between the Orłowińskie and Cisowskie ranges, in the Widełki locality (Figs 4, 7b), an outcrop of shales was documented as early as at the beginning of the 20th century (Czarnocki 1919). The site of these deposits is situated to the left of the road to Zarobiny (3A in Fig. 7), within a small depression on the eastern slope of the Włochy hill, composed of Devonian formations (Stupnicka and Stempień-Sałek 2001). Shales with graptolite and ostracode faunas from the upper Silurian occur here. In the upper part of the hill there are outcrops of sandstones with an admixture of volcanic material (Niewachlowskie greywackes), in which graptolites are sporadically found. Close to this site there is another outcrop of diabases, protected as an object of inanimate nature (3B in Fig. 7) (Wróblewski 2000). Similarly, as in the aforementioned sites, the shale graptolite-bearing outcrop at Widełki is currently covered with decomposed rocks. This shows the scale of disappearance of outcrops resulting from natural processes of erosion and plant succession. At this site, the waste rock is still thin enough for the shale outcrops to be uncovered without major expense and the excavation could be protected as a documentation site of inanimate nature (this would be a complementary action to the declaration of the natural monument mentioned earlier).

Ordovician and Silurian sediment outcrops have been found around the Czyżów and Koziel localities (Czarnocki 1919; Bednarczyk 1964) (Fig. 4, 7b). The site is situated within a hill called Powalisko, built of Cambrian sandstones, Ordovician siltstones with chalcedonies and Silurian shales (Bednarczyk 1962). The entire hill is under agricultural use which eliminated the outcrop of Silurian shales described by Czarnocki (1919). Only at the foot can some loose fragments of substrate rocks be found. Some 300 m northwest of the Powalisko hill there is a forest-covered hill adjacent to the Kamionka Mt. In a small gorge on its southern slope there are outcrops of Silurian sandstones. Pale grey and compact, the sandstone turns rusty when weathered and contains tiny common mica and hieroglyphs on the laminae surface. Chalcedonies found in the sandstone contained graptolites.

The Prągowiec gorge is a site of mass occurrence of graptolites (e.g. Czarnocki 1919; Kotański 1959; Kowalczewski and Tomczyk 1981; Stupnicka and Stempień-Sałek 2001) (Fig. 4, 7b). The gorge runs perpendicularly to the Kierdonka river valley at the foot of the Ryj hill. The gorge is up to 20 m deep and some 500 m long. It is overgrown by shrubs and trees, mostly beech and birch. The erosion caused by a stream flowing on the bottom resulted in a number of natural outcrops of substrate rocks (Fig. 9). Sylurian shales are exposed there (Kowalczewski and Tomczyk 1981). Apart from the graptolites of lower Silurian (Gothograptus nassa, Colonograptus colonus, Monograptus scianicus) and upper Silurian (Lobograptus scanicus, Neodiversograptus nillsoni, and Gothograptus nassa), trilobites (Odontopleura ovata, Raphiophorus spp.), brachiopods (Strophomena spp., Lingula spp., Orthris spp., Choneta spp., Pentamerus spp.), molluscs (Cardiola interrupta, Slava spp., Vlasta spp., Dualina spp.) and cephalopods (Orthoceras spp., Ophidioceras spp.) also occur there. Among shales there are dark-grey limestone concretions. At the mouth of the gorge, on a southern slope, an outcrop of diabases can be seen. Separate blocks of these vein igneous rocks rest also on the bottom of the stream.

This site is not under protection, despite suggestions which have been put forward for many years (Urban and Wróblewski 1999). Protecting the site is necessary, for fossils are sought and extracted in a ruthless manner in this gorge, because of the combination of unique and massive occurrence of graptolites and easy access to them. Protecting this site is justified by both scientific considerations (occurrence of abundant and diverse graptolite fauna) and the attraction of the landscape alike. The Prągowiec gorge fully deserves the status of a natural reserve of an inanimate nature site.

