Petrology

Thermobaric Regime of the Formation of the Dzirula Massif Rkvia Variscan Granitoid Intrusive

Avtandil Okrostsvaridze*, Bary Clarke, Robert Akhvlediani*, David Bluashvili#**

* *A. Janelidze Geological Institute of I. Javakhishvili Tbilisi State University*
** *Dalhousie University, Halifax, Canada*
\# *Georgian Technical University, Tbilisi*

(Presented by Academy Member David Shengelia)

ABSTRACT. Dzirula crystalline massif Rkvia variscan intrusive plagioclase, kalispar, biotite and muscovite chemical analyses have been carried out by the authors using the laser-dotted method on microprobe JOEL-960 in Dalhousie University (Halifax, Canada). On the basis of the obtained data, by means of various geothermometers and geobarometers, the thermobaric regime of the formation of these minerals and in general Rkvia intrusive has been reconstructed. It is assumed that in Rkvia intrusive protolith, that was mainly constructed by metamorphosed greywacke, arkose sandstones and tuffites, anatectic melt crystallizations probably started at $800-850^0$ C temperature and 9-11 kb total pressure conditions. Granitoid melt basic mass crystallization occurred at $600-690^0$ C temperature and 7.7-8.7 kilobar total pressure regime conditions, but magmatic melt crystallization process finally ended approximately at 500^0 C temperature conditions. *© 2011 Bull. Georg. Natl. Acad. Sci.*

Key words: *Dzirula massif, Rkvia intrusive, thermobaric regime, protolith.*

In the north-west part of Pre-Alpine consolidation Dzirula crystalline massif (1200 km^2), in the ravines of the Kvirila, Buja and their inflows, porphyraceous granitoid plutonium of Variscan generation is uncovered, that is known as Rkvia intrusive in geological literature. It has lens-like form of NW-SE strike. Its maximum length is 14 km and width reaches 4.5 km. The intrusive has been well studied petrologically [1-6], however the thermobaric regime of its formation has not been investigated.

Actual material and methods. In Dalhousie University (Halifax, Canada) we had an opportunity to carry out over 500 chemical analyses of Rkvia intrusive plagioclases, kalispars, biotites and muscovites (Tables 1, 2, 3 and 4) on microprobe JOEL-960, by means of laser-dotted analysis–on the basis of which by means of various geothermometers and geobarometers [6-10] we were able to restore the thermobaric regime of formation of these minerals and in general Rkvia intrusive within the errors of this method (Tables 5-8).

The chemical composition of minerals and thermobaric regime of formation. As Rkvia intrusive restite mineral paragenesis shows, in its protolith, which consisted of metamorphosed greywackes, arkosic sandstones and tuffites [5], ultra metamorphic processes started in amphibolitic facies sillimanite-biotite-kalispar subfacies [6].

As I. E. Kamenev [7] notes, the degree of proper ordering, which is widely spread in kalispars and less in plagioclases is directly connected with feldspar formation PT regime and not with further solid phase transformation processes. Hence, Kamenev considers that Na and Ca cation redistribution that determines Al-Si diffusion degree in crystalline structure, can be successfully used for the restoration of the above-mentioned mineral crystallization PT regime. It is this principle that forms the basis of feldspar geothermometers.

To determine the plagioclase formation temperature we have used I. Kamenev's geothermometers [7]. The average chemical composition of microprobe dotted analyses of these minerals, crystallochemical formulas, liquidus and solidus temperatures are given in Tables 1 and 2.

As we can see from Table 1 Rkvia intrusive plagioclases are characterized by zonal structure, this indicates their magmatic generation. The exception are plagioclases of Dz9 sample, in which zonal structure is not observed.

This must be caused by postmagmatic homogenization processes and as the microscopic studies show, the sample undergoes postmagmatic silicification. Plagioclase liquidus temperature, both of central part and edges is practically equal and corresponds to 880^0 C on the average.

