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OF POLAND

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”30 YEARS OF PETROGRAPHY DIRECTION
IN TEACHING AT THE
UNIVERSITY OF WROCŁAW”

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CONTENTS

JUBILEE SESSION "30 YEARS OF PETROGRAPHY DIRECTION IN TEACHING AT THE UNIVERSITY OF WROCŁAW"

Xth MEETING OF THE PETROLOGY GROUP OF THE MINERALOGICAL SOCIETY OF POLAND – CONTRIBUTIONS

JUBILEE SESSION
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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
Zeszyt 23, 2003; Volume 23, 2003

Czesław AUGUST[1]

POST-MAGMATIC CLAY MINERALS AND ZEOLITES IN ALKALI BASALTS FROM LOWER SILESIA, SW POLAND

INTRODUCTION

Alkali basalts and related rocks in Lower Silesia (SW Poland) represent the eastern part of the Central European Cainozoic Volcanic Province. These rocks occur as lava flows, more rarely as veins and volcanic necks. Nephelinites, basanites, tephrites and olivine basalts are most widespread. Post-magmatic, hydrothermal clay, zeolite and carbonate mineralisation is common and not preferably related to any of these petrographic types. The hydrothermal mineral associations crystallised in miaroles and other irregular cavities. Though generally no regular pattern of spatial distribution of the mineralised zones is found, a higher concentration of miaroles near the top of brecciated lava flows is observed (August, Awdankiewicz 1993). Clay and zeolite mineralisation is rare in the necks where the miaroles are mainly filled with calcite, aragonite and dolomite.

METHODS

Samples were collected in almost all quarries (c. 35) of the Cainozoic volcanic rocks in Lower Silesia. Representative samples were studied using the optical microscope, scanning electron microscope (Tesla BS-300), X-ray diffraction (SIEMENS 5005), thermal analysis (Derivatograph 1500Q) and electron microprobe (Cambridge Microscan 9, WDS method).

CLAY MINERALS AND ZEOLITES

Clay minerals are represented only by smectites which occur in two generations in the miaroles: 1) trioctahedral saponite found on the surface of the miaroles and forming the base for zeolites, and 2) dioctahedral Mg,Fe-montmorillonite (Tab. 1) formed after the zeolites. The third smectite generation is a light beige to pink mineral, filling cavities and fissures in volcanic breccias. According to Japa et al. (1986), it is a poorly crystalline dioctahedral Fe-smectite. Kościówko et al. (1986) described only two (the first and the third) of these clay mineral generations.

Two zeolites, natrolite and phillipsite, are most common in the miaroles. They occur in parageneses with scolecite, thomsonite, chabasite, offretite, and anal-

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cime; the number of mineral species inside one miarole is limited to 2-3 (August, Przylibski 1994). Analcime is also found in basalts and breccias as a rock-forming mineral (August, Kierakowicz 1995).

Tab.1. Chemical composition of hydrothermal smectites in basaltoids from Lower Silesia.

Component	Trioctahedral smectite				Dioctahedral smectite			
SiO_2	44,41	56,89	50,34	47,62	51,34	50,97	47,84	45,39
Al_2O_3	19,41	18,02	8,53	6,43	28,84	19,40	24,76	23,50
Fe tot.	2,17	3,42	5,58	6,34	2,18	5,84	9,53	10,35
MgO	21,43	10,90	22,10	21,78	3,78	5,78	6,27	5,23
CaO	1,48	1,76	1,84	1,99	1,69	2,55	2,22	2,34
K_2O	0,07	0,66	0,15	0,23	0.43	0,65	0,69	0,48
Na_2O	0,03	0,01	0,12	0,12	0,49	0,59	0,93	0,99
TiO_2	-	-	0,09	0,02	0.02	0,02	0,13	0,20
MnO	0,22	0,02	0,06	0,02	0,02	0,05	0,17	0,14
Total (without H_2O & OH)	89,22	91,68	89,61	84,55	88,79	85,85	92,54	88,62

Tab.2. Chemical composition of zeolites in alkali basalts from Lower Silesia.

Zeolite	Chemical formula	Localities
natrolite	$Na_{15.7}\ K_{0.01}(Al_{15.9}\ Si_{24.03}O_{80})\ nH_2O$ (sample from Gracze)	Ligota Tuł., Gracze, Kowalskie,Targowica, Wilcza G., Żółkiewka, Jałowiec, Księginki, Rębiszów
phillipsite	$K_{1.9}Ca_{2.4}(Al_{3.93}Si_{10.3}O_{32})$ nH_2O (from Księginki quarry)	Gracze, Targowica, Kowalskie, Wilcza Góra, Lubień, Łysanka, Winna G., Bukowa G., Zaręba, Sulików, Jałowiec, Rębiszów
chabasite	$Ca_{1.46}\ Na_{0.08}K_{0.5}(Al_{3.8}Si_{8.2}O_{24})\ nH_2O$ (from Żółkiewka quarry)	Kowalskie, Targowica, Żółkiewka, Wilcza Góra, Księginki, Zaręba, Sulików, Leśna, Uniegoszcz
offretite	$K_{0.8}Ca_{1.0}\ Mg_{1.0}\ (Al_{5.1}Si_{12.9}O_{36})\ nH_2O$	Sulików
thomsonite	$Na_{10.8}\ Ca_{3.42}\ (Al_{17.2}Si_{22.2}\ O_{80})\ nH_2O$	Gracze
analcime	$Na_{15.9}\ (Al_{15.9}Si_{32}O_{96})\ nH_2O$	Sulików
scolecite	no chemical data	Rębiszów

Parageneses dominated by natrolite occur mainly in nephelinites whereas those with phillipsite are characteristic of basanites and basalts. The zeolites mentioned represent various structural groups, but their chemical varieties are limited to Ca-K-Na and, occasionally, Mg-Ca-K members of the zeolite group (Tab. 2).

CONCLUSIONS

The distribution and structures of the post-magmatic mineral associations in the miaroles indicate that these minerals formed due to various hydrothermal processes. Saponite, Mg,Fe-montmorillonite and zeolites crystallised from aqueous solutions enriched in Mg, Fe, Ca, Na, and K originated from magma degassing during the final stage of lava cooling. The smectite found in volcanic breccias formed in a different process, probably linked with the decomposition of sideromelane by low-temperature hydrothermal solutions rich in Si, Fe and Al, with minor Ca and K, partly of meteoric origin, penetrating the breccias.

The identified zeolites represent various structural types which indicate various thermal conditions of crystallisation. However, they display rather uniform chemical compositions – most of them belong to the Ca-K-Na, low-silica varieties, with rare Mg-members of the zeolite group.

The observed crystallization sequence of the smectites and various zeolite species reflects changing temperature and composition of hydrothermal fluids in the miaroles. The smectites and zeolites stability diagrams (e.g. Kawano, Tomita 1997) show that Mg,Ca members of the mineral association crystallise at relatively high pH, high Si/Al and Na/K ratios, and high temperatures whereas at lower values of these parameters (but still relatively high Na/K ratio), crystallisation of thomsonite and natrolite is stimulated in hydrothermal solutions.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Marek AWDANKIEWICZ[1]

PETROGENESIS OF THE PERMIAN INTERMEDIATE VOLCANIC SUITE OF THE NORTH-SUDETIC BASIN, SW POLAND: FRACTIONATION, REPLENISHMENT AND ASSIMILATION IN CRUSTAL MAGMA CHAMBERS

The Permian intermediate-composition volcanic rocks of the North-Sudetic Basin represent a high-K calc-alkaline suite that erupted in an extensional, intracontinental, post-collisional setting in the eastern part of the Variscan belt of Europe (Fig. 1). The volcanic rocks were emplaced as lava flows (and minor subvolcanic intrusions) from, probably, fissure vents or small shield-type volcanoes. Several eruptive episodes separated by repose and sedimentation periods are marked by lava flow successions interbedded by clastic rocks.

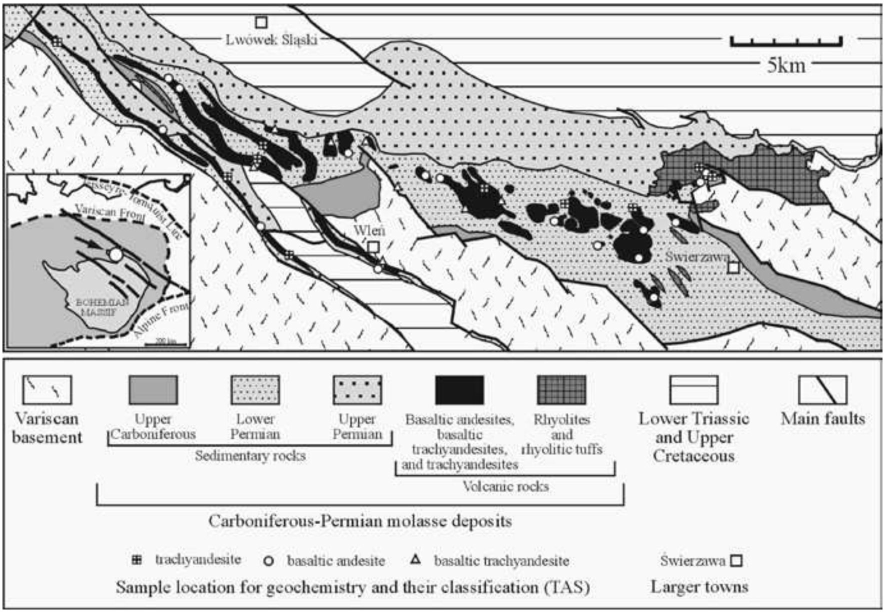

Fig. 1. Distribution of the Permian volcanic rocks in the North-Sudetic Basin (based on Milewicz, 1965 and Kozłowski, Parachoniak, 1967). Inset shows location of the area in the eastern part of the Variscan Belt of Europe.

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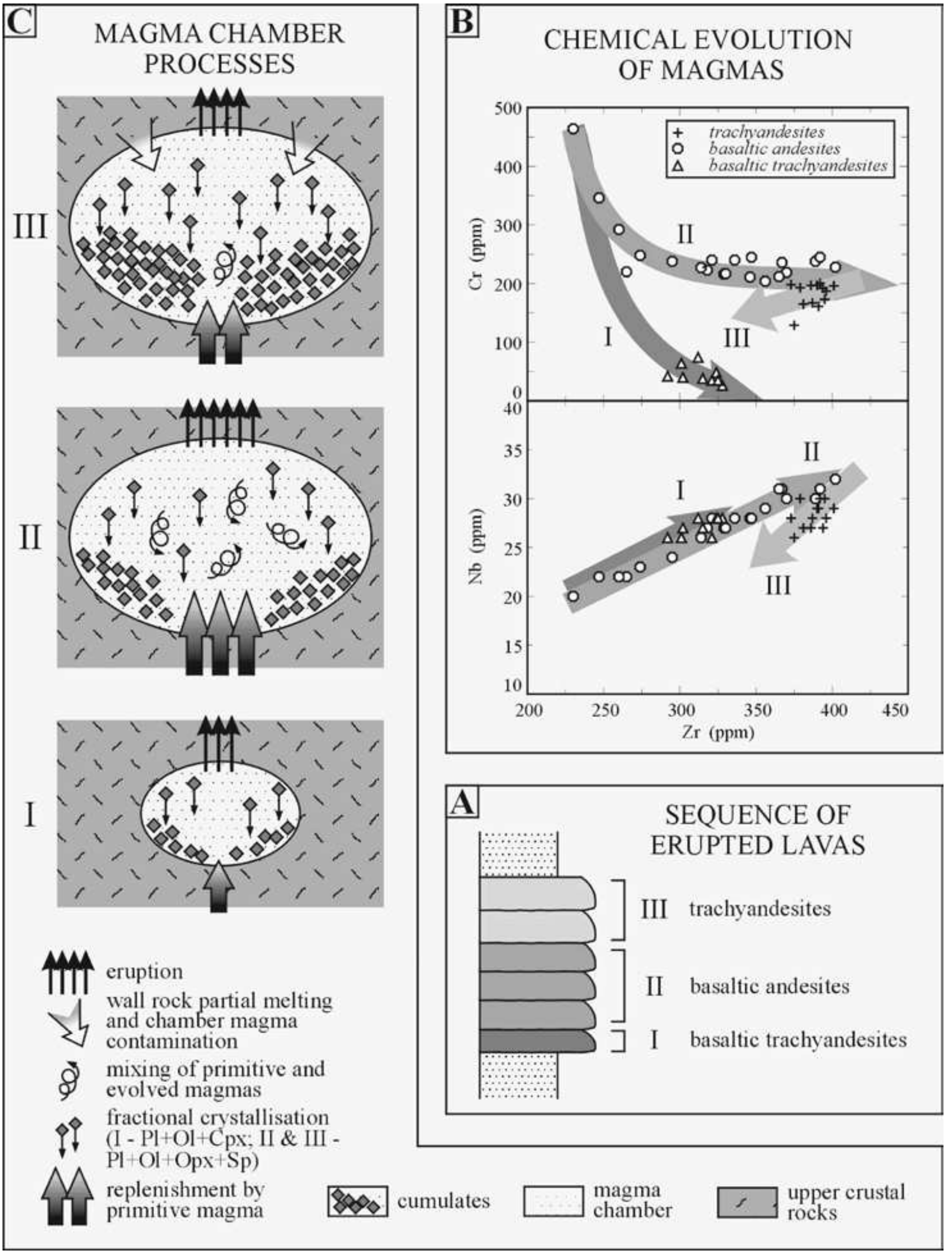

Fig. 2. Cartoon showing the general sequence of erupted lavas (A) and their geochemical variation together with inferred differentiation paths and magma chamber processes (B and C; I – fractional crystallisation, II – fractional crystallisation and mafic replenishment, III – crustal assimilation and fractional crystallisation).

A complete, single eruptive episode comprised initial emplacement of basaltic trachyandesite lavas, basaltic andesites at the main stage of activity, and trachyandesites at the end of the eruptive period (Fig. 2 A). Such successions of lava flows, sometimes incomplete, were erupted several times, and the total volume of the lavas is possibly close to a hundred cubic km, with the basaltic andesites predominant.

The geochemical variation within the suite is characterised by well-defined trends for several trace elements (Fig. 2 B). The basaltic andesites show a systematic increase of incompatible trace element contents at constant ratios of these elements (e.g. Zr and Nb), and more complex, curved and segmented trends for such elements as Cr or Ti. Incompatible trace element ratios are slightly different in the other rock types compared to the basaltic andesites. In particular, the trachyandesites, the most evolved members of the suite, show a distinctive Nb depletion and LILE enrichment. Relatively high Cr and Ni contents are observed even in silica-rich rocks (up to 200 ppm Cr at 60-63% SiO_2). The geochemical data and modelling, as well as petrographic and mineralogical data, reflect a very similar parental magma for all members of the suite, but various differentiation processes involved in their petrogenesis (Fig. 2 B): (I) fractional crystallisation (plagioclase, olivine and clinopyroxene) for the basaltic trachyandesites, (II) fractional crystallisation (plagioclase, olivine and orthopyroxene) coupled with mafic replenishment and mixing of evolved and primitive melts for the basaltic andesites, and (III) assimilation of upper crustal rocks for the trachyandesites. Variation in the minor components of the fractionating assemblages (Cr-spinel, Fe-Ti oxides, apatite and other minerals) also influenced the trace element patterns of the volcanic rocks. Considering the emplacement sequence of the lavas and the petrogenetic processes involved it is suggested that the suite originated in magma chambers, in which the differentiation processes evolved with time (Fig. 2 C) from (I), through (II) to (III). In this context the general trace element characteristics of the volcanic rocks (enrichment in LILE, LREE and the more incompatible HFSE, relative depletion in Nb and Ta) seem to be unrelated to shallow level differentiation processes at crustal levels. It is more likely that the parental magmas of the suite originated from enriched lithospheric mantle sources carrying an upper crustal signature related to subduction processes during the earlier stages of the Variscan orogeny.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Ryszard KRYZA[1]

MONAZITE AS A GEOCHRONOMETER: USEFUL, INEXPENSIVE – BUT NOT SIMPLE

INTRODUCTION

During the last two decades, a rapid development of micro-sample geochronology ("microgeochronology") has taken place, enabling the dating of single mineral grains and their micro-domains. Recently, among a range of instrumental techniques (SIMS, SHRIMP, LA-ICPMS, TIMS, Micro-PIXE, EMMA etc.), Electron Microprobe (EMP) dating, in particular, is becoming popular. As a chemical dating method, it does not require analysis of isotopes, only of the bulk contents of "parent" and "daughter" elements. The concept is not new but the method has been undergoing a renaissance since the 1990's, when EMP began to be routinely applied for precise analysis of Th, U and Pb in monazite (Mnz) (e.g. Suzuki and Adachi 1994, Montel et al. 1996). In Poland, monazite has been chemically dated by M.Michalik, M.Kusiak and M.Paszkowski (Cracow: refs. in Lekki et al. 2003) and by J.Janeczek and colleagues (Sosnowiec). This paper outlines the technique in the context of ongoing KBN-supported studies in Karelia, Ukraine and SW Poland.

CHEMICAL DATING OF MONAZITE: THEORETICAL BACKGROUND

Monazite is a LREE phosphate, rich in Th (often 3 to 25 wt. %) and U (c. 100 ppm to 5 wt. %). Virually, all Pb in Mnz is, normally, radiogenic in origin. It quickly attains levels high enough for precise measuring by EMP.

The obtained age is geologically meaningful provided that (a) the amount of non-radiogenic lead in the mineral is negligible, and (b) the U, Th and Pb concentrations are governed by radioactive decay and not by, say, elemental diffusion or hydrothermal alteration. The first condition is normally fulfilled, and the second is possible to assess by careful analysis (Montel et al. 1996).

PRACTICAL ASPECTS

Monazite is a common accessory mineral in many granitoids and high-grade metapelites. Small grains (5-20 μm) are fairly common in mafic rocks, and authigenic Mnz nodules are also found in sedimentary rocks (Evans and Zalasiewicz 1996). The mineral can be found in conventional polished thin sections, although optical identification is difficult. The simplest way to identify it and to characterize its textural

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position and internal structure (e.g. zonation) is to use BSE imaging (Fig. 1) and EDS spectra. Potential Pb-contaminants must be avoided during sample preparation.

The quality of EMP dating strongly depends on analytical procedures. The instrument requires careful standardization against optimal standards. Scherrer et al. (2000) suggest using synthesized REE-phosphates, and prefer, for Th-U-Pb dating, ThP_2O_7, a synthesized Th phosphate, over ThO_2 (which is often spongy), and UO_2 over elemental U; for Pb, crocoite or synthesized glass is best.

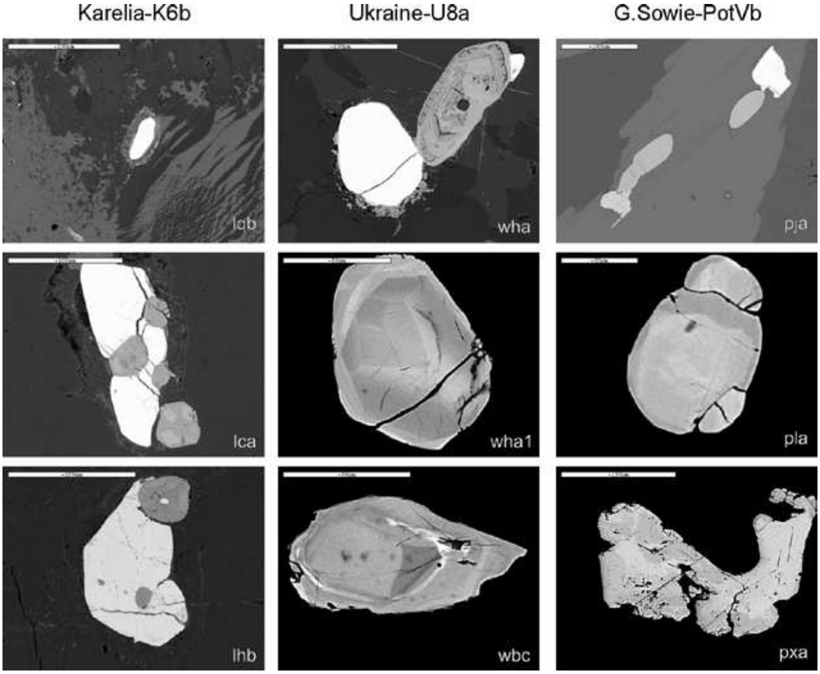

Fig. 1. BSE images of monazites in Precambrian granites from Karelia and Ukraine, and in Palaeozoic (Ordovician-Devonian?) anatexites from the Góry Sowie, Sudetes (SW Poland).

Though rarely published, background positions are crucial; optimally, they should be defined on each spectrometer using adequate standards. Peak overlaps, e.g. between U_{Mb} and Th_{Mg}, and between Pb_{Mb} and U_{Mz}, present serious problems. The measured U and, afterwards, the measured Pb, must be corrected using correction coefficients carefully determined for individual instrument and spectrometer settings. Finally, the quality of the results and analytical precision depend on the microprobe settings and counting statistics. The accelerating voltage commonly used is 15 or 20 kV, with a beam current between 20 and 250 nA. The counting times should be long enough to ensure good statistics: e.g. minimum 300 s for Pb, 150 s for U, and 100 s for Th (Scherrer et al. 2000).

Various strategies are possible to collect and treat data for monazite dating. The high spatial resolution of EMP enables separate analysis of grains of different textural relations, and of different domains of zoned crystals. Data interpretation should account for sources of uncertainty to explain age distributions within individual rock samples: (a) the presence of different age populations, (b) analysis of overlapping age domains, (c) Pb disturbances due to diffusion and/or dissolution/accumulation processes, (d) analytical uncertainties. Dating samples by other means can help to constrain the influence of these factors.

DRAWBACKS AND ADVANTAGES OF EMP DATING

Drawbacks:

(1) Mnz is relatively limited in occurrence, and the Mnz-forming reactions are poorly understood.

(2) The need for careful instrument standardization; peak interference; relatively poor detection limits and low precision (optimum results range within +/- 5 to +/- 15 Ma for ages ranging from 300 Ma to 3000 Ma). Dating rocks in rocks younger than c. 100 Ma is difficult.

Advantages:

(1) Good spatial resolution enabling analysis of small grains (c. 5 μm in size) and zoned crystals, and so recognition of different age domains. Efficient assessment of element diffusion/disturbance processes.

(2) "In situ" non-destructive analysis in conventional thin sections enables relation of ages to mineral parageneses and structural histories (P-T-t-d paths).

(3) The method is easily accessible, cheap and fast.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Alfred MAJEROWICZ[1], *Ryszard KRYZA*[1]

30 YEARS OF THE SPECIALIZATION “MINERALOGY AND PETROLOGY” AND OUTLINE OF PETROLOGICAL STUDIES AT WROCŁAW UNIVERSITY AFTER 1945

The academic year of 2002/2003 was the 300th anniversary of Wrocław University. In this long history, the geological sciences, including mineralogy and petrology, have played a notable part. Among the scientists connected with Wrocław University, were renowned geologists and mineralogists, starting with Karl von Raumer, the founder of the first “Mineralogical Cabinet” (1811). His successors included E.F.Glocker (who discovered 9 new minerals), M.L.Frankenheim (who introduced space frameworks in crystallography), F.Roemer (a famous geologist and academic lecturer), M.Websky (an outstanding mineralogist), and A.V.Lassaulx (inventor of the “Lassaulx lens” in the polarizing microscope; Sachanbiński & Wierzbicki 1997).

After 1945, this academic tradition was continued and Wrocław University was a notable center for mineralogy, petrology and several other disciplines of the geological sciences. The Sudetes and neighbouring Fore-Sudetic Block, with their variety of intriguing rock complexes, has long been an excellent natural laboratory for geological studies. The starting point for more recent studies were the outline publications of M.Książkiewicz, and detailed review papers by H.Teisseyre and K.Smulikowski. These authors delineated the major lines of geological and petrographic studies for the newly-organized Institute at Wrocław University. The geological studies in the Institute were coordinated by H.Teisseyre, J.Zwierzycki and J.Oberc, whereas the Department of Mineralogy and Petrography and associated courses were organized by K.Maślankiewicz and his first assistant: M.Witkiewiczowa (Floryan 1970). New systematic geological research, following H.Teisseyre’s lead, was undertaken in the metamorphic complexes of Lower Silesia, while K.Smulikowski initiated detailed petrographic studies of large granitoid bodies. These studies required basic laboratory equipment: facilities for sample preparation, a thin section workshop and polarizing microscopes. In those difficult post-war times, the extraordinary organizing abilities of K.Maślankiewicz proved crucial. He gathered together a group of young assistants, including B.Bereś, K.Dziedzic, H.Dziedzic, E.Głowacki, Z.Śliwa and the first co-author of this text (A.M.); later, the team was joined by C.Juroszek. A.Grodzicki, J.Niśkiewicz, M.Sachanbiński and S.Lorenc. These first assistants had to teach, also to prepare teaching materials for crys-

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tallography, mineralogy and petrology. One difficult task was to transfer a large collection of minerals and rocks to a new location, and to arrange a new display. In 1955, the collection was considerably enlarged by a several hundred new specimens obtained by A.Majerowicz while attending a Soviet-led course on radioactive minerals in Kowary. The mineralogical display was then organized by M.Sachanbiński and his colleagues. By the 1970's, the Department of Mineralogy and Petrography possessed basic analytical facilities and could perform conventional mineralogical and petrographic studies (Jahn et al. 1988).

Given the political control of those times, only limited contacts with universities in other countries were possible; nevertheless, these gave the chance to keep up with new research trends and to undertake some scientific co-operation. For example, A.Majerowicz made a four month visit to Stockholm, followed by exchange two-week long geological excursions organized in 1968. These excursions, with 15 participating scientists and students on both sides, covered the most interesting geological sites in Poland and Sweden.

At that time, the University co-operated intensively with the Polish Geological Institute, in particular with regard to geological mapping projects, and with industrial companies where the university scientists applied their expertise to searching for mineral resources. Both the academic and applied research activities were frequently cited (e.g. A.Bolewski, K.Smulikowski, A.Gaweł, W.Żabiński).

In 1972, after K.Maślankiewicz's retirement, A.Majerowicz became the head of the Department of Mineralogy and Petrography. In the 1970's, the staff was enlarged by the following postgraduates: R.Kryza, A.Muszyński, C.August, J.Janeczek and, somewhat later by: J.Puziewicz, S.Koszela, P.Gunia, M.Jędrysek, A.Jasiński (the latter graduated from chemistry at Wrocław Technical University), K.Turniak, M.Awdankiewicz, and still more recently – D.Józefiak and W.Bartz. This enlarged team considerably extended the scope of research activities, arranged new laboratories and developed wide co-operation with other universities in Poland and abroad.

In the academic year 1973/74, a new programme for "Geology" was prepared, with three specializations: "Exploration Geology" (subsequently "Stratigraphy and Exploration Geology"), "Hydrogeology" and "Petrography" (subsequently "Mineralogy and Petrology"). The new programme was assessed and accepted by the Ministry of High Education and Techniques. The mineralogy and petrography programme was ratified without difficulty: by that time the Department was among the leading academic institutions of its type in Poland, with a long tradition, broad research activities and many international contacts. The coordinators of the new specializations were appointed: "Exploration Geology" – J.Kłapciński (later succeeded by M.Mierzejewski), "Hydrogeology" – M.Różycki (followed by J.Kryza and T.Bocheńska), and "Petrography" – A.Majerowicz (since 1995, R.Kryza). The new courses of started in the academic year 1974/1975, and the first "specialized" students graduated in 1978/79 (Gorczyca-Skała 1995).

The new specialized programme significantly influenced the development of mineralogical and petrological sciences in the Institute. The students were offered, apart from a solid background in geology, specialized knowledge covering various branches of mineralogy and petrology, including modern analytical techniques and practical aspects of applied mineralogy. The level of teaching increased, together with progress in research and links with leading academic centres abroad were strengthened. Apart from personal contacts with many foreign scientists and individual fellowships, there was important long-term bi-lateral co-operation with Universite B.Pascal (Clermont-Ferrand, France), Brno University (Czech Republic), British Geological Survey, Leicester University and Keele University (U.K.), Ruhr University in Bochum and the University of Hannover (Germany). All these activities resulted in a range of significant scientific achievements and many publications.

In 1994, "Geology" programme at the University was modified and a two-stage curriculum was introduced: stage I – three-year undergraduate studies (licence), and stage II – two-year MSc studies. The second stage remained subdivided into three specializations as before.

Petrology, combined with other branches of mineralogical and geological sciences (e.g. with structural and regional geology) is a distinctive feature of studies in "Geology" at Wrocław University. Apart from basic courses in mineralogy and petrology, the curriculum offers specialized lectures such as: "Physical chemistry of rock-forming processes", "Genesis and evolution of magma", "Volcanology", as well as interdisciplinary courses: "Petroarcheology", "Technical petrography: stone in architecture", "Gemology" and "Natural disasters". The students learn not only theory but also develop practical skills useful to applied studies, e.g. instrumental phase and chemical analysis of natural and man-made materials, and modern computer methods. The basic courses for the specialization are provided by the Department of Mineralogy and Petrology, and Mineralogical Museum and Department of Gemology; these two are supported by colleagues from other laboratories: the Department of Applied Geology (Laboratory of Isotope Geology), Department of Geology and Documentation of Mineral Deposits, and Department of Physical Geology.

In 1994, a new system of PhD studies was introduced in the Institute in: (a) hydrogeology and environmental studies, (b) mineralogy, petrology and geochemistry, and (c) hydrogeology and environmental issues. The studies were directed by J.Niśkiewicz, and since 1998 – by J.Puziewicz. Within this system, 6 PhD theses have been defended and four others are in progress in the Department.

The Department of Mineralogy and Petrology comprises several laboratories. The first of these, the Laboratory of Mineral Separation, was established in 1994 (head: A.Grodzicki) and, afterwards, the Laboratory of Isotope Geology was created in 1994 (since 1998 included in the Department of Applied Geology, head: M.Jędrysek). The new labs extended the spectrum of research activities of the Department of Mineralogy and Petrography.

In 1995 the position of the head of the Department was taken by R.Kryza and in 1996 its name became the Department of Mineralogy and Petrology.

Petroarcheology has long been important in the scientific activities of the Department. Lively co-operation between the Department and archeological institutions at Polish universities and the Polish Academy of Science, and with universities abroad, dates back to the early 1950's. Under A.Majerowicz's supervision, many scientific reports and expert opinions were prepared, and these often resulted in publications (see Majerowicz 2003). In 2003, a Laboratory of Petroarcheology and Technical Petrography was formally established in the Department, following its long traditions in petroarcheological and petroarchitectonic research activities (A.Majerowicz and A.Grodzicki). The new laboratory is coordinated by P.Gunia and its activities cover, beside conventional petroarcheology, problems of the deterioration and conservation of building stones.

The Departmental laboratories are well-equipped in modern analytical facilities for sample preparation and mineral separation (e.g. rock crushers, various types of separators, polishing equipment), as well as in analytical instruments: a Siemens 5005D X-ray diffractometer, a Q-1500D Derivatograph, a Philips PW1400 X-ray fluorescence spectrometer, a Pye-Unicam SP-9-900 atomic absorption spectrometer, a Cambridge Microscan M9 electron microprobe (EDS & WDS). These facilities enable the teaching and practices of modern analytical research.

The specialization Mineralogy and Petrology, since its inception in 1973/1974, has graduated more than 200 students. Many of these chose a scientific career at Polish universities and at the Polish Academy of Science, some obtained PhD and habilitation degrees, and several others succeeded in obtaining PhD and other fellowships in well-known universities abroad (e.g. in USA, Switzerland, U.K., Germany). Many graduates found jobs in geological and environmental institutions and companies. The broad-ranging, rigorous theoretical and practical education they received at the University facilitated obtaining of work in the difficult recent employment market.

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Xth MEETING
OF THE PETROLOGY GROUP
OF THE
MINERALOGICAL SOCIETY
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CONTRIBUTIONS

POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Paweł ALEKSANDROWSKI[1]

IS THE NOTION OF CALEDONIAN OROGENY APPROPRIATE TO BE APPLIED IN THE SUDETES?

THE LONG-LASTING CONTROVERSY

Controversies and radical changes of opinions concerning the role of Caledonian versus Variscan (Hercynian) orogeny have repeatedly occurred for many decades among the geologists studying the Sudetes and their surroundings. Since the end of the 19th century a major role in shaping the structure of the Sudetic Palaeozoic complexes was ascribed to Carboniferous diastrophism called Variscan or Hercynian (e.g. E. Suess 1888, F.E. Suess 1926, Kossmat 1927). During the 1920's a hypothesis assuming a significant influence of the pre-Late Devonian, Caledonian orogeny with only little Variscan reworking was put forward by Bederke (1924), whose ideas soon attracted many adherents in the 1940's 50's and 60's. Subsequently, due to new research findings, this hypothesis became gradually rejected in the 1970's and 1980's with an emerging consensus that the tectonic fabric of the Sudetes had been produced mainly by Late Devonian and Carboniferous Variscan tectonothermal activity, locally involving and affecting Neoproterozoic to Early Palaeozoic elements. However, Ordovician to Late Devonian/Early Carboniferous successions, showing uninterrupted basinal sedimentation were still reported to be juxtaposed with metamorphic complexes overlain unconformably by non-metamorphosed Upper Devonian strata. These relationships supported the idea of some Caledonian influence in the Sudetes (e.g. Don 1984).

NEW CALEDONIAN MODEL

Rather unexpectedly, Oliver et al. (1993) and Johnston et al. (1994) on the basis of newly acquired data, including new U-Pb age determinations, re-interpreted the Palaeozoic geology of the Sudetes and of SW Poland in favour of a dominant Caledonian deformation, re-defining the Sudetes as the "Metamorphic Polish Caledonides and, in practice, excluding this area from the central European Variscan belt. Similar opinions, assuming Caledonian accretion, followed by Variscan reworking were soon expressed by some other workers.

In the 'new Caledonian model' of Oliver et al. (1993) and Johnston et al. (1994) the main evidence in support of a Caledonian orogeny in the Sudetes are: (1) a regional pre-Upper Devonian unconformity, (2) Ordovician magmatism interpreted

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to indicate subduction and collision, (3) structural data from “key localities”, and (4) new, Early Palaeozoic radiometric ages. Oliver, Johnston et al. maintain that faunal and palaeomagnetic data indicated that the Tornquist sea, the SE branch of the Early Palaeozoic Iapetus ocean, which once separated Baltica from Gondwana, narrowed to less than 1000 km in width during the Late Ordovician and subsequently closed, producing a tectonic suture in the Sudetes, along which geologically contrasting Early Palaeozoic terranes had accreted into a Caledonian collage covering the area of SW Poland and northern Czechia. These terranes are believed to include Ordovician and Silurian batholith fragments, whereas the suture zone is interpreted to occur mainly along the Intra-Sudetic fault, being the continental-scale sinistral shear zone, periodically active from Middle Ordovician to Triassic times.

This interpretation became a matter of controversy (e.g. Żelaźniewicz, Franke 1994; Aleksandrowski 1994). In a comprehensive paper by Aleksandrowski et al. (2000) critical assessment has been given of evidence produced by supporters of the influence of the Caledonian orogeny in the Sudetes. It has been shown that the regional pre-Late Devonian unconformity does not exist in most Sudetic structural units, except in the Central Sudetes, where it is the result of Eo-Variscan, convergence of Armorican and Avalonian crustal fragments, but not of Caledonian continental collision (see also Aleksandrowski, Mazur 2002). The intense manifestations of Late Cambrian/Early Ordovician magmatism, resulted rather from the continental rifting leading to subsequent ocean opening (Furnes et al. 1994). The ca 500 Ma U-Pb ages abundant in the Sudetic crystalline complexes are protolith, intrusion ages and do not correspond to a Caledonian deformation The other arguments of Oliver and Johnston et al. were also critically discussed and dismissed as pieces of evidence in support of a supposed Ordovician to Early Devonian orogeny in the Sudetes. However, even if a record of a collision-related deformation and magmatism/metamorphism of early to mid-Palaeozoic age were found in the Sudetes, it could not have been considered as evidence for the Caledonian orogeny.

WHAT IS CALEDONIAN AND WHAT IS VARISCAN?

The most important reason for the so often encountered confusion and controversy regarding the tectonic interpretation of the Sudetes seems to stem from the current dichotomy in usage of the terms ‘Caledonian’ and ‘Variscan’, based on misunderstanding the implications the plate tectonics brought to geology. A dual perspective on orogeny continues to influence present-day geological thinking - an inheritance of the old controversies between catastrophists and uniformitarianists and, later, fixists or oscillationists and mobilists (see comprehensive discussion in Sengör 1990). The ideas of Kober (1921) and Stille (1924), assuming strict episodicity of world-wide contemporaneous orogenic phases and cycles, though incompatible with plate tectonic principles, can still be recognized in, for example, the tendency to refer to ‘Caledonian deformation’ in a temporal sense, instead of speaking about ‘Early Palaeozoic deformation’, irrespective of whether the deformed area lies in northern or central Europe, or, for example, in central Asia. Similarly, the ‘Variscan’ is often understood as Late Devonian through Carboniferous to Early Permian tectonic activity. However, it has long been known that orogenic “paroxysms are neither synchronous nor world-wide”, and also that, in a given province, “orogeny frequently lasts continuously through a number of epochs or periods” (Krejci-Graf 1950). The plate tectonic theory explained this as reflecting commonly long-lasting processes of subduction-related convergence of crustal blocks and to irregular shapes of their convergent margins, which collided at different times in different places. Therefore, in our opinion, accepting the plate tectonic paradigm should logically result in giving up such ‘chronostratigraphic’ usage of the term ‘Caledonian’, to denote every Early Palaeozoic tectonic activity irrespective of its (palaeo)geographical location. Thus, using the plate tectonic understanding of orogeny as representing the entirety of convergent margin processes (Sengör 1990), a useful criterion to distinguish between the Caledonian and Variscan (Hercynian) orogenic belts seems to be the provenance of given areas with respect to the oceanic basins whose closure produced these belts and to the adjoining continental margins. According to recent plate tectonic reconstructions, the Caledonian orogenic belt is that developed due to Early Palaeozoic to Early Devonian closure of the Iapetus and Tornquist Oceans between Baltica, Laurentia and Avalonia. The Variscan belt, on the other hand, originated from closure of the Rheic Ocean between Avalonia and Armorica, mostly accomplished by Mid-Devonian times and followed by Late Devonian - Early Carboniferous collision of the Avalonian/Armorican assemblage with Africa, resulting from consumption of the inferred Massif Central - Moldanubian Ocean. This scenario provides us with criteria more appropriate in a plate tectonic framework to distinguish between the Caledonian and Variscan orogenic belts than those relying solely on the timing of tectonothermal events. Consequently, the ‘Caledonian’ and ‘Variscan’ orogenies should preferably be understood as diastrophic, magmatic and metamorphic processes leading to the formation of the Caledonian and Variscan orogenic belts, respectively (Aleksandrowski et al. 2000). Identical views have recently been expressed by McKerrow et al. (2000), who stress the necessity of defining orogenies and orogens in spatial and not temporal terms, in a context of particular closing oceanic basins and their margins. They also suggest re-defining the notion of the Caledonian orogeny so as it could not be applied to e.g. areas within the Variscan belt, such as the Sudetes.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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MINERAL, WHOLE-ROCK CHEMISTRY AND Sr-Nd ISOTOPE STUDY OF KARKONOSZE-KOWARY GNEISSES (WEST SUDETES)

INTRODUCTION

Rocks of granite composition occurring in the southern part of East Karkonosze and eastern part of South Karkonosze are diversified structurally from coarse-grained granites, augen-gneisses to medium and fine-layered gneisses. Their intrusion age has been determined by Oliver et al. (1993) and Kröner et al. (2001), using single zircon U/Pb method, as 503 to 481 Ma. Analogous granites and gneisses occur in the Izera complex, north of the late Variscan Karkonosze Granite intrusion. The preliminary Rb-Sr study of the Karkonosze-Kowary Gneisses was reported in Bachliński and Smulikowski (2002). The present report is its continuation. The samples from the Czech territory were collected by the courtesy of Dr František Patočka from the Geological Institute of the Academy of Sciences of the Czech Republic and Dr Jan Vanek from Krkonoše National Park.

MINERAL CHEMISTRY

The electron micro-probe study revealed that *plagioclase,* with two exceptions only is represented by albite most often almost An-free. K-feldspar in most of the rocks shows better or worse developed cross-hatched twinning typical of *microcline.* Its Ab and An contents are very low. High proportion of the pure albite perthitic intergrowths indicates a high degree of secondary albitization rather than exsolution. *White mica* (muscovite), which almost always is more abundant than biotite, shows the Si/Al^{IV} ratios from 3.01 to 7.09 (6.007 – 7.011 Si p.f.u.) corresponding to *phengite. Biotite* has Mg/(Mg+Fe+Mn) ratios from 0.12 to 0.44. The TiO_2 content of the prevailing dark brown variety is about 2% and is distinctly higher than in the green variety (about 0.3%). *Titanite* of granites and gneisses is unusually rich in Al_2O_3. Often titanite forms thin rims around *ilmenite* grains. *Garnet* has been observed in quite many samples as usually scarce, small and relict grains. It contains almost equal but varying proportions of *almandine* and *grossular* with higher grossular content in the centres of the grains. *Spessartine* content is lower and rather stable but pyrope is very low. Other accessory minerals are represented by common *apatite, zircon, allanite, monazite, rutile* and one analysed grain of *xenotime.* Dark brown biotite present in granites and coarse grained augen gneisses is consi-

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dered as magmatic mineral. It is often replaced by chlorite. Similarly garnet (Grs ≅Alm>Sps>>Prp) of relict character may represent late magmatic stage. It is also replaced by chlorite ± light mica. Plagioclase represented by albite only, even in the rocks of higher CaO content, and epidote/clinozoisite inclusions in albite, indicate that conditions corresponded to epidote-amphibolite or greenschist facies. This is confirmed by the metabasic rocks associated with Karkonosze-Kowary gneisses. The widespread presence of phengite indicates a relatively high pressure of metamorphism. It appears that protolite granites were transformed into gneisses predominantly under the conditions of higher pressure part of the greenschist facies.

WHOLE-ROCK CHEMISTRY

Primitive mantle normalised trace element patterns (spider graphs) show no distinct differences between the rocks. The general shapes of the lines are the same, differing only in absolute values. However, in the LREE part of the graph all the samples have the same course, but in HREE part small differences may be observed. A strong Eu negative anomaly, most probably related to the low content of CaO, is conspicuous in all analysed samples.

On the major element discrimination diagram R1-R2 by Batchelor et al. (1985) all samples from the study area are located within syncollision granites. Also the detailed discrimination by Maniar and Piccoli (1989) shows that the Karkonosze-Kowary gneisses are characterised as CCG (continental collision granitoids). The trace element diagrams constructed after Pearce et al. (1984) may indicate that geochemical characteristics of the protolite is close to syncollision granites. Kachlik and Patočka (1999) however relate the Karkonosze-Izera gneisses to an extensional continental rift environment while Kröner et al. (2001) attributed them to a volcanic arc environment.

Sr AND Nd ISOTOPE STUDY

18 whole rock samples for Rb-Sr and 11 whole rock samples for Sm-Nd analyses were prepared by a standard chemical procedure for isotopes (Bachliński, Smulikowski, 2002). Newly constructed Rb-Sr isochron based on 16 samples of the Karkonosze-Kowary gneisses and granites (without samples 513a and 565 which show distinctly different isotopic ratios) yields 447 ± 21 Ma and the initial ratio 0.7056 ± 0.0087 (Fig. 1a). It appears that this age of Rb-Sr homogenization may corresponded rather to regional metamorphism (Maluski, Patočka, 1997) then the time of intrusion. The isochron based on 4 points of the Kowary granites only gave 472.7 ± 8 Ma and the initial ratio 0.7074 ± 0.0028 (op. cit). Sm-Nd isochron based on 11 samples was not possible to appoint, because all $^{143}Nd/^{144}Nd$ isotopic ratios were similar. The examination of diagram ε(Sr) vs ε(Nd) (Fig. 1b) (DePaolo, 1981) shows that points representing the Kowary granites are located along the mixing line between the mantle and the upper crust (paleozoic) including, however, more

mantle material. Points of other samples, representing gneisses (rocks deformed during metamorphism) are located outside the mixing line.

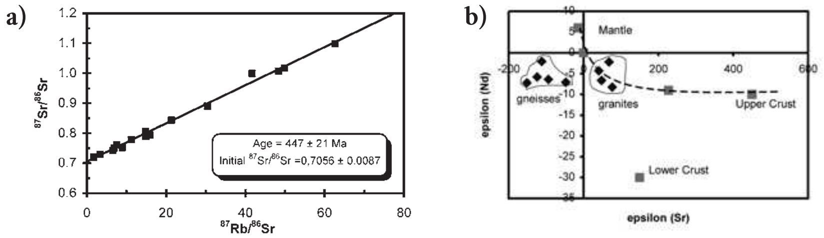

Fig. 1. a - Rb-Sr isochron for Karkonosze-Kowary gneisses and granites; b - diagram ε(Sr) vs ε(Nd) with mixing line between the mantle and upper crust (after DePaolo, 1981)

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Nonna BAKUN-CZUBAROW[1], *Anna BIAŁOWOLSKA*[2]

GABBROIC ENCLAVES FROM BASALTOIDS OF THE LUBAŃ AND ZŁOTORYJA REGIONS, LOWER SILESIA

Basaltoids of the Lubań and Złotoryja regions belong to the Tertiary Central European Volcanic Province characterized by considerable deficiency of silica in relation to alkalis as well as by high degree of depletion of basaltoid volcanics (Blusztajn, Hart 1989). In the discussed regions, the volcanic activity occurred, most likely, in the Early Miocene (Birkenmajer *et al.* 2002). Apart from the upper mantle peridotite enclaves and pyroxenite cumulates, there have been found in the basaltoids rare gabbroic enclaves, being usually smaller than peridotitic ones (Białowolska 1993).

In the present study the gabbroic enclaves from nephelinites in the vicinity of Jałowiec and of the Księginki quarry in the Lubań region as well as from basanites of the Trupień and Łysanka hills in the Złotoryja region were investigated. The size of gabbroic enclaves varies from relatively small, e.g. ball-shaped enclave T51 has only 5 cm in diameter and spindle-shaped T14 one is 17 cm long, to the unusually large,

Table 1. Representative microprobe analyses of olivine and spinel from gabbroic enclaves from basaltoids of the Lubań and Złotoryja regions.

