Plagiogranites from the Szklary serpentinite massif, a component of the Sudetic ophiolite

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Abstract: The Early Palaeozoic Szklary ophiolite fragment is situated in the southern edge of Niemcza dislocation zone (Foresudetic block, SW Poland), being a transition between Moldanubian unit (on west) and Moravian-Silesian unit (on east). Petrographic and geochemical investigations focusing on basic and VAG- related felsic, trondhjemitic rocks, demonstrate a geological evolution from the formation of oceanic crust, through island arc development, to post-obduction magmatism. The Szklary aplites are interpreted to be analogous to: 1) plagiogranites, probably formed by fractional crystallization of mid-ocean ridge-like basaltic magmas in a back-arc basin, 2) anorthosites, which may have formed by partial melting or fractional crystallization of mafic island arc tholeiitic magmas or 3) allochthonic dykes cutting the serpentinites have formed by partial melting of mafic rocks at the base of a thick pile of ocean floor- and island arc-derived rocks stacked onto the outermost part of a continental or microcontinental margin. The conclusions reached here thus support the idea, that the Caledonian ophiolite in Sudetes formed as part of extensive island arc/back-arc system.

Key words: geochemistry, petrography, aplite, VAG, plagiogranite, ophiolite, Foresudetic block, SW Poland

INTRODUCTION

In the meaning of classic ophiolite theory, leucocratic igneous rocks associated with mid -oceanic ridge plutonic complexes, known as “oceanic plagiogranites” are considered to be late products of the fractionation crystallization of MORB parental melts (Coleman 1977). Petrological data concerning the creation of oceanic lithosphere obtained from MAR and SWIR crest zones show, that three different types of acidic plutonic rocks are present at mid-oceanic ridges. They are: 1) a diorite-monzonite-granite suite derived from the most evolved and fractionated portion of the MORB parental melts in the fast spreading ridges, 2) plagiogranites, unrelated to gabbroic host and originated from other anomalous geochemically magmatic sources (hybrid or anatectic) typical of slow spreading cold litosphere, and 3) granitic rocks being relics of continental litosphere preserved in oceanic basins (allochthonous *after* Silantyev *et al*. 1998).

The geodynamic evolution of plagiogranites from normal MORB to more subduction influenced granitoids is consistent with evolution of mafic cumulate members of an ophiolite suite. Wang *et al*. (2002) suggested that basaltic magmas with arc affinities can form in back-arc basins as the basin propagates and widens, allowing fluids or melts from the nearby subduction zone to reach the source region. This magmatic evolution of the

Sudetic ophiolite appears to be compatible with formation and evolution of an oceanic back-arc basin (Narębski *et al.* 1982).

As it was shown in the case of petrogenetic evolution of Early Palaeozoic fragment of Bymarka ophiolite in Norway, the transition from MOR to BAB can be manifested by several stages of magmatic processes. They included: fractional crystallization of basaltic magmas with MORB compositions, partial melting of a mafic source with later trondhjemite intrusion, secondary intrusion of felsic magma after obduction causing partial melting at the base of a thick pile of mafic ocean floor- or island arc-related rocks, stacked onto a continental margin (Slagstad 2003).

An attempt to classify the plagiogranites from a small fragment of the ophiolitic suite is the aim of this study; the suite is situated at the eastern margin of Sowie Mts. gneissic block belonging to the NE margin of the Moldanubian unit. These felsic rocks (together with low-Ti amphibolites, pegmatites and kersantites) form thin isolated veins or tectonic fragments included in apo-harzburgitic serpentinites or their weathering products. This paper presents petrographic and geochemical data on plagiogranites from the Szklary ophiolite fragment, focusing on the felsic rocks, and discusses their pristine geotectonic setting. Evolution of the Szklary plagiogranites and their felsic equivalents fron the nearby Sudetic ophiolite is discussed in relation to the main processes forming primary melts.

