New approaches on crystallization pressure of some Late Cretaceous granitoids from Romania

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During Late Cretaceous and also at the beginning of Paleogene period an important intrusive and effusive igneous activity was occurred along the territory between the Western Carpathians and Iran. This magmatism evolved in a geodynamic context marked apart from the appearance of sedimentary basins with complex evolution, molasses in general, but also of a very deep Gosau type (Schuller, 2004; Schuller et al., 2009), whose configuration and distribution within the alpine chain was controlled by an extensional tectonics that post-dated the meso-cretaceous alpine collisions, and on the other hand by the occurrence and evolution of a complex magmatism from a compositional point of view and as manifestation (intrusive and extrusive), most of it calco-alkaline, known in the geological literature as "banatitic" (von Cotta, 1864). With this type of rocks are linked a whole series of metalliferous accumulations that, by their variety of composition and content, have attracted the attention of specialists. Excepting the ages obtained by the K-Ar method on total rock or on ferromagnesian minerals (Bleahu et al. 1984), all other data are grouped strictly in the Campanian interval (Gallhofer, 2015), suggesting a magmatism that evolved in a narrow time window ("short-lived magmatism") typical for events managed by transpressive-transtensive tectonics with adiabatic detention up to the crust-mantle interface. This aspect, of narrow time interval, is confirmed by several investigative methods with a high degree of reliability (Gallhofer, 2015; Ciobanu et al., 2002). Genetically, this magmatic province was initially geodynamically linked to the Jurassic and Meso-Cretaceous subductions, models that in the second half of the last century and at the beginning of this century were considered due to the level of understanding of the igneous processes, the only formational and rational reasoning (Giuscă et al., 1966; Rădulescu, 1974; Ștefan et al., 1988; Vlad, 1997; Jankovic, 1997; Karamata et al., 1997; Handy et al., 2014; Gallhofer, 2015). Occasionally, multiple subduction hypotheses are exposed to justify the presence of various petrogenetic associations of different ages in neighbouring areas although the geological realities do not support them (Handy et al., 2014). The first paper that argues the post-collisional character of the banatites, in the particular case of those from Banat is that of Nicolescu et al. (1999). In this work, the author presents the situation in the Moravița valley basin, where the Ocna de Fier intrusion crosses the Ezeriș-Colțan reverse fault, which separates the metamorphic series from Bocșița-Dâmoxa and Buchin from the Bocșa nappe. In a similar situation, along the Dognecea valley, the banatitic intrusions crossed the Dognecea thrust line that separates the supragetic nappes as Bocșa and Moniom. Both tectonic units were previously considered meso-cretaceous; Ezeriș-Colțan reverse fault is intra-Turonian (90 Ma), while the Dognecea thrust is Austrian (~ 100 Ma) (Iancu 1986; Dallmeyer et al., 1996). Similar situations we meet in the Apuseni Mountains: the intrusion from Valea Cepelor (Arieșul Mare basin) seals the tectonic contacts between the Biharea / Poiana / Arieșeni units; all contacts between the meso-cretaceous units within the Biharea massif are crossed by banatitic intrusions different in sizes: the Budureasa and Pietroasa massifs seal or cross meso-cretaceous units. To the ones presented above it is added that all the intrusions are non-deformed, and when this happens the deformation is broken, wide spaced, post intrusion.

Table 1. Estimation crystallisation pressure for some banatitic rocks of Romania and their zircon saturation temperatures

