RENDICONTI Soc. Italiana di Mineralogia e Petrologia, 32 (2) 669-680 (1976)

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ORIGIN OF THE GRANITIC CORE OF THE CERVO PLUTON OCCORDING TO THE Th/U RATIO OF FRACTIONATION

ABSTRACT. - U and Th content has been determined by means of neutron activation analysis on the separated rock forming and accessory minerals coming from granite, syenite and monzonite of Valle Cervo pluton. The sequence of crystal fractionation of minerals, arranged according to an increasing Th/U ratio, has been compared with the minerogenetic sequence that can be deduced from the textural relationships at the microscope. There is a satisfactory agreement follow the syenite one, but it runs almost parallel to the last. The feature plays in favour of a to be consecutive in the three rock-types of pluton. The granite range of fractionation doesn't follow the syenite one but it runs almost parallel to the last. The feature plays in favour of a recessive and not residual character of the granite showing thereby an indipendent trend of fractionation that can be related to an unmixed high-silica molten core. Chemical and modal composition, euhedral quartz, and other features strongly support such an interpretation together with the lack of disjunctive tectonic events in the host shell of syenite + monzonite.

RIASSUNTO. - Il contenuto di U e Th è stato determinato mediante attivazione neutronica sui minerali accessori ed essenziali separati dal granito, dalla sienite e dalla monzonite del plutone della Valle del Cervo. La sequenza di frazionamento cristallino ottenuta ordinando i minerali secondo un rapporto crescente Th/U è stata confrontata con la successione minerogenetica che si ricava dai rapporti strutturali al microscopio. Le due successioni concordano in modo soddisfacente nell'ambito di ciascuna facies, tuttavia il trend complessivo di frazionamento non appare consecutivo nei tre differenziati principali del plutone. L'intervallo di frazionamento del granito non consegue quello della sienite ma lo ricopre parzialmente. Questo depone a favore di un carattere recessivo e non residuale del granito, che mostra un decorso indipendente di frazionamento attribuibile ad un nucleo altamente siliceo smescolato già allo stato fuso dal magma monzonitico-sienitico. La composizione chimica e modale, l'abito esagonale idiomorfo e la distribuzione del quarzo suffragano fortemente questa interpretazione insieme alla mancanza di eventi tettonici disgiuntivi nell'involucro sienitico monzonitico.

Introduction

The present paper is an attempt to apply a geochemical ratio, e.g. the Th/U one, to a geological problem: the origin of the granitic core of the Cervo pluton.

The pluton shows in fact a gradual boundary between peripheral monzonite and syenite, whereas the boundary between syenite (or monzonite) and the inner

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granite appears to be a very rapid but not discontinuous transition (FIORENTINI POTENZA M., 1959 a); therefore the granitic rock forms a very regular and well differentiated core marked by a wide ring of peraciditic rock.

Taking into account the extraordinary U and Th content of the pluton rocks (FIORENTINI M., 1958; FIORENTINI POTENZA M., 1959 b) it has been made the attempt to arrange the separated rock-forming minerals of the three main rocks according to an increasing Th/U ratio.

If the assumption of an increasing Th/U ratio during the fractionation is virtually reliable, the obtained minerogenetic sequence would indicate probably if the Th/U ratio trend of fractionation in the granite continues the Th/U ratio trend of syenite and monzonite, otherwise if it belongs to an independent its own trend. This could help to answer to the question: is an eutectic granite or a preexisting exolution of granitic melt.

Theoretical

The crystallochemical behaviour of U and Th leads to believe that Th undergoes a concentration as regard as to U during the crystal fractionation and then it should tend to concentrate more than U in the last crystal fractions of the magma.

Electronegativity differences for Th-O and U-O bonds (1.9 and 1.8) suggests that the Th-O bond should have an higher percent of ionic bond — 52 %-54 % — (WEDEPOHL K. H., 1969) than U-O (48 %-50 %).

Thereby according to Taylor (1965), the Th/U ratio should decrease during the crystal fractionation. Although the electronegativity of U^{6+} is still unknown, it may be expected to be higher than U^{4+} and therefore the lower difference in electronegativity should indicate a more covalent U^{6+}-O bond than U^{4+}-O; then the Th/U ratio should decrease even more.

