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Araxa carbonatite deposit and its lateritization

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Abstract: Araxa niobium-bearing carbonatite deposit occurring in Barreiro carbonatite was studied preliminarily. The Barrairo (Araxa) complex located at approximately 6 kilometers south of Araxa city, Minas Gerais, Brazil, is intruded into the Araxa group of the lower Proterozoic system and is composed mainly of beforsite, phoscolite, sovite, glimmerite and fenite. This complex including the fenite zone with about 5.5 kilometers in diameter and both of the complex and the host Proterozoic systems have been deeply weathered and consequently the fresh rocks are scarecely observed in this area. According to exploration drilling data in the mining site, the thickness of the lateritized mantle vary from a several to two handred meters.

The lateritization has brought out the enrichment of niobium, titanium and phosphorus. This study reveals the concentration ratios of the ore components based on the chemical compositions between the primary carbonatite and the weathered mantle in the Barreiro complex. ZrO_2 in the beforsite has increased about 8 times in the weathered mantle and SiO_2, Al_2O_3 and BaO are 6 to 9 times. It is therefore concluded that the formation of anomalously high-grade niobium ore deposit was clearly caused by the strong lateritizaion.

1. Introduction

Carbonatites that have been given special attention not only to the petrological interests but also to the economical importance are distributed interior and marginal portions of continental areas. There are more than five handreds localities of carbonatites in the world (KAMITANI and HIRANO, 1985). The unique mineral resources of carbonatites have high potentiality for niobium, rare-earth, titanium, zirconium and phosphorus (DEANS, 1978). Especially, niobium production from carbonatite ore deposits shares more than 98 per cent of the world production. Araxa and Catalao mines are famous for the niobium-bearing carbonatite ore deposits, and the other Brazilian carbonatite complexes have been paid attention to their mineral resources of phosphorus, titanium and rare-earth.

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In the southern Brazil, many carbonatite-alkaline/alkaline compelexes are recognizable particularly in the peripheries of the Parana basin (SCHOBBENHAUS, 1981) which consists mainly of Paleozoic to Mesozoic sediments with tholeiitic basalts (Fig. 1). The tholeiitic basalts were formed in Triassic to Jurassic age and the many carbonatite-alkaline/alkaline complexes were intruded principally in Jurassic to Cretaceous age (ULBRICH and GOMES, 1981). The Parana basalts are believed to be a result of large-scale fissure eruptions related to the break up of the Gondwana old continent. In the Angola and the South Africa similar intrusion age of carbonatite complexes are distributed (MARSH, 1973; ULBRICH and GOMES, 1981). Most of those K-Ar ages in the southern Brazil ranges from 135 to 60 Ma (AMARAL *et al.*, 1967). HERZ (1977) states that the northwest alignment of the complexes in the Cretaceous age including the Araxa and Catalao carbonatites are resulted from one of the failed arms of the tripple junctions. It might be kind of marginal fractrure zones that is roughly across at right angle to the plate margin