The outcrops of Ordovician and Silurian rocks occur in valleys of two unnamed streams in the Zalesie locality (Fig.4, 7b). Numerous outcrops are grouped at three sites. The first one is located in a small stream west of the Łagów-Raków road (6A in Fig. 7). Here, the Wenlockian stage of the Bardzka syncline is best developed (Tomczykowa and Tomczyk 1968); the Akidograptus acuminatus was found there. This site had been described under many different names. Early on, it was mentioned by Czarnocki (1919) who called it the Sadkowski gorge. Kotański (1959) referred to the outcrop as the Na Stawach gorge, while Bednarczyk and Tomczyk (1981) called it Bardo-Stawy. Heading upstream, one can see graptolite shales on the bottom. Some 300 m from the mouth there is an extensive (40 m long) outcrop of silicate shales of the lower Silurian (Bardo layers). The steep layers subside in a northern direction. The rocks are black (rusty on weathered surfaces) and contain numerous graptolites. This is where a contact between the harder shales and the thinly-layered siltstones can be observed. The exposed siltstone layer is ca. 8 m long. The contact can be seen better still in two other places, 50 and 100 m further north (upstream). The mudstones are grey and yellowish, form several centimetres thick layers, are much cracked, and contain rich graptolite fauna. A tectonically reduced Ordovician profile was exposed in a research pit nearby (Bednarczyk and Tomczyk 1981), which is now covered already by a layer of loess. In this profile, siltstones with chalcedonies, spotted shales with bentonite inserts and clay shales were found.

Two more sites in Zalesie are situated in a stream east of the Łagów-Raków road. The area is overgrown by trees,

Fig. 8. Outcrops of Ordovician rocks in the Kolonia Wysoki Małe locality ("Wysoczki" site). Photo by K. Miśkiewicz.

predominantly beeches, birches and alders. In the stream bed there are Cambrian shales exposed and on the left side of the valley there are outcrops of Ordovician and Silurian rocks (6B in Fig. 7). These sediments Czarnocki described as the "outcrop near the Modrzewiny village" or as "the profile in Zalesie Nowe" (1919 and 1928 respectively). This is a classic Ordovician site, on which the author presented the stratigraphic divisions of this system (Fig. 10). The profiles of lower and upper Ordovician are exposed where sandstones, layers of chalcedonies with graptolite fauna, layers of sandy siltstone, a dolomite and marl series, and shales (*loco citato*) are present. Some 50 m further north grey, loosely bound thinly-layered clay shales are found from the lower Silurian, containing numerous graptolites (visible in a ditch several meters long and some 15 m above the stream level).

Some 400 m upstream to the north-west there is a diabase outcrop cutting through Niewachlów greywackes of upper Silurian (6C in Fig. 7). These greywackes are exposed more to the north-west of the site. Their outcrops form small thresholds in the bottom of the stream providing the landscape with picturesque cascades. Graptolites occur also in the greywackes, albeit sporadically.

The Zalesie sites described above are situated in forested stream valleys far away from any buildings, which could not be easily taken under cultivation and owing to this have survived for almost a century. However, natural processes (e.g. solifluction and erosion) constantly change their appearance. The Ordovician profile in the Bardo-Stawy outcrop is barely visible now. On the steep slope along the stream, there can be seen the effects of intensive soil creeping in the form of the outcrop having been covered by loess. The sediments of the Silurian are still well exposed. All three sites are protected as monuments of nature. They have been included in the list of representative geosites for Poland (under GEOSITES initiative – Urban and Wróblewski 1999).

Another site with graptolite-bearing sediments is located between the Kędziorka and Chojny localities, in the Zbelutka *vel* Zbilutka gorge (Fig.4, 7b) (Czarnocki 1919, 1939) also called Chojnów Dół (Urban and Wróblewski 1999). There are outcrops of the Cambrian (shales and sandstones) and of Ordovician conglomerates, dolomites and sandstones with chalcedonies as well as shales and Silurian greywackes, cut through by a diabase vein (Czarnocki 1919, 1939). The gorge is some 700 m long and more than 10 m deep. The rocks can be seen only in the stream bed because the slopes of the valley are overgrown by beech wood; the outcrops of graptolite shales are particularly hard to notice because of the cover of decomposed rock and forest litter. This site has been suggested for protection as a reserve of inanimate natural forms and, like Zalesie, placed on the list of representative geosites in Poland (Urban, Wróblewski 1999).