	Księginki quarry		Trupień hill						
	enclave		enclaves						basalt
	K		T 14			T 51			T
	ol	sp	ol	ol agg.	sp	ol	ol agg.	sp	ol
	1	2	3	4	5	6	7	8	9
SiO_2	36.05	0.27	37.51	37.38	0.14	35.88	38.43	0.24	39.37
TiO_2	0.00	21.67	0.00	0.05	16.76	0.00	0.05	20.56	0.08
Al_2O_3		3.15			1.86			2.45	
Cr_2O_3		0.20			2.78			0.38	
Fe_2O_3		22.41			32.52			26.74	
FeO	34.92	49.02	25.78	26.64	41.94	30.79	25.86	43.94	21.29
MnO	0.68	0.49	0.75	0.82	0.64	0.69	0.66	0.57	0.23
NiO	0.12	0.00	0.21	0.00	0.13	0.00	0.18	0.30	0.29
MgO	28.38	1.39	34.38	33.80	2.76	31.81	34.71	3.55	38.73
CaO	0.33	0.02	0.39	0.37	0.08	0.36	0.32	0.28	0.31
Total	100.48	98.62	99.48	99.06	99.61	99.53	100.20	99.01	100.30
Fo	58.7		70.1	68.7		64.3	68.4		76.2
Ulv		60.5			46.4			56.5	

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loaf-shaped enclave K (28x19 cm big and up to 16 cm high). The studied enclaves are built up mainly of olivine gabbro, being composed of labradorite plagioclase, diopside, orthopyroxene (ferrohypersthene), Fe-rich olivine (hyalosiderite and chrysolite), titanomagnetite, interstitial glass and rare biotite surrounding titanomagnetite grains. The gabbroic rocks have mainly cumulus-like texture, excluding enclave K, that has subophitic one. The representative microprobe analyses from selected gabbroic enclaves are given in Tables 1 and 2.

Table 2. Representative microprobe analyses of pyroxenes and feldspars from gabbroic enclaves from basaltoids of the Lubań and Złotoryja regions.

	Księginki quarry		Trupień hill							
	enclave		enclaves							basalt
	K		T 14			T 51				T
	cpx	fld	cpx	fld-c	fld-r	opx	cpx	fld-c	fld-r	cpx
	1	2	3	4	5	6	7	8	9	10
SiO_2	50.42	53.13	50.86	54.68	65.05	52.55	51.75	56.31	65.26	43.70
TiO_2	1.56	0.04	1.65	0.00	0.22	0.18	0.54	0.01	0.48	4.70
Al_2O_3	2.21	28.60	2.23	27.61	19.94	1.75	3.06	27.18	19.77	9.39
Cr_2O_3	0.00		0.05			0.02	0.06			0.00
FeO	9.65	0.30	8.38	0.21	0.22	24.96	10.25	0.15	0.41	7.68
MnO	0.30		0.26			0.68	0.26			0.16
MgO	14.02	0.00	13.28	0.00	0.00	18.88	11.91	0.00	0.00	11.43
CaO	22.05	13.06	21.67	11.57	2.23	0.49	21.94	10.61	1.90	22.60
Na_2O	0.36	4.06	0.63	4.77	7.55	0.52	0.68	5.24	7.04	0.49
K_2O	0.03	0.36	0.07	0.36	3.73	0.06	0.00	0.40	4.08	0.00
Total	100.60	99.55	99.08	99.20	98.94	100.09	100.45	99.90	98.94	100.15
Wo	45.8		46.4			1.1	47.2			51.7
En	40.5		39.6			56.8	35.6			36.3
Fs	13.7		14.0			42.1	17.2			12.0
An		62.6		56.1	11.0			51.6	9.8	
Ab		35.3		41.8	67.2			46.1	65.3	
Or		2.1		2.1	21.8			2.3	24.9	

From among the studied enclaves, only the biggest enclave K from the Księginki nephelinite is conspiceous by its Fe-richest olivines, Ca-richest plagioclases and by slight alteration of minerals. Equilibration conditions of the cumulate type gabbroic enclaves from the Złotoryja region basanites have been tentatively estimated by means of conventional mineral geothermobarometers (including pyroxene thermo-meter of Wells, 1977) for 1100 °C under the pressure of about 10 kbars. The minerals within the enclaves underwent high-temperature metasomatic alterations caused by both fluid and magmatic agents of varying composition. On one hand, during these alterations Ca-richer clinopyroxene grains suffered stronger corrosion than the Ca-poorer ones. On the other hand, orthopyroxenes underwent wet, incongruent melting accompanied by crystallization of olivine aggregates and formation of anorthoclase rims around plagioclase crystals.

The gabbroic enclaves are distinctly diversified as far as contents and fractionation patterns of REE in relation to host basaltoids are concerned. On one hand, nephelinites of the Księginki quarry (in the Lubań area) are the richest in REE from among

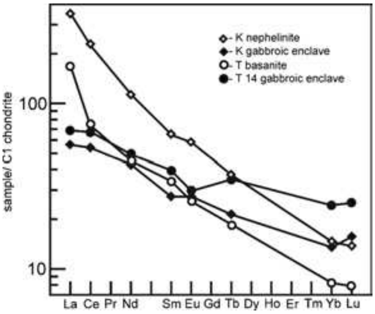

Fig. 1. REE patterns for selected gabbroic enclaves and host basaltoids

the basaltoids studied. They display extreme enrichment in LREE (Fig. 1), ranging from La = 350*(chondritic abundance) to Sm = 65*(chondritic abundance), and the highest fractionation of the whole REE group ($La_N/Lu_N = 25$). They also show higher degree of fractionation of LREE ($La_N/Sm_N = 5.4$) than of HREE ($Tb_N/Lu_N=2.6$). The gabbroic enclave from Księginki is much poorer in REE that are fractionated in a smaller degree ($La_N/Lu_N = 3.5$) than the host nephelinite. The enclave has distinctly fractio-nated LREE ($La_N/Sm_N = 2.1$), while the fractionation of HREE is much weaker ($Tb_N/Lu_N = 1.3$). On the other hand, the gabbroic enclave from the Trupień hill (in the Złotoryja region) is richer in majority of REE as compared to the host basanite, which shows markedly higher deg-ree of fractionation ($La_N/Lu_N = 21$) than the enclave ($La_N/Lu_N = 2.8$), where both LREE and HREE are only slightly fractionated ($La_N/Sm_N =1.7$ and $Tb_N/Lu_N = 1.4$).

On the basis of texture, the degree of alteration, mineral chemistry and REE geochemistry, the hypothesis can be put forward that the majority of the studied gabbroic enclaves found in basaltoids (from Trupień and Łysanka hills as well as from Jałowiec) are cognate and reflect the magma crystallization prior to eruption. The only exception is the big gabbroic enclave from the Księginki nephelinite which may represent a hypabyssal country rock or a fragment of doleritic dike.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Nonna BAKUN-CZUBAROW[1], *Anna BIAŁOWOLSKA*[2]

ENCLAVES OF BLACK CLINOPYROXENITE IN THE KSIĘGINKI NEPHELINITE NEAR LUBAŃ (LOWER SILESIA)

The Księginki nephelinite forms one of the biggest basaltoid bodies within the Lower Silesian part of the Tertiary Central European Volcanic Province. The nephelinite contains abundant enclaves of mantle peridotites (Białowolska 1980; Kozłowska-Koch 1981) as well as rare clinopyroxenite enclaves and clinopyroxene megacrysts. Among peridotitic enclaves harzburgites and lherzolites are common, while wehrlites and dunites can be rarely met. Black clinopyroxenite enclaves are also scarce. They are built up of black isometric clinopyroxene grains, often riddled with tiny glassy inclusions and rimmed with glass (Fig. 1). Moreover, they usually contain subordinate olivine (up to 5 vol. %) and accessory spinels.

In the present study, the two black clinopyroxenite enclaves from the Księginki nephelinite have been investigated in details: the smaller, ball-shaped enclave, 2cm in diameter, and the bigger, oval-shaped one, having 7 x 9 cm in section parallel to elongation. Representative microprobe analyses of minerals of both the enclaves studied, together with clinopyroxene mega- and phenocrysts are given in Table 1.

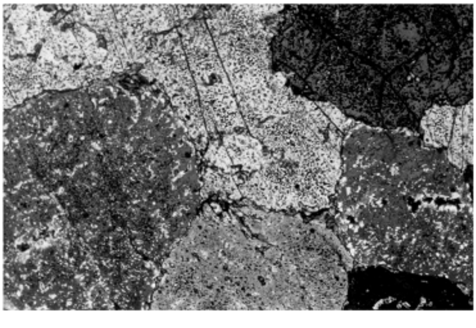

Fig. 1. Fine perforated clinopyroxenes in the black enclave from the Księginki nephelinite; picture length = 2.8 mm.

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Table 1. Representative microprobe analyses of minerals of clinopyroxenite enclaves from the Księginki nephelinites.

	smaller enclave				bigger enclave				mega-cryst	pheno-cryst
	cpx-c perfor.	cpx-r clear	ol	sp	cpx-c	cpx-r	ol	sp	cpx	cpx
	1	2	3	4	5	6	7	8	9	10
SiO_2	47.12	42.99	39.10	0.18	47.82	47.70	38.21	0.00	48.85	46.45
TiO_2	2.24	4.73	0.11	0.71	1.59	2.29	0.21	0.78	1.13	2.76
Al_2O_3	6.40	9.67	0.10	59.77	8.56	7.68	0.00	56.22	8.01	6.16
Cr_2O_3	0.31	0.00	0.20	3.13	0.18	0.04	0.07	1.65	0.55	0.11
Fe_2O_3				3.31				8.87		
FeO	5.27	7.48	17.84	15.54	6.59	5.89	19.98	15.28	5.52	6.66
MnO	0.03	0.10	0.44	0.55	0.19	0.17	0.41	0.06	0.86	0.11
NiO	0.00	0.00	0.60	0.05	0.11	0.00	0.29	0.28	0.00	0.00
MgO	12.97	10.26	40.19	17.19	12.71	12.72	39.40	16.93	13.45	11.75
CaO	24.01	24.29	0.49	0.00	20.88	23.49	0.53	0.00	20.52	23.92
Na_2O	0.58	0.34			0.94	0.48			0.76	0.40
K_2O	0.08	0.00			0.00	0.00			0.09	0.07
Total	99.01	99.86	99.07	100.43	99.46	100.46	99.10	100.07	99.74	98.39
Wo	53.1	55.7			48.0	51.7			47.1	53.2
En	39.9	32.8			40.5	39.0			43.0	36.4
Fs	7.0	11.5			11.5	9.3			9.9	10.4
Fo			79.7				77.5			
Ulv				1.4				1.6		
Cr #				3.4				2.0		

The black clinopyroxene of the studied enclaves is subsilicic diopside relatively rich in Al and Ti. It often displays rimward increase in Ca and Ti accompanied by decrease in either iron or magnesium. In the studied enclaves, perforated, full of glassy inclusions clinopyroxene grains predominate over the clear, homogeneous ones, that form sporadically rims around the fine perforated cores of grains. As to mineral chemistry, the perforated clinopyroxenes are richer in Si, Mg, Cr as well as poorer in Al and Fe than the clear ones. The perforated clinopyroxenes show closer chemical affinity to clinopyroxene megacrysts, while the clear ones resemble the phenocrysts found in the host nephelinite. The discussed clinopyroxenes from enclaves differ also from the HP augite megacrysts from basanites of the Lądek Zdrój area (Bakun-Czubarow, Białowolska 2001) in lower contents of SiO_2 and MgO as well as in distinctly higher content of CaO. Subordinate olivines of the clinopyroxenite enclaves are chrysolites ($Fo_{\leq 80}$). Accessory greenish-black spinel from the enclaves is chromium- and titanium-poor pleonaste. Similar to the above described mineral assemblages, but different from those of the upper mantle peridotites, have been found in Quaternary alkali-olivine basalts of Minusa and Transbaikalian regions, Siberia (Kutolin, Frolova 1970).

As far as REE distribution patterns are concerned the bigger black clinopyro-xenite enclave and clinopyroxene megacrysts from Księginki differ considerably from the host nephelinite in both REE contents and the shape of pattern (Fig. 2).

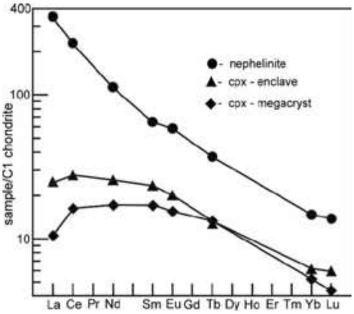

Fig.2. REE patterns for the bigger clinopyroxenite enclave, clinopyroxene megacryst and the host Księginki nephelinite

On one hand, the nephe-linite is the material richest in all the REE and displays the highest degree of fractionation of the whole REE group (La_N/Lu_N = 25). On the other hand, the clinopyroxene megacryst dis-plays the lowest abun-dances of REE, distinct convex in the LREE part of distribution pattern (La_N/Sm = 0.65) and considerable fractiona-tion of HREE (Tb_N/Lu_N= 3.0). The clinopyroxenite shows the REE pattern (La_N/Lu_N = 4.2) similar to that for clinopyroxene megacrysts (La_N/Lu_N = 2.6), but it is slightly richer in REE and displays a less pronounced LREE convex pattern (La_N/Sm_N = 1.04) as well as lower fractionation of HREE (Tb_N/Lu_N = 2.2) than the megacryst.

On the basis of mineral chemistry, textures, the affinity to the HP clinopyroxene megacrysts and the preliminary estimates of the olivine-clinopyroxene equilibra-tion pressures, the hypothesis can be put forward that the black clinopyroxenite enclaves are cognate cumulates which originated within the Cr-poor and Ti-rich basaltic magma, at the depths of lower lithosphere similar to those characteristic of the crystallization of the HP megacrysts. During the uprise of the host, continuously changing basaltic magma, at a halting stage, primary black clinopyroxenes became unstable and were perforated by fluid-rich melts, then, in some places, rimmed with SiO_2 -poorer clear clinopyroxene.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Andrzej BARCZUK[1]

GEOLOGICAL AND PETROLOGICAL INVESTIGATIONS OF KIMBERLITES IN KANSAS, U.S.A. – PRELIMINARY RESULTS

INTRODUCTION

The geological and geophysical investigations of the rock complexes which occur within the Midcontinent Rift System, performed for many years by the United States Geological Survey, led to elucidation of many tectonic, stratigraphic, petrological and ore deposit problems of this huge structure of the length exceeding 1000 km, extending from the Lake Superior to the south-west and reaching the states of Iowa and Kansas. Almost whole rift system is filled up by clastic and volcanoclastic rocks (Barczuk 1992). Moreover, a minor component of the rift consists of lamproites (Cullers et al. 1996) and related rocks, e.g. kimberlites.

The discovery of the more than ten kimberlite pipes in the north-eastern part of the State of Kansas, the Riley and Marshall Counties, is one of the most interesting results of this large prospecting project. The kimberlites are of Cretaceous age (ca. 90 Ma BP). Two of the pipes named Antioch and Tuttle were the objects of the pilot investigations as the representatives of the whole group.

This report presents a preliminary results of the petrological studies of those kimberlites performed till now.

SAMPLES AND METHODS

The samples were collected from cored and non-cored drillings. The microscope analysis was the main investigating method applied to 50 thin sections and polished preparations. The latter were used as well for the WDS analysis of chemical compositions of performed by means of the electron microprobe Cameca sx100 in the Inter-Institute Laboratory of Microanalysis of Minerals and Synthetic Substances at the Faculty of Geology of the Warsaw.

RESULTS

The microscope studies of the kimberlites of the Tuttle and Antioch pipes revealed their two textural varieties. The pseudodetrital (pseudoconglomeratic) variety of inequigranular texture is most common. It contains abundant kimberlite xenoliths, various phenocrysts as well as country rock xenoliths (Fig. 1). Kimberlite xenoliths are pelletal lapilli that represent magma droplets typically composed of

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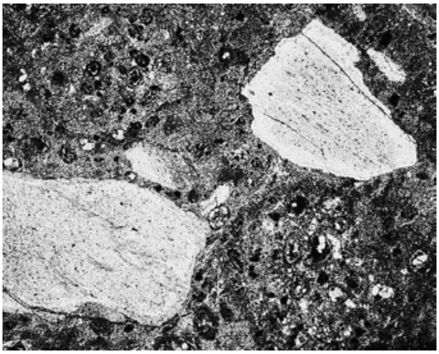

Fig. 1. Kimberlite and country rock xenoliths in fine-crystalline serpen-tinite groundmass, upper right xenolith is actually 3 mm long; sample A-7, crossed nicols.

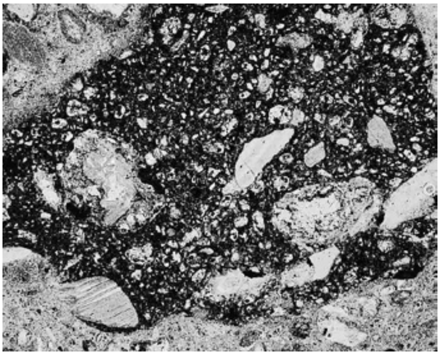

Fig. 2. Dark-coloured micaceous xenolith with phlogopite crystals; the horizontal side of the picture is actually 7 mm long, sample T-6, crossed nicols.

a thin selvage of kimberlite material surrounding a cognate or exotic clasts (sensu Field, Scott-Smith 1999). The rock can be referred to as an autolithic kimberlite (Dawson 1980) and typically occurs in the diatreme facies.

The second variety displays a more homogeneous, porphyritic texture and consists of a serpentine groundmass containing numerous small, highly altered phenocrysts. This type does not contain country rock xe-noliths and only a few kimberlite xenoliths. The rock is typical of the hypabyssal facies (sensu Field, Scott-Smith 1999) in the relatively deep parts of the diatreme.

Phlogopite phenocrysts are common, though serpen-tine pseudomorphs after olivine are the main pheno-crysts present, whilst chro-me diopside is least abundant among them. Nume-rous dark-coloured lampro-phyre-type (micaceous) xenoliths (Fig. 2) as well as less abundant perodotite–dunite kimberlite xenoliths are the essential components.

Preliminary microprobe analysis showed garnet from the Tuttle Creek kimberlite to be pyrope, typically with kelyphitic rims consisting of phyllosilicates and spinel. An unidentfied (mica-like) mineral having a high barium content (up to 20 wt. % BaO) also has been found. Many of the idiomorphic crystals of opaque minerals are ilmenite, the balance are mainly Ti-Fe spinels.

Modelling of the magnetic anomalies (unpublished data, courtesy Pieter Berendsen 2002) shows that final emplacement of the kimberlite bodies was controlled by N40°W trending structures, rather than NNE-trending structures and that the contacts between the sides of the kimberlite bodies and the Paleozoic country rock are steeply dipping. Petrological studies show that the kimberlites consolidated under the conditions of the crater and diatreme facies in Riley County and hypabyssal facies in Marshall County.

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Andrzej BARCZUK[1], *Andrzej TATUR*[2]

BIOGENIC PHOSPHATE AND SULPHATE MINERALS IN THE SOILS OF ANTARCTIC PENINSULA

INTRODUCTION

Phosphatization caused by bird manuring and weathering processes of sulphide-bearing sediments, are the examples of mineralization in Antarctic soils constrained by microbiological activity. The final result of both processes is clear, since they proceed in the environment undisturbed by the other natural processes occurring usually elsewhere in the background. Biogenic phosphates has not been described in Antarctica yet, except of one paper (Wilson and Bain 1976), in spite of numerous papers dealing with ornithogenic soils (Campbell and Claridge 1987). Both associations of minerals are durable in given conditions: phosphatization needs liquid water in soils, whereas sulphates required rather dry conditions. Therefore, phosphates occur exclusively in maritime, but sulphate were found till now only in continental climatic conditions.

SAMPLES AND METHODS

The samples for the present study, collected during many seasons of field works, came from King George Island and Seymour Island located near the Antarctic Peninsula. Usually soft “clay” accumulations of diversified minerals were taken for studies. The term “clay” means trditionaly in such case only grain size class. Chemical analysis of pre-concentrated samples has been conducted in the Institute of Ecology, Polish Academy of Sciences. AAS and spectrocolorimetric methods were applied. Chemical formulae of particular minerals have been calculated from almost pure accumulation of minerals. Petrological and mineralogical studies have been performed in the Institute of Mineralogy, Geochemistry and Petrology, Faculty of Geology, Warsaw University. Observations using scanning and petrographic microscopes and energy dispersive X-ray microanalyses were performed. X-ray diffraction pattern was used for mineral identification, thermal analyses (DTA, DTG, TG), infrared spectroscopy, microscopic observations and chemical analysis supported determinations.

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RESULTS

Ornithogenic soils in the maritime Antarctic (western side of the Antarctic Peninsula) consist of surface guano layer and phosphatization zone underneath, which has been formed due to action of aggressive, often supersaturated guano leachates on the bedrock. The main feature of microbiological phosphatization is a changeable reaction of solution percolating through the ornithogenic soil, which is controlled by microbiological processes of organic matter decomposition and transformations of mineral nitrogen forms in soil (amonification producing alkaline ammonia ions followed, or not, by nitrification producing acid nitrates). Association of minerals is then modified by perodic washing of soils by melt-water, that led to chemical degradation of phosphates by incongruent dissolving and excretion of new, more simple phases. Phosphatization in extreme case may lead to total removing of host silicates, which are replaced by phosphates (Tatur et al. 1993). The following phosphate minerals form ornithogenic soils in the humid climate of maritime Antarctic (Tatur, Barczuk 1985; Tatur 2002):

Minerals in the guano layer: urates – $(NH_4>>K,Na)_{0,8}(Mg,Ca,Fe)_{0,1}C_5H_3O_3N_4$; struvite – $Mg(NH_4)PO_4\times 6H_2O$; fluorapatite – $Ca_5(PO)_4F$; hydroxyapatite $Ca_5(PO)_4OH$; brushite - $Ca(HPO)_4\times 2H_2O$.

Minerals in the phosphatized zone: leucophosphite – $(NH_4,K)_2(Fe,Al)_4(PO_4)_4(OH,F)_2\times 4H_2O$; minyulite – $KAl_2(F,OH)(PO_4)_2\times 4H_2O$;
taranakite – $(K,NH_4)_3Al_5H_6\ (PO_4)_8\times 18H_2O$; highly hydrated, basic, amorphous aluminium phosphate bearing fluorine up to– $Al_{10}F_9(PO_4)\times nH_2O$.

Minerals found exclusively in phosphatized zone of relic soils in abandoned penguin rookeries: vashegyite A – $(Al_{0,9}F_{0,1})(PO_4)\times 3,15H_2O$; vashegyite B – $Al_{11}(OH,F)_3(PO_4)\times 3,15H_2O$; “arctowskite” – $(Al_{8,4}Fe_{0,6})_9(OH)_3(PO_4)_8\times 27H_2O$.

Phosphates from the surrounding areas: vivianite - $Fe_3(PO_4)_2\times 8H_2O$.

Oxidation of sulphides mediated by soil bacteria led to the formation of strongly acid solutions bearing sulphuric acid, which reacts with carbonates and silicates from the bedrock.. Results of this acid sulphate drainage were observed on Seymour Island (eastern side of Antarctic Peninsula), with dry continental climate protecting against easy dissolving of sulphates. The following simple salts were found in the weathering zone of Tertiary sand interbedded with sulphide-bearing clay and containing carbonates concretions and dispersed shell hash:

K-Na jarosite is an important component of yellow clay occurring commonly in the weathering zone where it forms lenses, striae, and irregular patches, especially at the contacts with layers of bituminous clay bearing sulphides. Na jarosite can be often found near the shoreline, whereas K jarosite rather in the inland sites.

Gypsum, a common minor mineral in the weathering zone, wherever common carbonates occur. It forms crusts on bottom sides of carbonate boulders, indurated calcic horizons, minute desert roses dispersed in the loose sand, surface encrustations, lamination inside hard lithified ferrihydrite banks.

Basic Ca-bearing aluminium sulphate, amorphous to X-ray. It occasionally forms white soft clay covering carbonate concretions as the result of its reaction with acid sulphate solutions bearing Al.

Ankerite forms crusts on calcium carbonate concretions originated due to action of iron $^{2+}$ rich acid solutions on carbonates.

Ferrihydrite sometimes rich in Al is together with gypsum the main component of cement in the common thick, erosion-resistant, brown coloured banks of lithified sand. This mineral is also the component of illuvial-type soil horizons and stains the upper side of stones laying on the soil surface. It may be considered as the final stable stage of the surface iron mineralization.

Ephemeral, minute yellow-to-white efflorescences, observed sometimes on the soil surface and obtained during evaporation of soil aqueous solutions in laboratory, were identified as a mixture of well crystallized water soluble **natrosiderite, hexahydrite, tamarugite**.

Cretaceous silty sands of Seymour Island do not contains sulphides and yielded only a simple mineralization on the bottom and upper surfaces of basaltic stones laying on the soil surface (stones are derived from nearby dykes).

Aragonite forms crusts on the underside of cobbles always drowned in the soil, green colouration comes from admixture of chlorite pigment.

Ferrihydrite forms reddish-brown staining on the upper side of the same cobbles. During dry periods a white superficial cover of **halite** occurs everywhere.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Wojciech BARTZ[1]

MICROSTRUCTURAL STUDY OF BROUSEK QUARTZITES (SUDETES, SW POLAND)– CHARACTER AND CONDITIONS OF DEFORMATION

The Stare Město Belt is located westwards the Ramzova thrust, which separates West and East Sudetes (NE Bohemian Massif). The so-called Brousek quartzites crop out directly eastwards of the northern part of the Stare Město Belt, at the Polish-Czech border, in the vicinity of Bielice village. The quartzites crop out as a small lens, few kilometers long, and several hundreds meters wide.

Quartzites are creamy or light gray, usually fine-grained, strongly foliated. The foliation dips to NNW at low angles, bearing almost horizontal stretching lineation dipping under very low angles to NNE. Quartzites contain subordinate white mica, opaques and graphite. Accessories are zircon, titanite.

Quartzites are usually strongly layered due to alternation of fine-grained and medium grained quartzose layers. Moreover, quartzites commonly display compositional banding. Their main constituents are segregated into sharply contacting pure quartzose layers and quartz-mica layers. The quartz-mica layers are locally strongly enriched in graphite and opaques, leading to the occurrence of types transitional between typical light quartzite and dark quartzo-graphitic schist. The layering is parallel to the foliation.

Anhedral quartz forms usually elongated grains, oriented parallel to the layering, up to 1.0 mm in long. Part of them are dynamically recrystallized (Passchier, Trouw 1996). The shape of those subgrains defines weak second foliation, subparallel to the primary one (op. cit.). Some quartz crystals exhibit undulose extinction and sutured boundaries. Sparse quartz ribbons occur. Those microstructures imply that quartz was deformed mainly due to subgrain rotation (SGR) with minor influence of grain boundary rotation (GBM, Stipp et. al. 2002, Passchier, Trouw 1996). The subgrain rotation is dominant within the temperatures of ~400-500 ° C (Stipp et. al. 2002). This suggests that quartzites were most likely deformed within this temperature range close to SGR/GBM transition boundary. In part of quartz grains prism-plane parallel subgrain boundaries are present and no evidence for “chessboard” quartz (i.e. prism- and basal-plane parallel subgrain boundaries) was found. Since the occurrence of “chessboard” quartz is strictly limited to the stability field of high-quartz (Kruhl 1996), the Brousek quartzi-

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tes recorded deformation and metamorphism below the temperature marking α-β transformation of quartz (i.e. T≈630 ° C at P≈2.5-3.0 kb).

Quartz lattice preferred orientation (LPO) study shows the occurrence of two main types of scatter. They are: (1) I-type of crossed girdle (Fig.1 A) and (2) single girdle inclined to the foliation (Fig. 1B). The girdles observed on diagrams are unequally populated with well developed submaxims, some of them are even discontinuous (Fig. 1 A). Strong Z (basal <a>) and Y-submaxims (prism <a>) occur in all diagrams, whereas submaxims intermediate between Z and Y (rhomb <a>) are less common.

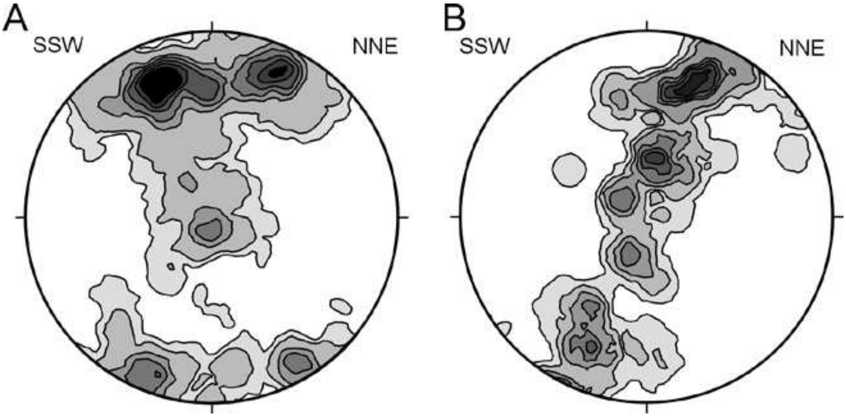

Fig. 1. Representative examples of quartz <c> axes patterns in the Brousek quartzites. Equal-area net, lower hemisphere. Density contours at 1% intervals. Projection plane is XZ plane of strain ellipsoid. Attitude of foliation corresponds to a plane perpendicular to the figure. L – lineation.

The internal symmetry of obtained quartz [c] axes scatters suggests that quartz LPO developed as a result of simple shear deformation (single girdle scatter) prevailing over coaxial deformation at plain strain (I-type of crossed girdles scatter; Schmid, Casey 1986, Passchier, Trouw 1996). However, the I-type of crossed girdle scatter may also be interpreted as a result of simple shear deformation too, but at very low strain (Etchecopar, Vasseur 1987, Dell'Angelo, Tullis 1989).

The external asymmetry of single girdle scatters implies a top-to-the-NNE shearing The presence of Y-submaxim indicates the deformation under amphibolite facies conditions (Schmid, Casey 1996). Observed submaxims allow to infer that only <a> slips were active in quartz during deformation. This conclusion and total lack of evidence for [c] slips suggests that the temperature of deformation did not exceed 650° C (Passchier, Trouw 1996) or 500 ° C (Okudaira et. al. 1995), which stays in good agreement with observed quartz microstructures.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Joanna BEYER[1]

PETROGRAPHY OF GRANITOIDS FROM BOREHOLES WIGANCICE-1 AND DĘBOWIEC-1 (S PART OF THE STRZELIN CRYSTALLINE MASSIF, SW POLAND)

INTRODUCTION

The Strzelin Crystalline Massif is situated in the southern part of Fore Sudetic Block (SW Poland). Crystalline rocks usually occur as small exposures therefore many important information about history of the Massif must be obtained from borehole material. This paper focuses on rocks from two boreholes in neighbourhood of Wigancice, in southern part of the Massif. The boreholes are at 5 km distance from each other.

Wigancice boreholes consist mainly of granitoids and they lack surrounding rocks. This characteristic is unusual comparing to other described drilled material. Cenozoic sediments form uppermost parts of the boreholes. Several types of granitoids were distinguished according to drill documentation. Detailed observation led to simplified division into three types of granitoids: (1) granodiorites (dominating type) and subordinate (2) tonalites and (3) two mica granites. The whole section is crosscutted by numerous pegmatites.

PETROGRAPHY

Granodiorites are medium- to coarse-grained and locally exhibit parallel alignment of minerals. They consist of quartz, plagioclase, K-feldspar, biotite, amphibole and accessory apatite, titanite and zircon.

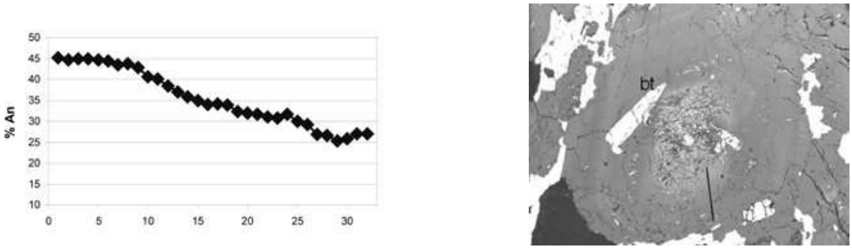

Fig.1. BSE image of type 1 plagioclase grain from granodiorite and corresponding traverse showing anorthite content (from core to rim)

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Plagioclases are commonly normally zoned (45% An in the core to 25% An in the rim) with slight oscillations (Fig.1). Inner parts of the cores are often strongly altered. Small inclusions of biotite occur in the mantles. Several grains exhibit different zonation style with reversely zoned cores (30% An in the inner core and 51% An in outer core) and constant anorthite content in the mantle (27% - 30% An, Fig. 2).

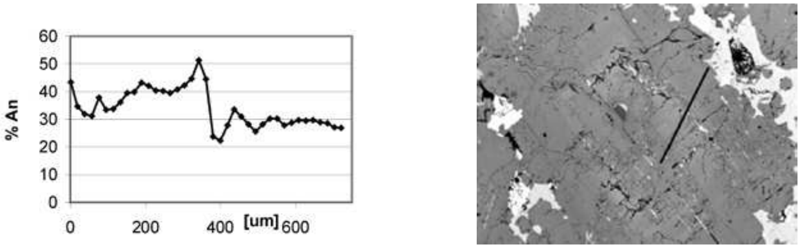
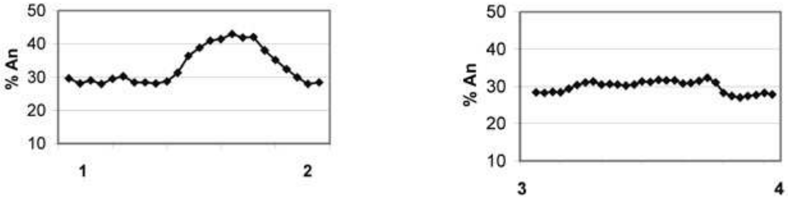


Fig.2. BSE image of type 2 plagioclase grain from granodiorite and corresponding traverse showing anorthite content (from core to rim)

Mafic minerals (biotite and amphibole) occur as aggregates or as individual grains. Biotite is characterized by slight decrease of Al^{IV}, Ti and $Mg/(Mg+Fe^{tot})$ from the cores towards the rims. Amphibole grains consist of Fe-hornblende and Mg-hornblende cores and thin actinolite rims.

Tonalites are fine- to medium-grained, consist of plagioclase, quartz, biotite, amphibole, K-feldspar and apatite, titanite and zircon as accessories.



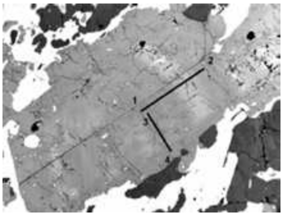


Fig. 3. BSE image of large plagioclase grain from tonalite and corresponding traverses showing anorthite content.

Two types of plagioclase grains occur: large and small ones. Large grains of plagioclases are characterized by complex zonation (Fig. 3). The poor in anorthite (29-33%) cores are surrounded by mantles richer in anorthite (43%). Anorthite content decreases again towards the rim to 28%. Small plagioclases are normally zoned from 39% An to 33% An.

Biotites form large aggregates up to 4 mm. Al^{IV} in biotites increases from the cores to the rims by 0.2 in average. Slight increase in Ti content is also noted in the same direction. Amphiboles consist of Fe-hornblende cores, Mg-hornblende mantles and rims (Mg content increases towards the rims).

The granites are fine-grained and consist of quartz, K-feldspar, plagioclase, muscovite and biotite.

CONCLUSIONS

Boreholes are drilled probably in one intrusion composed mainly of grandiorite but shape and size of the body is not constrained. The size of the intrusion is confined from the north as in boreholes localized 5 km to the north near Bożnowice village approximately 60% of surrounding rocks were drilled (Beyer 2002).

Only scarce contacts between granodiorites and tonalites were found but structural characteristics of both rocks together with previously described relationships (Oberc-Dziedzic, personal communication) indicate that tonalite forms veins crosscutting granodiorite. Two-mica granite crosscuts granodiorite and is supposedly the youngest rock type as it was described from field relations and dating in other parts of Strzelin Crystalline Massif (Oberc-Dziedzic et al. 1996, Oberc–Dziedzic 1999).

Normal zonation in type I plagioclases from granodiorite and crystallization of biotite and amphibole after plagioclase (structural evidence, Fig 1) indicates their crystallization in steadily cooled magma body progressively enriched in water (e.g. Naney 1983). Occurrence of second scarce type of plagioclase grain with reversely zoned cores suggests different, more complex origin of their formation, and then mixing of two types of grains in one magma reservoir.

Chemical compositions of minerals from tonalite (increase in An content towards the mantles in plagioclases, increase in Al^{IV} and Ti in biotites) indicate crystallization event in differentiating magma prior to emplacement into granodiorite sequence.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Hubert BRIL[1]

THE RELEASE OF METALLIC TRACE ELEMENTS FROM FORMER METALLIC MINES. MAIN MECHANISMS AND ENVIRONMENTAL IMPLICATIONS

Mining exploitations create galleries and fissures which modify underground water circulation. They also produce great quantities of solid waste falsely called "barren" : after the recovery of valuable elements it still contains up to 1-5% of sulphur, metalloids (As, Sb…) and metallic elements such as Pb, Zn, Ni (…) according to the composition of the primary ore. Until recently, these waste and galleries were abandoned when the extraction activity ended. Today, for most of the developed countries, the concerned administrations require specific treatments including for solid materials, recovering of the dump or their inclusion in cements. Concerning the groundwaters the treatments consist of water gathering in few dewatering points allowing the installation of chemical purification plants. For the galleries, the objective is to lower the permeability by their filling with appropriate solid material. However, the inheritance of the past remains significant for all the former mining districts, witnessed by numerous sites which are still untouched since the ending of the exploitation.

One of the most important impact of these activities is the release from the waste and/or galleries of metallic or metalloid (trace) elements (MTE) generally known as pollutants (As, Pb, Cr…). The crushing of primary ore materials to sandy or silty granulometry as well as the creation of fissures in the rocks surrounding the exploited zones, highly favour water circulation and as a consequence the exchanges between rocks and water. The release of MTE occurs in several ways such as acid mine drainage due to sulphide oxidation or as solid particles exportation to the neighbouring rivers and to estuaries. Depending on the local physico-chemical conditions, these particles can keep or release their metallic content during the different stages of their journey to the sea. As a result, pollutants can be transferred to hydrophere or biosphere (plants or animals).

Since seven years, our team in Limoges deals with the different aspects of the behaviour of MTE, after mining (or industrial) activities. I will present some parts of our work in order to illustrate the different ways of the MTE release.

METHODS

Significant conclusions can be made only if these studies are carried out considering the physico-chemical records in the field as well as in the laboratory. It

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is also necessary to consider in conjunction the liquid and the solid parts and to complete the analyses of natural products by laboratory experiments. For the liquid fraction, accurate analyses need liquid and gas chromatography for anions, ICP or AAS for (trace) cations. Solid phases are usually very small ; they can be studied only by SEM, electron microprobe, XRD and/or microXRD, (micro)infrared spectroscopy and TEM. Furthermore oxidation state and some structural data can be determined at the atomic scale using (micro)X-ray absorption spectroscopy.

Classical solution chemistry allow to study the interactions between solid phases and water such as *appropriate* selective or sequential extraction followed by careful examination of the solid residue with the above-cited methods.

Finally the future behaviour of MTE on the sites and downstream could be forecast using geochemical calculation models (MINETEQ, CHESS…).

THE INITIAL MECHANISM OF RELEASE: SULPHIDE OXIDATION

Metalliferous ores mainly contain sulphides which are very reactive when they are subject to weathering in highly oxidising conditions such as those prevailing in tailings impoundments. As a result, major cations, but also associated trace elements (Cd or Ge in sphalerite for example), are released and generate acid drainage water.

For pyrite, the most common sulphide, this instability depends on the partial pressure of oxygen and the quantities of water. The alteration reactions are classically written as follows :

$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2H^+$
$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{3+} + 2\ SO_4^{2-} + 16\ H^+$
or in summary
$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \rightarrow Fe(OH)_3\downarrow + 2\ H_2SO_4$

Nevertheless, other sulphides present different relative reactivity. For example, in most impoundments Jambor and Blowes (1994) pointed out that the increasing resistance of sulphides seems to be :

Pyrrhotite < sphalerite < pyrite - arsenopyrite < chalcopyrite.

Then this susceptibility to weathering processes depends on parameters concerning the minerals such as mineralogy, grain size, fracturation, as well as local environmental conditions (e.g. Dold and Fontboté 2002) : whole mineralogy, sulphide quantities, pH and Eh at microscale, climate, microbial activity, permeability, water / rocks ratio etc.

Usually, these oxidation processes are very fast : after only < 10 years, most of metallic or metalloids elements are no longer present in sulphide forms. The only remaining sulphides are found in very low permeability environments, several meters below the surface of the dump. Sulphur is more mobile : the greatest part has been exported and the remaining part is present in gypsum or epsomite forms, more rarely as metal sulphates.

ACID MINE DRAINAGE AND THE EXPORTATION OF DISSOLVED As AND MTE BY ACIDIC WATERS

The above-cited reactions leads to the production of important quantities of sulphuric acid, a change in the speciation form of MTE initially present as sulphides in the waste and to the production of iron-rich, coloured products.

One example is the medium-sized former gold mine studied by Roussel et al. (2000), which display a 600,000 metric tons of waste constituted by auriferous quartz crushed to 80µm and containing up to 0.8% As. Tailings, spread out on more than 7 hectares consist of a 30 meters high heap and settling basins. Only few arsenopyrite and other sulphides (pyrite or galena…) are still present throughout the waste. Therefore we have concluded that the sulphide oxidation induced in only several years, a change in the speciation of 4800 metric tons of As, more than ten thousands tons of iron and hundreds tons of other MTE.

However the rate of these changes as well as the nature of the secondary products strongly depend on environmental conditions defined at the microscale. The monitoring of the sites allow to distinguish different environments regarding to the physico-chemical conditions. For the previous example, within the heap Eh conditions are always oxidising and pH in the range 4-6. In the settling basins successive saturation-desaturation stages are observed in some parts whereas other zones are always submitted to saturated conditions.

Water analyses (13 water samples, two times a month, one year, ground and surface waters in relation to the rainfall and temperatures) show arsenic concentration 10 to 1000 times more than regional waters. They also show for a given sampling point a highly variable total dissolved As and other elements (1-100 times) and also a good correlation between total dissolved As and Fe in the water.

TEMPORARY TRAPPING OF ARSENIC BY IRON OXIDES AND OTHER SECONDARY PHASES

These reactions are highlighted by the emission of yellow to brown effluents in the water corresponding to the presence of numerous iron-rich secondary phases; these products are constituted by a mixture of iron - Fe(III) - hydroxides, oxyhydroxides, and sometimes, by sulphates and other minerals. All these phases are initially highly hydrated and do not present well defined composition nor well-ordered structure.

They can precipitate in situ leading to the formation of MTE-rich specific levels within the tailings. They constitute natural immobilisation of potentially toxic elements issued from the sulphide oxidation and can be indurated as crusts or cements. Chemical and mineralogical analyses performed on this material show that some of them are constituted by low-crystallised material (1) containing high percentages of MTE and numerous different solid phases whereas others (2) present a lower content in toxic elements and are constituted by more crystallised and stable mineral species such as goethite, hematite, jarosite… The transformation from (1) to (2) is due to local conditions such as instability of the local thermodynamic conditions, heavy runoff etc. (Courtin-Nomade et al., 2003) and is accompanied by a progressive release of MTE.

EXPORTATION OF MTE-BEARING SUSPENDED MATERIAL

These coloured effluents and MTE-rich secondary phases can also be exported from the sites as suspended material by erosion, for example during high rainfalls.

Artificial alteration, selective or sequential extractions in the laboratory help to appreciate the potential mobility of MTE from such materials. For example, As and iron species are frequently linked but these relationships occur in different ways (adsorption, co-precipitation or both). Nevertheless, such links are not exclusive : As can also be trapped by organic matter etc. As a consequence, in new conditions (river sediments…) only a part of arsenic is mobile, the adsorbed fraction for example.

REMEDIATION

A precise knowledge of the pollutants, their current and possible speciation in the future require to plan an adapted, effective and long-term remediation. Thermodynamic conditions prevailing on the different parts of the concerned sites and in the neighbourhood as well as possible modifications induced by the future remediation works must be taken into account.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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SECONDARY (Cu, Zn)-OXYMINERALS FROM THE MIEDZIANKA COPPER DEPOSIT IN RUDAWY JANOWICKIE, SUDETES MTS. PRELIMINARY REPORT

Polymetallic ore deposit in the Miedzianka vicinity is located in the northern edge of the Rudawy Janowickie (Sudetes Mts.). It was discovered and exploited in 12th century. Geological investigations were mainly published by Traube (1888), Teisseyre (1968), Zimnoch (1978) and Mochnacka (1982).

The complex ore deposit in the Rudawy Janowickie is known as a hydrothermal ore of chlorite copper system. It was formed as a result of the main Intra-Sudetic fault formation and the contact metamorphism of the Karkonosze granitic body. The surface of contact of granite with crystalline schists of Rudawy Janowickie is steep and extends from SW to NE (Zagożdżon, Zagożdżon, 2002).

The presence of secondary minerals formed in oxidation zone of Miedzianka ore deposit were mentioned even in early publications. But the characteristics of the minerals based mainly on macroscopic observations. Precise characteristics of secondary Cu-oxycompounds were collected by Lis and Sylwestrzak (1986), and published by Pieczka et al. (1988), Holeczek (1990) and Holeczek and Janeczek (1991). The following secondary minerals were described: chrysocolla, malachite, azurite, pyromorphite, pseudomalachite, wulfenite, chalcophyllite, erythrite, pharmacolite, mimetesite, olivenite, cornwallite, volborthite, torbernite and uranophane. Holeczek and Janeczek (1991) postulated, that many specimens collected from the Sudetes Mts. ore deposits and referred to as malachite may in fact be other species, e.g. pseudomalachite, tyrolite, olivenite, etc. It was confirmed by Gołębiowska (1999, 2000), who has found an abundance in a variety of Ca-Pb-Cu-Zn arsenates and vanadates in the deposit of dolostones in quarries at Rędziny.

The purpose of this paper is to characterise the identified (Cu, Zn)-oxyminerals in Miedzianka ore deposit as the investigations of specimens of malachite-like mineral have given us unexpected results.

On the basis of X-ray diffraction, IR absorption, scanning microscopy and chemical analyses (EDS, WDS) the Cu and Zn arsenates and phosphates were identified. They are macroscopically seen as massive or radial aggregates of acicular

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crystals up to two millimeters, of dark green to yellowish-green colour. The crystals are translucent.

X-ray data indicate the presence of the following mineral phases in investigated samples: cornwallite (hydrated, with Zn^{2+} substitution – JCPDS 12-0287 and anhydrous), philipsburgite (JCPDS 38-0384), and legrandite (JCPDS 42-1356). For some specimens all the d_{obs} values are consistent with intermediate data between pseudomalachite and anhydrous corwallite (JCPDS 36-0408 and 39-1357, respectively).