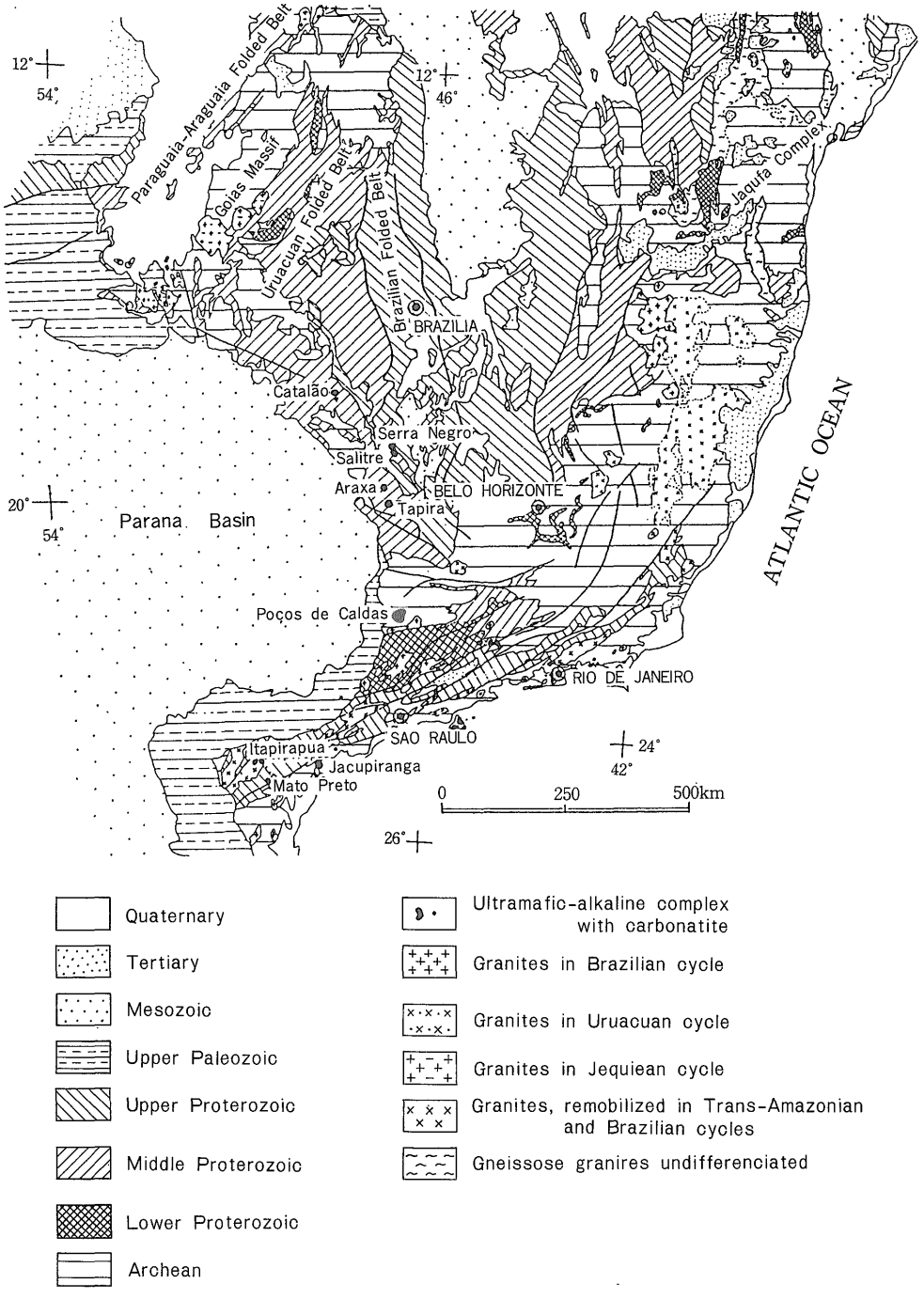

Fig. 1 Geologic map of southern Brazil.

(FRANCHETEAU and PICHON, 1972).

The carbonatite–alkaline/aklaline complexes in Brazil were grouped into eitht types by ULBRICH and GOMES (1981). All of the carbonatite–bearing complexes belonging to the Type III of Ulbrich and Gomes are always accompanied with glimmerites, dunites, peridotites and pyroxenites.

The Barreiro carbonatite complex is accompanied with niobium–bearing ore body in the central part of the complex, as well as phosphorus and rare–earth ore deposits in the north to the northeast (BERBERT, 1984). In this paper the secondary enrichment of niobium was preliminarily studied and the concentration process is discussed based on the chemical analysis data.

2. Geologic setting

2.1 Regional geology

Barreiro (Araxa) carbonatite complex is located at about 300 kilometers west of Belo Horizonte, the third largest city of the Brazil. The mining site of the Araxa niobium ore deposit has been constructed just south of Araxa city on the high–land area with the altitude from 1,000 to 1,200 meters.

There are five carbonatite alkaline complexes in the vicinity of Araxa city; Salitre I, II, Serra Negra, Barreiro and Tapira from north to south (Fig. 2). Their K–Ar ages according to HASUI and CORDANI (1968) indicate late Cretaceous but vary from 70 to 91 Ma.

The Salitre I, II, and Serra Negra complexes intruded into the Paraopeba formation of upper Proterozoic system are located at approximately 70 kilometers north of the Araxa. Those complexes with about 10 kilometers in diameter have been completely lateritized and therefore no fresh rock is recognizable in and around the complexes. Results of exploration trenches and drills indicate that the weathered mantle on the complexes contains an intermediate to high–grade of titanium ore deposits (Table 1).