Cambrian and Ordovician outcrops are found at Kolonia Wysoki Małe (Fig.4, 7c) (Samsonowicz 1948). This site is referred to in the literature as Wysoczki (Samsonowicz 1948; Tomczyk 1962; Mierzejewski 2000) which is probably an old

Fig. 9. Outcrops of Silurian sediments in the Prągowiec gorge. This site is suggested for protection as a nature reserve. Photo by K. Miśkiewicz.

vernacular name. The Ordovician formations developed in the area as grey glauconitic sandstones with chalcedonies. They can be seen in a small and long-abandoned quarry marked "point 3" by Samsonowicz (1948). The historic and scientific aspect of this outcrop is of particular nature: it is the site of classic research by R. Kozłowski. The rock material for his studies on graptolites was obtained from this site. The site is the *locus typicus* for many graptolite species. The 50 m long, 25 m wide and 3.5 m high quarry is now abandoned, covered with grass and some shrubs and the fragments of substrate rocks can only be seen in the waste rock and talus slopes covered with grass. Progressive erosion and succession of vegetation are not the only threats to the site; these small depressions are also subject to illegal dumping of refuse. The historic, scientific and didactic values of the site justify the idea of declaring this abandoned quarry as a legally protected monument of nature named after Professor Roman Kozłowski – in order to honour this great paleontologist and graptologist.

There is in an abandoned quarry at Międzygórz (Fig. 4, 7d), one of the largest outcrops of Ordovician and Silurian sediments in the Świętokrzyskie Mts. The quarry is situated on the right-hand slope of the Chełm gorge. The quarry measures 60 m wide, 120 m long, and its steep walls reach 20 m in height (Fig. 11). It is here where at first the sediments of the Tremadocian were found (Samsonowicz 1916) and called Międzygórz layers (Fig. 6). The formations seen in the quarry display a reverse sequence (overturned fold) and the boundary of Silurian and Devonian formations runs along the tectonic line (Kotański 1959). The Ordovician period is represented by basal conglomerate, quartzite, glauconitic sandstones as well as sandstones with *Orthis*, limestones and marls. The Silurian graptolite-bearing shales can be seen in a small depression at the entrance to the quarry. The continuation was exposed on the eastern slope of the Chełm gorge, but presently it has been covered by decomposed rock. The quarry is topped by loess. The steep walls feature slope displacement phenomena whose results can be observed (in the form of rock slides) in the south-western part of the quarry.

Fig. 10. Outcrops of Ordovician and Silurian sediments in Zalesie. Since 1987 the site has been protected as a nature monument. Photo by K. Miśkiewicz.

The Międzygórz quarry provides the opportunity to observe many geological facts and processes (including tectonic, sedimentary and paleontological phenomena); thus its educational importance is beyond question. However, the condition of the outcrops deteriorates due to the progressive invasion of vegetation, loess sliding down and the destruction of rocks by geologists. In order to preserve the permanent nature of the site and to ensure proper use of the outcrops by geologists conducting their research in the area, the Międzygórz quarry should definitely be placed under protection. The status of a documentation site seems to be the best-matching form for securing the site, with its didactic importance retained, and imposing on the geologist the duty to care for the object of their research.

The Ordovician outcrops are known from the Brzeziny locality near Morawica (Fig. 4, 7a). Czarnocki (1950) discovered graptolite-bearing shales there (mainly with *Didymograptus*). In this part of the Klimontowskie Anticlinorium, the graptolite facies of the lower Ordovician are a rare occurrence. The drilling exploration done in the area has revealed several levels of graptolites (Tomczyk 1962). Also occurring there are glauconitic sandstones (Tremadocian stage) and sandstones with chamoisite (Arening-Lanwirn) (Czarnocki 1950).

