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FROST WEATHERING OF MAIN ROCK TYPES OF THE ŚLĘŻA MASSIF, SW POLAND. AN EXPERIMENTAL APPROACH

Abstract

Experimental testing of frost resistance of the geomorphologically most important rocks in the Ślęża Massif, SW Poland, has been carried out. Thirteen specimens representing serpentinite, gabbro, amphibolite, granite and quartz-feldspar rock were subjected to 80 freeze-thaw cycles. Freezing temperatures were – 22°C to – 21°C and freezing duration was minimum 30 minutes, thawing temperatures were 20° C to 21°C and the specimens were left de-frosting for at least 3 hours 30 minutes. Prior to the experiment macroscopic features of specimens were described and porosity of samples measured. The results of the experiment show that the resistance of the examined rocks depends on their lithological features, especially, on the degree of chemical weathering. Positive correlation between porosity and efficacy of frost weathering has been recorded. Generally, gabbro and amphibolite are more resistant against frost action than serpentinite and granite. It is likely that this unequal resistance played an important part in landform development of the Ślęża Massif during periglacial periods. Typical periglacial landforms such as frost cliffs, blockfields, cryoplanation terraces and rock glaciers are associated mainly with gabbro and amphibolite slopes. Gabbro has proved highly resistant, which does not confirm the opinion that limited efficacy of frost weathering is associated with the fine-grained structure and the homogenous mineralogical composition of the rock. Grain size distribution of the debris produced during the experiment shows the complexity of frost weathering processes controlled by lithology, first of all, by the degree of chemical weathering prior to the experiment. Fresh rocks were subjected mainly to granular disintegration and produced mostly grains of a diameter smaller than 0.25 mm, whilst the chemically weathered specimens disintegrated into pieces of different sizes, with the bigger ones predominating. In both cases the amounts of clay-size particles were relatively low.

INTRODUCTION

The Ślęża Massif, an inselberg region in southwestern Poland, can very well be of use for research scoped on Pleistocene slope development in European Mid-Mountains. The premises for this are considerable altitude differences, heterogeneous geological setting, as well as an extraordinarily rich array of periglacial landforms present here. Additionally, a very

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important factor, predestining the massif for such investigations is that the highest elevation of it, which is the mount of Ślęża (718 m a.s.l.), was a nunatak (FRENCH, 1913; SZCZEPANKIEWICZ, 1958) during the glaciation which last reached the Sudetic Foreland, i.e. the Odranian (Drenthenian) (SCHWARZBACH, 1942). SZCZEPANKIEWICZ (1958) assumed on the premises of vertical extent of erratic material, the presence of saprolite without any glacial deformations on one of sub-summit flattenings, as well as the morphology of rock formations in the upper slope sections that the top of Mt. Ślęża stood out to that time above the ice surface for about 70 metres. So, the top part of Mt. Ślęża was subjected to periglacial environment, *sensu stricto* during Odranian, and *sensu largo* during the two next glacial periods (Warthanian and Vistulian). Both frost shattering and the processes controlled by presence of permafrost have been able to act in this section during the cold periods of Vistulian, since at least the end of the Elsterian. This let to the development of various slope covers, block- and block-debris covers as well, which were already in detail described by SCHOTT (1931), BARANIECKI (1951) and SZCZEPANKIEWICZ (1958, 1989), as well as cryoplanation terraces and rock glaciers (ŻURAWEK, 1999). The morphology and spatial pattern of those forms seems to be connected with the pattern of the properties of the bedrock. However, such a dependence has never been considered up to now. Presuming the important role of frost weathering in their evolution, showing how the frost susceptibility varies among individual rock types composing the slopes of the Ślęża Massif could give valuable hints for inferring about periglacial slope development.

The role of frost weathering acting as a factor determining the development of block-debris slope covers in European Mid-Mountains (*cf*. LOZINSKI, 1911; BALLANTYNE, HARRIS, 1994), or at least co-operating, together with chemical weathering, in their evolution (SCHOTT, 1931; HÖVERMANN, 1953; STRÖMQUIST, 1973) is actually beyond all question. Moreover, most authors do agree that frost weathering must be one of the most important factors being responsible for the forming of cryoplanation terraces and frost-riven cliffs or scarps (KARRASCH, 1974; PRIEßNITZ, 1988; CZUDEK, 1990, 1995), although this is sometimes called in question (THORN, 1988; HALL, 1997). Apart from this, also the forming of slope covers, including relict rock glaciers, we do observe in the recent and Pleistocene periglacial zone, must have been preceded by physical weathering, possibly controlled mostly by frost.

Identification of qualitatively important differences in frost weathering susceptibility among various types of solid rocks might help in explaining the question of spatial pattern of periglacial mezorelief on the slopes of the Ślęża Massif. The facts that they are very common on the slopes built of gabbro and amphibolite, are rather rare on serpentinite slopes, and are absolutely absent on those built by granite indicate, that lithological differences play an important part in such a pattern.

The contemporary efficacy of frost shattering on the area investigated must be relatively low. Thus, there was undertaken an attempt to determine the susceptibility (vs resistance) to this process of certain rock types, occurring in the Ślęża Massif, e.g. serpentinite, gabbro, amphibolite and granite, as well as, additionally, quartz on the way of laboratory experiment.

