ATTI

DELLA

SOCIETÀ TOSCANA

DI

SCIENZE NATURALI

RESIDENTE IN PISA

MEMORIE - SERIE A

VOL. LXXXI - ANNO 1974

ARTI GRAFICHE PACINI MARIOTTI - PISA - 1975

INDICE

MEMORIE

Atti Soc. Tosc. Sci. Nat., Mem., Serie A, **81** *(1974)*
pagg. 379-386, ff. 3, tab. 1.

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AN EVALUATION OF THE TEMPERATURE AND THE VOLATILE PRESSURE DURING THE CRYSTALLIZATION OF GRANITIC ROCKS ***

Abstract — A method to estimate temperatures and volatile pressures during the crystallization of granitic rocks is described. The temperature is estimated by measuring the Al content of quartz, while the volatile pressure is evaluated by the determination of the albite distribution between plagioclase and K-feldspar. The method has been applied to some igneous rocks belonging to the Apenninic post-orogenetic magmatism of Tuscany (Italy). The results agree well with temperatures and pressures expected from the geological setting.

Riassunto — Viene descritto un metodo per la determinazione della temperatura e della pressione in volatili durante la cristallizzazione di rocce granitiche. La temperatura viene stimata determinando il contenuto di Al nel quarzo, mentre la pressione in volatili è stimata determinando la distribuzione di Ab tra plagioglasio e feldspato potassico. Il metodo è stato applicato ad alcune rocce ignee della Toscana appartenenti al magmatismo appenninico post-orogenetico. I risultati ottenuti sono abbastanza in accordo con l'ambiente geologico di formazione delle rocce studiate.

INTRODUCTION

A very interesting problem in petrology is the determination of temperatures and volatiles pressures ($P_{(H_2O)}$) of formation of various geological materials. In the present work we describe a simple method which allows the determination of such parameters referred to the crystallization of granitic rocks.

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*** Running Title: «T°C. and $P_{(H_2O)}$ during the crystallization of granitic rocks».

In the last years a geothermometer widely used in many geological studies has been that proposed by Barth (BARTH [1951, 1962, 1968]), based on the determination of the distribution of albite between coexisting plagioclase and K-feldspar. Afterwards, however, SECK [1971] demonstrated that such distribution depends not only on the temperature but also on volatile pressure, the effect caused by a pressure increase of 1 Kb being equal to a decraese of temperature of about 15°C. Consequently the Barth geothermometer can be applied only if the pressure can be estimated independently; but it is evident that it can also be used as geobarometer, whenever an independent temperature determination can be achieved.

This is just what we propose for the granitic rocks, for which a geothermometer is provided by quartz, whose maximum Al content depends only on temperature and not on volatile pressure (DENNEN et Al. [1970]). Obviously this last geothermometer can be applied only to rocks crystallized from aluminium-saturated melts, that is rocks where normative corundum occurs.

GEOLOGICAL APPLICATION

As a test for the proposed method, which links together the evaluation of the temperature (through the determination of the Al content of quartz) with the evaluation of the volatile pressure (through the determination of the Ab distribution between plagioclase and K-feldspar), we have studied some well known igneous rocks of granitic composition, belonging to the Apenninic post-orogenetic magmatism of Tuscany.

The investigated rocks are:

— The granodiorite of M. Capanne (Elba Island). This rock forms a small pluton outcropping in the western part of Elba Island. Its petrographical and geological features have been fully described by MARINELLI [1959]. The main mineralogical constituents of the granodiorite are plagioclase, orthoclase, quartz and biotite. The orthoclase occurs in two generations: megacrysts and groundmass crystals; the albite distribution coefficient between plagioclase and K-feldspar determined for this rock is referred to the megacrysts, which, according to FRANZINI et Al. [1974], started their crystallization in an early magmatic stage.

— The porphyritic dikes of Elba Island. These rocks are genetically related to the granodiorite of M. Capanne (MARINELLI [1955]). They are characterized by the presence of phenocrysts of plagioclase, sanidine, quartz and biotite; the groundmass, which is microcrystalline, consists mainly of quartz and K-feldspar.

— The rhyolites of Roccastrada. These volcanites, which represent the most acid products of the Tuscan volcanism (MAZZUOLI [1967]), are characterized by the presence of plagioclase, sanidine, quartz, biotite and cordierite; their groundmass is glassy to partially crystalline. All the rocks investigated contain a small quantity of normative corundum.