CONCLUDING REMARKS

The presented sites with graptolite-bearing deposits were selected in the area under consideration as objects representative of the paleontological point of view. The needs were presented and a way of organising them into a system allowing their rational use, i.e. the use which will facilitate attainment of documentation, scientific, didactic and collection-related objectives (Fig. 6). The conservation-type protection of some sites combined with identifying substitute sites for those who want to search for fossils would contribute to these "windows into the past being permanently open" (Larwood 1999). For paleontological sites, a particular hazard – apart from threats typical to any geological objects – is connected with over-exploitation of fossils. Regulating this issue and reducing it to the justified actions necessary to maintain sustainability is a matter of culture and public awareness. The point is not in keeping the site secret in order to permanently preserve it (such cases are known not only in the field of geology but also in the protection of species).

To protect some of the sites presented and leave a certain number of sites open for taking samples (i.e. *de facto* for collecting fossils) is justified by tactics for the protection of fossils *in situ*. Two sites among those referred to in this paper

Fig. 11. Outcrops of Ordovician sediments and graptolite shales (lower Ludlowian in Międzygórz. The site is suggested for protection as a documentation site. Photo by K. Miśkiewicz.

have already been covered by a conservation-type of protection, as monuments of nature: outcrops of diabases and two Ordovician-Silurian sections in Zalesie, and a diabase outcrop (Silurian) in Widełki (Wróblewski 2000). This form of protection results in a situation where, by law, the sediments with graptolites exposed in Zalesie, are not available for any scientific studies which involve sample collection. The proposal to protect the outcrop of graptolite-bearing shales in the Prągowiec gorge is still current (Wróblewski 2000). The outcrops of these rocks have been excessively exploited and destroyed by both collectors and geologists (Fig. 9). Will such a decision prove to be an effective protection against devastation of graptolite-bearing shale outcrops? In order to achieve this, a substitute site should be identified both for obtaining paleontological material for purposes of professionals and collectors alike. Several sites were suggested (Fig. 6) which may fully satisfy the needs of these two groups. Under this arrangement, the *in situ* protection effort aimed at the most characteristic Ordovician-Silurian fossils could be considered as a supplement to the list of representative sites covered by the initiative project for geodiversity protecting, carried out by the International Union of Geological Sciences (Wimbledon 1996; Wimbledon *et al.* 1999).

Apart from the Świętokrzyskie Mts., only in two cases the Ordovician and Silurian rocks (i.e. graptolite-bearing) occur on the surface in Poland. They are available as *in situ* (outcrops) in the Sudety Mts., in the Bardzkie and Kaczawskie range (Malinowska 1955; Tomczyk 1962) and as *ex situ*, in the form of boulders (erratics) carried from Scandinavia by glaciers and left in these regions of Poland that the Scandinavian glaciers reached. Many scientific reports are known describing Ordovician-Silurian fossils in these erratics (Kozłowski 1959a, 1959b, 1961; Kozłowski and Gregus 1959; Urbanek 1958, 1959a, 1959b, 1963; Mierzejewski 1977, 1986; Urbanek and Mierzejewski 1984). Particularly worthy of attention is the accumulation of these boulders north-west of Warsaw, in the Vistula river valley (Mochty, Zakroczyn, Wyszogród), from which valuable specimens of graptolites were described. At present, these boulders are not available for studies as they are now fully immersed as a result of river training. Thus, the issue of the conservation-type protection of graptolite-bearing sites in the Sudety Mts. and of the Ordovician-Silurian erratics is still open. The latter are generally limestones, and among a great number of monuments of nature within the Polish lowlands there is not one case of any erratic representing limestones of the lower Paleozoic. What is the reason for this situation? These limestone erratics are certainly a rarer natural occurrence than granite erratics which are commonly protected as monuments of nature.

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REFERENCES

Alexandrowicz Z. (ed.) 1999. Representative geosites of Central Europe. Proceedings of the Central Europe Working Group Workshop ProGEO'97. Polish Geological Institute Special Papers, 2.

Armstrong W.G., Dilly P.N., Urbanek A. 1984. Collagen in the pterobranch coenecium and the problem of graptolite affinities. Lethaia 17, 2: 145-152.

