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PARTIAL MELTING PROCESSES IN THE WESTERN TATRA MTS.: GEOCHRONOLOGICAL AND GEOCHEMICAL STUDY

Abstract: Field relations, trace element geochemistry, zircon internal structures and chemical dating of monazite were used to prove the genetic link between migmatitic leucosomes and small-scale leucogranite bodies, coexisting in the metamorphic complex of the Western Tatra Mts. The leucosomes are interpreted as cumulates (40% of the primary melt) and leucogranites – fractionated portions (60% of the primary melt) with the internal zonation. Chemical monazite dating and internal zircon structures suggest at least two partial melting episodes which started at 337 Ma and finished at about 297-309 Ma with crystallisation of the internal portions of the fractionated leucogranites.

Key words: leucogranite, migmatite leucosome, fractionation, monazite dating

INTRODUCTION

Migmatitic terranes are often described as source areas for S-type magmas. The links between the granites and migmatites were a subject of debate and were described in many papers. As leucogranites are typical examples of S-type melts, their composition could be strongly influenced by the protolith composition while melt volume (the degree of partial melting) depends on the amount of volatiles available during melting and protolith composition (*i.e.* Ebadi, Johannes 1991). Analyses of small granite plutons originated in compressional regime, suggest that their morphology and location usually mirror the sites of local stress lowering or local, small-scale extension (Vigneresse *et al.* 1996) what makes the process similar to migmatites generation. The aim of the presented paper is to solve the questions what type of processes influence the small-scale leucogranites and migmatitic leucosomes, their genetic links and age relations.

GEOLOGICAL SETTING

Crystalline basement of the Tatra Mts. is formed by polygenetic granitoid intrusion and its metamorphic envelope, preserved in the western part of the massif, called the Western Tatra Mts. The metamorphic envelope is cut by two types of granites: older granite (gneiss, 405 Ma) and younger granite (350-360 Ma, Poller *at al.* 2001). The dykes of quartz diorites (341 Ma) are also present (Gawęda *et al.* 2005). A metamorphic envelope to the intrusion, is composed of two superimposed units, differing in petrographical and chemical character, P-T conditions of metamorphism and tectonic deformations (Gawęda, Burda 2004). The shear zone, dividing both units, is intruded by small (from some tens of metres to 100-150 m in thickness), fine- to medium grained leucogranitic bodies and their pegmatites (Gawęda 2001).

SAMPLING AND ANALYTICAL TECHNIQUES

For the consideration we used previously published chemical analyses of leucogranites

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and migmatites (for details see Gawęda 2001, Burda, Gawęda 1997). For zircon and monazite separation the representative samples of anatectic migmatites and leucogranites, weighting about 20-30 kg, were taken from Upper Kościeliska Valley and Ornak Ridge. CL and BSE images of both in situ and separated zircons and monazites were obtained using FET Philips XL 30 electron microscope (with 15 kV and 1 nA) at Silesian University, Sosnowiec. The analyses of this minerals were carried out in the Inter-Institution Laboratory of Microanalyses of Minerals and Synthetic Substances, Warsaw, on CAMECA SX-100 electron microprobe (15 kV, 20 nA).

RESULTS

Fine- to medium-grained **leucogranites** are composed of K-feldspar, oligoclase-albite, quartz, with minor garnet, muscovite, biotite, monazite, titanite and sporadically found zircon. They show variation in SiO_2 content in the range 69-78%, with a mean value at 74.6% wt. The high A/CNK values (1.01 – 1.45), with $K_2O \geq Na_2O$ are typical features of peraluminous melts. Leucogranites plot on the cotectic plane in the Ab-Or-An-Qtz diagram (James, Hamilton 1969). Among LILE the positive Ba–Sr correlation and negative Sr–Rb and Sr-Rb/Sr correlation are distinct. Low HFS and RE elements content (REE_{total} = 21-189 ppm) is a result of insignificant content of minerals–carriers of these elements: zircon, garnet, sphene, biotite, due to their predominantly resister and/or restite nature (Gawęda 2001). Positive correlation of Zr *versus* SiO_2 is also observed. Leucogranites are characterised by high $^{87}Sr/^{86}Sr$ ratio (0.7223 – 0.7947). The investigated population gave no Rb-Sr age, in contradiction to their pegmatites, giving 345±9.5 Ma isochrone age (compare: Gawęda 1995).