In contrast to liquidus temperatures, the temperatures of this plagioclase solidus are low, oscillating within 680-590^0 C. At the same time, the temperatures of solidus in the central part and edges are obviously different and in Dz2 sample make up 100^0 C, but in Dz16 – 31^0 **C.** As for Dz9 sample plagioclases, both solidus and liquidus in them are comparatively lower and this makes us think that this leveling must be caused by the above-mentioned silicification processes. The basic mass of kalispar chemical composition, crystallochemical formulas and their liquidus and solidus temperatures are given in Tables 3 and 4. We have done the analyses of these minerals both in the central part and at the edges, but their zonal structure is not practically noted, as a result of which in these tables only the entire average chemical analyses are given.

Kalispar liquidus temperatures are calculated according to G. Hewis [8] and those of solidus – according to S.W. Bachinsky and G. A.Muller [9]. As is seen from Table 4, in contrast to plagioclases, liquidus and solidus tem-

Table 1. Rkvia intrusive plagioclase chemical composition

Elements	Dz2 (52 dotted analyses)		Dz2 (52 dotted analyses)		Dz16 (51 dotted analyses)	
	Center	Edge	Center	Edge	Center	Edge
SiO_2	61.13	62.99	64.77	65.37	63.23	63.64
TiO_2	0.00	0.00	0.00	0.02	0.14	0.02
Al_2O_3	24.39	23.53	22.03	21.74	23.88	22.93
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.001
FeO	0.00	0.00	0.00	0.00	0.00	0.09
MnO	0.00	0.00	0.03	0.02	0.02	0.00
MgO	0.03	0.02	0.01	0.00	0.00	0.10
CaO	5.54	3.54	2.42	2.21	4.16	3.66
K_2O	0.16	0.58	0.21	0.28	0.13	0.19
Na_2O	8.88	8.86	9.83	10.28	8.88	9.56

Table 2. Crystallochemical formulas of Rkvia intrusive plagioclases and temperatures of their liquidus and solidus

Elements	Dz2 (52 dotted analyses)		Dz9 (21 dotted analyses)		Dz16 (51 dotted analyses)	
	Center	Edge	Center	Edge	Center	Edge
Si	2.621	2.794	2.866	2.877	2.807	2.807
Ti	0.000	0.000	0.000	0.01	0.001	0.000
Al	1.280	1.130	1.149	1.128	1.92	1.197
Fe	0.000	0.000	0.000	0.000	0.003	0.000
Fe2	0.000	0.000	0.000	0.000	0.003	0.000
Mn	0.000	0.000	0.001	0.001	0.000	0.000
Mg	0.002	0.001	0.001	0.000	0.007	0.001
Ca	0.264	0.168	0.115	0.104	0.173	0.180
K	0.009	0.033	0.012	0.016	0.011	0.009
Na	0.732	0.762	0.843	0.877	0.818	0.810
T liquidus	883 ^{0}C	881^0C	845^0C	830^0C	883^oC	886^0C
T solidus	648^oC	550^oC	475^oC	455^oC	688^oC	557^oC

Table 3. Rkvia intrusive kalispar chemical composition

Elements	Dz2 (6 dotted analyses)	Dz9 (56 dotted analyses)	Dz16 (27 dotted analyses)
SiO_2	64.49	64.18	63.88
TiO_2	0.11	0.13	0.00
Al_2O_3	19.06	18.77	19.15
Fe_2O_3	0.00	0.00	0.00
FeO	0.00	0.00	0.00
MnO	0.00	0.08	0.00
MgO	0.01	0.04	0.03
CaO	0.00	0.03	0.00
K_2O	14.9	14.82	15.04
Na_2O	1.33	1.30	0.90

Table 4. Rkvia intrusive kalispar crystallochemical compositions and their liquidus and solidus temperatures