EXPERIMENTAL FROST WEATHERING AS AN OBJECT OF STUDIES

The problem of efficacy of frost weathering, resulting from laboratory experiments, has been considered many times in the past, at least since 1899, when Bertil Högbom carried out his experiment on the breakdown of some rocks due to frost (Wiman, 1963). Especially worth mentioning from a number of works known from literature is that written by Jean Tricart (1956), who subjected fresh samples of certain sedimentary rocks to two different freeze-thaw regimes, representing both maritime climate (so-called Icelandic cycle) and continental one (Siberian cycle). This experiment allowed him to distinguish three groups of rocks, depending on their resistance to frost weathering, as well as three types of frost breakdown. Moreover, he stated that the efficacy of frost weathering in the continental climate is higher, than that in the maritime one. Results of a similar experimental study by Wiman (1963) let draw a rather different conclusion. The efficacy of frost weathering of rocks, in this case metamorphic and igneous ones, related to the time, and not to the number of freeze-thaw cycles, turned out to be higher in the Icelandic cycle. Moreover, in spite of the fact, that the samples were collected from their original environment, the efficacy of frost weathering, as ratio of weight of weathering products to sample weight before experiment, was very low and only in one case exceeded 1%.

Next important approach aimed at experimental frost weathering was the work of Martini (1967). He examined frost resistance of about forty types of Sudetic rocks, however, in the Icelandic cycle only, both in water, as well as in a humid environment. Accepting the three-class scale of frost weathering resistance, proposed by Tricart (1956), he qualified sandstone and some porphyritic granites, as well as some metamorphic schists into the class of rock types most susceptible (weight loss 10%–100 %), while equigrained granite, some sandstones, and to a small extent, metamorphic shists as well, fell into the class of more resistant rocks (weight loss 1%–10%) and fine-grained granites, most of metamorphic schists, crystalline limstones, gneisses, volcanites and vein quartz into the class of most resistant ones (weight loss below 1%). An important result of the Martini's study is that the efficacy of frost weathering depends quite closely upon lithological features of the rocks investigated, first of all on the degree of their initial chemical weathering. Martini (1967) found that to be one of the most important factors controlling frost weathering. Moreover, he explained the dualism of the process of frost weathering, identified first by Sukhodrovskiy (1962), as an effect of the growth of ice crystals, and, simultaneously, the thermal contraction of minerals of which the rock consists. Each of those processes allowed producing the debris of different grain size distribution.

Swantesson (1985) carried out an experiment on frost weathering on an even larger scale. He subjected practically not weathered specimens of about 90 rock types, occurring in Sweden, to 324 freeze-thaw cycles. The results showed a substantial divergence of frost weathering susceptibility between sedimentary rocks and all the other ones. The most resistant were porphyres, then leptites, granites, gneisses and coarse-grained alkaline rocks. The samples of all these rock types did not produce debris, weighing more than 0.1% of the original sample weight. It shows how slowly the frost weathering acts if igneous and metamorphic rocks subjected to it are not initially weathered.

No significant changes within the structure of all igneous and most metamorphic rocks, including rocks composing an ophiolite complex, which were examined during 729 freeze-thaw cycles by Evin (1987) could be noticed. According to her study only limestone, sandstone and green-schists were partly or totally disintegrated.

The experiments, described briefly above, were carried out in pure water (or in wet environment), and not in water solution of other compounds. However, as we know from the works of perhaps Williams and Robinson (1981) or Jerwood, Robinson and Williams (1990a, 1990b), water salt solutions can cause substantial increase in the efficacy of frost weathering, of course, depending on the kind of compound dissolved, as well as on the thermal regime of the experiment.

Laboratory work, conducted systematically in the Centre de Géomorphologie du CNRS in Caen, France, where up to one thousand samples are examined on frost susceptibility yearly (Lautridou, Ozouf, 1982), supply more and more data about the susceptibility itself, as well as about laboratory techniques used.

In spite of the undoubted progress resulting from all the work mentioned, or other not quoted above, no satisfying synthesis concerning the matter of the process, as well as the quantitative estimation of the influence of individual factors on frost shattering has been done so far (Lautridou, 1988; Ballantyne, Harris, 1994; Hall, 1997).

METHOD

Experimental studies in geomorphology are aimed at the quantitative description of the processes acting in a natural environment. However, it is never possible to reconstruct natural conditions very exactly. This is valid especially in the case of frost weathering. Most of methodical problems, leading to the deformation of natural conditions and, as a result, to error increase, depend upon two properties of frost weathering process. Firstly, frost weathering occurs simultaneously and in interactions with a number of other processes controlling the alteration of rock properties. It seems not to be possible to estimate quantitatively all the components of such a system, sometimes even very important ones, like the degree of chemical weathering, for instance. Moreover, synergetic co-operation of some factors controlling the process of frost weathering, perhaps the growth of salt crystals, or just the opposite, their function decreasing the final effects – for example the increase of the concentration of salt dissolved in water, causing the decrease of freezing point of the solution (see for instance WILLIAMS and ROBINSON, 1981), causes the increase of error again if the parameters were to be treated individually. Secondly, the efficacy of weathering processes, including frost weathering, in natural environment is so low that it requires acceleration in a laboratory simulation (in the case of frost weathering most often due to the short- ening of freeze-thaw cycles), which makes that the experiment conditions are not natural anymore (Fig. 1).