The Tapira complex is located at about 30 kilometers southeast of the Araxa and intruded into the Canastra formation of middle Proterozoic system. This complex with about 7 kilometers in dameter is presently underdeveloping by open pit as a titanium mine, but it has also considerable amount of niobium and phosphorus associated with the titanium deposit.

The geology of this area including the five carbonataite complexes consists mainly of Archean undiffrentiated system, middle Proterozoic system of Araxa, Canastra and Ibia formations, and Paraopeba formation of upper Proterozoic. These crystalline basements are unconformably covered with the Serra Jeral formation of late Jurassic in the west and the Paulu formation in the east (DNPM, 1978).

The Serra Jeral formation is characterized by a thick pile of tholeiitic basalts and their pyroclastics. This volcanism started with fissure eruption about 147 Ma ago in the Santa Catarina area and its peak is thought to be between 120 and 130 Ma (CORDANI and VANDROS, 1967). In the late stage of the volcanism many diabasic dykes were intruded into the basement along NW trending fractures which are parallel to that of magnetic linearments (SCHOBBENHAUS, 1981). The NW trending faults are also observable around the Salitre complexes, but obscure around the Barreiro and Tapira.

2.2 Geology and occurrence of the Araxa niobium ore deposit in the Barreiro complex

Table 1 Mineral resources of carbonatite complexes in Araxa area

	Niobium		Titanium		Phosphorus		Rare earth	
	$\times 10^6$ t,	$\%Nb_2O_5$	$\times 10^6$ t,	$\%TiO_2$	$\times 10^6$ t,	$\%P_2O_5$	$\times 10^6$ t,	$\%RE_2O_3$
ARAXA	462	2.48			460	15.07	560	10.5
TAPIRA	165	1.76	325	16.3	991	9.04		
SALITRE I			84	23.3				
SALITRE II			92	13.0				

