# Barium phlogopite from the Jacupiranga carbonatite, Brazil

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## Abstract

Phlogopites from the carbonatites intruded into the Jacupiranga alkalic complex have FeO/(FeO + MgO) within the restricted range 0.06 to 0.12, and BaO varying from 0.1 up to 10.3 wt.%. Zoning with respect to BaO may be small, or it may exceed 3–4% BaO. Phlogopites and biotites from other carbonatites contain much less BaO, commonly below 0.7%, but values of FeO/(FeO + MgO) range up to 0.66. Phlogopites from mantle peridotite nodules and kimberlites have BaO contents less than 0.7%, with FeO/(FeO + MgO) varying from low values for mantle phlogopites (corresponding to those of the Jacupiranga carbonatites) up to values of at least 0.7 for kimberlite phlogopites. Leucite-bearing lavas contain high Ba micas with FeO/(FeO + MgO) from 0.09–0.6, and BaO up to 7.3%.

## Introduction

The Jacupiranga alkalic complex is composed mainly of peridotites, pyroxenites, jacupirangites and ijolites, surrounded by fenites and nepheline syenites (Melcher, 1966). Detailed mapping by one of us (JCG) of the small carbonatite body, centrally located within the complex, has revealed five distinct intrusions of different ages. Their geology and mineralogy was summarized by Gaspar and Wyllie (1982). During a comprehensive survey of the mineralogy of the carbonatites (Gaspar and Wyllie, manuscripts in preparation), it was discovered that the BaO content of phlogopite (an accessory mineral in each carbonatite) is high enough to characterize it as barium phlogopite. Reported values for BaO in phlogopites from other carbonatites, from kimberlites, and from mantle peridotite nodules are much lower. Micas in some leucite-bearing lavas contain high BaO.

## Phlogopite from Jacupiranga

All five of the carbonatite intrusions in the Jacupiranga Complex contain light green euhedral crystals of phlogopite. The crystals vary from a few millimeters to more than 1 cm in diameter. The minerals were analyzed with an ARL/EMX automated electron microprobe. The accuracy of analyses is ±5% of the amount present up to 2 wt.%, and ±2% of the amount present for major elements. Careful peak positions and background determinations were carried out to avoid the Ba–Ti interference. Some representative analyses are presented in Table 1.

Analyses were made of the cores and rims of the phlogopites. The minerals are zoned (Table 1). Values of BaO and FeO/(FeO + MgO) for 32 core compositions and a number of rim compositions are plotted in Figure 1. FeO/(FeO + MgO) varies within a small range of 0.06 to 0.12, for both cores and rims of the minerals analyzed. BaO content varies from 0.10 up to 10.3 wt.%. Zoning with increase in BaO toward the rims is most common, but many grains exhibit decrease of BaO toward the rims. The range of zoning with respect to BaO is small for some grains, but it exceeds 3–4% BaO in several of them. $Ba^{2+}$ enters the structure of these micas replacing $K^+$. The balance of charge is made by the replacement of $Si^{4+}$ by $Al^{3+}$ in the tetrahedral site. Because the $TiO_2$ contents are very low (Table 1), the substitution mechanism described by Mansker *et*