Elements	Dz2 (6 dotted analyses)	Dz9 (56 dotted analyses)	Dz16 (27 dotted analyses)
Si	2.971	2.974	2.969
Ti	0.004	0.005	0.000
Al	1.035	1.026	1.049
Fe	0.000	0.000	0.000
Fe^2	0.000	0.000	0.000
Mn	0.000	0.003	0.000
Mg	0.001	0.003	0.002
Ca	0.000	0.001	0.000
K	0.876	0.876	0.892
Na	0.117	0.117	0.891
$T_{liquidus}$	510^0 C	560^0 C	520^0 C
$T_{solidus}$	495^0 C	450^0 C	495^0 C

peratures in kalispars are about equal. This proves that the basic mass microcline crystallization occurred at the latest stage of silicate melt crystallization. The maximum temperature difference is observed in Dz16 sample kalispars, reaching 25^0 C, but in the other 2 samples it corresponds to 15^0 C. In sample Dz 9, as in the case of plagioclase, here both liquidus (460^0) and solidus (450^0) are reduced as well, which is probably caused by silicification of this sample observed above. Liquidus temperature in unflawed kalispars oscillates within $510\text{-}520^0$ C, but solidus temperature of all kalispars is equal and corresponds to 495^0 C.

Unlike feldspars, in micas it is possible to restore both liquidus and solidus temperatures and corresponding pressures as well. The temperatures have been determined according to D.R Yonc and H.P. Ygster's [10] data and pressures according to D. Hiut and D. Yonc data [11]. In Tables 5 and 6 biotite chemical composi-

Table 5. Rkvia intrusive biotite chemical composition

Elements	Dz2 (74 dotted analyses)		Dz16 (43 dotted analyses)	
	Center	Edge	Center	Edge
SiO_2	33.75	33.91	34.08	34.02
TiO_2	2.71	3.06	2.79	2.60
Al_2O_3	18.08	18.69	18.30	18.65
Fe_2O_3	0.01	0.01	0.01	0.01
FeO	23.98	23.71	24.17	23.64
MnO	0.50	0.48	0.75	0.78
MgO	6.26	5.69	5.95	6.06
CaO	0.00	0.06	0.08	0.00
K_2O	9.36	9.44	9.12	9.51
Na_2O	0.30	0.13	0.22	0.30

Table 6. Rkvia intrusive biotite crystallochemical composition, their liquidus and solidus temperatures (^0C) and pressures (kilobar)

Elements	Dz2 (74 dotted analyses)		Dz16 (43 dotted analyses)	
Si	2.417	2.415	2.424	2.416
Ti	0.145	0.163	0.149	0.138
Al	1.526	1.569	1.534	1.561
Fe	0.000	0.000	0.000	0.000
Fe^2	1.436	1.412	1.438	1.404
Mn	0.030	0.028	0.045	0.046
Mg	0.668	0.603	0.630	0.641
Ca	0.000	0.004	0.006	0.000
K	0.855	0.857	0.827	0.861
Na	0.041	0.017	0.030	0.041
$T_{liquidus}$	681	655	677	692
$T_{solidus}$	663	644	660	671
$P_{liquidus}$	11.4	11.2	11.6	10.5
$P_{solidus}$	8.6	8.2	8.7	7.9

Table 7. Rkvia intrusive muscovite chemical composition

Elements	Dz2 (207 dotted analyses)		Dz9 (21 dotted analyses)		Dz16(51 dotted analyses)	
	Center	Edge	Center	Edge	Center	Edge
SiO_2	45.14	45.05	45.63	45.64	45.79	45.77
TiO_2	0.55	0.43	0.05	0.25	0.56	0.72
Al_2O_3	34.97	35.13	35.87	35.52	35.62	35.86
Fe_2O_3	0.01	0.01	0.01	0.01	0.01	0.01
FeO	1.44	1.38	1.71	1.70	1.44	1.36
MnO	0.00	0.04	0.00	0.12	0.00	0.04
MgO	0.66	0.71	0.58	0.71	0.66	0.68
CaO	0.02	0.07	0.00	0.00	0.00	0.05
K_2O	9.17	9.47	10.26	10.29	10.20	9.71
Na_2O	0.33	0.68	0.48	0.74	0.51	0.78

Table 8. Rkvia intrusive muscovite crystallochemical compositions, their liquidus and solidus temperatures (^0C) and pressures (kilobar)