GEOLOGICAL SETTING

The investigated area belongs to the southern part of the Niemcza dislocation zone (Foresudetic block) being the transition area between Moldanubian unit (on the west) and Moravian-Silesian unit (on the east). From the south the Niemcza zone is bordered by Sudetic marginal fault and on the north (near Łagiewniki) the Niemcza zone rocks dip beneath Quaternary deposits. The tectonic contacts of the Niemcza zone are marked on west by the Sowie Mts. gneisses, and on east by the Strzelin crystalline unit.

The main metamorphic rocks of the Niemcza zone are represented by cordierite or garnet -bearing blastomylonites and quartz-graphite schists with metarhyolitic and amphibolitic enclosures. The mylonitic protoliths are regarded to primary sedimentary slates (Dziedzicowa 1985) or mylonites originated at the expense of Sowie Mts. gneisses (Scheumann 1937). These mylonites could be formed at the left-handed, strike-slip shearing zone situated along the eastern margin of the Sowie Mts. gneissic block. The mylonitization phenomena took place in the post-orogenic regime in the shearing zone younger than the tectonic structures typical of early orogenic movements (Mazur, Puziewicz 1995). The Niemcza mylonites and metamorphic schists are transected by younger post-orogenic intrusion of granitoids, cropping out at Koźmin and Przedborowa (Lorenc, Kennan 2007).

The Szklary serpentinite massif is situated at the southern edge of the Niemcza dislocation zone (Foresudetic block) near the eastern margin of Sowie Mts. gneissic block (Fig. 1). This massif is situated about 7 km north of the town of Ząbkowice. Serpentinites occur as a small, N-S elongated and tectonically separated, ultrabasic body about 10 km long and 3 km wide. Szklary serpentinites form elongated range of hills longitudally oriented. From the north to the south there occur: Koźmickie Hill (307.2 m a.s.l.), Szklana Góra Hill (372,0 m a.s.l.), Tomickie Hill (345.0 m a.s.l.) and Siodłowe Hill (370,0 m a.s.l.). The Szklary massif is known as a famous site of green chalcedony (chrysoprase) veins within the weathering cover of serpentinites. Products of weathering of serpentinites were also used as poor Ni-Fe ore but its exploitation has been ceased in the 20th century.