IR spectrum of specimens with intermediate XRD data was compared with the IR spectrum of pseudomalachite from Radzimowice (Holeczek, Janeczek, 1991). Almost all absorption bands are shifted to lower wave numbers, indicating higher percentage of As^{5+} in sample from Miedzianka. As As^{5+} substitutes approximately 16% of P^{5+} in pseudomalachite from Radzimowice Holeczek and Janeczek (1991) suggest the existence of limited solid solution between pseudomalachite and cornvallite.

EDS analyses have indicated the presence of oxygen, Cu, As and P. Si is present in traces. Additionally Zn and V were determined in four samples. WDS analyses were done on three samples and the formulas based on 10 oxygens show discrepancies between P^{5+} and As^{5+} content (tab.1). Therefore, P/(As+P) ratio differs in any example and ranges from 0.1 to 0.7.

Table 1. Percentage of anionic ions in samples from Miedzianka.

No of samples	P^{5+} [%]	As^{5+} [%]	V^{5+} [%]	Si^{4+} [%]
499	42	52	-	6
MIII31	65	29	4	2
PM	10	82	6	2

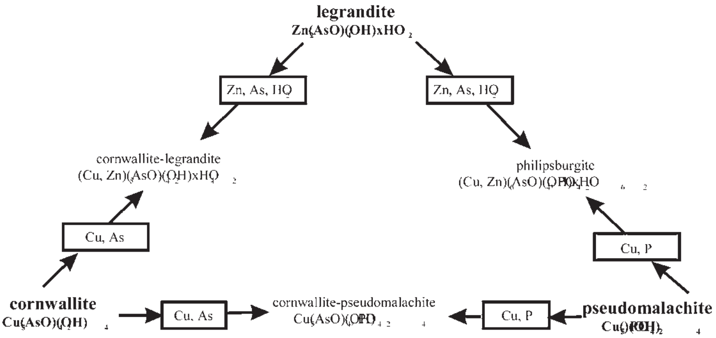

Fig. 1. Possibility of existence of limited solid solution between cornwallite, legrandite or pseudomalachite (marked in bold) based on identified mineral phases from the Miedzianka ore deposit (marked in normal type). Particles, which can be substitute in end-members, are closed in rectangles.

On the basis of identified mineral phases we postulate the coexistence of cornwallite, pseudomalachite and legrandite as a limited solid solution, from which minerals with different percentage of AsO_4^{3-} or PO_4^{3-}, and Cu^{2+} or Zn^{2+} can crystalize during the oxidation stage of polymetallic ore deposit in Miedzianka (Fig. 1). According to the phase diagrams (Clara et al., 1986, Magalhaes et al., 1988) the stability fields of these minerals superimpose each other.

The presence of volborthite or torbernite reported by Lis, Sylwestrzak (1986) and a presence of vanadium in investigated samples from the Miedzianka ore deposit may suggest that limited solid solution can coexist between arsenates and phosphates as well as tungstates and uranyl groups.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Justyna DOMAŃSKA[1], *Ewa SŁABY*[2]

ENCLAVES FROM THE VARISCAN STRZEGOM-SOBÓTKA HORNBLENDE-BIOTITE GRANITE.

INTRODUCTION

The Variscan Strzegom-Sobótka massif (Fore-Sudetic Block, NE Bohemian Massif) is composed of one granodiorite- (biotite-granodiorite) and three granite-facies (two-mica granite, biotite granite, hornblende-biotite granite). Domains of different lithology, tectonic style and age surround Variscan Strzegom-Sobótka granitoid massif. The source of granitic melt (protolith) is discussible and unsolved problem. Using isotopic data Pin et al. (1989) proposed different magma source for eastern and western part of the pluton. Low initial strontium isotopes ratio (0,705-0,7082) obtained for eastern part of the massif suggests dominant mantle input during granite formation or diversified crustal source. In the contrary, high initial strontium isotopes ratio (0,7098) obtained for western part of the massif indicates continental crustal rocks (argilites, greywakes, silica-rich volcanics) as possible magma source (Pin et al. 1989; Puziewicz, 1990).

Some of the granite facies comprises many enclaves of composition varying from diorite, tonalite to granodiorite (Domańska, 1984). The origin of the enclaves as well as their relation to granite is not precisely recognised. Puziewicz (1990) discussed the genesis of the enclaves occurring in the biotite granodiorite. He favoured, that enclaves could be restite of un-melted, young basaltic material. Numerous enclaves of similar composition have been found also in the hornblende-biotite granite (western part of the pluton).

ENCLAVES – MODAL COMPOSITION, GROWTH TEXTURES

Enclaves found in the hornblende-biotite granite (hbl-bi granite) display oval or sharp-bordered shape. This study considers only the first type. The modal composition of the oval enclaves locates them within diorite, quartz diorite, granodiorite. Fe-Ti oxides, hornblende and/or biotite accompany felsic minerals. Epidote, zircon and apatite, allanite occur as accessory phases. Feldspars in the marginal part of the enclave, especially plagioclases show outward growth into granite. They cross the enclave margin and precede their growth into granite quartz. Gra-

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nite minerals dive into the enclave showing typical "inward" growth morphology. Within enclaves big single plagioclase or alkali feldspar crystals are visible. Their growth morphology doesn't fit to the enclave's groundmass feldspars but show similar features with granite feldspars. The CL evidence supports this observation. They have been mechanically introduced into the enclave. Macroscopically well-defined contact between enclave and granite changes due to the interaction between both crystallization environments into almost unrecognised one under microscope. The enclaves are usually surrounded with "bleeding" zones enriched in quartz and K-feldspars (Vernon, 1991).

GEOCHEMISTRY

Twenty-one hbl-bi granite samples and twenty-six enclaves separated from the granite has been analysed for major and some trace elements (Rb, Sr, Ba, Cr, Nb, Y, Zn, Zr) by means of XRF method. Harker's diagrams (Fig. 1) show both data sets. Two kinds of trends appear on the plots. Some of the major and trace elements define linear trends over whole (enclave and granite) silica range (e.g. Al_2O_3, Fe_2O_3; Fig. 1a, b,), which could point to co-magmatic origin of both of the rock sets. For some of them the trends are different for enclaves and granite (e.g. K_2O, Rb; Fig. 1c, d), which in turn excludes the above-mentioned hypothesis.

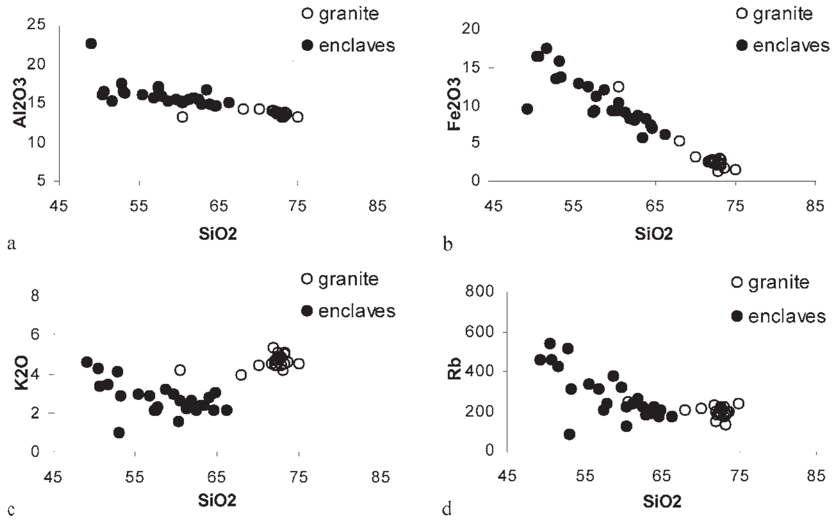

Fig. 1. Harker diagrams for: Al_2O_3 (a), Fe_2O_3 (b), K2O (c), Rb (d).

Basing on differences in trace elements behaviour during partial melting and fractional crystallization, the process accounting for enclave's differentiation trends has been recognised. Diagrams Log(compatible element) versus Log(incompatible element) have been drawn. All of them show sub-horizontal trend indicating partial melting. Partial melting however can't be the only process determining the differentiation trends, because of some inconsistency in elements behaviour. Strontium behaves like incompatible element and shows no affinity to calcium. Rubidium, yttrium and niobium behave like compatible elements.

FINAL REMARK

Due to mineral growth morphology observed in the oval enclaves found in hbl-bi granite the conclusion could be derived, that they present remnants of magma blobs introduced into the granitic melt. Mineral "inward" and "outward" growth textures recognised in the enclaves argue in favour of this hypothesis. Modal composition of the enclaves shows wide range from mafic till silica-oversaturated rocks. Geochemistry of the rocks points to their common origin with a partial melting as a process responsible for their differentiation. Some of the elements show however behaviour, which is not consistent with partial melting (e.g. lack of Sr affinity to Ca). The process seems to be obscured by interaction with felsic melt i.e. mixing-mingling. Mechanically introduced feldspars into the enclaves are records of this process. It is difficult to ascertain the interaction range between both melts. Using mass balance law for mixing and assuming the most silica-rich granite composition as felsic liquid contaminating initial mafic melt the degree of contamination for the most silica-rich enclave has been calculated. Due to the calculation the contamination degree might reach almost 40%. The result is unrealistic and acknowledges, that enclave's composition is a result of much more complicated process than suggested, i.e. including two interacting sources.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Said A. EL-NISR[1], *Mohamed M. EL-SAYED*[1] *and Gehad M. SALEH*[2]

GEOCHEMISTRY AND PETROGENESIS OF THE PAN-AFRICAN LATE- TO POST-OROGENIC YOUNGER GRANITOIDS AT SHALATIN-HALAIB DISTRICT, SOUTH EASTERN DESERT, EGYPT

The younger granitoids of the Shalatin-Halaib district in the south Eastern Desert of Egypt are of syenogranite compositions. Based on petrological and geochemical studies, the syenogranites have been differentiated into two distinct types, namely biotite-hornblende subsolvus syenogranite (SGR I), showing I-type affinity and biotite-bearing hypersolvus syenogranite (SGR II) with A-type affinity. On the basis of REE patterns, the SGR II is further subdivided into SGR IIa and SGR IIb. The SGR I is characterized by low Rb/Sr ratios and HFSE concentrations (e.g. Nb, Ta and Y), fractionated LREE with flat HREE, high LREE/HREE ratios, presence of a negative Nb-Ta anomalies and lack of negative Ba and Eu anomalies. On the other hand, the SGR II is characteried by high Rb/Sr ratios and HFSE concentrations, slightly fractionated (SGR IIa) to unfractionated (SGR IIb) LREE with a positive slope for the HREE, absence of negative Nb-Ta anomalies and significant negative Ba, Ce, Zr and Eu anomalies. According to the field and geochemical characteristics, the late-tectonic SGR I may be produced by dehydrated partial melting of an amphibolitic source followed by high-pressure fractionation processes. The post-tectonic SGR II is probably formed directly from the residual magma by crystallization of biotite, plagioclase, K-feldspar and accessory phases such as monazite, allanite and titanite in a shallow-level magma chamber occurring along strike-slip faults at convergent margins. Generally, the syenogranites were generated during a period of rapid tectonic transition from crustal thickening during subduction (SGR I) to crustal thinning during extension (SGR II) which represent the final magmatic stage of an extensive arc system.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Roman GOTOWAŁA[1]

THE TECTONIC INVOLVEMENT OF THE JAVORNIK GRANITOIDS – SKRZYNKA-ZŁOTY STOK SHEAR ZONE (SUDETES)

INTRODUCTION

In the Góry Złote and the Rychlebske hory Mts., the Javornik granitoids form a partly concordant, up to one km wide and north-west dipping vein, which is accompanied by a rim of streaky granitization in blastomylonites and phyllonites of the Stronie formation, particularly well-developed in rocks overlying the north-western side of the vein. Field data indicate that Javornik granitoids was deformed.

GEOLOGICAL OUTLINE AND NATURE OF THE GRANITOIDS

The main body of the Javornik granitoids, having the form of the vein, up to 1200 m thick, occurs on the Czech side, between the Růženec pass in the south and the Bilá Voda in the north (Němec, 1951). In this area, these granitoids represent deeper, root parts of the intrusion. To the south-west, on the Polish side, the granitoid vein becomes thinner and tapers out on the progressively lower sides of transverse faults.

A detailed petrographic description of the Javornik granitoids in the Polish part of the Śnieżnik metamorphic unit was presented by Burchart (1960), and in the Czech part by Němec (1951). These two fundamental petrographic studies contain totally different interpretations of the described granitoids' origin: Němec opted for an intrusive origin, whereas Burchart saw metasomatism as the major factor responsible for the formation of these rocks. The isotopic dating of the Javornik granitoids was made on biotite using the K-Ar method (Borucki 1966), yielding result of ca. 335 Ma.

MACRO- AND MESOSTRUCTURES

The tectonic involvement of the Javornik granitoids was mentioned by Finckh & Fischer (1938), Finckh et al. (1942) and Cwojdziński (1977).

In the Polish part of the Javornik granitoids one can observe apical parts of this intrusion, showing gneissic fabric, concordant with the main foliation of the wall rocks (Fig. 1). In this area, there are also mylonitic varieties of granitoids, through banded orthogneiss to ultramylonites (Fig. 2a, 2c). The main foliation in the wall rocks and outside the contact zone, defined by strongly developed differen-

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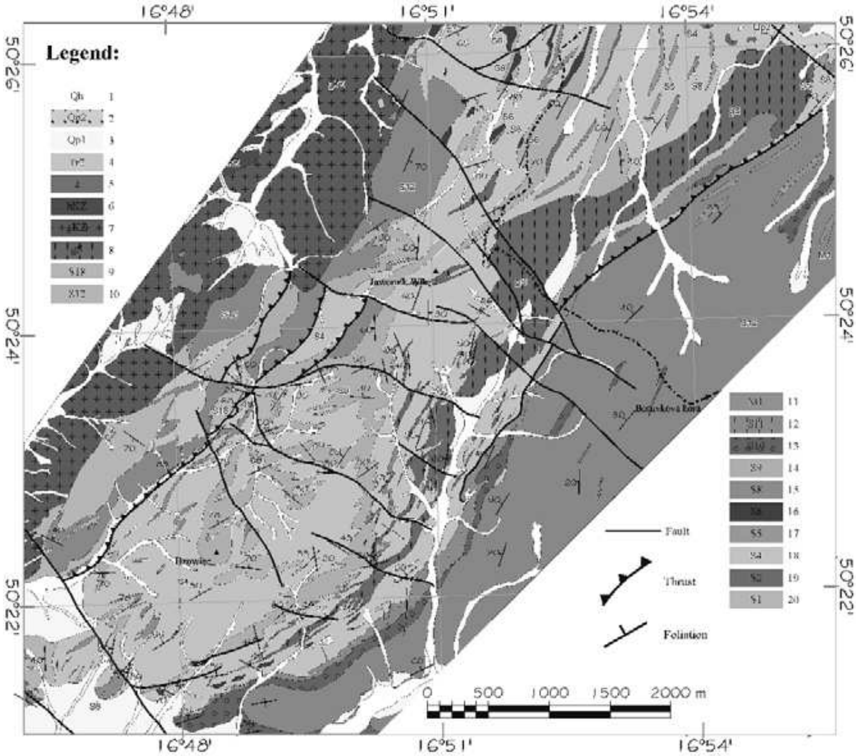

Fig. 1. Geological map of the of the Złoty Stok-Skrzynka zone, showing the Javornik granitoids and surrounding rocks of the Śnieznik metamorphic suite. 1, alluvia (Qh); 2, gravels and clays (Qp2); 3, sands and silts (Qp1); 4, clays, sands and gravels (Tr2); 5, vein aplites, pegmatites and lamprophyres (ż); 6, hornfelses and hornfels gneisses (hKZ); 7, Kłodzko-Złoty Stok granitoids and syenodiorites (gKZ); 8, Javornik granitoids (gS); 9, Gierałtów gneisses and migmatites with relicts of paragneisses of the Młynowiec formation (S18); 10, fine-grained or migmatic Gierałtów gneisses (S12); 11, Staré Město amphibolites (M1); 12, fine-augen and fine-laminated Śnieżnik orthogneiss (S11); 13, coarse-augen Śnieżnik orthogneiss (S10); 14, porphyroids and leptinites (S9); 15, amphibolites and amphibolite schists (S8); 16, crystalline limestones (S6); 17, graphite schists and quartzites (S5); 18, mica schists (S4); 19, amphibolites (S2); 20, biotite schists and paragneisses (S1).

tiated layering, may represent remnants of the one or more transposition events. The Foliation dips gently to moderately toward the north-west (Fig. 1). The folds within granitoids are typical of the envelope F2 and F3 structures and all show a consistent west-over-east sense of vergence (Fig. 2b, 2c). Fold axes and lineations (rodding and intersection l.), lying in the main foliation, plunge gently toward the north-east. Within the wall rocks noncylindrical meso- and macrofolds are common with axes rotated toward dip of the main foliation. Within Javornik granitoids F2/F3 folds show only an incipient tendency to be rotated or none.

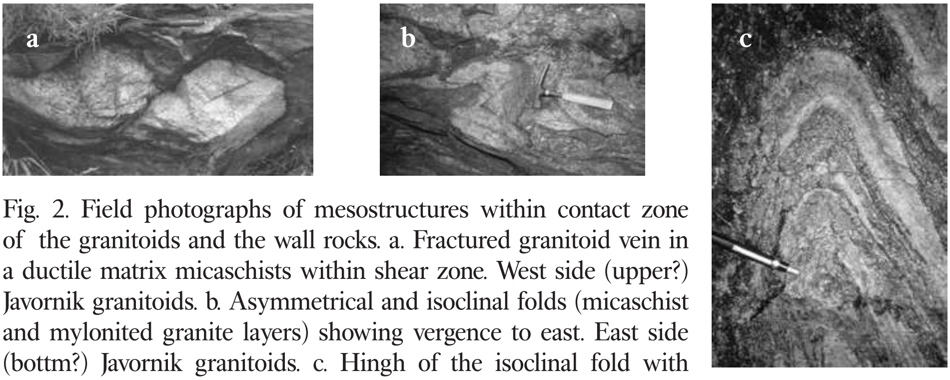

Fig. 2. Field photographs of mesostructures within contact zone of the granitoids and the wall rocks. a. Fractured granitoid vein in a ductile matrix micaschists within shear zone. West side (upper?) Javornik granitoids. b. Asymmetrical and isoclinal folds (micaschist and mylonited granite layers) showing vergence to east. East side (bottm?) Javornik granitoids. c. Hingh of the isoclinal fold with protomylonite-mylonite bands of the granitoid. East side (bottom?) Javornik granitoids.

Field data indicate that Javornik granitoids are probably intradeformational to D2/D3 transition stages in relate on to the Śnieżnik metamorphic deformation phases produce F2/F3 folds.

The Javornik granitoids isotopic data 335 Ma, overlaps with the age of the Staré Město granitoids (c. 339 Ma) and the isotopically determined age of the formation of the Gierałtów migmatite complex (c. 340 Ma).

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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MARLS OF THE SUB-SILESIAN UNIT (FLYSCH CARPATHIANS) – PRELIMINARY PETROGRAPHIC COMPARATIVE STUDY

INTRODUCTION

When compared with sandstones and shales, marls are the least known component of the Carpathian Flysch. The marls are defined as calcareous rocks of predominantly pelitic character, massive or showing slabby/flaggy parting. They are distinguished among sandstones and shales in all tectonic units of the Flysch Carpathians. They are differing in colour, compactness, grain size and sedimentary structures. Marls are particularly common within Upper Cretaceous series of the Sub-Silesian unit. Apart from two dominant Upper Cretaceous (mainly Campanian) marly facies: variegated Węglówka Marls occurring eastward of the Dunajec and grey Frydek Marls containing volcanic blocks described westward of this river, marly rocks of various lithologic character are also locally reported to occur. They are both older and younger than Campanian in age. Among them, there are hard, yellowish, locally spotted rocks called the Jasienica Marls and whitish, hard Żegocina Marls. Detailed study of mineral composition of these rocks tends to define their position in petrographic classification and to determine their origin, what can contribute to the reconstruction of evolution of geologic structure of the Flysch Carpathians.

SAMPLES DESCRIPTION

The Węglówka Marls (Campanian-Maastrichtian) were profiled and sampled in the Węglówka tectonic semi-window, whereas those of the Frydek type (Campanian-Maastrichtian) and the Żegocina marls (early Campanian) in the Żegocina tectonic window. Besides, the Jasienica Marls (Senonian) were sampled in the Jasienica tectonic window.

The Węglówka marls are red, green and variegated. All these varieties are soft, sand-free, often bioturbated, massive or showing flaggy parting. Green, spotty colouration in reddish marls is observed around fine fecal pellets, several to a dozen mm in size. Within marly beds there occur loaf-shaped beige phosphate concretions, up to about 10 cm in size, locally replaced by anhydrous and hydrated iron oxides. In Narębski's opinion their origin is related to submarine volcanic phenomena, producing gases enriched in fluorine.

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Marls of the Frydek type are grey-bluish, soft, arenaceous, containing mica flakes and showing coarse parting. They contain intercalations of grey, horizontally laminated, micaceous, calcareous sandstones and andesite exotic pebbles, several cm in size.

Żegocina marls are white, locally greenish, very hard, poorly arenaceous, structureless and horizontally laminated, locally convoluted. Within their beds siliceous concretions and hornstone intercalations are observed.

Jasienica marls are light beige in colour with subtle yellow or distinct dark-grey spots (bioturbations), hard, showing more or less visible horizontal lamination, locally slightly waved, marked by a change of colour intensity. Their thin beds are separated by stripes of beige-coloured calcareous shales.

PETROGRAPHY

As follows from the results of these studies, quantitative mineral composition of all the marly facies of the Subsilesian unit studied is very similar. They differ in quantitative proportions at three main mineral components: carbonates, minerals of silica group and clay minerals (Table 1). Their compactness results just from this diversity.

Table 1. Average proportions of main mineral components of the marls studied (wt.%)

Marly facies	Component		
	Carbonates	Minerals of silica group	Clay minerals
Węglówka Marls (17 samples)	20	5	75
Frydek Marls (5 samples)	10	20	70
Jasienica Marls (11 samples)	40	10	50
Żegocina Marls (10 samples)	75	5	20

Micas (muscovite and biotite) and feldspars are subordinate components of marls. Moreover, the Węglówka and Frydek Marls contain some iron minerals: oxides (hematite) and hydrated oxides (red Węglówka Marls). Besides, there also occur sulphides (pyrite), often oxidized (green Węglówka and Frydek Marls). The iron content, expressed as Fe_2O_3, amounts to about 4 wt.%.

The content of carbonates, minerals of silica group and clay minerals is taken into account in classification of rocks combining the properties of carbonate, clay and silica rocks and of sandstones. The estimation of systematic position of marls requires determinations of origin of these components.

ORIGIN OF THE MAJOR MINERAL COMPONENTS OF THE MARLS

Carbonates are represented by biogenic calcite and, in traces, by diagenetic dolomite.

Calcite occurs in the form of bioclasts and fine plates, as well as moldic microsparite. Biogenic calcite if differently preserved and occurs mainly in foraminiferal chambers or their fragments and as coccolites .

Fine-platy calcite is dispersed among clay minerals and is resembling them in morphology. In marls enriched in carbonates, foraminiferal chambers are filled with microsparite.

Individual rhombohedral dolomite crystals are dispersed in clay-calcite matrix.

Minerals of silica group are generally represented by low-crystalline biogenic silica and grains of detrital quartz. The former comes from dissolved sponge spicules and is fine-platy, similarly as clay minerals. Detrital quartz grains are, but rarely more than 0.1 mm in size.

Clay minerals are represented mainly by smectite mineral, locally with subordinate kaolinite admixtures, as well as by minerals of mica and chlorite groups. The first mineral shows specific features ascribed to volcanogenic smectites. It is dioctahedral, rich in magnesium mixed layer smectite/illite (the content of swelling layers is more than 80%), showing low charge (ca. 0.30), relatively high temperature of decomposition of structure (about 700^0C) and cornflake-like micromorphology.

ORIGINAL DEPOSITIONAL COMPONENTS OF THE MARLS

Homogeneity of mineral composition of the marls indicates a similar source of their components. As follows from the present author's studies the initial components of marls were mainly nannofosils (foraminifers and coccolites), sponge spicules, and pyroclastic material being the source of clay minerals. Similar sediments are reported to occur e.g. in the Atlantic and the Pacific oceans. Apart from the nature of clay minerals, the occurrence of biotite flakes also indicats the presence of pyroclastic material in the marls studied. The content of detrital quartz grains in marls is variable what is related to energy of environment of their sedimentation.

CONCLUSIONS

The current investigations have shown that the studied marls of the Sub-Silesian Unit are the products of diagenese of volcanogenic clay-bearing, nannofossil oozes (Żegocina Marls) or nannofossil-volcanogenic clays (Jasienica Marls). The Węglówka Marls originated from nannofossil- and spicule-bearing volcanogenic clays or similar deposits containing silt and sand admixture (Frydek Marls). Actually they represent a continuous series of rocks from calcareous claystones (Węglówka Marls), sometimes arenaceous (Frydek Marls), up to marls (Jasienica variety) and marly limestones, locally arenaceous and siliciefied (Żegocina Marls). The difference in their compactness depends mainly on the content of carbonates.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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MAJOR AND TRACE ELEMENT STUDY OF SERPENTINITE AND RODINGITE FROM STOBNA MELANGE (BARDZKIE MTS - SW POLAND)

INTRODUCTION

The loose blocks of gabbros and serpentinites are known from the poorly exposed outcrops situated in the Stobna stream valley about 12 km south of Ząbkowice Śląskie on the Sudetic Foreland. They belong to Carboniferous sediments of the Zdanów sedimentary sequence outcropped near Marginal Sudetic Fault. In this site, frequent blocks of serpentinites, gabbros, rodingites and sedimentary breccias are most common. They form several tens metres wide zone overlained by graywackes and mudstones with dipping on east at the angle about 40-50° (Wajsprych 1981). In the terms of sedimentary structures this unit is interpreted as nappe or olisthonappe (Wajsprych 1978).

Several petrographic groups of Stobna exotic "boulders" were recognised after the previous geologic studies. It includes: 1) antigorite serpentinites (after residual peridotites) with mesh structure, 2) augitic diopside-bearing metagabbros (locally mylonitised) and 3) grossularite-diopside rodingites (metasomatically altered primary gabbros) 4) breccias - composed of sharp-edged gabbro and serpentinite fragments embedded in fine-grained clay-bearing detrital matrix. The genetic connection of Stobna basic and ultrabasic rocks with ophiolite nappe, whereby short-distance and gravitational transport was previously postulated (Narębski et al. 1982).

However, other opinions about origin of Stobna serpentinites asumed: 1) emplacement of Braszowice gabbros and serpentinites in the MSF zone (Oberc 1977) or 1) incorporation of these as fragment of an ophiolite nappe transported along the MSF (Jamrozik 1981).

Aim of this article is to present new geochemical data concerning serpentinites and rodingites occurring in the Stobna melange.

PETROGRAPHY

Two samples of Stobna exotic "boulders" were examined geochemically. One of them represents antigorite serpentinite with relics of forsterite olivine and augite-diopside clinopyroxene. The studied ultrabasite specimen was dark-green in colo-

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ur, aphanitic in structure, locally transected by unoriented narrow pale green serpentine veins up to 1mm in thickness. Under microscope the flame-shaped, interpenetrating structure composed of antigorite (with yellow-greyish serpentine individuals up to several mm in size) is common. Locally, serpentinite exhibit rosette-like or interlocking texture in the sense of nomenclature of serpentine struc-tures after Wicks & Whittaker (1977). The single xenomorphic relics of forsterite (up to 2 mm in size) and larger clinopyroxene (diopside-augite) prisms also occur in the rock background. Commonly, on bigger prisms traces of their (100) cleve-ages are bent forming characteristic kink-bands. All rock-forming constituents of serpentinite are "covered" by very small magnetite microspherules, which locally form the cloudy-shaped assemblages.

The specimen of diopside-grossularite metasomatite (rodingite) is "patchy" in appearance, white-yellow in colour. Their structure is aphanitic, locally porphyroclastic. Occasionally, the ophitic intergrowths composed of small dark-green prisms embedded of white-yellowish fine-grained backgroud can be obser-ved. As it was confirmed under microscope, in the white, fine-grained parts of ro-dingite the framboidal idiomorphic garnets (up to 1 mm in size) predominate, which are sometimes intergroved with flaky Mg-chlorite (up to 2 mm in size). In the green-coloured parts of an ophitic intergrowths only prism-shaped pseu-domorphs (after primary pyroxenes?) filled of Mg-chlorite flakes replacing pristine fiber-shaped Ca-Mg amphiboles were ascertained. The narrow veins filled of recrystallised chalcedony also rarely occur there.

GEOCHEMISTRY

Bulk-rock chemistry, trace and rare earth element determinations was perfor-med using XRF, INAA and ICP method in the Canadian Laboratory Ltd with valuable assistance of GeoAnaliza Enterprise (Cracow). Sample of antigorite serpentinite is characterized of normative harzburgite composition (#Mg= 90), whilst geochemistry of diopside-grossularite metasomatite is comparable with pristine pyroxene-gabbro (except their strong CaO enrichment).

On the MORB-normalized multielement diagram both serpentinite and rodingite show the same distribution profile. It is characterised by the presence of slight K, Rb, Ba, Th, Nb enrichment, and displays the strong Ti and slight Ce negative anomalies. Such similarity of profile line positions, which is observed for samples representing different members of ophiolite suite, indicate, that LIL abundances in these rocks recorded only chemical "equlibration" event.

Conditions for such LIL "homogenization" could have taken place during serpentinization or strong deformation including flow in the solid-state. Despite of this, interpretation of MORB-normalized diagrams in this case is not suitable for petrologic purposes.

On primary mantle-normalized REE spider-diagram can be observed similarity of the La, Ce, and Tb contents in the serpentinites and rodingites. Generally, in the serpentinites the MREE and HREE abundances are slightly depleted in comparison with PM values. The rodingites display slight sloped LREE profile with small negative Ce and positive Eu anomalies, whilst in the Gd-Lu range (20-30 time PM composition) the flattening of profile line is observed. It can reflect an important role of fractional crystalisation in the early stage of mineral separation from the melt (basic cumulates?).

CONCLUDING REMARKS

The geochemistry results obtained for the Stobna serpentinite and rodingite may indicate, that they both represented fragments of the ancient oceanic crust. However, their primary chemical features (except REE components) were completely obliterated by advanced deformation and serpentinization of protholiths. Most probably the latter movements and shearing in the SMF zone could also the influence LIL mobility in the examined system. These reasons caused, that any attempts to detailed reconstruction of primary mantle-originated or magmatic processes of Stobna melange exotics could not be achieved using the traditional geochemical discrimination projections.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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PLATINUM-GROUP ELEMENTS CHARACTERISTIC OF SUB-CONTINENTAL ULTRAMAFIC ROCKS FROM SUDETES (SW POLAND): A PETROGENETIC INDICATOR

Ultramafic rock massifs associated with gneisses and amphibolites in the area of Sudetes has suffered melt depletion followed by metasomatism of different degrees (Hamdy and Meisel, 2002 and Hamdy, unpublished data). PGE and Re abundances were studied in order to obtain additional information on the origin and processes that modified the mantle beneath Sudetes (SW Poland).

The selection of the analyzed samples was carried out considering rocks represent different degrees of melt depletion and the overprinted metasomatism. Four massive peridotites from four localities in Sowie Mountains Block — SMB (spinel lherzolite from Niedźwiedź Mt. — NI and 3 spinel harzburgites from Wiewiórka Mt. — WI, Bystrzyca Górna — BG and Potoczek — PO) and one olivine websterite (formed in the uppermost mantle, as evidenced by the estimated P and T of crystallization of pyroxenes, Hamdy, unpublished) from Orlica — Śnieżnik Dome — OSD at Złoty Stok — Z were selected for the study.

The mineral composition was analyzed by means of the electron microprobe at Institute of Geological Sciences in Warsaw, PAS. Whole rock chemical composition was investigated by means of XRF and ICP-MS at Institute of General and Analytical Chemistry, University of Leoben. The PGE and Re concentrations were determined by isotope dilution ICP-MS (see Meisel et al., 2003). Sulfur concentration was measured with a LECO CS 300 Elemental Analyzer.

The composition of the olivine relics (Fo = 0.85 in lherzolite from NI to 0.91 in harzburgite of WI and 0.75 in websterite) and spinel (Cr# = 0.53-0.72 in peridotites and 0.79 in websterite) detecting the variable degree of melt depletion. Both cryptic (La_N/Yb_N = 79 in BG harzburgite to 5 in Z websterite) and modal metasomatism (growth of amphibole and phlogopite) are distinguished.

The effect of the geological processes in fractionation of the Re and PGE is well represented by the ratios between these elements. Thus data are presented here as ratios normalized to Ir (Fig. 1).

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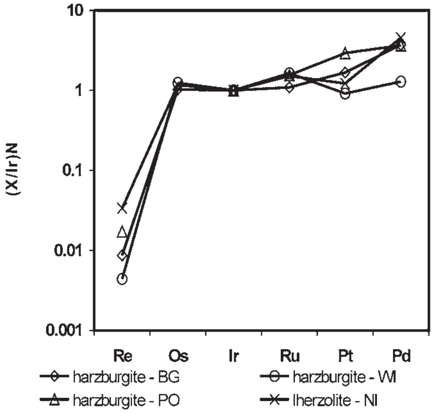
The Niedźwiedź lherzolite has extremely low PGE and Re concentrations (0.15-0.85) relatively to the composition of the Earth's primitive mantle — PM (McDonough and Sun, 1995), showing positively slopped abundance pattern. It has suprachondritic PGE/Ir ratios (Fig. 1). The SMB harzburgites represent highly refractory rocks with high degrees of melt depletion. Thus one could expect these residues should be depleted in sulfur and consequently display negatively slopping sub-chondritic PGE-Re abundance pattern (e.g. Barnes et al., 1985). This is not the case. Harzburgites have higher concentrations of Palladium — Platinum — Group Elements (PPGE) (0.79-3.9 × PM) and Iridium — Platinum — Group Elements (IPGE) concentrations (0.73-1.68 × PM) close to their estimates in PM. The olivine websterite has extremely low IPGE concentrations (0.004-0.009 × PM) and high PPGE and Re concentrations (0.081-9.5 × PM). The IPGEs group displays negatively slopping pattern unlikely to PPGEs group, which displays positively slopping one. The websterite rock sample has high sulfur (~5500 ppm) and copper (325 ppm) concentrations.

Fig. 1



It has been shown that the concentration patterns of PGE-Re and sulfur in the SMB peridotites are not consistent with the degrees of melt depletion. This indicates that the PGE-Re patterns of the studied SMB peridotites may record other processes or sources that are not recorded by the former mineralogical and geochemical studies.

The suprachondritic $PPGE_N/Ir_N$ ratios of harzburgites and the high concentrations of sulfur (up to 776 ppm in harzburgite — PO) indicate that depletion of melt during partial melting do not play a role of buffering the present PPGE fractionation. Fractionation of PGE occurred during partial melting was obscured by the introduction of sulfide liquids derived from percolating magmas. Crystallization of sulfides from these liquids enriched the ultramafic rocks in PPGE.

The low concentrations of PGE-Re in NI lherzolite displaying positively slopped pattern with high suprachondritic Pd_N/Ir_N and Pt_N/Ir_N ratios and high concentrations of sulfur indicates that the PGE-Re budget of this sample does not reflect that of PGE of a typical fertile mantle. It is conceivable, that the composition prior to this lherzolite was harzburgitic formed by melt depletion and subsequently refertilized by basaltic components of percolating magma. The introducing of percolating melt would deplete the IPGE in the rock (e.g. Handler and Bennett, 1999; Rehkämper et al. 1999). With cooling of magma, sulfide liquid would be extracted enriching the refertilized rock with PPGE elements.

The high Cr# of spinel and the negatively sloped IPGE pattern of the Z olivine websterite are indications that this rock represents ultramafic cumulate formed by high partial melting of upper mantle peridotite. The rock was penetrated by sulfide liquid rich in copper causing enrichment of PPGEs and Re and depletion of IPGEs.

By comparison La/Yb ratios (as a measure of the degree of metasomatism) with PGE_N/Ir_N ratios, it is shown ratios Ru/Ir and Os/Ir of peridotites from WI, PO and NI are positively correlated with the La/Yb ratios. Thus we can suggest that aqueous fluids being the agent of metasomatism caused the growth of Ru and Os fractionation. The negative correlation of La_N/Yb_N with the concentration of S in peridotites indicates that the sulfide addition did not accompany the metasomatic processes by hydrous fluids but occurred at a later event.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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CALCULATED MINERAL EQUILIBRIA IN THE SYSTEM NA_2O-CAO-FEO-MGO-AL_2O_3-SIO_2-H_2O (NCFMASH): PRELIMINARY RESULTS FOR AMPHIBOLITES FROM THE STARA KAMIENICA BELT, THE IZERA-KARKONOSZE BLOCK, WEST SUDETES

INTRODUCTION

One of the principal aims of metamorphic petrology is to decipher the pressure-temperature (PT) conditions experienced by the rocks and to construct relevant PT paths to infer the sequence of tectonometamorphic events within an orogen. Conventionally, this is achieved by applying thermodynamic equations defining geothermobarometers in which chemical compositions of minerals, which constitute equilibrium assemblages, are used. Alternatively, pressures and temperatures of metamorphism are estimated with petrogenetic grids (for a detailed review see Will 1998). Especially those calculated by using internally-consistent thermodynamic data and providing phase diagrams for systems involving solid solutions are of the utmost petrological importance. If phase diagrams are calculated for a given bulk composition of rocks (PT-*pseudosection*) which define PT stability fields of mineral assemblages and compared with petrographic observations, segments or entire PT path may be inferred. This approach is particularly efficient if PT paths are otherwise either difficult or, because of the lack of suitable conventional geothermobarometers, even impossible to obtain.

RESULTS

In the present study the petrogenetic grid of Will et al. (1998) was applied. The pseudosections were generated using the computer program THERMOCALC (Powell and Holland 1988) with the thermodynamic database of Holland and Powell (1990). The selected sample of amphibolite collected near Czerniawa Zdrój (CRK 2a) is composed mainly of Fe-tschermakite, plagioclase (An_{27-39}), quartz, ilmenite and accessory small blasts of garnet, chlorite and epidote. Based on several geothermobarometric calibrations, average temperatures of c. 570-590 ^{0}C at pressures of 8.6 and 8.0 kbar, respectively, were estimated by Ilnicki (2000). In the present study, investigations on the amphibolites were extended to infer the PT path associated with the metamorphic evolution of the amphibolites.

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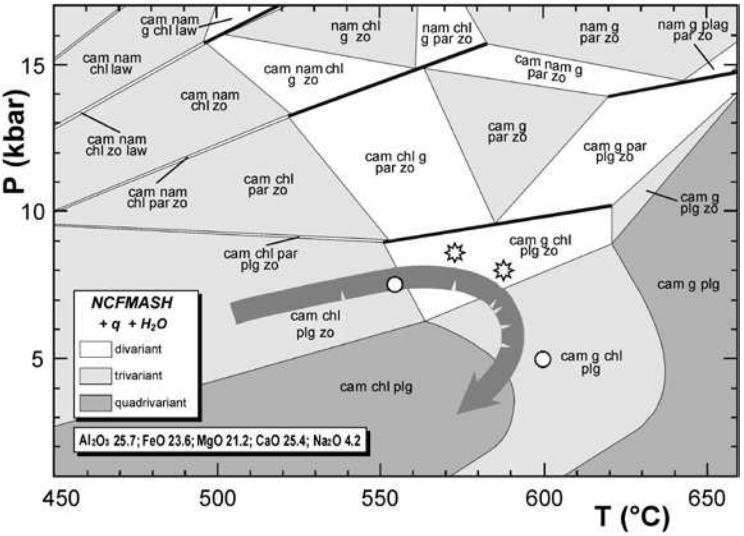

Fig. 1. PT pseudosection calculated for sample CRK 2a of amphibolite from vicinities of Czerniawa Zdrój (the bulk composition is expressed as normalized mole-proportions). The heavy line shows most probable PT path for the sample (this study), stars and circles denote PT conditions of metamorphism obtained from the conventional geothermobarometry for the sample and amphibolites from the Stara Kamienica belt, respectively (Ilnicki, 2000). Abbreviations: cam – Ca-amphibole, chl – chlorite, ga – garnet, law – lawsonite, nam – Na-amphibole, par – pargasite, plg – plagioclase, zo – zoisite/epidote.

The calculated NCFMASH PT pseudosection for sample CRK 2a (Fig. 1) consists of di-, tri- and quadrivariant fields that define stability of mineral assemblages typically occurring in medium-pressure – medium-temperature and high-pressure – medium-temperature metabasites. The fields at pressures below 10 kbar correspond very well to the mineral assemblages found in the studied rock. By contrast, di- and trivariant fields with paragonite and sodic amphibole or even lawsonite and omphacite are irrelevant due to the absence of these minerals in the sample.

Comparing the microscope observations with the calculated pseudosection, the PT path associated with the series of changes that occurred in the rock is inferred. In the starting assemblage cam-plg-chl-zo garnet appeared on entry into the divariant field cam-plg-chl-zo-ga. Epidote/zoisite must have reacted out after entry into the trivariant field cam-plg-ga-chl because the sample is almost free of epidote and its rare and tiny relicts are spatially related to garnet crystals. Most probably the quadrivariant field cam-plg-ga was not entered since small blasts of chlorite are ubiquitous in the sample. Instead, the quadrivariant field cam-plg-chl must have been entered, which led to the predominance of these three minerals and to disappearance of garnet, as indicated by the observed textural relationships in the sample. It is therefore assumed that peak conditions of metamorphism of c. 560-570 ^{0}C at pressures about 8 kbar were followed by slight temperature increase to about c. 590 ^{0}C at pressures of 5-6 kbar and a subsequent decrease towards greenschist facies conditions. The derived PT trajectory is similar to the one for amphibolites of the Stara Kamienica belt (Ilnicki 2000).

CONCLUSIONS

Preliminary though they are, the results presented here show that limitations of conventional geothermobarometry can be successfully circumvented by the phase diagrams approach. In the case of sample CRK 2a, calculation of an appropriate PT pseudosection enabled to infer the metamorphic conditions experienced by this rock and showed that there is no substantial discrepancy with PT path derived for other amphibolites from the Stara Kamienica belt. Undoubtedly, further calculations of mineral isopleths for the rock CRK 2a and phase diagrams modelling for other amphibolites samples will provide valuable tools to investigate the metamorphic evolution of the northern part of the Izera-Karkonosze block.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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EVOLUTION OF THE PERMO-CARBONIFEROUS BOSKOVICE FURROW (CZECH REP.)

INTRODUCTION AND GEOLOGICAL SETTING

Boskovice Furrow (BF) is an elongated asymmetrical basin oriented in the SSW-NNE direction filled with Permo-Carboniferous sediments, especially sandstones and conglomerates. Present width of the basin is only 5-12 km and the length is about 90 km, but the original extent was larger. The basin has been formed along the major SSW-NNE trending marginal fault (the main fault of the BF), which represents the continuations of the Diendorf fault in Austria. The whole length of the fault extends 200 km. Tectonic subsidence driven by this fault was important factor that controlled the deposition and depositional processes in the basin. The first stage of formation of the basin was the extensional period, during which the Permo-Carboniferous sediments were formed. The extensional period was accompanied by intermediate to acid volcanism. This period was followed by a compressional stage which deformed the sedimentary fill composed of the Carboniferous and Permian deposits. It also led to thrusting of the Brno Massif and locally also Devonian and Lower Carboniferous rocks over the eastern margin of the basin. Internal part of the basin was overthrust to the west forming a few duplexes.

The basin was also transversally segmented by a number of NW-SE trending faults/elevations. Existence of several sub-basins within the BF with partly different sedimentation history was predetermined by these structures. Tišnov – Kuřim Ridge is the most important transversal bedrock structure within the basin. It divides the basin into the north Letovice depression and the south Rosice - Oslavany depression.

The deposition in the basin started in its southern part (Rosice – Oslavany area) during Stephanian C with coarse-grained red conglomerates and breccias and spreaded towards the N and NE. The sedimentation ceased at different time in various parts of the basin, however, the deposition in the major part of the basin finished during Lower/Middle Autunian.

Strongly asymmetric distribution of sedimentary facies and depositional environments is typical for the BF. The deposition commenced with breccias and conglomerates within the whole basin, however, two different facies successions developed afterwards in the opposite (E – W) parts/ limbs of the basin.

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RESULTS OF THE STUDY

The eastern limb of the BF is characterized by monotonous deposits of the Rokytná conglomerates, which form the dominant fill of this part of the basin. These conglomerates represent a classical proximal facies (sediments of alluvial fans) with a typical rapid unsorted sedimentation. Clasts of older sediments like Lower Carboniferous greywackes and shales together with Devonian limestones dominate in the conglomerates along the whole eastern limb.

The basal formation of the western limb of the BF is represented by the Balinka conglomerates, which grade upward into heterogeneous but generally finer sediments. Clasts with local provenance derived from close vicinity are always present in the material on the base of all studied profiles. Clasts of greywackes, which were found in the highest members of the Balinka conglomerates, can be interpreted as re-sedimented material of the eastern provenance. This feature documents an important role of the axial and transversal transport within the basin.

CONCLUSIONS

In the initial stage of its depositional evolution, the basin represented a narrow and relatively shallow depression. The basal conglomerates (Balinka, Rokytná) provide evidence for this early stage. The basal sediments of the western limb of the BF are developed in the form of local alluvial fans. The clasts were derived from the local material, found in the basement of the studied profiles along the whole length of the western margin of the BF. On the other hand, the sedimentation at the eastern margin of the BF is controlled by the eastern marginal fault, which was a principal feature in the evolution of the depositional environment of the whole basin. The sedimentation took place in that area on slopes of alluvial fans, similarly to the western part of the BF. The Carboniferous sediments (greywackes, etc.), which form substantial portion of the Rokytná (eastern) conglomerates, however, have not been found at the basement of these deposits. Even more, the granitic rocks of the Precambrian Brno Batholith are locally thrust over the Rokytná conglomerates. Only small tectonic slices of Carboniferous sediments are sandwiched between Permian deposits and Precambrian basement.

The observed features with undisturbed transgressional contact of the BF sediments in the West and contrasting highly tectonised contact in the East indicate strong, syn- and postsedimentary movements along the marginal fault. The erosion reached the present day level on the west of the BF probably already in the Carboniferous or in the beginning of Permian, whereas the eastern margin of the BF was strongly modified in the post –Autunian time.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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CHARACTER OF DEFORMATION WITHIN SHEAR ZONES ON THE GALERIA CUBRYŃSKA RIDGE AND MIĘGUSZOWIECKA PRZEŁĘCZ POD CHŁOPKIEM PASS, HIGH TATRA MTS., POLAND

INTRODUCTION

The High Tatra Mts. granitoid massif intruded ca. 300 Ma (Burchart 1968, Janák 1994, Poller & Todt 2000), and after the Permian was situated at depths not exceeding 12 km (ca 250^{0}C). The uplift of the Tatra Mts. started from depths of approx. 10-11 km about 70-50 Ma ago and reached the 5 km (100^{0}C) depth level 30-15 Ma ago (Kováč et al. 1994).

