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Mineral species of alkaline-carbonatite complexes in Brazil

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Abstract Mineral species in alkaline-carbonatite complexes and pegmatites which are observed in the Brazilian shield in the region of the states of Santa Catarina (SC), São Paulo (SP), Minas Gerais (MG), Goiás (GO), Tocantins (TO) and Pará (PA) are identified based upon the data obtained by means of X-ray diffraction (XRD) and energy dispersive scanning electron microscopy (SEM-EDS). The rock and mineral samples are those which were collected in the years of 1987–1990 by support of the International Scientific Research Program of the Ministry of Education (Project Chief: Professor M. Tokonami, University of Tokyo) and they are now preserved in the National Museum of Nature and Science (Tsukuba). The listed minerals include mainly carbonates, sulphates, phosphates, oxides and silicates containing rare-metals such as rare-earth elements.
Key words: Brazil, alkaline rock, carbonatite, pegmatite, rare-earth mineral, weathering

Introduction

Many localities of carbonatite intrusions related to alkaline rocks are reported in Brazil. Most of them are due to igneous activities of the Mesozoic age. Brazilian carbonatites contain resources such as ores of Nb, Ti, rare earth elements (REEs) and phosphate rock. Their deposits are ordinarily found in thick, weathered, and layered soil. There are many reports on the Brazilian and world-wide alkaline-carbonatite complexes (e.g. Berbert, 1984; ITIT Projects No. 8316, 1987; Martin, 2008).

Despite the economic importance of these bodies, the origin of these carbonatites is still controversial although it has been widely investigated. The studies on paragenesis of igneous rock types associated with carbonatites from the worldwide localities have been reported (Woolley and Kjarsgaard, 2008). Ruberit *et al.* (2008) studied the mineralogical and chemical behaviors of REEs in carbonatites from southern Brazil with many related references.

Mineralogical and petrologic surveys of alkaline-carbonatite complexes related to this report were performed in the years of 1987–1990 by the support of the International Scientific Research Program of the Ministry of Education (Project Chief: Professor M. Tokonami, University of Tokyo) and by collaborating on this project with Professor Kenkichi Fujimori of the Instituto de Astronômico e Geofísico, Universidade de São Paulo, Brazil. The surveys were classified by two interest groups: the first was the survey of the samples associated with radioactive minerals, and the second was that of rock and mineral samples related to alkaline-carbonatite complexes with rare-earth minerals. The collected samples by the first group were provided to the Geological Museum, National Institute of Advanced

Industrial Science and Technology (AIST), and the second ones, to the Department of Geology and Paleontology, National Museum of Nature and Science (NMNS).

In this paper, main constituent minerals of the samples preserved in the NMNS are listed based on the results of powder X-ray diffraction (XRD) and energy dispersive scanning electron microscopy (SEM-EDS) as the useful data for detailed mineralogical studies in future. The XRD data were collected at NMNS using Rigaku-RINT2000 and SmartLab. The analyses of mineral assemblages were performed with aid of software QUALX2.0 (Altomare *et al.*, 2015). The names of mine companies and localities are those at that time when field surveys were performed in 1987–1990.

Geological background and collecting sites

Alkaline-carbonatite complexes in Brazil generally intrude into Precambrian rocks and they

Fig. 1. Main localities of alkaline and carbonatite intrusions in Brazil. The larger symbols show the points of investigations. Square symbols are not the points of alkaline and carbonatite intrusions but the places collected mineral samples at the area of Precambrian schist.

are mainly spotted along the lines from south to north as shown in Fig. 1. The ages of intrusive activities at the collecting sites except Peixe alkaline complex are approximately estimated in the range of 60–140 Ma. The minerals in those complexes are characterized to be rich in REEs, Nb, Ti, and P, *etc.*, and radioactive elements are often accompanied in these minerals. Weathering and/or alteration of the complexes are remarkable so that economically useful elements concentrate in the soil. Therefore, in the most of these areas are developed the mines to obtain resources such as K-P fertilizer and rare-metals including REEs. Furthermore, minerals formed by the combination of various elements and hydrothermal alterations are interested to know the diversity and the formation environment of them.

The investigations of rocks and minerals are classified into 11 areas, and these areas are also shown in Figure 1. The collected samples will be classified into 1) alkaline rocks, 2) carbonatites, 3) alkaline-carbonatite complexes, 4) ores from mines including phosphates, sulphate and oxides, 5) cores by drilling, 6) ultramafic rocks, 7) pegmatite and others. In addition, typical alkaline and alkaline-carbonatite rock samples were kindly provided by Professor Y. Hasui of the São Paulo University—Rio Claro.

Rock and mineral descriptions

The characteristics of collected samples are described in 11 areas, respectively.

1. Anitápolis (SC)

The area of the complex is oval with $4.0 \times 3.0\,km^2$. The complex is formed by the alkaline rock intrusion into the Precambrian granite. Rocks between the rim of the granite and intrusion are mainly composed of alkaline rocks with feldspathoid such as nepheline syenite. The K–Ar age of the complex is estimated as 129 Ma (CBMM Issue, 1984). Rock samples were collected at the mine of Indústria Fosftados Catarinense S.A. near to the north side of Anitápolis. The main resources are ores containing phosphor and potassium fertilizer, however, the mine was not in operation at the time when samples were collected. The cores by drilling were provided from the Mine Company. Anorthosite was collected at the quarry between Bocaiúva do Sul and Vitor near to Furnas. Other main collected samples are carbonatite and massive magnetite ore. Main mineral species composed of nepheline syenite, carbonatite and anorthosite in this area are indicated in Table 1.

2. Jacupiranga (SP)

Survey was performed at the Mines of Serrana S.A. de Mineração at Jacupiranga near to Cajati. The shape of intrusion is oval formed with the scale of $10.2 \times 6.6\,km^2$, the K–Ar age is estimated as 133 Ma (CBMM Issue, 1984). Early studies on the general structure and petrography of carbonatite in Jacupiranga were summarized

Table 1. Rocks and mineral constituents from Anitápolis (SC)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16365	891211-01	Carbonatite	Mine of the Indústria Fosfatados Catarinense S.A. and its vicinities	Calcite, Magnetite
16366	891211-02	Nepheline syenite	ditto	Aegirine, Zircon, Titanite, Nepheline, K-feldspar, Albite, Aegirine-augite, Calciohilairite, Apatite
16367	891211-03	Magnetite rock	ditto	Magnetite
16368	891211-04	Carbonatite (Dorilling cores)	ditto	Calcite, Phlogopite, Dolomite, Bastnäsite-(Ce), Ancylite-(Ce), Baddeleyite, Norsethite, Apatite, Baryte, Chlorite, Natrolite, Pyrrhotite
16369	891212-01	Anorthosite	ditto	Anorthite, Augite, Annite, Diopside, Annite, Hastingsite, Chevkinite-(Ce)

by Melcher (1966). Mining area is about 800 × 400 m^2. Main collected rock samples are carbonatite, jacupirangite and so on.

The mineral assemblage of carbonatites varies depending on its formation environment in the Mine, such as 1, calcite dominant; 2, dolomite dominant; 3, jacupirangite-xenolith and so on. The fenitization by carbonate magma shows a characteristic banded pattern at the contact zone between carbonate rock and pyroxene-rich jacupirangite of parent rock (Fig. 2). The boundary between the 1st and 2nd stages is called as fault zone. The P_2O_5 content of ore is enriched by weathering up to 20 wt.% at the part near to the surface. The main ore minerals of the Mine are magnetite, apatite, calcite, Ni-bearing minerals for the resources of Fe and Ni, fertilizer- and cement-materials. Main mineral species composed of carbonatite and jacupirangite in this area are indicated in Table 2. The typical carbonatites are shown in Fig. 3. Banded structure in Fig. 2 formed by fenitization shows the layers of carbonates, micas and amphiboles perpendicular to temperature gradient.

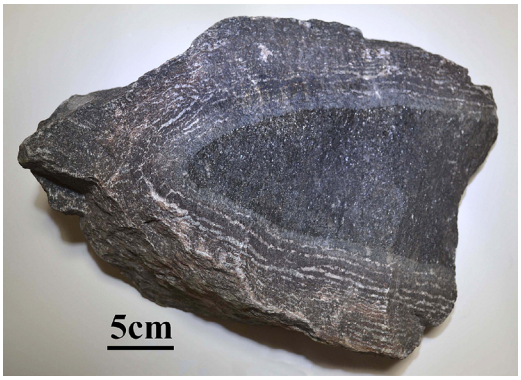


Fig. 2. Banded pattern composed from alteration of carbonates and amphibole. This texture is formed due to fenitization by the contact of carbonate magma and pyroxene-rich jacupirangite xenolith. Fibrous amphiboles grow along the temperature gradient. Mine of the Serrana S.A. de Mineração at Jacupiranga near to Cajati (SP).

