

## Jacupiranga carbonatites in Sao Paulo State, Brazil —Their mode of occurrence—

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**Abstract:** The Jacupiranga carbonatites, Sao Paulo State in Brazil were studied geologically. The carbonatite associated with the Mesozoic (130 Ma) alkaline rocks mainly composed of ultramafic rocks with minor ijolite and syenite, belongs to the deep seated plutonic type, similarly to the Phalaborwa carbonatites of the Proterozoic age, South Africa. The Jacupiranga carbonatites occur as two plugs in the core of the alkaline stock. Both plugs are composed of calcite carbonatite with dolomite carbonatite, later intruding into the center of the each plug. Calcite carbonatite exhibits a nearly vertical mineral bandings which is due to the concentration of early crystallized minerals from carbonatite magmas such as apatite, olivine and magnetite. Distinct mineral bandings in calcite carbonatite are thought to be developed in ascending magmas by nonstatic mechanisms; flow differentiation and spiral intrusion of carbonatite magmas.

### 1. Introduction

Although volumetrically insignificant among igneous rocks, carbonatites have significant potentiality of mineral resources, especially those of rare metals (HEINRICH, 1966; DEANS, 1966, 1978), and have played an important role in development of igneous petrology (e.g., LEBAS, 1977). During 1950's-60's, many carbonatite bodies were found and described intensively by uranium prospecting teams in the continental areas (TUTTLE and GITTINS, 1966); In 1956, 32 carbonatite localities were listed (PECOLA, 1956), then in 1966 the list had rapidly increased to about 320 occurrences (HEINRICH, 1966) and 500 localities were estimated in 1976 (HEINRICH, 1978). These carbonatites were classified based on their chemistry, associated rock suites and their mode of occurrence.

GARSON (1966) classified carbonatites into

four types based on the erosional levels (depth of the emplacement): they are from the surface to the depth; the volcanic cone, the intermediate volcanic level, the upper plutonic stem and the deep seated plutonic stem.

The Jacupiranga alkali-carbonatites of the Cretaceous age, as well as the Phalaborwa complex of the Proterozoic age, are one of the rare examples belonging to the deep-seated type in Garson's classification. We will describe and interpret the mode of occurrence of the Jacupiranga carbonatites in some details.

### 2. Geological Setting

At the present time, 21 carbonatite occurrences are listed in Brazil (RODRIGUES and LIMA, 1984). Most of them including the Jacupiranga complex are located around the Parana Basin of the Palaeozoic to Mesozoic age. They are associated with alkaline rocks of the limited intrusive age and rock-associations (ULBRICH and GOMES, 1981). They are distinctly concentrated in two areas, the inland and the coast (Fig. 1). The Jacupiranga alkali-carbonatite complex is a typical one in the coastal

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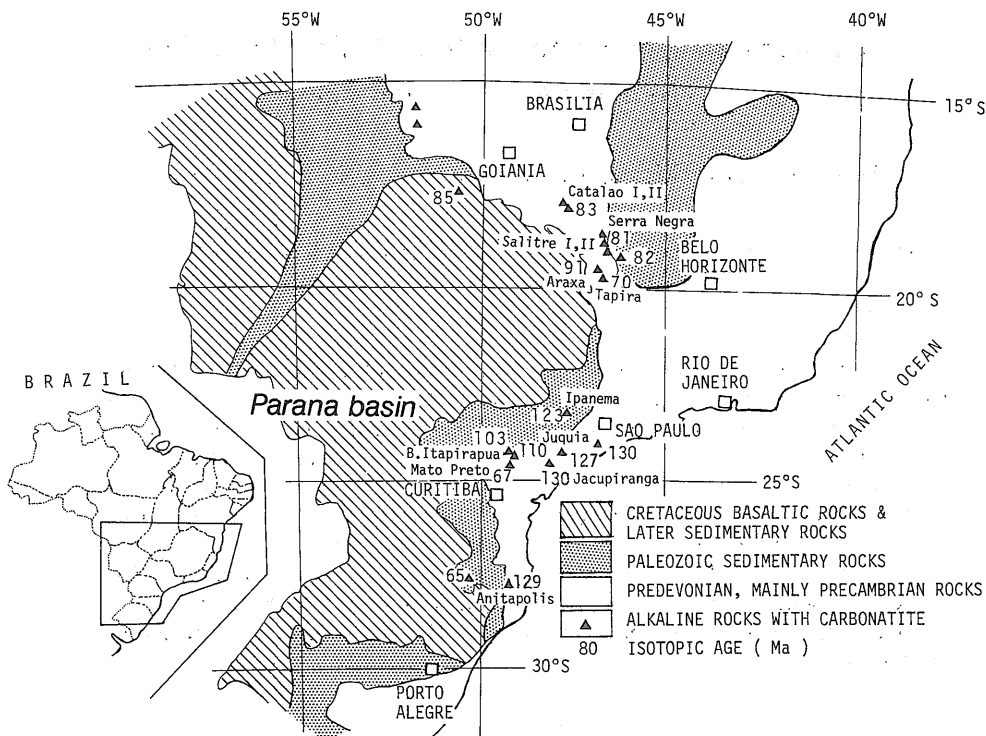


Fig. 1 Distribution of alkali-carbonatite complexes in southern Brazil.

area on the points of lithology and the age of the intrusion (RODRIGUES and LIMA, 1984). It belongs to the southern Sao Paulo-Parana sub-province (BERBERT, 1983) and have emplaced along the Ponta Grossa Arch, a domal uplift of the basement in NW-SE trending (ULBRICH & GOMES, 1981). This complex is interpreted as the node of a hot spot occurred at the triple junction during the initial opening of the Southern Atlantic Ocean (HELZ, 1977).