The granitoid core of the Tatra Mts. is cut by numerous dislocations of different types. Some of them display slickensided flat and smooth planes, others are several meters wide tectonic zones, showing evidences of repeated activity. Mylonitic textures are observed within some zones. In order to distinguish the different types of dislocations the geometrical criterion was applied, which allows to describe the following groups:

a) flat dipping faults, mineralised with quartz, epidote or chlorite (connected with Alpine thrust-napping processes)

b) steep dislocations comprising singular planes or systems of several parallel planes

c) steep dislocations associated with mylonite or cataclasite zones, several tens of centimetres to approximately 2-3 m wide.

RESULTS

Galeria Cubryńska Ridge shear zone, with the orientation 205/80, belongs to the third group of dislocations and shows evidences of repeated activation. It is one of the three parallel mylonitic zones cutting the Cubryna Massif. This zone, approx. 1.5 – 2 m wide, represents a several tens of meters deep fissure cutting into the massif, with a distinct rock-fall fan at its base. Within this zone the following deformation and mineralization stages took place, in chronological order:

1) development of S-C mylonites, indicating the south-ward down-dip displacement,

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2) milky quartz vein development,

3) greenish quartz mineralization, colour is connected with dispersed chlorite,

4) dip-slip movement along the shear zone boundary, leading to the development of tectonic striation 292/35 on mylonitic epidote-coated wallrocks,

5) quartz in druse character growing within extensional fractures,

6) carbonate mineralization filling spaces between euhedral quartz crystals; carbonate minerals with the following sequence: Fe-dolomite – ankerite – calcite are observed.

In order to establish the deformation conditions during the oldest stage when S-C mylonites were developed, the microtectonic analysis was applied. Brittle fracturing and undulose extinction within porphyroclasts of magmatic quartz, kink-band folding of twin lamellae within plagioclase porphyroclasts, undulose extinction within neomorphic quartz crystallised along S-C surfaces, mica fish-like structures, ductile deformation of biotite, and quartz porphyroclasts accompanied by asymmetric pressure shadows filled with fine grained calcite were observed. The coexistence of the presented structures allows estimation of the deformation temperature at approximately 300^0 C.

As new phases crystallized: quartz, chlorite, sericite/muscovite, albite, K-feldspar, epidote, calcite, apatite and titanite.

Mięguszowiecka Przełęcz Pod Chłopkiem Pass shear zone with the orientation 160/60, is ca 1-2 m wide and can be recognised along the distance of ca. 300 m. In the lower eastern part microfolds of mylonitic foliation can be observed, whereas in its western part – closer to the Pass – a tectonic gouge. Similarly to that of Galeria Cubryńska, is accompanied by ca 5-20 cm quartz veins, in some cases of druse character, in which the spaces between euhedral quartz crystals are filled with carbonates in the following sequence: from ferrous dolomite through ankerite to calcite. The carbonates are susceptible to weathering resulting the frequent occurrence of Fe-hydrooxides in quartz druses.

Investigations of fluid inclusions from the postdeformational vein of milky quartz (Kozłowski & Jurewicz 2001) indicated the temperature 264^0C and pressure of 1.6 kbar ($1.6\text{x}10^8$ PA). Pressure and temperature were also determined for neomorphic quartz from C shear surfaces in S-C mylonites, which yielded slightly lower P-T conditions: $t=216^0$C and P=1.3 kbar ($1.3\text{x}10^8$ PA). Temperature was also determined based on the chemical content analysis of chlorites in microprobe, using the geological thermometer Cathelineau & Nieva (1985) and Cathelineau (1988). Temperatures calculated in three samples yielded the following results: 200, 225 and 255^0C. Heterogeneity of chlorite composition led to considerable difference in obtained results that seem to indicate slightly too low temperatures.

CONCLUSIONS

Application of the chlorite thermometer - Cathelineau (1988) allowed determination of a wide range (caused by uncertainty of the thermometer) of chlorite formation temperatures (200-255⁰C). The obtained results are close to the temperatures measured by Kozłowski (in: Kornatowski 2002) for fluid inclusions in quartz on S-C surfaces in the mylonites (216⁰C) and slightly lower than the temperature of crystallization in the postdeformation milky quartz vein (264⁰C in: Kozłowski & Jurewicz 2001). Petrotectonic observations point to higher temperature condition during the formation of the shear zone (above 300⁰C).

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MORPHOLOGY AND SHRIMP STUDY OF ZIRCONS FROM THE LIGHT STACHÓW GNEISSES (LIPOWE HILLS, FORE-SUDETIC BLOCK): PETROLOGICAL IMPLICATIONS

The Lipowe Hills Massif (*LHM*) in the eastern part of the Fore-Sudetic Block, the NE part of the Bohemian Massif, comprises four principal varieties of gneisses (Oberc-Dziedzic, 1995): 1) light, layered or augen gneiss (the light Stachów gneiss - *LSg*), 2) dark, fine-grained migmatitic, sillimanite gneiss (the dark Stachów gneiss - *DSg*) - both varieties of gneisses are exposed in the northern part of the *LHM*, 3) light, migmatitic gneiss with sillimanite nodules (the Nowolesie gneiss - Ng), which is common in the middle part of the *LHM*, and 4) mylonitic, chlorite gneiss (the Henryków gneiss - *Hg*) - in the southern part of the *LHM*.

The zircons from five samples of the principal varieties of the *LHM* gneisses (Oberc-Dziedzic, 1995), were studied (morphology, morphometry and typology) (Klimas at al., 2002) in order to explain their petrogenesis and to make the effective selection of zircon crystals for U-Pb dating. The zircon crystals from the sample from Nieszkowice (*LSg*) are dominantly colourless, 95% euhedral and subhedral, normal and long prismatic, with predominance S_2, S_7, L_2, L_1 and S_4 types, which are typical of crustal anatectic rocks (Pupin, 1980; 1988). The Cl images reveal their complex internal structure with cores and rims. Some grains are simply zoned, totally dominated by inherited zircon with little new magmatic growth.

The SHRIMP zircon geochronological study on the *LSg* from Nieszkowice (Table 1) indicates the presence of: (a) inherited zircon cores of Palaeo- to Neoproterozoic ^{206}Pb-^{238}U ages (from 1916±25 to 636.3±8.4 - 560.3±6.9 Ma), and (b) mostly euhedral and zoned crystals, Cambrian/Ordovician in age, with distinct mean of 500±5 Ma interpreted as the age of emplacement of the magmatic precursor of the gneiss. The ages of inherited zircon cores from the Stachów gneiss suggest that source material for the Stachów gneiss and the Strzelin gneiss (with inherited zircon cores of 1230-1870 Ma; Oberc-Dziedzic et al., 2003) were different.

The results (Table 1) indicate that the cores of zircons (1916 ± 25 – 560.3 ± 6.9 Ma) have higher Th/U ratios; (1.51, 0.92, 0.43 to 0.07). In contrast, in the euhedral rims of

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the zircons (with mean 500 ± 5 Ma), the Th/U ratio varies in the range of 0.43-0.03, from which more than half are Th/U < 1.0.

The Th/U ratio in zircon is being used to distinguish zircons of different origins.

Table 1. Selected SHRIMP data of zircons from Nieszkowice (*JSg*) (* = rim of grain)

Grain Spot*	U ppm	Th ppm	Th/U	^{206}Pb/ ^{238}U age	Grain Spot*	U ppm	Th ppm	Th/U	^{206}Pb/ ^{238}U age
12.2	130	195	1.51	1916 ± 25	4.1*	689	105	0.15	507.6 ± 5.4
16.1	136	125	0.92	636.3 ± 8.4	12.1*	683	85	0.12	499.9 ± 5.4
10.1	1278	205	0.16	630.9 ± 6.4	17.2*	618	36	0.06	499.6 ± 6.2
17.1	485	158	0.32	619.4 ±7.9	19.1*	199	48	0.24	497.3 ± 6.3
11.1	602	256	0.43	567.0 ± 6.1	8.1*	530	56	0.11	497.1 ± 6.3
13.2	319	21	0.07	560.3± 6.9	7.1*	580	27	0.05	496.5 ± 5.3
3.1*	392	26	0.07	523.8 ± 6.4	15.1*	416	87	0.21	495.8 ± 5.6
9.1*	748	47	0.06	520.9 ± 5.7	5.1*	575	44	0.08	494.1 ± 5.3
1.1*	585	64	0.11	518.9 ± 6.1	14.1*	751	20	0.03	493.1 ± 6.1
18.1*	623	734	0.05	510.1 ± 6.0	13.1*	722	19	0.03	491.9 ± 5.3
14.2*	413	178	0.43	508.3 ± 5.7	6.1*	560	27	0.05	479.2 ± 5.3
2.1*	509	63	0.12	508.1 ± 5.5	10.2*	596	77	0.13	466.1 ± 5.5

Th/U ratios in igneous zircons from various rocks is greater than 1.0, while zircons grown under metamorphic conditions show Th/U lower than 1 (e.g. Rubatto & Gebauer, 2000). However, Rubatto (2002) describes zircon overgrowths crystallised during HT metamorphism in equilibrium with partial melt, which have chemical composition (U, Th, Hf, P, REE patterns) similar to that of magmatic zircon, but their Th/U ratio is low (<0.07). In spite of that, she considers the low Th/U ratio as the only feature which allows to distinguish the metamorphic zircons from the igneous ones.

The zircon crystals from the dated sample from Nieszkowice (*LSg*) have often low Th/U ratio (<0.08), but are unlikely to be of metamorphic origin. The euhedral crystals have igneous zoning and mainly show concordant Pb-U systems. The newly formed euhedral zircon crystals reveal magmatic zoning in SEM and CL images. Some zircons have cores relatively large compared to the new planar overgrowth zones composed of one or two bands. Euhedral zircons with smaller cores and distinct thin-oscillation zoning are found only sporadically Some oscillatory zoned euhedral zircon crystals reflect changes on the crystallization environment, from characteristic of more alkaline rocks, with dominance of {101} pyramides and {110} prisms to more peraluminous with {211}>{101} and {110}>{100}. The gneiss from Nieszkowice (*LSg*) was interpreted to have formed from S-granite protholits (Klimas et al. 2002, Madej, 2002). More detailed petrogenetic characteristics of the gneisses from the Lipowe Hills and their comparison with the gneisses from the Strzelin Massif is being prepared.

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MORPHOLOGICAL AND TYPOLOGICAL COMPARATIVE STUDY OF ZIRCONS FROM MYLONITES OF THE NIEMCZA SHEAR ZONE AND FROM THE GÓRY SOWIE GNEISSES (SW POLAND)

The N-S trending Niemcza Zone (NZ) is a major shear zone, c. 50 km long and up to 10 km wide, developed along the eastern margin of the Góry Sowie Block (GSB) in SW Poland. (Bederke (1929) and Dziedzicowa (1985) considered the dominating rocks of this zone as sedimentary-derived mica schists, while Scheumann (1937), and Mazur and Puziewicz (1995) interpreted them as mylonites developed from the Góry Sowie gneisses. The mylonites contain porphyroclasts of plagioclase, garnet and, locally, cordierite, embedded in a fine-grained, layered matrix composed of quartz, plagioclase, and syndeformation biotite, fibrolite, white mica and chlorite. According to Mazur and Puziewicz (1995), the assemblage of porphyroclasts in the mylonites, together with field evidence (gneiss and mylonite intercalations and gradational contacts between them) indicate that the mylonites were produced at the expense of the GSB migmatites. In this study we use the morphology and typology of zircon grains to test whether the mylonites of the NZ did develop from the GSB gneisses and migmatites or whether other protoliths could have been involved in the regional-scale mylonitisation processes.

Samples selected for the zircon studies represent two groups of mylonites defined by Mazur and Puziewicz (1995):

- mylonites deformed under the amphibolite facies: specimens 1, 6, 8 and 11, and
- mylonites deformed under the greenschist facies: specimens 5 and 19.

From the basic morphological and morphometric characteristics (Table 1) it is evident that zircons from most of the samples of the gneisses and migmatites of the GSB differ from those of the NZ mylonites in:

1. domination of coarser-grained zircon fractions;
2. higher elongation values;
3. higher standard deviations for of length, width and elongation of grains;
4. considerably larger proportion of euhedral and subhedral crystals, and smaller amount of subrounded and rounded grains;
5. less amount of grains with cracks and fractures.

The zircons from the mylonites display more features which can be interpreted as resulting from strong deformation (Klimas and Mazur, 2002). Typological distribution

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Table 1. Morphology, morphometry and typology of zircons from mylonites and migmatites of Niemcza Zone and from gneisses and migmatites of the Góry Sowie Block.

Morphology and morphometry of zircons	Mylonites from the greenschist facies (NZ)			Mylonites from the greenschist facies (NZ)			Migmatites from the NZ		Migmatites from the Góry Sowie Block				Granite-gneiss
Sample	1*	11*	9*	9A** M1-1	5A** M8-1	19	9b** M1B1	9c** M1 B2	M 3 - 1 M***	M3-1 L***	M5-1 ***	M2-1 ***	M6-1 ***
Quantity of investigated zircons	100	50	100	100	100	100	100	100	100	100	100	100	100
Euhedral and subhedral crystals, %	20	12	24	59	43	27	39	65	35	45	40	55	58
Subrounded forms, %	57	28	35	41	40	37	36	30	43	27	37	13	23
Rounded grains, %	5	54	18	0	16	28	25	5	22	24	23	32	19
Angular forms, %	18	6	23	-	-	8	-	-	-	-	-	-	-
Broken zircons, %	10	8	17	10	10	4	6	10	8	20	6	15	6
Fractured zircons, %	2	0	0	-	-	4	-	-	-	-	-	-	-
Zircons with "extinction angle",%	8	8	6	-	-	4	-	-	-	-	-	-	-
Mean length, mm	0.06	0.07	0.08	0.13	0.11	0.10	0.13	0.15	0.14	0.17	0.15	0.12	0.12
Standard deviation of length, mm	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.05	0.03	0.04	0.03	0.03	0.02
Mean width, mm	0.04	0.04	0.05	0.07	0.06	0.05	0.06	0.07	0.07	0.07	0.07	0.06	0.06
Standard deviation of width, mm	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.01
Mean elongation	1.8	1.6	1.8	2.1	2.0	1.9	2.1	2.5	2.2	2.4	2.0	1.9	2.0
Standard deviation of elongation	0.5	0.4	0.5	0.5	0.4	0.5	0.6	0.6	0.6	0.6	0.4	0.4	0.3
Main typological forms	S_7, S_2	S_{13}	S_2, S_7 S_{11}	S_4, S_{13} S_7	S_4, S_{25}	S_3, S_2	S_3, S_4 S_9	S_2, S_3 S_7	$S_{17,}S_{18}$ $S_{12,}$ S_{22}	$S_{17,}$ S_{18} S_{22}	S_{12}, S_7 S_2	S_7, S_8 S_9	S_7, S_9 S_{13}
Subordinate typological forms	S_3 S_4	S_{18} S_{12}	S_1, S_{12} S_8	S_8, S_2 $S_{12,}$ S_1	S_9	$S_{7,}$ S_8 S_9,S_4	S_7, S_8 S_{13}	S_1	S_{13}	$S_{23,}$ S_{19} S_{12}	S_{13} S_3	S_2 S_{13}	S_8 S_2

* symbols and location of samples as in Mazur and Puziewicz (1995); ** symbols and location of samples as in Jendrzejaczyk (1998), samples collected near the specimens studied by Mazur and Puziewicz (1995) and Klimas & Mazur (2002); *** symbols and location of samples as in Jendrzejaczyk (1998); Samples 5, 5A collected from an old quarries, south and SW of Ratajno; Samples 9, 9A, 9b, 9c are from Piekielko gorge, east of Gilów; Samples M3-1 NE; M5-1 and M6-1 from the NW vicinity of Owiesno (M3-1M = melanosome, M3-1L = leucosome).

(Pupin 1980) indicates that both the migmatites (9b and c) and mylonites (9 and 9a) which alternate in one exposure of Piekielko gorge (near the boundary between the GSB and NZ) have very similar subtypes of zircons. Similar forms are found also in the greenschist facies mylonite (sample 19) from Strach Hill near Koźmice, and from granite-gneiss (M6-1) from Owiesno. Furthermore, a mylonite sampled south of the road Piława-Przerzeczyn (sample 11) have zircon subtypes roughly similar to those from the melanosome M3-1M of migmatite collected NE of Owiesno. In the remaining samples of the GSB migmatites, the observed typological distribution within particular samples is wider than that in samples of mylonites and migmatites from the NZ. Most typically, the gneisses and migmatites of the GSB comprise dominating S17, S18 and S22 subtypes, while in the migmatites and mylonites of the NZ, subtypes S7, S2, S12 and S8 are most common.

The preliminary results of comparative zircon morphology studies show that the Niemcza Zone mylonites developed partly from gneisses and migmatites similar to those of the GSB. However, the observed systematic variation of zircon populations in the mylonites suggest that they could have developed in part also from other protoliths. More samples and application of other techniques (e.g. cathodoluminescence imaging) could highlight the problem in more detail.

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ARE OCEANIC PLAGIOGRANITES GENERATED BY PARTIAL MELTING OF GABBROS?

INTRODUCTION

Layer 3 of the oceanic crust, the plutonic section, consists of generally gabbroic rocks. Included in the gabbroic section are small, but ubiquitous amounts of leucocratic, evolved rocks composed of quartz diorites, tonalites, trondjhemites, so-called oceanic plagiogranites. Such rocks were drilled in several legs of the Ocean Drilling Program ("ODP", e.g., Southwest Indian Ridge, SWIR, Leg 176) and are also present in the plutonic sections of most ophiolites. For the genesis of oceanic plagiogranites at mid-ocean spreading systems, two models are under discussion: (1) Late-stage differentiation of a MORB-type melt and (2) partial melting of pre-existing gabbros within high-temperature shear zones. In this study, we have applied recent experimental data of the experimental lab in Hannover to the plagiogranite petrogenesis in order to test both models. The role of water during the genesis of these rocks (presence of amphibole as mafic phase in natural plagiogranites) was assessed by including water to the systems.

METHODS OF INVESTIGATION

Crystallization experiments were performed in a MORB system doped with different water contents at different redox conditions at 200 MPa (Berndt 2002), and hydrous partial melting experiments were performed at 200 MPa on typical oceanic gabbros (Koepke et al. 2003 in press). For the experiments we have used an internally heated pressure vessel (IHPV) for high temperatures (up to 1250^0C) equipped with a rapid-quench system and a hydrogen membrane for controlling the oxygen fugacity.

RESULTS

Liquid lines of descent obtained via crystallization experiments are mainly controlled by oxygen fugacity and only to a little extent by water activity. SiO_2–rich residual melts can be obtained under both oxidizing and reducing redox condition at low temperatures, but at least one fractionation step is required to reach high-silicic plagiogranites (SiO_2 > 70 wt%). The partial melting of typical oceanic gabbro leads at

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low temperatures also to plagiogranitic melts. At 940^{0}C, the normalized SiO_2 contents of the experimental melts range between 60 and 61 wt%, and at 900^{0}C from 63 and 68 wt% (based on 3 different oceanic gabbros from ODP Legs 176 and 153 as starting material). These melts coexist with orthopyroxene, amphibole, plagioclase and in one sample also with olivine. The experimental melt compositions are compared with those of natural plagiogranites of different tectonic settings and show in general a broad compositional overlap with those. Our experiments imply, in concordance with the natural systems, that TiO_2 is a key parameter for discrimination between both processes: TiO_2 is low in anatectic plagiogranitic and high in those plagiogranites generated by differentiation (Fig. 1).

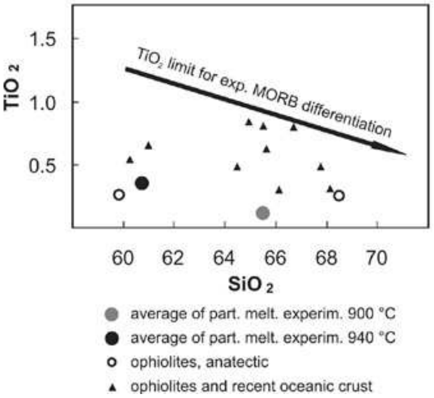

Fig. 1. Compositions of oceanic plagiogranites both from experiments and nature. The averages of the partial melting experiments on natural oceanic gabbros are based on 3 different compositions. The origin of those plagiogranites from ophiolites generated by anatexis is evidenced by field and textural relations. The curve of TiO_2-limit is based on crystallization experiments in a MORB system at low temperatures (with low melt fractions, Berndt 2002). All these experiments, even those under oxidizing conditions, lead to TiO_2 contents in the residual melts lying above this curve. References are given in Koepke et al. 2003 in press.

The ~1500 m long drilled gabbroic section of the Legs 118 and 176 from the Southwest Indian Ridge (SWIR) contains numerous felsic veins, most of them with a plagiogranitic composition. The compositions of the melts, observed in our experiments at low temperatures match those of natural SWIR-plagiogranites. This implies a model, that the felsic veins were generated by partial melting of gabbros. Further evidence is provided by high temperature microscopic veins within the SWIR gabbros, containing minerals which were formed by a water-rich fluid at temperatures up to 1000^{0}C. The othopyroxene and amphibole composition from the veins fit with the composition of crystals in our low temperature runs, indicating, that these minerals can be regarded as restitic minerals after removing of the coexisting (plagiogranitic) melt. Moreover, by carefully checking rocks from reference locations for oceanic gabbros (from East Pacific Rise, Mid-Atlantic Ridge, SWIR, and Oman ophiolite), we found nearly in every rock microstructures, which indicate that hydrous partial melting proceeded. This is manifested in plagioclase showing veins and irregular patterns that are significantly enriched in An, while clinopyroxene and olivine had reacted to orthopyroxene and pargasite. An-rich plagioclase, orthopyroxene, and pargasite are regarded as restitic crystals of a partial melting reaction. Striking is the compositional agreement with corresponding phases in our melting experiments on natural gabbro, indicating temperatures between 940 and 1000°C, shallow pressures in the crustal level, high water-activities (probably water-saturated) and slightly oxidizing conditions (~ Ni-NiO oxygen buffer) for the partial melting reactions. The temperature estimations are confirmed by geothermometry on coexisting pargasites and An-rich plagioclases leading to temperatures between 900 and 1000°C.

CONCLUSIONS

The experimental work shows that partial melting of oceanic gabbros has the potential to generate plagiogranitic melts, and the compositions of the experimental liquids fit with those of natural plagiogranites. Moreover we have observed nearly in all oceanic gabbros from reference locations the petrographical evidence that hydrous partial melting proceeded, indicating that hydrous partial melting is a "quite normal" processes occurring in the deep oceanic crust. The conclusion is that the oceanic plagiogranites typically found in the gabbroic oceanic crust may have generated by partial melting of gabbros and not by "extreme" differentiation of a MORB-type magma as assumed so far.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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MÉLANGE AT STANISŁAWÓW AND RZESZÓWEK IN THE KACZAWA MTS (SUDETES, SW POLAND): PRELIMINARY RESULTS OF NEW SEDIMENTOLOGICAL AND PETROGRAPHIC INVESTIGATIONS

INTRODUCTION

Mélanges have been recorded in deep boreholes near Stanisławów in the Chełmiec unit and cropping out along the Kamiennik stream at Rzeszówek in the Rzeszówek-Jakuszowa unit of the northern part of the Kaczawa Mts. They have been interpreted as mudrocks subjected to gravitational redeposition within an oceanic trench (Haydukiewicz 1987; Baranowski et al. 1998) and subsequently subjected to deformation and metamorphism during further evolution of the Variscan accretionary prism (Haydukiewicz 1987; Baranowski et al. 1990, 1998; Collins et al. 2000; Kryza et al. 2001).

The Kaczawa mélanges resemble those from recent accretionary prisms; being strongly lithified and amenable to detailed study, they are of considerable research value. Their depositional age remains controversial, though scarce conodonts in a part of the Rzeszówek profile suggest a Devonian - Early Carboniferous age (Haydukiewicz 1987). Our current investigations are part of a more extensive research project aiming at defining the spatial range of particular bodies of the Kaczawa mélanges, their sedimentological, petrographic and structural characteristics and, consequently, their age, origin and evolution.

METHODS AND SAMPLING

Our intial studies comprised logging and detailed sedimentological and petrographic description of selected drillcore segments from borehole 35/S near Stanisławów obtained from depths of 24.2-116.6 m (part of the "mélange association" according to Baranowski et al. 1998) and 914.2-916.0 m (the "metamudstone-diabase association"; op. cit.). Heavy mineral analysis was carried out using parts of the core fragments (Tab. 1, samples D & E) and three samples of the most characteristic rock varieties in the Rzeszówek section (Tab. 1, A, B & C). The grey muddy-siliceous slate (specimen C) was interpreted as a large block in the Różana mélange and dated by conodonts as Mid- to Upper Devonian; Haydukiewicz 1987). The heavy mineral concentrates

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(grain-size fractions of 0.125-0.09 and 0.18-0.125 mm, 300 grains identified in each fraction) were analysed using the EDS microprobe technique at Wrocław University.

RESULTS AND CONCLUSIONS

Based on the detailed sedimentological logging which we began in the Stanisławów mélange using the core segments from the depth interval of 24.2-116.6 m in borehole 35/S, three facies types in the mélange may be distinguished:

- type 1: dark-grey and black mudstones with several twenty millimeters-thick interlayers of fine to medium-grained light sandstone, deposited by a small scale turbidity current (Bouma D-E) in an anoxic environment (Fig. 1);
- type 2: green coarse-grained sandstones with interleaved mudstones (interlamination on a mm/cm scale), deposited by small scale turbidity currents (Bouma D-E);
- type 3: gray medium-grained laminated mudrock (associated with type 2); the mudstones are interleaved with very fine-grained brownish sandstones with reddish mineral spots (probably after pyrite).

Fig. 1. Scanned thin section of mélange (type 1): dark-grey mudstone with strongly deformed and partly disintegrated layers of pale sandstone. Borehole 35/S, depth 24.5 m. The longer edge of photo is 40 mm.

The rocks from the depth of 914.2-916.0 in the same drill core comprise mainly fine- to medium-grained bedded green sandstones (Bouma B-D). The beds vary in thickness from several to under a hundred cm, and are separated by thin (millimeter-size) interlayers of dark mudstone. The two segments of the drillcore, from very different depths, display some structures indicative of soft-sediment deformation (cf. Collins et al. 2002). No trace or body fossils have been noticed in any of the rocks examined by us.

The heavy mineral compositions of the two grain fractions investigated do not differ much. The two mélange matrix samples (Tab. 1. A, D) show a considerable amount of pyrite and dark micas (strongly altered biotite). The same components are abundant in the medium-grained green sandstones from Stanisławów (Tab. 1. E). This may be an argument (apart from the textural similarities noted above) for close affinity of some rock types within the “older stratigraphic succession” and the mélanges. Two other samples from the Kamiennik stream section (Tab. 1. A, C) contain, very characteristically, Fe-Mg-Mn carbonates (up to 81% in sample C). Further mineralogical and geochemical investigations, focused on more detailed characteristics of the mineral phases, may provide useful constraints for deciphering the origin of these intriguing rocks.

Table 1. Heavy mineral assemblages in studied samples (fraction 0.125-0.09 mm) in vol.%.

Sample		Apatite	Zircon	Ca-Mg-Fe carbonates	Fe-Mg-Mn carbonates	Dark micas	Pyrite	Chalcopyrite	Rutile	Other
A	Muddy mélange matrix (Kamiennik)	1	-	-	5	76	17	-	-	1
B	Sandstone olistolith (Kamiennik)	31	28	-	-	1	20	2	17	1
C	Grey muddy-siliceous slate (Kamiennik)	-	-	-	81	8	2	4	-	5
D	Mélange from Stanisławów (type 1, borehole 35/S, 24.2-5m)	2	1	-	-	12	84	-	1	-
E	Medium-grained green sandstone from Stanisławów (borehole 35/S, 915.2-4m)	7	3	14	-	11	60	-	5	-

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Stanisław KOSZELA[1]

RARE EARTH ELEMENTS CHARACTERISTIC OF CARBONATE ROCKS FROM THE KŁODZKO METAMORPHIC UNIT

GEOLOGICAL SETTING AND PETROGRAPHY

The Kłodzko Metamorphic Unit (Sudetes) is composed of metasedimentary and metaigneous rocks metamorphosed at greenschist to amphibolite facies conditions (Wojciechowska, 1990). In the upper part of the Kłodzko Metamorphic Unit there are metamorphic rocks that include marbles with corraline fauna of Givetian age (Hladil et al., 1999). They are unconformably covered by unmetamorphosed late Frasnian pelagic limestones of the Bardo Mountains Unit. The lenses of the marbles appear in the lower (Bożków) and in the upper (Łączna) formation of the Kłodzko Metamorphic Unit. These formations are composed mainly of phyllites and chlorite schists and they are probably in the tectonic contact (Mazur & Kryza, 1999).

The marbles are fine- to medium grained, distinctly laminated. As follow from the thin section observations, they are composed of calcite and dolomite laminas in varying proportions, with quartz, muscovite, chlorite and opaque grains (pyrite). Dolomite has a fine grained (0.1 to 1 mm) and calcite has a coarser grain size (1 to 3 mm). The calcite prevails over the dolomite.

METHODS

Rare earth elements (REE) concentrations in samples of marbles and schists from the Kłodzko Metamorphic Unit were determined by neutron activation analysis (NAA) at Activation Laboratories Ltd, Ontario, Canada. Rare earth elements (La, Ce, Nd, Sm, Eu, Tb, Yb, Lu) concentrations in marble samples are very low and concentration of Tb is below detection limit. In REE distribution patterns contents of this element were calculated by linear interpolation.

The samples of the marbles and schists were collected from the Łączna and Bożków formations.

RESULTS

The REE contents of the marbles and schists were normalized (REE_N) to Post-Archean Australian shale (PAAS) (Taylor & McLennan, 1985). The schists (samples K6, K716, K1516) and the marbles of the Kłodzko Metamorphic Unit reveal similar

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REE_N patterns (Fig. 1), and they are characterized by very low REE contents and a nearly flat light REE_N (LREE) patterns. They are showing relative enrichment in heavy REE (HREE), slight negative Ce anomaly in some marble samples and slight positive Eu anomaly. The slight negative Tb anomaly is noticed in the schist and distinctly negative Tb anomaly is observed in the marbles patterns.

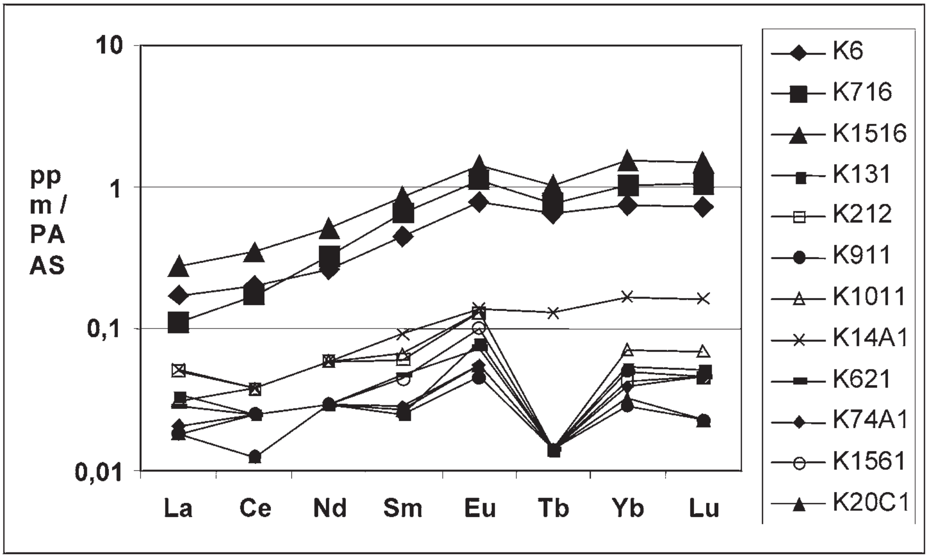

Fig. 1. REE diagram for selected schists (K6, K716, K1516) and crystalline carbonate rocks of the Kłodzko Metamorphic Unit, normalized to the PAAS (average 23 post-Archean shale from Australia /Taylor & McLennan, 1985/).

DISCUSSION

Marine water commonly possesses a negative Ce anomaly (Hu et al., 1988) which is then inherited by carbonates formed in equilibrium with seawater in marine environment. Absence of the Ce anomaly in some marble samples of Kłodzko Metamorphic Unit suggests diagenetic and/or metamorphic overprint which is most likely the reasons for some minor deviation of some REE_N patterns from the ideal marine signature.

The Eu anomaly in sedimentary rocks may be result of enrichment of plagioclase contents, sedimentation in alkaline pore water of anoxic marine conditions or interaction of the rocks with the magmatic fluids (McLennan, 1989). In diagenetic conditions, below 100 ^{O}C, the Eu in aqueous solutions is dominant by trivalent state (Sverjensky, 1984). Slight positive Eu anomaly in the marbles of Kłodzko Metamorphic Unit suggests that changes in REE contents of the sediments could not be attributed to diagenetic processes, but they might be connected with the interaction of magmatic or metamorphic fluids. The marbles protolith from Kłodzko Metamorphic Unit were deposited rather in normal redox conditions with only small changes in REE distributions connected to plagioclase contents.

The reason of the negative Tb anomaly is not clear.

The flat shape in $HRRE_N$ distributions (apart Tb anomaly) indicates no influence of the heavy mineral contents on the REE_N patters of metasediments of the Kłodzko Metamorphic Unit (McLennan, 1989). The similarity of the REE_N distributions in both marbles and schists from Kłodzko Metamorphic Unit suggest that these rocks were formed in the same sedimentary basin and probably in quite similar geochemical conditions.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Marek KOŚCIŃSKI[1]

DIVERSITY OF THE SULFUR ISOTOPIC COMPOSITION IN THE INDIVIDUAL SULFIDE MINERALS FROM THE COPPER LUBIN MINE, SW POLAND

INTRODUCTION

In this area ore minerals usually create dispersed deposits, veins and caverns. Sulfide minerals often associate with other minerals like: tennantie, tetraedrite; sulfates: gypsum, barite, anhydrite; and carbonates: calcite and dolomite. Sulfur isotopic composition of these sulfides has been investigated already (Jowett (1991); Sawłowicz (1989), etc), nevertheless, the next research may provide a potential source of information necessary to explain some aspects of the genesis of copper deposits.

MATERIAL AND METHODS

A hundred and four samples of sulfide minerals collected in the area of the Lubin mine were used for the isotopic studies. The ore minerals samples were purified of possible carbonates, sulfates and organic matter by the hydrochloric acid and magnetic separation method. Sulfides were subsequently transformed into SO_2 with the use of Cu_2S. Sulfur isotopic ratios were determined on modified MI-1305 mass spectrometer at Institute of Physics at Marie Curie - Sklodowska University in Lublin. Accuracy of the measurement was higher than 0,1‰. Isotopic ratios were presented with $\delta^{34}S$ in relation to the CDT standard.

RESULTS

The analyzed samples of the sulfides were collected from the Boundary Dolomite, located directly under the Kupferschiefer; from Kupferschiefer and the first 8 meters of Zechstein Limestone, located directly above the Kupferschiefer. The ore concentration in the higher parts of Zechstein Limestone are very poor or none. With growing distance from the Kupferschiefer up and down the profile, the content of sulfides in the ore body decreases. At the Lubin copper mine the Kupferschiefer and the Zechstein Limestone are the main sources of the ore-deposits. The minerals which have been separated:

- **Pyrite Fe_2S** – The samples were collected from the roof part of the Kupferschiefer and the sill part of the Zechstein Limestone. They were mostly represented by dis-

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persed forms. The values of $\delta^{34}S$ range from -44,91 to -42,01‰ (average -42,73‰ for 9 samples).

- **Chalcocite Cu_2S** – The samples were collected from the Boundary Dolomite, the Kupferschiefer, and the Zechstein Limestone. They were represented by dispersed and vein forms. The values of $\delta^{34}S$ range from -39,90 to -22,70‰ (average -33,01‰ for 13 samples).
- **Chalkopyrite $CuFeS_2$ and Bornite Cu_5FeS_4** – The samples were collected from the Kupferschiefer and the Zechstein Limestone. They were mostly represented by vein forms. Their sulfur isotopic composition is very diverse. The values $\delta^{34}S$ for Chalkopyrite range from -35,00 to -24,80‰ (average -28,89‰ for 17 samples), and for bornite from -37,20 to -23,30‰ (average -31,66‰ for 16 samples).
- **Covelline CuS** – The samples were collected from the Zechstein Limestone. They were represented by vein forms. The value $\delta^{34}S$ range from –25,10 to –23,90‰ (average –24,27‰ for 3 samples).
- **Digenite Cu_9S_5** – The samples were collected from the Kupferschiefer. They were represented by dispersed forms. The values $\delta^{34}S$ range from–38,80 to –33,36‰ (average –35,86‰ for 13 samples).
- **Galena PbS and Sfalerite ZnS** – The samples were collected from the Kupferschiefer and the Zechstein Limestone. They were mostly represented by fine-crystaline galena, and disperse sfalerite. The value $\delta^{34}S$ for galena range from –29,80 to 23,69‰(average 25,37‰ for 15 samples), for sfalerite from –31,50 to –23,55‰ (average 27,13‰ for 11 samples).
- **Tennantite $Cu_{12}Sb_4S_{13}$ and Tetraedrite $Cu_{12}As_4S_{13}$ (series)** - The samples were collected from Boundary Dolomite. They were mostly represented by vein forms. They are isotoply the heaviest among all the found minerals. The values $\delta^{34}S$ range from –10,23 to –7,68‰ (average –11,79‰ for 7 samples).

CONCLUSION

Diversity of the sulfur isotopic composition in individual minerals is very large. All the values are negative. The negative values, and such a big diversity of $\delta^{34}S$ could result from: differences in crystallochemical structure of the individual minerals (sulfides), conditions of pH – pOH, and value of $\delta^{34}S$ in H_2S. The source of sulfur in the particular sulfides was H_2S, produced probably as a result of a bacterial reduction of sulfates (Michalik, Sawłowicz 2000). It is possible that these sulfides were created in a progressively closing system (Nielsen 1985). The lightest sulfides like pyrite ($\delta^{34}S$ value are very close Jowett (1991b), Sawłowicz (1989)), were formed at the beginning when the access to sulfates was practically unlimited. Progressively when the system was closing, the access to sulfates was more and more limited; isotoply heavier H_2S was being formed and heavier sulfides followed. And so we can advance a hypothesis that pyrite was a mineral formed in the early stage of the producing of the polymetallic ore deposits, while the mineral series tennantite-tetraedrite is the one that was formed at the last one. We should notice that there is a big diversity of the sulfur isotopic composition within the same mineral e.g. chalcocite or bornite. It may prove that the process of formation the ore mineralization was prolonged, multi-staged and multi-phased (Michalik, Sawłowicz 2000).

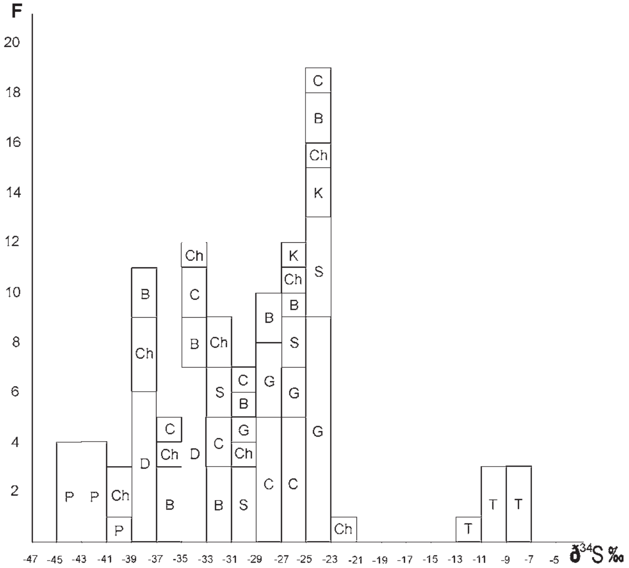

Fig. 1 Histogram of sulfur isotope composition of sulfide minerals, Lubin copper mine. *P-pyrite; Ch- chalcocite; D-digenite; B-bornite; C-chalkopyrite; S-sfalerite; G-galena; K- covelline; T-tennantite-tetraedrite*

Zechstein evaporates could be the second source of sulfur in the later stage of composing the sulfide mineralization, which explains the improvement of younger minerals in a heavier isotope (for Permian evaporates $\delta^{34}S=10‰$). The isotope research proved that the process of forming the polymetallic ore deposits on the Sudetic Monocline was very long and very complicated.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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LITHIUM IN QUARTZ IN THE ROCKS OF THE LOG ŚWIERADÓW – MROCZKOWICE ALONG THE KWISA RIVER, IZERA AREA, SW POLAND

INTRODUCTION

The investigated log in the bed of the Kwisa River is located in Izera area, the northern part of the metamorphic cover of the Variscan Karkonosze granitoid massif in Sudetes (Mazur 2002). This cover consists of the so-called Izera gneisses and granite-gneisses (Kozłowska-Koch 1965) of the age ca. 500 Ma (Borkowska et al. 1980), embedding four W–E zones of the epidote-albite-amphibolite facies (acc. to Turner 1948) metapelites and intercalations of amphibolites and leptinite gneiss, probably metamorphosed tuffs (Kozłowski1974). The gneisses are altered in many places to albite metasomatites (called leucogranites) and to quartz-topaz-mica-tourmaline greisens (Karwowski 1976). The investigated log extends from the point located ca. 1.5 km to the south of the town of Świeradów to the point ca. 1 km to the north of the village of Mroczkowice; its total length is ca. 6.7 km.

SAMPLES

The study has been performed on the rock samples collected in 62 points (24 points in gneisses, 16 – in leucogranites (albite metasomatites), 15 – in mica-chlorite schists, 4 – in greisens and 3 – in amphibolites) taken along a log located in the Kwisa River bed from above Świeradów to below Mroczkowice. From each specimen two separate analytical portions have been obtained.

LABORATORY PROCEDURES

The rock samples have been cut to 0.5 mm thick slices. After thorough selection under microscope the quartz grains not containing solid inclusions have been picked from the slices by use of a corundum blade. The grains have been washed in acetone, methanol, hot aqua regia and next rinsed in hot water of high purity. The 124 analytical quartz samples of the weight of 1–5 mg have been placed in carbon electrodes and decomposed with HF of special purity in an air-tight plastic box, and then lithium has been determined with use of the spectro-graphical emission procedure (Walenczak 1969); the analytical error was ±9%.

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LITHIUM IN QUARTZ

Lithium contents in quartz and the mode of its distribution in the Izera area, which is generally poor in this element, were discussed else-where (Smulikowski, Walenczak 1966, Walenczak 1969). Quartz in the Karkonosze granitoids has high contents of Li (10 to 20 ppm), whereas in quartz from the Izera gneisses – from 0.1 to 1 ppm (op. cit.). The high ability of lithium to migrate was evidenced in the Karkonosze-Izera exocontact quartz (Kozłowski 2002).

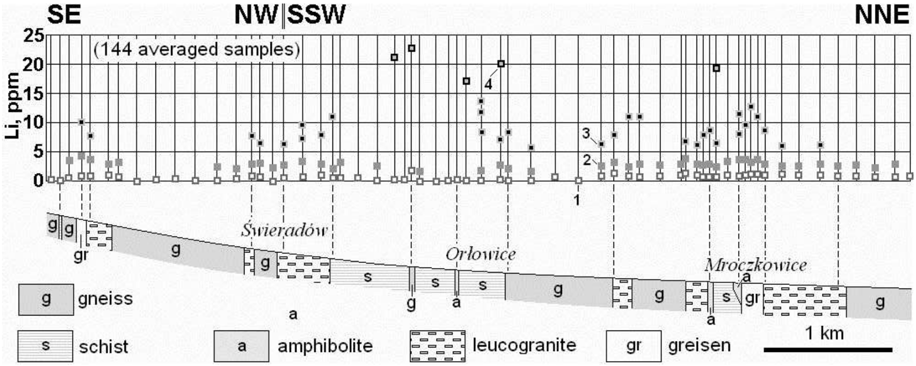

Fig. 1. Lithium contents in quartz from the rocks of the log in the Kwisa River bed, the distance from Świeradów to Mroczkowice, the symbols 1 – 4 are explained in the text.

The samples of quartz from the Kwisa log had four ranges of lithium concentrations (Fig. 1). Bluish metamorphic quartz in Izera gneisses and its relics in albite metasomatites and greisens contained Li concentrations from <1 to 2 ppm (symbols 1 in Fig. 1). The aggregates of the younger gray quartz, especially in albite metasomatites and greisens yielded Li contents 2–4 ppm (symbols 2 in Fig. 1), and quartz of the next generation from thin veinlets – 5–10 ppm (symbols 3 in Fig. 1). The quartz segregations, rarely occurring in leptinite gneiss and in amphibolite, had high contents of lithium, from 17 to 23 ppm (symbols 4 in Fig. 1).

CONCLUSIONS

The data, obtained by the studies of the lithium contents in the rock-forming quartz in the Kwisa log confirmed the original low concentrations of lithium (<2 ppm) in the metamorphic Izera complex. However, the quartz aggregates, formed due to the metasomatic processes, contained distinctly higher Li concentrations (2–4 ppm), what may be related to the influence of the external source of this element like e.g. lithium-rich Karkonosze granitoid. The hydrothermal process of metasomatosis in its final stage, when thin quartz veinlets were formed, caused crystallization of quartz rich in lithium (5–10 ppm). The enrichment of hydrothermal-metasomatic quartz in lithium is consistent with the relatively high concentrations of this element in hydrothermal solutions (0.1–1.8 wt. %), found by the leachate method in fluid inclusions by Karwowski (1976).

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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POST-MAGMATIC MINERALISATION IN THE GRANITOIDS OF THE STRZELIN MASSIF, SW POLAND – A FLUID INCLUSION STUDY

INTRODUCTION

The Strzelin crystalline massif in Lower Silesia, SW Poland, consists of the metamorphic unit comprising Upper Precambrian – Cambrian gneisses, older Precambrian or Lower Paleozoic schists and younger Middle Devonian schists (Oberc-Dziedzic 1999a), intruded by a complex assembly of stock and dyke granitoids of Variscan age dated for 347±12Ma to 330±6Ma (Oberc-Dziedzic 1999b). The granitoids contain moderately abundant pegmatite pockets, veins and metasomatic zones. Till now, preliminary fluid inclusion data for the post-magmatic mineralisation in the Strzelin granitoids were published by Stępisiewicz (1977), and the suggestions on the characteristics of fluids which altered Strzelin granite were proposed by Ciesielczuk and Janeczek (1999), and Ciesielczuk (2001). The chlorite geothermometry for the post-magmatic deposits in this granite was given by Ciesielczuk (2002).

