

Nonna BAKUN-CZUBAROW¹, Danuta KUSY¹, Jiři FIALA²

**TRACE ELEMENT ABUNDANCES IN RUTILE
FROM ECLOGITE–GRANULITE ROCK SERIES
OF THE ZŁOTE MOUNTAINS IN THE SUDETES (SW POLAND)**

Abstract: In rutile from eclogite-granulite rocks of the Złote Mountains in the Orlica-Śnieżnik Dome (OSD III), the contents of high field strength (Zr, Nb), 3d type transition (Cr, Fe) and other trace elements (Al, Si, Ca) were determined by means of electron microprobe. The rutile studied is distinctly richer in Zr than the other rutiles from the Sudetic eclogites. The new Cr-Zr-Nb discrimination diagram for rutile provenance studies (Bakun-Czubarow *et al.* 2004) has been extended and verified. In this diagram, separate field for Zr-rich rutile from OSD III eclogite-granulite rocks was distinguished. The usefulness of Zr-in-rutile geothermometer has been tested and confirmed for HT eclogite-granulite rocks from OSD III.

Keywords: HFSE, 3d type trace transition elements, Cr-Zr-Nb discrimination diagram, rutile provenance study, Zr-in-rutile geothermometer

INTRODUCTION

Our paper presents the results of the continued study on geochemistry of rutile from high grade metamorphic Sudetic rocks – eclogites and HP/UHP granulites. In the previous papers (Bakun-Czubarow *et al.* 2004; Bakun-Czubarow 2005), the main subject of the study was rutile from the two types of the Sudetic eclogites: the Mg-Al-Cr eclogites from the Międzygórze and Radochów tectonic units of the Orlica-Śnieżnik Dome (OSD I and OSD IV) and Fe-Ti eclogites from Kamieniec Żąbkowicki metamorphic complex in the Fore-Sudetic Block (FSB). The subject of the study presented here is focused on geochemistry of rutile from eclogite-granulite rocks of the Gierałtów tectonic unit in the Orlica Śnieżnik Dome (OSD III). The aim of the study was testing a particular trace element preference for rutile, refinement of the newly constructed Cr-Zr-Nb discrimination diagram as well as verification of usefulness of Zr-in-rutile geothermometer for HT metamorphic rocks.

GEOLOGICAL SETTING

The eclogite-granulite rock series of the Złote Mountains occurs within granitogneisses of the Gierałtów tectonic unit within the NE part of the core of Orlica-Śnieżnik Dome (OSD III). The series is distinctly dominated by acid granulites (Qtz–Pl–Kfs–Grt–Rt±Ky±Bt). Subordinate intercalations consist of basic omphacite granulites (Cpx–Grt–Pl–

¹Institute of Geological Sciences, Polish Academy of Sciences, ul. Twarda 51/55, 00-818 Warszawa, Poland; e-mail: nbakun@twarda.pan.pl; dkusy@twarda.pan.pl

²Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, CZ-16502 Praha 6 - Lysolaje, Czech Republic; e-mail: fiala@gli.cas.cz.

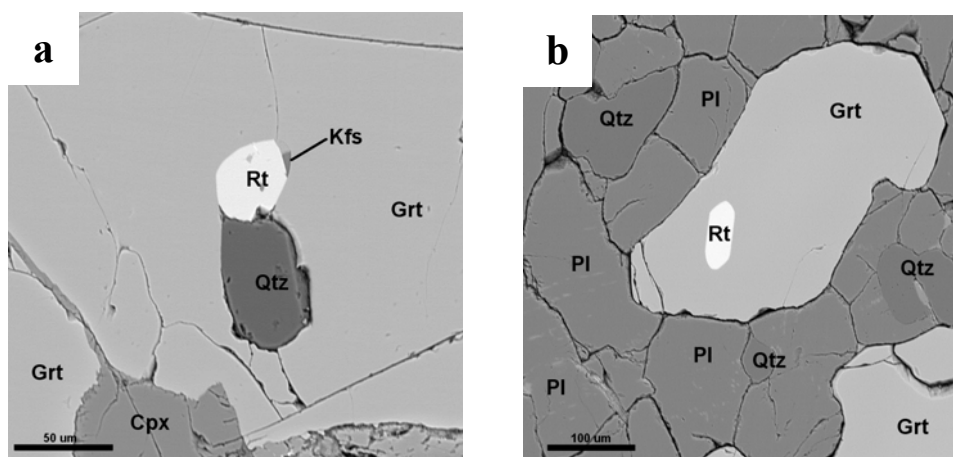


Fig. 1. BSE images of rutile grains included in garnets of **a**– eclogite no h4 and **b**– omphacite granulite no A/88. Cpx– omphacite; Grt– garnet; Kfs– K-feldspar; Pl– plagioclase; Qtz– quartz; Rt– rutile

Qtz–Rt–Ilm±Kfs±Ky) with scarce thin layers of true eclogites (Fig. 1a) with the peak metamorphism assemblage of Cpx–Grt–Qtz–Rt–Ilm. The eclogite-granulite rocks originated most likely at the expense of bimodal volcanics that had extruded during Cadomian time on a continental crust under extensional regime. During Variscan subduction the protolith submerged to the asthenospheric depths and underwent there the UHP metamorphism under continental collisional regime. Then the rocks experienced the two-stage uplift, separated by residence of the rocks at the depths of about 60 km at $T \geq 900^{\circ}\text{C}$, where granulite assemblages were developed (Bakun-Czubarow 1991, 1992, 1998).