### 3. Jacupiranga alkaline carbonatite complex

#### 3.1 Alkaline carbonatite complex

This complex is located at the contact of granitic rocks and mica schists belonging to the Precambrian Acungai series (ca. 550 Ma) which crop out along the coast in the southern Sao Paulo and eastern Parana States. The Precambrian country rocks intruded by the alkaline-carbonatite complex, are fenitized,

where sodic pyroxene, alkali feldspar and nepheline are newly generated.

The alkaline-carbonatite complex occurs as an oval shaped stock occupying the area of 65 km<sup>2</sup> and is mainly composed of ultramafic to mafic rocks surrounded by leucocratic alkaline rocks. A detailed geologic map on the complex was made by MELCHER (1966) as shown in Fig. 2. No extrusive rocks have been found in and around the complex and the present level of erosion was estimated geologically to be more than 1500 m depth from the surface at that time when the complex was emplaced (MELCHER, 1966). A large amount of ultramafic plutonics occupy the complex. This is one of the characteristic of the deep-seated alkaline-carbonatite complex. Peridotite distributes in the northern part of the complex and change gradually into the jacupirangite-clinopyroxenite to the margin and to the south. According to MELCHER (1966) the sequence of the intrusives is as follows:

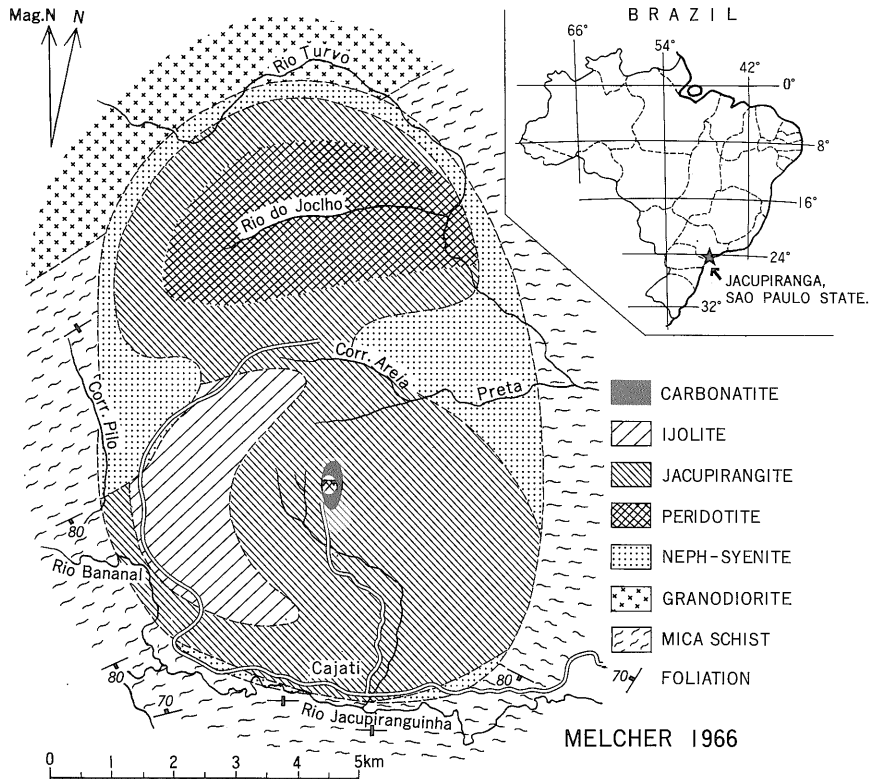


Fig. 2 Geologic map of the Jacupiranga alkali-carbonatite complex, Sao Paulo State, by MELCHER (1966).

Peridotitic body was emplaced in the earliest stage in the northern half of the complex surrounded by clinopyroxenite. After that, the circular body of clinopyroxenite intruded into the southern half of the complex and differentiated partly into the crescent-shaped ijolite body. Finally, carbonatite intruded as small plugs into the central part of the southern clinopyroxenite body. Leucocratic alkaline rocks, called as syenite, distributing east and west of the contact between two main ultramafic intrusives (Fig. 2), may be mostly rheomorphically mobilized fenite.

Radiometric ages of the Jacupiranga alkaline carbonatite complex are given as  $130 \pm 5$  Ma by K-Ar method for the rocks and minerals from the main facies of the complex (AMARAL, 1978). There is no distinct interval of the intrusive ages among the carbonatites and alkaline rocks.

Rb-Sr isochron age was obtained as  $131 \pm 3$  Ma for the Jacupiranga carbonatites with initial  $^{87}\text{Sr}/^{86}\text{Sr} = 0.7050$  (RODEN, MURTHY and GASPARG, 1985). This isochron age is in good agreement with the K-Ar age.

### 3.2 Carbonatite bodies

Carbonatites are located in the central part of the alkaline complex. The Jacupiranga carbonatites are economically significant on phosphate ore deposits (reserves: 97 million tons, 5.59%  $\text{P}_2\text{O}_5$ , BERBERT, 1983) but insignificant on niobium, though some Nb-bearing minerals such as pyrochlore (MELCHER, 1966) and high-Nb ilmenite (contains up to 3.7%  $\text{Nb}_2\text{O}_5$ , GASPARG & WYLLIE, 1983b) are found in the rocks.

