GEOLOGY OF THE CLUGGER FLUORITE DEPOSIT, MATO PRETO, PARANÁ, BRAZIL

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ABSTRACT The Mato Preto fluorite deposits are located in the Ribeira River valley 80 km NNE from Curitiba, Paraná, Brazil. They consist of three known orebodies and numerous minor occurrences within an area of about 15 km². Clugger, the largest deposit, is a hydrothermal replacement and fracture-filling type in a brecciated and sheared contact zone among carbonatite, nepheline syenite, phonolite, and tinguaitite of the Cretaceous-Paleocene age Mato Preto Igneous Complex. Fluorite occurs as four subparallel but coalescing ore lenses which form envelopes about dikes of phonolite-tinguaitite and have strike lengths of 250 m, aggregate thickness up to 80 m, and extend to at least 120 m in depth. Dikes and lenses strike N50-55E and dip steeply to the northwest. Fluorite forms matrix replacements and crosscutting veins in premineral and intermineral breccias adjacent to dikes. Fluorite mineralization has been introduced in at least two pulses and is associated with barite-celestite, apatite, rare earth minerals, and sulfides. Late explosive venting of the system has formed pipes of volcanic breccia with crackle breccia in ore adjacent. Fluorite along breakage planes is recrystallized into monomineralic veinlets. Mineralization is associated with fracture controlled epidote alteration, but major silicification apparently predates ore. The Clugger deposit was probably formed at low pressures and temperatures, possibly within a vent of a now-eroded Mato Preto volcano.

RESUMO Os depósitos de fluorita de Mato Preto situam-se no vale do Rio Ribeira, 80 km a NNE de Curitiba, Paraná. Consistem em três corpos de minério e numerosas ocorrências menores numa área de cerca de 15km². Clugger, o maior dos depósitos, é do tipo substituição hidrotermal e preenchimento de fratura, em zona de contato brechada e cisalhada, entre carbonatito, nefelina-sienito, fonólito e tinguaito do Complexo Ígneo Cretácico-Paleocênico de Mato Preto. A fluorita ocorre como quatro lentes subparalelas e coalescentes de minério, as quais constituem envelopes ao redor de diques de fonólito-tinguaito, com extensões superficiais de 250 m, espessuras acumuladas de até 80 m e extensões verticais de pelo menos 120m. Os diques e as lentes têm direção N50-55E e mergulho acentuado para noroeste. Em brechas de eventos "pré e intermineralização", adjacentes aos diques, a fluorita substitui a matriz e forma veios inter cruzados, respectivamente. A mineralização foi introduzida em pelo menos dois pulsos e está associada com barita-celestita, apatita, minerais de terras-raras e vários sulfetos. Manifestações explosivas tardias do sistema formaram *pipes* de brecha vulcânica, assim como brechas do tipo *crackle breccia* no minério original. A fluorita, ao longo dos planos de fratura, encontra-se recristalizada em pequenos veios monominerálicos. A mineralização está associada a um processo de epidotização controlada por fraturas e posterior à silicificação principal. O depósito Clugger foi provavelmente formado a baixas pressões e temperaturas, possivelmente no conduto de um vulcão atualmente erodido em Mato Preto.

INTRODUCTION Although the important association of fluorine mineralization with silicic-alkalic igneous rocks is well documented in the geologic literature, the coincidence of major fluorite deposition with silica-undersaturated and carbonatitic rock types appears to be much less common. This report describes a large new fluorite deposit at Mato Preto, Brazil, in which mineralization is spatially associated with and probably genetically related to carbonatite, nepheline syenite, phonolite, and brecciated equivalents.

The Mato Preto fluorite deposits are located in the upper valley of the Ribeira River, northern Paraná State, Brazil, Curitiba, capital city of Paraná, is 80 km south-southwest, and Cerro Azul, a small agricultural community, lies 22 km to the west (Fig. 1). The deposits are located in thickly vegetated mountainous terrain at elevations of 400-535 m. Mineralization occurs at a number of locations in an area of about 15 km².

Three fluorite deposits have been investigated, but this report describes only the geology of the Clugger orebody, the most important in that it contains about 80% of known reserves. A later paper will describe its geochemistry. Information herein presented is the result of exploration conducted by Du Pont do Brasil S.A. during the period 1982-1985.

The Clugger orebody is the largest fluorite deposit presently known in Brazil with reserves of 2.65 million tonnes in proven and indicated categories. Average grade of the orebody is 60.0 wt%.

REGIONAL GEOLOGY The dominant lithologic units of the Ribeira River valley consist of low to medium grade metamorphic rocks of the middle to upper Proterozoic age Setuva and Açungui groups as well as granites and "granitoid" rocks of the Upper Proterozoic age Três Córregos Complex (Fig. 1, Tab. 1).

The rocks of the region are broken into a number of structural blocks separated by large northeasterly trending fault zones (Fiori *et al.* 1984, in Ronchi 1986). Faults are marked either by a single zone of movement and breakage or by a concentration of minor fractures. Several periods of reactivation are indicated. Each structural block is characterized by relatively distinct stratigraphy and structural orientation. The latter is thought to relate to rotation and/or inclination of individual blocks relative to others.