METHODS OF INVESTIGATION

All microprobe analyses (EMPA) of rutile were conducted with a CAMECA SX 100 electron microprobe (WDS mode with LIF, PET and TAP crystal monochromators) in the Inter-Institution Laboratory of Microanalyses of Minerals and Synthetic Substances located at Warsaw University. For the trace element measurements in rutile the electron beam with energy of 20 keV, with 150 nA intensity and of 5 μm diameter as well as long counting times, ranging from 80 s for Si to 180 s for Zr and Nb, were chosen (Fialin *et al.* 1999, Bakun-Czubarow *et al.* 2004; Zack *et al.* 2002, 2004a). Detection limits varied from 15 ppm for Si to 60 ppm for Nb. About 30 trace element point analyses were performed in thin section of every rock sample.

Whole rocks were analyzed at the Activation Laboratories Ltd. Canada by means of ICP AES (major and minor elements) and ICP MS (trace elements).

RESULTS AND DISCUSSION

Rutile grains from different samples show large variations (1-2 orders of magnitude) for both compatible elements Cr (62–1018 ppm), Nb (130–1120 ppm), and incompatible ones (Ca: <25–2542 ppm, Si: <15–120 ppm, Al: <15–150 ppm) as well as moderate variations (3-6 times) for Zr (723–2163 ppm) and Fe (1400–8470 ppm).

Rutile grains from eclogite-granulite rocks are distinctly richer in Zr, Fe and Ca than

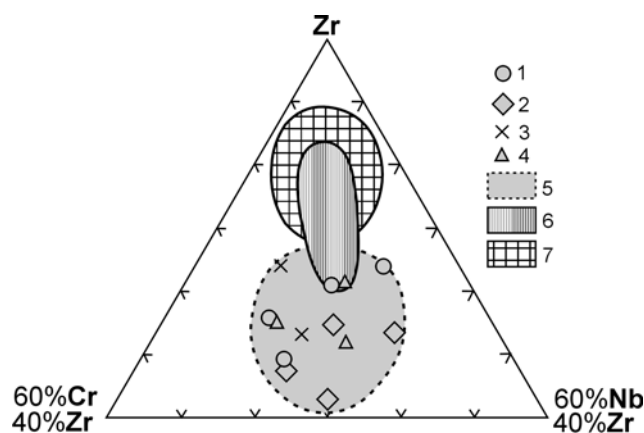


Fig. 2. The Cr-Zr-Nb diagram for rutile from OSD III eclogite-granulite rocks. Omphacite granulite no A/88: 1– intergranular rutile; 2– rutile included in garnet; 3– rutile included in plagioclase; 4– rutile included in omphacite; 5– field of rutile from omphacite granulite. Eclogite no h4: 6– field of rutile included in omphacite; 7– field of rutile included in garnet.

all the previously studied rutiles from the Sudetic eclogites (Bakun-Czubarow *et al.* 2004). As far as trace element contents are concerned, most of analyzed rutile grains are homogeneous on single grain scale, and to lesser extent between the grains in the same rock sample. There has been also checked the dependence of trace element abundances in rutile upon its host minerals or intergranular position. Two rock samples were studied in details: omphacite granulite (no A/88, cf. Fig. 1b) and true eclogite (no h4). In the Cr-Zr-Nb diagram all the rutiles from omphacite granulite plot randomly within a common field, while for rutiles from true eclogite two, partly overlapping fields can be distinguished: narrower for rutiles included in omphacite and wider for those included in garnets (Fig. 2). It seems, however, that for majority of the studied rocks these differences can be neglected as their rutiles plot randomly within common fields.

Table 1. Trace element atoms per 10^4 atoms of Ti in rutile and its host OSD III eclogite-granulite rocks.