The carbonatites occur as two plugs; the northern and the southern bodies. Both the plugs are composed of calcite carbonatite showing con-

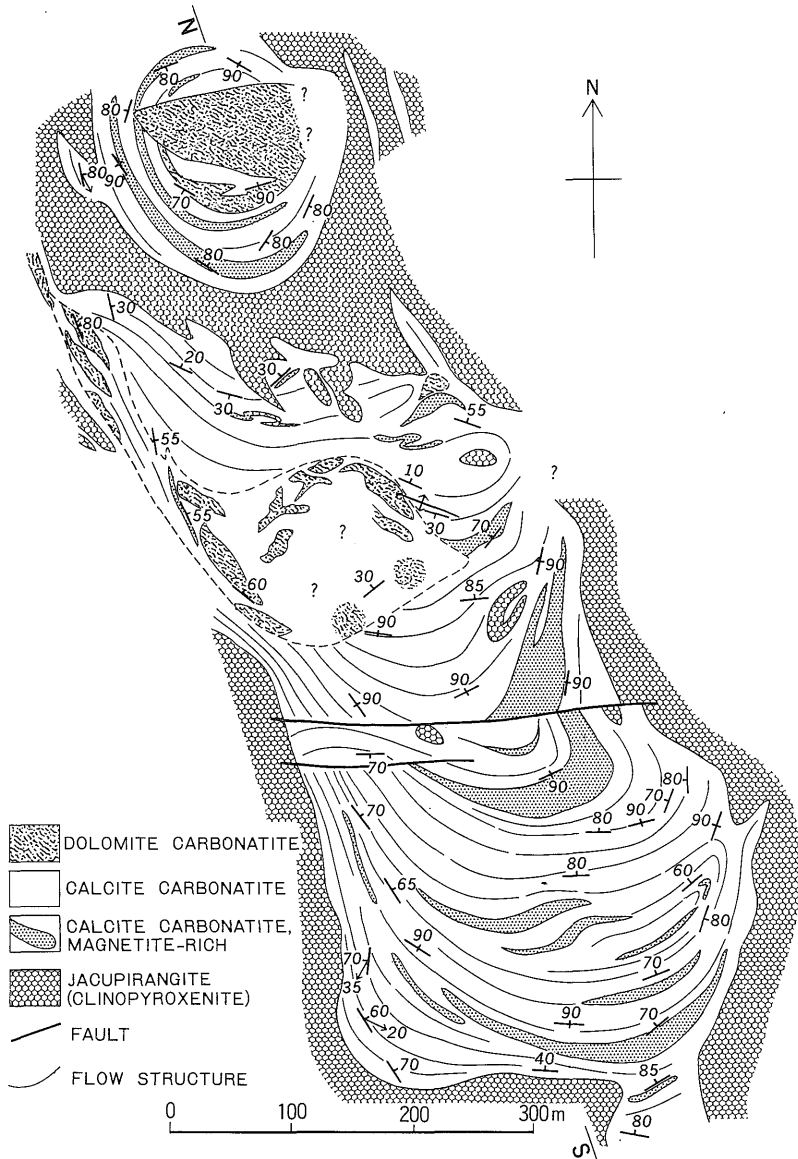


Fig. 3 Lithologic map of the Jacupiranga carbonatite body. Dashed line in the southern body shows an area for concentration of dolomite carbonatite. Strike-dip of flow bands and bearing-plunge of apatite crystals are also shown.

centric bands and dolomite carbonatite intruding into the center of the bodies (Figs. 3 and 4). Both the plugs intrude along fractures running NNW-SSE which is shown by small dikes of carbonatite (Fig. 3). The direction of the fractures are not parallel to the Ponta Grossa Arch which runs NW-SE. This fracture

filled with carbonatites may not be related to the large scale tectonics, but to the volume change of the alkaline stock during the cooling.

The fresh surface of the carbonatite can be seen everywhere at the open pit walls. According to MELCHER (1966), the carbonatites showed a highly irregular karst topography forming a

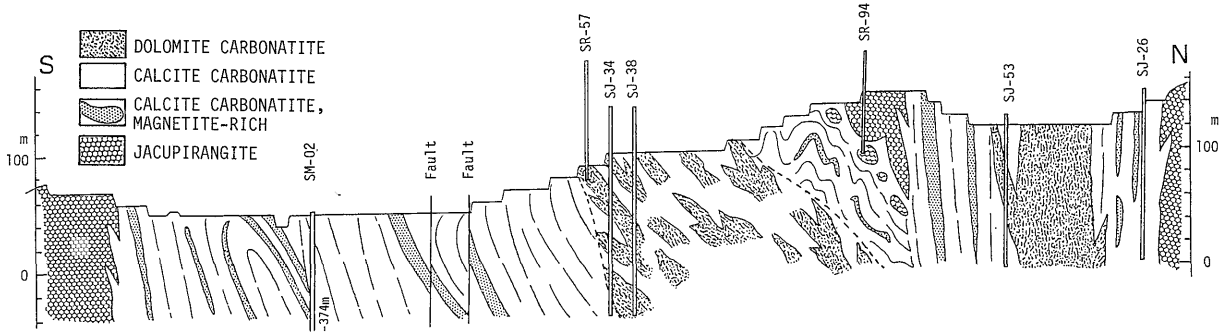


Fig. 4 Cross-section of the Jacupiranga carbonatite body. Dashed line in the southern body shows an area for concentration of dolomite carbonatite. Cutting planes are at the time on August 1984.

