Geologia Sudetica, 2000, 33: 71–83.

The petrology and geochemistry of mantle-derived basic and ultrabasic rocks from the Szklary massif in the Fore-Sudetic Block (SW Poland)

Piotr Gunia

Instytut Nauk Geologicznych Uniwersytetu Wrocławskiego, Zakład Mineralogii i Petrologii, pl. M. Borna 9, 50-204 Wrocław, Poland, e-mail: guniap@ing.uni.wroc.pl

Key words: ultrabasites, serpentinites, amphibolites, plagiogranites, petrology, geochemistry, Szklary, Fore-Sudetic Block.

Abstract This paper presents the results of petrological investigations of rocks from the Szklary serpentinite massif in the eastern margin of the Góry Sowie Block. Among the weakly serpentinised ultrabasites present, harzburgites, lherzolites and pyroxenites have been distinguished. Small enclaves of metabasites within the serpentinites represent low-Ti varieties and – like rodingites – they developed from initial gabbroides or picrites. They reveal a characteristic depletion in incompatible elements. This feature is reminiscent of high-Mg (boninite) basic magmas formed in island arc or back-arc basin environments. Plagiogranites, present within the serpentinites, most probably represent trondhjemites – more acid derivates formed during the fractional crystallisation of the same initial basic magma.

On the basis of the petrological investigation results, the hypothesis was put forward that – with regard to their initial composition – the ultrabasites of the Szklary massif may represent heterogeneous spinel residual peridotites impregnated with pyroxenite veins. Enclaves of metabasites and plagiogranites, having the properties of mafic cumulates and/or fractional differentiates, may reflect a stage of further magmatic processes which took place in a zone of lithospheric plate convergence.

Manuscript received 22 December 1999, accepted 13 December 2000.

INTRODUCTION

The Szklary serpentinite massif occupies the southern part of Niemcza Dislocation Zone, which is considered to be a transverse, left-side shear zone in the north-eastern part of the Bohemian Massif. It stretches out along the eastern flank of the Góry Sowie gneiss block (Mazur & Puziewicz, 1995; cf, Fig. 1).

The serpentinites around Szklary form a strip of hills with an almost meridional stretch, approximately 5 km long and 2 km wide. The contacts between the serpentinites and the surrounding gneisses and blastomylonites are sharp. However, the interpretation of drilling data implies interfingering of the serpentinites within the cover rocks. These contacts are in many places obliterated due to folding or mylonitisation (Niśkiewicz, 1967).

The most common rocks of the Szklary massif are ultrabasites serpentinised to various extents. They contain tectonic enclosures of amphibolites, aplites, pegmatites and, rarely, of lamprophyres. In the subsurface zone, the ultrabasites are covered with a rust-coloured weathering cover, in places incised by magnesite veins with clusters or veins of opal and chalcedony. The Szklary area is famous for its chrysoprase (a green variety of chalcedony) and poor Fe-Ni ores.

Investigations on the mineralogy and petrography of the massif's rocks were conducted earlier in order to recognise and determine mineral resources. New studies, carried out in recent years, have concentrated on petrological aspects.

The Szklary serpentinites are regarded to be a part of the so-called basic-ultrabasic complex (the Sudetic ophiolite) forming the Lower Palaeozoic structural stage of the Fore-Sudetic Block (Cwojdziński & Żelaźniewicz, 1995). According to the Caledonian-Variscan terranes theory, they represent a megaboudin of a dismembered ophiolite situated in a narrow strike-slip zone between terranes (Cymerman *et al.*, 1994).

In previous studies, the ultrabasites from Szklary were regarded as: a high-temperature intrusion within a zone of deep continental-type rifting (Teisseyre *et al.*, 1957); a fragment of a ring intrusion (protrusion) with zo-

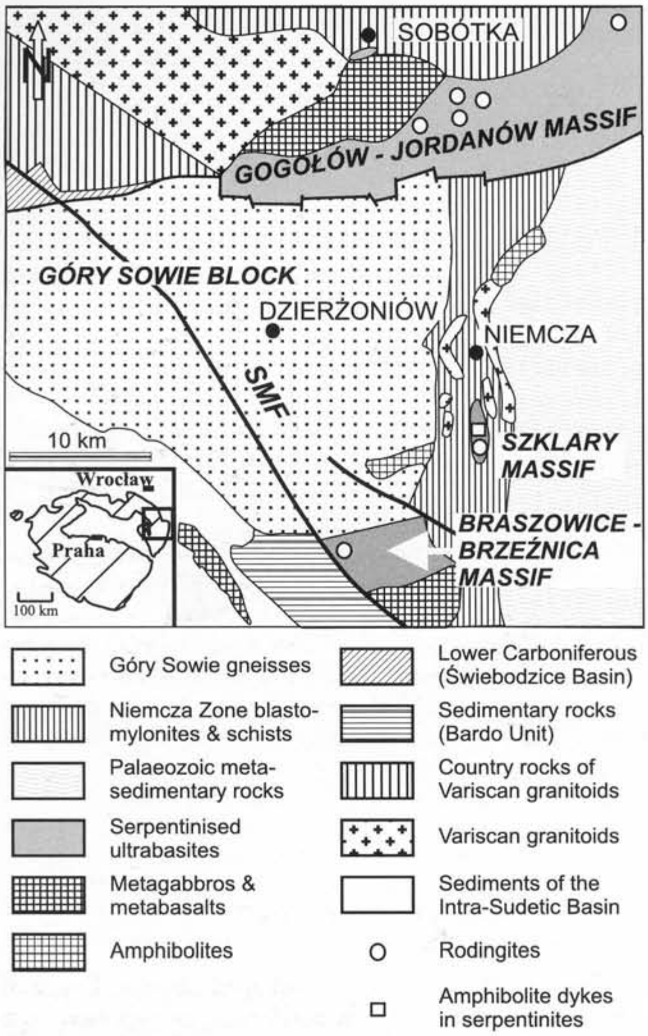

Fig. 1. Sketch map showing location of the Szklary massif in the eastern margin of the Góry Sowie Block. SMF – Sudetic Marginal Fault; Inset map locates the study area in the Bohemian Massif.

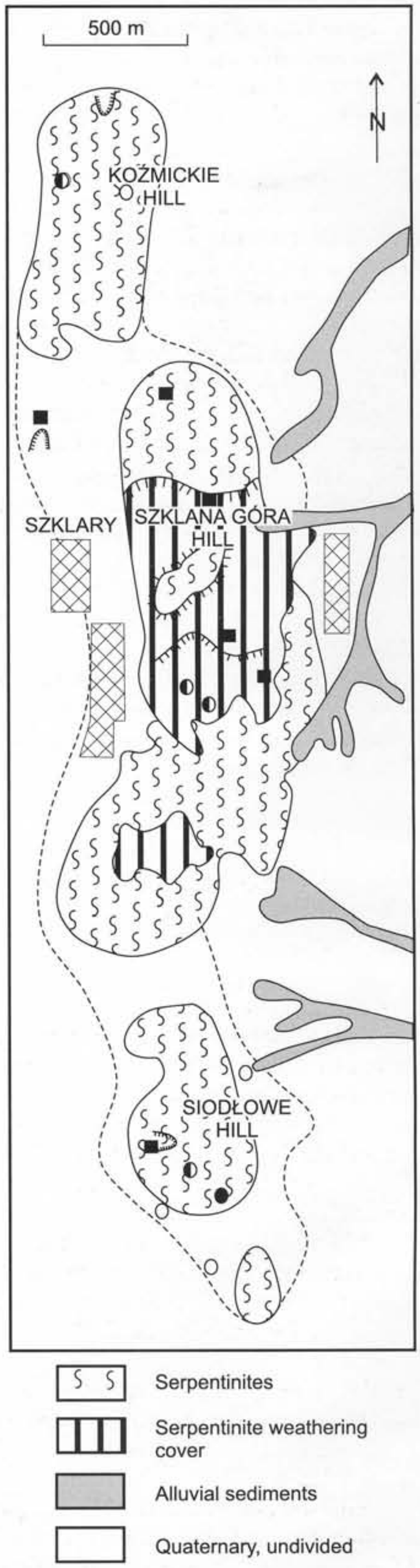

Fig. 2. Geological map of the Szklary massif (simplified) based on Badura & Dziemiańczuk. (1981). Sampling points for petrologic studies of specimens from the boreholes: *filled circles* – ultrabasites, *filled squares* – metabasites, *open circles* – rodingites, *half-filled circles* – aplites; natural and artificial outcrops are indicated by conventional symbols.

nal structure (Jamrozik, 1981); a fragment of the lowermost part of the old ocean litosphere (i.e. so-called tectonite peridotites; Dziedzicowa 1979; Narębski *et al.*, 1982; Narębski & Majerowicz, 1985).

