not only in respect of the Volta Grande pegmatites, but also of the regional geological setting. Lagache & Quéméneur alluded to the existence of a greenstone belt in the area without reference to Almeida (1976), who first recognized that suite of rocks, later referred to as the Barbacena Greenstone Belt (Pires 1977). The important geological map and field relations defined by Ebert (1956, 1957a, b) were not considered at all.

Upon examination of the previous results, some facts seem established, such as the initial replacement of oligoclase by microcline and the late formation of lepidolite at the expense of spodumene. Such paragenetic relations amongst pegmatite-forming minerals, as well as the suite of alteration minerals in the wall rock (wherein epidote, fluorite, anthophyllite and titanite are relatively common), were not defined by Lagache & Quéméneur (1997). As a consequence, the proposed evolution of the concentrations of Rb and Cs in the minerals using experimentally determined partition coefficients loses its strength inasmuch as the paragenetic evolution has not been taken into consideration.

Lagache & Quéméneur (1997) have documented a positive linear correlation between F and Rb in micas and demonstrated that the proportion of muscovite diminishes and that of polylithionite increases with increasing F content. This increase in HF fugacity is consistent with the common occurrence of lepidolite as a late-stage mineral in Li-bearing granitic pegmatites, where the presence of a F-bearing aqueous fluid medium favors subsolidus reaction of spodumene and K-feldspar (Munoz 1971). The high activity of F and H_2O would also destabilize tantalite in favor of microlite in this late (subsolidus) stage.

A concluding remark concerning the presence of holmquistite at Volta Grande is necessary. First identified by Leonardos (1973), the holmquistite was suggested to have been formed by replacement of hornblende of the amphibolite wallrock (Quéméneur & Lagache 1994). Its occurrence near such highly fractionated, Li-rich pegmatites as at Volta Grande can be used as a guide to exploration for Li-rich rare-element-enriched pegmatites (London 1986).

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THE VOLTA GRANDE PEGMATITES, MINAS GERAIS, BRAZIL: AN EXAMPLE OF RARE-ELEMENT GRANITIC PEGMATITES EXCEPTIONALLY ENRICHED IN LITHIUM AND RUBIDIUM: REPLY

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The Discussion of Pires and Cabral focusses on three themes, to which we intend to reply in sequence.

Bibliography

We could, indeed, have written a section to review the historical aspects of the discovery of the deposit and the early writings of geologists who provided the first descriptions. These references were to a large extent cited in the 1987 article. In view of the length of our article, we restricted our coverage of the previous literature to a citation to Heinrich (1964). We selected this article because the author wrote a synthesis of the earlier work on Volta Grande and because it was published in an international journal. In addition, we did not use, in our article, any ideas or findings attributable to the

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authors cited by Pires and Cabral. These articles focus mainly on aspects of tin and tantalum mineralization, for which the granitic pegmatites are exploited.

Mineralogy and Paragenesis of the Host Rocks

It is convenient here to separate the minerals of the pegmatite proper from the alteration-induced minerals of the amphibolitic host-rocks. Concerning the first theme, we really do not believe that a study of columbite – tantalite inclusions in cassiterite will help us greatly to understand the distribution of Rb and Cs in minerals of the pegmatite; we were more interested in the more abundant minerals of the pegmatite.

Concerning the presence of epidote, of sparse amounts of chlorite, and of rare examples of anthophyllite, these are retrograde minerals accompanying greenschist-facies metamorphism affecting the entire region, and independent of the pegmatites. The titanite does not seem to have anything to do with this episode of recrystallization, being instead related to Archean metamorphism of amphibolite-facies grade. The chemical compositions of minerals in the contact-metasomatized rocks were likely not affected by retrograde metamorphism, as the analyzed crystals, zinnwaldite and lithian phlogopite, were selected among those (the majority) devoid of chlorite. One can anticipate that where it is important, such retrograde metamorphism, involving a migrating aqueous fluid, could locally deplete micas in Rb and Cs.

Ideas and Suggestions for Studies of the Pegmatite Bodies

Pires and Cabral emphasize the notion of geochemical "stages" utilized by previous authors, for example Guimarães (1950) and Francesconi (1972), to explain the cristallization of the pegmatites. In particular, they refer to a hypothetical "calcic–sodic stage" enriched in oligoclase. This notion could serve as the basis of a discussion if there existed oligoclase in the pegmatites of Grande Volta. Up until now, however, all the grains of plagioclase analyzed, from the border zone as well as from the intermediate zone, consist of pure albite (An_0 to $An_{2.4}$). An ultimate replacement of oligoclase by microcline represents a completely hypothetical scenario if we consider that the small cristals of plagioclase contained in the microcline invariably consist of albite, and that the concentration of Ca in microcline in various samples is invariably below the detection limit of the electron microprobe method used.

So far as "paragenetic" relations involving cassiterite, tantalite and microlite are concerned, the topic is probably not fully understood, but it does not seem to us directly related to the K/Rb and K/Cs values of the potassium-bearing minerals and the coexisting fluid phase.

One of the authors points out that we have not referred to his abstract, published in proceedings of the 37th Brasilian Congress of Geology (Pires & Pires 1992), in which he proposes an explanation of the zonation in the pegmatitic field at Volta Grande. In our opinion, their model is not very useful; furthermore, it is based on data of questionable quality. In particular, nearly all the occurrences now consist of saprolite in which only relics of muscovite remain. In the only locality in which there is an important component of fresh rock, the Volta Grande mine, the trace of the contact between lepidolite-bearing masses and those devoid of lepidolite is not accurate. It is shown as passing between bodies A and E, whereas it should pass between A and B, as B contained lepidolite prior to its depletion owing to mining activity.