Sample	Lithology	SiO_2	Q	or	ab	Total	Q (%)	or (%)	ab (%)	Total	P(1)	P(2)	T sat Zr	T sat ap
R39	Rh	71.25	30.84	25.21	32.11	88.16	34.98	28.60	36.42	100.00	166	158	783	924
DG019	G	70.02	26.06	26.46	32.63	85.15	30.60	31.07	38.33	100.00	314	304	760	880
DG026	Gd	67.61	25.92	18.58	33.24	77.74	33.34	23.91	42.76	100.00	211	202	719	895
DG047	Gd	66.88	25.27	16.22	40.33	81.81	30.88	19.82	49.30	100.00	301	291	748	878
DG084	G	68.74	29.17	25.25	28.36	82.78	35.24	30.50	34.26	100.00	160	151	780	898
DG085	Gd	67.95	28.28	23.86	28.99	81.12	34.85	29.41	35.73	100.00	169	161	787	899
DG104	Gd	66.74	24.42	16.69	35.45	76.56	31.90	21.80	46.30	100.00	259	250	770	886
DG108	Gd	67.79	27.23	20.82	32.88	80.93	33.64	25.73	40.63	100.00	202	193	780	888
DG110	Gd	67.96	24.59	18.87	36.84	80.30	30.62	23.50	45.88	100.00	313	303	775	890
98R23	Gd	66.91	20.99	17.31	39.56	77.86	26.96	22.23	50.80	100.00	551	540	745	896
98R16	Gd	66.50	20.16	20.38	36.92	77.47	26.03	26.31	47.66	100.00	638	627	753	883
9335	G	68.37	26.22	23.56	33.12	82.91	31.63	28.42	39.95	100.00	269	260		
9339	Gd	67.93	26.47	23.42	32.31	82.20	32.20	28.49	39.30	100.00	248	239		
9321	Gd	67.25	25.13	18.19	35.19	78.51	32.01	23.16	44.82	100.00	255	245		
9345	Gd	65.73	23.70	20.64	30.62	74.97	31.62	27.54	40.85	100.00	270	260		
12	Rh	71.98	31.44	25.30	34.01	90.75	34.64	27.88	37.48	100.00	175	166		
16	Rh	70.74	29.53	24.45	33.63	87.61	33.71	27.90	38.39	100.00	200	191		
19	Rh	69.00	27.47	22.08	33.50	83.05	33.07	26.59	40.34	100.00	219	210		
20	G	68.00	26.60	21.65	32.73	80.98	32.85	26.73	40.42	100.00	226	217		
21	Gd	67.96	26.91	17.99	36.71	81.62	32.98	22.05	44.98	100.00	222	213		
24	Rh	70.24	25.17	20.87	37.60	83.64	30.10	24.95	44.96	100.00	338	329		
4	G	72.05	30.94	24.34	35.46	90.74	34.10	26.83	39.08	100.00	189	180		
5	G	69.31	30.52	28.61	27.48	86.60	35.24	33.03	31.73	100.00	160	151		
7	G	67.34	27.35	20.45	34.86	82.66	33.09	24.74	42.17	100.00	218	209		
24	G	70.21	25.13	20.93	37.60	83.66	30.04	25.01	44.95	100.00	341	331		

Source of samples: R39 (Vander Auwera J. et al, 2015); DG019 – DG110 (Gallhofer D. 2015): 98R23, 98R16 (Dupont A. et al 2002); 9335 – 9345 (Stefan A. et al 1992); 12 – 21 (Stefan A. 1980); 24 (Istrate Gh. 1978); 4 – 24 (Istrate Gh., Bratosin I. 1976); lithology: Rh = rhyolite; G = granite; Gd = granodirite. Pressures P(1) and P(2) are in MPa and temperatures are in ^{0}C.

This igneous province consists of granitoidic rocks and mafic rocks that proof various information about of the associated mineral deposits, the granite intrusions furnishing critical industrial materials and metals. For instance, porphyry copper (±Au) deposits are related to intrusions emplaced at relatively shallow depth (Chiaradia et al., 2012), while skarn copper (±Au) deposits are completely connected with comparatively deep intrusions (Burt, 1998; Meinert, 1998), as also the intrusions related gold deposits (Yang et al., 2008). For that reason, estimation of the crystallization pressure (or depth) of granite intrusions can facilitate the elaboration of exploration models. Moreover, the depth of granite intrusions provides important data about the erosion depth and rate, and can thus supply solution for geodynamic reconstruction.

Several methods have been employed to assess the crystallisation pressures (or depths) of granite intrusions: geological mapping to recreate stratigraphic columns containing the intrusions; petrologic studies of the contact of associated rocks, fluid inclusion investigations, in experimental domain, in order to reproduce the environment of T-P-X-H2O for granite crystallization (Scaillet et al., 2016; Tuttle & Bowen, 1958), geophysical investigation in order to obtain 3D architecture of intrusions, and automatic phase-equilibrium modelling (Gualda and Ghiorso, 2013, 2014; Ghiorso and Gualda, 2015).

In 2017, Xue-Ming Yang from Manitoba Geological Survey (Canada) proposed a new numerical method in order to estimate the crystallization pressure of granite intrusions. This method is based on two polynomial equations obtained by an investigation of the existing haplogranite ternary phase diagram. The results of this study indicate that the crystallization pressure of the haplogranite system is directly correlated with normative quartz (Qtz) content and with the sum between the normative albite (Ab) and normative orthoclase (Or) contents of some granitic rocks.

$$P = -0.2426*(Qtz)^3+26.392*(Qtz)^2-980.74*(Qtz)+12563 \quad (1)$$

$$P = 0.2426*(Ab+Or)^3-46.397*(Ab+Or)^2+2981.3*(Ab+Or)-64224 \quad (2)$$

$R^2=0.9943$

where P is pressure in MPa, and R represents the correlation coefficient.