The mechanisms of the formation of the initial basic magmas were discussed separately. The suggested ideas included mantle diapir formation (Jamrozik, 1981; Dziedzic, 1994) and a more convincing subduction of the oceanic crust (Majerowicz & Pin, 1989, 1994).

This paper attempts to present a petrogenetic interpretation of the various rock varieties from the Szklary massif and to compare them with rocks from various geotectonic environments.

SAMPLE COLLECTION AND METHODS USED IN THE STUDIES

Petrological studies were carried out on approximately 500 rock samples from the Szklary massif, collected by the author during several years of field investigations of Lower Silesian serpentinites. The samples included those collected by the author in the field, as well as drill core fragments from Professor Jerzy Niśkiewicz's collection, which is now kept in the Institute of Geological Sciences of Wrocław University.

Microscopic investigations of thin sections in transmitted light were performed on 100 serpentinite, 30 metabasite and 20 aplite samples. The precise location of the sampling points is shown in Fig. 2 and Table 1.

Most of the main and trace element determinations, the results of which are presented in the tables and diagrams, were performed using X-ray fluorescence spectroscopy (XRF) in the chemical laboratory of the Geology Department of Keele University (Great Britain), as well as with the help of methods ICP, AES and neutron activation (INNA) in the Activation Laboratory Ltd. (Canada).

The precision of the determinations obtained with the various methods was the following: 2 ppm for Cu, Nb, Ni, Rb, Sr and Zn; 4 ppm for Ga, Pb, Y, Zr; 14 ppm for Cr and V; for rare earth elements: 1 ppm for Ce, Nd; 0.5 ppm for Th; 0.2 ppm for Ta, Hf, La; 0.05 ppm for Tb, Eu, Yb; 0.01 ppm for Sm and Lu.

Geochemical data were supplied with analysis results from 1960–1978, as well as with the results of main and trace element concentration assays published earlier (e.g. Gunia, 1995a; Dubińska, 1997).

Because the advancement of the serpentinisation phenomena varied strongly, for the calculation of the normative composition, the chemical composition of the ultrabasites (without volatiles) was calculated to 100 wt %. The total iron oxide content was standardised with the Coleman method (Coleman, 1977). The chemical analyses of representative samples of the Szklary massif rocks are presented in Table 1.

Phase X-ray analysis (powder X-ray diffraction) was used to analyse the serpentine minerals composing the serpentinites. Minerals were separated by hand under a binocular microscope and analysed in unoriented preparations with a DRON 2.0 apparatus. Analyses were performed with an X-ray source Cu K_α and Ni filter, within a 2Θ angle range from 4 to 66°. The X-ray patterns were compared with the JCPDS data base and Whittaker & Zussmann's (1956) article.

The chemical composition of selected minerals was determined with a Cameca electron EDS microprobe in the Geology Department of Blaise Pascal University in Clermont-Ferrand (France) using BRGM synthetic standards. The following parameters of analysis were used: acceleration voltage 15 kV, beam current: 10 nA, counting time: 10 s; results were subject to correction using the ZAF procedure.

RESULTS OF THE PETROLOGICAL INVESTIGATIONS

ULTRABASITES

Petrography

Numerous classifications of the ultrabasic rocks from the Szklary massif, based on petrographic criteria, have been put forward. In earlier papers, authors distinguished the so-called "olivine" serpentinites, in which relict minerals prevailed, and the "proper" serpentinites, in which serpentine minerals prevailed in the rock groundmass (Roth, 1867; Juskowiak 1957, 1960 *fide* Niśkiewicz, 1967). According to a different group of authors, the ultrabasites from Szklary represent five varieties with different degrees of secondary alteration advancement, including such processes as: silification, carbonatisation and weathering (Natkaniec-Nowak & Pitera, 1986).

Petrographic investigations of samples cut from drill cores allowed the distinction of harzburgites, lherzolites and orthopyroxenites among the weakly serpentinised ultrabasites from Szklary.

All the peridotites described here are composed of xenomorphic, often dismembered olivine grains with a high content of forsterite (Fo_{88-91}), and brown prismatic enstatite-bronzite (En_{87-93}) with clinopyroxene exsolution lamellae occurring locally. These minerals are in places accompanied by: fine-prismatic greenish augite diopside with distinctive traces of diallage cleavage {100}, amoeboid chromium spinel with brown-coloured translucent central parts of grains, and microspherical magnetite present locally in the form of cloud-shaped clusters. Traces of a plastic deformation in the solid state are expressed as a rule by olivine polygon aggregates with interstitial brown spinels having formed.

Orthopyroxenite was only encountered in a sample from well 231 (depth approx. 55.5 m, S slope of Siodłowe hill). It is a medium-crystalline rock with unoriented texture, with pan-xenomorphic orthopyroxene prisms covered with tiny inclusions of Fe oxides (magnetite?). The 2V angle measurement results (86–89°) imply that the pyroxenes belong to enstatite-bronzite group.

Ultrabasites with over 40 vol. % content occupied by primary components, were included as serpentinites.

According to the Wicks and Whittaker (1977) classification of serpentinites, it is possible to distinguish here serpentinites with mesh texture, vein serpentinites and intermediate serpentinites.

In the northern part of the massif, mesh texture predominates, characterised by a distinct orientation of chrysotile asbestos veins. In places, a window-like texture was formed, consisting of two systems of perpendicular serpentine veins (Gunia, 1993).

Vein serpentine was encountered in serpentinites from boreholes on the N and NW slopes of Tomickie hill (boreholes: 98, depth 33.3 m, and 242, depth 13.5 m) and on the NE slope of Koźmickie hill (346, depth 42.6 m). The serpentinite in this case is filled with variously oriented serpentine veins with ribbon or serrate forms. In

Table 1

Chemical composition of ultrabasic and metabasic rocks from the Szklary massif

Analysis	1	2	3	4	5	6	7
Sample	27/8/8	8/33	173/11	1	3B	3/Sz	173/11
Main oxides (wt. %)							
SiO_2	41.43	49.21	47.94	45.34	75.26	71.18	40.10
TiO_2	0.05	0.38	0.22	0.19	0.03	0.08	0.05
Al_2O_3	0.69	16.65	17.76	12.92	14.25	14.94	16.70
Fe_2O_3	8.63*	5.64	6.29*	6.36*	0.11	0.17	6.52*
FeO	-	1.68	-	-	0.38	0.65	-
MnO	0.12	0.13	0.16	0.11	0.03	0.02	0.14
MgO	39.60	9.71	8.69	16.05	0.08	0.52	18.80
CaO	1.60	10.57	12.37	15.74	1.32	1.57	13.50
Na_2O	-	4.13	2.23	0.63	6.90	5.73	0.13
K_2O	0.07	0.69	0.28	0.12	0.67	3.63	0.32
P_2O_5	-	0.17	-	-	-	-	-
L.O.I.	0.17	1.19	3.91	2.16	0.70	1.16	6.18
Total:	100.25	100.15	99.84	99.62	99.03	98.49	99.50
Trace elements (ppm)							
Ba	69	34	128	36	770	1100	nd
Co	100	59	38	nd	5	2	nd
Cr	2397	674	466	1062	23	23	650
Cu	5	51	47	39	2	5	nd
Ga	4	11	13	8	nd	nd	nd
Hf	<1	<1	<1	nd	1	1	2.8
Nb	1	1	1	1	2	8	0.7
Ni	2187	651	148	707	75	411	527
Pb	6	11	53	15	90	63	nd
Rb	7	9	13	8	4	5	nd
Sc	9.8	28	28	nd	3	3	nd
Sr	16	215	204	137	1775	594	nd
Ta	<0.5	<0.5	<0.5	nd	1.5	2.2	nd
Th	<0.5	<0.5	0.5	0.5	17	18	0.6
U	<0.5	<0.5	1.1	nd	1.5	2.2	nd
V	56	111	94	90	6	18	27
Y	1	7	5	5	7	6	1.14
Zn	44	41	194	40	7	15	nd
Zr	16	20	20	19	24	23	3
Rare earth elements (ppm)							
La	<0.50	<0.50	<0.50	<0.50	25.00	22.00	0.79
Ce	<3.00	<3.00	<3.00	2.00	33.00	32.00	1.53
Nd	<5.00	<5.00	<5.00	9.00	11.00	13.00	0.76
Sm	<0.10	0.50	0.40	nd	3.40	3.90	0.13
Eu	<0.20	0.30	0.40	nd	0.80	0.50	0.14
Tb	<0.50	<0.50	<0.50	nd	0.50	0.50	0.04
Yb	0.20	0.70	0.70	nd	0.60	0.60	0.14
Lu	<0.05	0.07	0.06	nd	0.08	0.08	0.03

L.O.I - lost on ignition, nd - not determined, * - total Fe calculated to Fe_2O_3; 1 - serpentinite with mesh texture, borehole 278, S slope of Siodlowe hill, 2 - coarse-grained amphibolite, W slope of Szklana Gora hill, 3 - aphanic amphibolite, borehole 173, S slope of Siodłowe hill, 4 - laminated amphibolite, N. slope of Tomickie hill (analyses 2-4 after Gunia 1995a), 5 - plagiogranite-'white' aplite, S slope of Tomickie hill, 6 - plagiogranite-'grey' aplite, S slope of Tomickie hill (analyses 5-6 after Pater, 1997, unpublished), 7 - rodingite, Szklary (after Dubińska, 1997).

many places, single tremolite needles or browny, cryptocrystalline weathered aggregate after primary olivine are clearly visible.