On the other hand, the ionization potential of Th results to be higher than U, although some incertanties still exist in these data. It leads to the opposite conclusion that U-O bond and therefore Th/U ratio should increase during the crystal fractionation. Moreover the expected but not yet experimented higher ability to be leached of the U^{6+} (McKELVEY V. E. et al., 1955) should favour its removal from the lattices as more as the mineral belongs to an high stage. Such a tendence like the above one should increase even more the Th/U ratio during the crystal fractionation.

The comparison of ionic radii of U (0.97) and Th (1.02) eventually suggets that Th should tend to concentrate in the final mineral fractions (WITHFIELD J.M. et al., 1959).

From the above crystallochemical discussion, three suggestions rise in favour of an increasing Th/U ratio during the crystal fractionation against only one in favour of a decreasing trend: that is the suggestion given by the differences of electronegativity.

Geochemical reliability of an assumption of increasing Th/U ratio

In the light of the preceding discussion we believe it is theoretically correct to consider like more probable that Th/U ratio should increase during the igneous crystal fractionation.

No many experimental supports of this assumption can be drawn directly from the literature. There is in fact a general tendency to perform carefully U and Th determinations on statistical collections of rock-forming minerals, coming from various and independent intrusive bodies.

This may be the reason, probably, why the natural Th/U trend of fractionation is still known with several uncertanties.

Experimental

All the rock-forming minerals of the granite, syenite, monzonite have been separeted one from the other by means of a Franz isodynamic magnetic separator.

TABLE 1
Modal composition of the selected intrusive rocks

Rocks and provenience	Plag.	K-feld.	Amph.	Pyrox.	Biot.	Quartz	Ore min.	Sphene	Apat.	Access. minerals
Porphyritic pink granite (Migliacci)	34.02	32.24	4.45		6.5	20.59	1.07	0.57	0.55	
White granite (Campiglia)	31.62	42.62	4.46		0.47	19.05	0.24	0.58	0.24	
Syenite (Balma) ⊥ Texture	27	53	12		0.6	4				4
Syenite (Balma) // Texture	30.5	40.7	17.9	0.8	0.6	5.3				3.9
Syenite (Rialbella) ⊥ Texture	24	46.7	18.5	0.1	2	5.5				3
Syenite (Rialbella) // Texture	23	43	24.5		2.3	2.8				4.1
Monzonite (Cascina Veglio)	41.6	39.2	8.9		4.1	3.5	1.06	0.5	0.2	
Monzonite (Casoni)	40.4	38.4	3.9	6.3	5.5	3.0				2.4
Quartz monzonite (La Pietraccia)	27.1	42.8	7.6		7.0	12.5	1.5	0.9	1.3	
Monzonite granite (Cascina Fienbello)	30.33	43.81	15.56		0.82	7.89				1.71
Monzonite granite (Rialbella)	31.12	35.56	15.78		5.9	9.23	1.13	0.55	0.78	
Monzonite (Rosazza)	33.54	42.62	16	0.49	0.11	3.6				3.5

In this way it has been investigated the fractionation trend in a single intrusion so as to lower as more as possible the number of geochemical variable affecting the solidification history (age, pressure, temperature...).

TABLE 2

U and Th content of the rock-forming and accessory minerals in the main rock types of the pluton

	SAMPLES	U (ppm)	Th (ppm)	Th/U
a	Sphene	450.40 (2%)	497.30 (2%)	1.10
	Biotite	12.50 (3%)	15.90 (3%)	1.27
	K-feldspar	3.28 (4%)	5.20 (4%)	1.59
	Feldspars + euhedral exagonal quartz	5.23 (4%)	8.84 (4%)	1.69
	Magnetite	240.27 (2%)	538.80 (2%)	2.24
	Amphibole	27.18 (3%)	282.70 (2%)	10.40
b	Biotite	77.45 (2%)	30.50 (3%)	0.39
	Sphene	620.95 (2%)	505.00 (2%)	0.81
	Magnetite	42.84 (2%)	51.72 (3%)	1.21
	Amphibole	6.75 (4%)	9.40 (4%)	1.39
	K-feldspar	1.65 (5%)	2.83 (5%)	1.72
	Feldspars + quartz	3.28 (4%)	6.31 (4%)	1.92
c	Amphibole + pyroxene	14.39 (3%)	30.94 (3%)	2.15
	Magnetite	20.24 (3%)	54.60 (3%)	2.70
	Biotite	5.01 (4%)	15.40 (3%)	3.08
	Feldspars + quartz	11.49 (3%)	36.87 (3%)	3.21

a) from pink porphyritic granite (Piaro) - b) from syenite (Balma)

c) from monzonite (pyrox.amph. bearing)

Afterwards each mineral fraction of all the selected rocks underwent further manual refinement by means of the stereomicroscope in order to improve the pureness of the mineral.