SAMPLES AND METHODS

The pegmatite parageneses, studied in the current project, consisted of the mi-nerals listed in Table 1 and white albite, biotite and muscovite. Veins contained varieties of quartz, micas, K- and Na-feldspars, chlorite, laumontite, prehnite, fluo-rite and ore minerals. The sequence in Table 1 from garnet to calcite is the general crystallisation sequence found by petrographic methods. Zeolites crystallised later than earliest cleavelandite, and ore minerals essentially together with smoky and gray quartz, and chlorite; only bismuth was younger. The 56 samples of the post-magmatic assemblages (31 pegmatites and 25 veins) were used for the fluid inclu-sion investigations. The samples came from the biotite granite quarries at Strzelin and Mikoszów, and from the biotite-muscovite granite quarry at Gębczyce. Fluid inclusions were studied according to the procedure described by Marcinowska and Kozłowski (2003). The total of 1006 inclusions was investigated in all the samples (Table 1). The size of fluid inclusions ranged from ca. 50 μm in quartz, fluorite and calcite to less than 1 μm in zircon, epidote and garnet. The smallest investigated inclusions (in zircon and garnet) were 2.5 μm long and ca. 1 μm wide.

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RESULTS

The results of the studies of 1006 fluid inclusions (Table 1) yielded temperature ranges of the post-magmatic mineralisation in the Strzelin granitoids from 570 to 100°C and pressure from 1.4 to 0.8 kbar. The earliest solutions were pneumato-lytic, and after condensation the hydrothermal ones had total concentrations 6–7 wt. % with dominating NaCl and appreciable content of KCl. During decrease of temperature to 250–200°C the total concentration of the mineral-forming solutions increased

Table 1. Crystallisation conditions of the post-magmatic minerals in the Strzelin granites

Mineral	Fluid inclusion data (*N* – number of the studied inclusions)								
	Filling	*Tcr*, °C	*P*, kb	*S*, wt. %	NaCl	KCl	CaCl$_2$	CO$_2$	*N*
Gray quartz	G	*570*–430	*1.4*	?	?	?	?	+	74
	L	460–290	1.4-0.9	7–12	50–80	0–20	0–40	+	127
Morion, smoky quartz	G	*460*–350	*1.4*-0.8	?	?	?	?	+	39
	L	390–230	1.2-0.8	10–17	50–70	0–15	20–50	+	179
Rock crystal	L	250–120	0.9-0.8	1.5–18	70–95	0–5	5–30	+	155
Garnet	L	450–430	1.4	7–8	80	15	5	+	9
Topaz	L	455–410	1.4	6–9	85	15	–	+	7
Beryl	L	440–410	1.4	7–9	85	15	–	+	11
Tourmaline	L	420–390	1.4-1.3	7–9	80	15	5	+	10
Apatite	L	430–320	1.3-0.9	8–9	80	10	10	+	12
Sphene	L	440–400	1.4	7–8	80	10	10	+	8
Zircon	L	450–420	1.4	7–10	70	20	10	+	9
Cleavelandite	L	340–190	1.1-1.0	10–15	60	10	30	+	41
Prehnite	L	*195–170*	*~1.0*	14–16	65	10	25	?	19
Apophyllite	L	200–160	0.9	14–15	65	10	25	+	23
Epidote	L	230–180	*0.9*	14–15	65	10	25	+?	17
Fluorite	L	240–140	0.9-0.8	14–18	50-65	0–10	25-40	+	59
Chlorite*	L	300-260	1.0-0.9	13–14	70	10	20	+	14
	L	210–180	0.8	14–15	50	15	35	+	11
	L	160–150	0.8	5.4	70	10	20	+	10
Calcite	L	190–<90	0.8	1.5–14	60-80	5-10	10-35	+;–	73
Stilbite*	L	210–140	0.8	5–14	60-80	5-10	10-35	+;–	10
Laumontite*	L	230–170	0.8	14–15	50-65	0–10	25-40	+;–	14
Chabasite*	L	200–140	0.8	5–14	60-80	5-10	10-35	+;–	8
Pyrrhotite*	L	340–280	1.1	9–16	50–70	10	20–50	?	6
Pyrite*	L	280–170	1.0-0.9	14–15	65	10	25	+;–	14
Chalcopyrite*	L	350–260	1.1-1.0	10–14	65	10	25	+;–	15
Sphalerite*	L	345–220	1.1-1.0	10–15	60–65	10	25–30	+;–	19
Molybdenite*	L	350–300	1.1-1.0	8–12	70–75	0–10	15–25	+;–	9
Galena*	L	190–140	0.8	3–13	70-80	5-10	10-35	+;–	5
Aikinite*	L	230	0.8	12	80	5	15	?	3
Emplectite*	L	220	0.8	12	80	5	15	?	5
Bismuth*	L	190	0.8	14	80	0	20	?	6

Tcr, *P* crystallisation temp. and pressure, *S* total salinity, salt components in % of total content. Asterisks mark minerals, which occurred as inclusions in quartz, fluorite and calcite in the same growth zones as fluid inclusions and that were the basis of their parent fluid characteristic; G mainly gas, L mainly liquid; italics mean approximate values; "+" CO$_2$ present, "–" CO$_2$ absent; "?" determination impossible. Mineral identification by the WDS method.

to 15–18 wt. %, with high contents of $CaCl_2$. Afterwards, concentrations decreased to 3–1.5 wt. % and the solutions became again of the NaCl type. The lat-ter change was found earlier by Stępisiewicz (op. cit.), but the recent study did not confirm his statement on the very high concentration of Al in fluids. This author's rough determinations of decrepitation temperatures of sulphide minerals by metho-dic reasons cannot be compared to the values determined for the respective mine-rals in this study. The conditions of formation of chlorites, zeolites and ore mine-rals were determined from fluid inclusions in the growth zones of quartz, fluorite and calcite, in which the included grains of the listed minerals were found, thus the obtained values may be extended to these minerals. The presence of carbon dioxi-de in the mineral-forming fluids is common, what made possible to determine pres-sure of crystallisation of the minerals. The hydrothermal origin of the 0.5–1 mm zircon grains found in the quartz-chlorite assemblage, was recognised. Ciesielczuk (2002) obtained by chlorite thermometers 358 or 208°C as formation temperatures of this mineral, and she discarded these values. One her value meets the range 210–180°C obtained from inclusions and further precise recognition is reasonable.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Ewa KRZEMIŃSKA[1], *Bogusław BAGIŃSKI*[2]

THE KOŚCIERZYNA AND ŻARNOWIEC ENDERBITES (N-POLAND) PETROGRAPHY, MINERALOGY, GEOCHEMISTRY AND P –T RESULTS

INTRODUCTION

The Kościerzyna and Żarnowiec enderbites have traditionally been included to Kaszuby metamorphic complex within of Precambrian crystalline basement of northeastern Poland. This unit is recognized only by four deep boreholes, with scarce observations relating to the rock relationships. Kubicki and Ryka (1982) and Ryka (1990) presented hypothesis on polymetamorphic evolution of sedimentary rocks and al emphasized structural and petrogenetical analogy to Podlasie Complex. In contrast, Bagiński et al. (1999) suggested, that the enderbites formed as multiphase intrusion.

The age of studied enderbites is unknown, but they are interpreted as Palaeoproterozoic (Ryka, 1998). The aim of our study was to give petrographic and preliminary geochemical characteristic of Kościerzyna and Żarnowiec enderbites and reveal their geotectonic setting and relation to the adjacent East European Craton units.

ANALYTICAL METHODS

Electron microprobe analyses of minerals were performed at Lund University, Sweden and at the PGI in Warsaw. The whole-rock samples from Kościerzyna were analysed for major and trace elements by XRF. Also, whole rock analyses were selected from published studies (Dziedzic, 1982).

RESULTS

Mineral assemblages observed in Kościerzyna (KOS) and Żarnowiec (ZAR) enderbites are similar to each other: Qtz + Pl + Kfs + Cpx ± Opx + Hb + Bt + Ilm + Mag ± Ep + Ap + Chl. The clinopyroxene composition is in the range $Wo_{39–46}$ $En_{29–37}$ $Fs_{20–25}$ for the KOS and $Wo_{42–48}$ $En_{36–40}$ $Fs_{17–19}$ for the ZAR. The composition of orthopyroxene is in the range $Wo_{1.4–3}$ $En_{35–45}$ $Fs_{52–62}$ and $Wo_{1.3–1.7}$ $En_{42–48}$ $Fs_{50–56}$, respectively. The amphiboles from KOS are ferropargasite with 6.33–6.43 Si and 1.63–1.83 Al_{tot} a.p.f.u. (based on 23 oxygens). The amphiboles from ZAR

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are richer in Al_{tot} (1.8–2.1 a.p.f.u.) They fall into ferropargasite and magnesiohastingsite fields of Leake classification (1997). Biotite has relatively high TiO_2 contents in the range 6.06–4.24 wt %. The majority of the Mg- and Ti-rich biotite analyses come from the cores of grains. Plagioclases from the ZAR are more calcic ($An_{48–57}$) than those from the KOS ($An_{38–46}$). The coexisting K-feldspar has 92–93 % of the Or molecule.

Thermobarometric results from both KOS and ZAR enderbites are summarized in Fig.1. These were determined from the core compositions of large grains (c) and from the rim (r). Calibrations of pyroxene thermometer: Kretz (1994) and Fonarev and Graphchikov (1991) were applied. Temperatures were also estimated using the hornblende-plagioclase (Blundy and Holland, 1990), two feldspar (Fuhrman and Lindsley, 1988; Elkins and Grove, 1990) and orthopyroxene-biotite (Sengupta et al.,1990) termometers. Most samples give temperatures of 800–850°C and pressure 6 kbar. For partly chloritized orthopyroxene grains the two-pyroxene and opx-bt thermometers yield temperatures between 490 and 550°C.

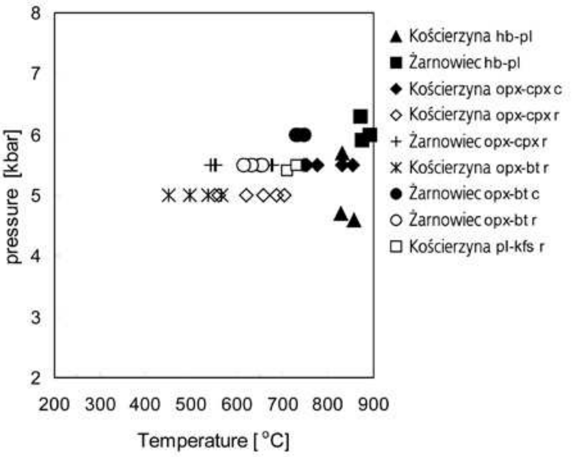

Fig. 1. P –T diagram for Kościerzyna and Żarnowiec enderbites.

The analysed enderbitic rocks have diorite-granodiorite composition. The samples span a wide range in SiO_2 (57.9 to 64.8 wt %). On the Harker variation diagrams, they display fairly distinct trends, analogous with trends presented by rapakivi-like granitoids from the Mazury Complex (Bagiński et al., 2001).

CONCLUSIONS

Detailed petrographic observations, electron microprobe studies and comparison of bulk-rock chemical analyses of the samples from Kościerzyna and Żarnowiec, yield new insights into the origin of enderbites from the Kaszuby Complex. On the basis of textural observations and p-T results, retrograde origin of amphiboles maintained in the earlier publications must be regarded as questionable. The p-T study demonstrates that rocks formed at relatively higher temperatures than earlier publications assumed.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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EPIMETAMORPHIC COMPLEX FROM PEŁCZNICA (NE PART OF ŚWIEBODZICE DEPRESSION) – REMARKS ON PETROLOGY AND TECTONOMETAMORPHIC HISTORY

INTRODUCTION

In the northern part of the Świebodzice Depression (Sudetes), among the Upper Devonian-Lower Carboniferous sedimentary infill of the basin, several epimetamorphic bodies occur. They are interpreted either as outcrops of fragmented Lower Palaeozoic basement of the basin (Dathe and Zimmermann 1912, Bederke 1929) or as folded nappes thrust over from the north, then folded together with the Upper Palaeozoic sedimentary sequence (Teisseyre 1968). In the area of Świebodzice, six separate bodies of greenschists and spilitic rocks have been documented, all interpreted as remnants of a nappe structure called Świebodzice Unit (Teisseyre 1968). This study presents the results of petrological, geochemical and structural investigations carried out within the epimetamorphic complex outcropping on 120 m section in Świebodzice-Pełcznica in the Pełcznica River bank.

PETROGRAPHY AND GEOCHEMISTRY

The Pełcznica epimetamorphic complex (PEC) comprises succession of basic and acidic metavolcanogenic rocks (laminated greenschists at the base and light-coloured to grey felsic, mainly Qtz-Ab schists at the top).

The greenschists series begins with laminated Ab-Chl-Ep schists in which dark laminae are composed of fractured, massive Ep-Zo aggregates with Chl and recrystallized Ab-Qtz aggregates sealing the fractures. Light-coloured laminae consist of variably recrystallized Ab-Qtz aggregates. Towards the top, these rocks grade into mylonitized greenschists with distinct relicts of primary volcanic structures: Ab and Ep porphyroclasts and flow structures. The matrix is built of recrystallized, anhedral, elongated Ab and Qtz with bands of Chl+Cc+Opq and strips of Pmp after Chl. Distinctly laminated Ab-Chl-Tr schists occur closer to the boundary with felsic rocks. Their green laminae consist of Chl, Pmp and Cc pseudomorphs after Tr, with relicts of Tr nematoblasts preserved. The dark-brownish laminae are composed of fine Opq and Ab-Qtz aggregates ± large Ep porphyroclasts overgrown with Cc and Qtz – probably pseudoporphs after Px.

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Felsic Qtz-Ab schists are built mainly of subhedral, elongeted Ab porphyroclasts, rarely Qtz. The matrix locally reveals lamination or, less commonly, brecciation. It consists of fine, tabular Ab grains and, occasionally, of Qtz. Bands of Ms grading into Chl are common. Chl is occasionally substituted by Pmp and bands or veinlets of Opq ± Stp(?).

The geochemical analysis of four samples from PEC, made by ICP, INAA method at Activation Laboratories Ltd. In Canada, revealed that the mafic rocks represent subalkaline (SALK) suite (Nb/Y <0.7; Zr/Nb ~13-20 with positive correlation suggesting co-magmatism) and can be classified as andesite-basalt (Zr/TiO_2-Nb/Y). On discrimination diagrams they plot within DPM (IA, VA, Th-Hf/3-Ta), VAB or VAB/WPT fields (Th-Hf/3-Y) as well as ACM field (Th/Yb-Ta/Yb). Inclination of curves on chondrite-normalized REE diagrams $(La/Lu)_N$ ~5 and low content of Yb (~4-5 times the chondrite value) may indicate enriched magma source or low degree of melting. MORB-normalized trace-element patterns exhibit a strong Y, Ta, Nb depletion and positive Th anomaly suggesting crustal contamination typical of active continental margin and within-plate environments.

Acidic metavolcanogenic rocks of PEC belong to SALK suite (Nb/Y <0.7; Zr/Nb ~35-50 with negative correlation), locating in rhyodacites field (Zr/TiO_2-Nb/Y classification diagram). On discrimination diagrams one of the samples locates in VAG field, another sample in ORG (e.g. Nb-Y; Ta-Yb; Rb-Y+Nb). REE diagrams are characterized by relative parallelism of flat curves (40-50 times the chondrite value) with significant negative Eu anomaly. Typical of acidic rocks depletion of Ti, P and Sr suggests fractionation of accessory minerals and Pl. Negative Y, Ta, Nb and positive Th anomalies indicate common contamination of magma with crustal material, while Th, LILE and LREE enrichment relative to Zr and Hf may indicate genetic relationship with active continental margin environment.

STRUCTURAL OBSERVATIONS

Mezoscopically observed tectonic features of PEC include foliation, faults, veinlets and kink-folds. The rocks possess very distinct, continuous and pervasive foliation, concordant with internal layering which dips almost vertically and strikes NW-SE. A fault zone can be traced at the boundary between the basic and acidic rock successions, which is conformable with the strike of foliation but inclined at about 15° angle to it. Macroscopically distinguishable veinlets (<1 mm thickness), dominantly composed of Cc, are very abundant. They form variously oriented conjugate sets. The veinlets are either continues or occur as arrays of low-angle tension gashes. Minor kink-folds occur irregularly in the whole metamorphic succession. Their geometry points to two genetic types – of contractional and extensional origin.

Microstructural observations carried out in thin sections revealed that the rocks are additionally cut by abundant, variously oriented veinlets composed of Ab-Qtz, Chl and Opq. Some of the Qtz-Ab veins consist of relicts of fibrous constituents, other evidence recrystallization. The veinlets form conjugate sets, as well as fill interboudine necks. Asymmetric boudinage of dark laminae and porphyroclasts is the dominant type of microboudinage. Both the host rock and some of Ab-Qtz veinlets recorded ductile deformation and recrystallization. Undulose extinction, deformation lamellae in Qtz, deformation twins with tapered edges in Ab, as well as irregular grain boundaries, subgrains, core-and-mantle structures of porphyroclasts are the most common indicators of such deformation.

CONCLUSIONS

PEC consists of SALK andesite-basalts and ryodacites. Beacuse of differences in curve distribution on REE diagrams and weak differences on trace-element patterns, it is difficult to assess genetic association of both rock types. Parallelism of the curves for both rock types may indicate co-magmatism. Mafic member of PEC probably derive from magma generated in active continental margin environment (VA or IA), contaminated with crustal material, however, it is also possible to associate them with within-plate environment of continental initial rift type. Ryodacite type rocks most probably represent products of partial melting of continental crust or, alternatively, they are contaminated by such material.

The rocks has experienced complex deformation of ductile and brittle type. The ductile deformation took place at low-grade metamorphic conditions. Recrystallization features recorded by Ab-Qtz suggest temperature in a range of 300-400 °C and differential stress in a range of 200-400 MPa. The presence of microboudines both in dark laminae and in recrystallized porphyroclasts evidences varying composition and competence of rocks prior to metamorphism. Asymmetric boudinage, abundant veinlets and relicts of fibrous minerals indicate deformation in general extensional regime. The same regime prevailed during subsequent brittle deformation.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Leszek KUROWSKI[1], *Patrycja KRAWCZYK*[1]

PETROGRAPHY OF THE SŁUPIEC FORMATION SANDSTONES (MIDLLE LOWER PERMIAN) IN THE NOWA RUDA REGION (INTRASUDETIC BASIN, SUDETES, SW POLAND)
– PRELIMINARY RESULTS

The Słupiec Formation makes up a considerable part of the clastic sediments profile of the Lower Permian strata in the Intra-Sudetic Basin. Its thickness reaches approximately 600 m. The sediments belong to the Middle Rotliegend (Upper Autunian). The Słupiec Formation is underlain by a horizon of fine-grained rocks called the Upper Anthracosia Shale, which forms the top of the Krajanów Formation (Lower Rotliegend = Lower Autunian). It is topped, on the other hand, by conglomerates (fanglomerates) of the Radków Formation – Upper Rotliegend (Saxonian) (Nemec et al.,1982).

The lower part of the Słupiec Formation is predominantly formed of sandstones with minor conglomerates and is referred to as the Building Sandstone. The top of the formation is dominated by fine-grained sediments of the Walchia Shale. All types of the sediments display characteristic red colour.

The article presents the preliminary results of petrographic analysis of the sandstone units of the Słupiec Formation. The samples were obtained from a set of outcrops on the Kościelec hill (S part of the Włodzickie Hills) near Nowa Ruda. The analysis comprised macroscopic and microscopic observations. Nine samples of mainly medium-grained (samples I/P1A, I/P1B, II/P5, IV/P2, VII/P5, IX/P1), more seldom coarse- (sample IV/P1) and fine-grained (samples VIII/P3, IX/P3) sandstones (tab. 1), were selected for microscopic observations The analysis was carried out using a semiautomatic Eltinor 3 point counter.

The sandstones of the Słupiec Formation are medium sorted with poorly (2-3) rounded particles (Pettijohn, 1975). The framework is generally compact. The relative abundance of matrix, exceeding 15% in all the samples, allows to classify the sandstones to wackes. However in some samples matrix exceeds 15% only slightly. The cement is mainly siliceous with admixture of clay and iron compounds (hematite, goethite). The framework is built of: (1) quartz – Q=Qm+Qp (where Qm and Qp stands for monocrystalline and polycrystalline grains respectively), (2) feldspars – F, comprising potassium feldspars (Fk) and plagioclases (Fp) and (3) lithic grains – L and Lt (where Lt=L+Qp).

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Quartz constitutes from 42,4 to 57,7% of the framework of the Słupiec Formation sandstones (tab. 1). Usually polycrystalline quartz dominates over monocrystalline (Qm/Qp ranges from 0,4 to 1,0). The size of quartz grains varies from 0,3 to 0,6 mm, rarely reaching 2,0 mm. The grains usually exhibit wavy or patchy extinction, some contain inclusions, mainly of muscovite. The feldspar content in the investigated samples varies from 10,1 to 23,8% (tab. 1). Plagioclases (8,3 – 17,9%) are noticeably more abundant than potassium feldspars (1,8 to 5,2%). Fk/Fp ratio is typically 0,2-0,3 and only in two samples reaches 0,5-0,6. Feldspar grains are mainly isometric, though there may also be elongated or irregular. Plagioclase grains from the Słupiec Formation sandstones often show polysynthetic twinning. Some grains of alkali feldspar are perthitic. Intergrowths of feldspar and quartz may also be noticed. Lithic grains are an important constituent of the sandstones. Their amount varies from 18,8 to 42,5%. Unstable lithic fragments are dominated by various types of metamorphic schists. The amount of volcanoclasts is also noticeable. The amount of sedimentary rock fragments is relatively small. Other lithic fragments are mainly plates of mica, usually muscovite or strongly chloritised biotite. Lithic grains are small, from 0,1 to 0,3 mm. Only some clasts of sedimentary origin reach up to 5,0 mm (mudstone intraclasts, mud curls).

Tab. 1. Petrographic composition of the Słupiec Formation sandstones.

Outcrop.	Sample.	Petrographic composition of framework [%].									Mtx.
		Q	Qm	Qp	F	Fk	Fp	L	Lt	∑	
I	P1A	56,9	18,6	38,3	15,4	5,2	10,2	27,6	65,9	99,9	15,3
	P1B	46,0	13,9	32,1	18,3	4,8	13,5	35,8	67,9	100,1	19,0
II	P5	57,4	21,5	35,9	23,8	8,2	15,6	18,8	54,7	100,0	17,0
IV	P1	46,9	22,7	24,2	10,1	1,8	8,3	43,1	67,3	100,1	15,4
	P2	43,2	15,1	28,1	14,3	3,6	10,7	42,5	70,6	100,0	17,2
VII	P5	46,5	18,6	27,9	19,9	4,8	15,1	33,5	61,4	99,9	20,3
VIII	P3	42,4	21,8	20,6	22,2	4,3	17,9	35,2	55,8	99,8	26,9
IX	P1	43,3	16,7	26,6	16,5	2,6	13,9	40,2	66,8	100,0	15,0
	P3	44,3	19,1	25,2	22,5	5,2	17,3	33,2	58,4	100,0	17,7

Q-quartz grains, Qm-monocrystalline quartz grains, Qp-polycrystalline quartzose lithic fragments, F-feldspar grains, Fk-K-feldspar, Fp-plagioclase, L-unstable polycrystalline lithic fragments, Lt=L+Qp, Mtx-matrix.

On the Q-F-L plot (Pettijohn, 1975) the Słupiec Formation sandstones cluster within the lithic wacke field (8 samples), except one sample that falls into the feldspar wacke field (Fig. 1A). On the Qm-F-Lt diagram (Dickinson & Suczek, 1979) they all gather in the lithic wacke field (Fig. 1B). This may suggest low maturity of the sediment. However it must be pointed out that this is due to high content of polycrystalline quartz (Qp) included in Lt.

On the Q-F-L projection (Fig. 1C) the Słupiec Formation sandstones fall in the field of sandstones derived from a recycled orogen (Dickinson & Suczek, 1979). Their projection points cluster mainly towards the lower boundary of the field suggesting that the sandstones composition corresponds best with the sediments of the uplifted foreland provenance. The alimentation area (uplifted foreland) was most probably formed of metamorphic rocks. This agrees well with high amount of metamorphic lithic fragments in the sandstones. On the Qm-F-Lt triangle (Fig. 1D) the Słupiec Formation sandstones plot along the boundary between magmatic arc (4 samples) and recycled orogen (5 samples) fields. This, on the other hand, may point to deeply dissected volcanic province as an alimentation area for the detrital material of the sandstones (Dickinson & Suczek, 1979).

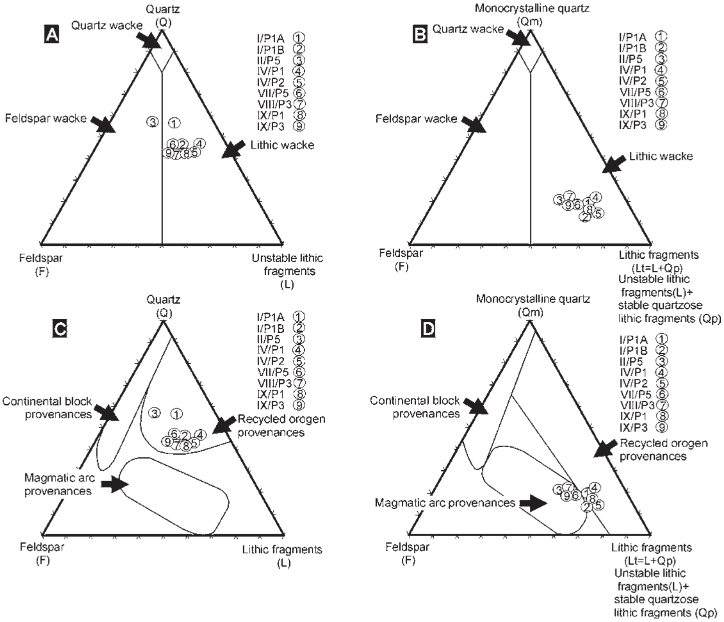

Fig. 1. Petrography of theSłupiec Formation sandstones on the Q-F-L (Pettijohn, 1975) (A) and Qm-F-Lt triangular diagrams (Dickinson & Suczek, 1979)(B) and the provenance of the detrital material inferred from the plots Q-F-L (C) and Qm-F-Lt (D) (Dickinson & Suczek, 1979)

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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SILESIAN BATHOLITH – AN IMPORTANT SUBSURFACE PHENOMENON IN THE EASTERN SILESICUM

Two large variscan granitic plutons crop out in the eastern Silesicum. They are the Žulova pluton on the North and the Šumperk Pluton in the South.

The major-element chemistry as well as mineralogy indicates that Žulová pluton could be classified as fractionated I-type granite. The less fractionated amphibole – biotite tonalites and granodiorites form enclaves with remarkable cumulate textures. They are enriched in HFSE and REE as a consequence of crystal accumulation of allanite, apatite, ilmenite and titanite, their feldspar shows a rather simple internal fabric in CL. The more fractionated biotite granites constitute substantial part of the batholith. The enrichment in LILE and depletion in HFSE and REE corresponds to higher content of K-feldspar and lower amount of accessory phases. Feldspars exhibit complex internal fabric in CL, indicating a major role for feldspar fractionation in the evolution of the batholith, as does the pronounced negative Eu anomaly and higher K/Ba ratio. The interpretation of gravity data indicates a fair homogeneity of the batholith.

The much smaller and poorly exposed Šumperk pluton could be petrological and geochemical well compared with the biotite granites from Žulova pluton. The major difference between both bodies is the degree of oxidation. The less oxidized Žulova pluton contains ilmenite, whereas the highly oxidized Šumperk contains magnetite and hematite. The presence of ilmenite in the Žulova pluton instead of magnetite, which is normally more common in I - type granites, could be explained by intrusion of the I-type magma in graphite bearing rocks (Branná or Velké Vrbno groups) serving as a reducing agent (Zachovalova et al. 2002).

Both bodies form local minima in a huge regional negative gravity anomaly. This regional anomaly firstly appears near the city Brzeg, on the Polish territory and continues in the NNE – SSW direction on a distance more then 130 km.

Preliminary estimate of the depth to the center of gravity of the Žulová pluton range from 3.3 to 5.0 km. Šumperk pluton seems to be much shallower. Its centre of gravity lies at the depth of 1.5 km only.

Geophysical, as well as petrological data indicate that the Žulova pluton together with Šumperk pluton are parts of much larger, but mostly unexposed granitic body. Rychtar et al. (1991) firstly term this hidden body as Silesian Pluton.

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Because of the granitic body seems to by quite large and composed of different lithologies eg. tonalites, granites, the more correct designation would be Silesian Batholith. The strong gravity gradient on the eastern edge of the gravity anomaly is a manifestation of the Červenohorske sedlo zone. This zone was probably responsible for the intrusion of the batholith. The area still exhibits certain tectonic activity, manifested by microearthquakes recorded recently south from Hanusovice. The focal depth of those tectonic events is approximately 20 km (Sýkorová at al. 2003).

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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PROVENANCE OF CLASTIC MATERIAL OF SANDSTONES OF THE S.C. CIECHOCINEK BEDS (LOWER JURASSIC) IN THE CZĘSTOCHOWA-WIELUŃ REGION (SW POLAND)

INTRODUCTION

The purpose of the study is to recognize the provenance of clastic material of sandstone intercalations within the Ciechocinek Beds outcroping at the Silesian-Kraków Upland. Early Jurassic (late Pliensbachian – early Toarcian) Ciechocinek Beds are silty-clayey deposits, distinguishing from other Liassic deposits in their characteristic greenish hue. They consist of poorly lithificated claystones, mudstones and siltstones with irregular, lenticular sand and sandstone interbeds, interpreted as brackish water sediments deposited in a shallow epicontinental sea (Pieńkowski 1997, Leonowicz 2002).

In the purpose of the provenance interpretation sandstones were studied for their mineral composition and properties of quartz grains by using methods proposed by Basu et al. (1975) and Dickinson et al. (1983).

METHODS

Dickinson et al. (1983) demonstrated that standard QFL and Q_mFL_t diagrams for plotting framework modes of sandstones can be used for the provenance interpretation of detrital material in relation to tectonic setting. Basu et al. (1975) showed that four parameters of detrital sand-size quartz: (a) amount of undulatory quartz, (b) amount of non-undulatory quartz, (c) amount of polycrystalline quartz and (d) number of crystal units per single polycrystalline grain, are useful for discrimination of sands of plutonic, low-rank and high-rank metamorphic parentage.

According to principles of those methods 18 samples of sandstones and 5 samples of sandy siltstones from exposure in Kozłowice and 12 drill-cores were sectioned and point-counted using the Gazzi-Dickinson method (Ingersoll et al. 1984). For each thin section 300 points were counted, taking into account following categories of grains: stable quartzose grains – Q (including monocrystalline quartz grains: Q_m and polycrystalline quartzose lithic fragments: Q_p), feldspar grains – F and unstable lithic fragments - L. Undulosity in quartz grains (undulatory quartz: Q_u, non-undulatory quartz: Q_n) and number of crystal units per single polycrystalline quartz grain (2-3 crystal units per grain: Q_{2-3}, more than 3 crystal units per grain: $Q_{>3}$) were also observed and counted. Presence of other components, such as micas and heavy minerals were noted, however they were not counted.

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In addition five samples of unconsolidated sands from exposure in Kozłowice were sieved to extract grains between 0,1 and 0,125 mm in diameter and heavy minerals were separated from them by gravity settling in bromoform. Heavy fraction were impregnated, sectioned and identified. For each thin section 600 points were counted.

RESULTS

Analysed sandstones are fine- and very fine-grained quartzose arenites and subarkoses (sensu Pettijohn et al. 1973). The major component of their framework is quartz (76 – 94%), which occurs as both, mono- and polycrystalline grains (Q_m and Q_p). Quartz Q_m is more common than quartz Q_p but the amount of the latter is also large (14 – 36%). Besides, up to 35% of the quartz Q_p contains more than 3 crystal units per grain ($Q_{>3}$). Non-undulatory quartz (Q_n) is more abundant (58 – 83%), but the amount of quartz Q_u is relatively large (17 – 42%).

Other detrital components of sandstones are: K-feldspars (showing usually advanced kaolinization), micas (mainly muscovite; strongly chloritizated biotite is less common), scarce plates of green chlorites, heavy minerals and unstable lithic fragments - L). The most common lithic clasts are fragments of sedimentary rocks: mainly cherts, rarely mudstones, siltstones and quartzose sandstones, and metamorphic rocks: quartzites, mica schists and quartz-mica schists. Fragments of volcanic rocks appear occasionally.

Heavy minerals suite is not diversified. It consists of components, which belong to the most resistant to weathering: zircon, rutile and turmaline. Staurolite and garnets are also common. Simultaneously in 2 samples biotite and chlorite plates were observed. Almost all minerals occur as several morphological types differing in shape and roundness. The most common are: euhedral forms, angular fragments and well-rounded oval grains.

Analysed sandy siltstones have similar mineral composition of detrital framework and differ from sandstones mainly in a grain size.

PROVENANCE OF DETRITAL MATERIAL

Source rocks

Comparing properties of quartz grains with criterions presented by Basu et al. (1975) it can be stated that clastic material of studied sandstones are mainly of middle- and high-rank metamorphic parentage. However, taking into account the fine fraction and compositional maturity of deposits, it is very probable that amount of polycrystalline and undulatory quartz was originally higher and the presence of low-rank metamorphic rocks in a source area is likely. Contribution of plutonic rocks was also possible. Composition of lithic fragments and heavy minerals suite confirms such interpretation.

Tectonic setting of source area

Framework modes plotted on QFL and Q_mFL_t diagrams (Dickinson et al. 1983) point to quartzose recycled orogenic provenance of studied sandstones. The compositional maturity of deposits, presence of different morphological types of heavy minerals and occurrence of the most resistant to weathering components together with biotite and chlorite lead to the conclusion that the detrital material had to be redeposited several times.

Interpretation of source area setting

During Late Pliensbachian-Early Toarcian time the Polish part of epicontinental sedimentary basin was bordered to the south-west by Sudety and Silesian-Kraków Land (Deczkowski, Franczyk 1988), where various metamorphic and clastic rocks were exposed. It is the most likely that those rocks supplied detrital material forming studied sandstones of the Ciechocinek Beds. For the first time detrital material could be redeposited in Variscian cycle, when clastic rocks of the Upper Silesian area were deposited. Next stages of redeposition could occur in Late Triassic and beginning of Early Jurassic time, when clastic sedimentation persisted in different continental environments of the Silesian-Kraków area.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Anna LEWANDOWSKA[1], *Mariusz ROSPONDEK*[1]

GEOCHEMISTRY OF VOLCANICS OF THE ZALAS AREA NEAR KRAKÓW, SOUTH POLAND

Volcanic rocks, cropping out in several places between villages Głuchówki, Zalas, and Frywałd, result from the Late Carboniferous-Early Permian igneous activity along the NE margin of the Upper Silesian Block. They exposures are concordant with the gravimetric anomaly of a diameter of 4-6 square km (Kurbiel 1978). The outcropping porphyritic rocks differ in their structure, colour (red, dark grey to black) and phenocrysts content. Their macroscopic and microscopic diversity, in the Zalas quarry, lead Harańczyk (1989) to the concept that they represent several magmatic events. Red varieties were classified as rhyodacides (Sutowicz 1982, Muszyński 1995 and the literature cited therein, Czerny and Muszyński 1997). Dark varieties were described as andesites (Harańczyk 1989). The subsequent studies confirmed the presence of black "andesites like" varieties but their chemical classification based on major elements placed them in the field of medium-K rhyolites close to the border with dacites (Musiał and Muszyński 1996). The black colour of these rocks is ascribed to their enrichment in ilmenite up to 15 % vol. (Musiał and Muszyński 1996). Judging from the earlier study on the tectonics of the porphyritic intrusion, all the outcrops belong to a single magmatic stock (a laccolith), resulting from magma injection into the Lower Carboniferous mudstones (Dżułyński 1955).

This study presents the new geochemical on volcanic rocks outcropping in the Zalas, Zalas Skała, Frywałd and Głuchówki - Orlej area, which is based on XRF analysis of major and trace elements, aiming to reveal these rocks geochemical diversity. These results are compared with those obtained earlier (Czerny and Muszyński 1997; Musiał and Muszyński 1996).

METHODS

Felsic rock samples were collected in the Zalas main quarry (five samples differing in colour from red to dark grey), in the old quarry "with the fault" - one sample), Frywałd (two samples) and Głuchówki-Orlej (three samples). The dark matrix varieties from the main Zalas quarry resembled those described by Harańczyk (as andesites). The rocks were analysed at Keele University, UK, using an ARL 8420 X-ray fluorescence spectrometer, calibrated against both international and internal Keel standards of appropriate composition. Analytical methods and precision were described by Floyd and Castillo 1992.

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RESULTS AND DISCUSSION

The porphyritic rocks of the area studied have the SiO2 content varying between 67 and 71% and show low iron and magnesium content. On the TAS diagram the analysis projection points are clustered at the joint of the rhyolite-dacite fields (Fig. 1a). Similarly, on the SiO2-K2O diagram they plot in the rhyolite and dacite field (Fig. 1b), though they are scattered between medium- and high-K varieties. This variation is attributed to potassium metasomatism (Słaby 1987). On the Zr/TiO2-SiO2 plot (Fig. 2a), the samples are placed at rhyodacite/dacite field. The enhanced Nb content causes them to plot along the border with trachyandesite field on the Nb/Y-Zr/TiO2 diagram (Fig. 2b).

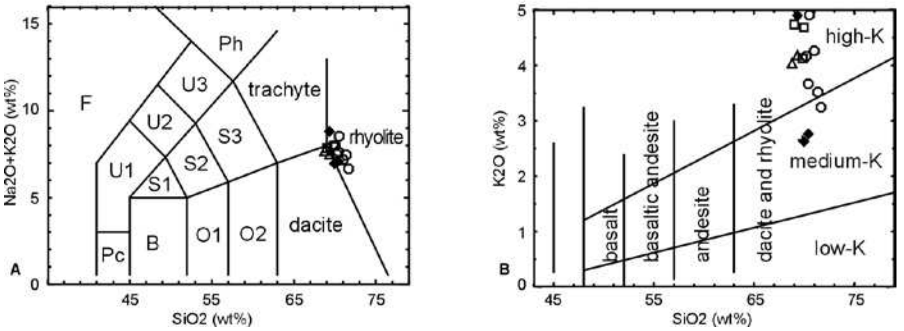

Fig. 1. Discriminant diagrams illustrating the magmatic affinities of rocks (after Le Maitre et al. 1989): A) Total alkali-silica diagram TAS; B) SiO_2-K_2O diagram, (O - main quarry-Zalas, Frywałd; + - Zalas quarry "with the fault"; ☐ - Głuchówki-Orlej; Δ- Zalas Skała; ♦ - data from Czerny and Muszyński (1997), and Musiał and Muszyński (1996).

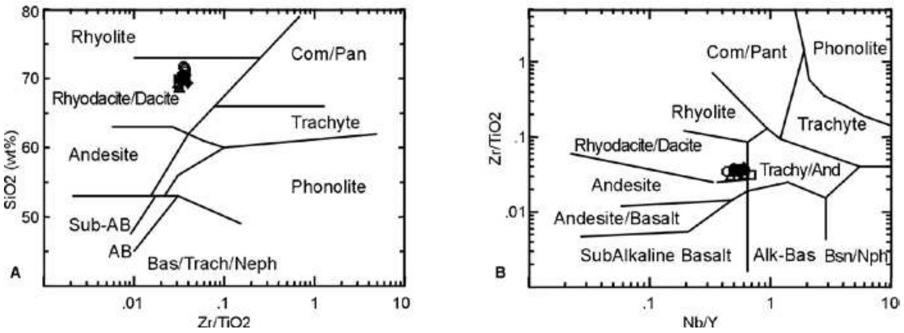

Fig. 2. Discriminant diagrams (after Winchester and Floyd 1977): A) Zr/TiO_2 - SiO_2 diagram, B) Nb/Y-Zr/TiO_2 diagram, symbols as in Fig. 1.

All the rocks analysed plot as a single uniform cluster in (Fig. 2A and B) and showed that these rocks can be classified as rhyodacites. This agrees with earlier data by Musiał and Muszyński (1996) and Czerny and Muszyński (1997). The geochemical analyses on both the main and trace elements give no support for distinguishing andesites.

SUMMARY

The geochemical characteristics of volcanic rocks studied does not show any difference neither among rocks from different localities in the Zalas area nor among varieties of different colour and structure. The rocks are entirely rhyodacites, andesitic varieties have not been found. This confirms the results of the earlier studies suggesting that these rocks represent comagmatic suite with rather small variation in the magma differentiation procgress..

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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FLUID INCLUSIONS IN QUARTZ FROM METAPELITES OF THE STARA KAMIENICA CHAIN, SUDETES, POLAND

INTRODUCTION

The metapelite Stara Kamienica complex (chlorite-mica-quartz schists with garnets, cf. e.g. Kozłowski 1974, Marcinowska 2002) of the Izera area in the northern metamorphic cover of the Karkonosze granitoid massif in Sudetes (Mazur 2002) forms a west-east stripe within the so-called Izera gneisses and granite-gneisses (Kozłowska-Koch 1965) of the age ca. 500 Ma (Borkowska et al. 1980). The schists host the cassiterite-polymetal and Co mineralization (Szałamacha, Szałamacha 1974, Wiszniewska 1984), which is out of scope of the current study and fluid inclusions in the quartz of the ore parageneses were described elsewhere (Kozłowski 1978, Wiszniewska et al. 1998).

SAMPLES AND METHODS

The 174 samples of quartz were collected from the studied complex, among which 139 samples were appropriate for the fluid inclusion studies. The studied samples came from the whole length of the Stara Kamienica chain (76 samples) and from three N–S logs at the settlements of Proszowa (17 samples), Krobica (22 samples) and Czerniawa Zdrój (24 samples). The sampling points were selected to avoid the signs of the ore mineralization. From each sample two to four double-side polished preparations 0.2–0.5 mm thick were prepared. The routine homogenisation and freezing methods were applied for the investigated inclusions (Roedder 1984); the dual-purpose heating–freezing microscope stage (type Fluid Co.) was used. For the calculations of the fluid inclusion data the programme *Fluids*, kindly supplied by Dr. Ronald Bakker from the Montanuniversität Leoben, was used.

FLUID INCLUSIONS

The total of 2340 inclusions was investigated in all the 139 samples. This number does not include 711 inclusions in 54 preparations made from other 29 samples, in which the compositions of solutions and gases were studied earlier (Marcinowska, Kozłowski 1997). The characteristic, given in the latter publication, albeit consistent with the currently obtained data, will not be repeated here. The present elaboration will discuss only crystallization temperatures, pressures and salt concentrations of the

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parent solutions of quartz, obtained from fluid inclusions in this study. The characteristics of the inclusions, filled with nitrogen, carbon dioxide and methane, used for calculations of the temperatures and pressures of crystallization of quartz, were presented earlier (Marcinowska, Kozłowski 1997).

The following seven types of aqueous inclusions were found in the recent studies (listed in sequence of formation, from the oldest to the youngest ones):

1. Inclusions, which occurred rarely, <1 μm to 7 μm in size, filled by solution of the total salinity (S) of 16–27 wt. %. The inclusions up to 3 μm had no signs of changes of their vacuoles and yielded temperatures (*Tcr;* here and later the temperatures of crystallization) from 480 to 540ºC and pressures (P) ca. 2.8 kbar. However, the larger ones showed evident leakage and did not yield any consistent temperature and pressure data. Such inclusions occurred in small (1–2 mm) "grains" of quartz, separated from the surrounding quartz by a zone of submicrometer-size inclusions of silicates of iron and magnesium with variable aluminium and occasional potassium presence (Cameca sx100 electron probe determinations). These tiny mineral grains probably were micas and chlorites.

2. Inclusions of aqueous solutions with S 7–9 wt. %, *Tcr* 280–340ºC, P 2.4–2.6 kbar; those, that were 1–4 μm in size, had no signs of leakage, the larger ones were damaged.

3. Inclusions of aqueous solutions with S 16–20 wt. %, *Tcr* 350–420ºC, P 3.1–3.4 kbar; small part of the inclu-sions, which were larger than 4 or 5 μm, were damaged.

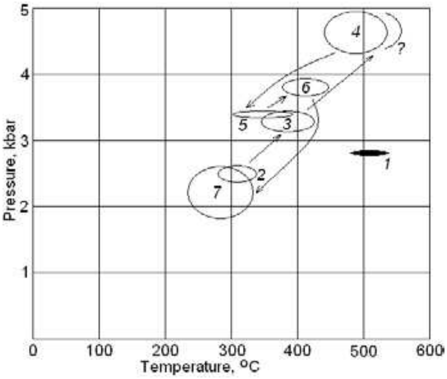

Fig. 1. Pressure and temperature changes during metamorphism of the Stara Kamienica schists.

4. Inclusions of aqueous solutions with S 17–23 wt. %, *Tcr* 440–530ºC, P 4.3–4.9 kbar; few, not very reliable determinations yielded *Tcr* ca. 550ºC; inclusions smaller than 4 μm, some with apparent stretching traces.

5. Inclusions of aqueous solutions with S 13–14 wt. %, *Tcr* 300–390ºC, P 3.3–3.4 kbar; inclusions were smaller than 3 μm.

6. Inclusions of aqueous solutions with S 16–20 wt. %, *Tcr* 380–440ºC, P 3.7–3.9 kbar; inclusions were smaller than 5 μm.

7. Inclusions of aqueous solutions with S 8–13 wt. %, *Tcr* 330–230ºC, P 1.8–2.6 kbar; inclusions were smaller than 10 μm.

CONCLUSIONS

The fluid inclusion study in metamorphic quartz from the schists of the Stara Kamienica belt indicated, that some relic quartz grains contain probably pre-metamorphic inclusions (type 1). Metamorphic fluid inclusions recorded the events at *Tcr* 280–

340ºC, P 2.4–2.6 kbar, *Tcr* 350–420ºC, P 3.1–3.4 kbar, *Tcr* 440–530ºC, P 4.3–4.9 kbar, *Tcr* 300–390ºC, P 3.3–3.4 kbar, *Tcr* 380–440ºC, P 3.7–3.9 kbar and *Tcr* 330–230ºC, P 1.8–2.6 kbar (Fig. 1). Note the increased P and T of the metamorphic process evidenced by the inclusions of the type 6.