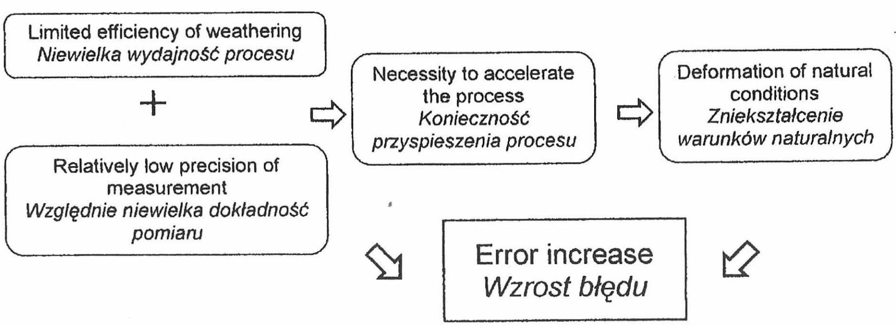

Fig. 1. Cartoon to show how limited efficacy of frost weathering influences experimental designs which in turn may upset the results

A review of the results of experiments carried out by many authors using various techniques and taking into consideration various parameters, allows one to state that such results can only very generally be compared witch each other and that in most cases it is not possible to draw any general conclusions taking into account the course of the process. BRUNSDEN (1985) represents such an opinion and supposes, furthermore, that it will never be possible to define the controls of frost weathering precisely enough.

Therefore, the attempt to examine the susceptibility of main rock types of Ślęża Massif to frost weathering, described below, was carried out under the restriction that its results can be interpreted only with reference to local lithological, geomorphological, etc. situation. Such a presumption has let one to simplify the experiment procedure, fit it in terms of laboratory equipment, as well as to complete the work within only six weeks.

Twelve samples, representing serpentinite, gabbro, amphibolite and granite, and additionally one sample of vein quartz, or saying more precisely quartz rock with some feldspar incrustation, were subjected to the experiment. The location of sampling and brief description of macroscopic features of specimens is shown in the Table I. Besides, the location is shown on a map (Fig. 2).

Serpentinite, gabbro and amphibolite are the components of an Upper Devonian ophiolite complex of the Ślęża-Massif (MAJEROWICZ, PIN, 1994) and have the largest extent among all massive rocks in the region. Granite, which occurs on the north-western slopes of Mt. Ślęża only, belongs to a Variscan granitoide intrusion, called 'Strzegom–Sobótka Massif' (MAJEROWICZ, 1972). It is cut by a number of various protrusive vein rocks, including quartz, being characteristic for veins in the granites occurring on the slopes of Mt. Ślęża (MAJEROWICZ, 1963).

Samples were collected only from outcrops, either natural exposures or quarries (Tab. I), so that they all do represent the rock occurring *in situ*. They were gathered by using a hammer, from surfaces, representing various initial weathering. Attention was paid, to collect samples possibly similar in shape and dimensions. After that, rock pieces were dried for about two weeks in room temperature and subsequently weighed, then saturated in vacuum with distilled water. After the complete saturation the specimens were weighed again, the volume of each of them was measured and they were put into plastic bags, filled subsequently with water, distilled one as well.

The freezing of the samples proceeded in a liquid medium, e.g. water solution of radiator liquid (Pl. 1), contrary to most of the experiments, known from literature (*cf.* TRICART, 1956; WIMAN, 1963; MARTINI, 1967) and each freezing phase lasted for at least 30 minutes. Such a period can be very possibly assumed as long enough to enable the cold to penetrate the whole volume of the samples, taking into account their dimensions and temperature regime. Thawing (Pl. 2) went on in room temperature (20°C