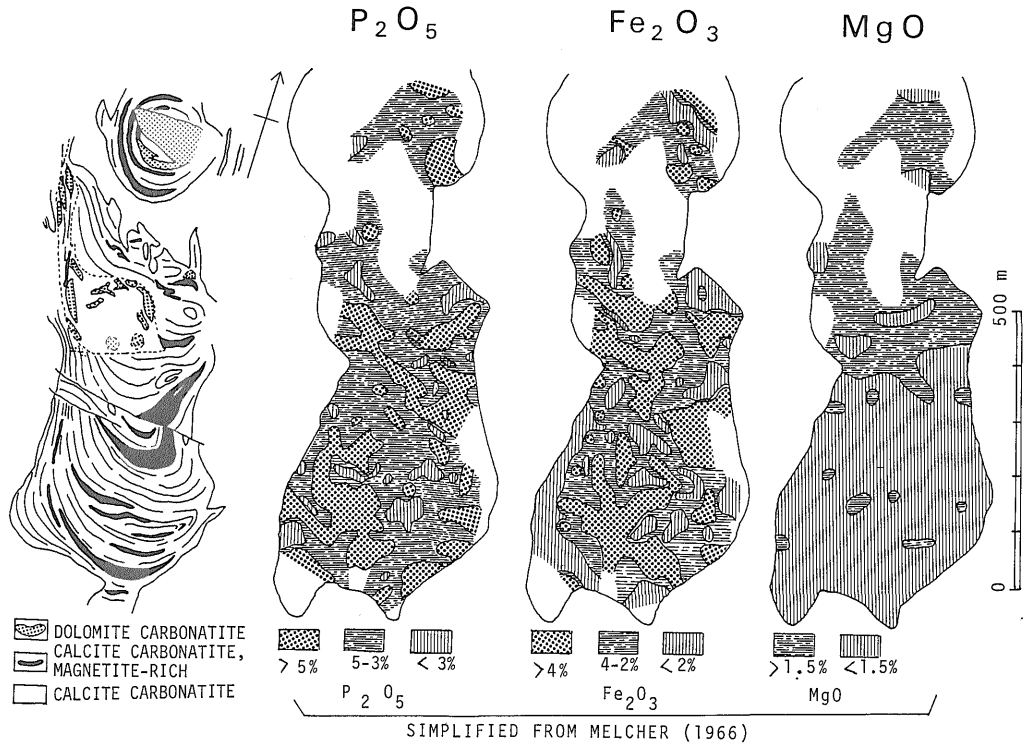


Fig. 5 Maps comparing with the lithology (left) and distribution of  $P_2O_5$ ,  $Fe_2O_3$  and  $MgO$  on the surface samples analysed by MELCHER (1966).

low hill about 100 meters above the surrounding clinopyroxenite. The highest level of the carbonatite body was 225 m above the sea level when the mining started. The topography of the carbonatites has been changed during more than 20 years by the mining activity; in 1985,

the highest and lowest elevation of the open pits were 160 m and 30 m above the sea level, respectively.

Distribution maps for  $P_2O_5$ , total  $Fe_2O_3$  and  $MgO$  were made by MELCHER (1966) based on more than 400 carbonatite samples from the sur-

Table 1 Classification and main features of Jacupiranga carbonatites

Rock name	Occurrence	Main carbonate mineral	Other major and accessory minerals (decreasing order of abundance)
Calcite carbonatite (CC)	Major constituent of the southern and northern plugs. Some CC intrude into other CC as sheets and dikes.		Apatite, magnetite, dolomite ± phlogopite ± olivine ± sulphides
Magnetite-rich calcite carbonatite (CCmt)	CCmt occurs as rhythmic bands in CC of both the plugs.	calcite	Magnetite, dolomite, phlogopite, apatite ± olivine ± sulphides
Apatite-rich calcite carbonatite (CCap)	CCap occurs as xenoliths and bands in CC, especially in the marginal zones of the southern carbonatite plug.		Apatite, olivine, magnetite, dolomite ± phlogopite ± sulphides
Fine to medium grained dolomite carbonatite (DCfg) and Coarse grained dolomite carbonatite (DCcg)	DCfg intrudes in the center of both the carbonatite plugs. DCcg occurs mainly in the center of the northern plug as rhythmic bands with DCfg. Some large crystals of dolomite develop from the wall of DCfg.	dolomite	Apatite, magnetite, phlogopite ± calcite ± sulphides

face in those days (Fig. 5). Our lithologic map in 1985 is also shown for comparison. Although the topography has been changed during the past 20 years, there is a good correlation between the maps of current lithology and of the past chemical data, especially in  $Fe_2O_3$  and MgO. This fact coincides with the high-angle structure of the carbonatite bodies (Plate I-3, -4). Distribution of high  $P_2O_5$  contents is caused by the high concentration of two types of apatite; fine-grained apatite in dolomite carbonatite of the northern and southern plugs and coarse-grained apatite in apatite-rich calcite carbonatite in the marginal zone of the southern plug. Distribution of high total  $Fe_2O_3$  is correlated to the thick bands of magnetite-rich calcite carbonatite. Dolomite carbonatite is responsible for the distribution of the high MgO contents.

### 3.2.1 Petrography

The Jacupiranga carbonatites are classified into the following four rock facies on the basis of their constituent minerals (Table 1).

**Calcite carbonatite (CC):** The calcite carbonatite (CC) is the majority of both the northern and southern carbonatite plugs.

CC showing weakly banded structure due to concentration of magnetite, is medium-grained, leucocratic rocks. It usually contains less than 10 percent mafic minerals ( $CI < 10$ )\* as shown

in Fig. 6. The constituent minerals are mainly fine- to medium-grained anhedral calcite (up to 5 mm in diameter) with columnar apatite, subhedral magnetite rich in MgO (BOCTOR & SVISERO, 1978; MICHELL, 1978) and bladed dolomite. Platy phlogopite (containing up to 10% BaO, GASPAR & WYLLIE, 1982), corroded olivine ( $FO_{93}$ , MICHELL, 1978), anhedral pyrrhotite, chalcopyrite and vallerite (BOCTOR & SVISERO, 1978) are sometimes observed. Clinohumite is also found as reaction rims around olivine (MICHELL, 1978). Some crystals of calcite and dolomite showing a worm-like texture, are exsolution rods of dolomite from the calcite host. This texture suggests a high-temperature origin of calcite.