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VARISCAN ACID MAGMATISM AND RELEVANT PORPHYRY TYPE MINERALISATION IN THE CRACOW-LUBLINIEC TECTONIC ZONE (SOUTHERN POLAND)

INTRODUCTION

Manifestations of the Late Carboniferous magmatism and relevant mineralisation of porphyry type are observed in the area situated between Myszków and Mrzygłód within Cracow-Lubliniec tectonic zone.

The magmatism, mainly of granitoid type, was recognized in the border zone of Małopolska Block (Myszków-Mrzygłód, Zawiercie, Pilica, Będkowska Valley). These intrusives may represent small individual bodies localized along the tectonic zone or the apical zones of the deep situated batholith. The plutonic rocks are commonly associated with subvolcanic dacites and rhyolites.

The granitoids and dacites are altered to varying degree by autometasomatic and hydrothermal processes (J.Markiewicz, 2002). The spatial relationships between potassium metasomatism (feldspathisation, biotitisation, and sericitisation) and ore mineralisation are observed. The main ore minerals are: molybdenite, scheelite, chalkopyrite and pyrite.

METHODS

Chemical analyses of 502 rock samples were carried out for 54 variables in the Central Chemical Laboratory of the PGI in Warsaw and the US Geological Survey Laboratory in Denver (by XRF, AAS, ICP-AES method). About 180 samples from 7 boreholes were analyzed by optical microscopy. Electron microprobe and spectral laser analyses were used to identify crystalline phases in the inclusions.

RESULTS

Granitoids are medium grained, semi-automorphic, and usually porphyritic. Fine grained matrix constitutes 10-30% by volume of a typical rock. In some specimens, the matrix makes up higher percentage of the rock, and in others it is completely absent, producing eugranitic texture.

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Plagioclase, quartz, and biotite are the main mineral components of the granitoids; apatite, zircon, magnetite, rutile, and sphene, are common accessory minerals found in the rocks.

Granitoids of Myszków-Mrzygłód area have peraluminous to metaluminous compositions (A/CNK = 0.85-1.23), and might have been formed due to the anatectic differentiaton after melting of the clayey or sandy rocks at P-T conditions of the low-pressure amplibolite facies. According to W.Ryka (1989) the partial pressure of water, present in the weakly metamorphosed rocks, lowered the melting temperature and increased the rate of magma formation.

The results of chemical analyses have been recalculated using the formula of de La Roche et al. (1980). The position of the granitoids on a R_1-R_2 diagram classifies them mostly as granodiorites, and more rarely as granites.

The distribution of major and trace elements is similar in granitoids and dacites samples. The contents of REE (Fig. 1) are low (REE < 150 ppm). LREE are moderately enriched relative to HREE $(La/Yb)_n$ = 11-23. The REE normalized concentration patterns show small negative Eu anomaly (Eu/Eu* = 0.71-0.96).

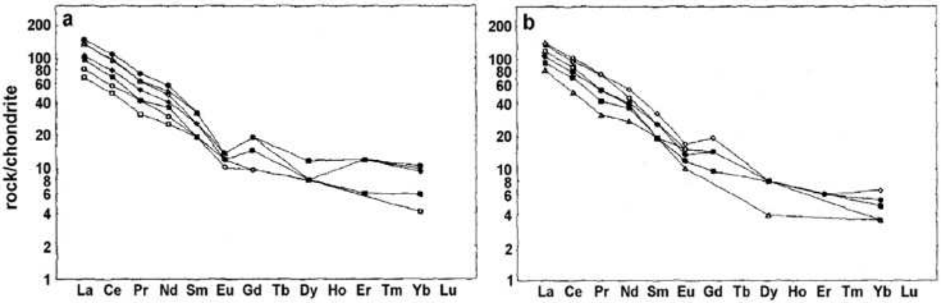

Fig. 1. REE distribution pattern (chondrite normalized) for granodiorite (a) and dacite (b).

Relicts of melt magmatic inclusions in zircon, apatite and quartz allowed to determined the initial crystalisation temperatures of:

- 1360°C-1260°C for zircon, apatite
- 1260°C-1220°C for quartz

The main crystallization of quartz occurred at the temperature between 1160°C-860°C. Crystallisation temperatures of matrix in the dacite porphyries ranged from 900°C to 800°C.

Silica-rich melt and chloride-rich melt inclusions were indentified in magmatic, quartzes. These latter inclusions may indicate the separation of a chloride-rich fluid from the silica-rich fluid. However, it is also possible that those inclusions could have been partly filled at a later time with highly saturated, chloride-rich brines. The presence of chloride phase is the main indicator of development of postmagmatic fluids responsible for ore mineralisation.

The Myszków deposit is the only one completely drilled-out and well-investigated manifestation of magmatism and mineralisation within Cracow-Lubliniec tectonic zone.

The geochemical studies allow to define the Myszków deposit as:

- stockwork molybdenite deposit related to granodiorite (according to F.Mutschler`s et al., 1981 classification);
- stock type of calc-alkaline molybdenum stockwork deposits (according to G.Westra`s and S.Keith`s, 1981 classification) or
- fluorine-defiecient porphyry molybdenum deposit (according to T.Theodore`s and W.Menzie`s, 1984 classification).

Geochemical investigations of Myszków mineralisation suggest that the following pathfinders, listed in increasing distance from the center, may be used in the search for concealed porphyry deposit: W, Mo, Cu (Ag), K, Be?, F, Sb, Hg, Au, Pb, Ba, As, Ag, Zn (Cd), Bi and Te.

The location of magmatic rocks along the Kraków-Lubliniec zone suggests the economic mineral deposit potential of whole this area.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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COMPOSING THE VARISCAN COLLAGE OF THE SUDETES: PRESENT STATE-OF-THE-ART

The Variscan structural complex of the Sudetic area is a composite mosaic of geologically diverse pre-Permian units, separated from one another by tectonic contacts of contractional, extensional or strike-slip kinematics. The mutually different evolutionary histories of most of those units, combined with the occurrence of ophiolites or igneous bodies of MORB-type affinities along some of their contacts, as well as of HP metamorphic complexes (including the blueschist and eclogite facies), clearly suggest a coexistence of (fragments of) several tectonostratigraphic terranes contacting along tectonic sutures and major fault and shear zones. Variable configurations of various terranes in the northern part of the Bohemian Massif have been a matter of lively discussion (e.g. Matte et al. 1990; Aleksandrowski 1990, 1995; Oliver et al. 1993; Cymerman, Piasecki 1994; Franke et al. 1995; Cymerman et al. 1997; Franke, Żelaźniewicz 2000). Recent results of the present authors make it possible to critically discuss the hitherto made attempts at application of the terrane concept in the Sudetes and to propose a modified, updated and partly new terrane model of the Variscan structural level of the Sudetes (Aleksandrowski, Mazur 2002). The model is based on an assumption that all the major constituent units ('zones') of the central European Variscan belt known from the Bohemian Massif continue into the Sudetic area. The proposed concept rejects some and modifies other previous terrane models; it also gives a palaeotectonic interpretation of particular Sudetic units and a possible scenario for their accretion.

Based on various aspects of the geology of individual Sudetic structural units, a relatively simple division of the Sudetes can be made into distinct tectonostratigraphic terranes of different provenance and evolution. From NW to SE, we propose the following tectonostratigraphic terranes to be distinguished on the NE margin of the Bohemian Massif (Fig. 1): (1) The Lusatia-Izera terrane comprises the Lusatian massif and the Kowary-Izera unit of the Karkonosze-Izera massif, which both correspond to crystalline basement of the passive margin of the Saxothuringian epicontinental area. The Görlitz slate belt and the Ještěd unit are made up of Variscan-deformed sedimentary successions deposited on this passive margin. (2) The South-East Karkonosze terrane is thrust over the Lusatia-Izera terrane and comprises the South Karkonosze and Leszczyniec units of the Karkonosze-Izera massif. These units contain the

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(meta)sedimentary-volcanic succession of the Saxothuringian oceanic basin and the oceanic basin floor, respectively, the latter overthrust upon the basin's infill during Late Devonian-Early Carboniferous times. This terrane contains a fragment of the Saxothuringian suture. (3) The Kaczawa terrane is separated from the Lusatia-Izera terrane by the strike-slip Intra-Sudetic fault zone and from the Góry Sowie-Kłodzko terrane by an inferred thrust contact. It contains a Palaeozoic rift-to-oceanic volcano-sedimentary succession involved in a Variscan accretionary prism, which formed during latest Devonian-earliest Carboniferous(?) times. The affinities of the Kaczawa succession are still unclear (Saxothuringian or Rheic oceanic basin infill?). (4) The composite Góry Sowie-Kłodzko terrane includes, apart from the Góry Sowie massif and the NE part of the Kłodzko metamorphic unit, also the Świebodzice and Bardo basins, the Central Sudetic ophiolites, the Niemcza shear zone, and the NE part of the basement of the Intra-Sudetic basin. These units represent a variety of palaeotectonic environments, including subducted continental crust (the Góry Sowie), Middle Devonian passive margin (the NE part of the Kłodzko metamorphic unit), oceanic crust (the Central Sudetic ophiolites) and synorogenic basins (of Świebodzice and Bardo). The principal common feature for the units of this terrane is Eo-Variscan, pre-Late Devonian deformation, metamorphism and exhumation, which took place significantly earlier than in the other Sudetic terranes. This terrane shows affinities with parts of the NE Massif Central and Armorican massif, as well as with the Tepla-Barrandian terrane in the Bohemian Massif. (5) The Teplá-Barrandian terrane in its Sudetic segment is interpreted here to incorporate the Nové Město belt, Zábřeh unit and the SW part of the basement to the Intra-Sudetic basin, which crops out in the SW part of the Kłodzko metamorphic unit. It cannot be excluded, though, that the Góry Sowie-Kłodzko terrane is part of the Teplá-Barrandian, and/or that the Góry Sowie massif may represent still another separate terrane (fragment of the Mid-German crystalline zone from the northern rim of Saxothuringia?). (6) The Moldanubian terrane in the Sudetes seems to comprise the Orlica-Śnieżnik massif and the Kamieniec and the Staré Město metamorphic belts. Its western boundary with the Góry Sowie-Kłodzko terrane is probably located along the sinistral Niemcza and Skrzynka shear zones, with the Teplá-Barrandian terrane – along a thrust that was later converted into a dextral ductile fault in the Orlica mountains, and with the Moravian terrane – along a thrust belt of the East Sudetes. The rock complexes of the terrane display prominent effects of Early Carboniferous collision-related medium- to high-grade HP-HT and HT--MP/LP metamorphism and deformation, analogous to those known from the Moldanubian domain in the Bohemian Massif further south. (7) The Moravian terrane is inferred to occur between the Moldanubian and Brunovistulian terranes, by analogy to the situation further south in Moravia. This narrow terrane is represented by the Velké Vrbno and Branná thrust units of the East Sudetes. (8) The Brunovistulian terrane comprises the Keprník nappe and Desná dome and the successive, easterly located units of the East Sudetes, including the Culm basin and the coal-bearing molasse basin at the East-Sudetic foreland, both basins being established on Brunovistulian basement of

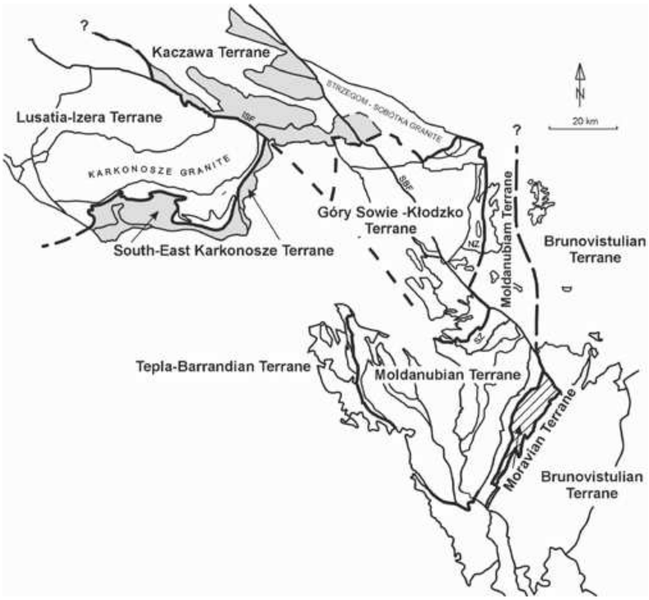

Fig. 1. Distribution of tectonostratigraphic terranes in the Sudetes according to Aleksandrowski and Mazur (2002)

hypothesised Avalonian affinities. Within the Fore-Sudetic block, the Brunovistulian terrane includes also the Strzelin crystalline massif of similar geological characteristics. The latter two terranes (7 and 8) are equivalent of the traditionally distinguished Moravo-Silesian zone of the Variscides.

The proposed terrane distribution is in many respects similar to those earlier suggested by Matte et al. (1990), Cymerman and Piasecki (1994) and Cymerman et al. (1997). Particular solutions, however, adopted in our model differ significantly from solutions assumed in the latter concepts due to applying new data and, in part, also different criteria, to distinguish the tectonostratigraphic terranes.

Recently, another terrane distribution was suggested by Franke and Żelaźniewicz (2002), assuming the continuation of the Saxothuringian realm across the central Sudetes (our Góry Sowie-Kłodzko terrane and the Sudetic part of the Moldanubian terrane) up to the contact with the Moravo-Silesian domain in the east. This solution we consider as less probable than ours because of significant differences between the timing of deformation and exhumation and/or the history of metamorphism in our Góry Sowie-Kłodzko and Moldanubian terranes in comparison to those of the West Sudetes, which are all jointly considered as Saxothuringian by Franke and Żelaźniewicz (2002).

New research results, in particular new radiometric, structural, sedimentologi-cal, geochemical and petrological data are necessary to approach the still many unsolved problems of Sudetic geology, the answers to which can significantly improve knowledge of the tectonic structure and evolution of the Variscan Belt in central Europe.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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SECONDARY XENOTIME-LIKE MINERAL IN A PEGMATITIC FELDSPAR FROM GOŁASZYCE (STRZEGOM - SOBÓTKA GRANITOID MASSIF)

INTRODUCTION

Xenotime (Y,HREE)PO_4 is an accessory mineral present in granitic rocks of various composition and granitic pegmatites usually in very low amount but it can contain significant fraction of Y and HREE of the rock (Bea, 1996). Its fate in granitic rocks is important for understanding the processes of remobilisation of Y, U, and HRRE during alteration, stabilization of these elements during crystallization of secondary phases, interpretation of geochronological data and radioactive waste management.

In granites and pegmatites of the Strzegom–Sobótka massif, accessory phosphate phases (apatite, monacite and xenotime) are commonly present as small inclusions in biotite flakes. From all those phases xenotime is the least frequent although it is highly probable that it was not recognized due to its resemblance to zircon under optical microscope.

GEOLOGIC SETTING

The xenotime-like mineral investigated by the authors was obtained from the biotite granodiorite quarry at Gołaszyce located on a hill less than 1 km west of the village. The intrusion, forming the eastern part of the Strzegom–Sobótka granitic massif, solidified at the depth not exceeding 15 km, from water-poor, hot (>850ˉC) magma derived probably from material of oceanic crust provenance about 280 Ma (Pin et al, 1989).

The Gołaszyce granodiorite is a light gray, massive rock consisting of plagioclases, alkali feldspars, quartz, biotite and accessory allanite, rutile, epidote, sphene, zircon, apatite and opaque phases (Majerowicz, 1972). It is cut by aplite and pegmatite veins that in places penetrate also the cover rocks. The thickness of the veins ranges from several centimeters up to well over a meter. Macroscopically, mineral phases forming the pegmatites comprise quartz, alkali feldspars and biotite as predominant constituents. Garnet and beryl are present in variable amounts as minor phases. The investigated sample consists of an automorphic crystal of a perthitic microcline separated out

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from a 40 cm thick pegmatite vein dipping at about 70ˉ towards SE. Two zones may be distinguished in the pegmatite from the margins inwards. The outer zone is built of alkali feldspars and quartz often forming graphic intergrowths whereas the center is dominated by big automorphic feldspars surrounded by smoky quartz mass. Biotite flakes tend to lay roughly perpendicular to the margins. Garnets are scarce and locally form garnet-quartz aggregates.

RESULTS

The xenotime-like mineral occurs in the microcline, with a mean composition of a potassic phase – $Ab_{4,7}An_{0}Or_{95,3}$, in a form of very thin veinlets filling small cracks. The veinlets are up to 2-3 μm thick and often split into numerous thinner veinlets (~0.1 μm thick) forming a complex network. Some veinlets follow phase boundaries in the perthite. Groups of nest-like accumulations of the material with similar composition can also be noted. The chemical composition of the material from veinlets varies within a broad range (Tab. 1). High content of Si, Al, Na, and Ca can be related to X-rays generated in feldspar in veinlets neighbourhood.

DISCUSSION OF RESULTS AND CONCLUSIONS

The chemical composition of the veinlets material indicates the presence of Fe-oxides. The presence of albite cannot be excluded. The proportion of HREE, Y, U corresponds to xenotime characterized by YPO_4 dominating over HREE-PO_4. Substitutions of coffinite ($USiO_4$) and brabantite ($CaTh(PO_4)_2$) are of minor importance. Surplus of P can be attributed to apatite or Fe phosphate. It should be noted that at the present state of study the presence of hydrated REE-Y phosphates (e.g. rhabdophane or churchite) cannot be ruled out.

Primary accessory minerals were probably the dominant source of HREE, Y, U, P in solution. Mobilization of elements was related to hydrothermal alteration of granite (cf. Cathelineau, 1987). Leaching of rocks from the granite surroundings can also be considered as a source of these elements. The occurrence of xenotime together with Fe oxides can indicate the mechanism of veinlets material precipitation. Scavenging of Y and REE by iron oxyhydroxides has been observed and experimentally measured (e.g. Bau, 1999). REE content in igneous-related hydrothermal Fe-oxide can be 5 – 50 times higher than in the associated rocks (Gleason et al., 2000). Low-temperature coating of minerals with high specific surface (as Fe or Mn oxyhydroxide) by U-rich (Y,HREE)-phosphate was described by De Putter et al. (1999). The temperature of formation of xenotime containing veinlets cannot be evaluated basing on the presented results. Both hydrothermal and weathering-related low temperature solutions could have controlled the origin of the veinlets.

The results of the study indicate Y, HREE, U, P, Cu, Pb, and Fe mobility during alterations of the Gołaszyce granite.

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Table 1. Selected analyses of veinlet material (recalculated to 100 wt.%; H2O and OH contents are neglected)(----- not determined using EDS)

Element (wt.%)	Point of analysis			
	21A-12-2	21A-12-1	21A-11-1	21A10-1
Si	18.28	20.48	35.22	26.61
Al	10.29	11.31	8.42	12.64
Na	2.79	3.12	3.39	4.99
Ca	2.00	1.80	1.80	2.30
Mg	0.16	-----	----	-----
Fe	38.14	33.06	22.40	11.43
Mn	0.74	0.43	0.47	----
S	0.38	0.42	0.38	0.63
Cu	1.14	1.57	0.62	----
Cl	0.21	----	----	----
P	5.40	8.05	6.32	10.57
Y	9.72	9.38	7.78	16.45
U	3.16	4.33	2.72	6.62
Th	----	0.05	0.18	----
Pb	0.70	----	1.05	0.96
Ce	----	----	----	0.42
Nd	0.51	0.07	0.49	----
Sm	0.64	0.35	----	0.58
Gd	1.77	1.17	1.64	1.20
Tb	2.42	----	1.20	----
Dy	----	----	3.40	1.83
Er	----	2.18	1.01	0.99
Tm	0.69	1.50	----	----
Lu	0.03	----	0.27	----
Yb	----	----	----	1.79

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Arno MÜCKE[1]

THE ORIGIN OF THE NIGERIAN IRON-FORMATIONS ESPECIALLY OF THE SILICATE FACIES

INTRODUCTION

Various models about the origin of iron-formations are known. In most of these models (e. g. Goodwin, 1973; Button, 1982; James, 1992; Klein and Beukes, 1992) the protolith of the iron-formation precipitated as chemical sediment from a relatively open Precambrian ocean. This ocean was stratified consisting of an upper oxic layer which overlies a much larger volume of deep anoxic water in which iron and silica, both originating from a submarine hydrothermal source, are dissolved. Through upwelling or other mixing processes the anoxic water masses were mixed with the more oxygenated shallower water with the result that iron precipitated in the form of iron hydroxides and/or oxides, carbonates and sulphides. The nature of iron precipitates formed in aqueous media is governed in large part by the pH and Eh-conditions of the depositional environment. Therefore in all the models distinct precipitation products are distinctly distributed within the marine basins. This lead James (1954 and 1992) to classify iron-formations according to their mineralogical associations which are known as the so-called facies. Four major facies are known. These are the oxide, silicate, carbonate and sulphide facies. The oxide facies is subdivided into the magnetite and hematite subfacies. Within the marine basins of the various models, three of the four facies, namely the oxide, carbonate and sulphide facies have a defined position whereas the silicate facies is not considered within these models.

In this paper, the attempt will be undertaken to close this gap. As an example, the Nigerian iron-formations are considered, where the oxide (magnetite and hematite subfacies; the latter is not considered in this paper) as well as the silicate facies are developed in nearly the same proportions. The development of the Nigerian Algoma-type iron-formations which, in comparison to many other iron-formations of the world, are relatively rich in Mn and Al, will be briefly presented according to Mücke and Annor (1993), Mücke et al. (1996) and Annor et al. (1997). In the basement complex, the latter being an ancient shield reworked in the Pan-African, various schist belts occur (Malumfashi, Maru, Birnin Gwari, Kushaka, and Egbe-Isanlu), composed of metasediments including the meta-protoliths of the iron-formations and metavolcanics. Within various schist belts, mainly located in northern Nigeria, the iron-formations occur as one or a few closely spaced and relatively thin (30 cm to 20 m thick

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and usually less than 7 km long) tabular sheets. The iron-formations are concordantly interbanded with metasedimentary phyllites (= host rocks of the iron-formations) with which they share common metamorphic and deformational imprints. The alternated banding of iron-formation and phyllite is considered to be the result of material from two sources to the marine basin(s) of Nigeria during Birimian time. Sediments of continental origin and of pelitic to psammitic composition were slowly, but continuously deposited, while hydrothermal solutions of volcanic-exhalative origin were discontinuously, but rapidly supplied and deposited as a mudstone-like chemical precipitate. During regional metamorphism (probably of Eburnian age), the continentally derived material was transformed into phyllite and the sediments which precipitated from hydrothermal solutions into the mineral assemblages of the iron-formation. The alternating distribution of layers of iron-formation within the phyllites is the result of the intermittent deep sea hydrothermal activity.

WHOLE-ROCK COMPOSITION

Comparison of the chemical composition of the iron-formations with that of the associated phyllitic host rock clearly reveals that the iron-formations have relatively high Mn, Fe, Ca and low alkalies (Na and K), Al and Si concentrations, whereas the phyllite reveals just an opposite element concentration. Using these characteristic element oxides in the form of the (Al_2O_3 + Na_2O + K_2O)/(FeO_{tot} + MnO)-diagram (Fig. 1) it becomes obvious that the analytical points of the phyllites are distinctly distributed and clearly seperated from those of the iron-formations with the analytical points of the silicate facies lying between those of the magnetite facies and the phyllites. Similar to Fig. 1, the Al_2O_3/SiO_2-diagram of Fig. 2 shows that the analytical points of the silicate facies have the same position lying between the phyllites and the magnetite facies. The phyllites show continuous compositions between clayey-pelitic pronounced (on the left side) and sandy-psammitic pronounced material (on the right side). Having slightly to moderately reduced Al_2O_3 and SiO_2 contents, the silicate facies shows a similar compositional range. Due to their high Fe-content, the analytical points of the magnetite facies lie predominantly in a small field between in maximum about 10 wt% Al_2O_3 and 40 wt% SiO_2.

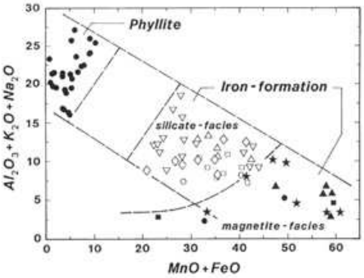

Fig. 1: (Al_2O_3 + Na_2O + K_2O)/(FeOtot + MnO) - diagram and the analytical points of the phyllites, the magnetite and silicate facies.

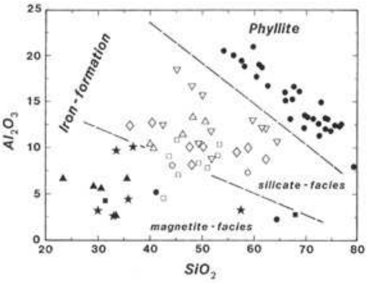

Fig. 2: The Al_2O_3/SiO_2-diagram and the analytical points of the phyllites, the magnetite and silicate facies.

MINERALOGICAL COMPOSITION

The mineralogical composition of the three rock types are (in brackets: variation of the minerals) as follows. Phyllite: muscovite, rarely biotite and strongly varying proportions of quartz (30 to 60 vol%); magnetite facies: magnetite $Fe^{2+}Fe^{3+}_2O_4$ (10 to 55 vol%), quartz (20 to 50 vol %), almandine-spessartine garnet $(Mn,Fe)_3Al_2[SiO_4]_3$ (10 to 40 vol%), Mn-bearing grunerite-cummingtonite $(Fe, Mg, Mn)_7[(OH)_2/(Si, Al)_8O_{22}]$ (0.0 to 20 vol%); and silicate facies: grunerite-cummingtonite (10 to 80 vol%), almandine-spessartine (20 to 60 vol%), quartz (5 to 40 vol%), and Mn-bearing ilmenite $(Mn,Fe)TiO_3$ (1 to 5 vol%).

Deduced from whole rock compositions the FeO : Fe_2O_3-ratio varies within the magnetite facies from 0.17 to 0.52 (on average of 14 analyses: 0.33), the silicate facies from 4.2 to 10.5 (on average of 28 analyses: 6.4) and the phyllite from 1.1 to 6.5 (on average of 12 analyses: 3.8).

DISCUSSION

The phyllites represent continental-derived material which was laid down in the marine basins of Nigeria during phases of strongly reduced or even absent volcanic activity, whereas the protolith of the magnetite facies was formed during phases of high volcanic activity. Both the $Al_2O_3+Na_2O+K_2O/$ FeO+MnO and the Al_2O_3/SiO_2-diagrams show that the position of the silicate facies lies between the composition of materials of the two sources mentioned above. Therefore the protolith of the silicate facies consists of mixtures of Al-bearing continental-derived material and material which precipitated from volcanic exhalations which, in contrast to other iron-formations, are relatively rich in manganese. The abundance of garnet and amphibole in the silicate facies resulted from the Al_2O_3-content of the admixed continental-derived material. Therefore it can also be inferred, based on the relationships presented in Fig. 2, that the SiO_2-content of the Nigerian iron-formations is not necessarily only of exhalative origin, but may be substantially continentally derived.

The two facies cannot only be differentiated by differently composed sedimentary protoliths, but also by their differing FeO:Fe_2O_3-ratios established within their mineralogical equivalents after metamorphism. This implies that the metamorphic formation of the magnetite and the silicate facies depended not only on temperature and pressure (according to greenschist facies conditions), but also on the existing redox conditions. The silicate facies (as well as the host rock) represents conditions of low oxygen fugacity where minerals predominantly containing divalent iron were formed. Under more oxidizing conditions magnetite was formed. The differing redox conditions of the two facies is inferred to be the result of whether the protoliths are in interaction with carbon supply (probably mainly from benthic organism) or not. According to Klein and Beukes (1992) the organic carbon supply to the marine basin is much higher during the regressive than in the transgressive stage. This implies that the occurrence of the two facies is the result of changes from regression to transgression or vice versa. In the regressional stage or close to it, the protolith of the silicate facies was laid down together with a substantial amount of organic material.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Stanisław Z. MIKULSKI[1], *Stanisław SPECZIK*[2]

UNSTRUCTURED ORGANIC MATTER AND ITS RELATION TO GOLD MINERALIZATION IN ZŁOTY STOK AU-AS DEPOSIT (WESTERN SUDETES)

INTRODUCTION

Unstructured organic matter composed mainly of low molecular weight aromatics occurs within the contacts between the Kłodzko-Złoty Stok granitoids and Paleozoic rocks hosting the gold-bearing arsenic and magnetite-pyrrhotite mineralizations. Mineralized samples have the higher TOC content, pointing to remobilization of organic matter by the hydrothermal fluids. Results of organic geochemical and previous isotope studies suggest that the hydrocarbons were formed by thermal alteration of indigenous kerogen, and that at least part of the sedimentary/metamorphic cover was not metamorphosed prior to intrusion.

METHODS OF INVESTIGATION

Rock samples for chemical analyses were collected from the Western and Central Ore Fields of the Złoty Stok deposit. Gold contents were measured by the FASS and GF-AAS methods, and major elements and trace metals by XRF method carried out on the Philips PW 2400. For organic geochemical analyses, culometric method and Coulomat 702 LI-Ströhlein device, applied to finely ground samples (0.063 mm).

RESULTS

The organic matters have been found in samples with loellingite and sulfides mineralization represented by arsenopyrite, pyrite, and pyrrhotite in association with magnetite. Sulfide aggregates encrustate large blebs of elongated unstructured organic matter, or occur on the contact of organic forms with carbonates, quartz and serpentine group minerals (Mikulski and Speczik, submitted). Three major types of mineralized rocks hosting organic matter have been recognized:

1) Black serpentinites with dominance of magnetite–pyrrhotite or loellingite-arsenopyrite ores,

2) Dolomitic marbles with thin black serpentinite veinlets accompanied by sulfides (pyrite, pyrrhotite, arsenopyrite–loellingite) mineralization,

3) Altered calc-silicate rocks with loellingite-arsenopyrite mineralization.

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Table 1. Total organic carbon concentrations (wt%) in mineralized rocks from the Western Ore Field of Złoty Stok Au-As deposit

Lithology	Type of ore mineralization*	Arithmetic mean / number of samples	Range
Black serpentinites	mg–po; lo–asp	0.54 / n=8	0.16–3.23 0.08–0.19
Dolomitic marbles	py; po; lo–asp	0.62 / n=7	0.12–1.89
Calc-silicate rocks	lo–asp	0.11 / n=17	0.04–0.23

*Abbreviations: mg–magnetite; po–pyrrhotite; lo–loellingite; asp–arsenopyrite; py–pyrite

The total organic carbon (TOC) content of 32 samples ranges between 0.04 and 3.20 wt% with an arithmetic mean value of 0.33 wt% for the whole population. In general the calc-silicate rocks have lower contents of organic matter and only in strongly mineralised samples TOC slightly increased up to 0.23 wt%. Most of black serpentinites are strongly mineralized and have high arsenic and gold concentrations with arithmetic mean values 8.07 % and 5.27 ppm, respectively. The barren dolomitic marbles have TOC values ranging between 0.12 and 0.21 wt% and traces of gold (6–41 ppb) and arsenic (232–675 ppm). The mean value of TOC for barren dolomitic marbles is 0.16 wt%, i.e. almost 4 times lower than for mineralised dolomitic marbles. There is no correlation between TOC and major or trace elements (Fig. 1), (Mikulski and Speczik, submitted).

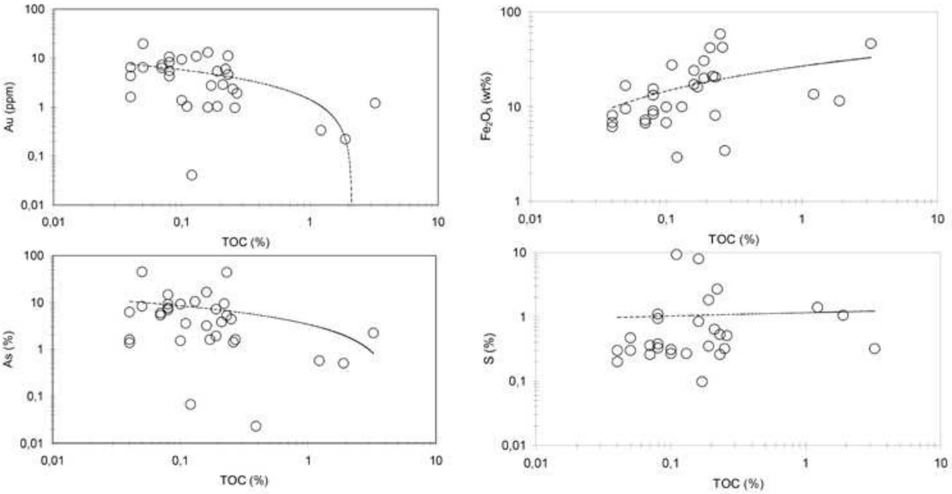

Fig. 1. The variation logarithmic plots of TOC and selected elements in mineralized samples from the Western Ore Field of the Złoty Stok Au-As deposit.

In the specific group there occur several correlations of TOC with S (2nd group cc = 0.84; 3rd group cc = 0.54), Fe_2O_3 (1st group cc = 0.43; 2nd group cc = 0.51), MgO

(2nd group cc = 0.80), Cu (2nd group cc = 0.94). No notable differences in gold correlations, with other elements, were found between the different data sets, except for elements characteristic for specific host rocks. Gold shows a very strong correlation with As (cc = 0.83; n = 32), and weaker correlation with Co (cc = 0.39), Cd (cc = 0.47), and SiO_2 (cc = 0.42). This is confirmed by mineralogical and microprobe studies, that yield a gold association with loellingite, arsenopyrite, and less frequently with Co, Ni sulfoarsenides. Gold correlation with quartz is explained by development of silification in zones of arsenic mineralization.

CONCLUSIONS

In the Western Ore Field of the Złoty Stok Au-As deposit mineralised samples from fractured zones have elevated TOC contents. However, geo-chemical results revealed no correlation of TOC with gold, metals and major elements distribution. It is explained by remobilisation of organic carbon from primary sediments by mineralized hydrothermal fluids originated in magmatic source. The temperatures that affected organic matter of marine origin were credibly above 400^0C, what agrees with results from mineralogical and fluid inclusion studies (Mikulski 1996). Preliminary results of the REE distribution in arsenopyrite-loellingite and pyrrhotite–magnetite ores show negative Eu anomaly and strong correlation coefficients of Au with, Bi, As, and with REE that indicate for strong affinities of metal-bearing post-magmatic hydrothermal fluids with granitoid magmas (Mikulski and Speczik, submitted).

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Szymon OSTROWSKI[1]

CALCIFICATION OF SKELETONS OF SILICEOUS SPONGES – AN EARLY DIAGENETIC PHENOMENON

INTRODUCTION

Calcification of skeletons of siliceous sponges is supposed to be an early diagenetic process. However it is more difficult to determine the exact moment of diagenetic history in which the calcification of sponge skeleton takes place.

The paper shows new evidence showing that the process of calcification should be located i very early diagenesis on the border of the depositional processes.

GEOLOGICAL SETTING

Upper Jurassic carbonate sponge megafacies (Matyja, Pisera 1991) was developing on the northern shelf of the Tethys Ocean, and is widespread in the western and central Europe. It is well known from the territory of Poland (Matyja Wierzbowski 1995). Outcrops of this megafacies can be observed in the Kraków – Wieluń Upland, Mesozoic margin of the Holly Cross Mountains and in the Kujawy Region. Sponge megafacies is characterised by occurrence of biohermal carbonate buildups. Siliceous sponges contributed apparently to the formation of this bioherms.

RESULTS

Sponges soft tissue is preserved as an outline of the body composed of darker micrite (so called "sponge mummy"). Skeletons of sponges are originally composed of opal (Pisera 1997) but in most cases it is diagenetically replaced by calcite. Original silica can be found sporadically.

In rocks surrounding bioherms, early diagenetic flints are abundant. The sponge skeletons, dissolved in bioherms, are the main source of silica for flints (Świerczewska 1990). In spite of common high porosity of rocks, pores do not occur in place of skeleton.

Recent researches in the Bielawy quarry in Kujawy region (Ostrowski 2001) brought new data supporting early diagenetic calcification. Bioherms typically are surrounded by platy limestones. Bioherm outcropping in the quarry are surrounded by quartz mudstones of the Łyna Formation (Matyja et al. 1985). Sponges occur in the mudstones also, but are not subjected to calcification so intensely and many of their skeletons are preserved as original silica skeletons. Fragments of sediment

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and skeletal debris are found in mudstones. Some particles are incorporated into the sponge body and overgrown by the skeleton (Fig. 2).

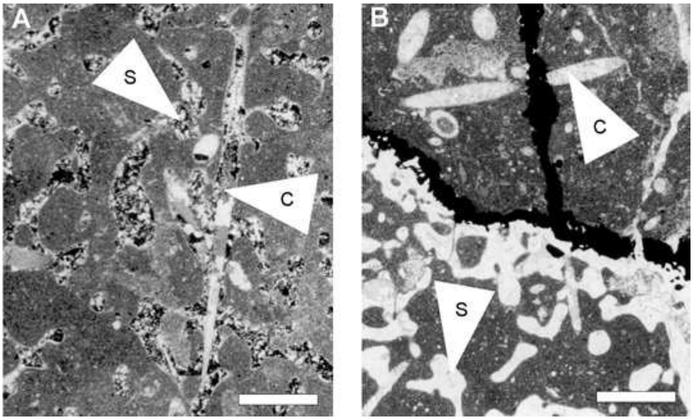

Fig. 2. A – calcified spicule (C) incorporated into silica sponge skeleton (S), B – lithoclast with calcified spicules (C) overgrown by silica sponge skeleton (S). Scale bar is 1 mm

Incorporated fragments of carbonate sediments with already calcified fragments of sponge skeletons and single calcified spicules (fragments of skeleton) are found within diagenetically unaltered, silica skeletons of other sponges. This clearly proves very early calcification of siliceous sponge skeletons.

DISCUSSION

Sedimentological observations shows that lithification of soft parts of sponges is a very early diagenetic process (e. g. Gwinner 1976, Matyja 1977, Matyszkiewicz 1994). Existence of flints in facies surrounding bioherms also points to rather early diagenetic mobilisation of silica from sponge skeletons and probably early calcification.

Process of calcification is probably related to the activity of symbiotic bacteria taking control over chemical reactions within host cells after death (Schumann-Kindel et al. 1997). Bacterial decay of soft tissue of sponges cause slight decrease of pH value followed by increase of pH and increase of carbonate alkalinity. These changes lead to precipitation of calcium carbonate within and around dead cells (op. cit.). It can be suggested that the same process was responsible for calcification of sponge skeleton.

Evidences from the Bielawy quarry show that the calcification took place in a bioherm simultaneously with deposition and growth of sponges in the vicinity. Bioherms formed prominent elevations on the sea bottom (Matyja, Wierzbowski 1996). Fragments of sediments with already calcified spicules were redeposited from bioherm into surrounding facies. Some fragments deposited on the surface of living sponges were overgrown and incorporated into skeletons. The last mentioned skeletons reminded unaltered by calcification. This resulted in preservation of sponges previously described.

CONCLUSIONS

Process of calcification of siliceous sponge skeletons took place in very early stage of diagenesis on the border of depositional processes. Calcification of skeletons was probably simultaneous with calcification of soft bodies of sponges. Changes of chemical environment, caused by bacterial decay of sponge, is suggested to be crucial for the process of calcification.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Marek PĘKALA[1], Artur WÓJTOWICZ[2], Marek MICHALIK[1]

POST-ERUPTIVE HISTORY OF LOWER PERMIAN VOLCANIC ROCK (TRACHYBASALT FROM LUBIECHOWA; THE NORTH-SUDETIC BASIN)

INTRODUCTION

Lower Permian volcanic rocks in the Polish Rotliegend basin exhibit numerous hydrothermal alterations (e.g. albitization, chloritization, carbonatization)(Ryka 1981, Siemaszko 1981). Very low-grade metamorphism of volcanic rocks was noted in central part of the Basin (Dubińska et al. 1997). Timing of alteration processes has been unknown.

The aim of the study was to describe the products and the age of alteration processes in trachybasalt from Lubiechowa (North-Sudetic Basin, SW Poland).

GEOLOGICAL BACKGROUND AND METHODS

Trachybasalt, where five successive lava flows are exposed, was studied. The upper part of each flow contains numerous vesicles and amygdales. Carbonate veins cut the whole volcanic sequence. Volcanic rocks, amygdales, and carbonate veins were studied using XRD, SEM-EDS and K-Ar dating of celadonite and altered rock.

RESULTS

Mafic phenocrysts in trachybasalt are transformed into chlorite, carbonates and chalcedony aggregates. Primary plagioclase in the groundmass is albitized. Initial forms of illite-like mineral growth can be seen (crystals up to 2 μm long). Aggregates of carbonates and small carbonate veins are common in the rock groundmass. Amygdales can be filled with calcite, quartz/chalcedony, celadonite, chlorite, and regular mixed-layered chlorite/vermiculite and chlorite/smectite. Several types of amygdales infills can be distinguished. There is no relationship between composition and position of amygdales within lava flow or lava flows sequence what indicates relatively late crystallization of minerals in vesicles. In thick calcite vein, aggregates of celadonite with small amount of swelling minerals are present.

K-Ar dating results indicate long-lasting process of newly formed minerals crystallization (Table 1). It should be noted that K-Ar ages of celadonite from

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amygdales and groundmass could be slightly influenced by inhomogeneity of material related to difficulties in mechanical separation.

Table 1. K-Ar ages of samples studied.

Sample symbol and description	K_2O [wt.%]	$^{40}Ar^*$ [pmol/g]	$^{40}Ar^*$ [%]	Age ± 1σ [Ma]
BN; groundmass of slightly altered rock	1.27	341.0	78.0	177.5 ± 2.2
BP; groundmass of heavily altered rocks	1.10	324.9	75.2	194.4 ± 2.4
LM-4; celadonite from amygdales	4.37	1704.6	94.0	210.2 ± 2.4
LZ-2; celadonite from calcite vein	3.84	1232.3	88.9	252.5 ± 2.8

DISCUSSION OF RESULTS AND CONCLUSIONS

Trachybasalt from Lubiechowa is strongly altered. Paragenesis of newly formed minerals indicate that alteration took place under conditions corresponding to very-low grade metamorphism as it was pointed out by Łączyński (2000). These processes can be attributed to Permian/Triassic - Triassic/Jurassic period. Triassic hydrothermal activity can correspond with fluid flow dated by Jowett et al. (1987) from southern part of the Polish Rotliegend basin.

Formation of illite-like mineral in volcanic rock (Lower and Middle Jurassic) matches with regional-scale illitization of Rotliegend sandstones in SW Poland (Michalik, 2001).

Both very-low grade metamorphism and illitization were caused probably by influx of hydrothermal solutions of different composition (Na- and K-rich) related to tectonic events noted in whole Europe (e.g. Liewig et al. 1987, Clauer et al. 1996, Zwingman et al. 1999). Mesozoic hydrothermal alteration of Late Carboniferous/Lower Permian volcanic rocks is documented in numerous localities in Central Europe (e.g. Jacobs, Breitkreuz 2003; Goll et al. 2003).

The results of the isotopic dating can be interpreted in different ways. The ages obtained by mean of K-Ar method might be affected by overlapping of K-containing minerals crystallization during subsequent hydrothermal events which would result in rejuvenation of the ages. It is also possible that data record separate hydrothermal events in the study area. In these interpretations two opposite possibilities are considered: open system vs. closed system after the crystallization of hydrothermal minerals.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Anna PIETRANIK[1]

CRYSTALLIZATION OF OSCILLATORY ZONED PLAGIOCLASES IN GRANODIORITE MAGMA (THE GĘSINIEC INTRUSIVE, STRZELIN CRYSTALLINE MASSIF, SW POLAND)

INTRODUCTION

The Gęsiniec Intrusive is situated in the northern part of the Strzelin Crystalline Massif (eastern part of Fore-Sudetic Block, SW Poland). It has few hundreds of meters in diameter, and is dominated by tonalites with subordinate granodiorite, quartz diorite and two-mica granite (Oberc-Dziedzic 1999). Granodiorite occurs as veins up to few meters crosscutting the tonalite. In this paper the examples of plagioclase oscillatory zonation in the Gęsiniec granodiorite are presented and interpreted.

Plagioclase grains from five thin sections representing four granodiorite samples from different parts of granodiorite dyke were analyzed. Only the grains being axial sections and exhibiting under optical microscope well defined internal structure were analyzed by electron microprobe (CAMECA SX100 at the Institute of Mineralogy, University of Hannover). Most of the traverses for An were located in direction of fast growing crystal face. Major and trace (Sr, Fe) element data were obtained following measuring conditions described by Ginibre et al. (2002). Detection limits were 150 and 190 ppm for Sr and FeO^{TOT} respectively.

PETROGRAPHY

Granodiorite consists of plagioclase, biotite, alkali feldspar and quartz and shows linear fabric defined by arrangement of plagioclase and biotite. Plagioclases vary in size and were divided in three groups: large (>1mm length of longer axis), medium (0,5-1mm) and small (0,5mm).

Plagioclase grains exhibit complex internal structures. They consist of:

CORES. Small, rounded cores containing 25-35 %An occur in majority of large plagioclase grains (Fig 1). Their Sr content ranges from 157 to 480 ppm and it is always positively correlated with An content, FeO^{TOT} is above 0,1 w.t. %, The cores are often patchy zoned or have resorbed surfaces. In this case they contain 36-38 % An.

INNER MANTLE. Zones richer in An (38-49%), Sr (323-656 ppm) and slightly impoverished in FeO^{TOT} (usually below 1000 ppm) surround cores. Their An content is approximately constant (38-46% An, depending on the grain). The saw tooth

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resorption (STR) oscillations occurs in large grains (wavelength of the oscillations is 30-50µm, with An amplitude up to 8%, Fig 1a).

OUTER MANTLE. The zone with An content decreasing gradually from 38-46% An to 25-30% outwards surround the inner mantle. They often contain alkali feldspar inclusions (Fig 1), strong outwards decrease in Sr content also occurs.

RESORPTION ZONES follow outer mantle in all grains. Three morphological types can be distinguished: (1) rounded, double resorbed (dominating in large grains, Fig 1a), (2) rounded, single resorbed (dominating in small grains) and (3) patchy (occurring in large and medium plagioclase grains, Fig 1b). An content increases outwards from 25-30% at the contact with the outer mantle to 33-52 % (depending on grain). Strontium and iron distribution is highly variable, generally it increases outwards. The resorption zones reach maximal thickness at crystal edges (Fig 1a), on the surfaces of resorption zones smaller grains of plagioclase are often accumulated.

RIMS of 50-100 µm in thickness and An content varying from 27 to 33 % occur on all grains.