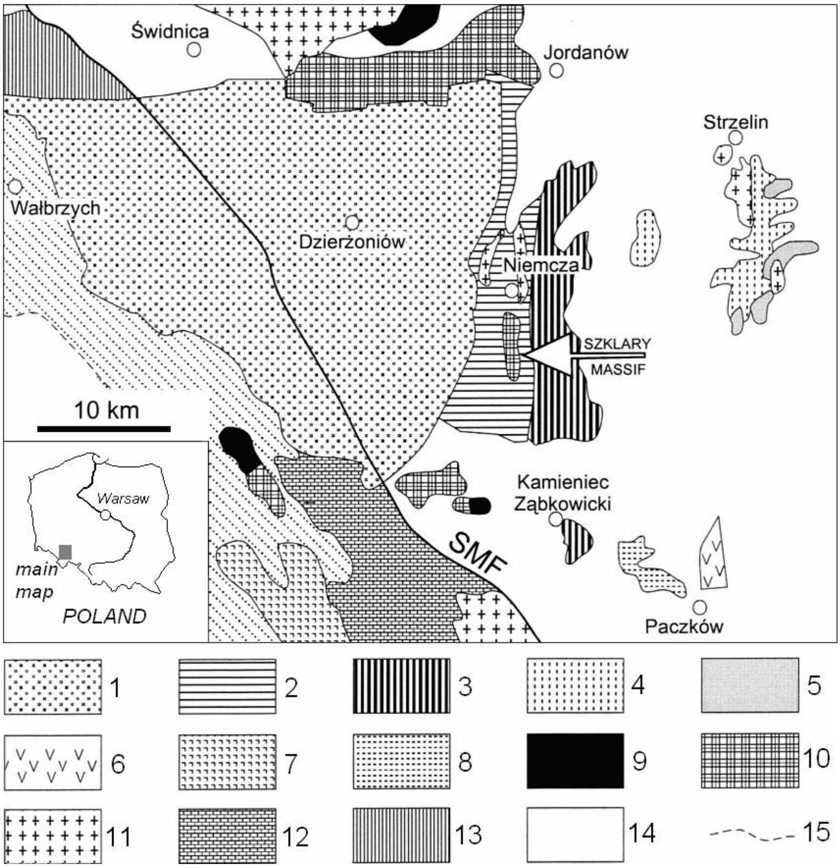


Fig. 1. Geological sketch map showing position of Szklary massif in the Foresudetic block; 1 – Moldanubian gneisses of Sowie Mts., 2 – metamorphic rocks of the Niemcza dislocation zone, 3 – micaceous schists of Niemcza-Kamieniec unit, 4 – Doboszowice gneisses, 5 – metamorphic cover of the Strzelin intrusion, 6 – Niedźwiedź metabasic massif, 7 – Kłodzko metamorphic unit, 8 – volcanic and sedimentary rocks of the Intrasudetic basin 9 – gabbros of the Sudetic ophiolite, 10 – serpentinites of the Sudetic ophiolite, 11 – granitoid intrusions, 12 – sedimentary rocks of Bardzkie Mts. structure, 13 – sedimentary rocks of Świebodzice depression, 14 – Quaternary cover, 15 – faults and dislocations, SMF – Sudetic marginal fault.

The results of the earlier petrographic studies indicate that among the less serpentinized ultrabasic rocks of Szklary massif, harzburgites, lherzolites and orthopyroxenites can be distinguished. All of them are composed of xenomorphic forsteritic olivine Fo_{88-91}, prismatic augitic diopside with well marked (100) cleveage planes and brownish prismatic enstatite-bronzite (En_{87-93}) locally containing clinopyroxene exsolution laths. The main accessory minerals are: chromian spinels occurring as single grains of ameboidal shape and microspherulitic magnetite. All the mentioned rocks are slightly serpentinized by systems of narrow veins composed of glassy-lustre lizardite transecting the rock background. In several samples the traces of structures caused by flowing in solid state were found. They are marked by occurrences of areas with polygonization of the olivine grains containing small brown spinel microspherules in triple junctions.

Another kind of ultrabasic rocks is represented by "sheared peridotites" with the cataclastic and mylonitic structures. They are composed of the mosaic of angular fragments of olivines and pyroxenes which are cut by secondary serpentine veinlets or talc-chlorite intergrowths. The primary (residual) Szklary harzburgites can be considered as the lowest fragment of the ophiolite suite. Position of orthopyroxenites and lherzolites is still unknown. Most probably they can be regarded as “magmatic pockets” in the lowest part of the oceanic crust, or alternatively, they can form early cumulates connected with deposition of cumulocrystals at the bottom of magma chamber during the later stage of Lower Palaeozoic evolution of oceanic crust (Gunia 2000).

Among the serpentinites of the Szklary massif the mesh structures occur most frequently. In one case, serpentinites show structure composed of randomly oriented veins surrounding angular olivine relics. Another types of serpentinite structure occurs, when serpentine veins form parallel oriented systems or form characteristic window-like structures, when two perpendicularly oriented systems of serpentine veins transected one another. These structures are composed mainly of lizardite and asbestiform chrysotile. Presence such serpentines can reflect low-temperature and infiltrational mechanism of serpentinisation of the primary ultrabasic rocks.

The Szklary ultrabasic rocks in part are covered by rusty brown weathering cover containing poor Ni-Fe ores. Some places in this cover are impregnated by veins containing colloidal silica mineralisation (chalcedony with chrysoprase variety, and opal) or thin magnesite veins (*cf. e.g.* Niśkiewicz 1967; Sachanbiński 1980).

According to the field and drilling core data within the Szklary serpentinites the vein-shaped tectonic enclaves of amphibolites, lamprophyres (spessartite and kersantite), pegmatites and aplites (plagiogranites) can be distinguished. The presence of the grossular-diopside-Mg-chlorite-(clintonite) rodingites also have been recently ascertained (Dubińska 1997).

