

ment of the Western Outer Carpathians. *Romanian Journal of Tectonics and Regional Geology*, 77(1): 24.

DONELICK R.A., 1995. A method of fission track analysis utilizing bulk chemical etching of apatite. *Australia patent 658,800*.

FODOR L., CSONTOS L., BADA G., GYÖRFI I. and BENKOVICS L., 1999. Tertiary tectonic evolution of the Pannonian basin system and neighbouring orogens: a new synthesis of palaeostress data. In: B. DURAND, L. JOLIVET, F. HORVÁTH and M. SÉRANNE (Editors), *The Mediterranean Basins: Tertiary Extension within the Alpine Orogen*. *Geological Society, London, Special Publications*, 156: 295-334.

GOLONKA J., OSZCZYPKO N. and ŚLĄCZKA A., 2000. Late Carboniferous-Neogene geodynamic evolution and paleogeography of the circum-Carpathian region and adjacent areas. *Annales Societatis Geologorum Poloniae*, 70: 107-136.

HURAI V., KIHLE J., KOTULOVA J., MARKO F. and SWIERCZEWSKA A., 2002. Origin of methane in quartz crystals from Tertiary accretionary wedge and fore-arc basin of the Western Carpathians. *App. Chem.*, 1259-1271.

JARMOLOWICZ-SZULC K. and DUDOK I., 2005. Migration of paleofluids in the contact between the Dukla nad Silesian

units, Western Carpathians – evidence from fluid inclusions and stable isotopes in quartz and calcite. *Geol. Quart*, 49(3): 291-304.

KETCHAM R.A., 2005. HeFTy (ver. 4) software manual.

KOVÁČ M., KRÁL J., MÁRTON E., PLAŠIENKA D. and UHER P., 1994. Alpine uplift history of the Central Western Carpathians: geochronological, paleomagnetic, sedimentary and structural data. *Geologica Carpathica*, 45: 83-96.

SWIERCZEWSKA A., HURAI V. and TOKARSKI A., 1999. Quartz mineralization in the Magura nappe: a combined microstructural and microthermometry approach. *Geologica Carpathica*, 50: 174-177.

ŚWIERCZEWSKA A. and TOKARSKI A.K., 1998. Deformation bands and the history of folding in the Magura nappe, Western Outer Carpathians (Poland), *Tectonophysics*, 297: 73-90.

WÓJCIK A., MARCINIEC P. and NESCIERUK P., 2001. Tectonic units in the zone of the Carpathian overthrust – the folded Miocene between Zebrzydowice and Andrychów (the Andrychów unit). *Biuletyn Państwowego Instytutu Geologicznego*, 396: 164-166.

REE Accessory Minerals in the Gneiss and Granulite Clasts from the Silesian Unit (Western Outer Carpathians, SE Poland) as Indicators of Metamorphic Processes

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Introduction

REE accessory minerals play the important role in metamorphic petrology. Their significance is related to their hosting of trace elements in metamorphic rocks and, therefore, providing important information about evolution that these rocks experienced. Phosphates (especially apatite, monazite and xenotime) are probably the most important group of metamorphic minerals, because they might be used in wide range of investigations, including geochronology and geothermobarometry (see e.g. Spear and Pyle 2002 and references therein). Moreover, reactions in which these minerals took part might provide significant information about history a rock experienced (e.g. Finger et al. 1998, Wing et al. 2002).

Gravel size extrabasinal clasts (so-called “exotics”) of gneisses and granulites, which are present in the Silesian Unit (Western Outer Carpathians), preserve mineral assemblages, as well as structural relationships between minerals, that might provide important information about evolution of their source area – the Silesian Ridge. Monazite-(Ce), xenotime, apatite, zircon, uraninite and unidentified Th-phases as the main host of REE in studied rocks are roughly described in this report.

Sample selection and methods of investigation

Twenty one samples of gneisses and four samples of granulites collected in six localities (Bukowiec, Gorlice, Izdebnik, Krzesławice, Siekierzyna and Skrzydlna regions) in the Silesian Unit were studied. Transmitted light microscopy and SEM-EDS method were used during investigations. Samples are considered to be derived from the Silesian Ridge.

Chemical compositions of minerals were determined using cold field emission scanning electron microscope (FESEM) Hitachi S-4700 coupled with energy dispersive spectrometer (EDS) NORAN Vantage. Analyses were performed in the Laboratory of Field Emission Scanning Electron Microscopy and Microanalysis at the Institute of Geological Sciences of the Jagiellonian University, Kraków.

Results

Gneisses are mainly composed of plagioclase (ranging from oligoclase to andesine), quartz, biotite, muscovite and K-feldspar.

Apatite, zircon, monazite-(Ce), xenotime, uraninite, rutile, chlorite, Fe-Mn-garnet, epidote, allanite, barite, calcite, ankerite, Fe and Ti oxides, Fe, Zn, Cu and Pb sulphides are present as accessory minerals. Main minerals of granulites are as follows: plagioclase (oligoclase or andesine), Fe-Mg-garnet, alkali feldspar (microperthite), quartz and minor biotite, with accessory kyanite, apatite, monazite-(Ce), zircon, rutile, iron and titanium oxides, iron and zinc sulphides. Various degree of sericitization of plagioclase, as well as chloritization of biotite can be noticed in analysed samples. More detailed information about descriptions of samples are given by e.g. Budzyń et al. (2005, 2006, in print).