Intermediate textures were described in rocks from borehole 346 (Koźmickie hill). Under a microscope, serpentine 'hour-glass' textures are visible. They are cut by serpentine veins. In places, it is also possible to encounter nests of larger-size serpentinite flakes intergrown with talc, Mg-chlorite flakes and secondary chalcedony veins.

On the basis of microscopic studies, it is possible to reconstruct the early stages of the Szklary massif serpentinite textures. In the initial stage, a glass-like serpentine appears in the interstitions and penetrates cracks in bigger olivine grains. Next, these veins become larger and surround sharp-edged fragments of olivines. The number of veins grows steadily, and the olivine relics become smaller and more and more fragmented. After that, veins with zonal or ribbon texture are formed, and the chrysotile asbestos fibres grow larger.

Powder X-ray diffraction measurements revealed that the main constituents of the serpentinite textures in the Szklary massif are lizardite and clinochrysotile. The presence of mesh textures containing low-temperature serpentine varieties points to the infiltrational character of the ultrabasite serpentinisation. This process might have been related to a migration of fluids with high water vapour content, along planes of discontinuity formed as a result of an earlier shearing deformation.

From a comparison of the metamorphic mineral assemblages with data from the CMAS experimental system (Evans, 1977), it is possible to draw the conclusion that the maximum P,T conditions of the Szklary massif ultrabasite serpentinisation did not exceed the chrysotile stability limit, i.e. T_{max} = 350°C and P_{max} = 3 kbar, which corresponds to the lower range of the greenschist facies (Evans, 1977).

Geochemistry

The rocks under study reveal a high variability of Al_2O_3 content. The majority of samples have over 3 wt % of aluminium oxide, while some of them contain less than 1.0 wt %. CaO concentrations show similar variability. Mg-number values #Mg = (100 Mg/(Mg + Fe; atomic %), most often fall between 89 and 91, which is characteristic of residual spinel peridotites (Coleman, 1977). However, it is possible to encounter samples with #Mg values between 80 and 88.

Some of these parameters may be regarded as typical of ultrabasites representing the lowest member of the ophiolitic sequence (tectonite peridotites *sensu* Coleman, 1977). These ultrabasites often form a residue after basaltic magma melting (#Mg= 0.90, Al_2O_3 < 1.0 wt %.

It should be stressed that some ultrabasites from the Szklary massif show features characteristic of high-Al continental pyroxenites or pyroxenites from the upper member of the ophiolite sequence (ultramafic cumulates). This fact may be confirmed by the positions of the composition points in the systems: CaO-Al_2O_3-MgO (Fig. 3) and Na_2O+K_2O-FeO*-MgO (Fig. 4). In these systems, some of the points representing ultrabasites from the Szklary massif lie within the tectonite peridotite field, and some of them in the ultramafic cumulate field.

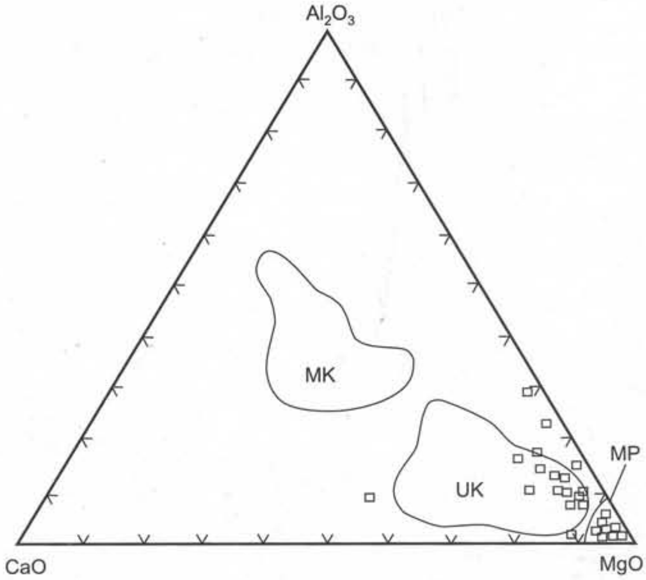

Fig. 3. Ultrabasites of the Szklary massif on the CaO-Al_2O_3-MgO diagram (after Coleman, 1977). MP – metamorphic (tectonite) peridotites, UK – ultramafic cumulates, MK – mafic cumulates.

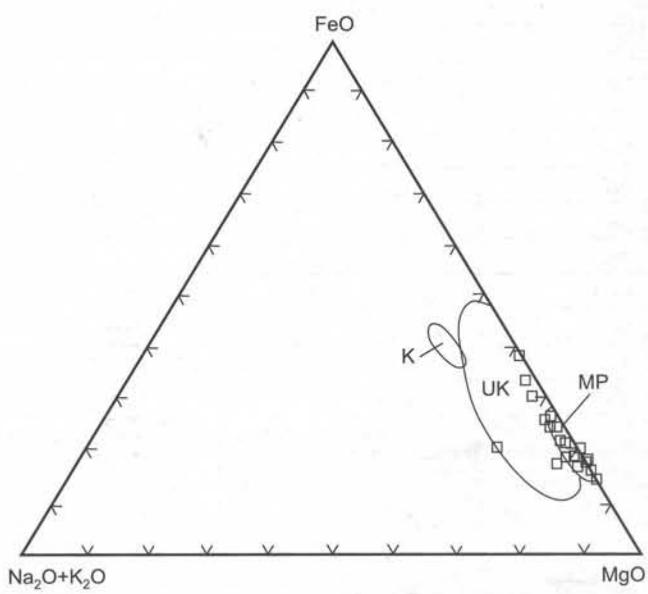

Fig. 4. Ultrabasites of the Szklary massif on the Na_2O+K_2O-FeO-MgO diagram (after Coleman, 1977). MP – metamorphic (tectonite) peridotites, UK – ultramafic cumulates, K – komatiites.

The normative composition of the primary ultrabasites from the Szklary massif (calculated using the CIPW method) corresponds, in general, to their modal composition. As per the IUGS diagram, harzburgites and lherzolites prevail, with single projection points falling within the fields of dunites, websterites and orthopyroxenites (Fig. 5).

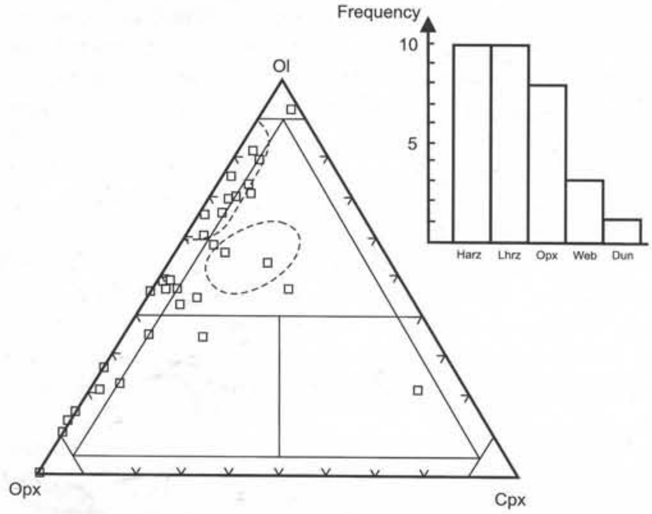

Fig. 5. Ultrabasites of the Szklary massif on the Opx-Ol-Cpx IUGS classification diagram. 1 – field of tectonite peridotites of the oceanic crust is marked by dotted line (after Coleman, 1977). Abreviations to the inset frequency plot: Harz – harzburgites, Lhrz – lherzolites, Opx – orthopyroxenites, Web – websterites, Dun – dunites.

Differences in the primary ultrabasite composition led to attempts to evaluate a percent share of partial melting products in a theoretical primary mantle substrate. A similar evaluation of the melt and residue content in ultrabasites was carried out by Bodinier (1988) for lherzolites from the Lanzo Massif in the West Alps.

In the calculations, the following formula was applied: $C_o = F \times C_l + (1 - F) \times C_r$, where: C_o – the theoretical composition of the Earth's upper mantle, C_l – the average composition of the 'ophiolitic' basalt from the West Alps, C_r – the composition of the sample studied, F – the percent share of the partial melting products. The alculations were performed for contents of Si, Ti, Al, Mn, Mg, Ca, Na and K. The highest repeatability of results was obtained for Al, Mg and Ca.