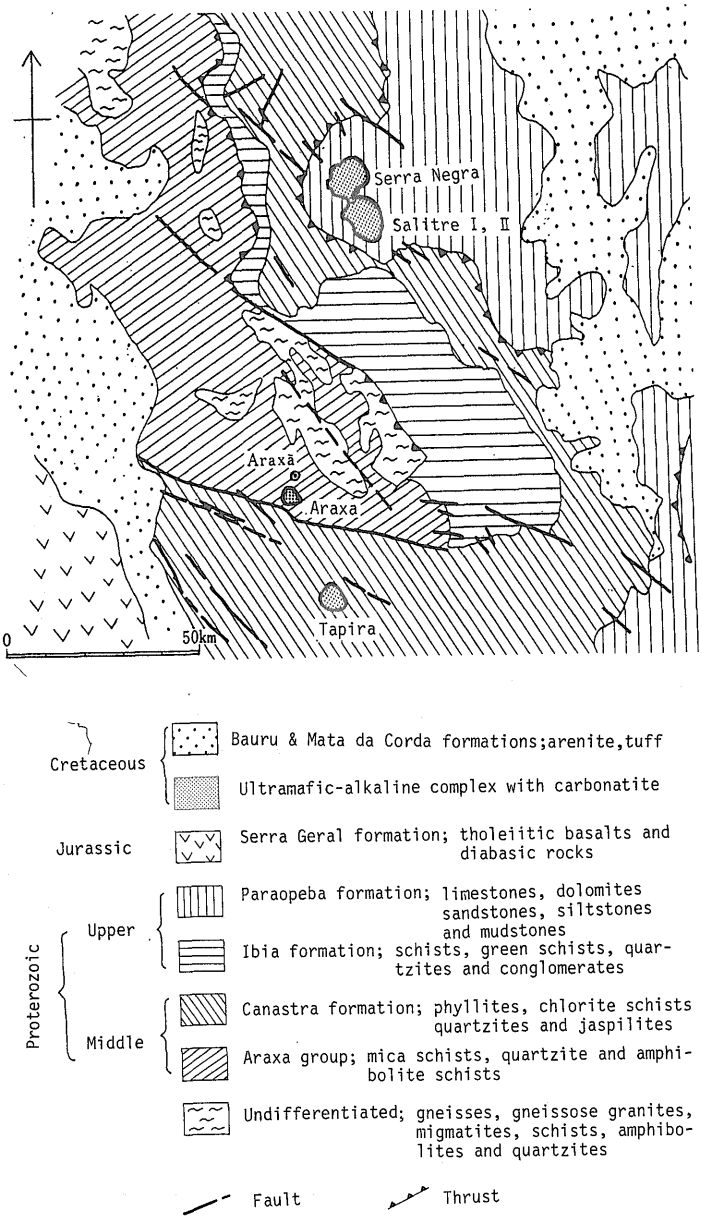

Fig. 2 Geologic map of Araxa area, Minas Gerais.

The Araxa mine area is underlein by Precambrian undifferentiated system and lower Proterozoic Araxa group. The former consisting of gneisses, gneissose granites, migmatites, quarzites, amphibolits and schists, is distributed as a basement in the northern to northeastern part of this area. The Araxa group comprising of mica schists, quartzites and amphibolites is widely distributed in the area and overlies unconformably the Precambrian undifferentiated system. Geologic structure of this group around the Barreiro carbonatite complex has been deformed by the intrusion of the complex and then the surrounding quartzite and mica schist

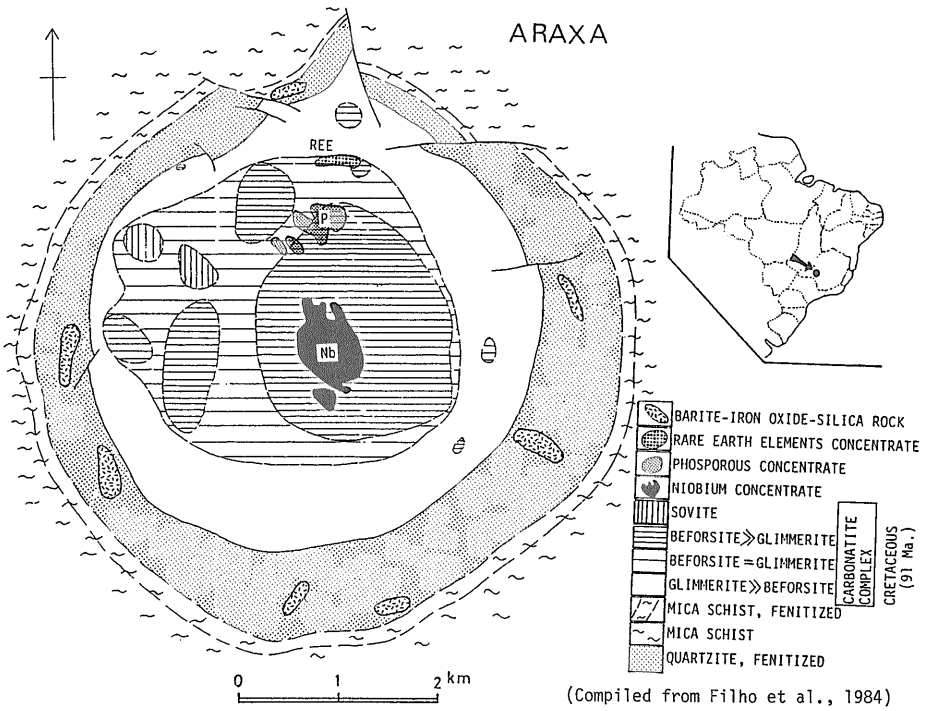

Fig. 3 Geologic map of Barreiro (Araxa) carbonatite complex. Nb, P and REE ore deposits developed in the weathered mantle are projected in the map.

beds were turned up along the wall of the intrusive body. A ring-like structure around the complex is clearly recognizable (Fig. 3).

The Barreiro carbonatite shows a concentric zonation; carbonatites concentrate in the core zone and glimmerite in the outer zone. The core zone of the complex consists mainly of beforsite, phoscolite, glimmerite and sövite. Fenitization which is resulted from alkali metasomatism of the intrusive body is observable as a circular halo in the wall rock as seen in Fig. 3.