	Eclogite		Omphacite granulites					
	h4		A/88		SG 98 e		SG 98 ga	
	Rt 1	wh rock	Rt 2	wh rock	Rt 3	wh rock	Rt 4	wh rock
Al	3.0		<1.0		<1.0		1.6	
Si	1.7		1.0		1.0		1.7	
Ca	23.0		38.0		44.0		34.0	
Ti	10^4	10^4	10^4	10^4	10^4	10^4	10^4	10^4
Cr	5.6	63.0	16.8	172	10.3	225	5.7	23.0
Fe	79.0		105		108		132	
Zr	19.0	50.9	21.2	136	21.6	73.3	22.2	96.3
Nb	3.3	2.9	7.8	2.3	7.9	2.4	8.9	3.4

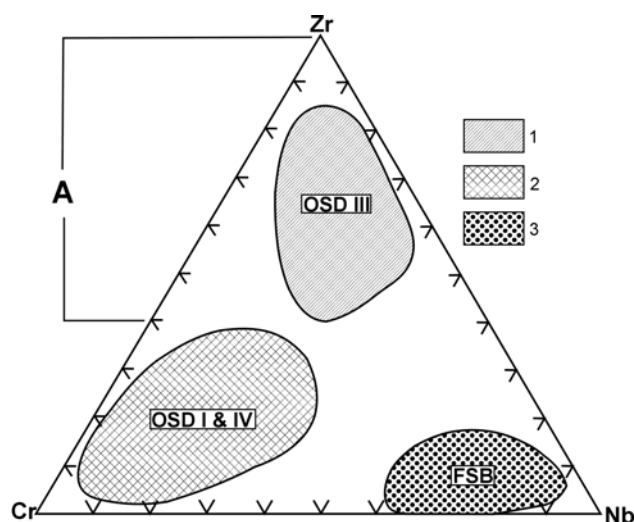


Fig. 3. The extended Cr-Zr-Nb discrimination diagram for rutile from the Sudetic eclogites. 1– field of rutile from the eclogite-granulite rocks of the Gierałtów unit (OSD III); 2– field of rutile from the Mg-Al-Cr type eclogites of the Międzygórze and Radochów units (OSD I & IV); 3– field of rutile from the Fe-Ti type eclogites from Kamieniec Ząbkowicki complex in Fore-Sudetic Block (FSB); A– part of the diagram used in Fig. 2 for Zr-rich rutiles from two rock samples of eclogite-granulite series.

Rutile enrichment in trace elements was measured by partition coefficients D_i being the ratio of i element content in rutile to its value in the host rock. Rutiles from OSD III eclogite-granulite rocks show higher enrichment in Nb ($D_{Nb}=40-180$) than rutiles from the other Sudetic eclogites studied hitherto ($D_{Nb}=24-110$). Cr shows similar enrichment in rutile from eclogite-granulite rocks ($D_{Cr}=2-5$) as in rutile from all the other Sudetic eclogites ($D_{Cr}=4-7$), whereas Zr in the studied rutile displays enrichment ($D_{Zr}=4-14$) similar to that in the Mg-Al-Cr type of the Sudetic eclogites ($D_{Zr}=4.5-14$).

Trace element abundances in rutile from OSD III eclogite-granulite rocks do not confirm the order of decreasing preference for rutile $Nb > Ti > Cr > Zr$ established by Zack *et al.* (2002) on Trescolmen eclogites (Central Alps), as enrichment in Zr is often higher than that for Cr. Trace element contents in studied rutile and its host rocks in atoms per 10^4 atoms of Ti are presented in Table 1. These data confirm the strong preference of rutile for Nb that is the main Nb carrier and controls budget of the element in whole rock. Cr shows only slight preference for rutile, but this accessory mineral does not seem to control Cr budget in whole rock. The analyzed trace transition and HFS elements are of great significance for the rutile provenance study. The Nb vs Cr discrimination diagram suggested by Zack *et al.* (2002, 2004a) is not applicable for the Sudetic eclogites, as the rutiles from Fe-Ti type FSB eclogites plot there into the field of metapelites. In a new extended Cr-Zr-Nb discrimination diagram the Zr-rich rutiles plot within separate field and confirm the usefulness of this diagram for provenance study of rutile. For this purpose a single-mineral Zr-in-rutile geothermometer calibrated recently by Zack *et al.* (2004b) can be useful. The thermometer formulated as $T \text{ (in } ^\circ\text{C)} = 127.8 * \ln(\text{Zr in ppm}) - 10$, applied for estimation of equilibration temperature for rutile–quartz–zircon paragenesis in OSD III rocks gives the results clustering around $930 \text{ }^\circ\text{C}$, close to upper limit of previous geothermometric estimates (Bakun-Czubarow 1991, 1992, 1998; Kryza *et al.* 1996).

CONCLUDING REMARKS

1. It has been confirmed that rutile is strongly dominant carrier of Nb also in eclogite-granulite rocks of OSD III.
2. Rutiles from the eclogite-granulite rock series are strongly enriched in Zr.
3. The Zr-in-rutile geothermometer has been successfully tested on HT/HP eclogite-granulites from OSD III.
4. The usefulness of the new, extended Cr-Zr-Nb discrimination diagram for rutile provenance studies has been confirmed.
5. For further perspective studies the possibility of recognition dense TiO₂ polymorphs from rocks of ultradeep origin, on the basis of trace element partitioning, should be also considered (Goresy *et al.* 2001).

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