3. Poços de Caldas Plateau (SP, MG)

Poços de Caldas Plateau is on the border of the

Table 2. Rocks and mineral constituents from Jacupiranga (SP)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16227	881006-01a	Carbonatite (Xenolith zone)	Mine of the Serrana S.A. de Mineração at Jacupiranga near to Cajati	Dolomite, Forsterite, Zirconolite, Calcite, Phlogopite, Magnetite, Apatite
16228	881006-01b	ditto	ditto	Dolomite, Calcite, Magnetite, Apatite, Augite
16229	881006-01c	ditto	ditto	Dolomite, Magnetite, Phlogopite
16230	881006-01d	Carbonatite (Banded structure)	ditto	Phlogopite, Magnetite, Richterite, Calcite, Zirconolite, Apatite, Chalcopyrite
16231	881006-01e	Jacupirangite (banded structure) (xenolith zone)	ditto	Phlogopite, Magnetite, Zirconolite, Diopside, Augite
16232	881006-02a	Carbonatite (fault zone)	ditto	Calcite, Apatite, Siderite, Ancylite-(Ce), Phlogopite, Dolomite, Magnetite
16233	881006-02b	ditto	ditto	Chlorite, Baddeleyite, Tetraferriphlogopite, Calcite, Dolomite, Zirconolite, Apatite, Geikielite
16234	881006-02c	ditto	ditto	Magnetite, Calcite, Dolomite, Apatite, Phlogopite
16235	881006-02d	ditto	ditto	Magnetite, Forsterite, Calcite, Dolomite, Apatite
16236	881006-02e	ditto	ditto	Calcite, Dolomite, Forsterite, Clinohumite, Pyrochlore, Apatite, Baryte, Pyrrhotite
16237	881006-02f	ditto	ditto	Phlogopite, Pyrochlore, Baddeleyite, Forsterite, Clinohumite, Calcite, Dolomite, Pyrochlore

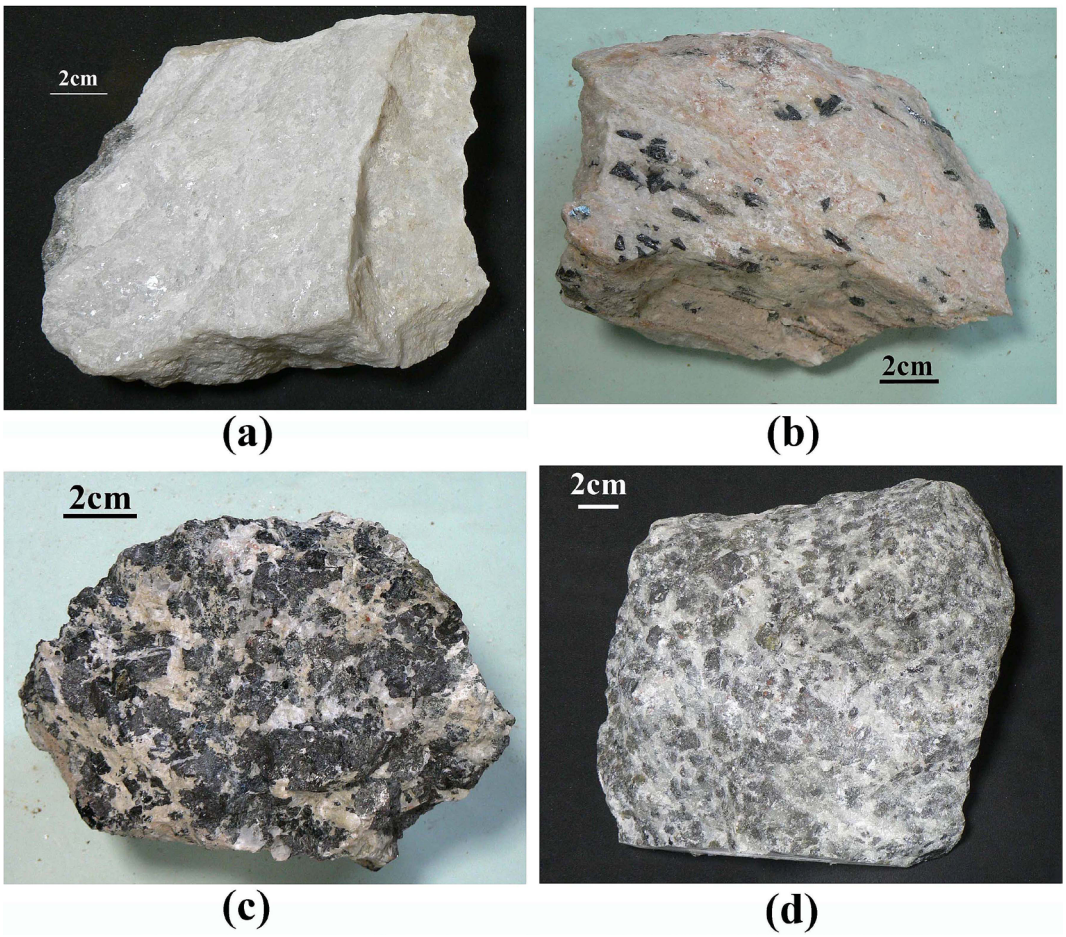


Fig. 3. Various carbonatites. Samples obtained at the Mines of Serrana S.A. de Mineração at Jacupiranga (SP). All of them contain calcite, dolomite and apatite as main constituents of rocks. Remarks are, (a) apatite is dominant, (b) some of magnetite, ilmenite are observed, (c) magnetite is dominant, and (d) olivine is included.

States of São Paulo (SP) and Minas Gerais (MG). The Plateau is formed by a circular intrusion approximately 1,000 km^2 in area and it is mostly composed of alkaline rocks. Uraniferous deposits and zirconium-rich rocks called as "caldasite" are also remarkable in the intrusions. Intrusive activities are complicated, and on the ages of the activities, Barretto and Fujimori (1986) reported as follows: the K–Ar age dating of the Plateau rocks (Bushee, 1971; Fujimori, 1983) indicates the magmatic chronology: ankaratrites and associated pyroclastics 87 Myr. B.P.; tinguaitic intrusions 80–75 Myr. B.P.; nepheline syenite including lujavrites 63–60 Ma and phonolite dykes 54 Myr. B.P.

Main collected rock samples are altered alkaline rocks, weathered surface soil, massive magnetite, phonolite, tinguaite, caldasite and lujavrite. At the Morro de Ferro alkaline rocks are generally suffered from weathering, and massive magnetite ore is considered to be magmatic origin. The magnetite ore is composed of mostly magnetite and minor hematite, and includes white to gray phenocrysts considered to be pseudoleucite. Caldasite covered by weathered soil from Pouso Allegre (Fig. 4a) is a unique rock mostly composed of baddeleyite and zircon. They show a typical colloform texture formed by colloidal precipitation (Fig. 4b). Some minerals in this rock suffer from structural damages due to

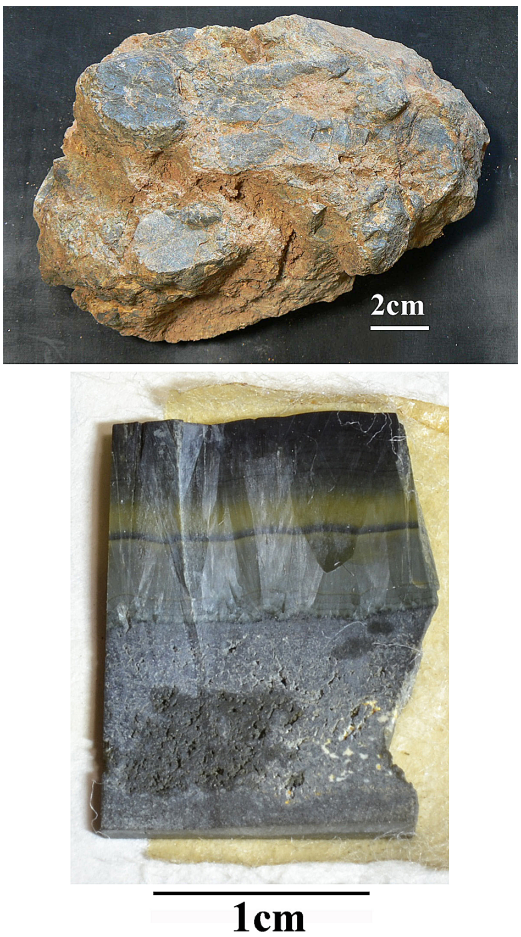


Fig. 4. (a) Caldasite with 16 cm in width. Pouso Allegre, Poços de Caldas (MG). (b) Sliced caldasite showing colloform texture.

metamictization. Lujavrite from Pedra Balão is distinctive of large eudialyte phenocrysts. Phonolite is dense and hard rock and is one of typical rocks in this area. Samples were collected at three point, Pocinhos, Dona Rita and Serrote of the Plateau. The mineral compositions are not so much different among their samples. The Zr content is a little higher in phonolite from Pocinhos than those from the other points. Table 3 indicates the main constituent mineral species of altered alkaline rock, surface soil and magnetite ore from Morro de Ferro, phonolite from Pocinhos, Dona Rita and Serrote, tinguaite from Pocinhos, caldasite from Pouso Allegre and Serrote, and lujavrite from Pedra Balão.

4. Tapira (MG)

The intrusion is oval with the scale of $7.0 \times 6.0\,km^2$ and the K–Ar age is estimated to 70 Ma (CBMM Issue, 1984). Country rocks are mainly quartzite and schist of upper Precambrian. The intrusive rocks are mainly composed of carbonatites and pyroxenites. Fenitization by the contact of carbonate magma and pyroxenite is characteristic. The main resources are ores containing titanium, phosphor and niobium. The rock samples were collected at the mines of the Compania Vale do Rio Doce (CVRD). Main collected samples are carbonatites, alkaline-carbonatite complexes, massive magnetite, agglomerates of apatite, anatase and perovskite, and separated ore minerals.

Most of alkaline-carbonatite complexes in the mine are hydrothermally altered and/or suffering from weathering, resulting in the concentration of P, Ti, rare-metal elements including REEs in various minerals, so that this improves the ore qualities. On the other hand, fresh carbonatite and alkaline-carbonatite complexes were obtained at the point near to the bottom of the mine. Euhedral perovskite crystals, which are mostly unaltered, are also found as mass with apatite (Fig. 5). Thin section of perovskite shows a fine twinning texture as shown in Fig. 6a. These twinning scheme was analyzed by means of micro-area single crystal XRD technique (Horiuchi and Tanaka, 1992), so that the orientation relationship among twinning domains are common *c*-axes of orthorhombic symmetry in each domain and mirror symmetries of (110) or $(1\bar{1}0)$ against the each neighboring domain (Fig. 6b). This twinning scheme is similar to those of dielectric materials such as $BaTiO_3$, so it will be concluded that twinning textures occurred by phase transformation at the temperature decrease. Single crystals of perovskite contain many other minerals such as apatite, pyroxene, mica, *etc*. as inclusion.

