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RELICT ROCK GLACIERS IN THE CENTRAL EUROPEAN MID-MOUNTAINS. STATE-OF-THE-ART

Abstract

Landforms in Central European Mid-Mountains, which already have been defined as relict rock glaciers or, at least, have been suggested to be ones, have been revisited. Following locations have been taken into account: Mt. Meißner (Germany), Karkonosze Mts. (Czech Republic and Poland), Hrubý Jeseník Mts. (Czech Republic), Ślęża Massif (Poland) and Bernese Jura.

All these landforms have been examined for their morphological and, where possible, sedimentological features, which were defined by Barsch (1996b) as diagnostic for relict rock glaciers. The comparison shows that none of these landforms fulfils all the criteria required and that there is no single geomorphic characteristic common to all of them. However, they undoubtedly have developed due to slow downslope movement of regolith. The basic question about the role of interstitial ice in their evolution cannot be answered definitively in the light of available sedimentological data. On the contrary, micromorphology and dimensions, as well as their geomorphological context do show that most of them required interstitial ice to form and hence, may indeed be called rock glaciers.

According to morphology and inferred origin the landforms can be classified into four groups: (1) tongue-shaped rock glaciers, showing relatively distinct morphology that resembles relief of active rock glaciers, (2) embryonic, lobate talus rock glaciers, (3) features, which have possibly developed due to deformation of ice accumulated between blocks and hence, can be called rock glaciers, but do not show any distinct relief; they resemble the "kurum-glaciers" known from Siberia and (4) other landforms, which could be called rock glaciers only if their structure would confirm importance of interstitial ice in their development.

All the features occur on slopes efficiently remodelled by periglacial processes as testified by distinct microrelief of block covers, or tors or cryoplanation terraces, and have either talus or scree as a source of debris. In most cases the landforms have developed on slopes built of massive igneous or metamorphic rock and only embryonic talus rock glaciers in Jura dveloped from limestone debris. Rock glacier shape and, in places, locations have been controlled by local topography.

Because of lack of quantitative dating, the age of relict rock glaciers cannot be precisely defined; however, most of them seem to have developed during cold phase (phases?) of last glaciation.

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INTRODUCTION

Although periglacial research in the Central European Mid-Mountains has a long tradition dating back to the work of WALERY ŁOZIŃSKI at the beginning of this century, only a few relict rock glaciers have been identified in this region up to now. However, as these spectacular geomorphic features may serve as a tool for palaeoclimatic reconstructions (cf. KERSCHNER, 1985; BARSCH, 1983), it seems promising to pay more attention to their distribution, age, and lithological and geomorphic controls. Hence, the aim of this paper is to review the data about the few known relict rock glaciers in the Central European Mid-Mountains, and to develop ideas recently presented by BARSCH (1993a, 1993b, 1996a) in order to provisionally define factors to control the occurrence of rock glaciers. These criteria could then serve as a key in any attempts to look for similar features in other regions, where geomorphological evolution has taken place in a periglacial environment.

This work does not aspire to be a complete synthesis of the topic; rather, it is a summary of the present knowledge and could be a basis for possible further research. All landforms described or suggested by BARSCH (1993b) to be relict rock glaciers have been revisited and present author's observations have been confronted with existing interpretations.

Special attention has been paid to geomorphic and lithologic features defined by BARSCH (1996b) as indicative for relict rock glaciers, i.e.:

1. Still visible relief of furrows and ridges.
2. Two-layered stratigraphy visible on front and side slopes, maximum height at the outer ridges, and all grain sizes occurring at the surface.
3. Thickness of deposits of a front ridge to be 5–10 m.
4. Area of deposit to be one-fourth to one-third of the area of the rock shed for talus rock glaciers or a distinct source of debris.

Following locations have been taken (Fig. 1): Mt. Meißner (Hessian Highland, Germany), Karkonosze Mts. (Polish and Czech Sudetes), Hrubý Jeseník Mts. (Czech Sudetes) and Ślęża Massif (Sudetic Foreland, Poland). Additionally, landforms in the Swiss Jura reported as examples from the Mid-Mountains by BARSCH (1969, 1996a), although this region does actually not belong to the Hercynian Mid-Mountain belt, have been considered.

MEIßNER

Mt. Meißner is a part of the Hessian Highland, located in central Germany, about 35 km south of Göttingen. It is a structure-controlled plateau with the top at 700–750 m a.s.l. (the maximum altitude is 754 m a.s.l.), limited by up to 400 m high slopes, especially steep on the eastern and southern sides. The uppermost unit within an almost horizontally lying

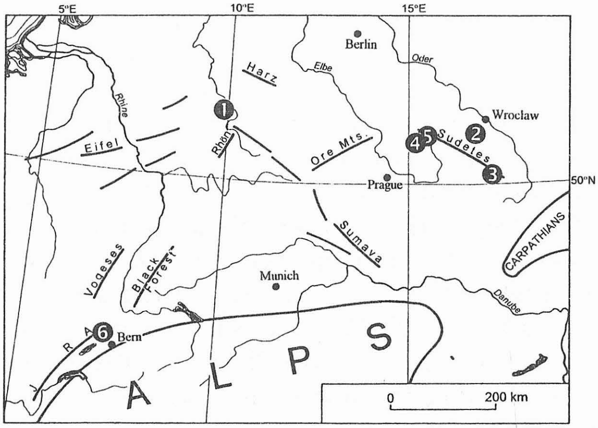


Fig. 1. Location map
1 – Mt. Meißner, 2 – Ślęża Massif, 3 – Hrubý Jeseník Mts., 4 – Karkonosze Mts. (Czech side), 5 – Karkonosze Mts. (Polish side), 6 – Bernese Jura

rock series is a basalt cap, which covers Miocene sediments including lignite, as well as Bunter sandstone.

The slopes of Mt. Meißner are extensively covered by block debris derived from basalt (Pl. 1), witch forms a rare variety of landforms, which often can hardly be put into conventional classifications. Poser (1933) studied periglacial relief of this area in detail and distinguished eight

Pl. 1. Typical block cover on the slopes of Mt. Meißner. At the break of slope it changes into the system of lobes and ramparts, most often covered by forest

types of landforms built of block debris, i. e. "block ramparts" (Germ. Blockwälle), "landslide-like block masses" (abrutschartige Blockmassen), blockfields (Blockmeere), "block tongues" (Blockzungen), "block swellings" (Blockwülsten), "block steps" (Blockstufen), "block scatter" (Blockstreu) and block streams (Blockströme). The "block ramparts" have been interpreted as features, which have originated due to accumulation of debris rolling down over a snow patch surface hence as protalus ramparts in modern terminology, and the forms called "landslide-like block masses" have been described to develop through mass movements such as landslides or rockfalls. All other landforms listed above would have developed, according to POSER (1933), due to solifluction understood as a creep of an active layer of permafrost. BARSCH (1993b) proposed a new interpretation appreciating the role of interstitial ice, but did not develop this idea in any detail.

Some years after POSER's monography a special attention was paid by POSER and BROCHU (1954) to an assemblage of landforms consisting of a hollow within the upper part of slope and a water-filled depression located on the slope below (Frau-Holle-Teich) surrounded by a rampart. As the core of the rampart consists of basalt columns, which cannot occur *in situ* at such a low altitude, and it is covered by debris resembling a moraine deposits, the authors inferred that the depression was primarily shaped by tectonics or mass movements and afterwards remodelled by a glacier or multi-annual snow-patch. However, it seems more likely that the enigmatic rampart has not developed as a result of glacial activity but, partly at least, due to creep of slope covers. But, since there is no clear supporting evidence, it will not be discussed here in any more detail.