The peridotites from the Szklary massif are characterised by a considerable variability (bimodality ?) of the percent share of the partial melting products (F%), which ranges from 16% to 20% (average 17%) and from 3% to 11% (average 7%). This fact implies the existence of different possibilities for the formation of the primary phase balance of the peridotites from the Szklary massif. Apart from restite harzburgites, ultrabasic rocks with a high share of partial melting products occur here. They may represent both the relict fragments of primary mantle (continental?) lherzolites, and ultramafic cumulates formed in the early stages of magma chamber evolution in the oceanic crust (Gunia, 1994a).

The trace element concentrations in the Szklary massif ultrabasites are typical of restite harzburgites with a low content of incompatible components, e.g. Zr = 16 ppm, Y = 1 ppm, Nb = 1 ppm, Co = 100 ppm, Sc = 9.8 ppm (see Table 1). Due to the exceptionally low concentrations of REE in the rocks, their geochemical discrimination on multi-element patterns (spider diagrams) was not possible.

The results of the geochemical investigations on the ultrabasites point to a certain variability of chemical composition of the Szklary massif ultrabasites. It may be a reflection of heterogeneity of the primary substrate of the ultrabasites in conditions corresponding to the Earth's upper mantle, or may reflect their composition modification as a result of e.g. re-equilibration caused by e.g. plastic deformation in the solid state.

Mineral chemistry

An electron microprobe was used to analyse olivines, Cr-spinels, orthopyroxene, serpentine group minerals and amphiboles. The results of the chemical analyses of representative samples are quoted later in this chapter.

Olivines represent a high-Mg variety with a forsterite content of about 92 vol. %. NiO concentration (0.33–0.38 wt %.) measured in the Szklary massif serpentinites resembles the NiO content for ocean floor ultrabasites (0.27–0.40 wt %; after Coleman, 1977).

For composition analysis, large accessory Cr-spinels with ameboid shape were selected. The points analysed were located in the central, brownish, translucent parts of grains as well as in their opaque marginal parts. Most of the points have a composition corresponding with chromium magnetite according to the Stevens classification (1944), and can be described by the formula:
$(Cr_{3.364\text{-}3.772}, Al_{0.267\text{-}0.326}, Fe^{3+}{}_{6.758\text{-}12.190}) (Mg_{1.002\text{-}1.009}, Fe^{2+}{}_{6.689\text{-}11.765}) O_{32}$.

The composition of the sample XX/51 is different from that of the spinel group presented above. It has considerably higher Cr, Al and Mg content, and thus it can be described as Cr-spinel (*sensu* Stevens, 1944).

When interpreting the composition of the Szklary massif spinels, one should stress the drop in Cr and Mg concentrations towards the grain margins and a simultaneous increase in Fe^{3+} content. The values of the coefficient #Cr = Cr/(Cr + Al), ranging from 0.21 to 0.48, indicate that the spinels belong to the Acoje type (*sensu* Evans & Hawkins, 1989). This variety's composition reflects the heterogeneity of the initial mantle substrate, or points to multiple modifications of its composition as a result of melting or astenospheric "plastic flow" in the solid state (Evans & Hawkins, 1989).

The equilibrium temperatures of the olivine – Cr-spinel pairs, calculated using the Sack method (1982), amount to 585–618°C (for sample XX/51 to 690°C), and calculated using Fabries (1979) method, to 666–749°C (for sample XX/51 to 753°C). These paleo-temperatures resemble the equilibrium temperatures of ol-sp pairs for the Gogołów–Jordanów Massif ultrabasites (618–697°C; Gunia & Lebda 1994), the Braszowice–Brzeźnica Massif (630–650°C; Gunia, 1995b) ultrabasites, and ultrabasites from the Owiesno vicinity in the Fore-Sudetic part of the Góry Sowie Block (610–690°C; Gunia, 1994b).

An electron microprobe was also used to analyse a fragment of an *orthopyroxene* prism set in an olivine groundmass. Its enstatite content amounts to about 89%. The pyroxene represents a low-Al variety with a relatively high alkali content.

Minerals analysed from the *serpentine group* formed vein fillings between sharp-edged olivine relics in the serpentinites with mesh (directional) texture. With regard to their composition, they represent low-Al clinochryzotiles which do not have an enhanced Ni content. As in Wicks & Plant (1979), they represent a variety in which no significant replacement of Si by Al ions took place (Gunia, 1993).

Amphiboles set in the groundmass, in the form of long single, needles are Ca-amphiboles, and represent tremolite with the following composition:

$Ca_{1.888\text{-}1.889}$, $(Mg_{4.772\text{-}4.778}$, $Fe^{2+}{}_{0.177\text{-}1.192})$ $Si_{7.972\text{-}7.879}$ O_{22} (OH).

In amphibolite sample XX/6c, elevated contents of Mn and Ni were observed.

METABASITES

Petrography

The metabasites present in the Szklary massif form small tectonic enclosures, up to 1 meter in diameter, often surrounded by a several-centimetre-thick chlorite contact rim. They are visible in the walls of old excavations of the "Szklary" nickel ore mine on the slopes of Tomickie and Szklana Góra hills and in a dormant serpentinite quarry on the western slope of the Siodłowe hill.

In other places, the amphibolites form narrow veins up to 4 m long and 0.6 m thick, which are often displaced. The contacts of the amphibolites with the surrounding serpentinites are sharp and tectonic, with the strike orientation of the contact planes varying from N–S through NW–SE to E–W, and steep dip angles (60–90°). These metabasites outcrop on the slopes of Koźmickie hill.

The geological position of the amphibolites encountered in boreholes in the western part of the Szklary massif is unclear. According to Niśkiewicz (1967), these rocks form several-tens-of-meters-thick enclosures at the contact of serpentinites with he blastomylonites of the Szklary massif cover.

On the basis of petrographic features, it is possible to distinguish two varieties of the metabasites, i.e. amphibolites I, with unoriented texture, and amphibolites II, which are laminated (amphibole-feldspar schists) with a distinctly marked directional texture.

Amphibolites I, with unoriented texture, are dark-green or grey-green, locally with white spots. These rocks have various textures, and macroscopically it is possible to distinguish coarse-granoblastic, medium-granoblastic and aphanitic varieties.

Under a microscope, it is possible to observe various textures of these metabasites: from granonematoblastic, through porphyroblastic to nematoblastic.

In the groundmass, green common hornblende predominates. Its most frequent forms are almost idiomorphic prisms. Locally it is accompanied by amphiboles from the tremolite-actinolite group, which form aggregates of tiny needles arranged in fan-like or hour-glass assemblages. In some of the samples it is possible to observe single relicts of kaolinitised and saussuritised plagioclase laths of andesine composition. Clinozoisite, Mg-chlorite, titanite, pyrite and iron oxides occur in smaller amounts.

In several thin sections, relict textures resembling ophitic or subophitic intergrowths were encountered. These textures are composed of bent fragments of monoclinic pyroxene prisms (diopside augite?) intergrown with albite twinned and strongly saussuritised plagioclases (andesine-labrador). Most of the amphibolites of this variety were strongly deformed.

The deformation is expressed as the compression and breaking of amphibole prisms, and as local intensive chloritisation of hornblende. Polygonal, chlorite-filled pseudomorphs after amphiboles are locally bent into microfolds. They may even have the form of typical crenulation packs.

Amphibolites II with parallel texture (amphibole-feldspar schists) occur mainly in the western and southern part of the Szklary massif, most commonly along the contact of the serpentinites with the gneisses or blastomylonites of the Niemcza Zone.

Typically, these rocks are laminated, with fine-granoblastic texture and grey or grey-green colour. On the surface of the metabasites, there are alternating layers of amphiboles and plagioclases. The thickness of the alternating layers generally does not exceed 2 centimetres. In places, it is possible to observe varieties with lenticular-augen texture or amphibolites cut by thin veins of microcrystalline carbonate. Most commonly, the amphibole layers have nematoblastic texture. Such textures as porphyro-, granonematoblastic and in places lenticular-augen texture are observed within the amphibole-plagioclase layers.

The main rock-forming component is green common hornblende. It takes the form of flattened, up to several millimetres long prisms. Plagioclases, with $An_{25\text{-}37}$ composition, are chiefly xenomorphic or ameboidal, and in places form albite or pericline twins. These feldspars most commonly occur in oval aggregates composed of several grains, which are surrounded by fine-prism amphibole groundmass.

Accessory minerals are represented by titanite, Fe-Ti oxides and, sporadically, by single, tiny garnet grains and crushed zircon prisms. Locally, in zones of strong tectonic deformation, secondary Ca-Mg amphiboles (tremolite-actinolite) are present in the form of felty aggregates composed of microfibres or tiny needles.

Geochemistry

The results of bulk-rock chemistry analyses imply that the Szklary massif metabasites correspond to low-Ti toleitic basalts (Table 1). Taking MgO content into account, it was possible to distinguish: (i) high-Mg metabasites which probably originated from initial pyroxenites (picrites?) or gabbroids; (ii) amphibolites with a moderate MgO content originating from primary basalts or dolerites (Gunia, 1995a).