Eventually X-ray diffraction patterns cheked the presence of impurities of masuyte in the biotite and of thorite in the hornblende fraction.

The modal percents of each mineral phase in the various kinds of granite, syenite and monzonite of the pluton have been carried out in the thin section by means of the point counter (see Table 1).

U and Th concentrations in the separated minerals were measured by neutron activation analysis, at CeSNEF-Politecnico Milano.

Without any else handling, the samples were sealed in lucite phials: their weight was from 40 to 100 mg according to the eventually separable quantity. The irradiations were performed at the surface of the core of L54 reactor with a total available flux $= 3.5\ 10^{11}\ n/cm^2 \times sec.$ for a time of about two hours.

The obtained γ-spectra were analysed by a coaxial 35 cm^3 Ge-Li detector connected to a Laben 8192 channel pulse height analyser.

For each sample a « standard » adding to it a known amount of Th and U in the form of solution was prepared then it was dried (KRUGER P., 1972).

U content determination was made, beside γ-ray counting, also by delayed neutron counting, following fission of ^{235}U (ECHO M. W. et al., 1957).

For irradiation the sample was pneumatically transferred in a « rabbit » to the reactor core surface. After two minutes, the sample was automatically taken back to the counting apparatus consisting of a BF_3 proportional counter in a paraffin block connected to a scaler for a 100 sec. count.

The U content is simply determined from the relationship:

$$\text{Weight of uranium} = \frac{C_s - C_b}{C_{std}} \times \text{weight of uranium in the standard}$$

were: C_s is the neutron count due to the sample;
C_b is the mean neutron count of background;
C_{std} is the mean neutron count for standard samples.

The results of analysis are shown in Table 2: for uranium the concentration is given as weight mean value of the concentrations measured in the different methods.

Results

The U and Th determination, in the rock-forming and accessory minerals of the rocks of the pluton, shows that sphene and magnetite are the most enriched phases in U and Th.

The statement agrees with the total radioactivity that has been evalueted by Longinelli (1958) who investigated however by autoradiographic method only one sample of the syenite facies of the pluton. More particularly Table 2 displays that the sphene, drawn from syenite, has an higher U content than the sphene drawn from granite. However the former turns to be out the only mineral phase which is able to concentrate U more than Th ($Th/U < 1$).

All the remaining mineral phases of granite, syenite and monzonite show a somewhat wide range of U and Th content.

Then the analyzed minerals can be arranged into a paragenetic sequence according to the geochemical considerations that allowed us to postulate an increasing trend of Th/U ratio during the igneous mineral fractionation.

The paragenetic sequence resulting from the geochemical arrangement are the following (see Fig. 1):

— in the granite: sphene-biotite-K/feldspar-(feldspars + quartz)-magnetite-hornblende;

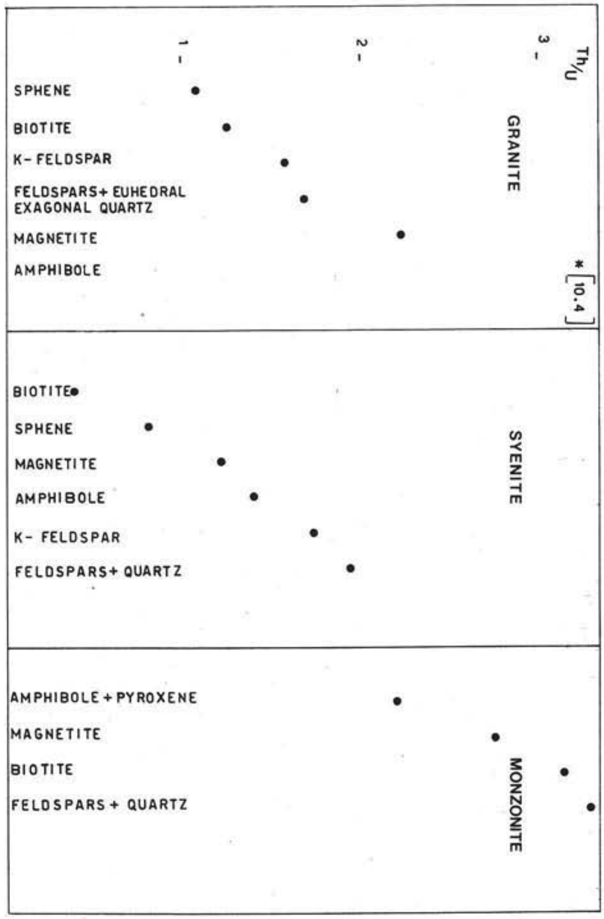

Fig. 1.