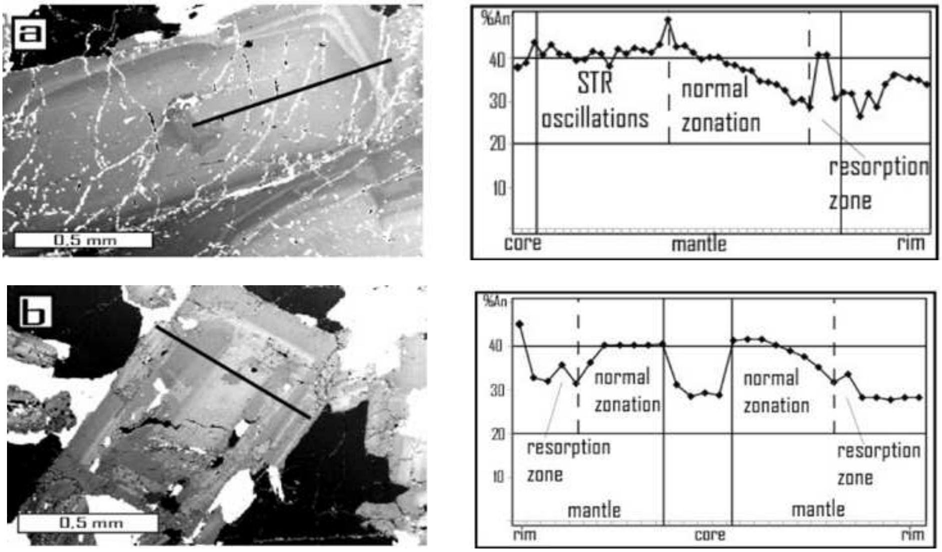

Fig. 1. Representative plagioclases from Gęsiniec granodiorite: BSE images and traverses.

CONCLUSIONS

Due to sluggish diffusion, major and trace element zonation in plagioclases provide valuable information on crystallization conditions in igneous rocks. If the equilibrium crystallization is assumed, apparent Sr content of melt can be ascertained (Blundy and Wood 1991).

Rounded shape of the cores and increase of An and Sr content at the contact between core and inner mantle indicate cores resorption in hotter and compositionally different magma. It was followed by crystallization in chemically undisturbed environment, as is suggested by constant An content in inner mantle. The occurrence of STR oscillations in inner mantles of the larger grains indicates repeated temperature shifts in surrounding magma. This is possible due to movement of these crystals in convection cells or due to multiply recharging of magma in the chamber (Ginibre et al. 2002). Small regular recharge events (6-12 depending on grain for Gęsiniec granodiorite, Fig 1) are of little probability, therefore the first alternative is preferred.

Conditions of crystallization changed as normally zoned outer mantle started to form. This suggests crystallization in a cooling environment. Strong decrease in An and Sr indicate rather fast, diffusion limited growth.

Resorption zones enriched in anorthite and Sr are probably the result of injection of hotter and richer in Sr magma into the magma chamber. Due to the injection, plagioclases were affected first by increase in temperature (rounded resorption zones - simple dissolution) and then by change in magma composition towards the more mafic one (patchy resorption zones - partial dissolution) as observed in experiments of Tsuchiyama (1995). Alternative scenario is equilibrium crystallization in magma richer in water (e.g. as a result of pressure decrease). However resorption zones recorded also fast disequilibrium growth (Fig 1) together with increase in Sr melt content up to the values typical for inner mantle crystallization. This excludes the latter scenario as only cause of resorption. Normally zoned rims crystallized during late stage in cooled granodiorite dyke.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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Jacek PUZIEWICZ[1], *Marek JAROSIŃSKI*[2]

PETROLOGICAL INTERPRETATION OF GEOPHYSICAL DATA: MIDDLE- AND LOWER CRUST IN THE TRANS-EUROPEAN SUTURE ZONE IN POLAND

Trans-European Suture Zone (TESZ) is located at the contact of the East European Craton with Neoproterozoic(?)-Palaeozoic terranes, that occur in the basement of the Palaeozoic platform of SW Poland (Fig. 1). TESZ consists of a number of minor crustal basement blocks, whose origin and timing of consolidation is still a matter of debate. The evolution of TESZ comprises late Proterozoic-Early Palaeozoic rifting of Pangea, leading to the opening of the Tornquist Ocean and formation of passive continental margin at the SW of newly formed Baltica paleocontinent. The Tornquist Ocean was finally closed in Silurian times. Equivocal geological evidence suggests that the Avalonian terrane was accreted to Baltica in the Polish part of TESZ (Mazur and Puziewicz 2003 and references therein). Trans European Suture Zone is overlain by a sedimentary platform cover, accumulated since Late Carboniferous/Permian. The thickness of the sedimentary cover reaches 10 000 m in the central part of the Mid-Polish Through, being the center of Permian-Mesosoic subsidence along the margin of the East European Craton. For this reason, the middle and lower crustal structure of Polish part of the TESZ can be recognized only by geophysical methods.

Huge amount of seismic refraction data regarding TESZ were accumulated during the POLONAISE 97 experiment as well as during earlier seismic experiments (Grad et al. 2002 and references therein). They are recently interpreted and summarized in the series of P-wave velocity model profiles. Most of them are oriented both NE-SW (i.e. perpendicular to the SW margin of the East European Craton) and some parallel the axis of the Mid-Polish Through. The interpretation of geophysical data in terms of mineral composition of middle and lower crust yields no unique results. Typical problem of this kind of modeling is that various mineral assemblages exhibit similar geophysical properties, especially in terms of seismic wave velocities. Volcanic extrusives, which are the potential source of lower crust/upper mantle derived xenoliths, if present, are hidden under the thick Permo-Mesosoic and Cenozoic sedimentary cover. Thus, the interpretation must be based solely on geophysical data (the seismic profiles and the heat flow, magnetic and gravimetric data compared with laboratory measurements of geophysical parameters of various rocks under appropriate pressures and temperatures). The most probable rock types can be ascribed to the domains with

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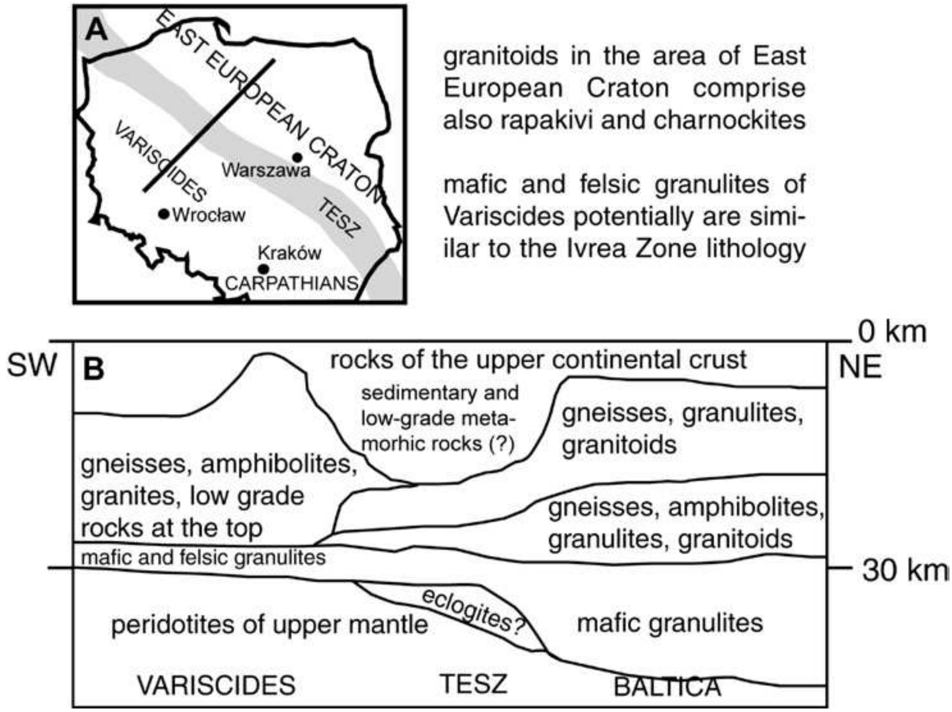

Fig. 1. (A). Location of the Trans European Suture Zone in Poland (after Grad et al. 2002). The line marks the location of the cross-section. (B) Idealized hypothetical lithological cross-section through the TESZ and neighbouring areas in Poland. based on unpublished data of Mazur and Puziewicz (2003).

particular P-wave velocities based on the assumed geological and petrological evolution of the area, enhanced by comparison with the middle- and lower-crust sections exposed at the surface elsewhere in the world. In the following, petrological model of the Polish part of the TESZ, based on the interpretation of seismic data is shown.

The prominent feature of part of the East European Craton located close to the TESZ is south-eastwards increase of P-wave velocities in the lower crust and their decreasein the middle crust. Assuming essentially granulitic composition of the lower crust, this suggests increase of pyroxene contents and/or increase of the Mg/(Mg+Fe) ratio of pyroxene, and/or appearance of another "high-velocity" component in the lower crustal granulite. All those features are indicative of post-melting restite component in the lower crust. The intrusive rocks produced by that melting are probably emplaced in the overlying middle crust. This enriches that part of the crust in "low velocity" components, such as low- to medium anorthitic plagioclase and K-feldspar, and leads to the observed south-westward decrease of P-wave velocities.

The thickness of the crust decreases by ca. 10 km in the TESZ relative to that of the East European Craton. The P-wave velocities in the middle- and lower crust are similar to those of the East European Craton middle- and lower crust, but the layers defined by them are much thinner (Fig. 1). The middle-to lower crust of the TESZ is interpreted as a continuation of crust of the East European Craton (Grad et al. 2002). The thinned crust of TESZ must have originated during extension that preceded the opening of the Tornquist Ocean. Therefore, the mineral assemblages forming the middle- to lower crust in the TESZ are similar to those forming the neighbouring parts of the East European Craton, although the rock fabric might have been strongly reworked during successive extensional and strike-slip events.

The crystalline rocks of the middle- and lower crust of the TESZ are overlain by 6 – 10 km thick assemblage of rocks of P-wave velocities ranging from ca. 5.70 km/s at the bottom to ca. 5.20 km/s at the top. This is interpreted to be an Avalonian accretionary prism, consisting of low grade metasedimentary and metavolcanic rocks (Grad et al. 2002). Mazur and Puziewicz (2003) proposed that the rocks forming the prism are of greenschist to subgreenschist facies in its lower and middle parts, and possibly unmetamorphosed in the upper parts. An Alternative interpretation of Jarosiński et al. (2002) suggests that the upper crust (similarly as the middle and lower ones) is of the Baltica origin. If this is the case, the relatively low P-waves velocities result from anisotropic fabric of the medium- and high grade metamorphic rocks and granitoids. This possibility is supported by gravimetric and tectonic data suggesting that the TESZ is a mega-shear zone with steeply dipping faults in the upper crust.

The SW border of TESZ is marked by a thin, seismically well-layered lower crust typical of Variscan areas, overlain by thick middle crust consisting of various metamorphic and igneous rocks.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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PETROLOGY OF DIORITIC/SYENITIC ROCKS OF THE NIEMCZA ZONE (FORE-SUDETIC BLOCK, SW POLAND)

The Niemcza Zone (Fig. 1) is located at the eastern margin of the Góry Sowie Gneissic Block (NE Bohemian Massif). The Zone originated due to a late Variscan sinistral shearing along the eastern margin of the Góry Sowie Block, which produced the few kilometers wide N-S trending zone of low- to medium grade mylonites (Mazur and Puziewicz 1995). The mylonites are intruded by (1) the syntectonic medium-grained granodiorites and (2) the suite of fine-grained, dioritic to syenitic rocks relatively rich in dark minerals (30 – 50 vol. %). In this paper the latter are discussed, basing on the detailed petrological study undertaken in the last few years. The data presented are based on vast amount of petrographical and mineral-chemical data, the latter collected by CAMECA SX50 and SX100 microprobes in various laboratories.

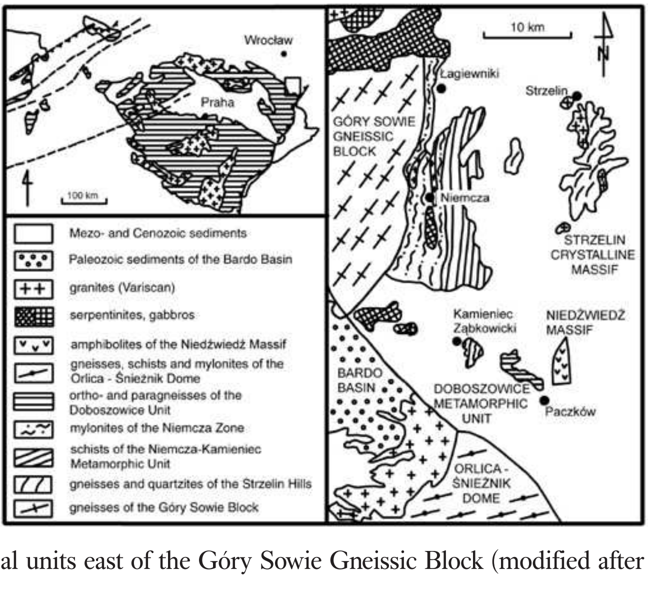

Fig. 1. Geological units east of the Góry Sowie Gneissic Block (modified after Puziewicz et al. 1999).

The rocks of the dioritic suite occur as small intrusives whose size ranges from tens of centimeters to hundreds of meters. Some of them are undeformed, whereas

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the other exhibit metamorphic deformational structures and related changes in mineral composition. The primary mineral assemblage of the dioritic rocks consists of clinopyroxene, biotite, plagioclase and hornblende. Quartz occurs in small amounts, but is present in all rocks of the suite. The amount of potassium feldspar varies from negligible to significant, which leads to variation in the rock systematic position (IUGS classification scheme) from dioritic/quartz dioritic through monzodioritic to syenitic. Part of the K-feldspar occurring in the deformed varieties may be of secondary (i. e. metamorphic) origin.

The undeformed rocks occur in the Koźmice quarry (monzodiorite; Puziewicz 1988, 1992), in quarries of the Kłośnik Hill (quartz diorite) and in the Przedborowa quarry (quartz monzodiorite; Dziedzicowa 1963). The exposure of quartz syenite in Piława Górna (Puziewicz 1987) became unaccesible due to industrial constructions. The deformed rocks form small (tens of centimeters) occurrences in Brodziszów (diorite) and Sienice (no data on systematic position) and larger ones (tens of metres) in Wilków Wielki (syenite) and Niemcza (quartz diorite).

Diopside + biotite are the primary magmatic ferromagnesian minerals. Typically diopside is followed by biotite. The latter has the Fe/(Fe+Mg) ratio between 0.20 and 0.40. The pyroxene is rimmed by hornblende, or hornblende crystals contain relics of diopside in their central parts. The composition of hornblende as well as its relationship to diopside indicate that both the minerals crystallized at the magmatic stage. Locally, the pyroxene-bearing parts of the rocks are intermingled with the amphibole-bearing ones (Koźmice), or even the amphibole-bearing varieties are dominating (Przedborowa). Large part of the quartz monzodiorite occurring in Przedborowa contains magmatic hornblende with no relics of diopside.

Plagioclase typically forms normally zoned crystals, containing from 54 - 64 % of anorthite in cores and 21 – 24 % in the rims.

Magmatic mineral assemblages are preserved to a different degree in deformed varieties of the diorites/syenites. The hornblende is, however, commonly converted to actinolite, the plagioclase is usually oligoclase, and albite replaces large part of plagioclase. The syenite from Wilków Wielki is the most interesting in this group, since it is highly magnesian ond contains unusually high concentration of phosphorous (1.56 wt % in the whole-rock).

Variations in the proportions of diopside to hornblende and of plagioclase to potassium feldspar are the prominent features of the described rock suite. Thus, they crystallized from melts of various water activity (determining the hornblende/diopside ratio) and of various potassium content (determining the amount of potassium feldspar). Relatively anorthite-rich plagioclase composition and presence of diopside indicate the presence of basic component in the parental melts of the dioritic/syenitic suite. Variations in water activity and potassium content are best explained by adding various amounts of water and potassium to the primary basic melt. This is supposedly due to interaction of basic magma with crustal melts. The interaction (mixing?) was of local character, and the crustal melts may have been of variable composition, which led to the compositional variability observed in the dioritic/syenitic suite. This model follows the early idea of Puziewicz (1987), who basing on the comparison of the Piława Górna quartz syenite and the Przedborowa monzodiorite suggested that they originated from basic magma contaminated by crustal partial melts of various potassium contents.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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Ewa SŁABY[1], *Jens GÖTZE*[2]

ALKALI FELDSPAR MEGACRYSTS FROM THE KARKONOSZE MASSIF – DIFFERENCES IN CRYSTALLIZATION CONDITIONS REVEALED BY MEANS OF CATODOLUMINESCENCE AND GEOCHEMISTRY

INTRODUCTION

Alkali feldspar megacrysts appear in granites (mostly in porphyritic facies) and granodiorites within Karkonosze pluton (Sudetes, NW Bohemian Massif). The data on thermal condition of the granite feldspar crystallization as well as some remarks on their growth morphology have been published recently (Słaby et al., 2002; Słaby & Galbarczyk-Gąsiorowska, 2002). The megacrysts usually show rapakivi texture. Feldspars surrounding the K-megacrysts are not the only ones included in the texture. Plagioclase laths trails occur within megacryst checking off various stages of its formation. Despite of their heritage (internal or rapakivi rim) plagioclase crystals usually show growth morphology pointing to dissolution – reprecipitation (Słaby & Galbarczyk-Gąsiorowska, 2002). The lack of equilibrium during mineral growth could be correlated with stepwise change of the melt composition and thermal regime in the system. The facts argue in favour of magma mixing as a process responsible for rapakivi feldspar occurrence.

Rapakivi feldspars from granodiorites haven't been until now subject of detailed research. The occurrences of granodiorites are mainly located within the Czech part of the pluton in Fojtka (F) and Rudolfov (R) inoperative quarries. The samples of megacrysts from both granodiorite quarries as well as from Michałowice (MI) and Szklarska Poręba Huta (SPH) quarries have been collected for comparative cathodoluminescence study.

GRANODIORITE AND GRANITE MEGACRYSTS

The geochemistry of granite and granodiorite megacrysts shows distinct differences. The differences especially concern trace element pattern. Uniform trace element concentration along crystal profile is usually found in R megacrysts. Granite megacrysts show in contrary to R samples stepwise trace element pattern, with the highest value for core part and the lowest for marginal part. The most complicated trace element pattern is that of the F megacrysts, which indicates no regularity. The profiles along K-megacrysts from F granodiorite display increase and decrease of element concentration regarding core or marginal part. The variations in the concentration are high. Strong increase is sometimes accompanied with immediate deep decrease.

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CL investigations obeyed textures observed within megacrysts: of rapakivi rim as well as internal plagioclase inclusions. Matrix minerals have been additionally studied. Plagioclase inclusions in R, SPH and MI samples exhibit the same luminescence characteristic. The rim on MI and R megacrysts seems to have similar genesis (reciprocal activators). The crystallization of rapakivi rim on SPH megacrysts proceeded under different conditions. Although R, MI and SPH megacrysts show some similarities, especially in core crystallisation path, there are visible differences in crystallization of their marginal part. Also the nucleation process of rim plagioclases is different for R and SPH – MI samples. F megacrysts comprise plagioclase inclusions of variant origin. The origin of the inclusion and of the rapakivi rim is reciprocal only in F samples. The luminescence of the inclusion is additionally very much alike the rim plagioclases from the R sample.

Noteworthy is the habit of matrix minerals associated with R, F, SPH and MI megacrysts. Some of the matrix plagioclases in MI samples show textures compatible with lack of equilibrium (Fig. 1a-a'). K-feldspars from granodiorites reveal inconstant kinetic during their growth (Fig. 1b-b'). The same minerals in granites are homogeneous. Apatites in both granite and granodiorite record the change of the melt composition (Fig. 1c-c'), (Kempe, U. & Götze, J., 2002).

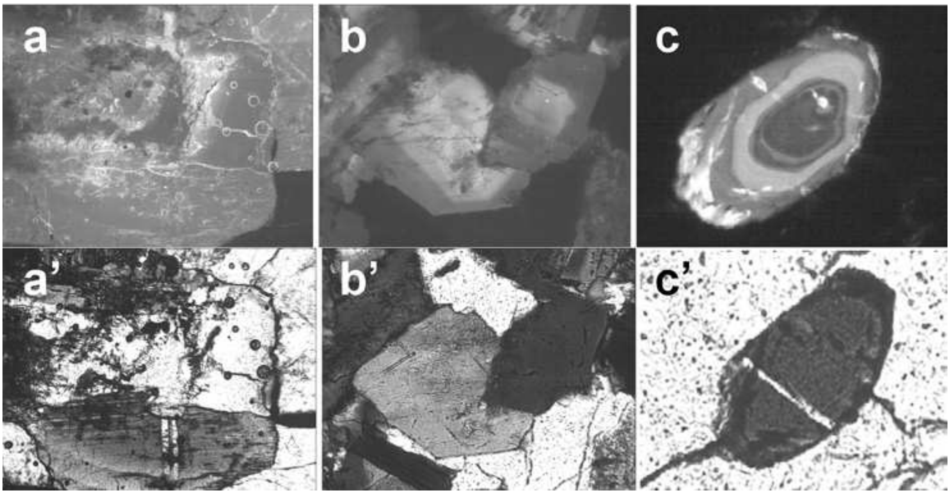

Fig. 1 Matrix minerals imaged by cathodoluminescence (CL) and crossed polarized images: a) plagioclase from MI sample – CL, a') crossed nicols image – 38x; b) matrix alkali feldspar from granodiorite – CL, b') crossed nicols image – 50x; c) apatite from MI granite – CL, c') crossed nicols image – 150x.

FINAL REMARKS

Although R, SPH and MI megacrysts appear in rocks showing different modal and geochemical composition, their core parts nucleated and grew under similar conditions. The growth dynamics are different in all three environments. The most kinetically fluctuating environment is recognised in R samples. The R granodiorites show also field evidence for magma mingling and mixing. The records of environment fluctuations have been preserved in megacrysts and in matrix minerals. K-megacrysts and K-matrix feldspars display zoning (visibly only under CL) caused by different structural defect densities. The R megacrysts growth timing might be compared with the first stage of SPH and MI K-megacrysts formation. The chemistry of the cores of all of the samples is similar in term of trace elements concentration. The duration of SPH and MI K-megacrysts formation obeys next stages, absent in R samples. Each stage is preceded by loss of equilibrium due to the change of magma composition. The marginal parts of SPH and MI megacrysts show basic differences reflected in CL images. The heritage of plagioclase attached as a rim in both samples is different. Plagioclases from the rims of MI megacrysts show affinity to R and F samples. Their growth is interrupted many times. In the contrary, plagioclases from the rim of SPH megacrysts show signs of equilibrium growth. Generally, F megacrysts show weak relation to the origin of R, MI and SPH samples. The F granodiorite similarly to R display field evidence for magma mingling and mixing.

The cathodoluminescence method allowed to identify similar heritage of some of the megacrysts despite different rock composition. The feldspars seem to crystallise under magma mixing conditions. Consequently their parent rocks are items formed due to the same process. CL investigation argues also for crystal transport within the magma chamber. The idea has been introduced by Cloos and developed by Mierzejewski (see for instance Mierzejewski, 2002). Taking into account the position of feldspars Mierzejewski reconstructed funellike structures, the ways used by magma pulses.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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BREAKDOWN ON MONAZITE AND REE, Th, U MOBILITY IN THE HIGH TATRA GRANITOIDS

INTRODUCTION

Monazite in granitoids is a minor accessory minerals but it can contain 40-80% of REE of the rock (e.g. Bea 1996) and significant amount of Th (e.g. Cathelineau 1987). Monazite is unstable during metamorphism of granites. Finger et al. (1998) described formation of apatite-allanite-epidote coronas around replaced monazite in an amphibolite facies granite. Broska and Siman (1998) noted complete breakdown of monazite in metagranites in the Veporic Unit in the Carpathians but only low degree of alteration of monazite in Tatric granitoids. Michalik and Skublicki (1999) noticed that monazite enclosed in Fe-Ti oxides is almost unaltered whereas monazite present in biotite, feldspars or quartz can be more or less altered but never surrounded by regular allanite and/or apatite corona. They interpreted this difference as a result of different availability of fluids carrying Ca^{2+} and other elements.

Studies of monazite breakdown give information on mobility of REE, Th and U during alteration of granites (Cathelineau 1987; Poitrasson et al. 1996). Data on stability of monazite are important because this mineral is often used for geochronology or can be considered as nuclear waste repository.

CHARACTERISTICS OF THE HIGH TATRA GRANITOIDS

The High Tatra granitoids are mostly granodiorites and tonalities. Granites are related spatially to so-called pegmatitic marginal zone (Michalik 1951). The High Tatra granitoids are mostly peraluminous; metaluminous are less common. Peraluminous characteristics can be induced by secondary alterations. Chloritization, sericitization, albitization, carbonatization, epidotitization are common secondary alterations in all types of granitoids (Duraman et al. 2001).

RESULTS

Monazites were studied in granodiorites and tonalities samples collected in the High Tatra. Thin sections were studied using optical microscopy and electron microscope fitted with energy dispersive spectrometer.

Analyses of monazite grains from the High Tatra granitoids indicate that chemical composition is dominated by monazite (s.s.) with small amount of other end-members of solid solution (brabantite and huttonite).

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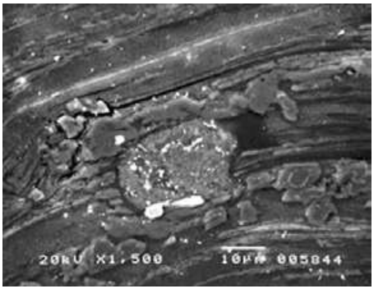
Monazite without any alteration features occur inside Fe-Ti oxide grains or apatite. Monazite surrounded by plagioclases, biotite (or minerals resulting from biotite transformation – chlorite, epidote, titanite), K-feldspar or quartz is more or less decomposed. Degree of decomposition and assemblages of secondary minerals replacing monazite or formed in its vicinity can differ within broad range. Some examples are listed below:

1. Monazite partly replaced by apatite. Irregular and discontinuous rim of apatite and small grains of allanite (or REE rich epidote) and titanite close to monazite grain can be noticed.
2. Monazite completely replaced by apatite containing Th (up to 8.6 wt.%) and small amounts of REE. Inside newly formed apatite, there are "spots" of phases rich in Th (up to 50 wt.%) and Si (Fig. 1). Monazite with irregular rim of apatite with high Th (and REE in some examples) and Si content has been also found. The grain is enclosed in biotite partly converted to chlorite and epidote enriched in REE.
3. Monazite partly replaced by apatite without secondary concentration of REE and Th around it. Apatite enriched in REE (but without Th) can be found in the vicinity (Fig. 2).
4. Monazite partly replaced by apatite without rims or secondary rims. Th and U concentration areas mimic the original shape of monazite crystal but slight decrease of content towards rims can be noted. REE are present exclusively in monazite remains.



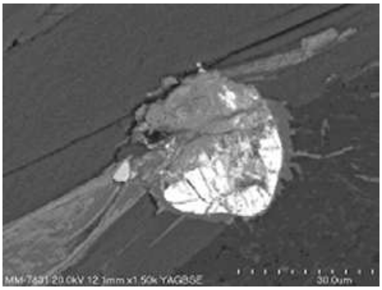


Fig. 1. (left) Monazite completely replaced by apatite; bright spots – Th and Si rich phase.
Fig. 2. (right) Monazite (bright field) partly replaced by apatite.

DICUSSION AND CONCLUSIONS

The breakdown of monazite in the High Tatra granitoids is common. Only crystals insulated against Ca bearing solutions (enclosed in Fe-Ti oxides or apatite) are non-altered. Regular coronas of secondary minerals, typical of amphibolite facies granite (Finger et al. 1998), are absent. It can be concluded that lack of coronas is typical of low-temperature (200-300°C; determination based on chlorite composition) alterations of the Tatra granitoids. Formation of apatite is the most widespread alteration process and is controlled by availability of Ca ions in solution. Ca is released mainly during sericitization and albitization of plagioclases.

Secondary apatite contains usually Th but the form of Th occurrence is unknown. It is possible that substitution $2REE^{3+}$ -- $Th^{4+} + Ca^{2+}$ was important in this type of alteration of monazite. In the second, less common type of alteration, Th silicate (huttonite or thorite) is formed inside secondary apatite probably by substitution $2REE^{3+} + P^{5+}$ -- $Th^{4+} + Si^{4+}$. According to Poitrasson et al. (1996) these two types of substitutions are related to different hydrothermal alterations of granite (chloritization and greisenisation, respectively). Enrichmenet in Th and Si can be also explain by concentration of residual Th silicate during monazite decomposition (Mathieu et al. 2001).

Different types of monazite alteration processes can be attributed to different conditions (T, P) during different period of granitoid alteration processes or to local variations of chemical composition of fluids.

Absence on REE-bearing minerals around altered monazite (and low content of REE in apatite) indicate mobilization of REE during granitoid alteration. REE-containing epidote (spatially not related to altered monazite) can be noted (beside epidote devoid of REE) in the High Tatra granitoid. Th (and U) seems to be only partly mobilized during monazite alteration. The distance of transport of these elements is unknown.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
Zeszyt 23, 2003; Volume 23, 2003

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METAMORPHIC RECORDS IN THE METASEDIMENTS FROM THE BYSTRZYCKIE MTS, WEST SUDETES

The Orlica-Śnieżnik dome is situated in the easternmost part of the West Sudetes. The western part of the dome, called the Bystrzyckie Mts, comprises a large orthogneiss body (the Śnieżnik orthogneiss) mantled by rocks of the Stronie formation. The latter mainly includes mica schists, paragneisses, basic and acid metavolcanics and marbles. The orthogneiss represents deformed and metamorphosed granitic body dated, using single zircon evaporation and SHRIMP method, at 495-515 Ma (Kröner et al. 2001). The Stronie formation, originally forming metasedimentary cover of the orthogneiss protolith is believed to be of the Late Proterozoic or Early Paleozoic age on the basis of micropaleontological findings (Gunia & Wierzchołowski 1979).

In the Bystrzyckie Mts, rocks of the Stronie formation form four separate outcrops described by Dumicz (1964) as individual tectonic units. From the NE to SW and from bottom to top of the structural sequence they are: Równia Łomnicka, Mostowice-Jagodna, Gniewoszów-Kamieńczyk and Niemojów-Czerwony Strumień units. The Stronie formation recorded a sequence of five deformation events (Szczepański 2001). The oldest D_1 structures are represented by the S_1 foliation preserved as inclusion trails mainly within plagioclase blasts. Subsequently, the S_1 foliation was deformed by F_2 isoclinal folds. The new S_2 foliation developed parallel to axial planes of these folds. Results of the first two events are best preserved in the rocks of the Równia Łomnicka Unit. The following the D_3 deformation phase was associated with reactivation of the older S_2 foliation. The newly formed complex $S_{2=3}$ foliation, the main planar structure visible in the rocks of the southern part of the Bystrzyckie Mts, dips steeply to W or SW. On the $S_{2=3}$ planes the N-S trending L_3 mineral lineation is developed. Evident and abundant kinematic indicators show top-to-the-NNE asymmetry. They document noncaoxial shear being the main component of the D_3 event. Thus, the D_3 episode was connected to the dextral non-coaxial shearing. Effects of the D_3 event are exclusively recorded in the Gniewoszów-Kamieńczyk and Niemojów Czerwony Strumień Units. The following D_4 deformation involved a regional scale folding which produced east-vergent F_4 folds. Finally, east-west trending F_5 kink-folds were formed by a brittle-ductile deformation at a shallow crustal level. Every tectonic episode except of the D_5 was connected with growth of new mineral assemblages. Consequently, it is suggested that

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investigated metasediments recorded four metamorphic events M_1-M_4 related to four tectonic events D_1-D_4.

The present study is based on the petrological investigation of 80 thin sections. In order to establish PT conditions of metamorphism, mineral chemistry data (ca. 600 microprobe analyses) from selected 11 thin sections were used. The study samples were collected within the Równia Łomnicka (samples s3, s5, s16 and s25) and Gniewoszów-Kamieńczyk (samples s22, s45, s63, s68, s78 and s82) and Niemojów-Czerwony Strumień (sample s54) units. These units represent the largest outcrops of the Stronie formation rocks in the studied area. Obtained chemical data were employed for P-T estimations by means of the garnet-biotite (Holdaway 2000), garnet-muscovite (Green and Hellman 1982, Chun-Ming et al. 2002) and plagioclase-muscovite (Green and Usdansky 1986) thermometers plus GPMB barometer (Powell & Holland 1988) and also phengite barometer (Massonne & Schreyer 1987).

Metasediments comprised in the structurally lowermost Równia Łomnicka unit underwent greenschist facies metamorphism. Peak temperatures calculated for these rocks, using the garnet-biotite, garnet-muscovite and plagioclase-muscovite geothermometers, vary in the range of 518 - 590 °C. The maximum pressures estimated with Grt-Pl-Ms-Bt geobarometer reach values of 8.3 - 9.9 kbar. These peak metamorphic conditions were probably achieved during the D_2 deformation event. In the Gniewoszów-Kamieńczyk unit, overlying the Równia Łomnicka unit, peak mineral assemblages are related to the D_3 episode and form a typical Barrowian type sequence with biotite, garnet and staurolite zones. The garnet-biotite, garnet-muscovite and plagioclase-muscovite geothermometers produced values of 435 - 490 °C for biotite zone, 580 – 588 °C for garnet zone and 615 °C for staurolite zone. The phengite geobarometer yielded pressure of 4.9 - 6.4 kbar. Finally, metasediments comprised in the structurally uppermost Niemojów-Czerwony Strumień unit experienced amphibolite facies metamorphism. Peak temperatures calculated for mineral assemblages defining the D_3 structures in these rocks using garnet-biotite and garnet-muscovite geothermometers are scattered in the range of 615 - 650 °C. Pressures of 6.8 kbar were calculated using the fengite geobarometer for the same rocks.

Summing up, the tectonic units comprised in the Bystrzyckie Mts recorded different metamorphic conditions related to different tectonic events. Metamorphic record (M_2) comprised in the Równia Łomnicka unit, related to the D_2 event, was relatively HP/LT. In contrast, peak metamorphic conditions (M_3) recorded by rocks of the Gniewoszów-Kamieńczyk and Niemojów-Czerwony Strumień units, related to the D_3 tectonic event, were relatively MP/MT. As yet no traces of the M_2 metamorphism were found in the Gniewoszów-Kamieńczyk and Niemojów-Czerwony Strumień units. Consequently, it is still unclear whether those units underwent the same or different P-T path. The M_3 metamorphism in the southern part of the Bystrzyckie Mts developed the Barrowian type sequence probably under the D_3 transpressive regime. It was possibly associated with the postulated by Aleksandrowski et al., (2003) dextral strike-slip displacement along the contact of the Teplá-Barrandian and Moldanubian terranes.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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ZEOLITIZATION OF BASALTIC TUFF FROM THE GRACZE QUARRY

INTRODUCTION

Determination of products and conditions of alteration of basaltic tuff from the Gracze quarry (the Opole Silesia) was the aim of the study. The area is situated in the easternmost part of Central European Volcanic Province (CEVP). The occurrence of basalts is related to the Odra fault zone (Birkenmajer 1974). Volcanic rocks from the main Gracze quarry date to the Oligocene/Miocene (Birkenmajer and Pécskay (2001).

According to Kapuściński and Probierz (1999), the tuff is composed of pyroxene group minerals – augite and diopside (present in all studied samples), magnetite, nepheline, antigorite and clay minerals (illite and montmorillonite). Chabasite series of zeolites (phillipsite, chabasite, analcime) is present. Calcite, iddingsite, Fe-oxides, serpentine and zeolites replace primary olivine. Kapuściński and Probierz (1999) noted that – dark red tuff is more altered that gray and green ones.

SAMPLING AND ANALYTICAL METHODS

Samples collected in the Gracze quarry from different locations and exploitation levels, represent tuff from the contact with marls (two samples) and tuff emplaced between lava flows. Fine-grain gray tuff, dark red tuff, coarse-grain gray tuff and green breccia-like tuff (with fragments of sedimentary rocks and lapilli), which forms a thin layer on the contact with marls were studied.

Scanning electron microscopy with energy dispersive spectrometry, X-ray diffractometry and optical microscopy were used during investigations.

RESULTS

The tuff is composed of pyroxene (augite – diopside), nepheline and oxide minerals (magnetite and minor amount of chromite, and probably anatase and Mg, Fe, Al spinel), calcite, serpentine and smectite. Zeolites represent two groups: natrolite type (NAT according to International Zeolite Association classification) noted in one sample and phillipsite type zeolites (PHI according to IZA classification) present in other samples. Chemical composition of zeolite minerals is strongly variable, especially in the content of Fe, K, Mg. Zeolite crystals are present on the pyroxenes and calcite. Halite occasionally overgrows zeolite crystals. NAT phases are present close to basalt/marls contact and PHI dominates in tuff emplaced by lava flows.

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Morphology of zeolite crystals is variable: euhedral prismatic crystals often are overgrown by fibrous branchy zeolite (fig. 1). Both natrolite and phillipsite occur in prismatic (older) and fibrous branchy (younger) forms.

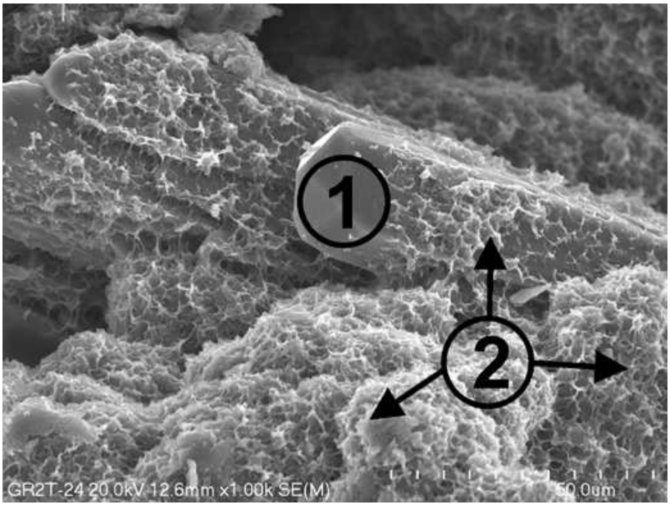

Fig. 1. Euhedral (1) and fibrous branchy form (2) of zeolites.

DISCUSSION OF RESULTS AND CONCLUSIONS

Primary (magmatic) components of tuff (pyroxene, nepheline and olivine) are partly transformed into secondary minerals (calcite, Fe oxides and zeolites). Development of zeolites is widespread and voluminously very significant (up to 40%).

Formation of NAT and PHI phases is related probably more to temperature of crystallization then to availability of Na and Ca. Na zeolites growth (NAT group) at the contact marls/tuffs is probably related to low temperature and relatively high pH conditions. Wirsching (1979, 1981) synthesised NAT phase at ~150^{-} C and pH ~12,5. NAT phase crystallization may be connected with rapid cooling of tuff (after deposition) by fluids from marls. Supply of Na ions was probably related to nepheline decomposition.

It is possible that PHI zeolites grow at higher temperature. Experimental data suggest the temperature range of 150 – 250 $^{-}$C and pH 12-13 (Kawano, Tomita 1997). However, low temperature crystallization of phillipsite (sea floor environment) is also possible (Lee, Lee 1998; Ibrahim, Hall 1996). PHI zeolites could also replace older NAT zeolites during re-heating of tuff related to subsequent stages of volcanic activity. Replacement of Na-zeolites by Ca-zeolites related to increase of temperature was suggested by Thugutt (1899).

It can be supposed that growth of unusual fibrous branchy forms of zeolites was related to the presence of specific template (conf. Collinson 2002; Griffiths, Hemsley 2002) probably of microbial (bacterial?) origin. The role of organic template was pointed out by Nesterova et al. (2003) in formation of biomimetic nanocrystalline FeOOH characterised by morphology similar to that of zeolites from studied tuffs.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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THERMAL STRUCTURE OF ŚWIĄTKOWA AND KLĘCZANY-LIMANOWA TECTONIC WINDOWS (POLISH SEGMENT OF THE OUTER CARPATHIANS) BASING ON CLAY MINERALS

INTRODUCTION

The degree of illite/smectite (I/S) diagenesis have been used to reconstruct the thermal history and structural evolution of two tectonic windows exposed within the Magura nappe. These windows have been chosen as the study object, because results of magnetotelluric studies imply that each of the windows underwent different structural development depending on morphology of the Carpathian basement (Ryłko, Tomaś 2001). Furthermore, studies of illite/smectite (I/S) diagenesis within the Polish segment of the Outer Carpathians are most advanced for the Magura nappe (Świerczewska unpublished).

GEOLOGICAL SETTING

Outer Carpathians are thrust-and-fold belt, north-verging in the Polish segment. Main tectonic features of the belt were formed during Tertiary times due to southward subduction of the southern part of the European Platform (Fig. 1). Outer Carpathians comprise several nappes, the innermost of which within the Polish segment is the Magura nappe. The Magura nappe is underlied by Dukla nappe and its equivalents (Fore-Magura group sensu Cieszkowski & Ślączka 2001). Dukla nappe and its equivalents are exposed within discussed tectonic windows.

Both discussed tectonic windows are located in the outer part of the Magura nappe. Within the windows, crop out largely Paleogene strata (Koszarski, Tokarski 1968, Burtan et al. 1992). Only in the eastern part of the Klęczany-Limanowa window, crop out Cretaceous strata. However, the tectonic position of these strata is not clear (Burtan et al. 1992). On the surface, the windows are surrounded by Late Cretaceous through Oligocene strata of the Magura nappe (Koszarski, Tokarski 1968, Burtan et al. 1992).

MATERIALS AND METHODS

The studies of illite/smectite (I/S) diagenesis were performed on 22 surface samples of claystones. In the windows, the samples were collected mostly from the Oligocene strata whereas in the Magura nappe the sampled strata range in age from

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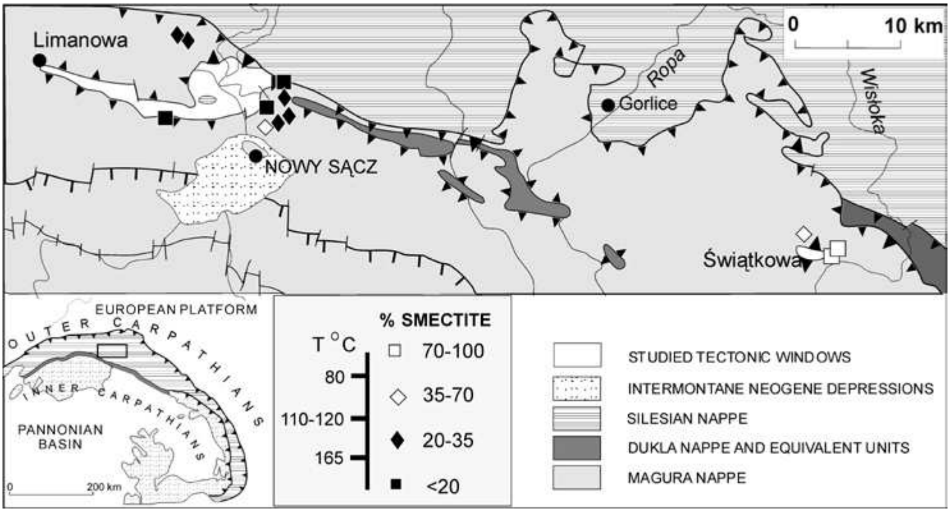

Fig. 1 Geological map of the study areas with the location of the sample sites (after Żytko et al. 1988); inset shows the location of the study areas (boxed) within the Carpathian arc.

Late Cretaceous to Oligocene. Within the Magura nappe, the sampled exposures are situated less than 3 km from the windows. Illitization of smectite has been studied in the clay fraction (<0.2 μm) by X-ray diffraction. Air-dried and glycolated preparations were analysed by the Philips diffractometer equipped with Cu tube and graphite monochromator, and scanned from 2 to 37 ¯2θ with 0.02¯2θ step and counting time 5s/ step at 45mA and 60kV. The degree of diagenesis has been expressed as the percentage of smectite (%S) in mixed-layer illite/smectite minerals and the type of ordering (R) using XRD techniques of Środoń (1984).

RESULTS AND CONCLUSIONS

The Świątkowa window samples contain I/S (28 ±6 %S) characterised by R= 1. This would imply (eg. Jennings, Thompson 1986, Šucha et al. 1993) that sampled rocks were subjected to temperatures of 110-165 ºC. Samples collected in the Magura nappe, close to the Świątkowa window, are higher in smectite (I/S 60-75%S) characterised by random interstratification (R=0). This suggests that the sampled strata were subjected to temperatures of probably lower than 110ºC or even lower then 80 ºC. In contrast, the degree of I/S diagenesis in the Limanowa-Klęczany window samples is much more advanced. I/S in the samples contains 10-18 % smectite layers and is characterised by R>1 ordering. Samples collected from the Magura nappe, at the rim of the window, show the same degree of diagenesis as the window samples. The high degree of diagenesis suggests that elevated temperatures, exceeding 165 ºC, affected the sampled rocks. However, in adjoining area, 1 to 3 km from the window boundary, %S in the rocks of the Magura nappe varies from 25 to 45 %. The samples show both random and ordered interstratification (R=1). This suggests maximum paleotemperatures of <165 °Cand 80-120 °C.

In both studied regions, the degree of I/S diagenesis increases from the strata of the Magura nappe to those of the underlying Dukla nappe. This implies that the diagenetic maturity results from burial. Assuming that both regions were affected by similar heat flow, we may infer that the amount of post-diagenetic erosion and uplift was larger in the Klęczany-Limanowa region than that in the Świątkowa region. This conclusion fits well in the tectonic models of Ryłko and Tomaś (1991) in which Klęczany-Limanowa window is located above prominent escarpment in the Carpathian basement. The sudden change of diagenetic maturity between the strata exposed in the widows and in the surrounding Magura nappe suggests that the uplift of the windows strata was larger than and independent of that of the Magura rocks.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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TALC – TREMOLITE - CALCITE PARAGENESIS FROM THE CONTACT METAMORPHOSED DOLOMITES (NW ROMANIA)

The intrusion of the Upper Cretaceous-Lower Palaeocene granodiorites (Cioflica et al. 1995) into the Middle Triassic dolomites in the North Apuseni Mts. (NW Romania, Bihor Mountains) generated an extensive zone of contact alterations.

The contact aureole is complex and composed of skarns in the inner part and predazzites in the outer part (Fig. 1). Its width ranges from tens up to 400 meters. The skarn zone is built mainly of carbonates with forsterite, garnet, diopside, chlorites, phlogopite, serpentine and magnesioferrite, whereas the predazzite zone is composed of calcite, brucite and dolomite (Bleahu et al. 1981; Marincea 1992; Ionescu 1987; Ghergari and Ionescu 2000; Ionescu and Ghergari, 2001).