Due to low SiO_2 and alkali concentrations in the Szklary massif metabasites, on the TAS diagram their points fell within the fields for picrite basalts and basalts (Gunia, 1995a). On the Jensen (1976) discrimination diagram, some points were the komatiites area (Fig. 6) and

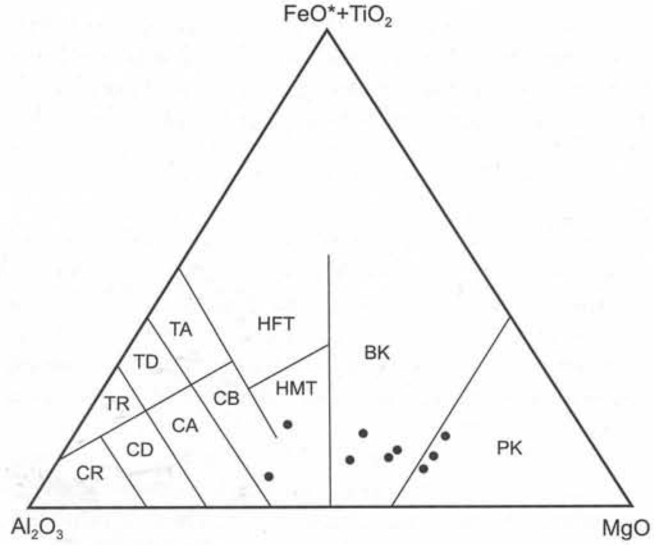

Fig. 6. Metabasites of the Szklary massif on the Al_2O_3-FeO^*+TiO_2-MgO diagram (after Jensen, 1976). PK - komatiites, BK - basite komatiites, HMT - high-Mg tholeiites, HFT - high-Fe tholeiites, TA - tholeiitic basalts, TD - dacites, TR - trachytes, CB - calc-alkaline basalts, CA - andesites of calc-alkaline series, CD - dacites of calc-alkaline series, CR - rhyolites. FeO* - total Fe calculated as FeO.

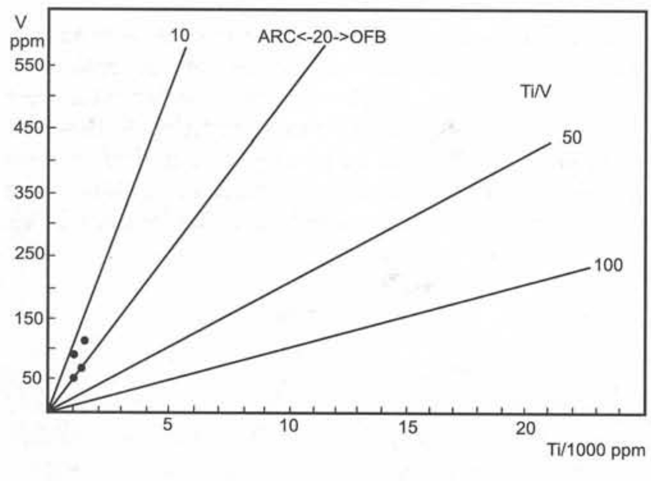

Fig. 7. Metabasites of the Szklary massif on the V-Ti diagram (after Shervais,1982). ARC - island arcs basalts, OFB - ocean floor basalts.

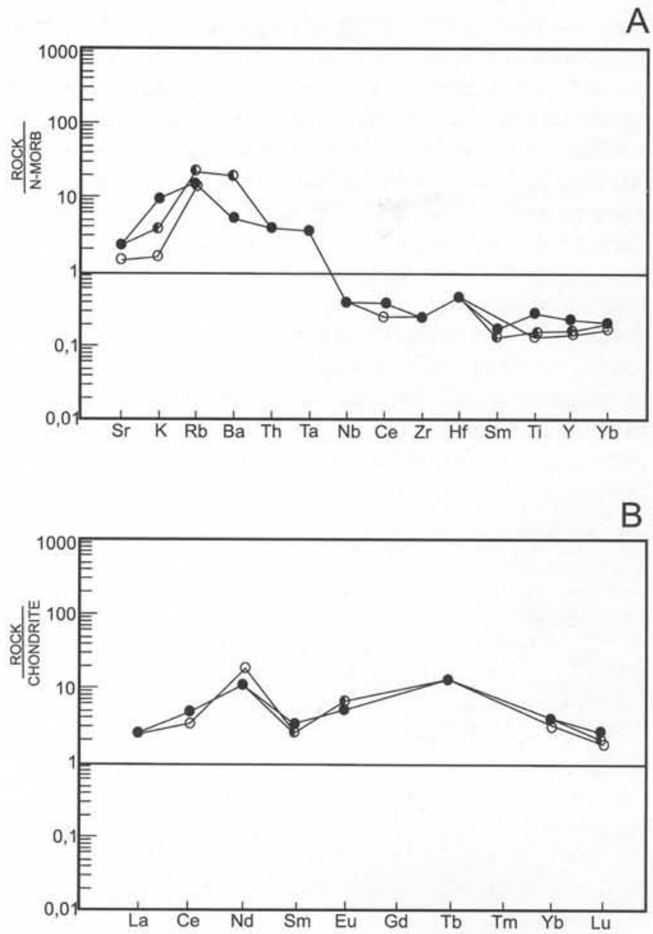

Fig. 8. Multi-element diagrams of the Szklary massif metabasites. A - values standarized to the composition of Mid-Ocean Ridge Basalts, B - values standarized to chondrite composition. *Solid circles* - coarse-grained amphibolite (W slope of Szklana Góra hill); *half-filled circles* - aphanic amphibolite (S slope of the Siodłowe hill); *empty circles* - laminated amphibolite (N slope of the Tomickie hill).

the calculated CIPW normative composition implied that varieties with high hypersthene and nepheline contents predominate here.

The metabasites of the Szklary massif have low concentrations of incompatible elements, like Ti, Zr, Y and Sc, and the values of the Ti/V ratio (10–25) are similar, to those in the boninite-resembling, basalt series of island arc or back-arc basin zones (Gunia, 1995a; Dubińska, 1997; Dubińska & Gunia, 1997; Fig. 7).

The multi-element diagram of trace elements shows elevated concentrations of lithophile elements: Sr, K, Rb, Ba, Th, while incompatible elements within Nb-Yb are strongly depleted compared to the MORB standard. The profile of their distribution line runs almost horizontally below the MORB standard line (Fig. 8A). According to Pearce (1983), such an arrangement of the profile may point to an advanced process of partial melting of the source rocks.

On the spider diagram of rare earths, it is possible to observe a characteristic rugged graph line. As a rule, concentrations do not exceed twenty-fold chondrite value (Fig. 8B). A positive anomaly of Nd (20 x chondrite) and Tb (10 x chondrite) concentration and a (slightly marked) negative anomaly of Eu concentration (2 x chondrite) are very distinct.

Thus, it can be assumed with considerable certainty, that the initial basalts from the Szklary massif might have formed during the advanced partial melting of the Earth's upper mantle material. This process usually leads to the formation of the so-called harzburgite residue and the formation of basic cumulates with a reversed crystallisation sequence in the following order: olivine - monoclinic pyroxene - plagioclase - rhombic pyroxene - Fe-Ti oxides (Beccaluva & Serri, 1988).

Another matter to explain is the relative enrichment of the metabasites in the LILE components of supra-subduction zones *sensu* Saunders & Tarney (1984). According to Pearce (1983), this phenomenon may have been caused by a supply of these elements as a result of considerable hydrated fluid activity in the plates convergence zone, or it may reflect contamination by crustal material of an ocean floor fragment in the subduction zone. Taking the small number of samples investigated into account, it is not possible to exclude an additional secondary enrichment under the thermal influence of acidic magmatic rock veins or during hydrothermal metamorphism phenomena of the "ocean floor" type.

LEUCOCRATIC ROCKS

Petrography

Granitoids mainly occur in the north-eastern part of the subsurface zone of the Szklary massif. According to Niśkiewicz (1967), they form an approximately 200-metre-thick N–S striking vein.

Petrographic investigations of drill cores, carried out by Pater (1997), revealed that fine-crystalline leucocratic rocks are present in the form of small enclosures in the serpentinites and their weathering cover. Their thickness varies from a tenth of a meter to several meters. These enclosures are frequently surrounded by contact zones (reaction rims) of talc-anthophyllite, tremolite-chlorite and chlorite schists (Dubińska, 1981, 1984).

In the northern part of the massif, leucocratic rocks were observed on the N and SE slopes of Koźmickie hill (borehole 297, depth 19.60 m; borehole 298, depth 19.6 and 37.0 m; borehole 315, 14.0 and 21.0 m; borehole 370, 19.8 and 36.0 m).