Table 1. Representative analyses of phlogopites

|  | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 32.4 | 36.7 | 39.2 | 37.1 |
| $TiO_2$ | 0.00 | 0.04 | 0.10 | 0.15 |
| $Al_2O_3$ | 20.5 | 16.7 | 16.4 | 18.3 |
| FeO* | 1.83 | 1.69 | 2.70 | 2.32 |
| MnO | 0.00 | 0.00 | 0.00 | 0.00 |
| MgO | 22.9 | 25.5 | 25.9 | 24.4 |
| CaO | 0.04 | 0.06 | 0.05 | 0.28 |
| $Na_2O$ | 0.47 | 0.15 | 0.39 | 0.74 |
| $K_2O$ | 6.83 | 9.16 | 9.49 | 8.97 |
| BaO | 10.03 | 4.78 | 2.55 | 4.82 |
| TOTAL | 94.96 | 94.73 | 96.80 | 97.00 |
| *Cation number (22 oxygens)* | | | | |
| Si | 4.862 | 5.332 | 5.494 | 5.277 |
| $Al^{IV}$ | 3.138 | 2.668 | 2.506 | 2.723 |
| Al | 0.536 | 0.232 | 0.241 | 0.379 |
| Ti | 0.000 | 0.009 | 0.009 | 0.017 |
| Fe | 0.229 | 0.212 | 0.324 | 0.277 |
| Mn | 0.000 | 0.000 | 0.000 | 0.000 |
| Mg | 5.192 | 5.597 | 5.485 | 5.242 |
| Ca | 0.009 | 0.009 | 0.009 | 0.043 |
| Na | 0.146 | 0.035 | 0.102 | 0.208 |
| K | 1.334 | 1.715 | 1.723 | 1.646 |
| Ba | 0.594 | 0.274 | 0.145 | 0.269 |
| TOTAL | 16.040 | 16.083 | 16.038 | 16.081 |

*1,2—Core compositions ($C_2$ sovite)*
*3,4—Core and rim respectively ($C_3$ sovite)*
*\*All iron calculated as FeO*
*See Gaspar and Wyllie (1982) for $C_2$ and $C_3$ details*

al. (1979) for Ti- and Ba-rich micas does not apply for the Jacupiranga phlogopites.

### Phlogopite from other rocks

Phlogopites from other carbonatites contain much less BaO than most of the Jacupiranga phlogopites, as shown in Figure 1. Only one, from Iron Hill, exceeds 1% BaO, and the others range from 0.7% to 0.03%. The values of FeO/(FeO + MgO) range from the low values for the Jacupiranga phlogopites up to 0.66, which characterizes several of them as biotites, rather than phlogopites. The micas from Alnö display the widest range of FeO/(FeO + MgO). The range of zoning plotted for two Iron Hill phlogopites demonstrates decreasing BaO with increasing FeO/(FeO + MgO). Despite the fact that most of the increase in FeO/(FeO + MgO) is due to $Fe^{3+}$ substituting for Al in the tetrahedral positions (Nash, 1972), the observed slight decrease in MgO (Nash, 1972) suggests that $Fe^{2+}$/Mg also increases.

The phlogopites with primary textures from mantle peridotite nodules analyzed by Delaney et al. (1980) occupy a small field at the low BaO end of the Jacupiranga analyses. The maximum BaO reported is 0.7 wt.%. They have the same restricted range of FeO/(FeO + MgO) as the Jacupiranga phlogopites, which differs from that for the other rocks compared in Figure 1.

Smith et al. (1978) distinguished several different types of phlogopite in kimberlites, and the compositional ranges of their Type I (5 analyses) and Type II (9 analyses) are shown in Figure 1. They have low values of BaO, corresponding to the phlogopites from mantle peridotites. Their compositions lie
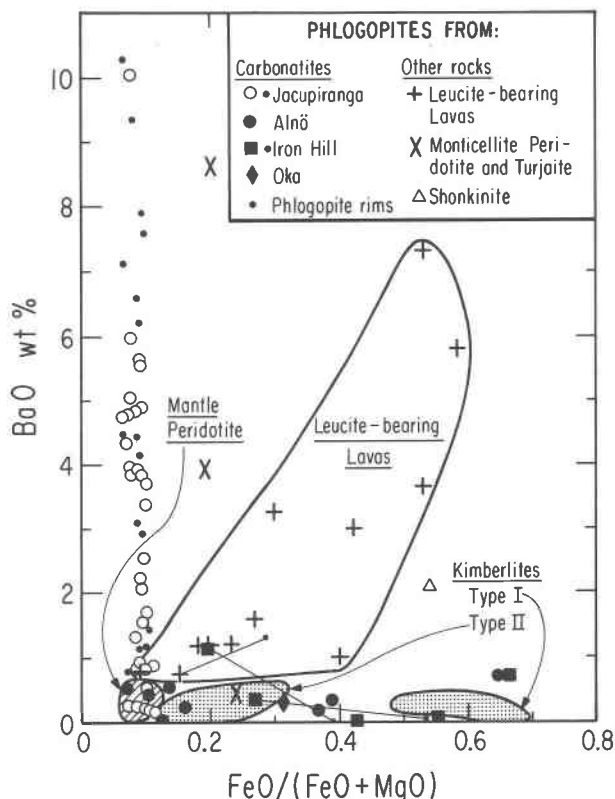