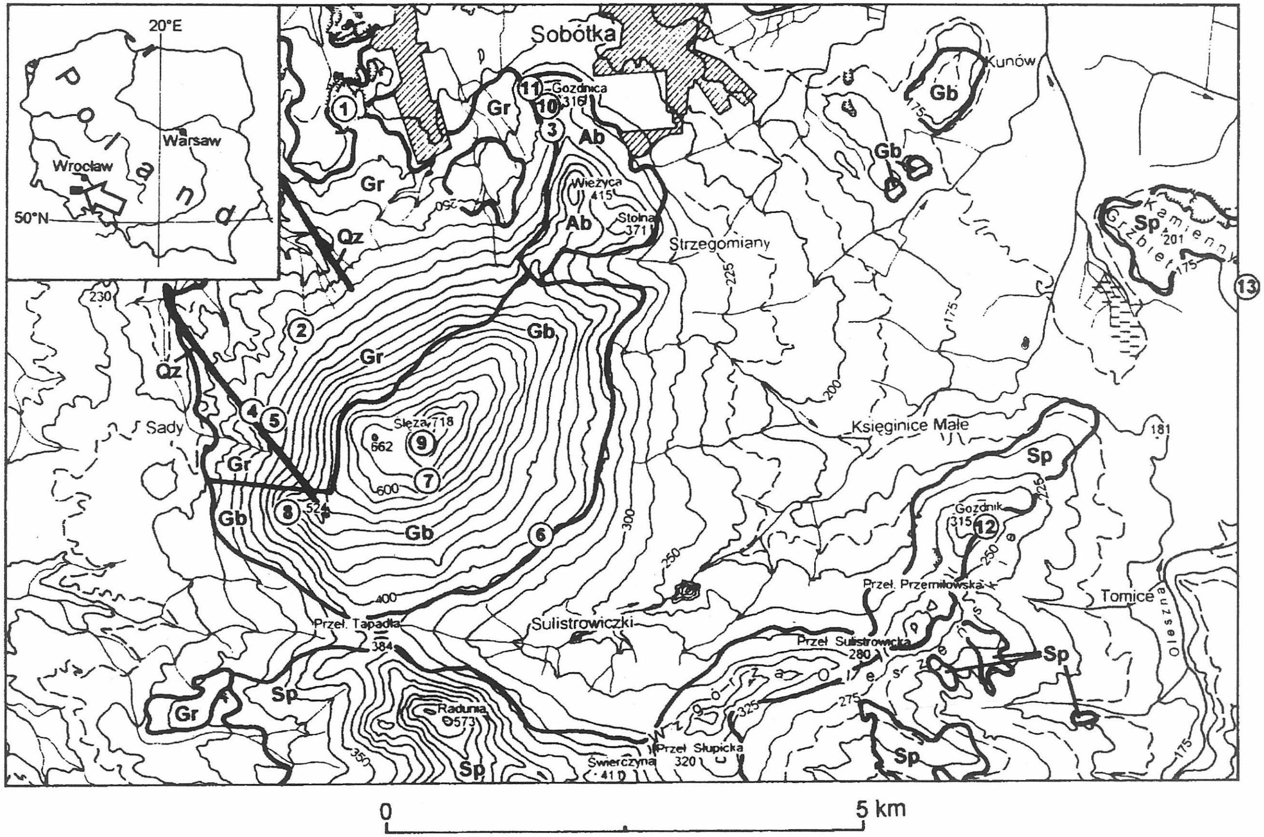

Fig. 2. Location and geology of the Ślęża Massif and location of sampling points.

Numbering of samples like in tab. I; Sp – serpentinite, Gb – gabbro, Ab – amphibolite, Gr – granite, Qz – quartz veins

Location of sampling points and main macroscopic features of the samples

Table I

Sample number	Location of sampling points	Altitude of sampling points [m a.s.l.]	Rock type	Macroscopic features of sample
1	wall of working quarry in Chwałków	about 190	granite	massive, fresh mid-grained biotite granite, sharp edged
2	an excavation located about 2 km to the NE from the top of Mt. Ślęża (718)	315	granite	massive, relatively fresh mid-grained granite
3	abandoned quarry below the pass between hills Wieżyca (415) and Gozdnica (315)	260	granite	strongly chemically weathered two-mica granite, very well developed big crystals, brownish coloured
4	abandoned quartz quarry situated closely to the village of Sady	330	granite	leucogranite, visibly weathered chemically, with thin concentration of silica on one of its surfaces
5	abandoned quartz quarry situated closely to the village of Sady	335	quartz-feldspar rock	massive quartz-feldspar rock, chemically weathered feldspar fills fissures within the quartz
6	rock formation located about 1.25 km to the SSE from the top of the Mt. Ślęża (718)	390	gabbro	massive rock, but with distinct traces of chemical weathering (locally brown spots)
7	rock formation located about 0.9 km to the S from the top of the Mt. Ślęża (718)	605	gabbro	massive rock, however with traces of chemical weathering
8	rock formation located about 1.75 km to the SW from the top of the Mt. Ślęża (718)	450	gabbro	massive rock, however with traces of chemical weathering
9	rock formation located just below the Mt. Ślęża (718)	705	gabbro	massive rock, however with distinct traces of both chemical and physical weathering (surface exposed to air very rough, plagioclases removed from the surface)
10	rock formation located just below the hill Gozdnica (315)	312	amphibolite	massive rock, insignificant weathering changes
11	rock formation located about 0.2 km to the NW from the top of the hill Gozdnica (315)	280	amphibolite	massive rock, insignificant weathering changes
12	abandoned quarry in Jordanów Śląski	170	serpentinite	fresh, very massive rock with insignificant traces of chemical weathering on one of its surfaces
13	bottom of an excavation on the top of the hill Gozdnik (315)	312	serpentinite	very heavily weathered rock, cracks by some heavier pressure

to 21°C) the time being not shorter than 3.5 hours. The temperature of radiator liquid was −22°C to −21°C at the moment when the samples were put in, after that increased slightly, but after several minutes stabilised on the same level of about −22°C to −21°C. Presuming that the temperature inside the samples were not much higher, it can be assumed, that the pressure which could have been exerted on the partitions of fissures or pores was maximum and if the pores etc. had been closed, the pressure would theoretically have lain by 2115 atm. (VON MOOS, DE QUERVAIN, 1948). Very fast freezing, resulting from such big temperature amplitude, deviates surely from those typical of a natural environment; nevertheless, it makes it possible to accelerate the experiment considerably.

After the 25th freeze-thaw cycle, the first attempt to measure the weight loss was undertaken. However, because of very high error, resulting from the fact that the samples weighed were wet, measuring during the experiment was abandoned.

Unfortunately, two plastic bags, with samples 1 and 4, became not tight close to he end of the experiment and some amount of radiator liquid got in, changing properties of water used. Nevertheless, the rock pieces were frozen and before the next freeze-thaw cycle the water has been changed.

After the 80th freeze-thaw cycle, the debris produced was removed from the bags and collected separately, the specimens and debris were dried in room temperature again and after that measured. If the amount of debris produced was big enough, the grain size distribution of weathering products was analysed by sieving. Fractions smaller than 0,1 mm were analysed in ranges of phi 0,25, using a laser method. Before both analyses, the samples were dried in the temperature of 110°C.