The detailed petrologic study of the mentioned amphibolites indicates their cumulate provenience (Dziedzicowa 1979). On the basis of their petrographic features two main groups can be distinguished. One representing apo-gabbroic (apo-diabasic?) primary cumulates with similarity of their probably boninitic protoliths to basic rocks originated in back-arc or arc related geotectonic setting (Gunia 1995).

The presence of felsic rocks has been reported first from the north-eastern part of the Szklary massif, where the granitic rocks were found both in the field outcrops and in boreholes. In this region, leucocratic rocks form a relatively large vein up to 250 m in thickness, that generally strikes to N-S with N shortening, and on south they are bordered by steeply dipped fault. The medium-grained to fine-grained diorites, with non-oriented or oriented texture have been recognized there. From geologic point of view they were considered as a continuation of younger (Carboniferous) Koźmin granitodiorites well exposed near the Strachów village north of the Szklary massif (Niśkiewicz 1967).

Other occurrences of plagiogranites are known from the Szklary serpentinites. They occur within serpentinites which are sporadically transected by narrow veins of fine-grained acid rocks (aplites), pegmatites and sporadically lamprophyres (*e.g.* spessartite and kersantite). Thickness of these varies from 0,2 to 3 m and most of them are characterized by N-S, NW-SE or E-W striking with high angles of dipping (Niśkiewicz 1967). Some leucocratic veins are surrounded by characteristic reaction zones composed of sheared talc-anthophyllite, tremolite-chlorite or chlorite-bearing schists (Dubińska 1993). On the basis of the typomorphic assemblages of minerals occurring in the pegmatite veins from Szklana Góra, their allochthonic position from source localized in the Moldanubian Sowie Mts. gneisses is postulated (Pieczka 2000).

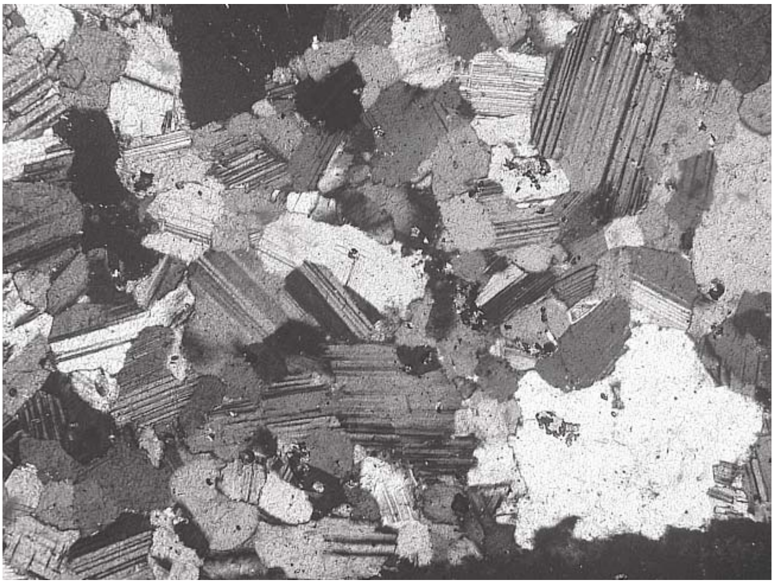


Fig. 2. Plagiogranite from the central part of the Szklary massif; nicols crossed, magn. 20×.

PETROGRAPHIC CHARACTERISTIC

Samples for petrologic studies of Szklary plagiogranites were taken from small surface outcrops (loose blocks zones on weathering cover of serpentinites) localized on southern slope of Tomickie Hill (central part of the massif). Other specimens have been collected by prof. J. Niśkiewicz from the boreholes bored in the years 1959-1964 years. Plagiogranite was found in the boreholes localized on N and NW slopes of Koźmickie Hill (10 specimens from three boreholes), S slopes of Tomickie Hill (3 specimens from one borehole), and N and S slopes of Siodłowe Hill (7 specimens from three boreholes).