For each of the first two rocks, two samples collected in different localities have been studied.

Table 1 reports the plagioclase and K-feldspar composition (expressed as mole %), the Al contents of quartz and the estimated temperatures and volatile pressures.

TABLE 1 - *Feldspar compositions, Al contents of quartz, temperatures and volatile pressures estimated.*

M. Capanne granodiorite

Sample	Plag.	K-feldspar	Al (in quartz)	T° C	$P_{(H_2O)}$ (Kb)
	An 28.3	Or 75.4	189 (±5.6)	713[a] (±20)	8.5
8	Ab 71.7	Ab 22.3		(~600)[b]	
		An 2.3			
	An 29.8	Or 74.6	192	724[a]	7.5
17	Ab 70.2	Ab 23.3		(~630)[b]	
		An 2.1			
Porphyritic dikes					
	An 30.7	Or 74.3	188	710[a]	5
9	Ab 69.3	Ab 23.2		(~650)[b]	
		An 2.5			
	An 36.6	Or 76.0	192	724[a]	6
10	Ab 63.4	Ab 21.7		(~650)[b]	
		An 2.3			
Rhyolites					
	An 32.5	Or 66.0	228	854[a]	1 - 2
140	Ab 58.9	Ab 30.9		(~850)[b]	
	Or 8.3	An 3.1			

a - Temperature values estimated from the Al contents of quartz
b - Temperature values estimated from Seck's diagram (fig. 1).

The values of temperature have been determined from the equation (DENNEN et Al. [1970]): $Y = 3.6\ X + 33.0$, where Y is the temperature and X the Al content of quartz (for analytical precision of the Al determination see appendix).

Volatile pressures were derived from differences between temperatures determined from this equation and those determined from the first diagram of SECK [1971] (fig. 1). The experimental data obtained by this author are in fact summarized in the two diagrams reported in fig. 1 and fig. 2 respectively. In the first