Landforms called by POSER (1933) "block ramparts" and "block swellings" are easier for interpretation and are clearly linked with the question of relict rock glaciers. They have developed as either ramparts running parallel to the lower break of slope or as lobes overlying each other to some extent. Both can be more than 10 m high and their length usually does not exceed 15–25 m. The width varies very considerably from less than 20 m at smaller lobes to several tens of meters or even 100–150 m at ramparts. Their downslope facing slopes are, as a rule, much higher than the upslope-facing ones; their inclination reaches often app. 35°. On the contrary, the upslope-facing side is almost horizontal and shallow depressions are often developed within it. The blocky cover, consisting almost entirely of basaltic clasts, with an original contraction structure often retained, can be well seen at the surface of the lobes, close to the slope break or, occasionally, on front sides of other lobes located below. In other places soil and undergrowth have masked it. In some places debris accumulation forms take a different shape; they are developed as much more elongated bodies and these were called "block tongues" (Blockzungen) by

POSER (1933). Actually, it is even the compendious description given by POSER that allows one assume that true relict rock glaciers might be considered here. According to POSER (p. 164), these landforms are elongated downslope, up to 200 m long and 80 m wide. They have convex cross-profile, with the margin differing very distinctly from the adjacent slope. The front is usually bent downslope and shows convex profile as well. The upper sections of "Blockzungen" are connected with scree slopes about. Blocks are loose, but stable. Most of the blocks seem to be pushed to the front.

One of the debris tongues, located below the enigmatic rampart closing the Frau-Holle-Teich depression, has been studied by the present author in more detail. It fills the bottom of a small valley, and is located at the altitude 520–600 m a.s.l., above the site called Teufelslöcher (Fig. 2). The upper limit of the landform cannot be recognised easily, because a rather less varied surface changes into higher relief without a distinct boundary.

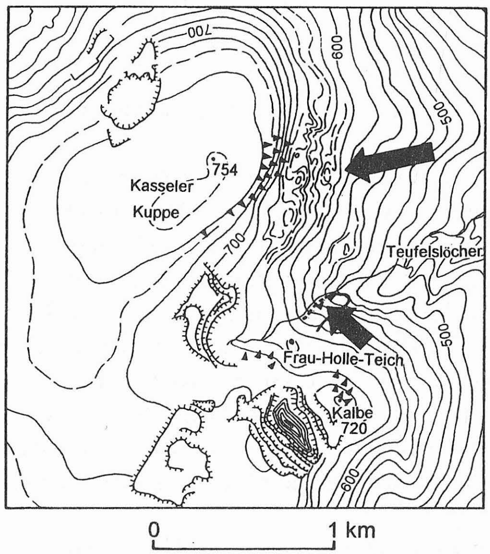


Fig. 2. Topography of the north-eastern part of Mt. Meißner plateau. "Block ramparts" and "block lobes" (both marked by the longer arrow) can be recognised in the shape of contour lines (main contour lines each 20 m) and the biggest "block tongue" is marked by the shorter arrow. Map drawn after Topographische Karte der Bundesrepublik Deutschland, 1:25000, sheet Bad Sooden–Allendorf

The tongue is better developed in its lower part. Its margin sharply differs from the north-facing valley slope even in the middle part of the landform, whereas the limit against the south-facing slope must be determined rather arbitrarily. The microrelief of the tongue surface is rather rough. It consists of several lobe-like elevations separated by small depressions varying in size and shape, which seem to have been originated due to unequal movement of various parts of the entire debris body. Although the pattern of longitudinal and transverse ridges, typical for active rock glaciers, cannot be evidently demonstrated, two distinct elongated ramparts about 2–4 m in height, running parallel to each other and to the valley slope as well, can be observed in the southern part of the tongue. They could be considered as longitudinal ridges, especially, because they change in their lower parts into frontal lobes, arranged perpendicularly to the valley slope. Although the major part of the "block tongue" is covered by forest, its surface consists almost entirely of basaltic blocks and pebble-size debris. The lower limit of the tongue is distinctly emphasised by a steep blocky surface of the terminus, approx. 6–10 m high.

Both ramparts and lobes, as well as the block tongues, show no clear control of aspect. The largest blockfields and the best-developed block lobes, ramparts and tongues are located on the east-facing slope of the plateau, but not all aspects are represented to the same extent, since the plateau of Mt. Meißner is elongated from the north to the south. According to the map published by Poser (1933), the altitude range of the occurrence of the landforms considered is 450–700 m a.s.l. The best-developed block tongue lies at 520–~600 m a.s.l. and the most distinct "debris lobes" at 600–660 m a.s.l.

As there are no suitable excavations, no data concerning internal structure of debris forms on the slopes of Mt. Meißner is available, except some remarks inferred from the surface and shallow pits (Poser, 1933). According to these, the upslope facing surfaces of debris lobes and ramparts are built of material of various sizes, including relatively high percentage of fines. On the contrary, the downslope-facing surface consists more often almost entirely of coarse clasts with local imbrication. The later contribution of Poser and Brochu (1954) provides more precise information about the inner structure of the problematic rampart closing Frau-Holle-Teich. They observed a blocky mantle, covering a heterogenic deposit (p. 119).

Landsliding or similar phenomena cannot account for the development of both lobes and tongues. No head scarps or flanks on slopes above lobes north of Frau-Holle-Teich can be seen. Taking into account very fresh morphology of the accumulation area, such features would have survived, if they have ever existed. Only in the case of the tongue above Teufelslöcher there is a valley head, which could have hosted the amount of debris large enough for the tongue. However, here the microrelief seems to deny landslide hypothesis, as its morphology, including quite well developed longitudinal ridges, indicates rather continuous slow movement.

Concluding, one can state that there is an assemblage of landforms developed on the slopes of the Mt. Meißner, which represent at least two types of accumulation developed in the Pleistocene due to the creep of debris. As the former ice content within the debris is debatable, the problem of genetic classification of these landforms will be considered separately below.

Since the emphasis in POSER's work (1933) was on the question, if such landforms are climatically controlled and if they are connected with periglacial environment, he did not consider their age in any more detail, except defining it to be Pleistocene. Afterward, a short information can be found in the contribution dealing with the Frau-Holle-Teich rampart (POSER, BROCHU, 1954), that the debris bodies developed "mostly" during the last glaciation. In regard to the very fresh morphology this estimate seems to be more likely, but no unequivocal evidence is available.

ŚLĘŻA MASSIF

Ślęża Massif is an inselberg region located in south-western part of Poland and it is the highest part of Sudetic Foreland. Four main rock types occur here, i.e. gabbro, serpentinite, amphibolite (metabasalt) and granite. The highest elevation of the massif is Mt. Ślęża (718 m n.p.m.), which is a stately monolith standing out about 500 m above the adjacent lowland. Its top, as well as east- and south-facing slopes consist of gabbro, which belongs to a Devonian ophiolite complex (MAJEROWICZ, PIN, 1994). On the contrary, lower sections of north-west-facing slopes of Mt. Ślęża have developed in Variscan granitoides.

A complex of huge debris accumulation forms occurs on eastern and southern slopes of Mt. Ślęża. They were interpreted as either terminal moraines of Pleistocene ice-sheet (FINCKH, 1928), or block streams (Blockströme) (SCHOTT, 1931), or "warps" (a kind of landforms developed due to rapid mass movements) (BARANIECKI, 1951; SZCZEPANKIEWICZ, 1958), or as an effect of debris flows (HORWATH, 1981). Most recently, they have been regarded as relict rock glaciers and the evidence for such an interpretation has been considered by ŻURAWEK (1999 a).

The landforms in question have developed as at least eight rather elongated bodies, occupying an area from 0.06 to 0.24 km^2 for an individual tongue. At least three of them join together into a system over 2 km long and almost 0.6 km^2 in size, whilst the maximum length of an individual form is slightly more than 1 km. Width of the landforms varies between over 200 m and approx. 570 m. They are situated in the altitude range of about 250–500 m a.s.l. Both distal limits and the lateral ones, especially in their lower sections, are easily recognisable in morphology (Pl. 2), whereas the change of the tongues change into "regular" slopes in the rooting zones is gradual. The fronts are usually steep, up to 35°–37° on outward sides and reach up to about 18 m in height. Melt-out relief is expressed here, as there occurs a number of closed depressions, locally

Pl. 2. Lateral ridge of a relict rock glacier in Ślęża Massif

Pl. 3. One of closed depressions within the surface of a relict rock glacier in Ślęża Massif

filled perennially by water (Pl. 3), and connected in places by small streams veering between irregular ramparts.