Glimmerite of which main constituent minerals are phlogopite and dolomite might be an alteration product (GITTINS *et al.*, 1975) from ultramafic rocks formed by a kind of alkali metasomatism due to carbonatite magma intrusion. Small amount of magnetite and apatite are contained within the glimmerite but pyrochlore is very little. Clinopyroxene is reported from some deep drilling cores as relicts replaced by phlogopite. No olivine has been obseved but serpentinite occurs as a relict in some drillling cores (FILHO *et al.*, 1984).

Beforsite which is dolomitic carbonatite contains mainly dolomite and with variable amount of calcite and ankerite. Apatite, pyrochlore, phlogopite and alkali-amphiboles are associated within the rock. According to FILHO *et al.* (1984), phoscolite-like rocks are recognizable in the beforsite zones within the core of the complex as brecciated masses containing apatite, phlogopite, magnetite and pyrochlore, but olivine and pyroxene minerals seen in Phalaborwa and Sokli carbonatite complexes (Palabora Mining Company, 1976; VARTIAINEN and PAARMA, 1979) are not observed. In the Barreiro complex the phoscolite associated with pyrochlore is always cut by carbonatite veins.

Sövite corresponding to calcite carbonatite is observed in the outer zone of the complex. This rock contains a little amount of apatite, pyrite and pyrrhotite, and is often intruded into the fenitized wall rock as small dykes and veins.

In the case of the Barreiro complex, detailed

occurrence and relationship between the rocks in each stage of the carbonatite magmatism have not been clear because of perfect decomposition of the complex by the chemical weathering. In general, fractional crystallization process of carbonatite magma yields sövite, alvikite and beforsite from early to late stage (LEBAS, 1981).

As stated above, the crystallization sequence of the Barreiro complex itself might be estimated as follows; calcite carbonatite and phoscorite, beforsite, and then ankeritic carbonatites.

2.3 Ore minerals

Main niobium minerals of the Barreiro carbonatite complex are pyrochlore and bariopyrochlore. The former occurs mainly in the inner core zone consisting of beforsite, and phoscorite. The latter mineral, on the other hand, is thought to be formed in the lateritized mantle of the complex. Although soil samples from the lateritized mantle were collected from the open pit, no fresh carbonatite was obtained from the surface by one of the authors (M.K.). Therefore detailed description on the occurrence and character of the original ore minerals can not be described here.

As seen in Table 2, the main constituent minerals of the lateritized mantle are barite, goethite, hematite, magnetite, anatase, apatite, bariopyrochlore, gibbsite, alunite and kaolinite in order of abundance. A small amount of silica mineral is observed in some part of the mantle. Calcite, dolomite, ankerite and phlogopite which are the main constituent minerals of the fresh carbonatitic rocks were not observed in the weathered mantle. Monazite, magnetite and zircon/baddeleyite are observable as minor constituent minerals in both the carbonatite and lateritized mantle, since these minerals have a resistance to the chemical weathering.

Table 2 Minerals in Araxa niobium ore deposit

Profile	Depth	Mineral Composition
Reddish laterite (overburden)	0–20 m	goethite, hematite, magnetite, anatase, gibbsite, vermicurite, alunite, kaolinite, silica minerals
Laterite (ore body)	20–100 m	goethite, hematite, magnetite, barite, apatite, anatase, bariopyrochlore
Beforsite & phoscolite Original rock (carbonatite)	>100 m	dolomite, calcite, ankerite, magnetite, apatite, perowskite, phlogopite, pyrite, pyrrhotite, pyrochlore

3. Migration of chemical composition and secondary enrichment in the niobium ore deposit

Lateritic weathering mantle have been distinctly developed in the whole area of the Brazil. Araxa and its surrounding are also subjected to the strong lateritization and then no hard fresh rock is seen in and around the mine area except for river terraces. The thickness of the weathered mantle is estimated about 100 meters in average based on the result of many exploration drillings by CBMM (GROSSI and TORRES, 1978). In some part within the Barreiro complex, the weathered mantle is over 200 meters in thickness (FILHO *et al.*, 1984).

It is well known phenomenon that laterite-type of nickel and aluminum deposits in the tropical areas are formed by secondary enrichment of strong chemical weathering. Some high-grade of ore deposits containing niobium, titanium and phosphorus have been also considered as a result of the chemical weathering for the enrichment.