**Magnetite-rich calcite carbonatite (CCmt):** The calcite carbonatite rich in magnetite (CCmt) occurs as bands in CC of both carbonatite plugs. CCmt is medium- to coarse-grained, mesocratic rocks ( $CI = 30$  to  $80$ ), composed of anhedral calcite (mainly 3 mm in diameter) and magnetite (3-15 mm in diameter) with dolomite, phlogopite, apatite, olivine and sulphides. Magnetite occurs as euhedral to anhedral crystals which sometimes includes euhedral apatite. Anhedral crystals of magnetite are considered to be the result of resorption in the carbonatite magma (MELCHER, 1966). Chemical zonations are commonly observed in magnetite crystals in which  $Fe_3O_4$  components increase toward the rim (GASPAR & WYLLIE, 1983). Olivine and

\* Color indexes, CI were measured on the area of about 25 cm<sup>2</sup> on the surface of sliced carbonatites, because of their heterogeneity.

phlogopite show corroded and subhedral forms, respectively. A worm-like texture of calcite host with dolomite rod is also observed. Dolomite occurs as bladed but anhedral crystals which sometimes include euhedral apatite.

**Apatite-rich calcite carbonatite (CCap):** Calcite carbonatite rich in apatite (CCap) occurs as xenoliths or bands in CC of the marginal zone of the southern carbonatite plug (Fig. 7).

CCap consists of medium-grained crystals of apatite (mainly 3 mm in diameter) and olivine with calcite, phlogopite and magnetite. Small amount of dolomite is also contained. Its mafic contents are rather variable, CI=1 to 30. Apatite contents are more than 40 percent of the rocks. Euhedral and subhedral crystals of apatite are sometimes surrounded by interstitial calcite and dolomite. Some crystals of apatite include globular carbonates that may show a primary composition of the Jacupiranga carbonatite magma. Olivine crystals in CCap are anhedral and show a wide range of the grain size. Some grains of olivine include euhedral apatite crystals.

CCap may represent the earliest facies of the carbonatite series magma based upon their modes of occurrence described above. CCap in Jacupiranga may correspond to phoscolite (foscolite) of the Phalaborwa alkaline carbonatite complex, South Africa (e.g., Palabola Mining Company, 1976) in term of mineralogical similarity.

**Dolomite carbonatite (DC):** Dolomite carbonatite (DC) occurs as small dikes in the central parts of both the carbonatite bodies.

DC is made up of dolomite with subordinate amounts of apatite. Almost all the DC contain less than 10 percent mafic minerals, such as phlogopite, magnetite and sulphides. Color index value of DC is 2 in average, which is lower than that of CC. Two types of DC, finer- and coarser-grained, are recognized in the Jacupiranga carbonatites. They shows a distinct banded structure due to the grain size of dolomite crystals. Their constituent minerals are the same in each other.

*⟨Dolomite carbonatite, fine-grained (DCfg)⟩*  
Constituent minerals of this rock are fine- to medium-grained anhedral dolomite (1 to 3 mm

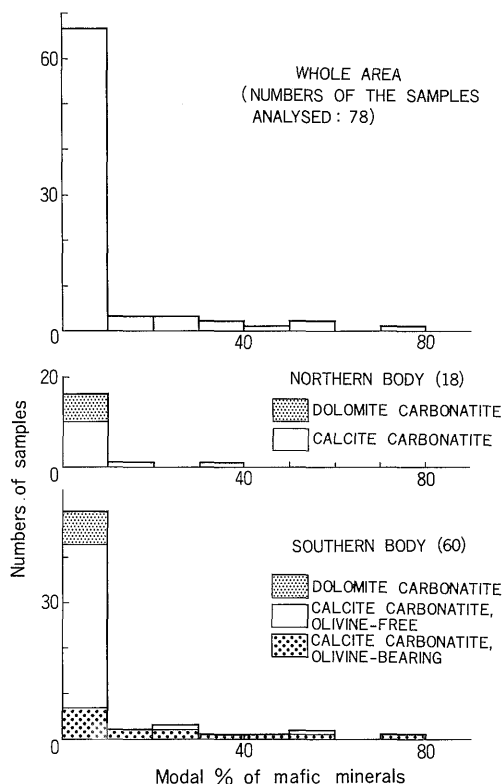


Fig. 6 Variation of mafic mineral contents in the Jacupiranga carbonatites. Number in parenthesis gives the number of analysed samples.

in diameter, 70 to 95 modal percent), acicular or columnar apatites (10 to 30 percent) with small amounts (2 to 8 percent) of subhedral to anhedral magnetite, phlogopite and anhedral calcite. Most of columnar apatites are distributed within anhedral crystals of dolomite. Aggregates of acicular apatite occurs as a veinlet in DC, associated with sulphides and phlogopite. Olivine with phlogopite rim is rarely observed in DC.

*⟨Dolomite carbonatite, coarse-grained (DCcg)⟩*  
This type of carbonatite (DCcg) occurs as bands in DCfg of the northern carbonatite plug. Most of dolomite crystals in DCcg are anhedral and coarse-grained (8 to 15 mm in diameter). Some of them are elongated perpendicular to the band (wall) of DCfg, suggesting that DCcg were formed after solidification of DCfg.