The landforms are situated in wide and shallow depressions on long slopes of inclination of approx. 7–8°, which are not dissected by any distinct erosional cuttings. The slopes in their uppermost sections bear traces of intensive weathering processes, i. e. numerous frost cliffs with accompanying cryoplanation flattenings and extensive blocky and block-loamy covers often consisting of gabbro clasts, including very big ones.

The blocky cover on the surface of relict rock glaciers in Ślęża Massif is not continuous and, as a rule, not denser than on the adjacent slopes. Several shallow pits, dug in order to examine structure of deposits have showed that the sediments consist of very heterogenic material. No two-layered stratigraphy, i. e. rock glacier core overlain by blocky rock glacier mantle, has been found in any profile. On the contrary, the deposits, at least in the lower parts of debris bodies, show a structure of big blocks swimming in fine matrix that consists mainly of silt and clay (Żurawek, 1999a).

Big amount of fine material and the absence of rock glacier mantle must be regarded as rather confusing characteristic and shows that another hypothesis of tongue origin has to be taken into account as well. Interpretation by Żurawek (1999a) has been based on the presumption that flow of active layer cannot result in landforms up to 20 m in height. However, this is contradicted by findings of Chaus (1995) who reports, from Siberia, features even 30 m high and resultant from more rapid movement of active layer, than usual solifluction. "Earthflows on permafrost" (Chaus, 1995) would, hovewer, contradict opinion, that solifluction cannot produce landforms higher than several meters maximally (cf. perhaps Humlum, 1998b). Nevertheless, in the case of Ślęża Massif indices such as very regular closed depressions within the surface, steep margins, uniform (not dissected into smaller steps) outer slopes of marginal ramparts, and large amounts of very coarse material along with rather thin regolith cover on slopes are difficult to reconcile with the solifluction hypothesis. Additionally, as the description of morphology of the Siberian landforms is not very precise, and no similar features have been recognised in Europe up to now, no reinterpretation is justified at the moment.

The rock glaciers in the Ślęża Massif cannot be older than the decline of Odranian (Drenthe in German stratigraphy) ice-sheet. Unfortunately, no evidence is available as to allow one to determine the age more precisely. On the stratigraphical and morphological premises it has been estimated to be Vistulian, most probably end of Plenivistulian or Late Vistulian (Żurawek, 1999a).

The landforms in Ślęża Massif are relatively big and, according to the classification proposed by Corte (1987) and modified by Barsch (1996 b), should be included, with one exception, into the class of huge relict rock glaciers. However, they do not have any distinct source area, like moraine or talus, and they could not have developed as protalus ramparts either. Uppermost slope sections have supplied debris, which probably could have accumulated there during very long time period, as the top of Mt. Ślęża is supposed to have been a nunatak during Odranian, and possibly the Elsterian glaciation (SZCZEPANKIEWICZ, 1958; BADURA, PRZYBYLSKI, 1998) as well.

The occurrence of relict rock glaciers is supposed to be linked either with the mesoclimatic differences within the slopes of Mt. Ślęża (718) related to aspect, especially with so-called seeder-feeder effect, which has been identified in this region (BŁAŚ, 1997), or with snow-drift processes, or with lithological control. HARRIS *et al.* (1998) maintain that rock glaciers need higher precipitation for their development than block streams. If such a statement is valid universally, it supports the paleoclimatic hypothesis for the Ślęża Massif very well, as only a number of rock streams (TRACZYK, ŻURAWEK, 1999) and not true rock glaciers developed on the north–west facing slopes, i. e. wind-facing ones. However, since the correlation between lithological properties and the occurrence of rock glaciers is more evident, a supposition that they developed due to specific properties of gabbro is favoured (ŻURAWEK, 1999 a, b).

HRUBÝ JESENÍK

The first reference about a Pleistocene rock glacier in the Central European Mid-Mountains has been given by J. PETRÁNEK as early as 1953. He described a debris tongue, located in the Hrubý Jeseník mountain group, which is central and the highest part of East Sudetes, and defined it as a rock glacier. The interpretation is based mainly on the description of active forms in Alaska by CAPPS (1910).

Although PETRÁNEK's contribution was the first one, dealing in detail with the considered feature, it had been preceded by a rather general work of WILSCHOWITZ (1939) who found the debris accumulation to be the result of a kind of catastrophic mass movement. Interesting is, that he put in this way in question a hypothesis of glacial origin of the landform, but unfortunately does not called author of such a supposition.

The alleged rock glacier fills a small valley, shifting two small streams on its sides. Actually only its front is expressed in morphology quite distinctly (Pl. 4) as it stands out for about 6–10 m above the riverbeds of the mentioned streams (PETRÁNEK, 1953). Except its frontal part, the relief is rather subdued. The surface is quite uniform, nearly flat and only slightly convex in the cross-profile. However, the extent of the feature is quite clearly marked by the differences in slope cover characteristics. Numerous blocks of quartzite are dispersed within the valley fill, and although they do not form any dense block cover, they do contrast with the adjacent slopes, where loamy covers without block-size clasts predominate.

Pl. 4. Front of the conjectural rock glacier in the Hrubý Jeseník Mts

According to PETRÁNEK, the tongue-shaped debris body can be distinguished in the morphology going upslope from its front located on 820 m a.s.l. to at least altitude of 1000–1100 m a.s.l., where it grades into "regular" slope. The length of the landform to this limit is about 1650 m. PETRÁNEK supposes, that the rooting zone could have been situated as high as an extensive blockfield below Mt. Suť (1221). Then, the entire length would be about 1900 m. The width increases steadily upslope from 50–100 m in the frontal section, up to 350 m at the altitude of 960 m a.s.l. Higher above it is difficult to estimate because of indistinct boundaries. The mean slope of it surface is 8°–9° and only locally exceeds 20°.

There are no longitudinal ridges developed and features described as transverse ridges could be considered doubtful as well. There is a number of very shallow depressions often filled by humus, moss and peat which keep water near or at the surface. They could have originated as a result of melting out of interstitial ice, but neither their irregular shape nor openness and a mere depth of 0.5–1 m four such an explanation.

There are no exposures to show the sediments. PETRÁNEK (1953) inferred their maximum thickness to be 10–20 m from superficial morphology. The debris consists almost entirely of quartzite, and only subordinately some phyllite and greenstone occur. Coarse blocks, up to 5 m (PETRÁNEK, 1953) in diameter, can be observed at the surface, but they do not form any rock glacier mantle and fine material is present in considerable quantities as well.

As PETRÁNEK focussed on the problem of the origin rather than the age of the landform, the latter has been defined rather generally to be Pleistocene. Probably more precise dating would be difficult, at least on the basis of stratigraphical evidence.

Certainly, the landform in question must have developed in a consequence of a rather slow movement of debris that was gradually filling the valley. The mechanism of transport is, nevertheless, difficult to recognise on the basis of geomorphic premises. Taking into account low inclination of slope and strong periglacial component in regional geomorphology, it seems to be valid to causally link the form with the periglacial environment. Relatively big dimensions of the debris body indicate that it would hardly be produced by creep of active layer of permafrost only and thus, be called a solifluction lobe. On the other side, geomorphic features typical for relict rock glaciers such as distinct frontal rampart, distinct melt-out microrelief and longitudinal and transverse ridges are not present or are questionable at least. Even Petrβnek himself considers between these two possible ways of explanation and does not defence the rock glacier interpretation dogmatically, since he admits difficulties in distinguishing between relict forms formed by these processes. Arguments for the rock glacier hypothesis he advanced included the properties of quartzite, which produces regolith that is too permeable for large-scale solifluction (1), location of the Pleistocene ELA (literally: snow line) at the altitude of 1150 m a.s.l., corresponding with the rooting zone of the debris body and hence, sufficient supply of ice; moreover, the presence of a true glacier in one of adjacent valleys of similar altitude and aspect was quoted (2), location of both debris tongue and the glaciated valley (see above) on the same, east-facing slope, which gathers higher precipitation than any other slope in this region (3), resistance of local blocky material against solifluction creep (4), presumption that if solifluction was the mechanism of landform development, then similar features should be expected in adjacent areas, which is, however, not the case (5) and, actually not very evident decrease of dimensions of blocks with increasing distance from the front (6).