— in the syenite: biotite-sphene-magnetite-hornblende-K/feldspar-(feldspars + + quartz);

— in the monzonite: (hornblende + dyopside)-magnetite-biotite-(feldspart + quartz).

Discussion

The mineral fractionation of monzonite, as indicated by increasing Th/U ratio, seems to continue the mineral fractionation of the syenite. On the contrary, the mineral fractionation of granite runs almost parallel to the syenite one.

In this light the granite mineral assemblage seems to represent the product of an indipendent its own trend of fractionation rather than a final product of fractionation of the pluton magma.

TABLE 3

Comparision between the trend of Th/U ratio in the differentiated rocks of Cervo and White Mountain plutons

	Rocks	U (ppm)		Th (ppm)		Th/U
		average	range	average	range	average
a	Granite	33.98	30-38	65.61	62-70	1.93
a	Syenite	34.27	29-40	93.25	84-99	2.72
a	Monzonite	32.76	29-37	82.66	72-97	2.52
b	Biotite granite	8.74	7-14	48.94	24-98	5.60
b	Hastingsite granite	7.38	-	29.59	-	4.01
b	Quartz-syenite	1.50	0.7-2.3	6.70	3-10	4.47
b	Monzonite	3.35	3-3.7	17.0	14-20	5.07
b	Monzodiorite	1.2	-	2.3	-	1.9
b	Gabbro	0.9	-	0.9	-	1

a) Valle Cervo pluton: direct measurements - b) White Mountain intrusive serie: data from (Butler A.P., 1961) (Rogers J.J.W. et al., 1961)

More particulary the paragenetic sequence of rock-forming and accessory minerals of the granite, arranged according to an increasing Th/U ratio, agrees with the eutectic considerations that can be deduced from the textural relationships among the mineral shapes in the thin section of the granite. The arrangement is the following: sphene-biotite-K/feldspar-(feldspars + quartz)-magnetite-hornblende. The hornblende appears to be the most eteromorphic mineral phase also in the thin section. Its low modal percent (4-7 %) agrees with its role of late crystal phase.

The late role of magnetite on the contrary is more difficult to explain; the Th/U ratio results to remain constant in different fractions of magnetite in spite of the observed great variability of its U and Th content; moreover in the thin section the magnetite appears to give constantly typical association of sphene + + zircon + black-oxides. These features lead to believe that the magnetite with black-oxides of the granite could rapresent a late stage segregation product of the above association of the first stage radioactive minerals.

Nevertheless some comparison and further geological-petrographic considerations need to support more satisfactory the choise we have to made between the two hypotheses: the granitic core is a post-crystalline intrusion of a residua system (eutectic granite) or a preexisting exsolution of high-silica granitic melt.

Taking into consideration the trend of the average of the Th/U ratio in the total rock, we can observe that in the selected rocks of the pluton the ratio increases from monzonites to syenites but it appears to decrease again in the granite.

In the Table 3 the above trend of variation of the Th/U ratio in the Cervo pluton is compared with the analogous trend in the serie of igneous rocks of the White Mountain pluton (Butler A. P., 1961).

In these rocks the mean Th/U ratio appears to increase regularly in the sequence gabbro-monzodiorite-monzonite-quartz syenite-hastingsite granite; passing to the last term-biotite granite-Th/U ratio still increases showing however a discontinuity towards high values.

Then it appears that both the compared igneous sequences of plutonic rocks show a break in the increasing trend of the Th/U ratio passing to the last granitic term.

However while in the White Mountain pluton there is a break with rising of Th/U ratio passing to the final granitic term, in the Cervo pluton we observe that the Th/U ratio undergoes to a recessive break.