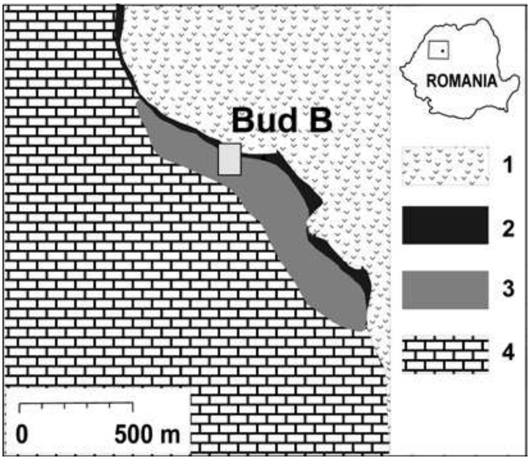

Fig. 1. The geological map of the Budureasa area with talc-tremolite occurrence (1 - granodiorite; 2 – skarn zone; 3 - predazzite zone; 4 – Triassic dolomites and limestones, Bud B – sample described).

The skarn zone of contact aureole ranges from 2 m up to 6 m of width and is mineralogically differentiated. Thirty samples have been collected in this zone, from several outcrops near Budureasa village. The aim of the study was the detailed mineralogical characteristics of the mineral assemblages and paragenesis developed in the altered rocks, as well as the reconstruction of the TX_{CO_2} paths of the contact metamorphism. Hereby the talc-tremolite-calcite paragenesis, present in one sample from the outer part of the skarn zone of the contact aureole is described.

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METHODS

All samples were analysed by powder X-ray diffractometry (XRD) by means of a X'Pert APD Philips diffractometer, CuKa radiation and a graphite monochromator. The observations of crystal habits were performed with a Hitachi S-4700 scanning electron microscope (SEM) coupled with an energy depressive spectrometer EDS (Noran Vantage) and petrographic microscope. BIO-RAD Fourier Transform Spectrometer (FTS 135) equipped with a Michelson interferometer was employed for infrared absorption analyses.

RESULTS

In the outermost part of skarn zone small lenses (some centimetres) of calc-silicate rock containing white fibrous mineral (tremolite) were noted. The XRD analyses allowed the identification of prevailing calcite and talc (d_{hkl}= 9,38Å, 4,68Å; 4,56Å; 3,11Å). Additionally tremolite (d_{hkl} = 9.38Å; 4.57Å; 3.34Å; 3.12Å, 2.51Å, 1.67Å and 1.51Å), quartz and dolomite were detected. The FT-IR absorption spectroscopy data confirmed the XRD identification.

Microscope observations revealed abundant talc and carbonates with rare tremolite and quartz crystals. Talc crystals, of a size of micrometres up to one millimetre are intergrown with calcite (up to 2 mm) and colourless tremolite fibres. In the studied rocks tremolite crystals (up to 5 mm of length) are scarce (<5 vol. %) and forms fan-like structures. Petrographic and scanning electron microscope observations revealed that calcite, talc and tremolite are in mutual contact idicating that they constitute mineral paragenesis.

EDS point analysis show that talc from Budureasa is pure magnesium silicate, whereas tremolite contains small amounts of aluminium as well as chlorine.

DISCUSSION

The contact metamorphism of high-Mg rocks, in the presence of hydrous metamorphic fluids, led to the crystallisation of many hydrous mineral phases, including talc and tremolite. The presence of calcite and dolomite in all studied samples indicates that they were excess minerals in the alteration process. In the dolomites, during the contact metamorphism with the presence of silica, in low-pressure subvolcanic conditions, talc and tremolite may form in the following reactions:

3Dolomite + 4Quartz + H_2O –> Talc + 3Calcite + $3CO_2$

5Dolomite + 8Quartz + H_2O –> Tremolite + 3Calcite + $7CO_2$

The record of the talc and tremolite paragenesis suggests that the equilibrium conditions of the following reaction were established:

2Talc + 3Calcite –> Tremolite + Dolomite + CO_2 + H_2O

This univariant reaction was observed in a wide range 0.05 to 0.5 of mole fractions of CO_2 (X_{CO2}) and at temperatures below 450^0C (Fig. 2, solid line) Bucher and Frey (1994). The higher temperature bivariant field (marked as "tremolite" Fig. 2) requires talc dispersal.

SUMMARY

Talc-tremolite-calcite paragenesis occurs in association with quartz and dolomite in the outer zone of the contact aureole, caused by the intrusion of the Upper Cretaceous-Lower Paleocene granodiorite pluton into the Anisian dolomites. The presence of this paragenesis suggests low temperature (<450°C) metamorphic conditions. The composition of metamorphic fluid might have varied in the range of low X_{CO2}, suggesting an open system conditions.

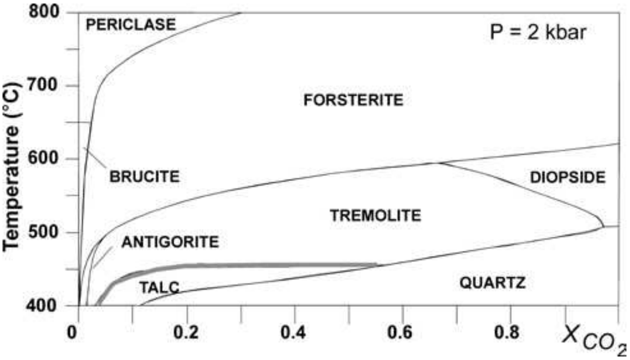

Fig. 2. TX_{CO2} phase relationships in altered carbonates containing excess dolomite and calcite (Bucher and Frey 1994), with metamorphic reaction representing calcite-talc-tremolite paragenesis.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
Zeszyt 23, 2003; Volume 23, 2003

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SKARNS AND SKARN MINERALISATION IN THE CRACOW-LUBLINIEC REGION (SOUTHERN POLAND)

INTRODUCTION

Skarns and skarn-like rocks as well as the ore mineralization ocuur in the Myszków and Zawiercie (the Małopolska Block) and Koziegłowy (the Upper Silesia Block) areas. Skarns were formed due to the thermal – metasomatic metamorphism of the Early and Late Palaeozoic carbonate deposits, that was initiated during the Variscan intrusions of acid magmatic rocks – granites, dacite and rhyolite porphyries (Harańczyk et al., 1980; Markiewicz, 1998).

METHODS

Petrologic investigations presented here are based on samples of rocks from 17 boreholes. About 200 samples were analyzed by optical microscopy. Electron microprobe and spectral laser analyses were used to identify crystalline phases in the inclusions. Chemical analyses were carried out in the Central Chemical Laboratory of the PGI in Warsaw (by XRF, AAS, ICP-AES method).

RESULTS

The studied rocks were classified as exoskarns (Einaudi, Burt, 1982) and infiltrating skarns.

They are formed in skarned zones of the width ranging from several centimeters to several dozen meters and occur several dozen to several hundred meters from the granites, dacite and rhyolite porphyries. The skarns form: lenses, veins and nest impregnations. The garnet, pyroxene, amphibole skarns, skarn-like rocks and marbles were found in the studied regions.

Garnet skarns build several meters insertions and nests of brown colour in rocks from boreholes RK-1 (Zawiercie region) and Pz-10 (Myszków region). The main mineral of the skarns is the xenoblastic andradite, 0,1-0,5 mm in diameter and chemical formula: Ca3.12 Mn0.01 Na0.02 Al0.22 Ti0.02 Fe1.67 [Si1.06 O4]3. It usually forms the massive textures, locally with grains of pyroxenes, quartzite and calcite.

The pyroxene skarns form irregular, brecciated inserts of green – grayish colour and they were found in each studied region. These skarns have a heterogra-

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nular texture. They consist of pyroxene (augite and diopside). Amphiboles, epidotes, quartzes and albites occur subordinately. Pyroxenes occur as heterogranular aggregates or individual grains 0,5 m in diameter and extincton angle z/γ = 38o- 42o. Quartz is observed in the contact zones between pyroxene grains. Very fine nods of olive-green epidote occur sporadically.

The amphibole skarns occur at the contact zones with the pyroxene skarns. They consist of light-green fibrous amphiboles of the tremolite-actinolite assemblage and extinction angle z/γ = 16o- 18o.Minerals are arranged in fans or bunches. Fine-flacky chlorite and talc occur subordinately. This chemical composition of amphiboles and Mg/(Mg + Fe2+) ratio between 0,6 and 0,7 is typical for actinolite (Leake, 1978).

Skarn – like rocks. These are clay – mudish rocks impregnated by skarn minerals, that occur in many forms: individual grains, nests, lenses, massive impregnations. These rocks have xenoblastic textures and mineral components are between 0,2 and 0,1 in diameter. They occur in boreholes: RK-1, RK-2, RK-3, 24-WB and 37-WB. They consist of the following association of skarn minerals: pyroxenes, amphiboles, epidotes, garnets, chlorites.

Marbles. White – grayish marbles occur between skarn zones and zones of unaltered calcareous rocks. They are built mainly of calcite and have massive texture. Crystals are 0,5 mm in diameter. Granulated calcareous mass of the dolomite composition occur among large grains of calcite.

Rich mineralization was ascertained in skarns and skarn-like rocks. It is associated with the magnetite-chalcopyrite formation, closlly related to the Palaeozoic porphyry copper and molibdenite formation of the studied regions (Harańczyk, 1980; Ślósarz, 1985; Truszel, Markowiak, 1999; Truszel, Markowiak, 2000).

Massive or nest aggregations of the coars – crystalline magnetite, hematite and chalcopyrite are associated with the andradite, pyroxene and amphibole skarns. The thickness of the mineralized zones varies between a few cm and several tens of centimeters.

Molybdenite is found in skarns only sporadically and is in the form of fine flackes. Scheelite, which is present in the form of large aggregates that are a few mm in diameter, is more common than molybdenite. Chalcopyrite and pyrite are found filling the space between magnetite grains.

Magnetite, pyrite, hematite and sphalerite were the principal ore minerals found in both skarn-like rocks and veins. More rarely, scheelite, pyrrholite, galena, ilmenite, marcasite, cubanite, bismuthinite, native Bi and Bi sulphosalts were identified.

CONCLUSIONS

– The products of contact thermal-metasomatism on carbonate rocks represented by andradite, pyroxene and amphibole skarns, skarn-like rocks and marbles have been found in the Cracow-Lubliniec area, in Myszków, Zawiercie and Koziegłowy.

– The main components of the skarns: garnets, pyroxenes, amphiboles and epidotes suggest the temperature range of metamorphism between 350°C and 550°C (Zharikov, 1998).

– Succesion of the ore mineralization is seen by the replacement of magnetite with chalcopyrite and pyrite. The presence of scheelite alonogside sulphides emphasises the significant variations in the physico – chemical conditions of the stage of mineralization.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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THE SEQUENCE AND ORIGIN OF MINERALIZATION IN THE TECTONIC ZONES IN THE SUWAŁKI ANORTHOSITE MASSIF, NE POLAND

INTRODUCTION

The Suwałki Anorthosite Massif (SAM) is emplaced within the Mesoproterozoic rapakivi-type Mazury Complex (ca. 1.56 Ga) of the Anorthosite-Mangerite-Charnockite- Granite (AMCG) affinity (Wiszniewska, 2002, Wiszniewska et al, 2002,). This massif has been subjected to several tectono-hydrothermal events resulting in extensive mineralization. The sequence and origin of polyphase vein mineralisation and its relation to the deformation development is a subject of this study.

METHODS OF INVESTIGATION

The microscopical observations, X-ray and microprobe analyses were carried out at the University of Silesia, on the FET Philips XL 30 with EDS (EDAX), the acceleration voltage 15 kV, using the natural and synthetic standards. The X-ray analyses of separated minerals were done on Philips PW 3710, with Cu-Kα_1 40 Kv and 35 mA, 2 s. counting time. The stable oxygen and carbon isotopes were performed at the Institute of Geological Sciences, Wrocław University, Laboratory of Isotope Geology and Bioecology. Mass spectrometer used was the Finnigan Matt CH7 with a modified inlet detection system. Values are quoted relatively to PDB international standard.

A. STRUCTURAL DATA

A comprehensive structural study of the SAM requires investigation of numerous (99) boreholes because each well displays several structural components and the combination of these data can be used to summarize SAM evolution. The style of deformation in the SAM area ranges from localised ductile flow, producing shear zones (from a few cm to tens of metre wide) with a mylonitic foliation and a stretching lineation, to brittle fracturing and accompanying brecciation. The SAM features alternating zones of high- and low-strain, both in ductile and brittle conditions. Dip-parallel stretching lineations are inferred to be remnants of the Gothian shortening and ductile thrusting. Almost all shear sense indicators indicate reverse sense of movements. Younger planar fabrics in the fault zones include a well-developed pressure-solution cleavage and or fracture cleavage. Locally, the cleavage become parallel to the fault direction, suggesting rotation of a passive marker during shearing and shortening. The fault zones commonly exhibit

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newly formed subhorizontal stretching lineations that overprint the former dip-parallel stretching lineations.

B. MINERALOGICAL DATA

The kaolinization was the first brittle process, restricted to the close vicinity of the mylonitic structures. The syntectonic C_1 carbonate (calcite or Fe-dolomite) precipitated on the C planes of the S-C composite fabric. If C_1 is the calcite the carbonate is accompanied by the Fe-Mg chlorite. In case dolomite is present – no chlorite occurs.

The further faulting process was accompanied by the crushing, brecciation and thin pseudotachylite vein formation. Pseudotachylyte veins are often displaced to some mm by micro-scale faults.

The cracks and fissures are filed by fine grained quartz and C_2 calcite, forming the cement of the tectonic breccias. The following relaxation event caused the opening of the earlier formed cracks and the crystallization of the teeth-like idiomorphic C_3 carbonate accompanied by the trioctahedral saponite-like smectite, mixed with trioctahedral Fe-smectite (distinguishable 15.04 Å and 12.63 Å basic reflections) and locally interrupted by the precipitation of fine-grained quartz Q_1, due to the changes of fluid composition.

The crystallization of C_3 calcite continued in the open fissures and was followed by idiomorphic to hipidiomorphic barite precipitation. Barite crystals are show the increase of SrO content to the margins.

The last mineral in the crystallization sequence was anhydrite, sometimes following the Q_2 fine-grained quartz. Sulfate minerals (and Q_2) form the late-stage, post-deformational filling of the composite mineral veins as well as the irregular impregnations in the deformed and kaolinitized host rocks.

The vein calcites show $\delta^{13}C$ ranging from -2.95‰ to -5.26‰ and $\delta^{18}O$ ranging from –10.82‰ to –19.8‰, while the calcites forming impregnations in the kaolinitized "mantle" $\delta^{13}C$ values ranging from –4.2‰ to –5.89‰ and $\delta^{18}O$ ranging from –9.41‰ to –15.21‰.

CONCLUSSIONS

The deformation regime changed from the ductile compressional to brittle extentional. Both ductile and brittle shear zones enabled the mineralisation precipitation in the sequence C_1 (dolomite) or C_1 (calcite) + chlorite $\Rightarrow$ pseudotachylyte $\Rightarrow$ C_2 (calcite) $\Rightarrow$ C_3 (calcite) + smectite $\Rightarrow$ Q_1 $\Rightarrow$ C_3 (continued) $\Rightarrow$ Brt $\Rightarrow$ Q_2 $\Rightarrow$ Anh.

The composite mineralization is supposed to be originated from the mixed hydrothermal to hypergenic fluids with admixture of marine-type sulphate waters in the last stage of mineralization.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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METAVOLCANITES FROM ORLA HILL NEAR GORZUCHÓW (KŁODZKO METAMORPHIC UNIT) – PRELIMINARY GEOCHEMISTRY DATA

INTRODUCTION

Outcrops of crystalline rocks in the north-western part of the Kłodzko Metamorphic Unit are situated in the area of approximately 2km^2 between Piszkowice and Gorzuchów villages. The best exposures are on the Orla hill (395,3 m. u.s.l) and along gorge slopes of the Ścinawka Kłodzka river. Metavolcanic rocks are represented there mainly by massive or schistose metarhyolites which form lens-shaped enclosures within amphibole- and amphibole-epidote schists and amphibolites. Additionally, in the northern part of the Orla hill, the amphibole gabbros including pyroxenite enclaves occur (Finckh et.al 1942). Granitoids exposed on this hill form wide feldspatization aureole with quartz veins up to 2m thick. Metavolcanics are associated with graphite-bearing phyllites or metalydites and in the southern part of the area also by mylonites. The direction of lithological boundaries are generally close to latitude, whilst direction of penetrative metamorphic foliation is changeable and commonly dips steeply to SW or NE (Wojciechowska 1966,1990).

In metarhyolites, the larger porphyroblasts of quartz or feldspars (K-feldspar and plagioclase) can be recognised in the laminated aphanitic background. The metamorphic lamination is well marked by presence of thin sericite trails, sometimes accompanied of flaky chlorite (rarely epidote) sets.

Among small-scale tectonic structures the intersection lineation L1 and mineral lineation L2 are most common. Locally, the open folds with amplitude up to 1 m associated with frequent joints in the hinge zones occur. The older deformation events are marked by the presence of poorly preserved intrafoliation folds. The youngest deformation events are manifested by systems of meridionally oriented faults down-throwing western walls in a step-like arrays.

In the light of previous investigations intermediate metavolcanics from the Kłodzko Metamorphic Unit were interpreted as primary dikes and sills, which injected into slowly accumulating flischoid sediments connected with Mid-Palezoic submarine rift environment (Narębski et al. 1988). In contrast, the last published geochemistry and Sm-Nd data (Kryza et al. 2003) suggest that Kłodzko Metamorphic Unit is composed

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of several subunits and the metavolcanics from Orla hill originated in the subduction-related enviroment possibly during the latest Neoproterozoic.

PETROGRAPHY

Among metavolcanic rocks, known previously as "porphyroids", collected from the northern slope of the Orla hill, and from a site localized SW from it, two petrographic groups can be distinguished: I) light coloured (laminated or/and porphyroclastic), II) dark coloured (massive). The light-coloured metavolcanics are characterised by a presence of strongly mylonitic background which contain various porphyroclasts of quartz, K- feldspars and plagioclase (albite – oligoclase) often elongated consistently with the orientation of foliation planes. Some of them are oval- or lens-shaped (rarely tables) monocrystalline individuals, but many porphyroclasts are composed of tightly integrated sets of small, strongly recrystallized grains. The "pressure shadows" surrrounding many larger monocrystalline porphyroblasts show characteristic fine-grained mosaic containing quartz and feldspars. Thin veins composed of biotite plateletes as well as remnants of decomposed garnets occasionally also occur. In one sample the sharp-edged quartz porphyroclasts and myrmekite-like structures were observed. The dark-coloured metavolcanites display porphyroclastic structure. Among porphyroclasts the feldspars (plagioclase albite - oligoclase) predominate whilst actinolitic hornblende, epidote and chlorite occur in the subordinate amounts. Plagioclase grains have commonly well preserved tabular shapes and polisynthetic (albite) twinning, but in many places they are strongly altered. Locally, the surrounding matrix is strongly mylonitized. Locally, the thin veins filled of cryptocrystalline carbonate are also visible.

GEOCHEMISTRY

Three samples of "porphyroids" have been selected for geochemical studies. Two samples of dark "porphyroids" exhibit an andesite composition (SiO2=61,8% wt., #Mg= 51) or rhyodacite (SiO2 = 63,9 %wt., #Mg = 40) and one light-coloured sample is geochemically comparable with rhyolite (SiO2 = 78%wt., #Mg= 18). On Zr/TiO2 – Nb-Y discrimination diagram projection points occupy the andesite and rhyolite fields. All are characteristic for calc-alkaline differentiation trend. Similarly, the obtained values of Zr/Y ratio: 6-8 are indicative for the within-plate setting for both metaandesites and metarhyolites.

The contents of trace elements plotted on MORB - normalized multielement diagram of dark "porfiroids"show two kinds of distribution profiles. One profile - typical for andesites - is characterised by the presence of strong K, Rb, Ba,Th enrichment, slight Ce positive anomaly and depletion Ti . It can reflect subduction-related crustal contamination of andesitic lavas. The multi-element pattern of rhyolite shows selected LIL enrichment in comparison with andesites. In this case, the K,Rb abundances are slightly lower than in the andesites, but Ba,Th,Ta,Th, Nb, Zr, Hf, Sm are strongly enriched. The strong negative anomaly of Ti is also observed. Such position of profile line can suggests a very complicated, probably multi-stage conditions of primary melts formation including: 1) remelting of primary material in the mantle, 2) lower crustal enviroment or 3) intensive high-temperature mixing of pristine lavas with more basic melts (Pearce 1983).

On chondrite-normalized REE spider-diagram of andesites the slight enrichment of LREE (20-60 time chondrite) is observed. Rhyolite displays steeply sloped profile in the LREE range (80-200 time chondrite) with strong negative Eu anomaly and flat position of profile line in the MREE and HREE range (60-70 time chondrite). The obtained results can indicate, that primary andesites were only slightly contaminated of crustal (?) material. It can be also evidenced, that during last equilibration event of rhyolites extraction of phases accumulating Eu form primary felsic melt took place. It was accompanied with contemporaneous crystalisation of Zr nad Nb-rich phases (zircon, monacite?).

CONCLUDING REMARKS

The new geochemical results for intermediate and acid metavolcanics from the Orla hill may indicate, that the rocks are derived from primary andesitic and rhyolitic lavas or pyroclastics. Most probably the intermediate volcanics originated by shallow level fractional crystallisation of variably enriched mantle source. Such process was also associated with crustal contamination of primary melt. In the case of metarhyolite, the interpretation of its geochemistry is difficult. It is caused by many processes (mantle or crustal remelting, magma mixing, extraction of Eu -rich phases), which completely obliterated geochemical features of melts derived from primary source. Thus, the final definition of their geotectonic setting may not be undoubtedly done.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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ACID META-VOLCANIC ROCKS FROM KONRADÓW AREA (STRONIE SERIES, ORLICA – ŚNIEŻNIK DOME): STRUCTURAL, PETROGRAPHIC AND GEOCHEMICAL CHARACTERISTICS

INTRODUCTION

The Stronie Series in the area of Konradów is composed of variegated mica schists with subordinate interlayers of quartz-graphite schists, crystalline limestones, amphibolites and quartz - K-feldspar -plagioclase schists, also named as leptynites (Cwojdziński 1979, 1983, Smulikowski 1979, Wojciechowska 1972) The latter rocks form a horizon of several mega-boudins in the Krowiarki Mts between Romanowo – Ołdrzychowice (NW) and Stronie Śląskie (SE). These light-grey or yellowish, fine-grained rocks showing striped, gneissose fabric were interpreted as quartzites (Kuźniar, 1960), Gierałtów type gneisses (Don,1964), or blastomylonitic, microcline paragneisses (Butkiewicz, 1968).Wojciechowska (1976), basing on mineralogy and SiO_2 / Na_2O + K_2O ratio characteristic for acid magmatic rocks, concluded that they may represent primary lavas, tuffs or tuffites.

Lithological boundaries in the investigated area are always concordant with the main penetrative foliation developed during the first deformation phase D1 which is also documented by isolated intrafolial folds and quartz secretions and mineral lineation. The D2 phase is expressed by new set of folds (superposed on older folds) and pencil structures developed along L2 intersection lineation. Next – D3 episode produced open folds F3 with steep axial planes S3 (average orientation: 50/10) which are locally underlined by recrystallization of mica flakes. The last D4 phase is represented by kink-folds F4 showing amplitudes not greater than 20 cm.

PETROGRAPHICAL FEATURES

A new investigation of 6 samples of leptynites from Konradów area documents their fine- to coarse-grained granoblastic fabric. The dominant matrix is built of interfingering quartz-feldspar mass which surrounds bigger feldspar porphyroclasts, most often with partly preserved tabular habits, indicating their primary, magmatic origin. A state of feldspar preservation is diversified. K-feldspars are weakly changed, while plagioclases (albite, oligoclase) are strongly altered, with ubiquitous inclusions of heavy minerals and tiny mica flakes . In all samples foliation is mainly defined by white micas, partly by chloritized biotites Stripes of well recrystallised micas enclose K- feldspar porphyroclasts.

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Some of them are strongly deformed as evidenced by long, symmetric pressure shadows. Rare asymmetric shadows indicate limited effect of rotational, ductile deformation. Small amount of muscovites flakes positioned perpendicularly to the main foliation suggest their post-kinematic crystallization.

GEOCHEMISTRY

For geochemical analyses two samples from environs of Konradów and one from Romanów were selected .The bulk rock chemistry of studied samples shows that most of alkaline components were not removed from the system during deformation or recrystallisation. All obtained chemistry results can reflect rhyolithic or rhyodacitic composition of primary protolith (Winchester et.al.1977). The contents of trace elements plotted on ORG normalized multielement diagram (Pearce et al. 1984) show similar distribution profiles for all studied samples .They are characterised of K,Rb,Ba,Th enrichment and Ti, Zr depletion typical of within plate enviroment .On the chondrite-normalized REE spider diagram (Sun et.al. 1989) the relative enrichment of LRRE with slight positive anomaly of Ce and strong negative anomaly of Eu content can be observed.

CONCLUDING REMARKS

Most probably these volcanic rocks originated by shallow level fractional crystallisation of variably enriched mantle source. Such process might be also associated with crustal contamination of primary melt, together with the removing of plagioclases from the primary felsic melt.

The above presented rocks show many similarities with other acid meta-volcanics known from other parts of the Orlica – Śnieżnik Dome (Wojciechowska et al. 2001a, b).

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
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THERMAL EFFECTS OF THE ŽULOVÁ GRANITE PLUTON, SILESICUM, EASTERN VARISCAN FRONT

INTRODUCTION

The eastern mantle of the Variscan Žulová Pluton (ZP), is formed by a volcano-sedimentary complex, with characteristic periplutonic HT/LP-MP metamorphism continuously decreasing toward the east (Souček 1987). The zone of contact migmatitization (Bt + Grt + Sil + Crd + Kf) is 0.5-1 km wide but the periplutonic aureole (Bt + Grt + Sil + St+Ms) is several times wider. The contact in the N and NW is obscured due to extensive Quaternary cover and in the SW it is in tectonic contact with Keprník, Branná, and Staré Město Units along the Marginal Sudetic Fault (Fig.1).

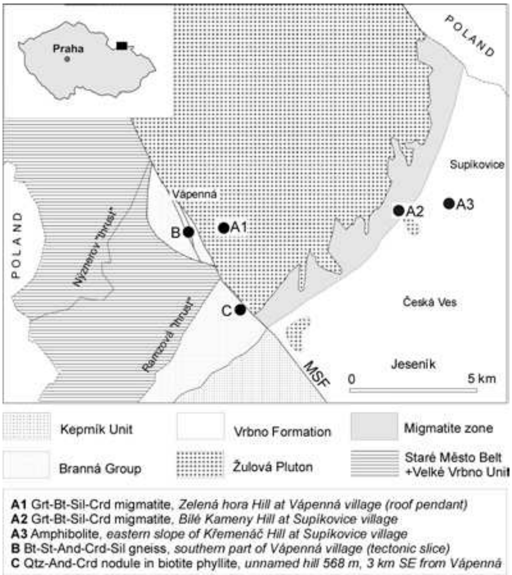

Fig. 1. Simplified geological map of the area studied.

The samples studied were collected during regional geological mapping at the scale 1: 25 000 (sheets 14-223 Lipová Lázně, 14-224 Jeseník). Besides “normal” rocks characteristic for the ZP mantle (type “A”), a peculiar gneiss, not reported till now from the Žulová Pluton Mantle, is described (type “B”). Biotite phyllite with quartz – andalusite – cordierite nodules (type “C”) was found in the Branná Group close to the Marginal Sudetic Fault (MSF). All these three different rock types are interpreted as periplutonic metamorphites related to the ZP.

PETROLOGY AND THERMOBAROMETRY

TYPE “A” rocks (A1-A2) represent migmatites from migmatite zone of ZP. The mineral assemblage comprise quartz + plagioclase + potassium feldspar + biotite +

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garnet + sillimanite + cordierite. Scarce muscovite and chlorite represent retrograde phases, ilmenite, graphite, zircon, rutile, titanite, apatite and monazite are accessory (Rozkošný - Souček 1989, Cháb - Žáček 1994). Staurolite, kyanite and andalusite are mostly absent and occur very rarely as tiny relics (kyanite and staurolite) or as components in pegmatitic metatect (andalusite). Garnet is Ca-poor almandine showing a weak progressive zoning and retrograde rims up to several hundreds of microns wide, and a compositional variability:

Alm$_{72\text{-}85}$ Prp$_{6\text{-}16}$ Sps$_{3\text{-}16}$ Ca-Grt$_{2\text{-}8}$, X$_{Mg}$ = 0.06-0.17.

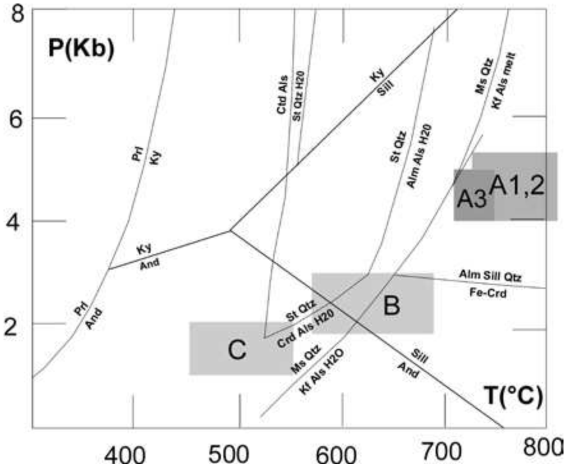

Fig. 2. P-T diagram for rocks affected by Žulová Pluton contact/periplutonic metamorphism.

Temperatures calculated for rocks from migmatite zone (samples A1, A2) show a wide range of values (720-947 ^{0}C) but the temperatures ranging between 720 and 800 ^{0}C are most frequent (at 4-5 kbar).

Sample A3 is amphibolite occurring outside of migmatite zone. The temperatures calculated are slightly lower, mostly 711-744 ^{0}C, at 4-5 kbar, (compare Souček 1987, Losos - Hladíková 1988).

TYPE "B" represents a relict of former metamorphic mantle of ZP preserved as a tectonic slice between two branches of MSF. The rock (biotite – staurolite – andalusite gneiss) has a mineral assemblage unusual for the area of ZP mantle. It is composed of prevailing quartz + oligoclase (18-32 An) + biotite (X$_{Mg}$ = 0.37-0.39) + muscovite + staurolite (X$_{Mg}$ = 0.12-0.18) + andalusite, minor cordierite (X$_{Mg}$ = 0.55-0.61), rare garnet (Alm$_{70\text{-}74}$ Prp$_{9\text{-}11}$ Sps$_{12\text{-}16}$ Ca-Grt$_{3\text{-}6}$, X$_{Mg}$ = 0.11-0.13) and sillimanite. Zn-rich spinel, ilmenite, apatite and tourmaline are accessory. The rocks (2 samples studied) contain early staurolite overgrown by andalusite, all these minerals are replaced by cordierite followed by growth of young muscovite + sillimanite, and Zn-rich spinel. The development of mineral assemblage shows a typical low - pressure contact metamorphic P-T path (Spear 1993). The P-T conditions calculated and inferred using P-T grids of Spear and Cheney (1989) range between 568-690 ^{0}C at 2-3 kbar (Fig 2).

TYPE "C" is biotite phyllite enclosing large quartz – andalusite – cordierite - apatite nodule. The rock was sampled at western slope of unnamed hill (568 m) about 3 km SE of Vápenná village, 400 m SW of the MSF. Cordierite crystals (1-2 cm long) are completely replaced by chlorite from chamosite group (detected by XRD) but the hexagonal prismatic shape of pseudomorphs indicates the nature of the primary mineral quite well. The assemblage andalusite + cordierite gives evidence for LP contact metamorphism of the Branná Group at least in the area close to the MSF. Approximate P-T conditions inferred from P-T grid correspond to 450-550 ^{0}C at pressures lower than 2 kbar (Table 1).

Table 1. P-T conditions of various rocks affected by Žulová Pluton contact / periplutonic metamorphis.

Sample	Rock	Method	Author	T (^{0}C)	P (Kb)	Reference
	migmatite, gneiss	garnet-biotite	Ferry - Spear (1978)	650-680	5	Souček (1987)
	calc-silicate rock (erlan)	carbon isotopes		560-730	3-5	Losos et al. (1988)
A1	Bt-Grt-Sil-Grd migmatite	garnet-biotite	several calibrations	720-925	(4-5)	this paper
A2	Bt-Grt-Sil-Grd migmatite	garnet-biotite	several calibrations	773-947	(4-5)	this paper
A3	amphibolite	edenite tremolite	Holland - Blundy (1994)	711-717	(4-5)	this paper
A3	amphibolite	edenite - richterite	Holland - Blundy (1994)	719-744	(4-5)	this paper
B	Bt-St-And gneiss	garnet-biotite, PT-grid	several calibrations	568-690	<3	this paper
C	Bt-And-Crd in phyllite	PT-grid	Spear - Cheney (1989)	450-550	<2	this paper

CONSLUSIONS

Samples from three tectonic levels of sedimentary rocks affected by contact/periplutonic metamorphism of the Žulová Pluton are described (See Figs. 1,2, Table 1).

1) HT/LP-MP “normal” metasediments and metavolcanics of the ZP mantle. The P-T conditions estimated correspond to 720-800 ^{0}C in migmatite zone, and 650-744 ^{0}C outside migmatite zone, about 2 km of the contact (all at pressures 4-5 kbar).

2) HT/LP “exotic” gneiss preserved tectonically at the MSF. The gneiss containing an “unusual” assemblage: Qtz + Plg + Bt + Ms + St + And + Crd + Grt + Sil + Sp + Ilm, yielded P-T conditions 568-690 ^{0}C and 2-3 kbar. Larger-scale geological situation clearly shows that the rock is a small tectonic relict preserved among the two branches of the MSF. The mineral assemblages and P-T conditions calculated indicate that the rock represents an upper part of contact aureole of the ZP which was in other places completely removed by erosion.

3) LT/LP metasediments of the Branná Group close to MSF. The presence of andalusite + cordierite in low-grade rocks of the Branná group provides evidence that these rocks were also affected by ZP intrusion at least in the vicinity of the MSF.

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POLSKIE TOWARZYSTWO MINERALOGICZNE – PRACE SPECJALNE
MINERALOGICAL SOCIETY OF POLAND – SPECIAL PAPERS
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PRIMARY PB-ZN- BEARING PHASES IN PYROMETALLURGICAL SLAG FROM ŚWIĘTOCHŁOWICE (UPPER SILESIA, POLAND)

INTRODUCTION

The zinc and lead mining metallurgy caused a great deal of devastation of the natural environment in the Upper Silesia, South Poland (Verner et al. 1996, Helios Rybicka et al. 1996). Huge amounts of metallurgical wastes are deposited in this region. The studied dump, located near the town of Świętochłowice, belongs to one the greatest plants related to zinc metallurgy. Currently, it consists of pyrometallurgical Zn-Pb rich material, dominated by slag. The heap, as high as 25 m covers 15 ha. Active since 1857, it was abandoned for ca. 30 years.

The knowledge of the distribution of Zn-Pb elements in the primary phases present in the slag is essential to assess the potential environmental impact related to smelting industries (Ettler et al. 2001). Therefore, the detailed study of the chemical composition and mineralogy of slags deposited in the dump was performed. In this abstract we discuss the primary phases constituting these Zn and Pb-bearing material. The described solid phases are not minerals in the sense of IMA definition, but we use the mineral names for simplicity in the following.

PETROGRAPHY AND SOLID PHASES CHEMISTRY

Collected samples are irregular in form, usually isometric and greyish coloured. Their size range from one to few meters. The largest are supposedly of the size close to that of the furnace (1 - 2 m in diameter). Usually, at the margins, the slag is vesicular (vesicles are from few µm to tens mm), whereas the core of the blocks is massive. Our chemical (Table 1) and petrographic (Table 2) determinations concern tens centimetres size blocks rich in Zn and Pb and they are based on combined bulk analyses, optical microscopy, SEM and microprobe analyses. They show two different mineral assemblages according to their position in the block.

Table 1. Chemical analyses of three studied samples.

	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	K_2O	TiO_2	ZnO	PbO	FL
CH06	23,59	3,38	9,86	0,35	3,60	5,89	0,63	0,13	47,26	2,04	6,58
CH20	33,23	4,19	14,45	0,66	10,68	23,27	0,38	0,20	1,96	2,29	7,89
CH21	12,43	14,40	14,83	0,34	7,74	4,97	0,18	0,24	27,96	6,71	16,34

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The first one (I), composed of melilite, willemite, zincite, red Zn-spinel and Pb-As-Ca-phase (Fig. 1a), forms the outer part (1-10 cm thick) of the blocks whereas the second (II), consisting of kirschsteinite, leucite, diopside, olivine, green Zn-spinel, Ba-Ti-rich mica, and pyrrhotite (Fig 1b), represents the core of the blocks.

Table 2. Primary phases identified in the studied slags (weight % element concentration).

		Si	Al	Ca	Fe	Mg	Zn	Pb	Other
zincite	**	-	-	-	-	0-1	78-82	-	-
willemite	**	13-15	-	-	0-1	2-7	47-56	-	-
Zn-spinel red	**	-	1-12	-	28-49	2	24-29	-	Mn 1-6
Zn-spinel green	**	-	28-32	-	12-23	3-9	5-9	-	-
melilite	**	17-19	0-1	21-27	0-5	1-5	2-18	0-13	-
Pb-As-Ca-phase	*	1-2	-	6-12	0-1	-	1-5	46-60	As 14-19
olivine	*	17-18	-	1-2	20-22	17-19	1-2	-	-
kirschsteinite	***	15-16	-	16-19	17-26	3-9	0-1	-	Mn 1
diopside	*	20-21	5-7	17	6-7	5-6	-	-	-
leucite	*	25-27	13	-	-	-	-	0-1	K 7-9, Ba 1-5
Ba-Ti-rich mica	*	12-14	8-9	-	8-13	5-9	-	-	K 2, Ba 10-17, Ti 3-6
pyrrhotite	*	-	-	-	60-63	-	-	-	S 35-38
Description: *** abundant, ** common, *present									

Assemblage I (Fig. 1a). Zn-spinel forms euhedral (0,02-0,2 mm) red grains irregularly distributed in the slag. Small anhedral grains of the Pb-As-Ca phase (about 0,04 mm) are located in interstices among the spinel grains. Zincite occurs as anhedral oval grains about 0.1 mm or as euhedral crystals on the surface of the blocks. Willemite and melilite fill interstices between Zn-spinel and zincite.

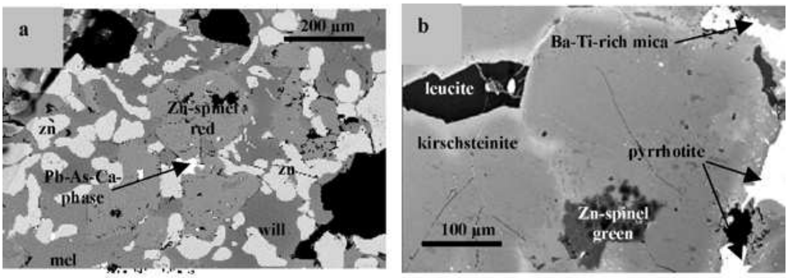

Fig. 1. BSE image of typical phase assemblages of the studied slag (mel– melilite, will– willemite, zn– zincite): a) assemblage (I), b) assemblage (II).

Assemblage II (Fig. 1b). Anhedral grains of kirschsteinite (0.5 mm) surround smaller, sparse grains of leucite, plates of Ba-Ti-rich mica and isolated grains of pyrrhotite (<0.1 mm). Zn-spinel occur as aggregates of fine green grains of size 0.05 to 50 µm. Sparse crystals of diopside, melilite and olivine occur locally in parts of slag blocks located close to the vesicles.

CONCLUDING REMARKS

Most of the primary phases constituting the studied slags contain important amounts of Zn et Pb. The phases located in the outer part of the slag blocks, are richer in zinc and lead than those occurring in the core. Water-rock interactions are favoured by the highly porous texture of the outer part of the slags and also by the presence of minerals unstable in meteoric conditions such as sulphides. Moreover, although oxide and silicate phases are known for a better stability in these conditions (e.g. Sidenko et al. 2001), part of them shows weathering evidences. These alteration processes allow a major release of heavy elements. Its importance is obvious at a macroscopic scale by the deposition of secondary phases coating primary material everywhere in the site. A detailed study of these authigenic phases is the topic of the following part of our work.

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THE EASTERN PART OF THE ŽULOVÁ PLUTON (NE BOHEMIAN MASSIF): A REVIEW

The Žulová Pluton (Fig. 1) is located at the south-eastern part of the Fore-Sudetic Block (NE Bohemian Massif). It consists of granitoids varying in composition from the two-mica granites through the biotite granites and granodiorites to subordinate tonalites. The age of granites was determined at 305 Ma (Novák et al. in press). They are considered to be the ilmenite-allanite I-type granitoids (Zachovalová et al. 2002). Northern edge of the Pluton is located in Poland, whereas the main part belongs to the Czech Republic. Since the description of Scharff (1920) no complete study of the Pluton was presented. In this paper we show a short review of geological and petrological data on the Pluton and its eastern cover.

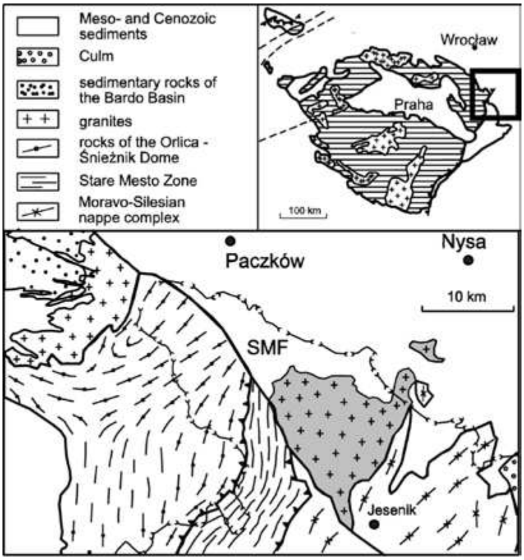

Fig. 1. Location of the Žulová Pluton at the eastern part of Fore-Sudetic Block. SMF = Sudetic marginal Fault

Granitoids (crosses) and metamorphic basement (lines) are marked at the inset.

The granitoids outcrop is relatively large, but northern and western parts the Pluton are covered by Tertiary and Quaternary sediments (Fig. 2). The granitoids and their cover rocks are exposed at the surface in a NNE-SSW trending zone forming the eastern part of the Pluton. Numerous roof pendants as well as contacts with the roof rocks demonstrate that apical parts of the pluton are exposed. The relationships among various granitoid varieties indicate that they were formed by multiple injections of magma of varying composition (Puziewicz 1999).

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Gneisses, amphibolites and quartzites of the cover occur in NNE-SSW trending zones (Fig. 2). They are considered to be Devonian sedimentary and volcanic rocks metamorphosed before the Pluton emplacement, and to be an equivalent of the Vrbno Series, which is situated to the south of the Sudetic Marginal Fault (Cháb and Žáček 1994). Large asymmetrical megasyncline with closure situated at Jeseník dominates the structure of the cover. The intrusion of granitoid magmas led to metamorphism and refoliation of adjoining rocks in the stability field of sillimanite and cordierite (Souček 1978, Cháb and Žáček 1994). Two belts of steep foliation paralleling the contour of the Žulová Pluton overprint the pre-plutonic foliations (Cháb and Žáček 1994).

The gneisses vary in structure, layered to stromatic migmatitic varieties are common close to the contact with the Pluton. They are accompanied by subordinate high-grade mica schists. Garnet-biotite-sillimanite paragneisses and garnet-sillimanite-cordierite-K-feldspar migmatites are most common.

Cháb and Žáček (1994) concluded that the feldspar quartzites adjoining the gneisses share the metamorphic grade of the latter. The quartzites are rich in feldspars (K-feldspar and smaller amounts of plagioclase) and their sedimentary fabric is usually obliterated. Detailed microscope and BSE microprobe study enabled to recognize the primary detrital grains and matrix containing metamorphic mineral assemblage: albitic plagioclase, pumpellyite, actinolite/ferroactinolite, chlorite, muscovite, clinozoisite, titanite and graphite (Puziewicz et al. 2003). This mineral assemblage is characteristic of pumpellyite-actinolite facies. In the opinion of Puziewicz et al. (2003) the quartzites contain no minerals characteristic of higher-grade metamorphism, and belong to the pumpellyite-actinolite facies. Thus, two different views on the metamorphic grade of the quartzites exist.

The amphibolites of the Žulová Pluton cover are a part of larger amphibolite mass, termed the Jeseník amphibolitic massif. The amphibolites occurring in the cover usually overly the quartzites (Jelínek and Souček 1981). Volcanic-sedimentary rocks with significant carbonate content were the protolith of the amphibolites. Typically the amphibolites occurring in the cover of the Žulová Pluton are layered and consist of amphibolite and calc-silicate layers. The amphibolite layers are composed of hornblende with subordinate plagioclase of highly variable composition (An85 – An 31), quartz, chlorite and accessory titanite and ilmenite; locally clinozoisite-epidote and pumpellyite occur (Olejniczak 2002). The calc-silicate layers consist of diopside, plagioclase of highly variable composition (An64 – An9), acicular amphibole, chlorite, accessory ilmenite and locally prehnite and K-feldspar (Olejniczak 2002). The zoning patterns of amphibole and plagioclase vary from place to place (Olejniczak 2002). Mineral assemblages of amphibolites as well as zoning patterns were strongly dependent on local variations in water activity, analogically to the example shown by Puziewicz and Olejniczak (2001).

Numerous dikes of barren pegmatite of simple mineral composition (quartz, plagioclase, K-feldspar, biotite) with rare sillimanite, tourmaline and garnet occur in the cover of the Žulová Pluton. Isolated inhomogenous coarse-grained pegmatitic granite dikes and stocks contain abundant accessory garnet and locally muscovite. Lenses of marble occur between Pisečná and Velké Kunětice. The small occurrences of calc-silicate rocks are known for their museum-class specimens of grossular garnet and vesuvianite.

THE FIELD TRIP

The intention of the field trip is to show a full cross section of the eastern cover of the Žulová Pluton. We will visit the apical parts of the pluton and their cover gneisses in the Kamienna Góra quarry first. This point will show the relationships of the granites to the gneisses as well as the characteristic features of the gneisses occurring at the contact with the granites. The quartzites follow the gneisses eastwards of the granites, and we will visit the quartzites at the Kamenny vrch, which contain well formed and complete mineral assemblage indicative of pumpellyite-actinolite facies. If time allows, we will visit another quartzite exposure in the Lubina stream valley, to demonstrate the calc-silicate diopside-bearing veins in the quartzites Finally, we will visit the Bukovice quarry. Amphibolites, occurring next to the quartzites, are exposed here. This point will demonstrate the amphibolites typical of the Žulová Pluton cover.

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