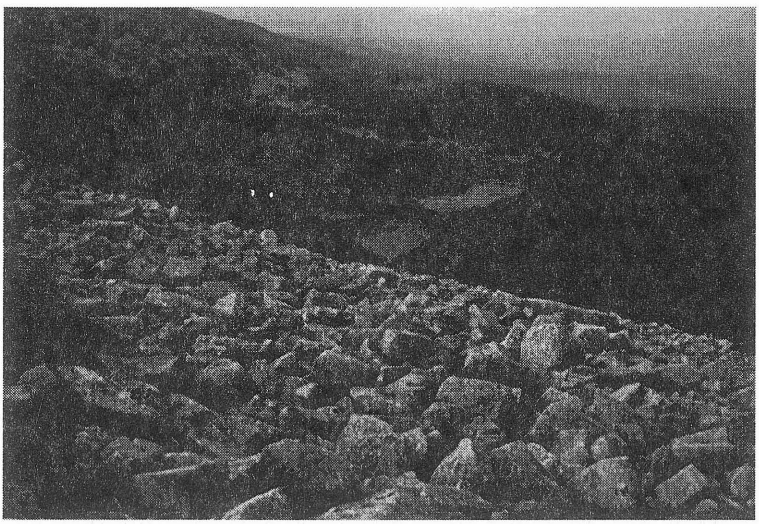
Apart from the discussion about appropriateness and weight of each individual argument, it has to be emphasised that no direct observation on morphology or structure of sediments confirms that the feature needed ground ice for its evolution. On the contrary, with regards to morphology alone it seems to be fairly similar to landforms defined as rock streams (or block streams) and reported from the Czech Shield by FENCL and SVATOŠ (1962, 1968), KARÁSEK (1977), TRACZYK and ŻURAWEK (1999). Hence, the landform could be called as a relict rock glacier only conditionally, but this problem will be explored further below.

KARKONOSZE MTS.

Karkonosze Mts. is the highest part of the Sudetes and of the entire Central European Mid-Mountains and hence, merit special attention, as climate during the Pleistocene must have been here especially suitable for development of rock glaciers.

The existing references about Pleistocene rock glaciers in the Karkonosze Mts. are the report by CHMAL and TRACZYK (1993) and a suggestion of BARSCH (1993) who regards moraines described formerly by PARTSCH (1882) as possible rock glaciers.

CHMAL and TRACZYK (1993) have interpreted block accumulation patch on the slope of the main ridge of the Karkonosze Mts. near the Mały Śnieżny Kocioł glacial cirque to be a true relict rock glacier and maintained that several other ones are initial forms of rock glaciers (Pl. 5). According to their description, the mature form is located on north facing slope of 26o in inclination, at the altitude of 1120–1300 m a.s.l. Its length exceeds 400 m and the maximal width is 250 m. The form consists of large granite blocks and is as much as 10–15 m thick. CHMAL and TRACZYK (1993) reported geomorphic features such as slope fronts of ramparts 5–8 m high in the lower part, a number of steps 2–4 m high in the upper one, and ellipsoidal depressions within the block cover.



Pl. 5. Surface of a block cover, interpreted by CHMAL and TRACZYK (1993) as a relict initial rock glacier, moraine lakes below the Śnieżne Kotły glacial cirques, and terminal moraines below them

The initial features are, according to CHMAL and TRACZYK (1993), up to 100–150 m long and 40–60 m wide. The fronts are 3 to 8 m high and ridges within block bodies are up to 2 m. Upper limit of their occurrence is 1440 m a.s.l., while the lower one is about 1200 m a.s.l.

Both mature landforms, as well as the initial ones, have developed from blocky scree that actually covers the slope along its entire length, and as they do not show any distinct relief can be regarded as a part of the block cover itself.

Chmal and Traczyk (1993) suppose that the debris accumulation forms have developed in two phases. The first one would be a period after the Odranian glaciation and before Vistulian and the second one during Vistulian. This opinion is exclusively based on geomorphic premises. Although the block covers considered, especially those regarded as the initial rock glaciers, do not show features defined by Barsch (1996 b) as necessary for identification of relict rock glaciers, especially no distinct frontal rampart and no two-layered stratigraphy have been reported, the blocks seem to have been transported in ice matrix. Even deposits composed of very big clasts show distinct open-work structure. The majority of them is reoriented and their long axis direction is parallel to the slope inclination.

Barsch (1993) suggested that a few other geomorphic features in the Karkonosze Mts. might have originated due to creep of permafrost. He supposed that accumulation forms within and below the Śnieżne Kotły (Germ. Schneegruben) glacial cirques, which have formerly been interpreted as moraines (Partsch, 1882), could have developed in this way. As there exist several features of different shape and location, each of these should be considered individually.

The smallest one, located within the bottom of the Wielki Śnieżny Kocioł glacial cirque (marked by "1" in the Fig. 3), actually the only one located "in" the glacial cirques, is a simple rampart crescentic in shape and bent downslope. Its both sides are quite steep. The height of the upslope-facing side is about 5 m and does not differ considerably from the height of the downslope facing one, in spite of inclination of adjacent surface and accumulation of fine sediments within a depression closed by the rampart. Partsch (1882) suggested that the rampart has developed due to accumulation of stones rolling over a surface of snow patch (protalus rampart), as the distance to the walls of glacial cirque is only about 300 m. However, the very regular crescentic shape suggest that the form developed due to push and is a terminal moraine of a small glacieret rather than any nivation feature. Moreover, since the extent of a snow patch varies even seasonally, one should expect more irregular form, probably less steep on the inner side, whilst in reality a distinct ice-contact slope can be observed. Furthermore, as there is only one steep rampart that shows no connection to the adjacent slopes, the role of permafrost creep seems unlikely.

Other landforms which should be considered are located close to the outlet of the glacial cirques ("2" in the Fig. 3) at the altitude of app. 1150 (foothill) – 1270 m a.s.l. These are a row of hills closing both the Mały

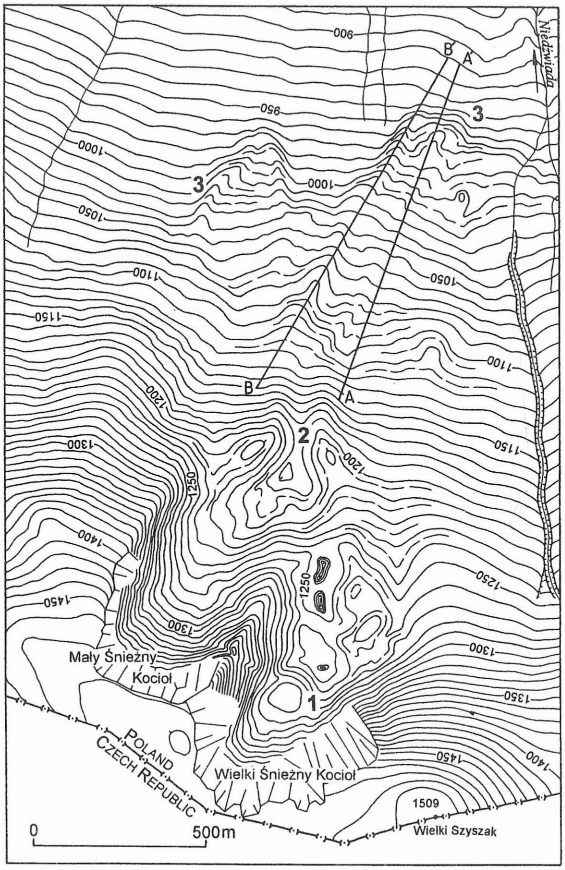


Fig. 3. Topography of the Śnieżne Kotły glacial cirques in the Karkonosze Mts. and their forefield. Numbers refer to accumulation forms considered in the text, AA' and BB' are profile shown in the Fig. 4

Śnieżny Kocioł and Wielki Śnieżny Kocioł glacial cirques. Their surface is covered by big blocks, mostly granitic, and dips steeply on both sides. They are up to app. 70–80 m in high and do not show any microrelief which would indicate former cohesive flow. PARTSCH (1882) and CHMAL and TRACZYK (1999) did not have any doubts to classify this feature as terminal moraine and there seems to be no need to look for another explanations, indeed.