Main mineral species composed of titanium ore, carbonatite, altered rock of at the contact of pyroxenite and carbonatite, phonolite, magnetite ore and phosphorus ore, and also separated min-

Table 3. Rocks and mineral constituents from Poços de Caldas Plateau (SP, MG)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16102	871010-01	Hydrothermally sericitized altered alkaline rock	Morro de Ferro, MG	Rhabdophane-(Ce), Brockite, K-feldspar, Albite, Diopside, Zircon, Muscovite, Apatite, Magnetite, Hematite, Goethite, Rutile
16103	871010-02	Surface soil	ditto	Gibbsite, Cryptomelane, Goethite
16104	871010-03	Massive magnetite	ditto	Magnetite, Hematite, Eudialyte, Muscovite
16226	871019-13	Massive magnetite	Morro de Ferro, MG	Magnetite, Hematite, Anatase, Muscovite, Andradite, Pyrolusite, Kaolinite, Chlorite, Baddeleyite, Hollandite
16105	871010-05	Phonolite	Pocinhos, MG	Diopside, Mosandrite-(Ce), K-feldspar, Albite, Nepheline, Muscovite, Aegirine, Augite, Aegirine-augite, Titanite, Chamosite, Baddeleyite, Ilmenite, Pyrophanite, Bastnäsite-(Ce), REE-rich burbankite, Calcite, Strontianite, Pyrite, Sphalerite, Galena, Analcime
16106	871010-06	Tinguite	ditto	Diopside, Aegirine, Monazite-(Ce), K-feldspar, Albite, Muscovite, Aegirin-augite, Edenite, Zircon, Baryte, Apatite, Magnetite, Bastnäsite-(Ce), Dolomite, Strontianite, Galena
16107	871010-07	Phonolite	Dona Rita, MG	Diopsite, Aegirine, Cerite-(Ce), Augite, Aegirine-augite, Titanite, Mosandrite-(Ce), Pyrophanite, Magnetite, Sphalerite, Galena, K-feldspar, Nepheline, Sodalite, Analcime
16108	871010-08	Caldasite	Pouso Allegre, MG	Zircon, Anatase, Bastnäsite-(Ce), Baddeleyite, Rutile, Siderite, Rhodochrosite, Goethite, Hollandite, Samarskite-(Y), Uraninite, Florencite, Crandallite, Analcime
16109	871010-09A	ditto	ditto	Baddeleyite, Zircon
16110	871010-09B	ditto	ditto	ditto
16111	871010-09C	ditto	ditto	ditto
16112	871010-09D	ditto	ditto	ditto
16113	871010-09E	ditto	ditto	ditto
16114	871010-09F	ditto	ditto	ditto
16115	871010-09G	ditto	ditto	ditto
16116	871010-09H	ditto	ditto	Baddeleyite, Zircon, Anatase, Magnetite, Hematite, Chromite, Goethite
16117	871010-09I	ditto	ditto	Baddeleyite, Zircon
16118	871010-09J	ditto	ditto	ditto
16119	871010-09K	ditto	ditto	Baddeleyite, Zircon, Muscovite, Anatase, Gibbsite
16120	871010-09L	ditto	ditto	Baddeleyite, Zircon
16121	871010-09M	ditto	ditto	ditto
16122	871010-09N	ditto	ditto	Baddeleyite, Zircon, Magnetite
16123	871011-01	Phonolite	Serrote, SP	Aegirine, Lamprophyllite, Låvenite, K-feldspar, Nepheline, Monticellite, Calcite, Potassic-magnesio-arfvedsonite, Perovskite, Sr-bearing apatite, Ilmenite, Pyrite, Galena, Sodalite, Analcime, Sphalerite
16124	871011-02	ditto	ditto	ditto
16125	871011-03	Caldasite	ditto	Zircon, Uraninite, Baddeleyite
16126	871011-04	Phonolite	ditto	Aegirine-augite, Mosandrite-(Ce), K-feldspar, Albite, Nepheline, Analcime Pottassic-magnesio-arfvedsonite, Titanite, Pectolite, Rinkite, Götzenite, Apatite, Pyrophanite, Loparite-(Ce), K-feldspar
16127	871011-04a	ditto	ditto	Aegirine-augite, Nepheline, Mosandrite-(Ce), Fluorlamprophyllite-Lamprophyllite, Manganokhomyakovite, Stronadelphite, Bastnäsite-(Ce), Bastnäsite-(La), K-feldspar
16128	871011-04b~04g	ditto	ditto	Aegirine, Potassic-magnesio-arfvedsonite, Titanite, Cerite-(Ce), Götzenite, Fluorlamprophyllite, Lamprophyllite, Stronadelphite, Apatite, Bastnäsite-(Ce), Bastnäsite-(La), K-feldspar, Nepheline, Sodalite, Analcime
16129	871011-05a~05g	Lujarvrite	Pedra Balão, MG	Eudialyte, Lamprophyllite, K-feldspar, Nepheline, Natrolite, Leucite, Muscovite
16130	871011-05h	ditto	ditto	Aegirine-augite, Bastnäsite-(La), Pectolite, Lamprophyllite, Rhodochrosite, Strontianite, Nepheline

Fig. 5. Euhedral perovskite associated with apatite from the Mines of the Compania Vale do Rio Doce (CVRD), Tapira (MG).

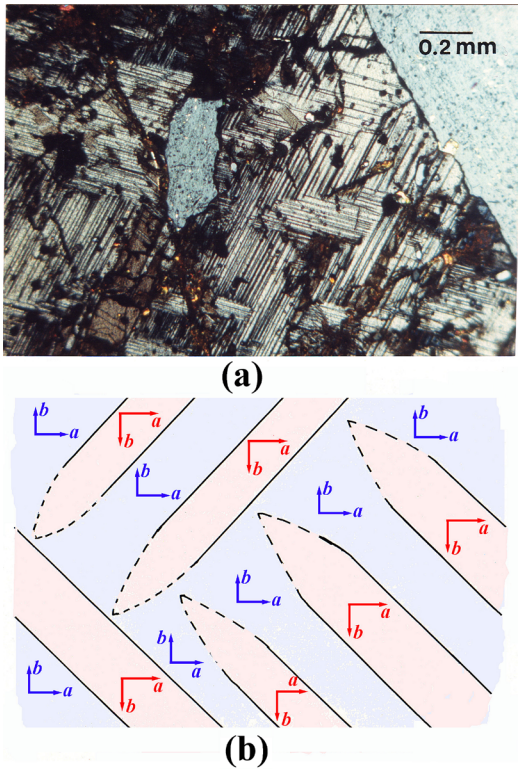


Fig. 6. Photomicrograph of twinning texture of perovskite. Crossed polars.

erals are indicated in Table 4. The titanium ore of the mine is mainly anatase containing minor magnetite, ilmenite and zircon. Agglomerates of anatase (Fig. 7) are actually pseudomorph after perovskite. This is interesting to know about the hydrothermal alteration process to concentrate anatase in the ore. In the altered alkaline-carbonatite complexes, only substantial minerals against alteration or weathering such as titanite, anatase, apatite, baryte, baddeleyite and zircon are finally remaining in the weathered soil. Partially separated ore samples such as pyrochlore, apatite, anatase, perovskite and magnetite are provided from the mine.

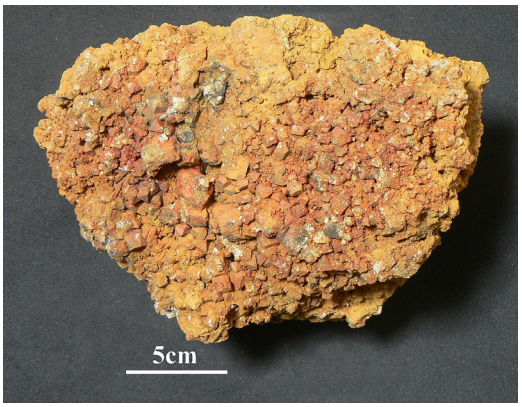


Fig. 7. Aggregate of anatase pseudomorph after perovskite. Partially perovskite remains. CVRD, Tapira (MG).

5. Araxá (MG)

This area is one of the most typical places of the occurrence of alkaline-carbonatite complexes in Brazil and is called as the Barreiro Complex. The shape of intrusion in plane is approximately circular with diameter around 4.5 km. The K–Ar age is estimated as 91 Ma (CBMM Issue, 1984). Weathering of alkaline-carbonatite complexes up to about 100 m in depth is remarkable and weath-