RESULTS AND DISCUSSION

Eightyfold crossing 0°C point could be compared with approximately two years in recent alpine periglacial zone. According to the data of Instytut Meteorlogii i Gospodarki Wodnej (Weather and Water Management Institute) (KOTARBA, KŁAPA, RĄCZKOWSKA, 1983) the number of days with temperature, crossing 0°C, measured on the ground surface in Hala Gasienicowa (1520 m a.s.l.), The High Tatra Mountains, is on average (1975–1979) 46.2. A similar number (43 days yearly, data for the period 1975–1979), but yet calculated on the basis of the data from measurements at 5 cm depth beneath the ground surface, was gathered in the Swiss Alps at the altitude of 2400 m a.s.l. (GAMPER, 1987). A number of days when air temperature raises above 0°C, that reported from northern Scandinavia by STRÖMQUIST (1973), shows, on the contrary that for this region freeze-thaw frequency is about twice as big. This number for years 1960–1970 is even 66–96, depending on the site investigated.

After 80 freeze-thaw cycles in the temperature regime described above, all specimens disintegrated al least partly (Pl. 3). The efficacy of weathering was defined as a relative weight loss, e.g. the quotient of the weight of debris obtained to the original weight of each specimen. Differences in values calculated are very big (Fig. 3) and vary between 0% (sample 6) and 68.78% (sample 13). Eight samples have produced less than 1% debris, whereas, more than 10% weight loss could be observed only in one case (sample 13). Table II shows complete results of the experiment.

Resistance to frost weathering, defined by means of weight-loss coefficient differs even within one rock type. It is valid especially for granites and serpentinites. In each case a dependence between initial chemical weathering, which could be described qualitative only (Tab. I), and efficacy of frost shattering, is well detectable. Very fresh granite from the granite quarry in Chwałków (sample 1), practically has not weathered, whereas some initially weathered rock of the same type (sample 2) undergoes the process more clearly, although it does not cause substantial disintegration yet, while strongly weathered granite, represented by samples 3 and 4, disintegrates incomparably easier. Also strongly initially weathered serpentinite (sample 13), disintegrated many times faster than the fresh one (sample 12). Nevertheless, the amount of debris produced by the fresh serpentinite is quite big and its weight exceeds 1% of the original sample weight.

Results of the experiment

Table II

Sample number	Porosity coefficient [%]	Primary weight [g]	Weight after 80 freeze-thaw cycles [g]	Weight loss [%]
1	1.13	226.25	226.10	0.07
2	2.95	255.95	255.15	0.31
3	3.36	168.45	160.31	4.83
4	5.59	139.19	131.12	5.80
5	1.31	156.96	150.78	3.94
6	0.84	303.10	303.10	0.00
7	1.20	260.66	259.24	0.54
8	0.86	200.23	199.77	0.23
9	0.90	207.79	207.37	0.20
10	1.21	151.28	150.90	0.25
11	1.12	138.67	138.65	0.01
12	1.43	131.69	129.91	1.35
13	6.93	110.38	34.46[1)]	68.78

[1)] Weight of the biggest piece

Slightly differently reacted the samples representing gabbro and amphibolite. In spite of their distinct initial weathering degree, the specimens remained actually resistant to the destructive action of frost. Small values of weight loss (Tab. II) do not allow to define the influence of initial weathering degree on the experiment results.

A relatively big amount of debris, produced by the sample 5, resulted, first of all, from its specific petrography. As the specimen did not represent a monomineralic quartz rock (*cf*. Tab II), the debris was obtained mainly from the disintegration of feldspar crust.

The experiment results described above, confirm the thesis appreciating the important role of lithological properties of rock, first of all the degree of its initial chemical weathering, in the effects of frost weathering (*cf*.MARTINI, 1967). Examples of specimens 12 and 13, as well as 1, 2 and 3, 4 (Fig. 3) suggest that this factor may be a decisive one. They show also, that initial frost weathering, i.e. frost weathering of fresh rock, acts extraordinarily slowly, which confirms the results of SWANTESSON (1985) and EVIN (1987), but also, that it varies very distinctly depending upon rock type.

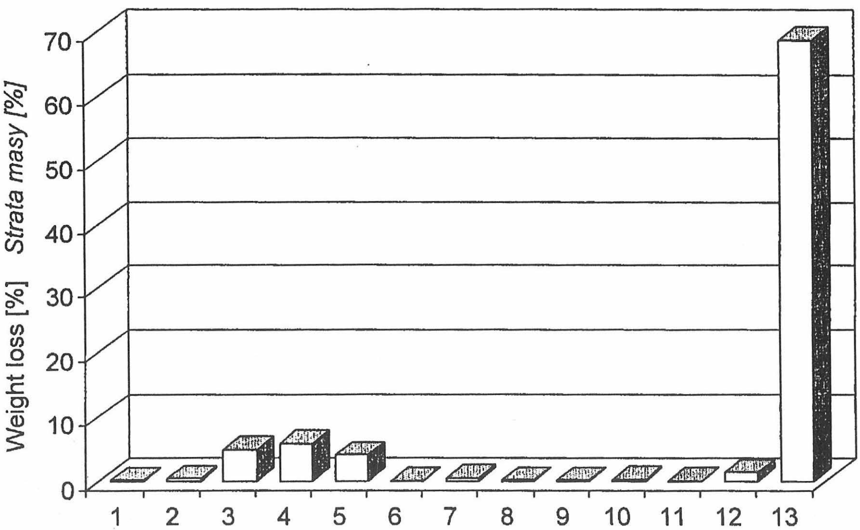

Fig. 3. Weight loss of the specimens after 80 freeze-thaw cycles. For the numbering of samples see tab. I

Very high resistance of gabbro contradicts MARTINI's (1967) opinion that more resistant against frost weathering are microcrystalline and monomineralic rocks, just the opposite to the coarse-grained ones. A small number of samples subjected to the experiment requires caution formulating more universal conclusions, nevertheless, it seems to be justified to state that gabbro of Mt. Ślęża can be classed into the group of very resistant rocks, although its consist of coarse plagioclase, hornblende, diallage etc. crystals. Among the rocks examined by MARTINI (1967) there was neither gabbro nor amphibolite.