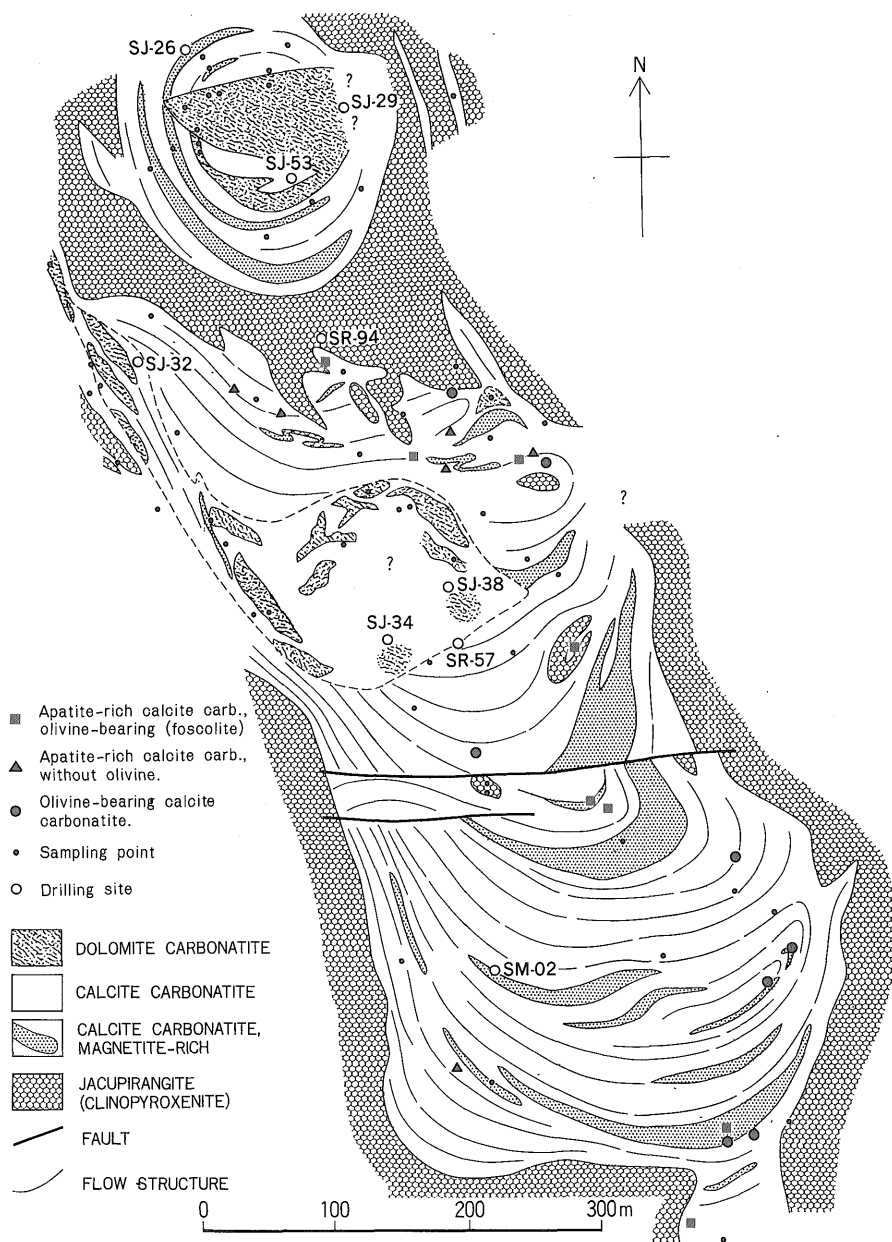


Fig. 7 Sampling points showing olivine-bearing and apatite-rich carbonatites. Dashed line in the southern body shows an area for concentration of dolomite carbonatite. Drill holes inferred in Fig. 8 are also presented.

Apatite occurs as aggregates of acicular crystals among coarse-grained dolomite. Subhedral crystals of magnetite and altered phlogopite are also observed.

### 3.2.2 Southern carbonatite body

The contact between the southern carbonatite body and the host jacupirangite-clinopyroxenite shows different patterns at nor-



thern and southern peripheries of the body. At the southern periphery, CC intrudes into the host jacupirangite-clinopyroxenite as dike swarms with nearly straight boundaries (see Plate I-1). On the other hand, CC of the northern margin is cutting and intruding in the host rocks giving a plastic deformation (Plate I-2).

At the border of the carbonatite body, there are many xenoliths of jacupirangite with the banded reaction zone composed of phlogopite, magnetite, alkali amphibole and thin veins of carbonate. It may be noticeable that the reaction zone is rather narrow as 0.1 to 1 meter wide, in the case of "the deepest type" carbonatite.

The southern body is mainly composed of CC with CCmt bands, showing a semi-concentric structure. DC intrudes as a bunch of small dikes in the northeastern part of the carbonatite body (Plate I-6). CC and CCmt exhibit mineral bandings due to mainly the magnetite concentration. These bandings are interpreted as flow structures (MELCHER, 1966). At the western

border of the southern body, the flow structure runs straight and parallel to the marginal contact, as shown in Fig. 3. The mineral banding at the northern margin of the body gently dips northward.

GASPAR & WYLLIE (1983) divided the southern body into three intrusive units; C1 (sovite as calcite carbonatite), C2 (dolomitic sovite) and C3 (sovite) in the order of intrusion. We did not find any outcrop where dolomite carbonatite is cut by calcite carbonatite. C3 defined by GASPAR & WYLLIE (1983) shows essentially the same mineralogy as C1. It may indicate that C3 is a part of the circular body, C1.

The drilling survey has been carried out extensively by Serrana Ltd. Some of the results are presented in Fig. 8. A vertical drill (SM-02) reached the jacupirangite situated under the calcite carbonatite at 374 m below the sea level. This fact suggests that the southern plug becomes narrower in the deeper level.