Fig. 1. The unique chemistry of the zoned barium phlogopites from Jacupiranga carbonatites compared with BaO and FeO/(FeO + MgO) of phlogopites and micas from other carbonatites (Alnö, von Eckermann, 1974; Iron Hill, Nash, 1972; Oka, Rimsaite, 1969), mantle-derived peridotites (Delaney et al., 1980), kimberlites (Smith et al., 1978; Smith et al., 1979), potassic lavas (Cosgrove, Birch, 1978; Alban Hill, Thompson, 1977; Gaussberg, Sheraton and Cundari, 1980; Ungino, Baldridge et al., 1981; Leucite Hills and West Kimberley, Carmichael, 1967), monticellite peridotite and turjaite (Highwood Mountains, Wendlandt, 1977) and shonkinite (Shonkin Sag, Nash and Wilkinson, 1970, 1971). Lines connect core (symbols) and rim (dots) compositions of zoned micas, except for the Jacupiranga phlogopites, where the lines were omitted for graphical clarity (but the trends are obvious from the plotted points).

within the range of those from carbonatites other than the Jacupiranga carbonatites.

Potassic lavas contain mica rich in barium, as shown in Figure 1 by the selection of analyses from leucitites (Thompson, 1977; Birch, 1978; Sheraton and Cundari, 1980), leucite-basanite (Baldridge *et al.,* 1981), wyomingite, olgidite and related rocks (Carmichael, 1967). The micas contain up to 7.3% BaO with values of FeO/(FeO + MgO) varying from 0.09 (for the average Leucite Hills phlogopites, Carmichael, 1967) to 0.6. They show a rough trend of sympathetic variation of BaO with FeO/(FeO + MgO). One of the West Kimberley micas (Carmichael, 1967) is zoned in the same direction (Fig. 1).

The phlogopites from monticellite peridotite and turjaite from the Highwood Mountains (Wendlandt, 1977) also contain high BaO, reaching up to 8.6% (Figure 1). The ratio FeO/(FeO + MgO) varies from 0.19 to .24 in a trend parallel to that of the Jacupiranga phlogopites.

A mica from shonkinite from the Shonkin Sag laccolith (Nash and Wilkinson, 1970, 1971) contains less BaO for similar FeO/(FeO + MgO) than the leucite-bearing lavas (Fig. 1).

Two additional occurrences of high barium micas are reported by Mansker *et al.* (1979) and by Frondel and Ito (1968). Mansker *et al.* (1979) reported late-magmatic biotites in nephelinites from Hawaii that contain up to 20 wt.% BaO and 14 wt.% $TiO_2$. These high $TiO_2$ contents associated with the FeO/(FeO + MgO) ratios (0.46 to 0.73), make them chemically distinct from the Jacupiranga phlogopites.

Frondel and Ito (1968) described a mica from Langban, Sweden, without any indication of the host rock, that contains 7.9% BaO, with FeO/(FeO + MgO) = 0.068. It plots in the Jacupiranga range of composition. However, the Langban mica has $(MnO + Mn_2O_3) = 4.2\%$, while Mn is a minor to trace element in the Jacupiranga phlogopites (Table 1).

## Concluding remarks

Figure 1 illustrates similar chemical variation for phlogopites from mantle peridotite through kimberlites and most carbonatites, with micas from potassic lavas diverging in the direction of increasing BaO and FeO/(FeO + MgO). The chemical variation of the phlogopites from Jacupiranga carbonatites is in striking contrast, with FeO/(FeO + MgO) remaining as low as that for the primary phlogopites from mantle peridotites, but with BaO ranging even higher than in the micas from the potassic lavas. Consideration of the implications of these chemical variations must await completion of the detailed mineralogical study of the Jacupiranga carbonatites.

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