Thereby the final biotite-granite of White Mountain pluton shows late character of final system (eutectic e.g.) while the central granite of the Cervo pluton shows the mentioned recessive character suggesting a primitive molten core of silice-rich unmixed melt. No other differentiated plutons are known unfortunately in regard to the trend of Th/U ratio in total rocks.

Besides the modal composition of the granite inth e core indicates a truly quartz bearing rock contrasting with the surrounding syenite typically void of quartz.

The following petrologic features have to be pointed out:

1) a band of quartz rich rock forms the ring of separation between the granitic core and the syenite, containing more than 70 % of modal quartz. In the system [SiO_2] [FeO+Mg+CaO] [$Na_2O+K_2O+Al_2O_3$] the quartz-rich facies, as well as the common granitic facies, close the field of exsolved silica-

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A) Hypothetic initial stage (Oligocene): in the deep igneous body a layer of high-silica unmixed granitic liquid floats on the molten monzonite; high silica unmixed liquid is more viscous and more light than the underlying molten monzonite.
M.G. = high silica molten granite.
M.M. = molten monzonite.

B) Hypothetic intermediate stage: under basal compressive conditions hotter and more fluid monzonite melt begins to rise, overlapping by convection the layer of viscous high-silica unmixed phase (molten granite). According to the « fluid mechanic » the following conditions must be verified: that the rising thrust does continue and that the emplacement process is able to make way, by jointing, cracking and roof digestion, to let the molten monzonite overlaps the granite melt.

C) Hypothetic last stage: the molten monzonite rising the border becomes more viscous by cooling and eventually can transmit the compressive deformation to the viscous high-silica melt and can enclose it.

D) Present stage: the Cervo valley erosion shows the pluton internal structure with the inner granitic core. (M = monzonite; G = granite).

rich melts: e.g. in the Campiglia granite we have (FIORENTINI POTENZA M., 1959 a; PEYRONEL PAGLIANI G., 1961 a) $[SiO_2] = 67.9$; $[FeO+Mg+CaO] = 7$; $[Na_2O+K_2O+Al_2O_3] = 25.1$. These values lead in the range of immiscibility of the above system;