Table 4. Rocks and mineral constituents from Tapira (MG)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16165	871016-01A	Titanium ore	Mine of Compania Vale do Rio Doce	Zircon, Magnetite, Baryte, Anatase, Ilmenite
16166	871016-01B	ditto	ditto	ditto
16167	871016-02A	Carbonatite	ditto	Diopside, Dolomite, Baryte, Calcite, Magnetite, Perovskite, Ilmenite, Apatite, Lucasite-(Ce)
16168	871016-02B	ditto	ditto	ditto
16169	871016-02C	ditto	ditto	Diopside, Dolomite, Baryte, Calcite, Magnetite, Perovskite
16170	871016-02D	ditto	ditto	ditto
16171	871016-03A	Altered rock of pyroxenite- carbonatite contact	ditto	Perovskite, Anatase, Apatite, Titanite
16172	871016-03B	ditto	ditto	ditto
16173	871016-03C	ditto	ditto	Perovskite, Anatase, Apatite, Titanite, Quartz, Magnetite, Vermiculite, Serpentine mineral
16174	871016-03D	ditto	ditto	Perovskite, Anatase, Apatite, Titanite
16175	871016-03E	ditto	ditto	ditto
16176	871016-03F	ditto	ditto	ditto
16177	871016-03G	ditto	ditto	ditto
16178	871016-03H	ditto	ditto	ditto
16179	871016-03I	ditto	ditto	Baryte, Apatite, Chlorite, Zircon, Perovskite, Vermiculite
16180	871016-03J	Separated specimens	ditto	Perovskite, Phlogopite
16181	871016-04	Phosphorus and titanium ore	ditto	Anatase, Perovskite, Vermiculite, Crandallite
16182	871016-05	ditto	ditto	Magnetite
16183	871016-06	Pyrochlore	ditto	Fluorcalciopyrochlore
16184	871016-07		ditto	Baryte
16185	871016-08	Separated specimen	ditto	Apatite, Anatase
16186	871016-09	Magnetite ore	ditto	Magnetite, Phlogopite, Perovskite, Anatase, Rhabdophane-(Ce), Calzirtite, Geikielite
16187	871016-10A	Pseudomorph after perovskite	ditto	Perovskite, Anatase
16188	871016-10B	Magnetite ore	ditto	Magnetite,Gypsum
16189	871016-10B2	ditto	ditto	Magnetite, Perovskite, Calzirtite, Anatase, Apatite
16190	871016-11Aa	Alkaline-carbonatite complex	ditto	Dolomite, Magnetite
16191	871016-11Ab	ditto	ditto	Baryte, Dolomite, Zirconolite, Anatase, Phlogopite, Nb-bearing calzirtite, Baddeleyite, Calcioburbankite, Ankerite, Strontianite, Pyrite
16192	871016-11Ac	ditto	ditto	ditto
16193	871016-11Ad	ditto	ditto	Dolomite, Magnetite
16194	871016-11Ae	ditto	ditto	Dolomite, Phlogopite, Magnetite
16195	871016-11Af	ditto	ditto	Dolomite, Magnetite
16196	871016-11Ag	ditto	ditto	Baryte, Apatite, Hollandite
16197	871016-11Ah	ditto	ditto	ditto
16198	871016-11Ba	Separated specimen	ditto	Magnetite
16199	871016-11Bb	ditto	ditto	Magnetite, Monazite-(Ce), Rhabdophane-(La), Florencite-(Ce), Anatase, Ilmenite, Lucasite-(Ce)
16200	871016-11Bc	Concentrated anatase (CVRD)	ditto	Anatase
16201	871016-11Bd		ditto	Magnetite
16238	881012-01	Magnetite ore	ditto	Magnetite, Anatase, Ilmenite, Zirconolite, Calzirtite, Pyrochlore
16239	881012-02	ditto	ditto	Magnetite
16240	881012-03	Separated specimen	ditto	Apatite
16241	881012-04	Phosphorus ore	ditto	Apatite, Magnetite, Anatase
16242	881012-05	Magnetite ore	ditto	Magnetite
16243	881012-06	Separated specimen	ditto	Perovskite, Magnetite, Anatase, Apatite
16244	881012-07	Pseudomorph after Perovskite	ditto	Anatase, Rhabdophane, Crandallite
16245	881012-08	Altered alkaline rock	ditto	Zircon, Phlogopite, Ilmenite, Apatite, Magnetite, Quartz, K-feldspar
16246	881012-09 ～-09c	Alkaline-carbonatite complex	ditto	Phlogopite, Apatite, Calcite, Augite
16247	881012-09d	Ditto	ditto	Perovskite, Magnetite, Diopside, Titanite, Chlorite, Calzirtite, Quartz
16248	881012-10a	Altered carbonatite	ditto	Diopside, Titanite, Chlorite, Dolomite, Perovskite, Apatite, Magnetite, Quartz
16249	881012-10b	ditto	ditto	Aegirine, Annite, Witherite, Loparite-(Ce)
16250	881012-10c	ditto	ditto	Calcite, Annite, Aegirine, Ferri-richterite～Arfvedsonite, Rhabdophan-(Ce), Chlorite, Hilairite, Kostylevite, Hydroxylbastnäsite-(Ce), Witherite, Baddeleyite, Loparite-(Ce), Hollandite, Perovskite, Rutile, Apatite, Dolomite, Vermiculite
16251	881012-10d	ditto	ditto	Aegirine, Potassic-magnesio-arfvedsonite, Titanite, Cerite-(Ce), Götzenite
16252	881012-10e	ditto	ditto	Fluorlamprophyllite, Lamprophyllite, Stronadelphite, Apatite, Bastnäsite-(Ce)
16253	881012-10f	ditto	ditto	Bastnäsite-(La), K-feldspar, Nepheline, Sodalite, Analcime
16302	881019-01	Phonolite	ditto	Aegirine-augite, Potassic-magnesio-arfvedsonite, Augite, Titanite, Pectolite, Lamprophyllite, Manganoeudialyte, Apatite, Sr-bearing apatite, K-feldspar, Albite, Nepheline, Analcime, Natrolite

Table 5. Rocks and mineral constituents from Araxá (MG)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16202	871016-12	Baryte (-Magnetite) rock	Mine of Arafertil S.A.	Baryte, Calcite
16203	871016-12b	ditto	ditto	Baryte, Calcite, Apatite, Albite, Pyrochlore, Zircon, Goethite
16204	871016-13	ditto	ditto	Baryte
16205	871016-14-1	Altered carbonatite	ditto	Calcite, Dolomite, Magnesite, Apatite, Vermiculite
16206	871016-14-2	ditto	ditto	Calcite, Dolomite, Apatite, Anatase, Perovskite, Vermiculite
16207	871016-15	Weathered carbonatite	ditto	Quartz, Goethite
16210	871017-05(1)	Baryte rock	ditto	Baryte, Apatite
16211	871017-05(2)	ditto	ditto	Baryte, Calzirtite, Chalcopyrite
16254	881013-01A	Carbonatite	ditto	Dolomite, Calcite, Phlogopite, Apatite
16255	881013-01B	ditto	ditto	ditto
16256	881013-01C	Alkaline-carbonatite complex	ditto	Richterite, Phlogopite, Strontianite, Potassic-magnesio-arfvedsonite, Potassic-ferri-leakeite, Tetraferriphlogopite, Daqingshanite-(Ce), Zirconolite, Chromite, Ilmenite, Rutile, Baryte, Priderite, Sphalerite, Chalcopyrite, Quartz, Dolomite, Calcite
16257	881013-01D	ditto	ditto	ditto
16258	881013-01E	ditto	ditto	ditto
16259	881013-01F	ditto	ditto	ditto
16260	881013-01G	ditto	ditto	ditto
16261	881013-02	Alkaline-carbonatite complex (Fenitized)	ditto	Augite, Richterite, Phlogopite, Magnesio-hastingsite, Titanite, Ilmenite, Baryte, Hematite, Pyrrohotite, Galena, Chalcopyrite
16262	881013-03a	Alkaline-carbonatite complex	ditto	Magnetite, Celadonite, Dolomite, Calcite, Apatite, Quartz
16263	881013-03b	ditto	ditto	Magnetite, Celadonite
16264	881013-03c	ditto	ditto	ditto
16265	881013-04	Carbonatite	ditto	Dolomite, Strontianite, Siderite, Zircon
16266	881013-05	ditto	ditto	Dolomite, Burbankite, Ancylite-(Ce)
16267	881013-06	ditto	ditto	Apatite, Goethite, Quartz
16268	881013-07	ditto	ditto	Calcite, Magnetite
16269	881013-08	ditto	ditto	Tetraferriphlogopite, Phlogopite, Dolomite
16270	881013-10A	Baryte rock	ditto	Baryte
16271	881013-10B	ditto	ditto	Baryte, Apatite, Romanèchite
16272	881013-10C	ditto	ditto	ditto
16273	881013-10D	ditto	ditto	ditto
16274	881013-10E	ditto	ditto	Baryte
16275	881013-10F	ditto	ditto	Baryte, Apatite, Goethite
16276	881013-10G	ditto	ditto	ditto
16277	881013-10H	ditto	ditto	ditto
16278	881013-11	Carbonatite-Jacupirangite	ditto	Apatite, Rhabdophane-(Ce), Baryte
16279	881013-12	Weathered glimmerite	ditto	Vermiculite
16280	881013-12b		ditto	Dolomite, Baryte
	881013-13a P1	Drilling cores		
16281	881013-13a, P1-0.0B	Surface soil	ditto	Goethite, Quartz
		2.0 m		
		4.0 m		
		6.0 m		
		8.0 m		
		10.55 m		
		12.45 m		
		14.0 m		
16282	ditto, P1-16.65B	16.65 m	ditto	Goethite, Quartz
		18.57 m		
		20.0 m		
		21.45 m		
		24.19 m		
		26.0 m		
		28.07 m		
		30.0 m		
		31.02 m		
16283	ditto, P1-34B	34.0 m	ditto	Goethite, Quartz
		36.0 m		
16284	ditto, P1-38B	38.0 m	ditto	Goethite, Anatase
		40.14 m		
		42.0 m		
16285	ditto, P1-44B	44.0 m	ditto	Goethite, Anatase
		46.24 m		
		48.0 m		
		50.0 m		
		52.34 m		
		54.0 m		
16286	ditto, P1-55.99B	55.99 m	ditto	Goethite, Anatase
		58.44 m		
		60.0 m		
16287	ditto, P1-61.5B	61.49 m	ditto	Goethite, Anatase
16288	ditto, P1-71B	71.04 m	ditto	Goethite, rutile
16289	ditto, P1-71W	71.04 m	ditto	ditto
		74.0 m		
		76.0 m		
16290	ditto, P1-78B	78.04 m	ditto	Apatite, Anatase
16291	ditto, P1-78W	78.04 m	ditto	ditto
		79.75 m		
		81.75 m		
		84.0 m		
		86.31 m		

Table 5. Continued

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16291	881013-13a, P1-78W	88.35 m 90.0 m 92.0 m 94.05 m 96.0 m		
16292	ditto, P1-98-1	98.0 m	ditto	Goethite
16293	ditto, P1-98-2	98.0 m	ditto	Goethite, Apatite
16294	ditto, P1-98-3	98.0 m	ditto	ditto
16295	ditto, P1-98-4	98.0 m 100.0 m 102.0 m 104.0 m 106.05 m 107.85 m 110.30 m 111.75 m 114.05 m 114.05 + m	ditto	Apatite, Baryte, Anatase, Goethite
16296	P1-116,	116.30 m		Calcite, Dolomite, Baryte, Apatite
16297	881013-13b, P2	Surface soil 2 m 4 m 6 m 8 m 10 m 12 m 14 m 16 m 18 m 20 m 22 m 24 m 26 m 28 m 30 m 32 m 34 m 36 m 38 m 40 m 42 m 44 m 46 m 48 m 50 m 52 m 54 m 56 m 58 m 60 m 62 m 64 m 66 m 68 m 70 m 72 m 74 m 76 m 78 m 80 m 82 m 84 m 86 m 88 m 90 m 92 m 94 m 96 m 98 m 100 m 102 m 104 m 106 m 108 m 110 m 112 m	ditto	Goethite, Quartz
16208	871017-01	Weathered pyrochlore ore	Mine of the Compania Brasileira de Metalurgia e Mineração S.A.	Goethite, Baryte, Pyrochlore
16011	871017-02a	ditto	ditto	Hydroxykenopyrochlore (type specimen)
16209	871017-02b～-02f	ditto	ditto	Magnetite, Baryte, Rhabdophane-(Ce)

ered soils are enriched by P, Ti, Nb, REEs and so on. The rock samples were collected at two mines. The Mine of Arafertil S.A. is mainly mining apatite as the resource of P. The Mine of Compania Brasileira de Met alurgiae Mineração S.A. (CBMM) is mining high quality niobium ores. During mineralogical survey for weathered pyrochlore ore from CBMM, the authors have recognized a new member of the pyrochlore supergroup, hydroxykenopyrochlore, $((\square,Ce,Ba)_2,Ce,Ba)_2(Nb,Ti)_2O_6(OH,F)$, approved by CNMNC of IMA (2017-030a) (Miyawaki *et al.*, 2017). Collected rock samples are secondary baryte rock, carbonatite, rocks of alkaline-carbonatite complex, carbonatite-jacupirangite complex, drilling cores, weathered glimmerite, weathered pyrochlore ore and so on. Main mineral constituents of these rocks and ores are indicated in Table 5.