The Araxa niobium deposit in the Barreiro complex is famous for the highest-grade and the biggest ore reserves in the world (PERRAULT and MANKER, 1981; BERBERT, 1984). The lateritization is considered to have played an important role for the secondary enrichment on niobium and others.

SILVA *et al.* (1979) reported a chemical composition of the representative carbonatite from the beforsite zone, which is given in Table 3. Five lateritic soil samples from the niobium-bearing ore horizon and two reddish lateritic soil samples from the overburden were collected by one of the authors and chemically analysed. Average chemical compositions of each lateritic horizon are presented in Table 3.

It is clear that MgO, CaO, CO_2 comprising dolomite and calcite which are the main consti-

Table 3 Chemical compositions of lateritized mantle and carbonatite in Araxa niobium deposit

	Carbonatite[1] Beforsite & Phoscolite	Laterite[2] (Ore body)	Reddish[3] laterite (overburden)
SiO_2	1.40%	2.50%	16.55%
Al_2O_3	1.80	1.23	29.97
Fe_2O_3	8.14	40.70	32.52
FeO	17.60	—	—
MnO	1.08	0.79	0.11
MgO	14.50	0.27	0.04
CaO	9.20	0.49	0.62
Na_2O	0.14	0.30	0.31
K_2O	0.42	0.14	0.18
P_2O_5	0.69	1.98	1.95
BaO	1.95	26.74**	0.76
SrO	0.59	0.31	0.26
TiO_2	2.30	2.59	3.72
ZrO_2	0.02	0.14	0.16
Nb_2O_5	0.72	3.00*	0.40*
H_2O^+	3.57	3.33	10.04
H_2O^-		0.28	0.96
CO_2	33.00	1.71	1.04
SO_3	1.95	13.50**	0.34**
Others	0.66		
total	99.73	100.00	100.00

1) SILVA *et al.*, 1989.
2) Average of 2 samples from −10 and −20 m levels.
3) Average of 5 samples from −30 and −40 m, and three from −50 m levels.
* Estimated value; ** Estimated value as $BaSO_4$.

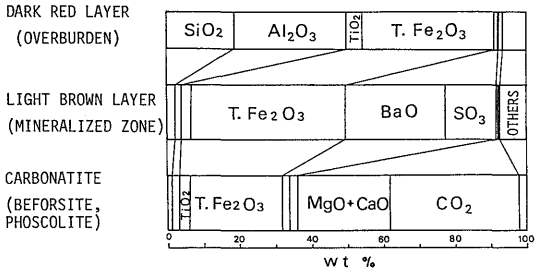

Fig. 4 Vertical change of chemical compositions due to lateritic weathering in Araxa niobium depost. Data from Table 3.

tuent minerals of the carbonaite, have been leached out from the weathered mantle and that magnetite components have been completely oxidized. The original volume of the carbonatite must have been remarkably decreased owing to the loss of MgO, CaO and CO_2 from the mantle (Fig. 4). Silicates and some oxides would have been remained in the mantle as secondary minerals although these were once decompoded perfectly by the weathering. That is, a primary mineral assemblage of magnetite, phlogopite, barite, apatite and pyrochlore were converted to goethite, hematite, gibbsite, barite, anatase, bariopyrochlore, quartz and amorphous silica mineral (Table 2).

A distinct volume depletion contributes to the grade-up of Nb_2O_5 content in the lateritized mantle. This is one of the reasons for the secondary enrichment of the ore deposit. In the case of the Araxa ore deposit, the primary ore grade (0.72% Nb_2O_5, SILVA *et al.*, 1979) in the fresh ore body has increased into 2.48 percent Nb_2O_5 in lateritized mantle (Annex 2 of RODRIGUES and LIMA, 1984). In some part of the present open pit, an ore horizon contains more than 3.0 percent Nb_2O_5 (personal communication from Mr. Souza, Geology Department, CBMM). SiO_2, Al_2O_3 and BaO contained in phlogopite and barite are perfectly removed and then some of them are enriched into the mantle. SiO_2, Al_2O_3 and BaO became approximately 6 to 9 times in weight per cent in the mantle. The original rock volume during the lateritization is estimated to become about 15 percent.