The origin of the next assemblage of accumulation forms, situated below the moraine ridge briefly described above, is more problematic. It consists of two elongated bodies ("3" in the Fig. 3), which also have been interpreted by PARTSCH (1882, 1894) as terminal moraines. Also CHMAL and TRACZYK (1999) do not consider any other origin of these features than a glacial one.

The tongues are approx. 0.9 and 0.7 km long and up to 0.4 and 0.25 km wide, respectively and they stand out above the adjacent slope most distinctly in their lowest sections. They terminate with steep fronts up to 40 m high at the bigger, eastern tongue and approx. 25 m at the other one. Their surface is covered by granite blocks, their dimensions being often as much as 1–2 m. The blocks do not show any distinct orientation. No sediments beneath surface cover have been excavated.

The age of the tongues has been determined as Riss, since the deposits filling closed depressions within the tongues have yielded the date 87–93 ka (TL dating) (Chmal, Traczyk, 1999).

Certainly, there are no doubts that the landforms consist of glacigenic material as they are situated exactly in the forefield of distinct glacial cirques and there is no alternative source of such a very big amount of coarse debris. However, there are indications that other than glacial origin of the tongues might be considered. Its surface in between the alleged terminal and lateral moraines is located as high or almost as high as the moraines themselves. This is especially the case of the bigger, eastern tongue (Fig. 3), whose frontal rampart resembles a feature typical for a rock glacier rather than for a terminal moraine. The surface encircled by the margins is situated up to about 20–30 m above the adjacent slope (Fig. 4).

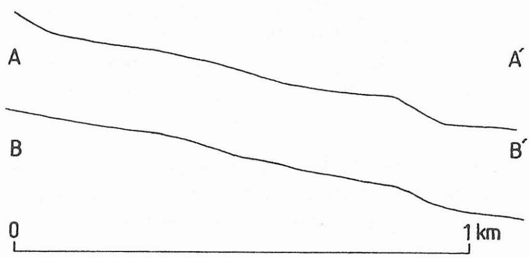
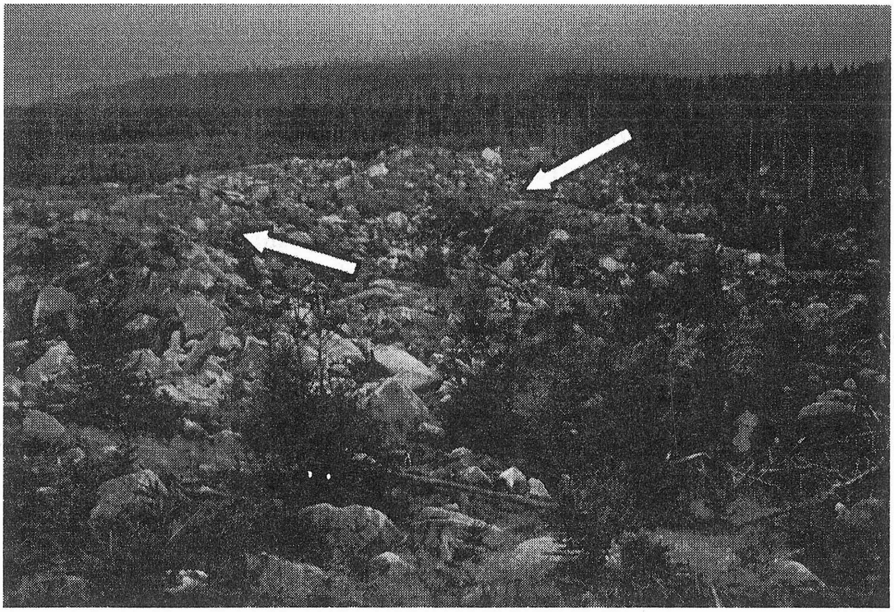


Fig. 4. Profiles of lowest accumulation forms on the forefield of the Śnieżne Kotły glacial cirques (for location see Fig. 3). Vertical scale not exaggerated

Furthermore, ridges and furrows running parallel to the outline of the landform can be observed (Pl. 6). They are 2–4 m high and covered by blocks with no distinct orientation. Two closed depressions filled with water have developed within the surface, just below the adjacent moraine rampart located above and close to the front, respectively.

The second, western feature (Fig. 3) shows relief more typical for glacial morphology, although its surface lies in places over 15–20 m higher than that of the adjacent slope, too. There are more distinct lateral ramparts, up to approx. 3–5 m high on the inner side. They do not join into a



Pl. 6. Surface relief of the eastern blocky tongue below the Śnieżne Kotły glacial cirques ("3" in the Fig. 3). Two parallel ridges (arrows) can be seen in the picture

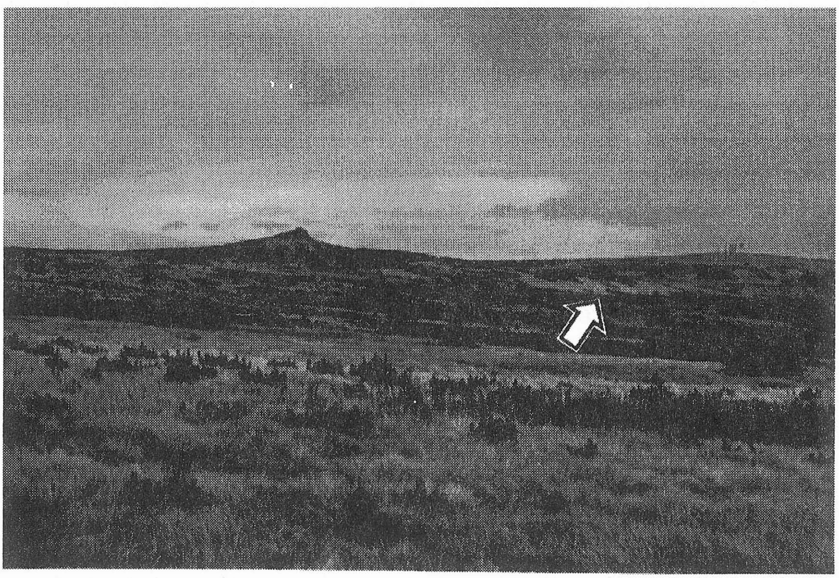
frontal rampart, but are separated by an erosional incision, subsequently filled by a small block stream.

The unusual surface relief of the two described tongues apparently created difficulties in genetic interpretation to PARTSCH (1882) himself, as he considered both moraine and landslide (Bergsturz) explanation. Since landslide variant must obviously be rejected, PARTSCH decided to define these features as terminal moraines. He supposed rather a typical relief to have resulted from a very slow glacier retreat, associated with deposition of successive ridges gradually filling space between lateral moraines.

The western feature, whose location makes a connection with any of the glacial cirques difficult (Fig. 3), has been explained by PARTSCH (1882) to resulted from activity of another glacial body, with no own cirque and located more to the west. On the contrary, a map presented by CHMAL and TRACZYK (1999) shows this feature as a moraine of the Mały Śnieżny Kocioł glacier, which confluenced with the bigger glacier flowing out of the Wielki Śnieżny Kocioł. If the glacial explanation of both features is right, such a linkage is much more likely and "shift" of the moraines in respect to glacial cirques might be explained by orientation of drainage lines, controlling flow of glacial ice in the past. If the rock glacier interpretation is right, both tongues have to be regarded as a result of creep of material accumulated as an older moraine or a kind of glacier-derived rock glacier.