The Mato Preto locale lies essentially at the junction of two blocks, along the trace of the Morro Agudo fault zone. "Granitoid" rocks of the Três Córregos Complex crop out abundantly in the block to the west, while phyllites, quartzites, and marbles, tentatively assigned to the Água Clara Formation of the Setuva Group (Tab. 1), occur to the east. The fault has probably played an important role in the localization of Mato Preto mineralization.

Coincident with extrusive magmatism in the Paraná Basin to the west and north, igneous activity was renewed in the Ribeira River region during the Jurassic (Ulbrich & Gomes 1981). Numerous dikes of diabase or diorite were initially intruded along NW trending fractures, and these were

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Figure 1 – Location and regional geology of the upper Ribeira River valley, northern Paraná, southern São Paulo, Brasil (Algarte et al. 1972, modified)

followed by injection of phonolite dikes along NE and E-W structures and by the emplacement of several plugs, chimneys, and compound alkaline stocks with compositions ranging from limburgite to carbonatite. Petrologic studies of individual stocks at Itaipirapuã and Banhadão are described by Gomes (1970) and Ruberti (1984), respectively. Carbonatite at Barra do Itaipirapuã and Mato Preto is reported by Loureiro & Tavares (1983).

Table 1 – Regional stratigraphy of the Ribeira River valley (Compiled from Silva et al. 1981, Chiodi F^o 1984, Hasui et al. 1984)

Era	Period	Group or Formation	Lithologies
Mesozoic	Jurassic-Cretaceous	Alkaline intrusive rocks	Dikes, chimneys, and stocks of Banhadão, Itaipirapuã, Mato Preto, Tunas, Bairro da Cruz, José Fernandes and others
Proterozoic	Middle to upper	"Granitoid" rocks (Três Córregos)	Porphyritic to equigranular granite, microgranite and alaskite, more than half composed of hybrid mixtures of igneous material with Setuva rocks, Brazilian Cycle in age
		Açungui Group	meta-conglomerates, marbles, and calc-silicate rocks, generally immature
		Setuva Group	Includes: Itaipococa Formation, Água Clara Formation, Peraú Formation and Turvo-Cajati Sequence

Fluorite deposits at Mato Preto are among a number of occurrences discovered in recent years in the upper valley of Ribeira River (Silva et al. 1981, (Fig. 1). Although differing in details of geology, these deposits show a number of features in common. Mineralization is spatially associated with carbonatite and alkaline igneous rocks at both Mato Preto and Barra do Itaipirapuã. Fluorite occurs along E-W to NE trending zones of shearing and brecciation at Sete Barras,

Volta Grande, Brás, and several minor occurrences at Mato Preto. Deposits at Mato Preto and Barra do Itaipirapuã are mineralogically complex in that fluorite is associated with apatite, rare earth minerals, and sulfides.

LOCAL GEOLOGY Igneous complex Alkaline rocks and carbonatite of the Mato Preto Igneous Complex crop out sparsely over an area of about 4 km² to the north, northwest, and southwest of Mato Preto village. The complex is easily distinguished on 1:25,000 and 1:60,000 scale aerial photography as four adjacent circular structures with attendant radiating and concentric features. Each circular structure has a diameter of about 1 km (Fig. 2).

Rock types of the complex include large amounts of calcite and ankerite carbonatite, nepheline syenite, phonolite, and tinguaita with lesser quantities of ijolite, melteigite, and volcanic breccia. Abundant fragmental debris of one alkalic type in another illustrates a complicated age sequence. Alkalic rock nomenclature used here follows that of Streckeisen (1967).

Ankerite and calcite carbonatites are the most abundant rock types of the igneous sequence and form a central plug in each of the circular structures. Ankerite carbonatite appears to be somewhat more abundant in the area designated Mato Preto 1 (Loureiro & Tavares 1983), while the calcitic variety more widespread in the complex.

Nepheline syenite occurs in apparently isolated bodies near the margins of circular structures at the north end of Clugger and to the southeast of FS-P structure (Fig. 1). It is also found as float in trenches at Mato Preto 1 together with phonolite porphyry. Age relationships between them are not known.

Phonolite is abundant at Mato Preto and displays a complex history. Phonolite: porphyry shows a transitional contact with ijolite near the margin of the circular structure south of FS-P (Fig. 1). It also occurs as scattered float at Mato Preto 1 and as abundant fragments in carbonatite. A phonolitic tuff-agglomerate overlies carbonatite in an apparently flat-lying sheet over a broad area 0.5 km south of FS-P. Phonolite and tinguaita dikes occurring at Clugger are described elsewhere.

Rocks of the ijolite-melteigite series occur in small quantities near the margins of all four circular structures and also as float throughout the Pinheirinho region to the east. Ijolite appears to be much more abundant than melteigite, while urtite has not been recognized. Volcanic breccia is found as three small pipes at Clugger, several at Mato Preto 1 and one at Pinheirinho.