Bates D.E.B., Kirk N.H. 1986. Mode of secretion of graptolite periderm, in normal and retiolite graptolites. In: C.P. Hughes, R.B. Rickards (eds.). Paleoecology and Biostratigraphy of Graptolites. Geological Society Special Publication 20: 221-236.

Bednarczyk W. 1962. Dolny ordowik okolicy wsi Koziel w Górach Świętokrzyskich [The lower Ordovician near the village of Koziel (Holy Cross Mts.)]. Księga Pamiątkowa Prof. J. Samsonowicza, Wydawnictwo Geologiczne Warszawa: 149-170 (in Polish with an English summary).

Bednarczyk W. 1964. Stratygrafia i fauna tremadoku i arenigu (Oelandianu) regionu kieleckiego Gór Świetokrzyskich [The stratigraphy and fauna of the Tremadocian and Arenigian (Ölandian) in the Kielce region of the Holy Cross Mountains (Middle Poland)]. Biul. Geol. Wydz. Geol. Uniw. Warsz. 4: 3-127 (in Polish with an English summary).

Bednarczyk W., Tomczyk H. 1981. Punkt 4 – Bardo-Stawy. Problem I (Station 4 – the Bardo Ponds. Problem I). In: Przewodnik LIII Zjazdu PTG w Kielcach (in Polish).

Briggs D.E.G., Erwin D.H., Collier F.J. 1994. The Fossils of the Burgess Shale. Smith. Inst. Washington.

Bulman O.M. 1955. Graptolithina. In: R.C. Moore (ed.). Treatise on Invertebrate Paleontology, University of Kansas, Part V.

CZARNOCKI J. 1919. Stratygrafia i tektonika Gór Świętokrzyskich (Stratigraphy and tectonics of the Świętokrzyskie Mts.). Prace Towarzystwa Naukowego Warszawskiego. Wydział Nauk Matematycznych i Przyrodniczych, 28, pp. 87 (in Polish).

CZARNOCKI J. 1928. Profil dolnego i górnego ordowiku w Zalesiu pod Łagowem w porównaniu z ordowikiem innych miejscowości środkowej części gór Świętokrzyskich (Profile of Lower and Upper Ordovician in Zalesie near Łagów compared with Ordovician of other localities of the central part of the Świętokrzyskie Mts.). Sprawozdania Pol. Inst. Geol. 4, 3-4: 555-581 (in Polish).

CZARNOCKI J. 1939. Sprawozdanie z badań terenowych wykonanych w Górach Świętokrzyskich w 1938 r. (Field work in the Święty Krzyż Mountains in 1938). Biul. Inst. Geol. 15: 1-41 (in Polish with an English summary).

CZARNOCKI J. 1950. O odkryciu facji graptolitowej w dolnym ordowiku Gór Świętokrzyskich [The discovery of the Graptolite facies within the Lower Ordovician in the Święty Krzyż (Holy Cross) Mts.]. Acta Geologica Polonica 1,1: 3-12 (in Polish with an English summary).

CZARNOCKI J. 1957. Geologia regionu łysogórskiego (Geology of the Łysogóry Region). Prace Inst. Geol. T. 18. Warszawa. pp. 138 (in Polish with an English summary).

DILLY P. N. 1986. Modern pterobranchs: observations on their behaviour and tube building. In: C.P. Hughes, R.B. Rickards (eds.). Paleoecology and Biostratigraphy of Graptolites, Geological Society Special Publication 20: 261-269.

DZIK J. 1992. Dzieje życia na Ziemi (History of the life on the Earth). PWN, Warszawa (in Polish).

FORTEY R. 1999. Życie. Nieautoryzowana biografia. (Life. Not authorized biography). Wyd. Albatros, Warszawa (in Polish).

GONERA M. 1997a. Can we stay on the lines of Agenda 21 working at paleontology? In: Marinos P.G., Koukis G.S., Tsiambaos G.C., Stournaras G.C. (eds.) Proceedings International Symposium on Engineering Geology and the Environment. A.A. Balkema: 2933-2938.