In general, zircon and baddeleyite are the most resistant minerals against the lateritization. Zirconium oxide content of the mantle increases into about 8.0 times compared with that of the fresh carbonatite. Hence, decreasing of the original rock volume is assumed to be more than 87.5 percent. Zirconium mineral is therefore considered as one of the indicative minerals to reveal a degree of the secondary enrichment during the lateritization.

REEDMAN (1984) assessed the secondary enrichment on the case of Sukulu carbonatite complex which was covered by thick residual soil containing pyrochlore, apatite and baddeleyite. He points out that pyrochlore and zirconium oxide in the soil were concentrated about 5 times to that of the fresh rock.

According to Table 4, the concentration ratios of Al_2O_3, BaO and ZrO_2 are essentially the same in each other and are 8 times. Total Fe_2O_3,

Table 4 Chemical variation under lateritization in Araxa niobium deposit. A, B, and C are calculated as dealkaline and anhydrous basis from the data in Table 3

	Carbonatite (beforsite & phoscolite) C	Laterite (orebody) B	Reddish laterite (overburden) A	Whole laterite (W) $0.6\times B+0.4\times C=W$ W	Concentration ratio W/C
SiO_2	1.5	2.7	19	9.2	6.1
Al_2O_3	1.9	1.3	35	15	7.9
$T.Fe_2O_3$	29	44	37	41	1.4
MnO	1.1	0.84	0.13	0.56	0.51
MgO	15	0.29	0.05	0.19	0.01
CaO	9.6	0.52	0.71	0.60	0.06
P_2O_5	0.72	2.1	2.2	2.1	2.9
BaO	2.0	28	0.87	17	8.5
TiO_2	2.4	2.8	4.3	3.4	1.4
ZrO_2	0.02	0.15	0.18	0.16	8.0
Nb_2O_5	0.75	3.2	0.46	2.1	2.8
CO_2	34	—	—	—	—
SO_3	2.0	14	0.39	8.6	4.3
Total	100	100	100	100	—

P_2O_5, TiO_2 and Nb_2O_5 vary from 1.4 to 2.9 times. Some of these components may have been transported to the outside of the system by the ground water, because the minerals of the primary rocks have been mostly decomposed and some of them changed into secondary minerals such as goethite, hematite, apatite, anatase, bariopyrochlore, gibbsite, kaolinite and amorphous silica.

4. Concluding remarks

The Barreiro carbonatite complex is a cylindrical mass with about 5 kilometers in diameter standing in the Proterozoic Araxa group. The complex consisting of beforsite, phoscolite, glimmerite, sövite and fenite intruded into the Proterozoic Araxa group during Cretaceous time which is shown by K–Ar phlogopite age of 80–83 Ma (HASUI and CORDANI, 1968). During the Cenozoic era the complex was strongly weathered and the top portion was converted to thick lateritized mantle with 100 meters thick. Main mineral resources of phosphorus, rare-earth, titanium and niobium originally contained in the complex were remarkably enriched within the lateritized mantle. Pyrochlore as a niobium mineral, for example, is contained mainly in the phoscolite of the beforsite zone. The Nb_2O_5 content of the fresh rock has been estimated approximately 0.8 percent based on the CBMM's exploration drillings. Niobium-bearing zone continues about 900 meters beneath the present surface. In the lateritized mantle, on the other hand, niobium mineral is bariopyrochlore which is niobium-bearing bario-hydroxide. Nb_2O_5 grade in the mantle with about 100 meters thick is about 2.1 percent in average. Therefore, it is concluded that the strong lateritization played a major role for the niobium concentration in the Araxa deposit.

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アラシャカーボナタイト鉱床とラテライト化作用

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要　旨

アラシャニオブ鉱床(ブラジル国ミナスジェライス州)の風化土壌の鉱物組成と化学組成を予察的に調べ以下の結果を得た．風化殻は，Al, Fe, Si の濃集する赤色ラテライト層とその下位に発達する Ba, Nb, P の濃集するラテライト層に区分され，それぞれに特徴的な風化生成鉱物が形成されている．ニオブ鉱床形成の主因は，ラテライト化作用により，ニオブが特定の風化土壌層に効果的に濃集したためと解釈された．

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