### 3.2.3 Northern carbonatite body

The northern carbonatite body is a pipe-like

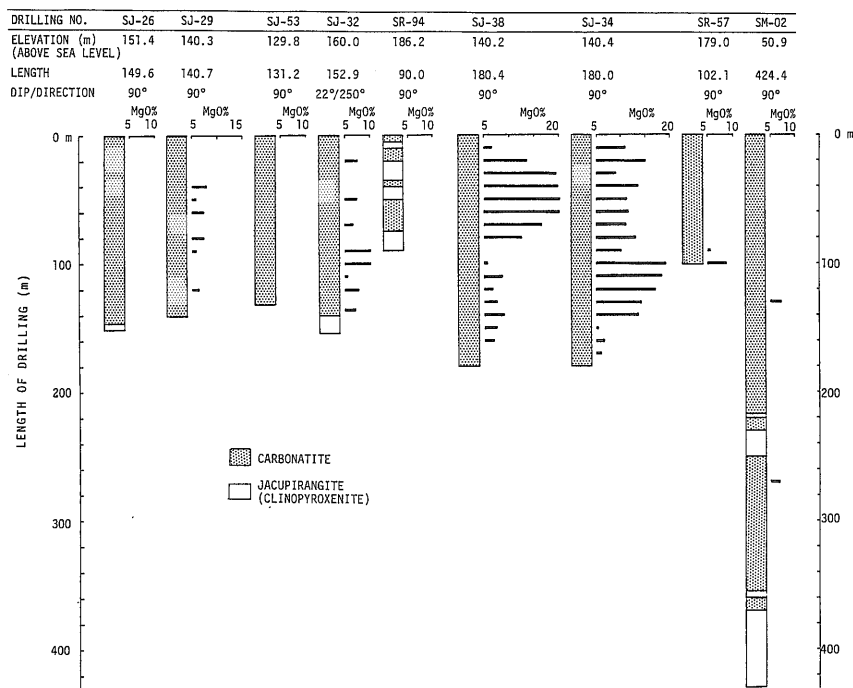


Fig. 8 Drill cores showing MgO contents in carbonatites. Samples were collected at each 10 m length of all drill cores and analysed by Serrana LTD.

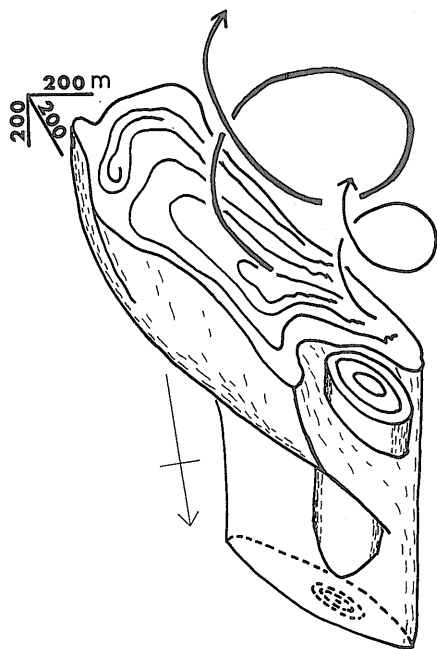


Fig. 9 Mode of emplacement of calcite carbonatites showing spiral intrusions. Dolomite carbonatites are omitted in this figure.

composite plug mainly composed of CC with the core of DC. CC associating with banded CCmt shows a distinct concentric structure with vertical dip. DC intrudes discordantly into the center of the plug.

Mineralogy of the northern CC and CCmt is essentially the same as those of the southern body except for the lack of olivine-bearing CC and CCap. DC of the northern body shows a distinct banding structure due to the grain size of dolomite crystals. The bandings has an east-west strike and a vertical dip. Coarse-grained dolomite carbonatite (DCcg) is younger than the fine-grained carbonatite (DCfg) because the dolomite crystals of DCcg elongate vertically on the wall of DCfg.

#### 4. Discussion

The distinct planer and linear structures are observed in most of the Jacupiranga carbonatites. They have the following features:

1. The banding structures are caused by the

concentration of the early-formed crystals, of mainly magnetite with or without apatite and olivine.

2. The bands are well developed especially in the calcite carbonatite.

3. They shows semi-concentric structures with the mostly vertical dip.

4. Magmatic cumulate (settled) textures, such as unsymmetrical size-grading and tightly packing texture of cumulates, are not seen in the carbonatite.

Item 3 may be characteristic of the dynamic flow suspended by early-formed crystals.

Similar banding structures are recognized in the old banded carbonatite of the Phalaborwa igneous complex, South Africa (PMC Ltd., 1976) and the Oka carbonatite in Canada (GOLD, *et al.*, 1967). They are also formed in the medium- to coarse-grained calcite-carbonatite.

Silicate dikes and sills, especially the more basic, show the rapid but gradual concentration of phenocrysts toward the centers (e.g. DREVER and JOHNSTON, 1967; GIBB, 1968; HEIMLICH and MANZER, 1973). This process is illustrated as a flow differentiation caused by migration of suspended phenocrysts from margins to centers during movement of the magma. The mechanism is examined by scale model experiments (BHATTACHARJI, 1967) and theoretical works (KOMAR, 1972).

This mechanism may be applied to the formation of the banding structure of the Jacupiranga carbonatite, which have intruded and solidified successively from the margin to the center of the plugs. Some of thin bands of magnetite may be a consequence of lamellae flows drawn out by compositional inhomogenities in the melt.

We can also observe a linear structure due to parallel arrangements of columnar apatite on the surface of banded calcite carbonatite. This lineation may be related to the final movement of the carbonatitic magma flow. A few measurements of the lineation are already shown in Fig. 3. All of them show the same spiral-sense in each other. If these lineations represent the general movement of the magma in the carbonatite plugs, both of CC plugs must have lifted up with a rotation, anti-screw sense (Fig. 9). This kind of the spiral intrusion may

also have developed the banding structure in CC.