GONERA M. 1997b. Skamieniałości fliszu karpackiego – motywy i kierunki ochrony (Carpathian flysch fossils – the arguments about conservation). Chrońmy Przyr. Ojcz. 53, 4: 24-38 (in Polish with an English summary).

GONERA M. 1999. Apel w sprawie ochrony stanowisk paleontologicznych. (An appeal on conservation of paleonthological sites). Przegl. Geol. 47, 6: 539-541 (in Polish).

GONERA M. 2001. Otwornice i paleośrodowisko formacji badenianu (miocen środkowy) na obszarze Górnego Śląska. [Foraminiferida and paleoenvironment of the Badenian formations (Middle Miocene) in Upper Silesia (Poland)]. Studia Naturae 48: 211 (in Polish with an English summary).

HECKMAN D. S., GEISER D. M., EIDELL B. R., STAUFFER R. L., KARDOS N. L., HEDGES S. B. 2001. Molecular evidence for the early colonization of land by fungi and plants. Science 293, 5532: 1129-1133.

JURA CZ. 1996. Bezkręgowce (Invertebrates). PWN, Warszawa (in Polish).

KOTAŃSKI Z. 1959. Przewodnik geologiczny po Górach Świętokrzyskich (Geological guide-book to the Świętokrzyskie Mts.). Wyd. Geol., Warszawa. 1-2 (in Polish).

KOTAŃSKI Z. 1968. Z plecakiem i młotkiem w Góry Świętokrzyskie. Przewodnik geologiczny dla turystów (With rucksack and hammer in the Świętokrzyskie Mts. A geological guide-book for tourists). Wyd. Geol., Warszawa (in Polish).

KOWALCZEWSKI Z. TOMCZYK H. 1981. Punkt 4b – wąwóz Prągowiec koło Barda. Problem I (Station 4b – the Prągowiec Gully near Bardo village). In: Przewodnik LIII Zjazdu PTG w Kielcach (in Polish).

KOZŁOWSKI R. 1938. Informations préliminaires sur les Graptolithes du Tremadoc de la Pologne et sur leur portée théorique. Annales Musei Zoologici Polonici 13, 16: 183-196.

KOZŁOWSKI R. 1947. Les affinités des Graptolithes. Biological Reviews 92, 93-108.

KOZŁOWSKI R. 1948. Les graptolithes et quelques nouveax groupes d'animaux du Tremadoc de la Pologne. Paleontologia Polonica 3, pp. 229.

KOZŁOWSKI R. 1956. Sur quelques appareils masticateurs des Annélides Polychètes ordoviciens. Acta Paleontologica Polonica 1, 3: 165-210.

KOZŁOWSKI R. 1959a. Les Hydroïdes ordoviciens a squelette chitineux. Acta Paleontologica Polonica 4, 3: 209-271.

KOZŁOWSKI R. 1959b. Un microfossile énigmatique. Acta Paleontologica Polonica 4, 3: 273-277.

KOZŁOWSKI R. 1961. Découverte d'un Rhabdopleuridé (Pterobranchia) ordovicien. Acta Paleontologica Polonica 6, 1: 3-16.

KOZŁOWSKI R. 1962. Crustoidea – nouveau groupe de Graptolites. Acta Paleontologica Polonica 7, 1-2: 3-52.

KOZŁOWSKI R. 1963a. Le dévelopment d'un Graptolite tuboide. Acta Paleontologica Polonica 8, 2: 103-134.

KOZŁOWSKI R. 1963b. Sur la nature des Chitinozoaries. Acta Paleontologica Polonica 8, 2: 425-450.

KOZŁOWSKI R. 1966. On the structure and relationship of graptolitides. Journal of Paleontology 40, 3: 489-501.

KOZŁOWSKI R. 1967. Sur certains fossiles ordoviciens a test organique. Acta Paleontologica Polonica 12, 2: 99-132.

KOZŁOWSKI R. 1968. Nouvelles observations sur les Conulaires. Acta Paleontologica Polonica 13, 4: 497-536.

KOZŁOWSKI R. 1970. Nouvelles observations sur les Rhabdopleurides (Pterobranches) Ordoviciens. Acta Paleontologica Polonica 15, 1: 3-17.