As it was stated by Niśkiewicz (1967), on the basis of petrographic features two groups of fine-grained acidic rocks (aplites) can be distinguished. One, representing “white” variety (with gray veins and patches), containing mainly plagioclases and the second one described as “grey ”variety (with stripped appearance) with coexisting quartz, plagioclases and biotite.

The plagioclase-bearing aplites are fine-grained monomineral rocks composed of panxenomorphic laths or xenomorphic grains of plagioclases (An_{30-34}) as shown in Fig. 2. The size of the plagioclase grains commonly does not exceed 0.5 mm. Plagioclase often shows multiple albite and rarely – pericline twins. Most of them display cataclastic and recrystallization phenomena. Locally, the characteristic poikilitic (sieve-like) structures are widespread (Fig. 3).

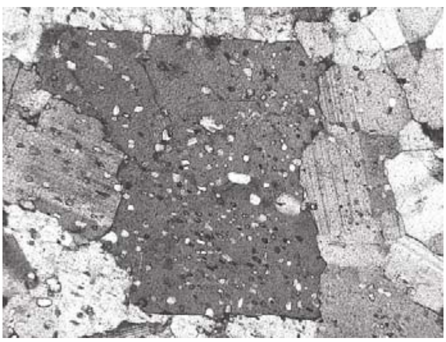


Fig. 3. Poikilitic intergrowths of plagiogranite from the central part of the Szklary massif; crossed nicols, magn. 30×.

Fig. 4. Fine-grained variety of the hornblende-bearing “grey” plagiogranite from northern part of the Szklary massif; crossed nicols, magn. 25×.

The quartz-bearing felsites consist of plagioclases with minor amounts of quartz, microcline, biotite, green common hornblende and accesoric sphene, garnet, and Fe-Ti oxides. The rock background is mainly composed of fine-grained xenomorphic individuals of plagioclases (An_{28-35}), which occupy near 70 vol. % of the rock. They surround single tables of potassium feldspars (up to 5 mm in size), small xenomorphic quartz grains or platelets of biotite which are bent and chloritized (Fig. 4). Often plagioclase assemblages form characteristic banded intergrowths with the bigger sets containing of parallel oriented green hornblende prisms (Fig. 5).

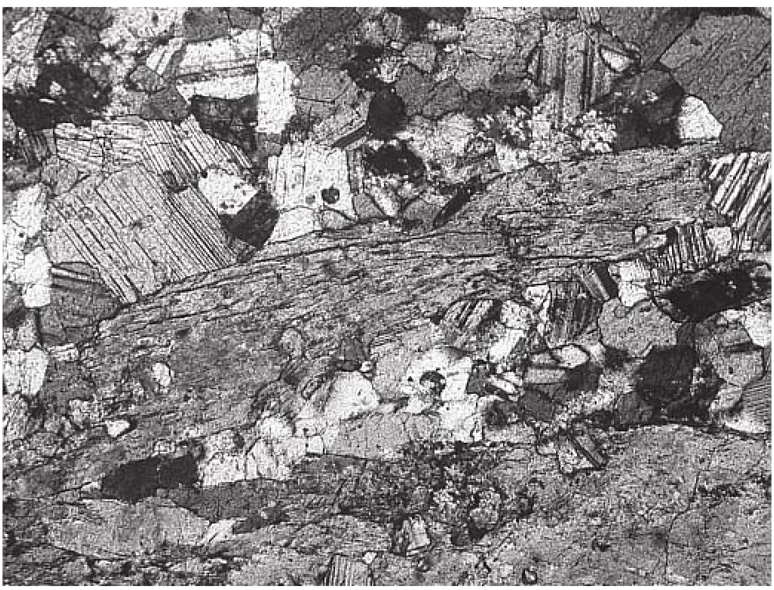


Fig. 5. Resorbed hornblende crystal in the “grey” plagiogranite, central part of the Szklary massif; crossed nicols, magn. 25×.