In the central part, aplites occur in boreholes on the N and S slopes of Tomickie hill (borehole 51, depth 34.6, 47.4, 70.5, and 80.0 m; borehole 253, depth 24.8 m), and in the S part, their presence was observed on the N and S slopes of Siodłowe hill (borehole 121, depth 9.5 m; borehole 129, depth 25.8 m, borehole 160, depth 26.0 m; borehole 173, depth 14.0 m; borehole 223, depth 31.4 m).

The results of petrographic investigations of the aplites are in accordance with the results of earlier studies of these rocks (Niśkiewicz, 1967). On the basis of petrographic properties it was possible to distinguish two varieties of acidic rocks, i.e. plagiogranites (the so-called 'white' aplites, sacharites) and granitoids containing hornblende (the so-called 'grey' aplites).

Plagiogranites (the so-called 'white' aplites) are a mono-mineral rock with fine-crystalline, unoriented texture. It typically consists of pan-xenomorphic laths or xenomorphic grains of plagioclases (An_{30-34}). Their size, in general, does not exceed 0.5 mm. Polysynthetic albite twinning is quite common, while pericline twins traces are rare. Most feldspar grains display signs of cataclase and recrystallisation.

The second variety of leucocratic rocks (the so-called "grey" aplites) is represented by rocks with a microcrystalline texture, composed of plagioclases and small amounts of quartz, microcline, biotite, green common hornblende and accessory minerals: sphene, garnet and Fe-Ti oxides. In their groundmass, the most common elements are plagioclase grains (An_{28-35}). They surround single laths of alkaline feldspars (microcline?) up to 5 mm in size and form intergrowths with small quartz grains and with bent and altered biotite flakes. Locally, plagioclases form layer intergrowths with aggregates of green common hornblende prisms. In places, plagioclases are substituted by zoisite that has the form of single, rounded drop-like grains growing on laths. Another mineral encountered in these rocks is clinozoisite with typical ink-blue interference colours.

The modal composition of the fine-crystalline leucocratic rocks from the Szklary massif on the Q-A-P diagram, according to IUGS, points to diorite/anorthosite or quartz diorite/anorthosite.

Geochemistry

In spite of their differences in mineral composition, the Szklary massif aplites have similar chemical compositions. These rocks may be described as peraluminous granitoids (A > CNK), which are rich in CaO and poor in K_2O and have high Na_2O/K_2O ratio values, typical of the type I granites (Gunia, 1996b).

Their normative composition on the Ab-Or-An discrimination diagram has a distribution of projection points concentrated chiefly in the trondhjemites field (Fig. 9). On the R1-R2 diagram (Betchelor & Bowden, 1985; not shown) these rocks may be classified as post-orogenic varieties from post-collision uplifts. The alkaline-calcium or calcium values of the Peacock index are also worth stressing.

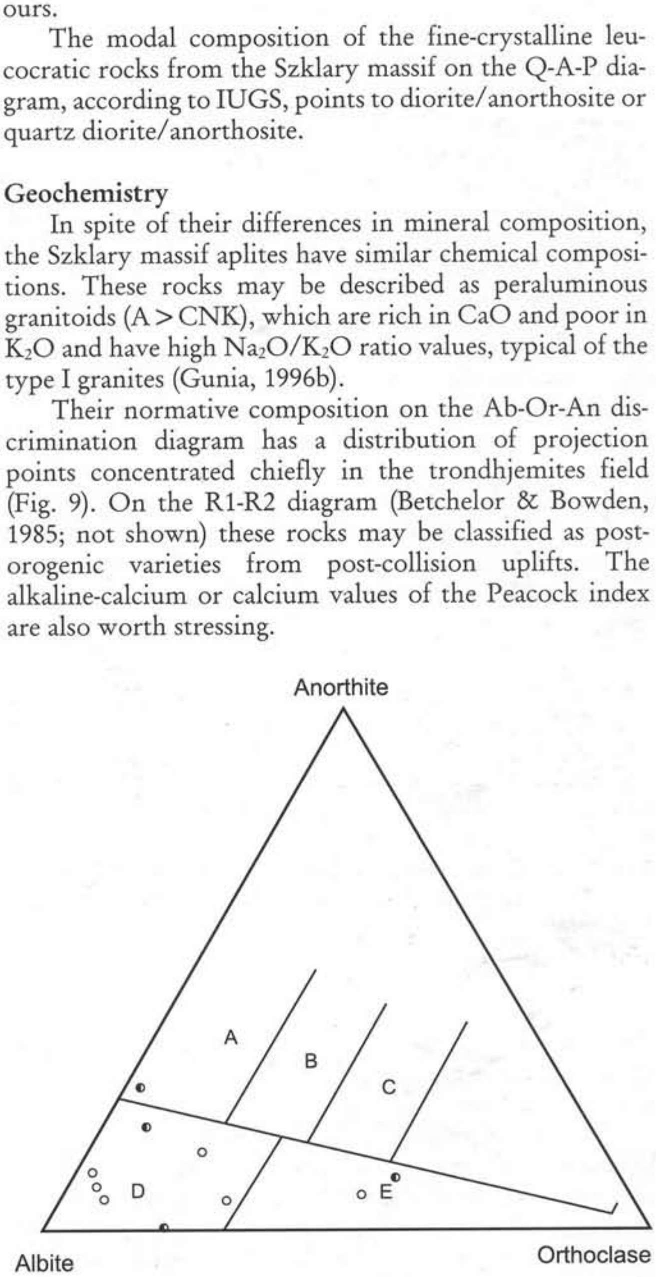

Fig. 9. Normative composition of the Szklary massif aplitic rocks in the system Albite-Anorthite-Orthoclase. A – tonalite, B – granodiorite, C – adamellite, D – trondhjemite, E – granite. *Empty circles* – "white" aplites; *half-filled circles* – "grey" aplites.

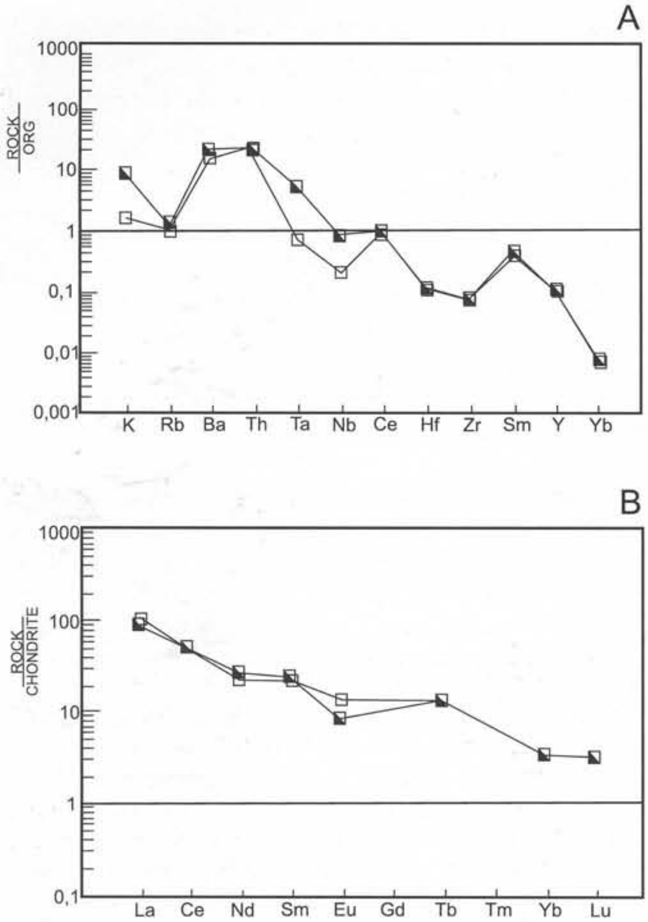

Fig. 10. Multi-element diagrams of the Szklary massif plagiogranites. A – values standarized to the composition of ocean ridge granites (ORG), B – values standarized to the composition of chondrites. Sample symbols as on Figure 9.

On the ORG-normalised multi-element diagram, the course of the Szklary massif aplite profile line implies enrichment in K, Ba and Th, while Ta concentration varies compared to the standard level. The rocks studied are strongly depleted in Hf, Zr, Sm, Y and Yb and the profile line runs below the standard line (Fig. 10A). Such depletion, in connection with selective enrichment in Th and Ba, is a typical feature of plagiogranites related to tholeiites of island arcs (Pearce *et al.*, 1984).

On the spider diagram of rare earths it is possible to observe an inclined profile line with a maximum enrichment in LREE, reaching 100 x chondrite value, a small negative anomaly of Eu and HREE concentration corresponding to 10 x chondrite (Fig. 10B).

The results of geochemical studies of the Szklary massif plagiogranites seem to confirm the hypothesis that they represent trondhjemites formed in the island arc environment. A certain similarity of their geochemical features to those of metabasites implies that these rocks may represent more acidic derivates formed as a result of fractional crystallisation of the same initial basic magma.