KOZŁOWSKI R. 1971. Early development stages and the mode of life of graptolites. Acta Paleontologica Polonica 16, 4: 313-343.

KOZŁOWSKI R., GREGUSS P. 1959. Discovery of Ordovician land plants (preliminary communication). Acta Paleontologica Polonica 4, 1: 1-10.

KOZŁOWSKI R., KAŹMIERCZAK K. 1968. On two Ordovician calcareous algae. Acta Paleontologica Polonica 13, 3: 325-358.

LARWOOD J. 1999. England's fossil heritage; managing our window into the past. In: D. Borettino, M. Vallejo, E. Gallego (eds.). Towards the Balanced Management and Conservation of the Geological heritage in the New Millenium. Madrid, pp. 55-59.

LEHMANN U., HILMER G. 1987. Bezkręgowce kopalne (Fossil invertebrates). Wyd. Geol., Warszawa (in Polish).

MALINOWSKA L. 1955. Stratygrafia Gotlandu Gór Bardzkich. (Stratigraphy of the Gothlandian of the Bardo Mountains). Biul. Inst. Geol. 95: 71 (in Polish with an English summary).

MIERZEJEWSKI P. 1977. The first discovery of Crustoidea (Graptolithina) and Rhabdopleurida (Pterobranchia) in the Silurian. Bulletin de'l Académie Polonaise des Sciences, Série des Sciences de laTerre 25, 103-107.

MIERZEJEWSKI P. 1986. Ultrastructure, taxonomy and affinities of some Ordovician and Silurian organic microfossils. Paleontologia Polonica 47: 129-216.

MIERZEJEWSKI P. 2000. On the nature of graptoblasts. Acat Paleontologica Polonica 45, 3: 227-238.

MIERZEJEWSKI P. 2001. A new graptolite, intermediate between the Tuboidea and the Camoroidea. Acta Paleontologica Polonica 46, 3: 367-376.

ORŁOWSKI S., SZULCZEWSKI M. 1990. Geologia historyczna (Historical geology). Wyd. Geol., Warszawa (in Polish).

SAMSONOWICZ J. 1916. Kambr i kambrosylur Gór Świętokrzyskich (Kambr and Kambrosilurian of the Świętokrzyskie Mts.). Spraw. z Pos. Tow. Nauk. Warsz. Zeszyt 4, 321-358 (in Polish).

SAMSONOWICZ J. 1928. Sprawozdanie z badań geologicznych, wykonanych w r. 1927 w okolicy Międzygórza na arkuszu Sandomierz mapy 1:100 000 (Report from geological fieldwork carried out in the environs of Międzygórze in 1927, on the Sandomierz chart of a map scaled 1: 100 000). Posiedz. Nauk. Państw. Inst. Geol. 19/20, Warszawa, pp. 25-27 (in Polish).

SAMSONOWICZ J. 1948. Caractéristique géologique du tremadoc de Wysoczki. In: R. Kozłowski (ed.). Les graptolithes et quelques nouveax groupes d'animaux du Tremadoc de la Pologne. Paleontologia Polonica 3: 1-5.

SCHEPOTIEFF A. 1905. Über die Stellung der Graptolithen im zoologischen System. Neues Jahrbuch für Mineralogie, Geologie, und Paläontologie, Jahrg. 2: 79-98.

SIMPSON G.G. 1999. Kopalny zapis historii życia (Fossil record of the life history). Wyd. Prószyński i S-ka, Warszawa (in Polish).

STARMACH K. 1963. Blue-green algae from the Tremadocian of the Holy Cross Mountains (Poland). Acat Paleontologica Polonica 8, 4: 451-463.

STUPNICKA E., STEMPIEŃ-SAŁEK M. 2001. Poznajemy Góry Świętokrzyskie. Wycieczki geologiczne (We know the Świętokrzyskie Mts. Geological excursions). PWN, Warszawa (in Polish).

TELLER L. 1969. The Silurian biostratigraphy of Poland based on graptolites. Acta Geologica Polonica 19, 3: 393-501.