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### References

- AMARAL, G. (1978) Potassium-argon age studies on the Jacupiranga alkaline district, State of Sao Paulo, Brazil. Proceedings of the first international symposium on carbonatites, p. 297-302. DNPM, Brasilia.
- BERBERT, C. O. (1984) Carbonatites and associated mineral deposits in Brazil. *Geol. Surv. Japan Rept.*, no. 263, p. 269-290.
- BHATTACHARJI, S. (1967) Mechanics of flow differentiation in ultramafic and mafic sills. *Jour. Geol.*, vol. 75, p. 101-112.
- BOCTOR, N. Z. and SVISERO, D. P. (1978) Iron-titanian oxide and sulfide minerals in carbonatite from Jacupiranga, Brazil. *Carnegie Inst. Wash., Year book 77*, p. 876-880.
- DEANS, T. (1966) Economic mineralogy of African carbonatites. In Tuttle, O.F. and Gittins J. eds., *Carbonatites*, p. 385-413. John Wiley & Sons, New York.
- (1978) Mineral production from carbonatite complexes: A world review, Proceedings of the first international symposium on carbonatites, p. 123-133. DNPM, Brasilia.
- DREVER, H. I. and JOHNSTON, R. (1967) Picritic minor intrusions. In Wyllie, P. J. ed. *Ultramafic and related rocks*, p. 71-82. John Wiley & Sons, New York.
- GARSON, M. S. (1966) Carbonatites in Malawi. In Tuttle, O. F. and Gittins J. eds., *Carbonatites*, p. 33-71. John Wiley & Sons, New York.
- GASPAR, J. C. and WYLLIE, P. J. (1982) Barium phlogopite from the Jacupiranga carbonatite, Brazil. *Amer. Mineral.* vol. 67, p. 997-1000.
- GASPAR, J. C. and WYLLIE, P. J. (1983) Magnetite in the carbonatites from the Jacupiranga complex, Brazil. *Amer. Mineral.* vol. 68, p. 195-213.
- and ——— (1983) Ilmenite (high Mg, Mn, Nb) in the carbonatites from the Jacupiranga complex, Brazil. *Amer. Mineral.* vol. 68, p. 960-971.
- GIBB, F. G. F. (1968) Flow differentiation in the xenolithic ultrabasic dikes of the Cuillins and the Strathaird Peninsula, Isle of Skye, Scotland. *Jour. Petrol.*, vol. 9, p. 411-443.
- GOLD, D. P., VALLEE, M. and CHARETTE, J. P. (1967) Economic geology and geophysics of the Oka alkaline complex, Quebec, Canadian *Inst. Mining Metallurgy, Bull.*, vol. 60, p. 1131-1144.
- HEIMLICH, R. A. and MANZER, G. K. Jr. (1973) Flow differentiation within Leopard rock dikes, Bighorn Mountains, Wyoming. *Earth Planet. Sci. Letters*, vol. 17, p. 350-356.
- HEINRICH, E. W. (1966) *The geology of carbonatites*. Rand McNally & Co. Chicago, 555p.
- HERZ, N. (1977) Timing of spreading in the South Atlantic: Information from Brazilian alkalic rocks. *Geol. Soc. Amer. Bull.*, vol. 88, p. 101-112.
- KOMAR, P. D. (1972) Flow differentiation in igneous dykes and sill: Profiles of velocity and phenocryst concentration. *Bull. Geol. Soc. Amer.* vol. 83, p. 3443-3448.
- LEBAS, M. J. (1977) *Carbonatite-nephelinite volcanism*. John Wiley & Sons, New York, 347p.
- MELCHER, G. C. (1966) The carbonatites of Jacupiranga, Sao Paulo, Brazil. In Tuttle, O. F. and Gittins J. eds. *Carbonatites*, p. 169-181. John Wiley & Sons, New York.
- MENEZES, L. A. D. Jr. and MARTINS, J. M. (1984) The Jacupiranga mine, Sao Paulo, Brazil. *Mineral. Record.* vol. 15, p. 261-270.
- MITCHELL, R. H. (1978) Manganoan magnesian ilmenite and titanian clinohumite from the Jacupiranga carbonatite, Sao Paulo, Brazil. *Amer. Mineral.* vol. 63, p. 544-547.
- PECORA, W. T. (1956) Carbonatites: A review. *Bull. Geol. Soc. Amer.* vol. 67, p. 1537-1556.
- PMC. LTD: Palabora mining company limited Geological and mineralogical staff (1976)

- The geology and economic deposits of copper, iron and vermiculite in Palabora igneous complex: a brief review. *Econ. Geol.* vol. 71, p. 177-193.
- RODEN, M. F., MURTHY, V. R. and GASPAR, J. C. (1985) Sr and Nd isotopic composition of the Jacupiranga carbonatite. *Jour. Geol.* vol. 93, p. 212-220.
- RODRIGUES, C. S. and LIMA, P. R. A. S. (1984) Complexos carbonatiticos do Brasil: Geologia. Companhia Brasileira de Metalurgia e Mineracao, Sao paulo. p. 1-17.
- TUTTLE, O. F. and GITTINS, J. eds. (1966) *Carbonatites*. 591p. Interscience Pub. New York.

ブラジル国サンパウロ州ジャクピランガカーボナタイト  
—その産出状態—

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要 旨

世界でも数少ない深部まで削剝されたジャクピランガ岩体(貫入年代: 130 Ma)の産状を記載した。カーボナタイトは、輝岩を主とするアルカリ複合岩体の中央部に、2つのプラグとして貫入している。両プラグとも、内核部はドロマイトカーボナタイト、外核部はカルサイトカーボナタイトからなり、外核部には急傾斜・同心円状の縞状構造(鉱物含有量のちがいによる)が発達している。この縞状構造の発達には、カーボナタイト質マグマの流動による分化作用と渦巻状貫入の結果であると推定した。

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Plate I

- 1 Dike swarms of calcite carbonatite (white) intruding jacupirangite-clinopyroxenite (black) with nearly straight boundaries. At the southern margin of the south carbonatite plug.
- 2 Carbonatite dike (white) intruding jacupirangite-clinopyroxenite (black) giving a plastic deformation. At the northern margin of the south carbonatite plug.
- 3 and 4 Mineral banding of calcite carbonatite showing nearly vertical structure in the south plug.
- 5 Folding structure of calcite carbonatite at the southeastern part of the south plug.
- 6 Dolomite-carbonatite dike cutting the calcite carbonatite in the south plug.