RODINGITES

Petrography

Rodingites in the Szklary massif are rare. On the surface, they are most commonly found in rock fragments as oval bright enclaves, up to 0.5 m in size, surrounded by a several-centimetre thick, fine-acicular amphibole contact rim.

These rocks probably represent primary tectonic enclaves in serpentinites and are found in outcrops on the S slope of Tomickie hill (Heflik & Natkaniec-Nowak, 1987).

On the basis of petrographic properties, it was possible to distinguish two varieties of Ca-rich metasomatic rocks in the Szklary massif: 1) rodingites with a preserved relict ophitic texture, composed of grossular, clinozoisite, Mg-chlorite, clintonite and spinel with pleonaste composition, and 2) the so-called rodingitised gabbroids, in which apart from the minerals listed above, there are: clinopyroxene, hornblende, epidote, and garnet with an intermediate composition between grossular, almandine and pyrope (Dubińska *et al.*, 1991).

The author carried out petrographic studies on rodingite samples from drill cores from boreholes situated on the eastern and southern slopes of Siodłowe hill (borehole 205, depth 22.5 m; borehole 256, depth 47.0 m and 56.2 m, and borehole 268, depth 60.0 m). Geological interpretation of data from these boreholes implies that rodingites form irregular (finger-like?) or lenticular enclosures in the amphibolites, and that their thickness is below 1.5 m.

The rodingites from the E slope of Siodłowe hill are grey-pink and frequently cut by brown veins. Their texture is aphanitic and unoriented. Under a microscope one can observe that in the fine-granoblastic rock groundmass the most abundant component is isotropic garnet (grossular?) which has the form of isometric, framboidal grains, with a size from 0.4 to 0.6 mm. The veins are filled with brown, fine-prismatic vesuvian.

The rodingites outcropping on the southern slope of Siodłowe hill are grey-green and have coarse-granoblastic and in places porphyroblastic texture. Locally, their texture is clearly directional, and in some places banded. Under a microscope, it is possible to notice alternating laminae composed of bigger clinopyroxene prisms and porphyroblastic aggregates containing various amounts of epidote, clinozoisite, garnet (grossular?) and adispersed flaky mineral, probably light mica (clintonite?).

Geochemistry

Due to their rarity, the rodingites have not been a subject of detailed geochemical investigations. Several full analyses of these rocks from drill cores on the E and S slopes of Siodłowe hill (Gunia, 1996a) were made, as were trace element and rare earth determinations for a rodingite sample from an outcrop in the central part of the massif (Dubińska, 1997).

The interpretation of these results points to a substantial supply of CaO and depletion in Ti relative to the probable composition of the protolith (gabbroic?). In Dubińska (1997), a genetic relationship (comagmatism?) is also stressed between the amphibolite and rodingite protolith from the Szklary massif. The proof for such a relationship might be the linear trends of points distributed on Yb-Lu and Dy-Y two-component diagrams. The strong depletion of the rodingites in HREE and variability of the Zr/Hf ratio reflect the low oxygen fugacity during the extraction of the initial melt. This indicates separation of the rodingite protolith from a HREE-poor source (Dubińska, 1997).

The results of fluidal inclusions studies on the minerals from the Szklary massif rodingites imply that the maximum temperature of metamorphism did not exceed 400°C (diopside formation). In the next stage, secondary grossular, epidote and clintonite formed at temperatures of 300–370°C (Dubińska, 1997).

These temperatures correspond, in principle, with the typical temperatures for the serpentinisation of ultrabasites in the greenschist facies of regional metamorphism.

CONCLUSIONS

The review of the petrological features of the Szklary massif rocks, based on the available data on mineral and chemical composition, points to variability in the serpentinite protolith. The variable concentration of Al_2O_3, a rather non-mobile component in ultrabasite metamorphism processes, may reflect the heterogeneity of the initial mantle substrate, generated at different intersection levels.

The most primitive initial material, least depleted in easy-melting constituents, could be high-Al lherzolites, which afterwards, during partial melting, released a significant proportion of tholeiitic melt.

This process led to the formation of low-Al harzburgites – a residue after basaltic magma generation. In their subsurface parts, these peridotites could have become impregnated with a rest melt with a higher Mg content, crystallising in the form of high-temperature pyroxenite dykes.

Interestingly, from a petrological point of view, there are enclaves of high-Mg metabasites strongly depleted in incompatible elements. Garnet-bearing peridotites could have been a source of such magmas, although, during the transport of the magmas from their source, the proportion of lithophile constituents increases.

Environments that are particularly favourable for such alterations are lithospheric plate contacts. In such zones, the intensive action of fluids rich in water vapour alters the initial element concentrations, causing enrichment in certain elements and depletion in others. The main mechanisms of these alteration types are, according to Pearce (1983), intermingling and remelting.

Enclaves of hornblende-rich plagiogranites (trondhjemites) in the serpentinites, might have formed from acidic derivates of basic magmas. Thus, it is possible to distinguish several acid vein rock varieties of different origin in the Szklary massif. Among these varieties there are aplites, crystallised during the magmatic evolution of the ophiolites, leucocratic vein rocks genetically related to the Niemcza Zone granitoids, and acidic fine-grained enclosures of aplitoids that originated from blastomylonites of the Szklary serpentinite massif cover.

The complexity of phenomena of the ultrabasic rock tectono-metamorphic evolution is expressed by the presence of structures formed during high-temperature plastic flow in the solid state, on which a low-temperature metamorphism was imposed. This metamorphism resulted in the penetration of fissures in the initial peridotites by vein serpentine; local zones, rich in vein serpentine were formed.

Moreover, in the Szklary massif serpentinites, rodingites occur, representing enclaves of basic or more acidic rocks, the initial mineral composition of which became altered by serpentinisation processes. This can mean that the initial rocks for the rodingites entered the serpentinites before the main metamorphic event.

The source of their material is, however, unknown. It is unclear whether it was autochthonous, or came from the erosion of other crystalline massifs (circum-Góry Sowie Block ophiolites, Góry Sowie Block gneisses).

However, it should be stressed that due to lack of data, this paper presents only some of the problems of the petrology of the rocks composing the Szklary massif of the Fore-Sudetic Block. An explanation of other issues and a more precise justification of the presented (working) hypotheses will only be possible after new results have been obtained from structural and petrographic studies, and new rock and mineral composition determinations and isotopic analyses and datings have been carried out.

REFERENCES

BADURA, J. & DZIEMIAŃCZUK, E., 1981. Mapa geologiczna Polski. 1:25 000. Arkusz: Ząbkowice Śl. Wydawnictwa Geologiczne, Warszawa.

BECCALUVA, L. & SERRI, G., 1988. Boninitic and low-Ti subduction related lavas from intraoceanic arc-back systems and low-Ti ophiolites: a reappraisal of their petrogenesis and original tectonic setting. *Tectonophysics*, 146: 296–315.

BETCHELOR, R. A. & BOWDEN, P., 1985. Petrogenetic interpretation of granitoid rock series using multicationic parameters. *Chemical Geology*. 48: 43–55.

BODINIER, J.L., 1988. Geochemistry and petrogenesis of the Lanzo peridotite body, western Alps. Tectonphysics, 149:

67–88.

COLEMAN, R.G., 1977. Ophiolites. Ancient Oceanic Litosphere? Rocks and Minerals. 12. Springer Verlag. New York, pp. 229.

CWOJDZIŃSKI, S. & ŻELAŹNIEWICZ, A., 1995. Podłoże krystaliczne Bloku Przedsudeckiego. Przewodnik LXVI Zjazdu Polskiego Towarzystwa Geologicznego. Geologia i ochrona środowiska Bloku Przedsudeckiego, Wrocław 21-24 09 1995: 11–28. {in Polish only}

CYMERMAN, Z., PIASECKI, M. A. & SESTON, R., 1994. Terranes and terrane boundaries in the Sudetes, northeast Bohemian Massif. *Geological Magazine*, 134: 5, 717–25.

DUBIŃSKA, E., 1981. O wietrzeniu skał chlorytowo-amfibolowych w Szklarach koło Ząbkowic Śl. *Archiwum Mineralogiczne*, 37: 73–82.

DUBIŃSKA, E., 1984. Interstratified minerals with chlorite layers from Szklary near Ząbkowice Śląskie (Lower Silesia). *Archiwum Mineralogiczne*, 39: 5–23.

DUBIŃSKA, E., 1997. Rodingites and amphibolites from the serpentinites surrounding Sowie Góry Block (Lower Silesia, Poland): Record of supra-subduction zone magmatism and serpentinisation. *Neues Jahrbuch für Mineralogie Abhandlungen*, 171: 3, 239–79.