Elements	Dz2 (52 dotted analyses)		Dz9 (21 dotted analyses)		Dz16 (51 dotted analyses)	
	Center	Edge	Center	Edge	Center	Edge
Si	2.797	2.782	2.683	2.777	2.781	2.797
Ti	0.025	0.019	0.005	0.011	0.025	0.038
Al	2.555	2.558	2.562	2.548	2.551	2.498
Fe	0.000	0.000	0.000	0.000	0.000	0.000
Fe^2	0.074	0.071	0.069	0.086	0.073	0.078
Mn	0.000	0.002	0.002	0.006	0.000	0.000
Mg	0.060	0.065	0.068	0.064	0.059	0.073
Ca	0.001	0.004	0.000	0.000	0.000	0.000
K	0.725	0.746	0.766	0.798	0.790	0.779
Na	0.039	0.081	0.054	0.087	0.060	0.071
$T_{liquidus}$	696	692	681	675	677	676
$T_{solidus}$	674	671	663	659	660	660
$P_{liquidus}$	12.6	11.5	12.8	11.2	12.8	11.4
$P_{solidus}$	8.1	7.6	8.4	8.0	7.7	7.7

tions are given, crystallochemical formulas, liquidus and solidus temperatures and pressures as well. Since in the chemical composition of these minerals a minor difference has been recorded between the central parts and edges, only the average data on all parameters are given (Table 6). As is seen from this Table, biotite liquidus temperature oscillates from 700^{0}C to 710^0 C and solidus temperature – from 665^0 C to 680^{0}C. We can see that in these minerals as well as in the case of kalispars the difference between solidus and liquidus temperatures is very small, reaching maximum 25^0 C. Biotite liquidus pressures are very high and vary from 10.5.5 kilobar to 11.5 kilobar, as for solidus pressures, they are comparatively homogeneous and low, oscillating within 7.9–8.7 kilobar.

In Tables 7 and 8 muscovite chemical composition, crystallochemical formulas, solidus and liquidus pressures and temperatures are shown. Little differences between muscovite central parts and edges are observed, which is revealed in Tables 7 and 8. As is seen from Table 8, muscovite liquidus temperatures oscillate within the range of 675^0 C to 695^0 C, as for solidus – from 660^{0}C to 675^{0}C.

As we see, in this case as well as in the case of kalispars and biotites, the difference between the temperatures of solidus and liquidus is very small, corresponding to 20^0 C. But as for muscovites formation pressure, as in the case of biotites, it is high. The pressures of liquidus oscillate from 9.2 kilobar to 10.5 kilobar, but the pressures of solidus oscillate within 7.6–8.4 kilobar.

Discussion. If we sum up the results of the work carried out, we can see that Rkvia intrusive protolith thermal treatment occurred under rather high temperature regime, conditioning the practical absence of restite parageneses in it. This is observed well from the plagioclase liquidus temperatures, which oscillates within 880^0 C on the average. As for micas, they have approximately the same temperatures of liquidus (660-690^0 C on average). From these data, it can be clearly seen that in the main phase of the studied intrusives, both biotite and muscovite are of magmatic origin and they start crystallizing from silicate melt nearly at the same time.

Plagioclase solidus temperatures are very low compared with its liquidus temperature and it oscillates within 550-450^{0}C, which in our opinion can be accounted by the fact that mobilized intrusive granitoid melt was of more acid composition than protolith constituent, which naturally lowered the plagioclase solidus temperature. Plagioclase crystallization temperatures decrease from 580^0 C to 550^0 C from the center to the periphery determining their zonal structure and pointing to their magmatic generation. The liquidus temperature of kalispar is close to their solidus temperature, corresponding to 445^{0}C on the average. Apparently, the crystallization of these minerals slightly lags behind in time the process of crystallization of the basic mass of plagioclase. As for the Rkvia intrusive complex formation pressures, they are rather high. According to the obtained data protolith liquidus pressures oscillate from 10 kilobar to 12 kilobar range on the average. As for the solidus pressures, they are reduced nearly half as much and oscillate in micas from 7.5 kilobar to 7.8 kilobar. Pressures are comparatively low during the crystallization of feldspar and quartz. Such sharp decrease of solidus pressures might be explained by the reason that the basic part of silicate melt started crystallization after the intrusion and it is natural that in this position a drastic decrease of total pressure took place in the magma system.