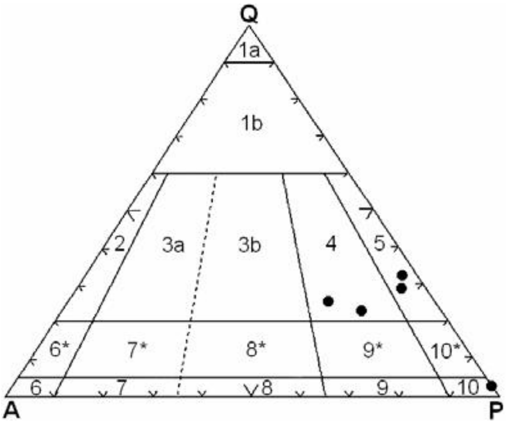


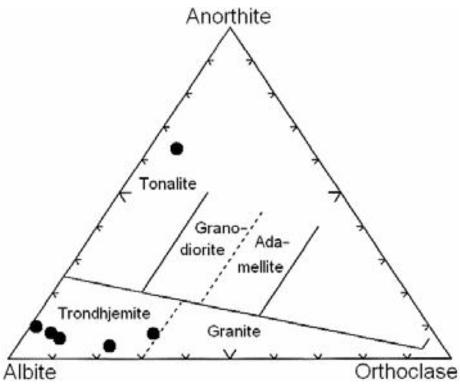
Fig. 6. Modal compositions of the Szklary plagio-granites.

WHOLE-ROCK GEOCHEMICAL FEATURES

The modal composition of the Szklary aplites plotted on the IUGS Q-A-P triangle shows that projection points occupy the granodiorite/tonalite and quartz diorite/quartz gabbro fields (Fig. 6). The investigated plagiogranites are peraluminous (A/CNK >1), enriched in CaO, poor in K_2O, with high Na_2O/K_2O ratio characteristic for the *I*-type granites.

Their normative mineral data plotted on the Al-An-Or diagram show that many projection points are distributed in the field of the trondhjemite composition and one point falls in the tonalite field (Fig. 7).

On the R1 *vs*. R2 plot proposed by Batchelor and Bowden (1985) the plagiogranites may be classified as the syn-collisional varieties or leucocratic rocks, except one sample situated in the field of the late-orogenic granitoids. In the majority, the studied granites also have alkali-lime values of the Peacock's index.



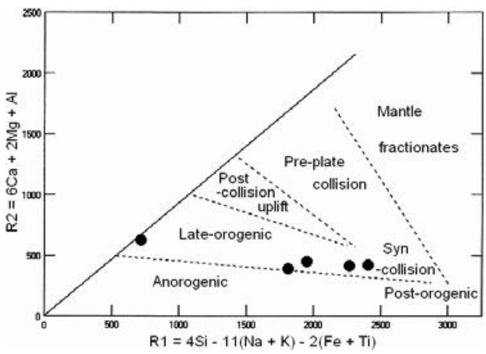
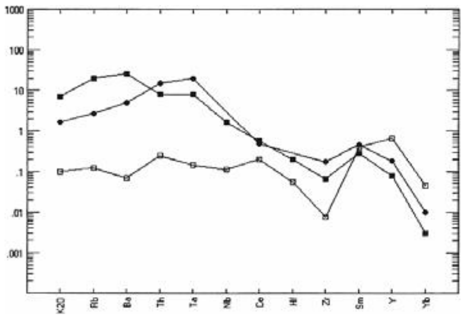


Fig. 7 (*left*). Normative composition of the Szklary plagiogranites.
Fig. 8 (*right*). The R1 *vs*. R2 plot of the Szklary plagiogranites.

The ocean-ridge-granite-normalized pattern demonstrate that the Szklary plagiogranites are characterized by three shapes of profiles. One is represented by flattened profile line along the ORG standard level, with small negative Zr and Sm positive anomalies. It probably reflects fractionation of MORB to an acid composition (Fig. 9). The second pattern is has typically slight enrichment of LILE with strong Zr depletion and Sm enrichment (Fig. 9) and it can be explained in term of derivation from mantle enriched in incompatible elements (Pearce *et al.* 1984). It should also be noted that the other Szklary plagiogranites plotted on the ORG normalized diagrams exhibit patterns with enrichment in Rb and Th as well as in Ce and Sm relative to the Nb and Ta contents (Fig. 7). Such selected enrichment can be attributed to a crustal involvement (Pearce *et al.* 1984), however in case of the ophiolitic plagiogranites can also be caused by variable mobilizations of the LIL elements under lower greenschist conditions (Floyd *et al.* 1998).