Monazite-(Ce) is present in most of studied samples and occur as primary and secondary mineral. Primary monazite-(Ce) forms subhedral to anhedral grains, up to ca. $70 \times 210 \mu\text{m}$. Monazite-(Ce) breakdown and its replacement by apatite is relatively common. Unusual formation of secondary monazite-(Ce) was stated in gneiss clast (sample B-2) from Bukowiec (see also Budzyń et al. 2006, in print). Monazite-(Ce) forms lamellae and irregular aggregates within and/or around calcite. These are usually enclosed in biotite and, rarely, are present at the borders of biotite crystals. Monazite-(Ce) from gneisses contains 3.24 wt.% of ThO₂ and 0.66 wt.% of UO₂ on average, and from granulites – up to 23.16 wt.% of ThO₂ and up to 1.08 wt.% of UO₂. Average Nd₂O₃/Ce₂O₃ ratio in gneisses and granulites is equal to ca. 0.35 and 0.38, respectively.

Xenotime forms anhedral grains, up to ca. $150 \times 55 \mu\text{m}$ in size, and is present in samples from Bukowiec, Izdebnik and Skrzydlna regions. Monazite-xenotime pair (both grains are $<15 \mu\text{m}$ in size), where xenotime partially mantles monazite was noticed in gneiss (sample B-1) from Bukowiec.

Zircon usually occurs as tiny, zoned grains (ca. $10 \mu\text{m}$ in diameter). However, grains up to ca. $220 \times 90 \mu\text{m}$ in size were also noticed. Complex zoning pattern with xenocrystic cores mantled by newly grown magmatic zircon is present in large grains.

Allanite is present only in one gneiss sample (sample B-5) from Bukowiec and forms anhedral grains, up to ca. $10 \times 30 \mu\text{m}$ in size. This mineral occurs as inclusion of monazite or contains inclusions of monazite.

Inclusion of uraninite (ca. $4 \times 25 \mu\text{m}$ in size) in muscovite was noticed in gneiss (sample G-6) from the Gorlice region. Uraninite contains 92.67 wt.% of UO₂ and 3.00 wt.% of PbO₂. Moreover, unidentified Th-phases that accompany apatite were noticed in gneiss (sample K-2) from Krzesławice region.

Conclusions

Origin of zircon, as well as primary monazite is probably related to Precambrian and/or early Caledonian magmatic events that were stated in other exotics (see Michalik et al., this volume). Further investigations will provide more data concerning gneiss protoliths, as well as P-T conditions and timing of metamorphism which affected studied rocks.

Allanite-monazite reactions, formation of uraninite and unidentified Th-phases are probably related to relatively low tem-

perature hydrothermal alterations. Chloritization and sericitization, as well as presence of barite, iron oxides, and iron, zinc, copper and lead sulphides also suggest relatively low temperature alterations. REE mobilization, and formation of Th-phases and uraninite might occur during the late Carboniferous-early Permian metamorphic episode dated in other clasts (e.g. Michalik et al. 2004, Poprawa et al. 2004). Younger age (ca. 225 Ma) was roughly determined using chemical method based on uraninite composition (content of U and Pb).

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References

- BUDZYŃ B., MICHALIK M., MALATA T. and POPRAWA P., 2006. Primary and secondary monazite in calcitized gneiss clast from Bukowiec (the Silesian Unit, Western Outer Carpathians). *Mineral. Polon.* (in print).
- BUDZYŃ B., MICHALIK M., MALATA T. and POPRAWA P., 2005. REE accessory minerals in the gneiss pebbles from the Upper Istebna Beds. Suggestion for the low temperature metamorphic event. *Pol. Tow. Mineral. Prace Spec.*, 26: 139-142.
- FINGER F., BROSKA I., ROBERTS M.P. and SCHERMAIER A., 1998. Replacement of primary monazite by apatite-allanite-epidote coronas in an amphibolite facies granite gneiss from the eastern Alps. *Am. Mineral.*, 83: 248-258.
- MICHALIK M., BROSKA I., JACHER-ŚLIWCZYŃSKA K., KONEČNY P. and HOLICKÝ I., 2004. Dating of gneissic clasts from Gródek on the Jezioro Rożnowskie Lake (Silesian Unit). VIII Ogólnopolska Sesja Naukowa "Datowanie minerałów i skał", Kraków, pp. 101-106.
- MICHALIK M., GEHRELS G. and BUDZYŃ B., 2006. Dating of the gneiss clasts from Gródek at the Jezioro Rożnowskie Lake (the Silesian Unit, SE Poland) based on U-Pb method. *Geolines* (this volume).
- POPRAWA P., MALATA T., PÉCSKAY Z., BANAŚ M., SKULICH J., PASZKOWSKI M. and KUSIAK M.A., 2004. Geochronology of crystalline basement of the Western Outer Carpathians' sediment source areas. *Pol. Tow. Mineral. Prace Spec.* 24: 329-332.
- SPEAR F.S. and PYLE J.M., 2002. Apatite, Monazite and Xenotime in Metamorphic Rocks. In: M.J. KOHN, J. RAKOVAN and J.M. HUGHES (Editors), *Phosphates – Geochemical, Geobiological and Materials Importance*, pp. 293-335.
- WING B., FERRY J.M. and HARRISON T.M., 2003. Prograde destruction and formation of monazite and allanite during contact and regional metamorphism of pelites: petrology and geochronology. *Contrib. Mineral. Petrol.*, 145: 228-250.