Reassuming the considerations about possible rock glacier formation on the forefield of the Śnieżne Kotły glacial cirques in the Karkonosze Mts., suggested by BARSCH (1993), there are very few supportive morphological indices.

Additionally, some other landscape features in the Karkonosze Mts. merit attention, since they are located very close to the landforms described by CHMAL and TRACZYK (1993), although they have never been mentioned as relict rock glaciers. These are aprons surrounding some of the summit elevations within the main ridge of the Karkonosze, especially distinct on its southern, Czech side. They occur around Mt. Łabski Szczyt (1471 m a.s.l.) (Pl. 7) and Mt. Wielki Szyszak (1509 m a.s.l.). The aprons are divided into a system of rather short lobes up to approx. 8–10 m high. Since it is blocky debris only at the surface and the landforms are quite regular in the shape, with convex or linear profile of their fronts, they seem to result purely from accumulation. As the top of Mt. Łabski Szczyt forms a distinct tor, there is a source area for the block aprons. Blocks might have been produced by disintegration of the tor. On the contrary, in the case of Mt. Wielki Szyszak, they have developed from blocky top detritus.



Pl. 7. Mt. Łabski Szczyt (1471 m a.s.l.) seen from the south. Wide block aprons (arrow) can be seen below the summit tor

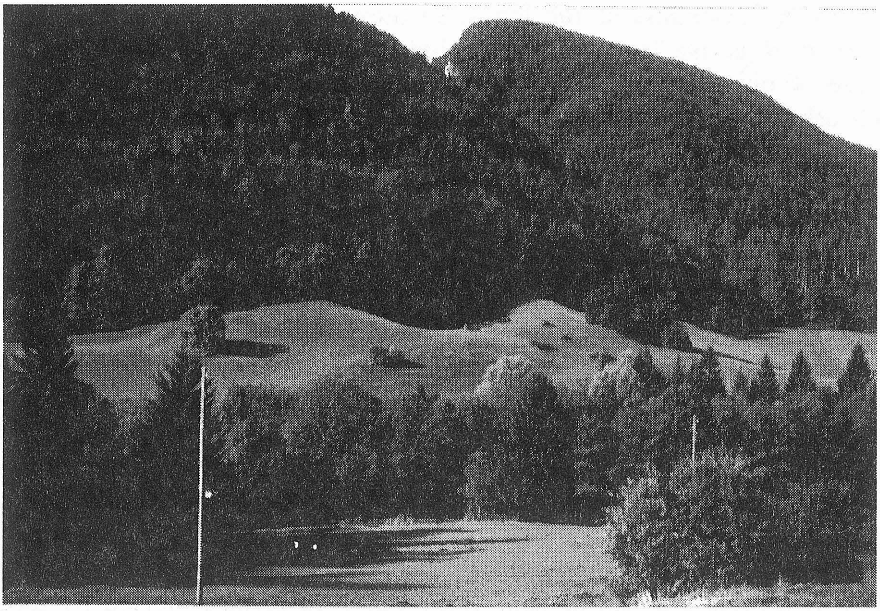
The origin of the considered lobes could be hardly explained by solifluction, as this process affects only the active layer. HUMLUM (1998 b) has recently put forward this argument as well while discussing the origin of much bigger landforms on the Faeroe Islands. According to him, solifluction typically involves sediments of mixed granulation up to about 10–20 cm and no examples of modern solifluction landforms in permafrost areas exceeding 2–3 m thick are known. Open-work structure of the considered features in the Karkonosze Mts., must have additionally hampered the heat flux, so it is even less likely that active layer was as deep as the thickness of the lobes. So they could hardly represent a result of creep of active layer, as they evidently seem to have developed in the course of one act and are not a combination of individual lobes overlying each other. The "earthflow" explanation given by CHAUS (1995) could only be applied if the former presence of fine sediments is confirmed.

BERNESE JURA

According to the works of BARSCH (1969, 1996 a), a number of landforms which could have developed as a result of creep of debris-ice masses during Pleistocene occurs in the Central Bernese Jura. This region does not differ considerably from the Mid-Mountains, in regard to both altitude and climatic conditions. On the contrary, as far as both geology and relief are considered, it is essentially different, as there are mostly Mesozoic sedimentary rocks, predominantly Jurassic limestones, present here. The most important geomorphic features are strongly elongated ridges separated by a system of subsequent valleys and, in places, incised by the consequent ones; in these places deep gorges have developed. The ridges are quite steep and often a free face in their upper sections occurs. The maximum altitudes in axis of the ridges vary between 1000 and 1100 m a.s.l., whereas the valley bottoms lie, as a rule, at the altitude 500–700 m a.s.l.

In the course of geomorphological mapping, BARSCH (1969) identified a number of accumulation landforms, which he called "slope-debris terraces" (Germ. Gehängeschutt-Terrassen). Although he primarily did not decide to call these landforms "rock glaciers" and created a purely descriptive term, he supposed that ground ice might have played a part in their evolution and considered the origin of the landforms in the context of Alpine permafrost relief. In later works he *explicite* defined these features as embryonic rock glaciers (1993b, 1996a).

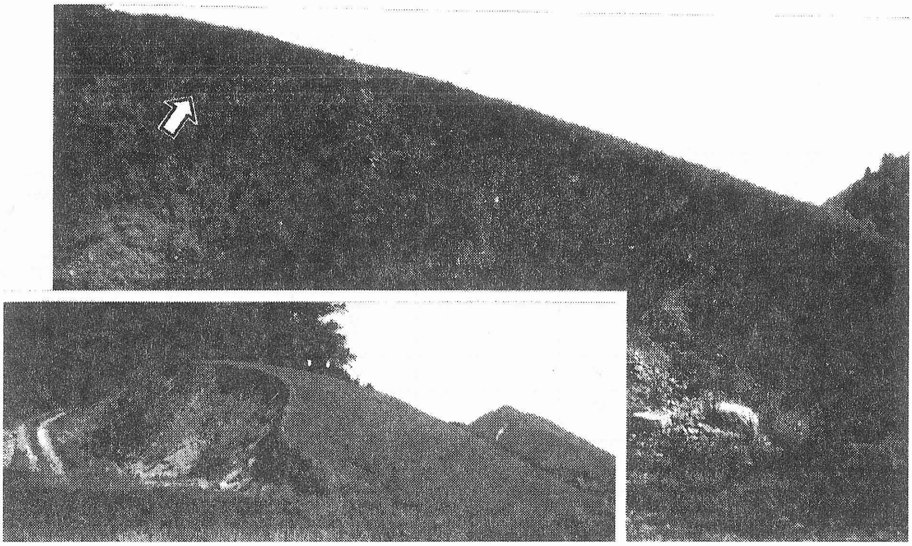
They occur as relatively short and wide lobe assemblages situated at the footslope of the ridges. Neither estimated length nor width of individual lobes does exceed several dozens of metres, and the height if measured from the underlying slope varies between several metres up to app. 15–20 m. Microrelief of smaller lobes consists of combination of irregular and gentle undulations, while the largest landforms often have more significant morphology. It consists of a shallow depression, more or less regular in shape, surrounded by ramparts being slightly lower at the front than on the sides (Pl. 8). As a rule, the upper limit is not very well expressed, unless a lobe joins either another one or a slope face. According to Barsch (1969), the depressions within the lobes can be from 3 up to 5 m deep.



Pl. 8. One of the embryonic lobate rock glaciers in the Bernese Jura. Ramparts surrounding a depression can be seen. The landform does not continue much more into the slope shade. Location: Le Montois by Undervelier

The "Gehängeschutt-Terrassen" have developed without respect to slope aspect, unless the latter is controlled by the macromorphology, that means the occurrence of ridges parallel to each other. They also do not show any clear connection to the mesorelief within the slopes above, but no detailed research has been carried out.