The ORG-normalized patterns of the plagiogranites are similar to those of the "supra -subduction zone" granites, and to the granites of the ensimatic island arcs.



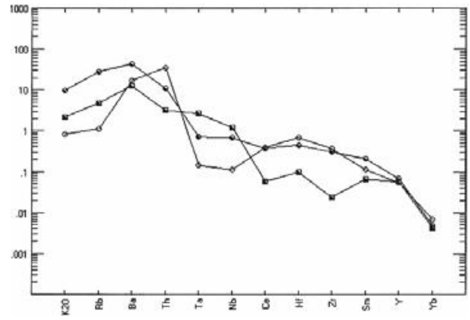
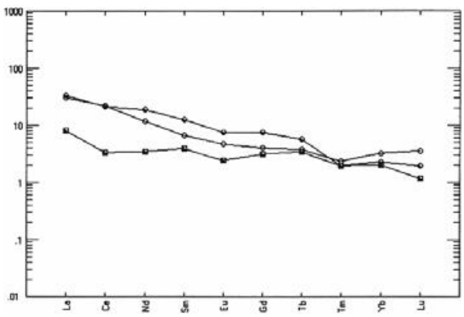


Fig. 9 (*left*). Multielement pattern of the Szklary plagiogranites (MORB-like fractionates); the values were normalized to the ORG composition after Pearce et al. (1984).
Fig. 10 (*right*). Multielement pattern of the Szklary plagiogranites (hybrid melting products); the values were normalized to the ORG composition after Pearce et al. (1984).

Chondrite-normalized REE patterns for three analyses show slightly sloped profile with absence of the negative Eu anomaly pointing out the cumulative plagioclase accumulation during slow fractional crystallization at the magma chamber (Fig. 11). As seen in Fig. 12, the other group of the Szklary plagiogranites on the REE pattern are characterized by the presence of varying negative Eu anomaly. It can be indicative of feldspar involvement during fractionation or melting (Floyd *et al*. 1998). It might indicate the dynamic evolution of magma chamber, when partial melting of hydrated gabbro and extreme fractionation of basic liquid produced the acidic melt.



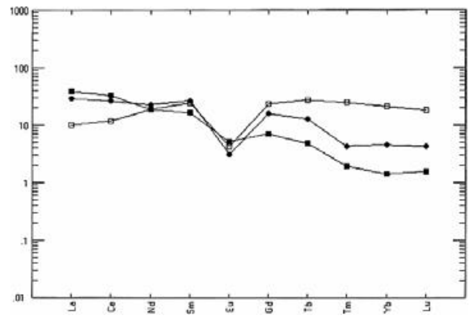


Fig. 11 (*left*). Multielement pattern of the Szklary plagiogranites (MORB-like fractionates); the values were normalized to the chondrite composition after Sun and Donough (1989).
Fig. 12 (*right*). Multielement pattern of the Szklary plagiogranites (hybrid melting products); the values were normalized to the chondrite composition after Sun and Donough (1989).

CONCLUDING REMARKS

On the basis of the geochemical features three groups of acidic rocks within the Szklary serpentinites can be distinguished. One group can be assumed as a product of slow fractional crystallization of hydrous gabbros in the mid-ocean ridge ennviroment. The second group, anorthosites, might have formed by partial melting or fractional crystallization of mafic island arc tholeiitic magmas influenced by crustal contamination. The third group representing probably allochthonic dykes cutting the serpentinites has formed by partial melting of mafic rocks at the base of a thick pile of ocean floor- and island arc-derived rocks stacked onto the outermost part of a continental margin.. The detailed recognition of role of the oceanic protholits of investigated plagiogranites in connection with development of rifting processes required further studies of acidic dykes occurring in the different parts of Sudetic ophiolite suite. Such studies are presently in progress.