Precise enough quantitative estimation of lithological properties of rocks, subjected to the laboratory experiment is not possible. However, the porosity coefficient can be used as a certain approximation. This coefficient, defined for the thirteen samples (Tab. II), is positively correlated with the weight of debris obtained. It confirms the results, gathered by WIMAN (1963). The strength of this dependence in the described experiment (Fig. 4) is expressed in the Pearson's coefficient, equalling 0.77. Certainly, this value comprises the error resulting mainly from the imperfection of techniques used, including the technique of defining the porosity. Moreover, it must be emphasised, that pores or fissures of capillary dimensions play the most important role in cracking due to frost action, and their part in general porosity has been not defined.

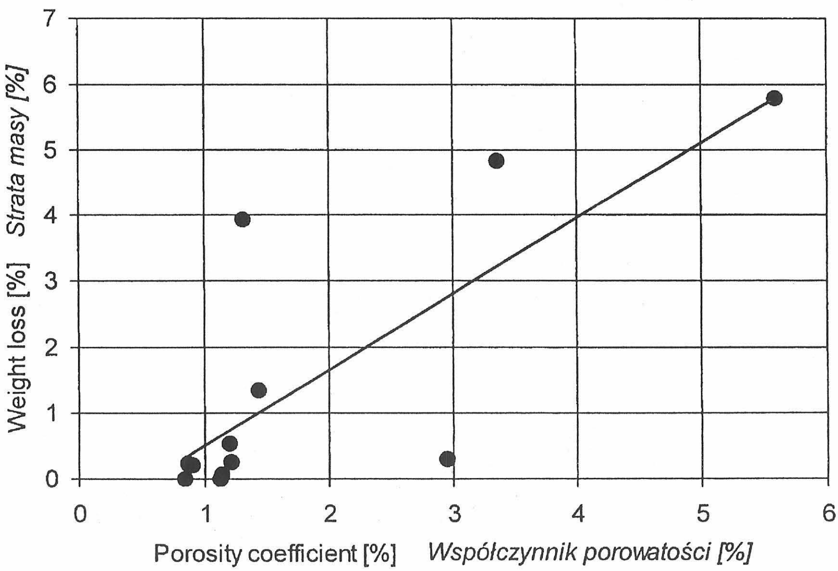

Fig. 4. Relationship between porosity coefficient and efficacy of frost weathering shown as weight loss (sample No. 13 omitted)

Grain size distribution, analysed for debris obtained from four samples, depends on lithological features of each rock type. Frequency within ranges on the histogram, showing the grain size distribution for granite (Fig. 5A) is quite similar for each class. For quartz-feldspar rock the distribution is more oblique (Fig. 5B), while for fresh serpentinite five out of eight ranges distinguished are empty or almost empty (Fig. 5C). On the histogram representing debris produced by sample 13 two maximums are detectable: the first one for grains with diameter 1–2 mm and the second