Sediments of the landforms in Jura merit a special attention. Although there are very few excavations, in some places sedimentary structures can be observed. They show limestone debris of very various sizes. However, big blocks occur rather seldom and have only been seen at the ground surface, but not in existing outcrops. The deposits are stratified and the layers dip against the slope (Pl. 9), as noticed by Barsch (1969). No blocky cover or at least higher proportion of more coarse material at the ground surface has been found. Thus, no two-layered stratigraphy of rock glacier mantle and core occurs here! It is interesting, that the original stratification is preserved even right below the ground surface and no significant impact of subsequent solifluction can be seen.



Pl. 9. Excavation within an embryonic rock glacier in the Bernese Jura. The structure of sediments excavated as seen on the smaller photograph is shown on the close-up. Distinct stratification with dip direction towards the slope shade is marked by arrow. Location: Pré de Joux near Undervelier

According to BARSCH (1993b), the age of the rock glaciers in Jura is the last glaciation (Würm) and they may have developed largely during Late Glacial.

DISCUSSION

Landforms in the Central European Mid-Mountains, which recently have been either interpreted as relict rock glaciers after analytical studies or intuitively suggested to be such, show a wide variety of features regarding their morphological and, if accessible, lithological features.

They occur on slopes built of massive rocks, at altitudes varying from 250 m a.s.l. (Ślęża Massif) to about 1400 m a.s.l. (Karkonosze Mts.). Almost all of them have developed on slopes covered by debris derived from massive and well-jointed igneous or metamorphic rocks. Only the lobes in Bernese Jura have developed from limestone debris. Shape and in places location of the landforms have been significantly controlled by local topography. In all cases they have developed on slopes, which show evident traces of periglacial remodelling, such as scree, dense blocky covers, tors, cryoplanation surfaces etc.

It must be emphasised clearly, that none of the considered landforms fulfils all the criteria defined by BARSCH (1996 b) as indicative for relict rock glaciers (see Table I). Their morphology and geomorphic context, Landforms described in the paper vs. Features

Table I

	Meißner	Ślęża	Karkonosze - landforms of Chmal & Traczyk (1993)	Karkonosze - older moraine deposits	Karkonosze - block aprons	Hrubý Jeseník	Bernese Jura
creep-generated relief	✓/?	✓	?/-	✓/?	-	-	✓/?
two-layered stratigraphy	?	-	-	?	?	?	-
higher outer ridges	✓/-	✓	-	✓	-	-	✓/-
all grains sizes on the surface	✓	✓	-	-	-	✓	✓
minimum 5-10 m thickness	✓	✓	✓/?	✓	✓	?	✓
source area	✓	✓/?	✓/?	✓	✓/?	✓/?	✓

including the setting within slopes, shows that all have certainly resulted from a rather slow downslope movement of debris. The role of interstitial ice in their development is less sure. However, most of the landforms seem to have resulted from creep of debris-ice mass. Since this question is crucial for any genetic consideration, it must be analysed in more detail.

The hypothesis emphasising the role of deformation of ice-debris masses is founded on the refutation of other concurrent hypotheses rather han on the demonstration that ice was a decisive formative agent. In other words, in most cases this is most likely explanation. Mass movements such as landslides, rockfalls or debris flows are easy to reject, so is glacial activity with one exception (conjectural moraines in Karkonosze Mts.).

In the case of debris accumulation forms located below steep slopes, i.e. "debris ramparts" and "debris swellings" in Mei ner, as well as "Gehängeschutt-Terrassen" in Bernese Jura, a protalus ramparts hypothesis, that is accumulation of stones rolling down over the surface of multi-annual snow patch, ought to be taken into consideration. However, such geomorphological features as very regular lobate shape of many landforms and their tile-like pattern, especially in Mt. Maißner, allow rejecting this interpretation either. Moreover, some of the lobes are located so far from the slope, that they can by no means reflect any former extent of hypothetical snow patches. The imbrication seen locally on the fronts of lobes in Mt. Meißner is an additional evidence of slow cohesive movement rather than of accumulation due to rapid mass movements.

On the contrary, the debris lobes and ramparts from Mt. Meißner and Jura perfectly fit protalus rampart characteristics as far as morphology is concerned, but in the sense of HAEBERLI (1985) and BARSCH (1993 b). These authors use the term "protalus rampart" to describe accumulation form that has developed not as a result of rolling of debris over a snow patch, but mainly due to creep of talus debris containing interstitial ice. According to the rock glacier definition, they consider these forms as initial or embryonic rock glaciers. Such an interpretation has been suggested firstly by BARSCH (1993 b) for both Jura and Mt. Meißner slopes, but not yet considered in any more detail.

The origin of "block tongues", represented by the landform located below the Frau-Holle-Teich in Mt. Meißner, cannot be explained using the protalus rampart hypothesis either. Both the microrelief and geomorphological context, as well as big dimensions and large amount of coarse material suggest the presence of a typical tongue-shaped relict rock glacier. Such a landform could have developed within a pre-existing valley, where creeping debris of "protalus ramparts" could have been concentrated. On the contrary, where no drainage lines existed, "block ramparts" or, if dissected and displaced downslope, "block swellings" have originated. No distinct margin of the northern part of the feature below Frau-Holle-Teich in the upper and even middle section probably resulted from the fact that from that direction the rock glacier has mainly been supplied by debris. This is confirmed by microrelief of the valley slope, which shows a number of irregular undulations, whereas the north-facing valley slope does not have any remarkable microrelief. In this context HAEBERLI's (1985) observations from the Alps are of crucial importance. He writes (p. 14) "From this embryonic form (protalus rampart – R. Ż.), depending on duration of the development and the topographical circumstances, a more lobe-like or tongue-shaped rock glacier develops. Sometimes entire slopes start moving and then it becomes difficult to discriminate between individual structures."

Nevertheless, the interpretation offered by POSER (1933), concerning the origin of the landforms seems generally valid, since they have been linked to the presence of Pleistocene permafrost. POSER did not considered role of interstitial ice in their development and did not call them "rock glaciers", probably only because of lack of field data on active rock glaciers at that time, at least in terms of BARSCH's (1993 b, 1996 a) approach.

The only one alternative explanation is the one appreciating the role of solifluction. If one agrees that creep of active layer, perhaps during degradation of permafrost can produce lobes and tongues up to 20–30 m high and of similar morphology to relict rock glaciers, the only way forward is to prove the former existence of ground ice in these landforms. Unfortunately, this is not at all easy to do.

First, there is no enough sedimentological data for any inferences. In a few places the sediments seem to show structures, which have analogues in the deposits of active rock glaciers. Perhaps the stratification identified by BARSCH (1969) in the sediments of "Gehängeschutt-Terrassen" in Bernese Jura can be well compared with structures described by Humlum (1996) in the deposits of a rock glacier on Disko Island in Greenland. The strata within rock glacier core, defined by variations in ice crystal size, bubbles and debris content, dip there steeply upstream by 35°–40°. On the contrary, diamictites excavated in frontal parts of the landforms in the Ślęża Massif can be interpreted as a structure of "swimming blocks", which is regarded typical for rock glacier core (cf. BARSCH, 1983, 1996 B; SCHRÖDER, 1992). In no case two-layered stratigraphy of blocky rock glacier mantle and the diamictic rock glacier core, has been confirmed. Interestingly, it is even the case of the landforms in Jura, although such a stratigraphy has been defined as necessary for identification of relict rock glaciers by BARSCH (1996 b) himself!

Decisive role of ground ice in the formation of described landforms can be inferred from geomorphological features rather than sedimentological characteristics. The presence of regular closed depressions, likely to be the results of melting out of interstitial ice, steep outside slopes of frontal and lateral ramparts, especially in their lower sections, and big dimensions of lobes or tongues are all difficult to reconcile with a solifluction hypothesis. Especially, the presence of melt-out depressions indicates that the present-day microrelief of debris bodies has resulted from collapse of an active rock glacier. Big dimensions, exceeding those typical for solifluction lobes, can only be used conditionally, as the work of CHAUS (1995) shows.