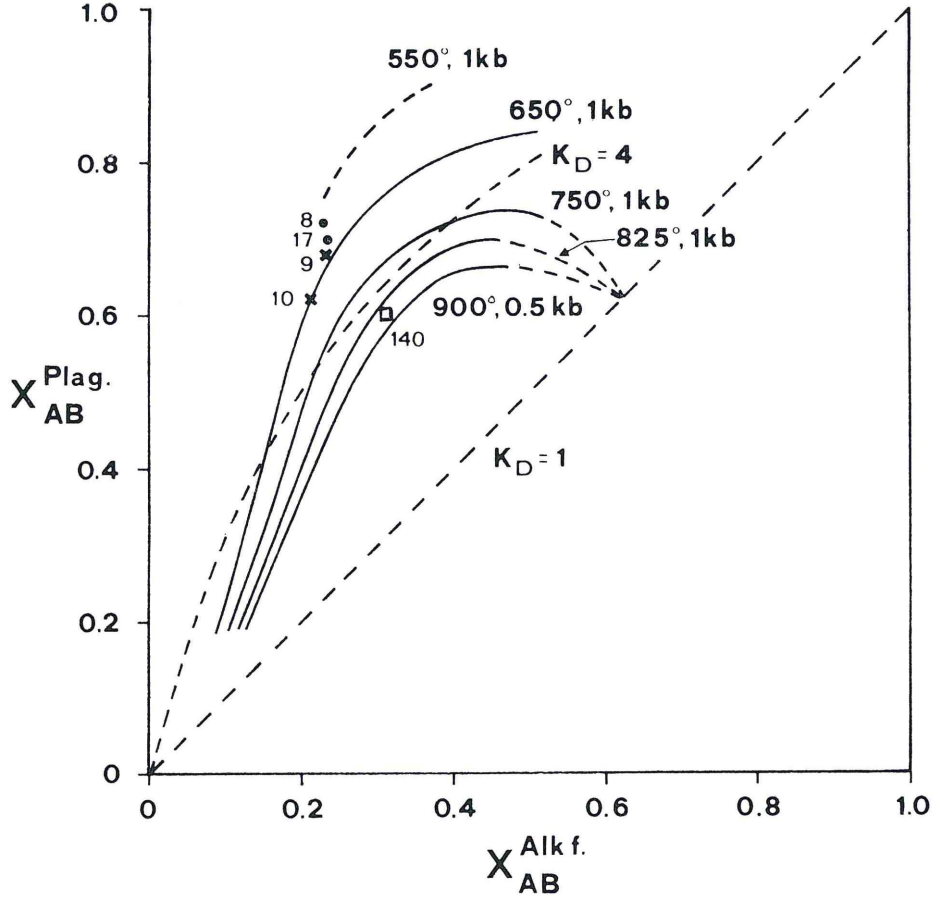

Fig. 1 - Diagram (by SECK [1971]) showing the variation of the Ab distribution between coexisting plagioclase and K-feldspar with temperature, at 1 Kb of volatile pressure ($P_{(H_2O)}$). ● (points) M. Capanne granodiorite; × (crosses) porphyritic dikes; □ (square) Roccastrada rhyolites.

diagram the distribution of albite molecule in coexisting feldspar in relation to some different temperatures, at the constant pressure of 1 Kb, is illustrated: the second diagram reports the variation of composition of coexisting feldspars in relation to pressure, at a temperature of 650°C. It is well evident that the effects of temperature and pressure are opposed each other: an increase in temperature increases the solubility of Ab in the K-feldspar while an increase in pressure decreases it. As already pointed out, Seck observed that the effect caused by a pressure increase of 1 Kb is equal to a decrease of temperature of about 15°C.

Then, if we determine, from the composition of the coexisting feldspars (first diagram of Seck, fig. 1), a crystallization temperature lower than the value derived from the independent method based on the Al content of quartz, we must infer that the pressure during the crystallization was higher than 1 Kb by a quantity $(1\ \text{Kb} \frac{T_a - T_b}{15})$ (where T_a is the temperature estimated from the

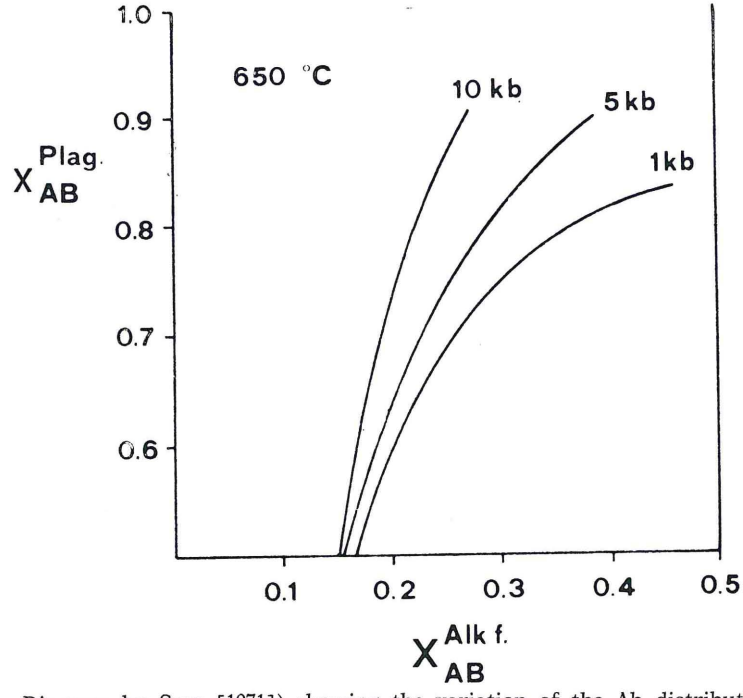

Fig. 2 - Diagram by SECK [1971]) showing the variation of the Ab distribution between coexisting plagioclase and K-feldspar with pressure, at a temperature of 650°C.

Al content of quartz and T_b is the temperature value estimated from Seck's diagram).

Discussion of results

The temperatures and volatile pressures estimated for the three granitic rocks by means of the proposed method are compatible for the particular environments.

For the granodiorite as well as for the porphyritic dikes the volatiles pressure estimated seem high, but reasonable with geological setting of these rocks. A particularly good agreement between our data and those inferred from petrological and geological reasoning is exhibited by the Roccastrada rhyolites, for whichMazzuoli [1967] estimated a volatile pressure of 1-2 Kb.