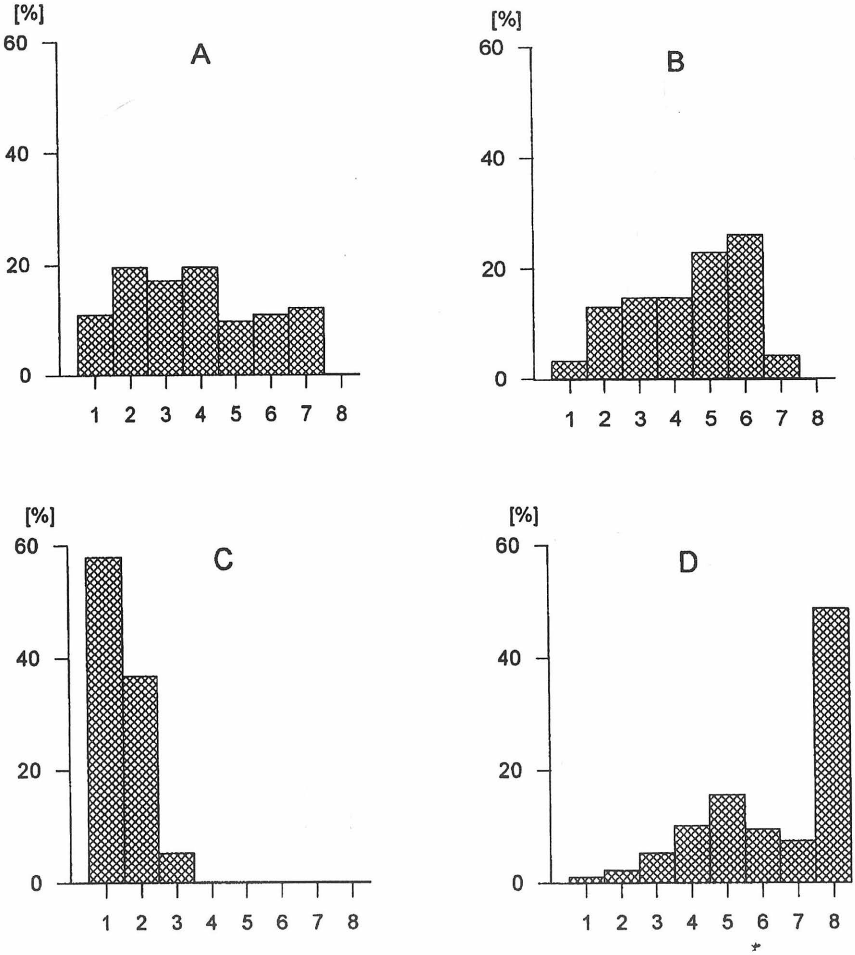

Fig. 5. Grain size distribution of debris from:

A – granite (specimen No. 4); B – quartz-feldspar rock (specimen No. 5); C – fresh serpentinite (specimen No. 12); D – chemically weathered serpentinite (specimen No. 13). Ranges of grain size in mm: 1–(<0,1); 2–(0,1–0,25); 3–(0,25–0,5); 4–(0,5–1,0); 5–(1–2); 6–(2–5); 7–(5–10); 8–(10<)

one for debris coarser than 10 mm (Fig. 5D). The differences in the distribution showed on the diagrams A, B and C, although surely influenced by the properties of individual specimens, generally reflect the petrographic composition of each rock type. Nevertheless, the diagrams C and D show that samples of the same rock type, but weathered chemically to different degree, can produce in the course of frost weathering debris of a different grain size composition. Each maximum, visible on the diagrams, reflects possibly different processes, connected with freezing and understood as frost weathering. TRICART (1956) distinguished three such processes: macro-gelivation resulting in boulders, macro-gelivation resulting in grains, as well as micro-gelivation. MARTINI (1967), continuing SUKHODROVSKIY's (1962) idea pointed to the dualism of frost weathering, which has already been mentioned above. LAUTRIDOU (1988) distinguished four ways of frost weathering: frost scaling, frost splitting, and frost wedging and granular disaggregation. Diagrams C and D on the Fig. 5 show that at least in the case of serpentinite, the processes leading to the production of coarse fractions act more intensively against rock weathered initially. On the contrary, fresh rock disintegrates mostly into finer grains.

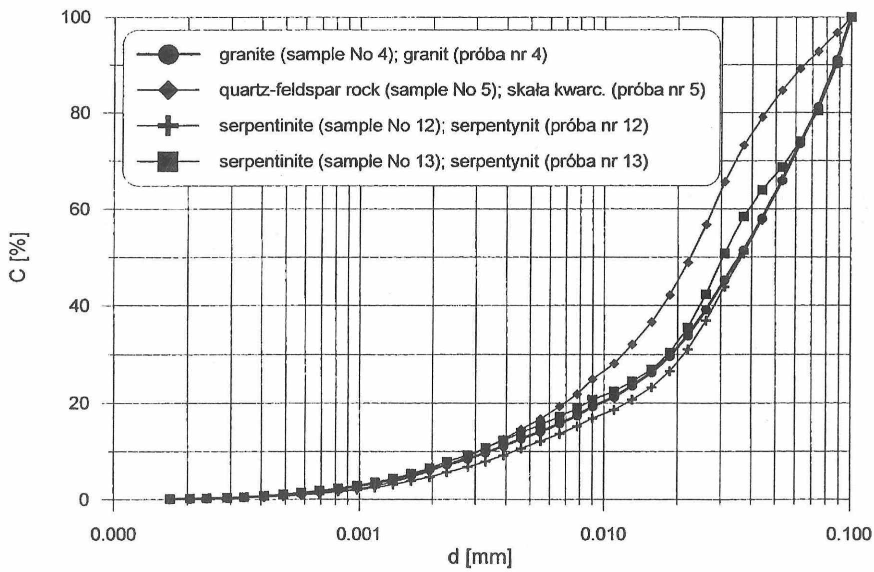

Fig. 6. Grain size distribution curves of debris liberated during the experiment for selected samples (only fractions under 0,1 mm).

C – content of grains smaller than d; d – defined diameter. For the numbering of samples see tab. I

In spite of a large variety of grain size distribution, among the finest fractions (diameter below 0,1 mm) differences become smaller (Fig. 6). The distribution curves for granite, quartz rock and serpentinites are generally concave (in logarithmic scale) it their shape. The diagram, showing the results of the analysis made for quartz rock resembles a sigmoidal curve, which is typical of granites and shists according to LAUTRIDOU and OZOUF (1982). In each case, part of silt fraction is higher than 50%, whereas the weight of particles smaller than 0.002 mm doas not exceed 10%. It confirms the results of the investigations made by LAUTRIDOU (1988), as well as HOPKINS and SIGAFOOS (1951, vide BRUNSDEN, 1985), who regarded silt fraction as the terminal one for frost weathering.