Paradoxically, some of the features originally recognised as relict rock glaciers (PETRÁNEK, 1953; CHMAL, TRACZYK, 1993) do not show the morphological indices required for relict rock glaciers, according to BARSCH (1996 b). The morphology is so indistinct in these cases that it is not possible to delimit the landforms, which only differ by cover sediment from adjacent slopes.

Coming to this point, a question needs to be addressed, if a morphology distinct for a rock glacier is an immanent result of creep of debris-ice mixture. Hence, if we agree that the role of interstitial ice in the mechanism of movement, and not morphology of its end-product, is the superior criterion, which allows one to define a landform as a rock glacier, the number of relict rock glaciers might considerably increase. CZUDEK (1997) suggests the presence of more landforms, called rock streams, in Moravia and Silesia (actually its Czech part), which during certain time period could have developed as rock glaciers. However, BARSCH (1987, 1996b) distinguishes very clearly between the origin of rock glaciers and of rock streams. In fact, this problem can be reduced to two questions:

1. Could the landforms, known from the Central European Mid-Mountains as rock streams or block streams, have developed due to deformation of interstitial ice?

2. If so, should we classify them as a variant of rock glaciers in spite of lacking morphological and sedimentological features typical for rock glaciers *per se*?

The first question is of crucial importance in periglacial geomorphology, but has not been answered definitely, neither in the light of theoretical considerations, nor based on observations of recent phenomena. Although the problem cannot be discussed here in detail, it has to be emphasised that both the approach appreciating the role of interstitial ice and one denying it are present. BARSCH (1996b) maintains that rock (block) streams develop as a result of solifluction. For instance, he quotes the assumption of ROTHER (1965) that presence of blocky clasts at the surface of block streams results from washing out of fine material. However, the hypothesis of removal of fines from block covers in general, although it has been present since the works of HÖGBOM (1914) (wash out) or ŁOZIŃSKI (1911) (wind action), is rather intuitive and has never been proved.

Field studies on active block streams are very scarce and available results have not provided any universal explanation yet. However, some contributions of Soviet authors (ROMANOVSKI, TYURIN 1986; ROMANOVSKI *et al.*, 1989) bring valuable information about their origin and seem to be a milestone in research on different kinds of periglacial covers in general. Block covers in the mountains of Eastern Siberia (ROMANOVSKI *et al.*, 1989), called "kurums", have been divided into several types, of which the so–called "kurum-glaciers" ("kurumogletchery") develop due to deformation of interstitial ice. In turn, among "kurum-glaciers" five types have been distinguished. Some show certain features similar to those of true rock glaciers, such as frontal rampart up to 5 m high, crescentic ridges and furrows or two-layered stratigraphy. Nevertheless, they generally seem to represent a kind of transitional features developing due to combination of processes typical for both rock glaciers and for others kind of creep. Although the morphology of individual types of "kurum-glaciers" has not been precisely characterised, their description may apply to some of relict forms in the Central European Mid-Mountains, including those described by PETRÁNEK (1953) or CHMAL and TRACZYK (1993) as rock glaciers.

On the contrary, HARRIS *et al.* (1998) distinguished two types of block streams depending on humidity of climate they develop in; typical for extremely dry climate, which have to be included into the capacious term "kurums" (1) and typical for wetter climate, which are developing recently, for instance in Tien-Shan Mts. (2). A detailed study of one of the block streams of the latter type did not allow for identification of the mechanism of movement, but the opinion is favoured, that the blocks slide on icy surface of underlying blocks, perhaps supported by melt water (HARRIS *et al.*, 1998).

The second of the two questions posed above is a purely conventional problem. If we agree that terms referring to the origin and nature of a landform are more useful, than simply descriptive ones, all geomorphic features, which have developed due to deformation of ice in debris-ice mixtures, may be called as rock glaciers.

The landforms described in this paper can thus be provisionally classified into four groups:

1. Relict tongue-shaped rock glaciers, with relatively distinct morphology akin to relief of active true rock glaciers. This class includes "debris tongues" on slopes of Mt. Meißner (POSER, 1933) and most of the landforms on the slopes of Mt. Ślęża, Sudetic Foreland (ŻURAWEK, 1999a).
2. Relict lobate rock glaciers or protalus ramparts in the sense of HAEBERLI (1985) and BARSCH (1993b). Landforms in the Bernese Jura, as well as "debris ramparts" and "debris lobes" on the slopes of Mt. Meißner belong to this class.
3. Features, which have possibly developed due to deformation of ice accumulated between blocks, hence rock glaciers, but do not show any distinct relief. They resemble present-day "kurum-glaciers" known from Siberia. The features described by CHMAL and TRACZYK (1993) from the Karkonosze Mts. and blocky aprons on the Czech side of the main ridge of the Karkonosze Mts. belong to this group.
4. Other landforms, which could only be called rock glaciers if their structure would point to the importance of interstitial ice in their development. Examination of deposits of the tongue described by PETRÁNEK (1953) from Hrubý Jeseník Mts. would be necessary because of lack of any evident morphological indications. On the contrary, the distal accumulation forms in the forefield of the Śnieżne Kotły glacial cirques show a microrelief which could be regarded as very typical for a relict rock glacier. In this case, however, geomorphic context suggests glacial activity as more likely factor controlling the development of the tongues.

As genetic interpretation of the landforms belonging to the fourth group is uncertain, these will be excluded from further considerations about paleoclimatic significance of relict rock glaciers in the Central European Mid-Mountains.

The occurrence of active rock glaciers in controlled by climatic factor, therefore it would be very important to date the relict forms in Central Europe. Following HAEBERLI (1983) and HUMLUM (1998 a), one can admit that the relict rock glaciers must have developed near ELA, in a cold and relatively dry climate. The age has been estimated mainly on basis of morphological and stratigraphical premises. In almost all cases, the last glaciation has been suggested to be the time span of rock glacier development. Both very fresh morphology and relationship to very young sediments (loess in the Ślęża Massif, Żurawek, 1999 a) suggest that the age of these landforms can be very young. Unfortunately, none of the landforms could have been dated using quantitative dating techniques and no precise dating is possible at the moment.

PROSPECTS FOR THE FUTURE

The above brief comparison shows how many questions about the nature and environmental controls of relict rock glaciers in the Central European Mid-Mountains need to be answered. Following points need to be considered in possible further research:

1. Sedimentary structures of relict rock glacier deposits and of conjectural rock glaciers should be investigated, especially aimed at verification of their division into rock glacier mantle and rock glacier core. A uniform method to examine sediments for former content of interstitial ice should be elaborated. Analogues from the present-day cold climate zone might prove helpful in comparative analysis.
2. Reliable dating of sediments of relict rock glaciers is indispensable for their paleoclimatic interpretation. Attempts of absolute dating of sediments of rock glaciers themselves, as well as of other deposits, which define their stratigraphical position, should be undertaken. Some further sites in the Mid-Mountains merit attention with regard to the possible occurrence of landforms developed due to creep of permafrost in the Pleistocene. Poser (1933) suggested that some landforms in the Mid-Mountains of Lower Saxonia and Hessia (Harz, Vogelsberg, Rhön) are similar to those reported from Mt. Meißner. Also, Petránek (1953) found analogues to the landform in the Hrubý Jeseník Mts. in older Czech literature (Ambrož, 1942, Roth, 1944, both citations after Petránek). Special attention should be paid to places, where coarse-grained deposits of Pleistocene mountain glaciation occur. Since there are some talus rock glaciers in the European Mid-Mountains, debris (moraine-derived) rock glaciers may be expected as well.

Extension of database of relict rock glaciers would possibly allow for more accurate identyfication of mesoclimatic, geomorphic and lithologic controls on their spatial distribution.

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