The result obtained show therefore that the proposed method is, on the whole, reliable. Its main source of errors lies in the crystallization history of the feldspars and quartz and in the zoning of plagioclase. In fact, if quartz crystallizes later than feldspars, i.e. at a lower temperature (as it normally occurs in granitic rocks), the volatiles pressure may be underestimated; furthemore if the plaglioclase are zonated the values of temperature and volatile pressure estimated by Seck's diagrams are approximative, because it is not known the true composition of plagioclase coexisting at equilibrium with K-feldspar. Anyhow the evaluation of this last parameter is approximate also because of Seck's experimental data, which nowadays are still incomplete and limited.

Appendix

Analytical methods

Aluminium concentration in quartz was determined by an X-ray fluorescence analytical procedure described by Leoni and Saitta [1973].

Individual samples were obtained by hand-picking at the binocular microscope ~ 30 to 40 mg. of optically clean material from quartz crushed to a grain size of 0.1 mm. Aluminium concentration was determined by use of the Al Kα line intensity as compared to external standards. Three quartz standards, containing 50, 150, 250 p.p.m. of Al respectively, were in fact prepared. In fig. 3 the

calibration curve relating the Al Kα intensities to Al concentrations (p.p.m.) is reported.

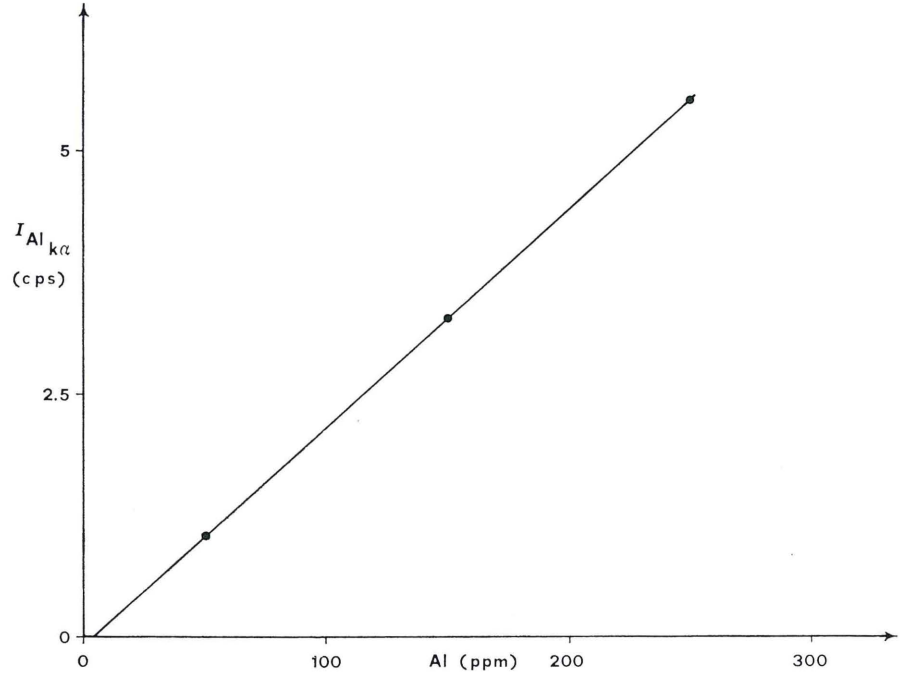

Fig. 3 - Calibration curve obtained by plotting the Al Kα intensities against the Al concentrations in some standard quartz samples. X-ray spectrometer conditions: Cr target (54 KW, 24 mA); P.E.: crystal; flow counter with discriminator as detector.

Since a low counting rate was involved, five measurements, whose counting time was 200 sec., were carried out; background corrections were made on the measured intensities. The standard counting error resulted about ± 3%. The accuracy of Al determination substantially reflects this error.

Comparison of these data on Al concentration determination with those of DENNEN et Al. [1970] shows therefore that the analytical precision of such determination is greatly improved by the use of a X-ray fluorescence analytic procedure; this method, however, requires quartz samples three to four times greater than those needed for Dennen's procedure.

Plaglioclase and K-feldspar composition were drawn from li-

terature: for M. CAPANNE granodiorite see FRANZINI et Al. [1974] (in press); for porphyritic dikes see LEONI [1974] (in press); for Roccastrada rhyolites see MAZZUOLI [1967].

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(*ms. pres. il 21 novembre 1974; ultime bozze 22 aprile 1975*).