INDICE

MEMORIE

Conato V., Segre A. G. - Ciottoli di rocce sedimentarie nel golfo di Pozzuoli Pag. 1

Conato V., Segre A. G. - Depositi marini quaternari e nuovi foraminiferi dell’Antartide (Terra Victoria, Valle Wright) » 6

Rapetti F., Vittorini S. - Osservazioni sulle variazioni dell’ala destra del delta dell’Arno » 25

Fierro G., Piacentino G. B., Tucci S. - Caratteri morfologici e litogenetici di una «beach-rock» della Liguria Occidentale » 89

Sighinolfi G. P., Shigemi Fujimori - Petrology and chemistry of diopsidic rocks in granulite terrains from the brazilian basement » 103

Plesi G. - L’unità di Canetolo nella struttura di Bobbio (Val Trebbia), Montegroppo (Val Gotra) e lungo la trasversale Cinque Terre-Pracchiola » 121

Magaldi D. - Caratteri e modalità dell’orientamento delle argille nell’orizzonte B di alcuni suoli » 152

Orlandi P. - Note di mineralogia toscana. 2. - Minerali delle geodi dei marmi di Carrara » 167

Giannelli G., Passerini P. - A K/Ar dating of the pillow lavas of Castiglioncello del Trinoro (Southern Tuscany) » 185

Leoni L. - Le rocce silicee non detritiche dell’Appennino Centro-Settentrionale » 187

Fancelli Galletti M. L. - Analisi pollinica di sedimenti sovrastanti la panchina tirreniana di Torre del Fanale in Livorno » 222

De Giuli C., Heintz E. - Gazella borbonica (Bovidae, Artiodactyla, Mammalia), nouveau élément de la faune villafranchienne de Montopoli, Valdarno inférieur, Pisa, Italia » 227

De Giuli C., Heintz E. - Croizetoceros ramosus (Cervidae, Artiodactyla, Mammalia) de Montopoli, nouveau élément de la faune villafranchienne d’Italie » 241

Giannetti B. - Nuove ricerche petrografiche e petrogenetiche sulle lave fono- nitiche della caldera vulcanica di Roccamonfina » 253

Caporusso A. M., Giacomelli G., Lardicci L. - On the reaction of tri-isobutylaluminium with pivalonitrile » 307

Ficcarelli G., Torre D. - Nuovi reperti del gatto villafranchiano di Olivola » 312
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAGGI G., TREVISAN L.</td>
<td>Il bacino idrogeologico di Valdottavo in Val di Serchio</td>
<td>323</td>
</tr>
<tr>
<td>DE MUNNO A., BERTINI V., MENCONI A., DENTI G.</td>
<td>Su alcuni nitroderivati del 3-fenil-1,2,5-ossadiazolo</td>
<td>334</td>
</tr>
<tr>
<td>RİFFALDI R., LEVI-MİNİZİ R.</td>
<td>Caratteristiche delle sostanze umiche estratte da rendzina</td>
<td>343</td>
</tr>
<tr>
<td>FRANZINI M., LEONİ L., ORLANDİ P.</td>
<td>Mineralogical and geochemical study of K-feldspar megacrysts from the Elba (Italy) granodiorite</td>
<td>356</td>
</tr>
<tr>
<td>LEONİ L., RIVALENTİ G.</td>
<td>An evaluation of the temperature and the volatile pressure during the crystallization of granitic rocks</td>
<td>379</td>
</tr>
<tr>
<td>DE MICHELE V., GIUSEPPETTI G., ORLANDI P.</td>
<td>Anapaite di Castelnuovo dei Sabbioni (Craviglia, Arezzo)</td>
<td>387</td>
</tr>
<tr>
<td>LEONİ L., TROYSİ M.</td>
<td>Ricerche sulla microdurezza dei silicati. I - Gli epidoti</td>
<td>397</td>
</tr>
<tr>
<td>Elenco dei Soci per l'anno 1974</td>
<td></td>
<td>405</td>
</tr>
<tr>
<td>Norme per la stampa di note e memorie sugli Atti della Società Toscana di Scienze Naturali</td>
<td></td>
<td>411</td>
</tr>
</tbody>
</table>
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.

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.
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 decrease 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.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Plag.</th>
<th>K-feldspar</th>
<th>Al (in quartz)</th>
<th>T°C</th>
<th>P (H₂O) (Kb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>An 28.3</td>
<td>Or 75.4</td>
<td>189 (±5.6)</td>
<td>713 ± 20</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Ab 71.7</td>
<td>Ab 22.3</td>
<td></td>
<td>(≈ 600)b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>An 2.3</td>
<td>Or 74.6</td>
<td>192</td>
<td>724a</td>
<td>7.5</td>
</tr>
<tr>
<td>17</td>
<td>An 29.8</td>
<td>Ab 70.2</td>
<td>(≈ 630)b</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ab 23.3</td>
<td>An 2.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>An 2.1</td>
<td>Or 74.6</td>
<td>192</td>
<td>724a</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>An 30.7</td>
<td>Ab 69.3</td>
<td>(≈ 650)b</td>
<td>710a</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Ab 23.2</td>
<td>An 2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>An 36.6</td>
<td>Ab 63.4</td>
<td>192</td>
<td>724a</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Ab 21.7</td>
<td>An 2.3</td>
<td>(≈ 650)b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rhyolites</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>140</td>
<td>An 32.5</td>
<td>Or 66.0</td>
<td>228</td>
<td>854a</td>
<td>1 - 2</td>
</tr>
<tr>
<td></td>
<td>Ab 58.9</td>
<td>Ab 30.9</td>
<td>(≈ 850)b</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Or 8.3</td>
<td>An 3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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]): $Y = 3.6X + 33.0$, 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 volatile 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 which Mazzuoli [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 volatile pressure may be underestimated; furthermore if the plagioclase 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 $\sim 30$ 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 $K_\alpha$ 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.

![Calibration curve](image)

**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.

Plagioclase and K-feldspar composition were drawn from li-
temperature; 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].

REFERENCES


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