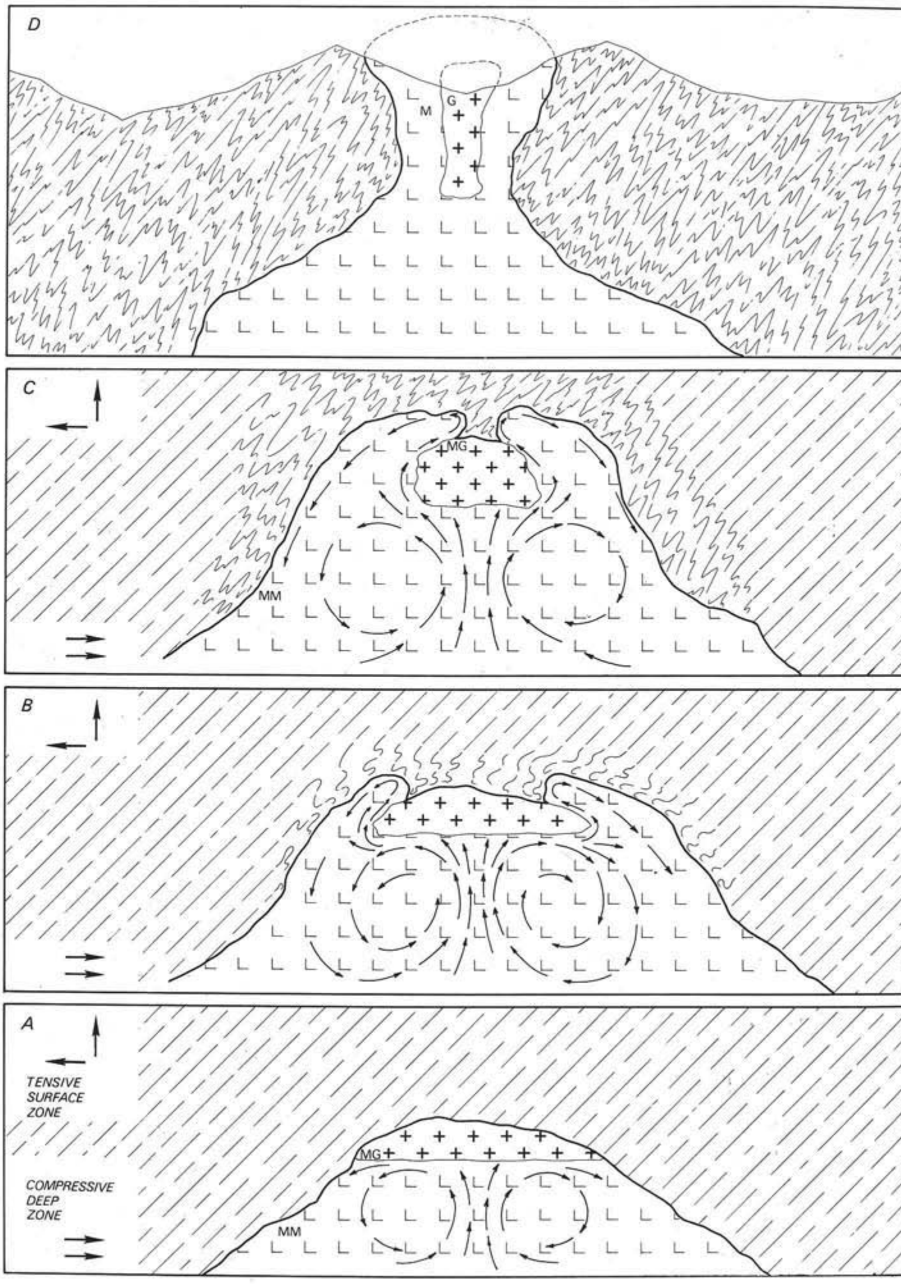

Fig. 2.

2) in the pink granite the quartz is present with two populations of grains: a first population of grains showing well-shaped exagonal habit and a late population of heteromorphic grains; this suggests that in its history of crystallization the granite melt stayed temporary in the quartz-phase field of the system silica-K/feldspar-plagioclase.

   Both points one and two lead still the primitive molten core into the range of immiscibility of the high silica melts.

   Eventually other features conflict with a postcrystalline intrusion of a molten core made of eutectic granite in the Cervo pluton;

3) the boundary between the granite core and its enclosing shell of syenite + monzonite appears to be a very rapid but not discontinuous transition; that is typic of a surface of separation between melts of different density and not of a solid-liquid separation;

4) the outcropping shape of the granitic core is that of a regular dome-shaped cupola;

5) the shell of syenite + monzonite, surrounding the granite core, shows a rigorous lack of a plastic and rigid radial deformations (PEYRONEL PAGLIANI G., 1961 b) such as it should be caused by an hypothetical late stage intrusion of granite melt in a rigid or plastic rock. In the granitic core there is besides a typical lack of fragments of syenite or monzonite while in the monzonite there are many fragments of metamorphic surrounding rocks disrupted by the intrusion. Keeping in mind the above features we lean towards the second hypothesis thinking of an emplacement of the molten pluton together with its unmixed granitic liquid core.

   The sequence of Fig. 2 sketchs a possible mechanism of emplacement of the Cervo pluton, we take into consideration.

Conclusion

The assumption of a general increasing trend of Th/U ratio during the crystal fractionation has been postulated theoretically on geochemical bases.

The result of the present attempt of application shows that the increasing trend of Th/U ratio seems to suggest mineral fractionation sequences that appear to be verified satisfactory within each selected petrographic facies of the Cervo Tertiary pluton as a whole. The observed fractionation trend in the monzonite mineral assemblage results in fact to continue the fractionation trend of the syenite one. From this point of view, the syenite should represent the differentiation product of the highest temperature in the pluton. The granite of the core shows, on the contrary, a recessive position of its range of Th/U ratio of fractionation. This fact plays in favour of an independent its trend of mineral fractionation in respect to the remaining part of the pluton.

Such a recessive character suggests a primitive unmixed molten core of silica-rich exsolved melt.

Unmixing of granite melt is supported also by its relative poorness in large cations in respect to the syenite (CESANA A. et al., 1976), by its modal composition, by euhedral exagonal quartz, by lack of plastic/rigid radial deformations in the enclosing syenites and monzonites and by other features mentioned in the discussion.

The richness in large cations showed by the syenite facies is apparently conflicting with its high thermal stage features and it asks for less common and less simple process to be satisfactorily explained.

Acknowledgments - To Prof. Ivo URAS for discussion and aids in the fluid-dynamic of molten magma.

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