Aggregates of baryte and/or magnetite are secondary minerals economically unwanted as ores in this mine. However, beautiful crystal growth of baryte will be a valuable mineralogical sample. Alkaline-carbonatite complexes near to the bottom of the mine may be called as fenite. Observed minerals of a part of drilling core samples with 2 m interval from the surface to 116 m depth, at the Mine of Arafertil S.A. Araxá (MG), are also listed in Table 5. Weathering is advanced up to the bottom since goethite and anatase are detected, however, the layer from 40 m to 70 m still retains the mineral assemblages of alkaline rocks so that nepheline is remaining, furthermore, the characteristics by fenitization of alkaline-carbonatite complexes are still observed from the layer 70 m to the bottom. Weathered pyrochlore ores (Fig. 8) obtained at CBMM show mineral assemblages of mainly goethite, baryte and pyrochlore.

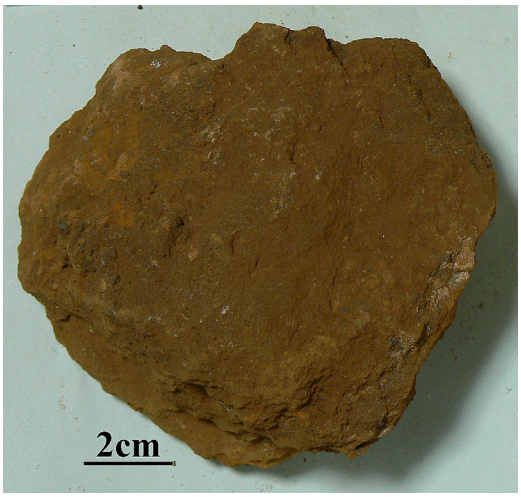


Fig. 8. Pyrochlore ore from the Mine of the Compania Brasileira de Met alurgia e Mineração S.A. (CBMM), Araxá (MG).

6. Catalão (GO)

Catalão is located at the south of the state of Goiás, near to the border of Minas Gerais. The shape of intrusion is oval formed by $10.2 \times 6.6\,km^2$, the K–Ar age is estimated as 133 Ma(CBMM Issue, 1984). Country rocks are decayed mica schist of middle Precambrian. Typical "phoscoritic" features can be observed in the drilling cores of the Mine of Goiasfertil S.A. and these samples were provided (Fig. 9) from the Mine. The "phoscorite" is explained as thick masses of a rock containing carbonate, phlogopite, apatite and magnetite (CBMM Issue, 1984). Weathering of carbonatite-alkaline complexes is remarkable, resulting in the concentration of rare earth minerals in the soil of the depth around 100 m. Main ore minerals are apatite, and pyrochlore, anatase and REE phosphates are mined as by-product. Collected rock samples are pyroxe-

Fig. 9. Drilling core at 46.6 m in depth, "Phoscorite." Mine of Goiasfertil S.A., Catalão (GO).

Table 6. Rocks and mineral constituents from Catalão (GO)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16131	871014-01a	Altered rock at Pyroxenite-Carbonatite contact	Mine of Goiasfertil S.A.	Magnetite, Perovskite, Calcite
16132	871014-01b	ditto	ditto	Magnetite, Perovskite, Calcite, Calzirtite, Baryte, Apatite, Chromite
16133	871014-01c	ditto	ditto	Magnetite, Perovskite, Calcite, Chlorite, Vermiculite, Apatite
16134	871014-03a1	Altered rock Magnetite xenolith and apatite	ditto	Magnetite, Perovskite, Calcite, Apatite, Vermiculite, Hydrobiotite
16135	871014-03a2	ditto	ditto	Magnetite, Perovskite, Calcite, Dolomite, Apatite, Diopside, Vermiculite
16136	871014-03a3, 03b	ditto	ditto	Magnetite, Perovskite, Calcite, Apatite, Vermiculite, Hydrobiotite
16137	871014-04a	Altered rock Weathered Apatite vein	ditto	Baryte, Calcite, Ancylite-(Ce)
16138	871014-04b	ditto	ditto	Baryte, Calcite, Ancylite-(Ce), Pyrochlore, Calcite, Dolomite, Hematite, Vermiculite
16139	871014-05 a～d	Carbonatite	ditto	Calcite, Tetraferriphlogopite, Calcite, Dolomite, Vermiculite, Baryte, Apatite, Oxycalciopyrochlore, Ancylite-(Ce), Fergusonite-(Ce), Pyrrhotite, Rasvumite
16140	871015-01B1	Pyroxenite (Drilling core)	ditto	Augite, Ferro-pargasite, Titanite, Ancylite-(Ce), Calcite, Pyrite, Chalcopyrite, K-feldspar
16141	871015-01B2	Alkaline-carbonatite (Dorilling core)	ditto	Dolomite, Tetraferriphlogopite, Monazite-(Ce), Baddeleyite, Baryte, Calcite, Apatite, Fluorcalciopyrochlore, Fluornatropyrochlore, Aegirine, Albite, Pyrite
16142	871015-01B3	ditto	ditto	Tetraferriphlogopite, Rhabdophane-(Ce), Zirconolite, Baddeleyite, Baryte, Ilmenite, Fersmite, Priderite, Dolomite, Pyrite, Cattierite
	871015-01SC1	Carbonatite (Dorilling cores)	ditto	
16143	ditto 32/20	ditto, 44.0～46.85 m	ditto	Dolomite, Forsterite, Baddeleyite, Teraferriphlogopite, Monazite-(Ce), Zirconolite, Apatite, Ilmenite, Calcite
16144	ditto 35/26	ditto, 42.10～43.65 m	ditto	Baryte, Phlogopite, Tetraferriphlogopite, Hydroxykenopyrochlore, Fluorocalciopyrochlore
16145	ditto 26/81	ditto, 39.61～41.50 m	ditto	Phlogopite, Zirconolite, Apatite, Ilmenite, Magnetite, Dolomite, Strontianite, Sphalerite
16146	ditto 23/06	ditto, 37.35～40.00 m	ditto	Aegirine, Ancylite-(Ce), Aegirine-augite, Titanite, Wadeite, Baryte, Calcite, Galena
16147	ditto 35/40	ditto, 35.40 m	ditto	Diopside, Potassic-richterite, Titanite, Phlogopite, Tetraferriphlogopite, Apatite, Ilmenite, Calcite, Pyrite, Chalcopyrite
16148	ditto 28/15	ditto, 44.35～46.40 m	ditto	Chlorite, Zircon, Phlogopite, Tetraferriphlogopite, Baryte, Apatite, Calcite, Dolomite
16149	ditto 22/11	ditto, 46.55～49.15 m	ditto	Potassic-magnesio-arfvedsonite, Tetraferriannite, Tetraferriannite-Tetraferriphlogopite, Phlogopite, Apatite, Ilmenite, Priderite, Ancylite-(Ce), Calcioburbankite, Calcite, Dolomite, Norsethite, Strontianite, Sphalerite, Galena
	871015-02SC2	Dorilling core	ditto	
16150	ditto	ditto, 0.8 m	ditto	Monazite-(Ce), Goethite, Crandallite, Quartz, Eudialyte
16151	ditto	ditto, 2.4 m	ditto	Monazite-(Ce), Goethite, Crandallite, Dolomite, Quartz, Eudialyte
16152	ditto	ditto, 5.9 m	ditto	Monazite-(Ce), Goethite, Quartz, Rhabdophane
16153	ditto	ditto, 8.6 m	ditto	Monazite-(Ce), Hollandite, Quartz, Chlorite, Goethite
16154	ditto	ditto, 20.4 m	ditto	Monazite-(Ce), Goethite, Apatite, Quartz, Rhabdophane, Magnetite
16155	ditto	ditto, 38.0 m	ditto	Monazite-(Ce), Goethite, Vermiculite, Quartz
16156	ditto	ditto, 45.0 m	ditto	Monazite-(Ce), Goethite, Chlorite, Quartz, Apatite, Vermiculite
16157	ditto	ditto, 53.0 m	ditto	Monazite-(Ce), Chlorite, Dolomite, Quartz, Vermiculite
16158	ditto	ditto, 62.0 m	ditto	Dolomite, Chlorite, Quartz, Monazite-(Ce), Anatase, Vermiculite
16159	ditto	ditto, 67.0 m	ditto	Dolomite, Chlorite, Monazite-(Ce), Vermiculite
16160	ditto	ditto, 91.0 m	ditto	Dolomite, Chlorite, Anatase, Ilmenite, Monazite-(Ce), Vermiculite
16161	ditto	ditto, 92.5 m	ditto	Dolomite, Chlorite, Monazite-(Ce), Vermiculite, Magnetite, Hollandite
16162	ditto	ditto, 95.4 m	ditto	Monazite-(Ce), Dolomite, Chlorite, Goethite, Phlogopite, Perovskite, Anatase
16163	ditto	ditto, 97.8 m	ditto	Monazite-(Ce), Dolomite, Calcite, Hematite, Xenotime-(Y), Baryte, Eudialyte
16164	871015-03	Phosphorus ore	ditto	Baryte, Apatite, Fersmite, Ba-bearing hydropyrochlore, Fergusonite-(Ce)
16298	881014-01a～f	Altered cabonatite	ditto	Rhabdophane-(Ce), Pyrochlore, Annnite, Quartz
16299	881014-01g	ditto	ditto	Baddeleyite, Apatite, Baryte, Magnetite, Quartz

nite-carbonatite complexes, "phoscorites", drilling cores of the weathered soil of 100 m in depth. The most of samples are strongly altered and/or affected by weathering. Main mineral constituents of these rocks and ores are listed in Table 6.