CONCLUSIONS

The results of the experimental attempt, described above, have to be considered with a number of restrictions, connected with methodical problems, a small number of analysed samples, as well as the thermal regime different from that usually used so far. Nevertheless, they allow one to conclude:

1. The susceptibility to frost weathering of the main massive rocks of the Ślęża Massif depends to an important extent upon their individual lithological properties, chiefly the degree of initial chemical weathering. MARTINI (1967) has already identified such a dependence for Sudetic rocks. Moreover, the positive correlation between porosity coefficient and the susceptibility could be stated. The results of the study allow also the making of the hypothesis that these rock types which are not very porous require some initial weathering to be efficiently disintegrated by frost action. The interaction between chemical weathering and physical breakdown must be a synergetic one.
2. Gabbro and amphibolite show generally a higher resistance against frost shattering than granites and serpentinites. This property may have at least partly controlled development of periglacial landforms in the Ślęża-Massif, which are shaped most distinctly on the slopes built of gabbro and amphibolite.
3. Considerable resistance against frost weathering is not typical only of microcrystalline and monomineralic rocks, which was suggested by Martini (1967). It can be stated on the basis of relatively high resistance of gabbro.
4. Degree of initial weathering influences the way of frost weathering and particle distribution of its products. Fresh, not chemically weathered rock disintegrates into rather small grains, whereas the breakdown of chemically weathered rocks results in the production of different, but often coarse, pieces. The part of clay fraction is insignificant in each case.

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Photo by the author

Pl. 1. Refrigerator in which the experiment was carried out. Plastic bags with rock samples were immersed into solution of non-freezing liquid

Photo by the author

Pl. 2. Thawing of rock samples

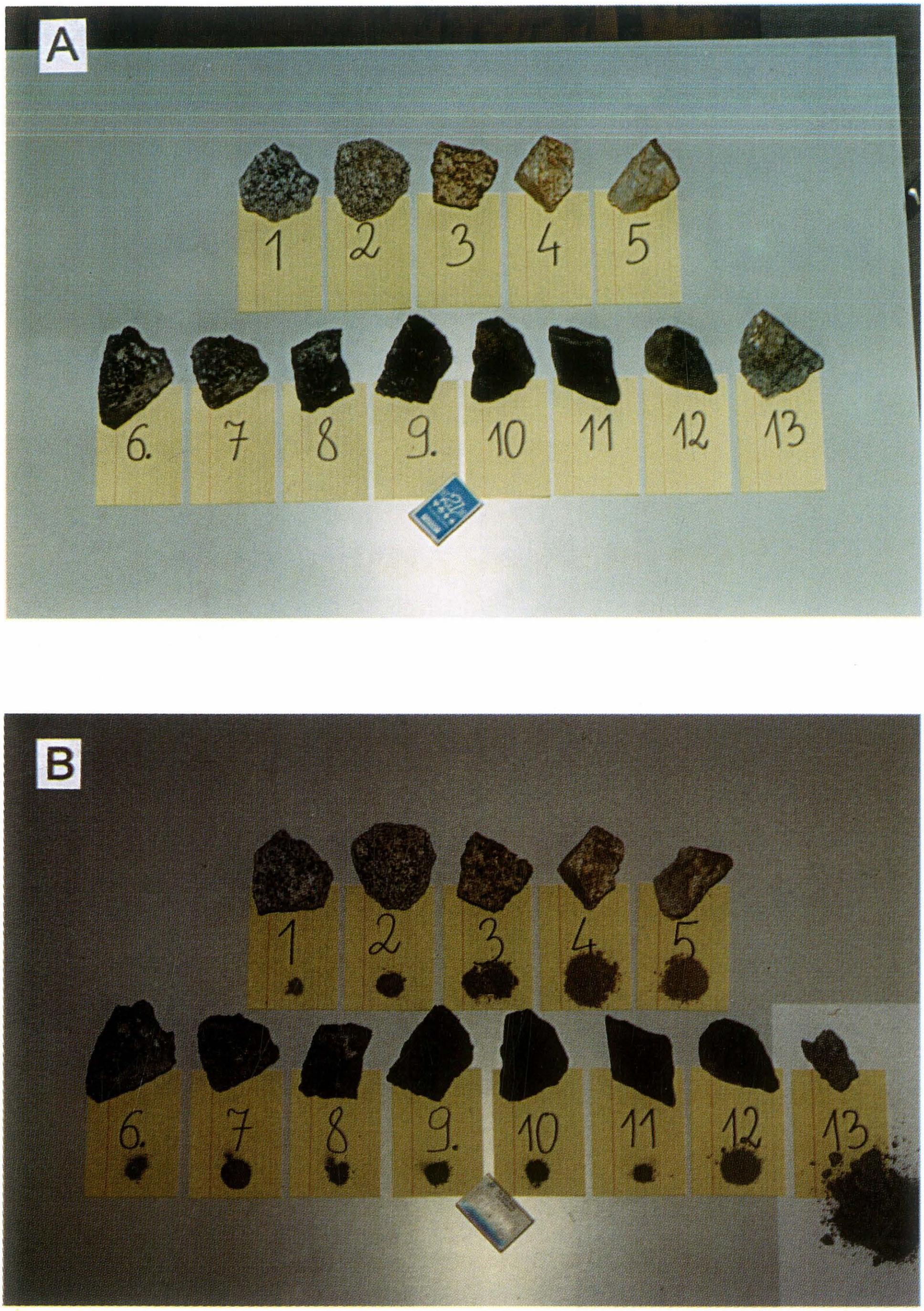

Photo by the author

Pl. 3. Effects of frost disintegration; A – specimens before experiment, B – specimens after the 80th freeze-thaw cycle