Two types of leucogranites were distinguished. The most common, 1st type show strong negative Eu anomaly (Eu/Eu* = 0.087 – 0.439). They also show the positive correlation of $(Ce/Yb)_N$ versus Eu/Eu*. Their REE patterns are flat, with $(Ce/Yb)_N$ about 1. The positive correlation of Eu/Eu* with Sr is noted, suggesting the plagioclase fractionation process. There is an observed decrease of both Sr, Ba, Zr, Nb and Y content, Eu/Eu* and $(Ce/Yb)_N$ ratios from the margin to the centre of each intrusion. In the same direction Rb increase. Less common, small leucogranitic bodies (2nd type) show LREE enrichment - expressed as $(Ce/Yb)_N$ ratios above 2, positive Eu anomaly (Eu/Eu* = 1.548 – 3892), no relation of Eu/Eu* to Sr and $(Ce/Yb)_N$, Sr to Ba. No chemical zonation was noted.

Migmatite leucosomes are trondhjemitic in composition, with Na_2O prevailing over K_2O. They plot far from the cotectic plane in the Ab-Or-An-Qtz diagram (James, Hamilton 1969). Consequently, the migmatitic leucosomes are enriched in Ca, Sr and Eu, but no corelation of Sr and Ba is observed. Weak negative correlation of Rb and Sr could be marked as well as the weak negative trend at the Sr *versus* Rb/Sr diagram. The REE patterns of leucosomes show LREE enrichment with $(Ce/Yb)_N$ = 1.459 - 15. 573, positive Eu anomaly (Eu/Eu* = 1.13-2.618). No correlation between $(Ce/Yb)_N$ and Eu/Eu* as well as between Ba and Sr were noted. A weak negative trend is observed between SiO_2 *versus* Zr. Concentration of some elements like Y, Nb is lower than in leucogranites. The measured $^{87}Sr/^{86}Sr$ ratios in leucosomes are also lower than in leucogranites, ranging from 0.7105 to 0.7152. Some metapelitic migmatites (both leucosomes and mezosomes) gave an errochron age of 343±9 Ma with IR_{Sr}= 0.709 (Gawęda, unpublished data).

ZIRCON CHEMISTRY

In leucogranites two types of zircons are found: euhedral magmatic, with fine oscillatory zonation and anhedral, usually corroded inherited zircon crystals showing advanced metamictization. Dark CL zones are enriched in Th, U, P (2.07-2.46 wt.%), Y (4,08-2.56 wt.%), Fe and Zr/Hf ratio in the range 50-58, while the lighter CL zones are almost pure $ZrSiO_4$ with Zr/Hf ratio in the range of 80-84.

In the migmatite leucomes two groups of zircons were also found, differing in internal structure. 1st type grains (S_{21-22}) show oscillatory zonation and Zr/Hf ratio 36-41, while in the 2nd type grains (S_{1-2}) three growth stages, adequate to three geological events are recorded (Burda 2005). In the polyphase zircon grains the cores show Zr/Hf ratio in the range of 51 – 54 and the outer zones: 37- 41. No significant YPO_4 substitution was noted in leucosome zircons.

MONAZITE GEOCHRONOLOGY

U-Th-total Pb electron microprobe dating have been use to establish monazite age for leucogranite. Monazite crystals are homogeneous in BSE or display only a weak zoning. A total of 18 points yielded an isochron age of 309±20 Ma following by the method of Suzuki and Adachi (1991).

In the migmatites three groups of monazites, differing in age were found: 398 ±20 Ma (17 points, monazite occluded in quartz), 337 ± 20 Ma (20 points, monazite occluded in biotite), 297 ± 16 Ma (16 points – interstitial monazite).

DISCUSSION

In leucogranites the positive relation between LREE and HREE and Sr *versus* Eu anomaly, suggest a fractional crystallisation, mainly plagioclase fractionation as a main process. The small fraction of zircon crystals (and consequently low Zr content) together with positive relation of SiO_2 and Zr suggest lack of Zr saturation of the anatectic magma. However, the presence of zircon zones enriched in phosphorus and Y could be interpreted as the fractionation effect, leading to an enrichment in YPO_4 in the evolved portion of the silicate melt. The same conclusion could be drawn from the decrease in Eu/Eu* and $(Ce/Yb)_N$ ratios to the centre of each intrusion.