REFERENCES

Coleman R. 1977. *Ophiolites – ancient oceanic lithosphere?* Springer Verlag., New York, 229 pp.

Dziedzicowa H. 1979. Zarys budowy geologicznej wschodniego obrzeżenia gnejsów sowiogórskich. In: *Wybrane zagadnienia stratygrafii, petrografii i tektoniki wschodniego obrzeżenia gnejsów sowiogórskich i metamorfiku kłodzkiego*, ed. T. Gunia,. Wyd. Uniw. Wrocł., Wrocław, 43-51.

Dziedzicowa H. 1985. Variscan rejuvenation of the Precambrian gneisses along the eastern margin of the Góry Sowie massif. *Krystalinikum*, 18, 7-27.

Dubińska E. 1993. Interstratified minerals with chlorite layers from Szklary near Ząbkowice Śl. *Arch. Mineral.*, 39, 5-23.

Dubińska E. 1997. Rodingites and amphibolites from the serpentinites surrounding of Sowie Góry block. Record of supra-subduction zone magmatism and serpentinisation. *N. Jb. Mineral. Abh.*, 171 (3), 239-279.

Floyd P. A., Yaliniz M. K., Goncuoglu M. C. 1998. Geochemistry and petrogenesis of intrusive and extrusive ophiolitic plagiogranites, Central Anatolian crystalline complex, Turkey. *Lithos*, 42, 225-241.

Gunia P. 1995. Petrology and geochemistry of the metabasic rocks from the Szklary massif (Fore-Sudetic block, SW Poland). Preliminary results. *Bull. Polish Acad. Sci.*, 43 (2), 123-134.

Gunia P. 2000. The petrology and geochemistry of mantle-derived basic and ultrabasic rocks from the Szklary massif in the Fore-Sudetic block (SW Poland). *Geologia Sudetica*, 33, 71-83.

Mazur S., Puziewicz J. 1995. Mylonity Strefy Niemczy. *Ann. Soc. Geol. Polon.*, 64, 23-52.

Narębski W., Wajsprych B., Bakun-Czubarow N. 1982. On the nature, origin and the significance of ophiolites and related rock suites in the Polish part of the Sudetes. *Ofioliti*, 2/3, 407-428.

Niśkiewicz J. 1967. Budowa geologiczna masywu Szklar (Dolny Śląsk). *Roczn. Pol. Tow.. Geol.*, 37 (2), 377-418.

Pearce J. A., Harris N. B. W., Tindle A. G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journ. Petrology*, 25, 201-206.

Pieczka A. 2000. A rare mineral-bearing pegmatite from the Szklary serpentinite massif, the Fore-Sudetic block, SW Poland. *Geologia Sudetica*, 33 (1), 23-31.

Scheumann H. 1937. Zur Frage nach dem Vorkommen von Kulm in der Niptscher Kristallizone. *Mineral. Petrograph. Mitt.*, 49, 216-240.

Sachanbiński M. 1980. Chrysoprase. *Mineral. Polon.*, 16, 3-12.

Silantyev S., Cherkashin D., Kostitsyn J., Dosso L., Karpenko S., Casey J. 2004.Granites in the oceanic lithosphere: their origin and geodynamic setting. *Res. Comm. Curr. Sci.*, 87 (7), 1005.

Slagstad T. 2003. Geochemistry of trondhjemites and mafic rocks in the Bymarka ophiolite fragment, Trondheim, Norway: petrogenesis and tectonic implications. *Norw. Journ. Geol.*, 83, 167-185.

Sun S., McDonough W. F. 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: *Magmatism in ocean basins*, ed. A. D. Saunders, M. J. Norry, *Geol. Soc. London Special Publications*, 42, 313–345.

Wang Z., Sun S., Li J., Hou Q. 2002. Petrogenesis of tholeiite associations in Kudi ophiolite (western Kunlun Mountains, northwestern China): implications for the evolution of back-arc basins. *Contrib. Mineral. Petrol.*, 143, 471-483.

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