Conclusion. Thus, as a result of obtained data analysis, we believe that in Rkvia intrusive protolith, which was mainly formed of metamorphosed greywackes, arkose sandstones and tuffites, anatectic melt crystallization probably started under 800-850^0 C temperature and 9-11 kilobar total pressure conditions. The crystallization of granitoid melt basic mass occurred under 660-690^{0}C temperature on the average and in 7.7-8.7 kilobar total pressure regime conditions, but the magmatic melt crystallization process finally ended approximately in the conditions of 500^0 C temperature.

პეტროლოგია

ძირულას მასივის რკვიის ვარისკული გრანიტოიდული ინტრუზივის ფორმირების თერმობარული რეჟიმი

ა. ოქროსცვარიძე*, ბ. კლარკი, რ. ახვლედიანი*, დ. ბლუაშვილი#**

** ი. ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტის ა. ჯანელიძის გეოლოგიის ინსტიტუტი*
*** დალჰაუზის უნივერსიტეტი, ჰალიფაქსი, კანადა*
 # საქართველოს ტექნიკური უნივერსიტეტი, თბილისი

(წარმოდგენილია აკადემიის წევრის დ. შენგელიას მიერ)

დალჰაუზის უნივერსიტეტში (ჰალიფაქსი, კანადა) მიკროზონდ JOEL-960-ზე, ავტორებმა განსაზღვრეს ძირულას კრისტალური მასივის რკვიის ვარისკული ინტრუზივის პლაგიოკლაზების, კალიშპატების, ბიოტიტების და მუსკოვიტების ქიმიური ანალიზები. მიღებული შედეგების საფუძველზე, სხვადასხვა გეოთერმომეტრების და გეობარომეტრების მეშვეობით, აღდგენილია აღნიშნული ინტრუზივის ფორმირების თერმობარული რეჟიმი.

მიღებული მონაცემების ანალიზის შედეგად დაშვებულია, რომ რკვიის ინტრუზივის პროტოლითში, რომელიც ძირითადად აგებული იყო მეტამორფიზებული გრაუვაკებით, არკოზული ქვიშაქვებით და ტუფიტებით, ანატექტური მდნარის კრისტალიზაცია სავარაუდოდ დაიწყო $800-850^0$ C ტემპერატურის და 9-11 კბ საერთო წნევის პირობებში. გრანიტოიდული მდნარის ძირითადი მასის კრისტალიზაცია მიმდინარეობდა საშუალოდ $660-690^0$ C ტემპერატურის და 7.7-8.7 კბ საერთო წნევის რეჟიმის პირობებში, ხოლო მაგმური მდნარის სრული გამოკრისტალება დასრულდა დაახლოებით 500^0 C ტემპერატურის პირობებში.

REFERENCES

1. *P. A. Topuria* (1938), Bull. GIN AN Gruzii, 4: 381-475 (in Russian).
2. *P. M. Manvelidze* (1968), Soobshch. AN GSSR, **50**, 3: 678-682 (in Russian).
3. *D. M. Shengelia, A. V. Okrostsvaridze* (1998), Dokl. RAN, **355**, 6: 801-806 (in Russian).
4. *K. S. Chikhelidze* (1998), Abstract of Candidate Thesis, Tbilisi: 25 p. (in Russian).
5. *P. A. Akhvlediani, I. U. Shvelidze, G. T. Vashakidze* (2002), Trudy GIN AN Gruzii, Nov. ser., vyp., 117: 166-172. (in Russian).
6. *I. P. Gamkrelidze, D. M. Shengelia* (2005), Dokembriisko-paleozoiskiy regionalnyi metamorfizm, granitoidnyi magmatizm i geodinamika Kavkaza, M., 458s (in Russian).
7. *I. K. Kamenev* (1984), Rukovodstvo po rentgenovskomu issledovaniyu polevykh shpatov, LGU, 52s (in Russian).
8. *V. Hevis* (1987), Amer. Mineral., 62: 672-679.
9. *W. Bachinski S. W., G. A. Muller* (1981), Petrol., **12**, 2: 329-356.
10. *D. R. Yonc, H.P. Ygster* (1986), Amer. Mineral., **50**, 9: 1228-1272.
11. *D. Hiut, D. R.Yonc* (1987), Amer. Mineral., 62: 137-150.

Received July, 2011