The drilling cores of fifteen soil samples of 100 m in depth from surface were examined and the results are also listed in Table 6. Most of the samples examined are strongly suffered from alteration and/or weathering, particularly till 60 m in depth. It is interested to note that Zr-dominant minerals are not found or quite less, and Mg content is higher than those of the Mine of Arafertil, Araxá. Carbonates, in particular, dolomite content are considered to be much higher than those of the Arafertil, on the other hand, Zr-dominant minerals such as baddeleyite, zircon and zirconolite are less. The distribution of rare earth minerals is almost uniform from the weathered surface soil to the bottom together with phosphate such as apatite.

7. Minaçu (GO)

This area is geologically called as a part of large 'Peixe alkaline complex area'. Two locations were investigated in this area. The first location is the Mine of SAMA, Mineração de Amianto at Mina da Cana Brava, and the second is a pegmatite at the Serra da Mesa area.

The Mine of SAMA is operated by open pit. The mining area in plane is elongated shape formed by $1 \times 0.3\,km^2$. A main rock of the mine is considered to be a serpentinite altered from ultrabasic rock such as peridotite due to regional hydrothermal metamorphism at relatively low temperature and low pressure. Since dolomite and graphite are also found as major minerals in the ore, then the chemical component of carbonates may be strongly concerned with the reaction as well.

One of the collected rock examples is shown in Fig. 10. On the whole, major minerals in ores are chrysotile, antigorite, dolomite and graphite. Powder XRD profiles become broad in case of containing chrysotile, antigorite and graphite. Pegmatite minerals were also collected at the Serra da Mesa area at the location of 30～40 km north from Minaçu. Large-scale amazonite vein is observed in this area. Main mineral constituents of the above rocks are indicated in Table 7.

8. Peixe (TO)

A large alkaline massif developed elliptically

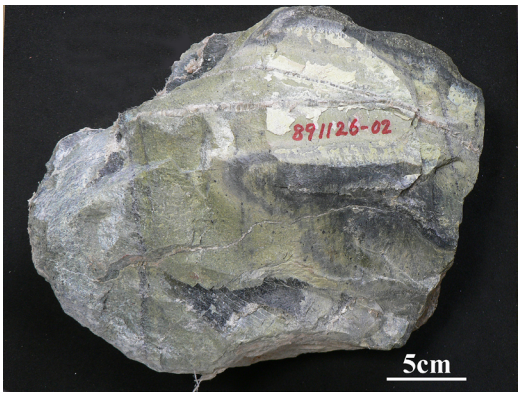


Fig. 10. Serpentinite from Mineração de Amianto at Mina da Cana Brava, Minaçu (GO).

Table 7. Rocks and mineral constituents from Minaçu (GO)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16303	891126-01a～-01d	Serpentinite	Mine of the SAMA, Mineração de Amianto at Mina de Cana Brava	Chrysotile
16304	891126-01e～-01f(3)SL	ditto	ditto	Chromite, Dolomite
16305	891126-02	ditto	ditto	Chrysotile
16306	891126-03	ditto	ditto	Graphite, Chrysotile
16307	891127-01	Single mineral	ditto	Quartz
16308	891127-02	ditto	ditto	Microcline (Amazonite)
16309	891127-03	ditto	ditto	Tantalite
16310	891127-03b	ditto	ditto	Monazite-(Ce)
16311	891127-03c	ditto	ditto	Fluorite

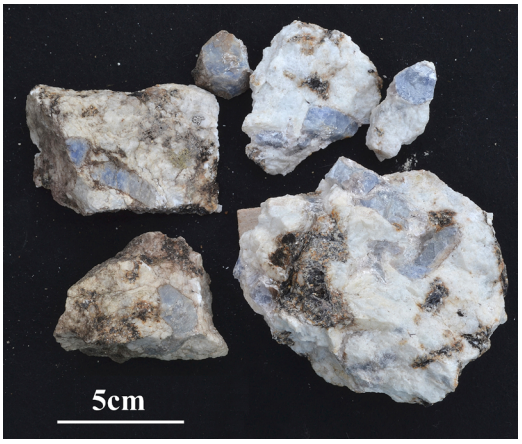


Fig. 11. Plumasite from Porteira, Peixe (TO). Corundum crystals are growing in Ca-rich albite.

Fig. 12. Zircon in placer deposit. Redenção, Peixe (TO).

$35 \times 6.5\,km^2$ in scale is recognized as area of 'Peixe alkaline complex.' The outcrops are observed geographically ranging from Mata Azul to Peixe at the border of the states of Goiás and Tocantins. The massif is considered as an original alkaline intrusive which was involved in collision tectonics, and is covered by gneiss, mica-schist and quartzite of the Serra da Mesa group. Presumed age of the alkaline massif is Archean (minimum age is 875 Ma by Rb-Sr method (Hasui, 1989 in private communications)), and U-Pb ages of zircon crystals which are included in pegmatitic corundum are estimated to be 560Ma of which age will indicate igneous events of the genesis of the corundum-bearing pegmatite, on the other hand, U-Pb ages of zircon crystals in nepheline syenite are presumed to be 1.5Ga of which age is in accordance with regional geologic evolution based on continental rifting (Kitajima, *et al.*, 2001).

The survey was performed at the area from Corrego de Marinbondo to Monteiropolis. Main rocks and minerals were collected at Corrego de Passagem Roçada (weathered alkaline rocks), Fazenda Oliveira (altered and weathered nepheline syenite), Fazenda Megamin (altered nepheline syenite), Porteira (plumasite including corundum phenocrysts; Fig. 11), Redenção (euhedral zircon crystals in pacer-deposit ; Fig. 12), Paranã (quartz and microcline crystals), Serra da Mesa (pegmatite) and Guara (zircon crystals, zircon-bearing placer ore, nepheline syenite including zircon phenocryst and plumasite). The collected rocks and mineral constituents are listed in Table 8.

9. Itinga, Itacolomi and Diamantina (MG)

The rocks of these areas are composed of Precambrian quartz and muscovite schist. Main rocks and minerals are collected at Mina de Baixod, Itinga (pegmatite and mica schist), Mina de Loranjeira, Mariana, Itacolomi (itacolumite) and Diamantina (quartz and muscovite schist). The itacolumite is a flexible schistose quartzite, and is composed of small pieces of quartz with 'jigsaw puzzle' like pattern, in which narrow spaces are observed among them. Some of quartz grains have cracks intersecting at 120 degrees with one another attributed by stress, and micas fill up some of the spaces along the quartz walls (Fig. 13) (Nagai *et al.*, 1988). Those rocks and mineral constituents are listed in Table 9.

10. Boca Nova (PA)

Boca Nova is the place about 120 km east from Belem. Rock samples of nepheline syenite were collected at the mine operated by the Companhia de Mineração do Pará (PARAMINÉRIOS). Detected minerals are listed in Table 10.

Table 8. Rocks and mineral constituents from Peixe (TO)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16312	891128-01b	Weathered alkaline rocks	Corrego de Passagem Roçada	Kaolinite
16313	891128-02a	Single mineral	ditto	Zircon
16314	891128-02b	Ditto	Fazenda Oliveira	Ilmenite
16315	891128-02c	Ditto	ditto	ditto
16316	891128-02d	Ditto	ditto	Quartz
16317	891128-02e	Ditto	ditto	Epidote
16318	891128-03	Altered Nepheline syenite	Fazenda Megamin, Monteiropolis	Hedenbergite, Ferro-hornblende, Ferriallanite-(Ce)
16319	891128-04	ditto	ditto	Nepheline, Albite, Analcime
16320	891128-05a	Single mineral	Porteira	Zircon
16321	891128-05b	ditto	ditto	Corundum
16322	891128-05c		ditto	Ilmenite
16323	891128-05c 2		ditto	Ilmenite
16324	891128-05d		ditto	Kyanite
16325	891128-05e		ditto	Kyanite
16326	891128-06a	Pegmatite	ditto	Elbaite
16327	891128-06c, d	Plumasite	ditto	Corundum
16328	891128-07	Placer deposit	Redenção	Zircon
16329	891128-08		ditto	Corundum
16330	891129-01		Fazenda Oliveira	Monazite-(Ce)
16331	891129-03A	Alkaline rocks	ditto	Hedenbergite, Ferriallanite-(Ce), Bastnäsite-(La)
16332	891129-03b		ditto	Magnetite
16333	891129-03c		ditto	ditto
16334	891129-04		ditto	Monazite-(Ce)
16335	891129-05Aa		Paranã	Quartz (Rock crystal)
16336	891129-05Ab		ditto	ditto
16337	891129-05B		ditto	Microcline
16370	900723-01A	Pegmatite	Serra da Mesa	Fluorite
16371	900723-01B	ditto	ditto	ditto
16372	900723-01C	ditto	ditto	Albite
16373	900723-01D	ditto	ditto	Fluorite
16374	900723-01E	ditto	ditto	Microcline (Amazonite)
16375	900723-01F	ditto	ditto	ditto
16376	900723-01G	ditto	ditto	ditto
16377	900723-01H	ditto	ditto	Albite
16378	900723-01I	ditto	ditto	Fluorite
16379	900723-01K	ditto	ditto	Microcline (Amazonite)
16380	900723-01L	ditto	ditto	Fluorite
16381	900723-01M	ditto	ditto	ditto
16382	900723-01N	ditto	ditto	ditto
16383	900723-01O	ditto	ditto	ditto
16384	900723-01P	ditto	ditto	ditto
16385	900723-01Q	ditto	ditto	ditto
16386	900723-01R	ditto	ditto	Schorl
16387	900723-01S	ditto	ditto	Beryl, Fluorite
16388	900723-01T	ditto	ditto	Microcline (Amazonite)
16389	900723-01U	ditto	ditto	ditto
16390	900723-01V	ditto	ditto	Microcline (Amazonite)
16391	900723-02	Gneiss	ditto	K-feldspar, Phlogopite
16392	900724-01		Guara	Zircon
16393	900724-02	Placer deposit	ditto	ditto
16394	900724-03	ditto	ditto	ditto
16395	900724-04a, b, d	Nepheline syenite	ditto	ditto
16396	900724-04c	ditto	ditto	Nepheline
16397	900724-04e	ditto	ditto	K-feldspar, Phlogopite
16398	900724-04f	ditto	ditto	Zircon
16399	900724-04g, h	ditto	ditto	ditto
16400	900724-04i	ditto	ditto	ditto
16401	900724-05A	Plumasite	ditto	Corundum
16402	900724-05B	ditto	ditto	ditto
16403	900724-05C	ditto	ditto	ditto
16404	900724-05D	ditto	ditto	ditto
16405	900724-05E	ditto	ditto	ditto
16406	900724-05F	ditto	ditto	ditto
16407	900724-05G	ditto	ditto	ditto
16408	900724-05H	ditto	ditto	ditto