DUBIŃSKA, E., KOZŁOWSKI, A. & BAGIŃSKI, B., 1991. Rodingity klintonitowe ze Szklar. In: Majerowicz, A. (Ed.). *Wybrane zagadnienia z dziedziny mineralogii, petrologii oraz historii nauk geologicznych*, Konferencja naukowa w 10 rocznicę śmierci prof. Kazimierza Maślankiewicza, Wrocław, 21–22 listopada, streszczenia referatów, Wydawnictwo Uniwersytetu Wrocławskiego, Wrocław, pp. 20–21. {in Polish only}

DUBIŃSKA, E. & GUNIA, P., 1997. The Sudetic Ophiolite: current view on its geodynamic model. *Geological Quarterly*, 41: 1–20.

DZIEDZICOWA H., 1979. Problem genezy magm bazaltowych i ich związek z ultrabazytami strefy Niemczy – proponowany model reżimu tektonicznego. In: Gunia T., (Ed.). *Wybrane zagadnienia stratygrafii, petrografii i tektoniki wschodniego obrzeżenia gnejsów sowiogórskich i metamorfiku kłodzkiego*. Materiały konferencji terenowej, Wydawnictwo Uniwersytetu Wrocławskiego: 107–17. {in Polish only}

DZIEDZICOWA, H., 1994. LP hornblende granulite facies within the Góry Sowie gneisses of the Fore-Sudetic Block. In: Kryza, R., (Ed.) Igneous activity and metamorphic evolution of the Sudetes area, Abstracts. Wrocław, 43.

EVANS, B., V., 1977. Metamorphism of alpine peridotite and serpentinite. *Annual Review Earth Planetary Sciences*, 5: 397–447.

EVANS, C. & HAWKINS, I., W., Jr., 1989. Compositional heterogeneities in upper mantle peridotites from the Zambales Range Ophiolite, Luzon, Philipines. *Tectonophysics*, 168: 23–41.

FABRIES, J., 1979. Spinel-olivine geothermometry in peridotites from the ultramafic complexes. *Contributions to Mineralogy and Petrology*, 69: 329–36.

GUNIA, P., 1993. Uwagi o strukturach serpentynitów z masywu Szklar. *Polskie Towarzystwo Mineralogiczne. Prace Specjalne*, 4: 63–8. {in Polish only}

GUNIA, P., 1994a. Partialne topienie ultrabazytów z ofiolitów wokół sowiogórskich. *Polskie Towarzystwo Mineralogiczne. Prace Specjalne*, 5: 94–95. {in Polish only}

GUNIA, P., 1994b. Geothermometry of the ultrabasic rocks from the environs of Owiesno (Fore-Sudetic Part of the Sowie Mts. Gneissic block) – Preliminary results. Mineralogia Polonica, 25: 51–62.

GUNIA, P., 1995a. Petrology and geochemistry of the metabasic rocks from the Szklary massif (Fore-Sudetic Block, SW Poland) – preliminary results. *Bulletin of the Polish Academy of Sciences. Earth Sciences*, 43: 123–34.

GUNIA, P., 1995b. Nowe dane o geotermometrii ol-sp ultrabazytów okolic Szklar i Braszowic. *Polskie Towarzystwo Mineralogiczne. Prace Specjalne*, 6: 42–4. {in Polish only}

GUNIA, P., 1996a. Dolnośląskie rodingity. *Acta Universitatis Wratislaviensis, No 1784. Prace Geologiczno-Mineralogiczne*, 51: 83–8.

GUNIA, P., 1996b. Geochemistry of aplites from Szklary serpentinite Massif (Fore-Sudetic Block; SW Poland) – preliminary results. *Polskie Towarzystwo Mineralogiczne. Prace Specjalne*, 7: 76–8. {in Polish only}

GUNIA, P. & LEBDA M., 1994. Pyroxene and olivine spinel geothermometry applied to the Ślęża ophiolite rocks: preliminary data. In: Kryza, R., (Ed.) *Igneous activity and metamorphic evolution of the Sudetes area, Abstracts.* Wrocław, 48–50.

HEFLIK, W. & NATKANIEC-NOWAK, L., 1987. Grossular from rodingitic zone in Szklary serpentinite massif (Lower Silesia, Poland). *Mineralogia Polonica*, 18: 27–32.

JAGOUTZ, E., PALME, H., BADDENHAUSEN, H., BLUM, K., CENDALES, M., DREIBUS, G., SPOTTEL, B., LORENZ, V. & WANKE, H., 1979. The abundancwes of major, minor and trace elemnts in the earth's mantle as derived from primitive ultramafic nodules. Proc. Lunar and Planet Sci. Conf. No10, *Geochim Cosmochim Acta*, Supplement 11: 2031–2050.

JAMROZIK, L., 1981. Tectonic position of ultrabasic-basic massifs surrounding the Sowie Góry Mts. Block. In: Narębski, W., (Ed.) *Ophiolites and initialites of northern border of the Bohemian massif.* Guide-book of excursions. May–June 1981. Potsdam-Freiberg, 2: 86–95

JENSEN, L., S., 1976. A new cation plot for classifying subalkalic volcanic rocks. Ontario Division of Mines, Miscellaneous Papers, 66: 1–22.

MAJEROWICZ, A. & PIN, C., 1989. Recent progress in petrologic study of the Ślęża ophiolite Complex. In: Narębski, W., Majerowicz, A., *Lower and Upper Paleozoic metabasites and ophiolites of the Polish Sudetes.* Guide-book of excursions in Poland, May 1989, Wrocław, 34–72.

MAJEROWICZ, A. & PIN, CH., 1994. The main petrologic problems of the Ślęża ophiolite complex, Sudetes, Poland. *Zentralblatt für Geologie und Paleontologie Abhandlungen*, Teil 2, 9/10: 989–1018.

MAZUR, S., & PUZIEWICZ, J., 1995. Mylonity Strefy Niemczy. Ann. Soc. Geol. Pol., 64: 23–52.

NARĘBSKI, W., WAJSPRYCH, B. & BAKUN-CZUBAROW, N., 1982. On the nature, origin and geotectonic significance of ophiolites and related rock suites in the Polish part of the Sudetes. Ofioliti, 2/3: 407–28.

NARĘBSKI, W. & MAJEROWICZ, A., 1985. Ofiolity obramlienija głyby Sowich Gor i rannie palieozojskije incjality polskich Sudet. In: Dobriecow E. (Ed.). *Rifiejsko-niżniepalieozojskie ofiolity siewiernoj Eurazji.* Nauka. Nowosybirsk. pp. 86–105.

NATKANIEC-NOWAK, L. & PITERA, H., 1986. Badania mineralogiczno-petrograficzne serpentynitów z masywu Szklar k. Ząbkowic Śl. Dolny Śląsk. Zeszyty Naukowe Akademii Górniczo-Hutniczej w Krakowie. Geologia, 12: 116–56.

NIŚKIEWICZ, J., 1967. Budowa geologiczna masywu Szklar. *Rocznik Polskiego Towarzystwa Geologicznego*, 37: 387–414.

PATER,T., 1997. Charakterystyka mineralogiczno-petrograficzna kwaśnych skał żyłowych z wierceń w masywie serpentynitowym Szklar na Bloku Przedsudeckim. Praca magisterska.(niepubl.). Archiwum Zakładu Mineralogii i Petrologii Instytutu Nauk Geologicznych Uniwersytetu Wrocławskiego, pp. 81. {in Polish only}

PEARCE, J., A., 1983. Role of the sub-continental litosphere in magma genesis at active continental margins. In: Hawkesworth, C., L., Norry, M., J., (Eds.) *Continental basalts and mantle xenoliths*. Shiva. Nantwich: 230–249.

PEARCE, J., A., HARRIS, N., B., W. & TINDLE, A., G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of Petrology*, 25: 956–83.

SACK, R., O., 1982. Spinels as petrogenetic indicators: activity composition relations at low pressures. *Contributions to Mineralogy and Petrology*, 79: 169–186.

SAUNDERS, A., D. & TARNEY, J., 1984. Geochemical characteristics of basaltic volcanism within back-arc basin. In: Kokelaar B., P, & Howells, M.,F., (Eds.). *Geological Society of London. Special Publications*, 16: 59–76.

STEVENS, R., F., 1944. Composition of some chromites of the western hemisphere. *American Mineralogist*, 29: 1–48.

TEISSEYRE, H., SMULIKOWSKI, K. & OBERC, J., 1957. Regionalna geologia Polski. T.3. Sudety. Utwory przedtrzeciorzędowe. pp. 300. {in Polish only}

WHITTAKER, E., J., W. & ZUSSMANN, J., 1956. The characterization of serpentine minerals by x-ray diffraction. *Mineralogical Magazine*, 31: 233: 107–26.

WICKS, F., J. & WHITTAKER, E., J., W., 1977. Serpentine textures and serpentinisation. *Canadian Mineralogist*, 15: 459–488.

WICKS, F., J. & PLANT, A., G., 1979. Electron microprobe and x-ray microbeam studies of serpentine textures. *Ibidem*, 17: 785–830.