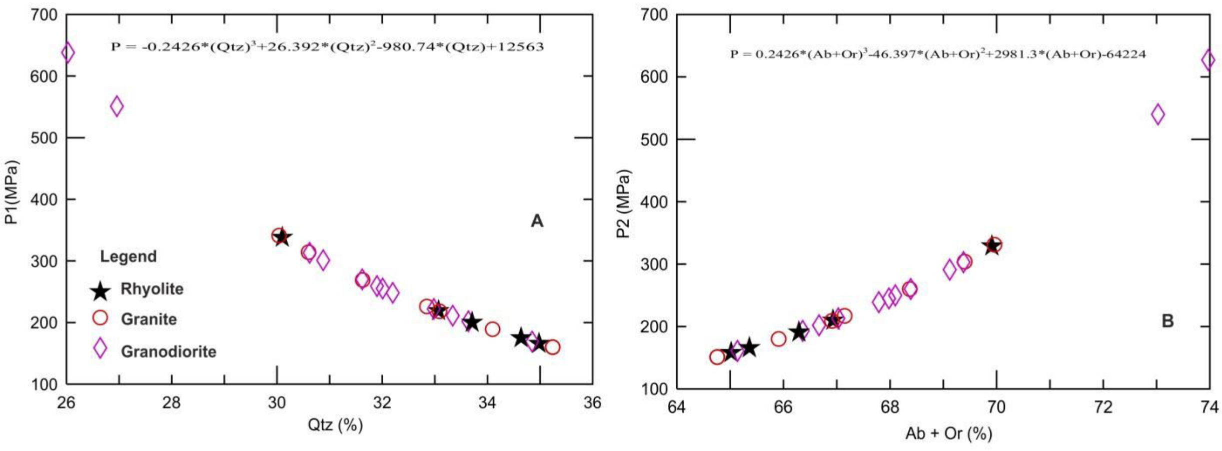

Fig. 1. Crystallization pressure (MPa) versus (a) normative Qtz content (wt.%) and (b) (Ab + Or) of some banatitic rocks.

The selected samples are recalculated to dry and the obtained results are used in the calculation of the CIPW norm. The Qtz, Ab, Or components are brought to 100% to be used in equations. The difference between the two equations must be ≤16 MPa, but not less than 9 Mpa. The range of normative quartz contents must range from 15 to 40 wt%. When the sum between Ab and Or is greater than 70%, the quartz is in equilibrium at eutectic with two feldspars, and when the sum is below 70%, only one feldspar is in equilibrium with quartz. We tried in our study to apply this methodology to estimate crystallization pressures in case of some Upper Cretaceous intrusive and effusive rocks that outcrop in Banat, Apuseni Mountains and Poiana Rusca. Our selection of samples that were to be used in polynomial equations in order to estimate the crystallization pressure was taken account by the recommendations expressed by Yang (2017), namely the granites, rhyolites and granodiorites must be evolved.

Our results are present in Table 1 and in Figures 1 and 2. It can be observed that most of the values representing the crystallization pressures fall in the range 150 - 330 MPa, corresponding for 6-8 Km in depths at which the intrusions were placed. Only samples 98R23 and 98R16 representing granodiorites from Tincova and Bocsa respectively indicate values in the range 540 - 638 MPa which would correspond to depths of 16 - 17 Km. In any case, the data projected in the two diagrams have a nicely square correlation coefficient R^2 of 0.94 and the Spearman rank correlation coefficient is 0.999. Plotting our data in the ternary diagram Ab-Or-Q (Fig. 2, Anderson, 1996) we have been obtained the similar configuration that confirms the results.

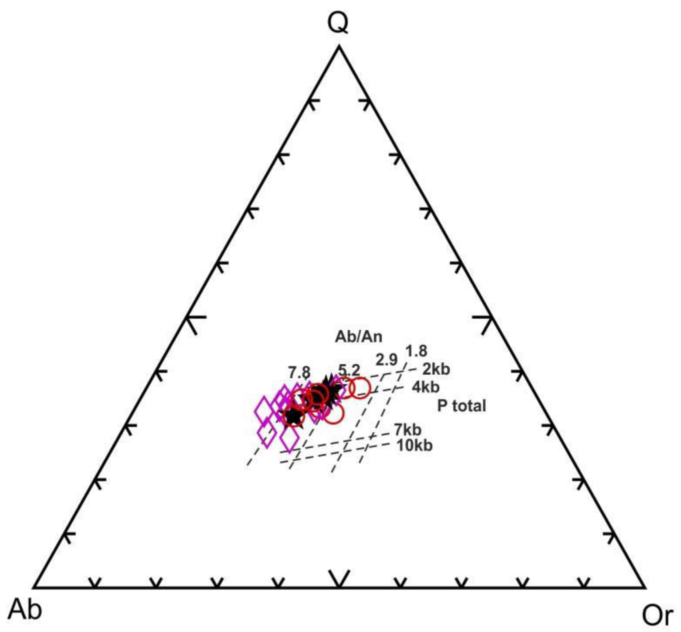

Fig. 2. Banatitic rocks plotted in ternary diagram Ab-Or-Q (Anderson, 1996). The legend is similar to the one from the figure 1

As Yang says (2017), the values of crystallisation pressure estimated from equations 1 and 2 generally confirm the crystallization pressure of quartz with a single feldspar (alongside cotectic curves, or at relatively lower emplacement pressure of hypersolvus granites), and with two feldspars (at eutectic points, or at higher emplacement pressure of subsolvus granites). However, these pressures are generally lower than those estimated by the Al-inhornblende barometry (Hammarstrom & Zen, 1986; Johnson & Rutherford, 1989; Schmidt, 1992), considering the importance of different fluids involved in crystallisation.

Acknowledgments

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