11. Rocks provided from Prof. Hasui

Prof. Y. Hasui provided various rocks in Brazil for reference. Those rocks and mineral constituents are listed in Table 11.

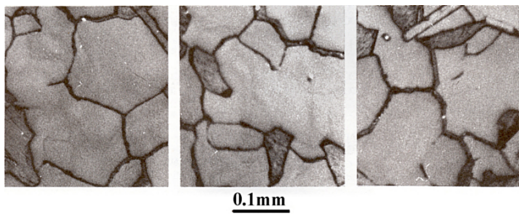


Fig. 13. Mineral textures in itacolumite (Nagai, T. *et al.*, 1988).

12. Others

Table 12 indicates beryl samples from Mina Fortaleza, Santa Teresa de Goiás (GO).

Weathering and mineral alteration

Chemical composition of the lateritic soil weathered from carbonatites was discussed on the drilling cores obtained at the Mine of Goiasfertil S.A., Catalão (GO) (Fig. 14) (Toyoda *et al.*, 1988). In deeper zones of mica-rich soil and decomposed rocks, carbonates mainly composed of dolomite occupy more than 60 wt.% of the whole body, while almost no carbonates are

Table 9. Rocks and mineral constituents from Itinga, Itacolomi and Diamantina (MG)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16212	871019-01		Itinga (Mina de Baixod)	Microcline
16213	871019-02	Micaschist	ditto	Annite, Muscovite, Quartz
16214	871019-03	Pegmatite	Itinga (Mina deLoranjeira)	Elbaite
16215	871019-04	ditto	ditto	ditto
16216	871019-05	ditto	ditto	Lepidolite
16217	871019-06	ditto	ditto	ditto
16218	871019-07a	ditto	ditto	Quartz (rose quartz)
16219	871019-07b	ditto	ditto	Quartz (yellow quartz)
16220	871019-07c	ditto	ditto	Quartz
16221	871019-08	ditto	ditto	Lepidolite, Elbaite
16222	871019-09	ditto	ditto	Quartz
16223	871019-10	ditto	ditto	Elbaite, Lepidolite
16224	871019-11	ditto	ditto	Elbaite
16225	871019-12	Micaschist	Itacolomi (Mariana)	Quartz (Itacolomite) (Konnyakuishi)
16300	881015-01	ditto	Diamantina	Muscovite, Quartz
16301	881015-02	Quartz schist	ditto	Quartz

Table 10. Rocks and mineral constituents from Boca Nova (PA)

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16409	900727-01A	Nepheline syenite	Mine of the Companhia de Mineração do Pará	Nepheline, Cancrinite
16410	900727-01B	ditto	ditto	ditto
16411	900727-01C	ditto	ditto	ditto
16412	900727-01D	ditto	ditto	ditto
16413	900727-01E	ditto	ditto	ditto
16414	900727-01F	ditto	ditto	ditto
16415	900727-01G	ditto	ditto	ditto
16416	900727-01H	ditto	ditto	ditto
16417	900727-01I	ditto	ditto	ditto
16418	900727-01J	ditto	ditto	ditto
16419	900727-01K	ditto	ditto	ditto
16420	900727-01L	ditto	ditto	ditto
16421	900727-01M	ditto	ditto	ditto
16422	900727-01N	ditto	ditto	ditto
16423	900727-01O	ditto	ditto	ditto
16424	900727-01P	ditto	ditto	ditto
16425	900727-01Q	ditto	ditto	ditto
16426	900727-01R	ditto	ditto	ditto

Table 11. Rocks provided from Prof. Y. Hasui

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16342	891206-01	Carbonatite	Anitápolis (SC)	Dolomite, Calcite, Richterite
16343	891206-02	Glimmerite	ditto	Augite, Phlogopite, Apatite
16344	891206-03	Sodalite syenite	Palmares (BA)	Sodalite
16345	891206-04	ditto	ditto	Sodalite, Cancrinite
16346	891206-05	ditto	ditto	Sodalite
16347	891206-06	ditto	ditto	Cancrinite, Sodalite
16348	891206-07	ditto	ditto	Sodalite
16349	891206-08	Syenite	Floresta Azul (BA)	K-feldspar, Quartz, Diopside
16350	891206-09	Alkali pegmatite	Palmares (BA)	Aegirine, Riebeckite, K-feldspar
16351	891206-10	Sodalite syenite?	Potiraguá (BA)	Siderophyllite, Calcite, Zircon
16352	891206-11～-15	Sodalite syenite	ditto	Sodalite
16353	891206-16	Nepheline syenite	Monte Santo (TO)	Calcite, Annite
16354	891206-17	ditto	ditto	Calcite, Magnetite
16355	891206-18	ditto	ditto	ditto
16356	891206-19	Unknown	Paraguay	Phlogopite
16357	891206-20	Nepheline syenite (Deformed and recrystallized)	Peixe (TO)	Nepheline
16358	891206-21	ditto	ditto	Calcite, Annite
16359	891206-22～-23	ditto	ditto	Nepheline, Phlogopite
16360	891206-24～25	Nepheline syenite	Serra da Estrela (TO)	Magnetite
16361	891206-26	ditto	ditto	ditto
16362	891206-YH1, 2	Recrystallized nepheline syenite	Bom Repouso	Aegirine,Nepheline, Annite
16363	891206-YH3, 4	ditto	ditto	Aegirine, Pargasite
16364	891206-MV185	Lamprophyre	Carmubé	Aegirine-augite, Britholite-(Ce), Perovskite

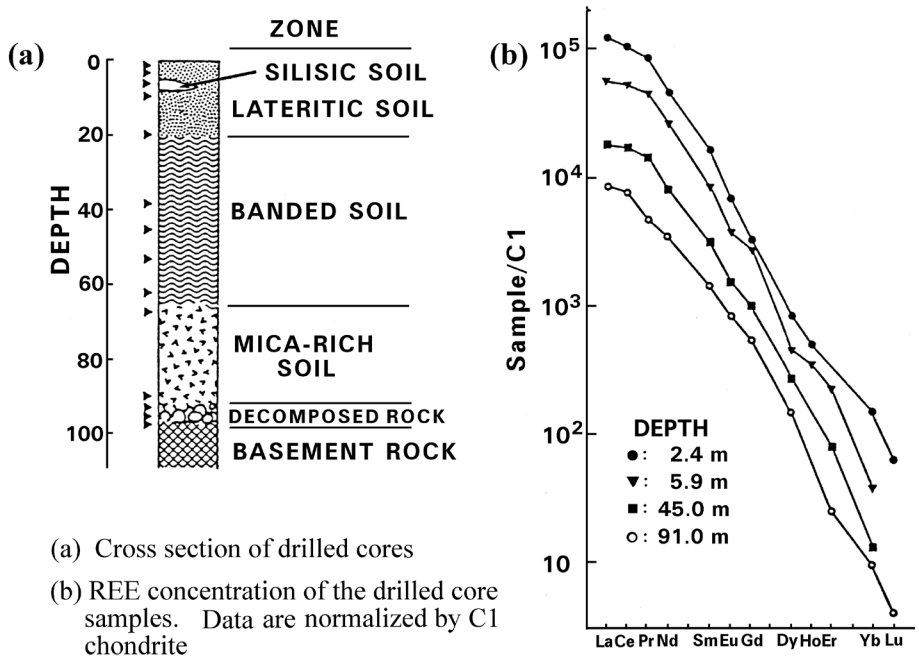
Table 12. Others

NSM-MF	Sample No.	Rock Name	Locality	Mineral Species
16338	891130-01a	Single mineral	Santa Teresa de Goiás (GO): Mina Fortaleza	Beryl (emerald)
16339	891130-01b	ditto	ditto	ditto
16340	891130-01c	ditto	ditto	ditto
16341	891130-01d	ditto	ditto	ditto

observed in the upper lateritic soil zone, and iron-oxides/hydro-oxides occupy more than 30 wt.%. At the soil near to the surface of a few meters in depth, silicic soil occupies more than 90 wt.%. In the banded zone, contents of Ti and P vary depending of the samples. The REE pattern in each drilling core shows the similar tendency from La to Lu, and they are gradually concentrated in accordance with the depth, resulting in more than 10% concentration by 100 m in depth. The mineral assemblages near to the basement of 90 m in depth of the mine were examined using SEM. It is interested to note that dolomites are retaining against alteration, and rhabdophane is stable and growing in a manner of surrounding dolomites (Fig. 15) (Ishida *et al.*, 1989).