Conerning the relation between F and Rb contents in the micas, we simply made a statement, as this fact has been well established by many authors, *e.g.*, Munoz (1984) and Robert *et al.* (1993). We do not formulate any hypothesis concerning the controls of crystallization of dioctahedral or trioctahedral micas. In fact, the greatest concentration of Rb, Cs and Mn in the trioctahedral micas seems related to structural factors and to the enrichment of these elements in this environment of crystallization (Robert *et al.* 1993).

In conclusion, we suggest that the authors set down their ideas concerning the Volta Grande pegmatites in print, in a full article, so that the debate can proceed in a proper scientific forum.

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References

Almeida, F.F.M. (1976): Estruturas do Pré-Cambriano Inferior brasileiro. *Congr. Bras. Geol. (Ouro Preto) Boletim de Resumos*, 200-201.

Belezkii, W. (1956): Mineralização tântalo–estanifera e uranifera do minicípio de São João del Rei, Minas Gerais. *Div. Fom. Prod. Min., Rio de Janeiro, Bol.* **99**, 1-42.

Ebert, H. (1956): Geologia do precambriano brasileiro. *Relatório da Diretoria* 1955, *Div. Geol. Mineral. (Rio de Janeiro)*, 67-81.

_____ (1957a): Beitrag zur Gliederung des Präkambriums in Minas Gerais. *Geol. Rundsch.* **45**, 471-521.

_____ (1957b): Mapa geológico preliminar da parte sul do Estado de Minas Gerais e adjacências. *Relatório da Diretoria* 1956, *Div. Geol. Mineral. (Rio de Janeiro)*, 100-107.

Francesconi, R. (1972): *Pegmatitos da região de São João del Rei, Minas Gerais.* Ph.D. thesis, Univ. São Paulo, São Paulo, Brazil.

GUIMARÃES, D. (1948): Age determination of quartz veins and pegmatites in Brazil. *Econ. Geol.* **43**, 100-118.

_____ (1950): A jazida de djalmaita de Volta Grande, rio das Mortes, Minas Gerais. *An. Acad. bras. Ci.* **22**(1), 51-71.

_____ & BELEZKIJ, W. (1956): The stanno-tantalo-uraniferous deposits and occurrences in the region of São João del Rei, Minas Gerais, Brazil. *Int. Conf. Peaceful Uses Atomic Energy, Proc.* **6**, 143-146.

_____ & GUEDES, S.V. (1944): Nota preliminar sobre a região estanifera de São João del Rei, Minas Gerais. *Div. Fom. Prod. Min., Rio de Janeiro, Av.* **58**.

_____ & _____ (1946): Title?? *In* ??? (A.I. Erichsen, ed.). *Relatório da diretoria* 1944, *Div. Fom. Prod. Mineral. (Rio de Janeiro), Bol.* **77**, 72-78.

HEINRICH, E.W. (1964): Tin – tantalum – lithium pegmatites of the São João del Rei district, Minas Gerais, Brazil. *Econ. Geol.* **59**, 982-1002.

LAGACHE, M. & QUÉMÉNEUR, J. (1997): The Volta Grande pegmatites, Minas Gerais, Brazil: an example of rare-element granitic pegmatite exceptionally enriched in lithium and rubidium. *Can. Mineral.* **35**, 153-165.

LEONARDOS, O.H., JR. (1973): *The Origin and Alteration of Granitic Rocks in Brazil: a Study of Metamorphism, Anatexis, Weathering and Fertility within a Granitic Terrain in Eastern Brazil.* Ph.D. thesis, Univ. of Manchester, Manchester, England.

LONDON, D. (1986): Holmquistite as a guide to pegmatitic rare metal deposits. *Econ. Geol.* **81**, 704- 712.

MUNOZ, J.L. (1971): Hydrothermal stability relations of synthetic lepidolite. *Am. Mineral.* **56**, 2069- 2087.

_____ (1984): F–OH and Cl–OH exchange in micas with application to the hydrothermal deposits. *Rev. Mineral.* **13**, 469-493.

PEIXOTO, F. & GUIMARÃES, D. (1953): Problemas de cronogeologia. *Univ. Minas Gerais (Belo Horizonte), Esc. Engen., Inst. Pesquisas Radio., Publ.* **1**.

PIRES, F.R.M. (1977): *Geologia do distrito manganisifero de Conselheiro Lafaiete, Minas Gerais.* M.Sc. thesis, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.

_____ & PIRES, H.L. (1992): Regional zoning in the São João del Rei pegmatite district and its relation with the collisional Santa Rita granite, Minas Gerais, Brazil. *An. 37º Cong. Bras. Geol. (São Paulo)* **1**, 269-272.

QUÉMÉNEUR, J.J.G. (1987): Petrography of the pegmatites from Rio das Mortes valley, southeast Minas Gerais, Brazil. *Rev. Bras. Geoc.* **17**, 595-600.

_____ & LAGACHE, M. (1994): La holmquistite des pegmatites de Volta Grande près de São João del Rei, Minas Gerais, Brésil: caractéristiques chimiques et minéralogiques. *Geonomos* **2**(2), 15-21.

ROBERT, J.-L., BENY, J.M., DELLA VENTURA, G. & HARDY, M. (1993): Fluorine in micas: crystal-chemical control of the OH–F between trioctahedral and dioctahedral sites. *Eur. J. Mineral.* **5**, 7-18.

ROLFF, P.M.A. (1948): A província estanifera do Rio das Mortes. *Rev. Esc. Minas* **13**(3), 5-10.