In migmatite leucosomes the no relationship between the Eu/Eu* and Sr suggests no influence of the fractionation during the leucosomes formation. No relation between LREE and HREE was also observed suggesting lack of the fractional crystallisation in the leucosome formation process, either. As plagioclases (An_{19-23}) are the most important components of the leucosomes, the positive Eu anomaly is a normal consequence of that fact.

REE patterns of leucosomes and leucogranites differ in shape and Eu anomaly value. Considering the interpretation of Turku migmatites and leucogranites by Johannes et al. (2003) leucosomes of migmatites (and 3 leucogranites with positive Eu anomaly) could represent the cumulate melt, while most of the leucogranites are fractionated final melts. That hypothesis was tested by simple mixing modelling (method suggested by Johannes at al. 2003), giving the best proportion of cumulate: fractionate melt in a parent anatectic magma = 40:60.

Ages recorded by monazite grains from the migmatite leucosome could be comparable with zircon internal structures and 3 recorded events (Burda 2005): old cores (398 Ma), mantle (337 Ma) and rims (297 Ma). In leucogranites monazite dating and internal zircon structure suggest one magmatic episode (309 Ma).

Table 1. Final results of the geochemical modelling (on the selected representative samples).

Sample No.	als19	24L	Mix 60:40	REE	als19	24L	Mix 60:40
SiO_2	76.79	71.23	74.57	La	4.31	26.00	12.99
TiO_2	0	0.22	0.09	Ce	10.20	54.00	27.72
Al_2O_3	12.78	15.69	13.94	Nd	4.18	22.00	11.31
Fe_2O_3	0.61	2.69	1.44	Sm	1.22	4.50	2.53
MnO	0.01	0.04	0.02	Eu	0.06	1.51	0.64
MgO	0.09	1.01	0.46	Gd	1.57	3.12	2.18
CaO	0.11	1.26	0.57	Tb	0.45	0.50	0.47
Na_2O	3.49	4.45	3.87	Yb	2.66	1.39	2.16
K_2O	5.37	2.07	4.05	Lu	0.37	0.20	0.30
P_2O_5	0.11	0.01	0.07	Eu/Eu*	0.130	1.228	1.002
Total	99.36	98.67	99.08				

Explanations: Als19 - leucogranite; 24L - leucosome; mix 60:40 - proposed primary composition.

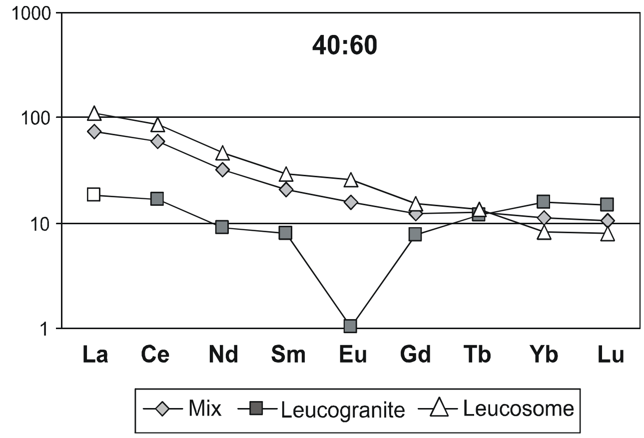

Fig. 1. Chondrite (C1)-normalised REE patterns for the representative leucosome, leucogranite and their mixture (40% of cumulate + 60% of fractionated melt). Details are enclosed in Table 1.

CONCLUSIONS

The monazite dating, with a support of internal zircon zonation and accessible Rb-Sr isotope ages suggest two stages of partial melting with the maximum at 337±20 (covering 345 Ma and 343 Ma Rb-Sr ages and 341 Ma U-Pb age) and the expulsion of the final melt and its fractionation at 309-297 Ma.

According to geochronological data, migmatitic leucosomes and leucogranite bodies, present in the metamorphic basement of the Western Tatra Mts., could represent the same stage of partial melting. The trondhjemitic leucosomes and 2nd type of leucogranite bodies might be interpreted as cumulate fraction, rich in plagioclases, forming about 40% of the primary melt. The leucogranites are fractionated final melts, with the composition changing from the margin to the centre of each intrusion.

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