Calcium ions in minerals have a tendency to be easily leached out by weathering. Figure 16 shows that Ca ion in diopside is removed under a hydrothermal condition and Si is relatively enriched at the spaces. Thus SiO_2 component will relatively increase by these chemical processes. Figure 17 shows the diminution of Ca from the rim and/or cracks of perovskite and they are enriched in remaining Ti (Horiuchi *et al.* (1988). As a result, fibrous anatase crystals grow under the appropriate hydrothermal condition (Fig. 18) and finally fill up the whole body of perovskite crystal, and thus, anatase pseudomorph after perovskite will be formed as shown in Fig. 7.

As results of weathering of intrusive rocks of



(a) Cross section of drilled cores

(b) REE concentration of the drilled core samples. Data are normalized by C1 chondrite

Fig. 14. Mineral assemblages of weathered soil and REE concentrate (Toyoda, K. *et al.*, 1988).

carbonatite and/or alkaline rocks in the period of around 100 million years, about 100 m thick weathered layer has been formed on the parent rocks. The original thickness is simply estimated as around 500 m, since REEs are 10 times concentrated in near to the surface soil against the basement rocks (Fig. 14). The rare-met als such as REEs mainly concentrate in phosphates such as monazite, apatite and crandallite. These minerals are considered to be stable in wide range from near to the surface to the basement parent rocks. If Zr is contained in the intrusive rocks, zircon is also formed as stable minerals. Up to the depth about 40 m, weathering is remarkable resulting in mineral assemblages of goethite, hematite, anatase, quartz in addition to monazite, zircon *etc*., while, from deeper zone around 40 m, silicates such as nepheline, K-feldspars, micas, olivine and pyroxene retain their stabilities from weathering.

Summary

A variety of rocks and minerals related alkaline rock, alkaline-carbonatite complex and pegmatite observed in Brazil have been studied and listed. The results of analyzed mineral assemblages in this paper would be worth applying samples for further mineralogical and petrological investigations. Also, it is worth mentioning the discovery of a new mineral, hydroxykenopyrochlore, from the Mine of Compania Brasileira de Metalurgia e Mineração, Araxã, MG.

The process of concentration of rare-metals including REEs in particular minerals by weathering and alteration will be also discussed from mineral assemblages summarized in this paper on various alkaline-carbonatite complex. In particular, the rock and mineral samples from deep earth accumulating long-term process of weathering and/or alteration around 100 million years will be interesting to discuss material cycling of the inner of the Earth.

Acknowledgments

We express our deep regret at the sudden death of Professor Kenkichi Fujimori by cancer in July

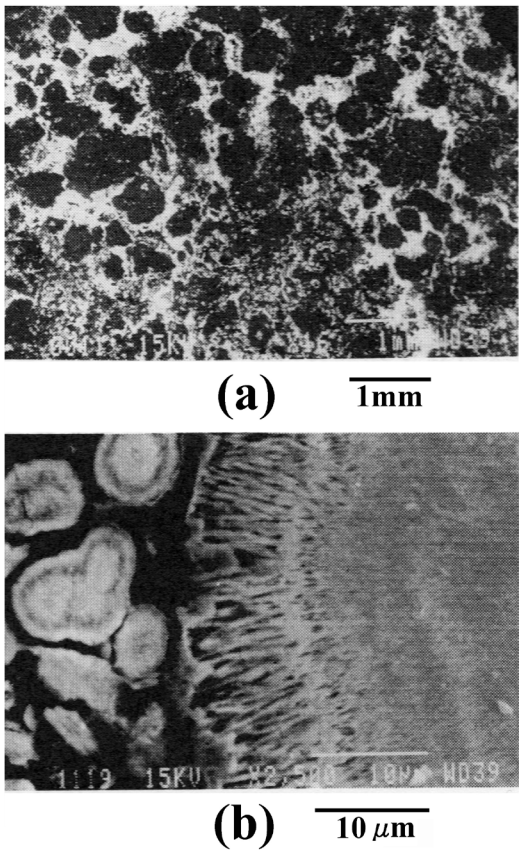


Fig. 15. SEM images of mineral assemblage near to the basement of 90 m depth of the mine. (a) Bright areas are rhabdophane. Spaces among dolomites are filled up by rhabdophane. (b) Magnified rhabdophane. Fibrous minerals are growing from the rim of rhabdophane.

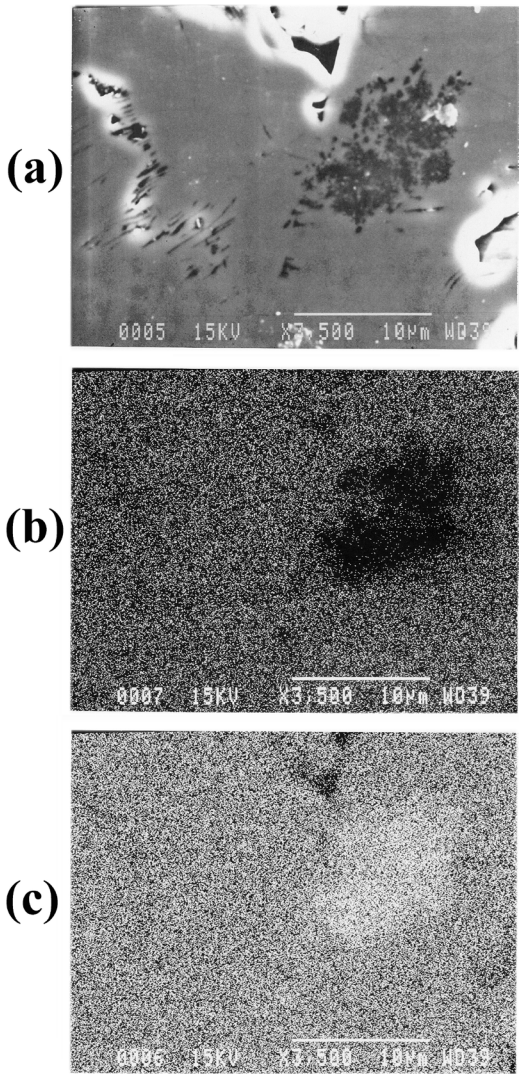


Fig. 16. (a) SEM image. (b) XES image of Ca*Kα*. (c) XES image of Si*Kα*. Diopside in glimmerite. Ca leaches out from diopside and silicic components relatively concentrate there. Sample from the CVRD, Tapira (MG).

of 1990. He strongly supported us and advanced this project, so we could never perform this project without him (Fig. 19). Dr. Fransisco Yukio Hiodo of the Instituto de Astronômico e Geofísico, Universidade de São Paulo and Mr. Jose K. Nakashima, Geologist of Goiânia (GO) supported us for over 4 years all of the field surveys.

Rock and mineral samples summarized in this study are those by the field surveys in the years of 1987–1990 by financial support of the International Scientific Research Program of the Ministry of Education. We would like to thank Professor Masayasu Tokonami, the Project Chief, Professor Emeritus Hideo Minato and Dr. Kazuhiro Toyoda, the project participants, for their collaborations, and Professor Tokuhei Tagai for his enthusiastic encouragement.

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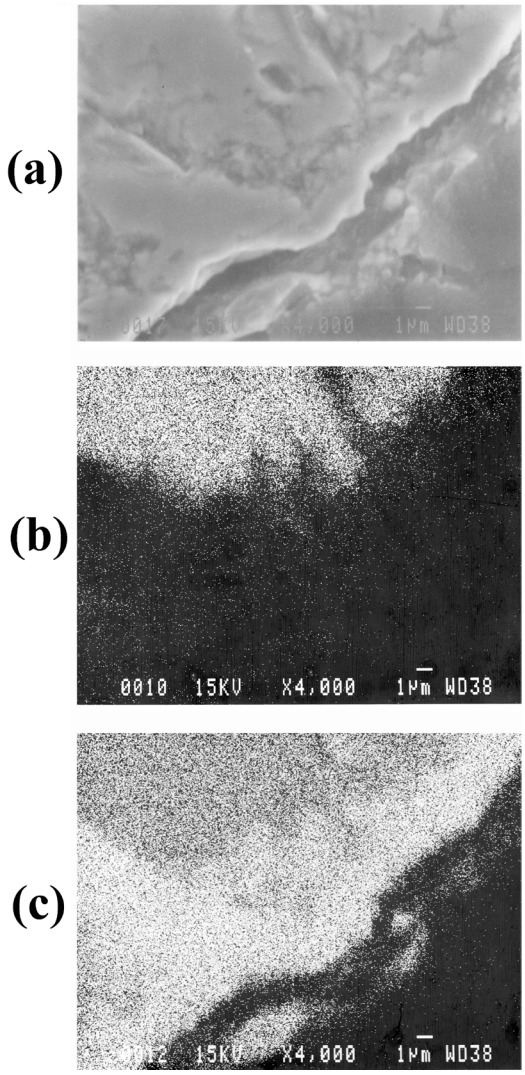

Fig. 17. (a) SEM image. (b) XES image of Ca*Kα*. (c) XES image of Ti*Kα*. Crystals of anatase are formed from the rim and/or cracks of perovskite by dispersion of Ca component. Sample from the CVRD, Tapira (MG).

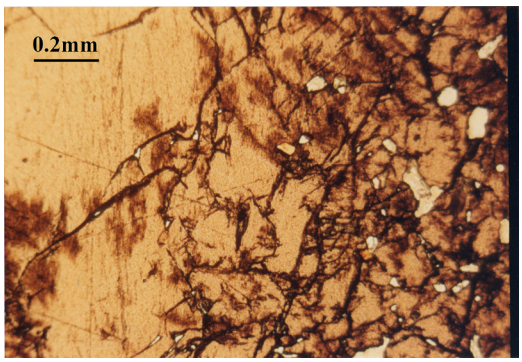

Fig. 18. Photomicrograph of fine fibrous anatase crystals formed from cracks of perovskite. One polar.

Fig. 19. The late Professor Kenkichi Fujimori in front of the block of Cadasite, Serrote, Poços de Caldas (SP). Photograph was taken on the 18th of October 1988 by Nobuhiko Haga. From left to right, Hiroyuki Horiuchi, Osamu Tachikawa, Professor Kenkichi Fujimori and Mr. Maruricio Antonio de Carvalho.

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All information described above are those at the time in 1987–1990 when field surveys were performed.

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