TOMCZYK H. 1962. Problem stratygrafii ordowiku i syluru w Polsce w świetle ostatnich badań (Stratigraphic problems of the Ordovician and Silurian in Poland in the light of recent studies). Prace Inst. Geol., Warszawa 35: 134 (in Polish with an English summary).

TOMCZYK H. 1964. The Ordovician and Silurian sedimentation cycles in Poland and the phenomena of Caledonian orogeny. Bull. Acad. Pol. Sc. Ser. Sc. geol. geogr. 12: 119-131.

TOMCZYK H. 1968. Sylur. Stratygrafia (Silurian. Stratygraphy). In: S. Sokołowski (ed.). Budowa geologiczna Polski. Stratygrafia. Prekambr i paleozoik (Geological structure of Poland. Stratigraphy. Prekambr and Paleozoic). Wyd. Geol., pp. 280-304 (in Polish).

TOMCZYKOWA E., TOMCZYK H. 1968. Ordowik. Stratygrafia (Ordovician. Stratygraphy). In: S. Sokołowski (ed.). Budowa geologiczna Polski. Stratygrafia. Prekambr i paleozoik (Geological structure of Poland. Stratigraphy. Prekambr and Paleozoic), Wyd. Geol., pp. 215-230 (in Polish).

TOWE K.M., URBANEK A. 1972. Collagen-like Structures in Ordovician graptolite Periderm. Nature 237: 443-445.

URBAN J., WRÓBLEWSKI T. 1999. Representative geosites of the Góry Świętokrzyskie (Holy Cross Mts.) and Nida Basin, Central Poland. In: Alexandrowicz Z. (ed.) Representative geosites of Central Europe. Proceedings of the Central Europe Working Group Workshop ProGEO'97. Polish Geological Institute Special Papers 2: 61-70.

URBANEK A. 1958. Monograptidae from erratic boulders of Poland. Paleontologia Polonica 9, pp. 115.

URBANEK A. 1959a. Studies on graptolites. I. Development and structure of *Pristiograptus gotlandicus* (Perner). Acta Paleontologica Polonica 4, 1: 11-26.

URBANEK A. 1959b. Studies on graptolites. II. On the development and structure of graptolite genus *Gymnograptus* Bulman. Acta Paleontologica Polonica 4, 3: 279-338.

URBANEK A. 1963. On generation and regeneration of *Cladia* in some Upper Silurian monograptids. Acta Paleontologica Polonica 8, 2: 135-258.

URBANEK A. 1986. The enigma of graptolite ancestry: lesson from a phylogenetic debate. In: A. Hoffman, M. Nitecki (eds.). Problematic Fossil Taxa. Oxford University Press, New York, pp. 184-225.

URBANEK A. 1998. Oligophyly and evolutionary parallelism: A case study of Silurian graptolites. Acta Paleontologica Polonica 43, 4: 549-572.

URBANEK A., DILLY P.N. 2000. The stolon system in *Rhabdopleura compacta* (Hemichordata) and its phylogenetic implications. Acta Paleontologica Polonica 45, 3: 201-226.

URBANEK A., MIERZEJEWSKI P. 1984. The ultrastructure of the Crustoidea and the evolution of graptolite skeletal tissues. Lethaia 17, 1: 73-91.

WIMBLEDON W.A.P. 1996. National site selection, a stop on the way to a European Geosite list. Proceedings of the special Symposium "Geological Heritage in South East Europe", May 1995. Geologica Balcanica 26: 15-27.

WIMBLEDON W.A.P., ISHCHENKO A.A., GERASIMENKO N.P., KARIS L.O., SUOMINEN V, JOHANSSON C.E., FREDEN C. 1999. GEOSITES – an IUGS initiative: science supported by conservation. In: D. Barettino, W.A.P. Wimbledon, E. Collego (eds.). Geological Heritage: its conservation and management. Madrid, pp. 69-94

WRÓBLEWSKI T. 2000. Ochrona georóżnorodności w regionie Świętokrzyskim. (Geodiversity conservation in the Świętokrzyskie Mts. region). Ministerstwo Środowiska, Państwowy Inst. Geol., Warszawa (in Polish).