The southward extension of the Morro Agudo fault zone passes through rocks of the complex just to the south of Clugger where it trends about N60E. This zone of shearing and brecciation varies from 50 to 500 m in width and is manifested geomorphologically by linear stream valleys and otherwise truncated topography. The circular structures described above are terminated against the fault zone.

The Clugger orebody The Clugger orebody occupies a brecciated and sheared contact zone among calcite carbonatite, nepheline syenite, phonolite, and tinguaita in the northernmost circular structure of the complex. The orebody consists of four subparallel ore lenses which measure at least 250 m in length, 80 m in aggregate thickness and which have been drilled to a vertical depth of 120 m. They are oriented N50-55E and dip steeply to the northwest. Fluorite mineralization appears to form envelopes about thin phonolite and tinguaita dikes which cut carbonatite and nepheline syenite. The dikes range up to 20 m in thickness and are themselves partly mineralized. Fluorite lenses pinch and swell dramatically along strike and coalesce at depth in the central region of the orebody (Figs. 3, 4a, 4b, 4c).

Figure 2 – Geology of the Mato Preto Igneous Complex

Clugger fluorite consists of fracture fillings and selective replacements of reactive host rocks, mostly calcite carbonatite. Host rocks have been extensively brecciated by several processes (as described below), and fluorite has largely replaced breccia matrix. Distribution of ore is thus controlled both by placement of igneous dikes and by distribution and nature of breccias.

Figure 3 – Geology of the Clugger orebody, Mato Preto (+ = carbonatite or weathered equivalent; = weathered phonolite-tinguaite; triangle = volcanic breccia; stipple = fluorite mineralization (+ 34 wt%); stipple + bar = "fresh" phonolite-tinguaite; rectangle = nepheline syenite)

The Mato Preto region is strongly but erratically weathered. The orebody itself shows development of red

Figure 4 – Cross-sections of the Clugger orebody (legend same as Fig. 3; diagonal rule = epidote alteration; horizontal equals vertical scale)

lateritic soils at vertical depths to 70 m. Laterization, largely of carbonatite and phonolite, has produced hard compact soils, consisting of montmorillonitic clays, kaolinite, iron, and aluminum oxides; quartz and residual flakes of micas; and apatite. Dense concretionary masses of specular hematite, maghemite (?) and manganese oxides up to 10 x 10 x 20 cm also occur within 5 to 10 m of the surface. In ore, nepheline syenite, and volcanic breccia weathering products penetrate fracture surfaces and vugs but are easily removed by washing.

LITHOLOGIC DESCRIPTIONS The descriptions below apply only to rock units and ores present at Clugger. They are the result of outcrop mapping at 1:500 and 1:5,000 scales, study, and sampling of 1.6 km of surface trenches and 130 m of underground workings and logging of more than 6,500 m (76 holes) of NX wireline core. Fifty-eight thin sections were examined and studies were conducted using the electron probe microanalyzer and X-ray diffraction.

Rock Units CARBONATITE Calcite carbonatite is a dense white to light brown rock composed of a tightly

interlocking mosaic of subhedral to euhedral calcite. Grain size varies up to 10 mm but averages around 2 mm. Carbonatite at Clugger is seldom free from fragmental debris and is consequently classified as breccia. The term, carbonatite, is thus utilized to describe both breccias and clast-free varieties. Fragmented materials include phonolite, nepheline syenite, granite, and phyllite. Fragments are sometimes rounded but more commonly angular to subangular. They range in size up to 10 m but are usually on the order of 5 to 10 cm in maximum dimension. Trace minerals in carbonatite include alkali feldspar, biotite, apatite, zircon, perovskite, and monazite. None has been observed in quantity greater than 1 vol%.

NEPHELINE SYENITE It is a rock unit much less abundant than carbonatite at Clugger. It is exposed in trenches only to the north and west of mine coordinates, 10080N, 10100E (Fig. 3) and is also cut in drill holes of that area. The syenite is a pale yellow to brownish yellow rock composed of 60-80 vol% alkali feldspar laths in a matrix of nepheline, apatite, and aegirine-augite. Alkali feldspar prisms average 8 mm in length. Nepheline occurs as anhedral grains and aggregates comprising the bulk of matrix. Apatite as euhedral prisms to 2 mm makes up 5-8 vol% of the rock. Aegirine-augite is a trace constituent. At the 450 m elevation and below nepheline syenite appears to occur as a single mass but extends upward as two or three dikelike apophyses (Fig. 4a).

PHONOLITE AND TINGUAITE Phonolite and tinguaita occur throughout the orebody area as NE trending dikes (Fig. 3). Phonolite is a dense aphanitic to porphyritic-aphanitic rock of dark green to green-black color. It is composed of 40-70vol% anhedral to euhedral nepheline and 30-40vol% euhedral to subhedral aegirine-augite, with up to 25 vol% alkali feldspar (grading into ijolite and feldspathic ijolite). Phenocrysts of nepheline and very occasional alkali feldspar range to 1 cm in maximum dimension but are not abundant. Trace constituents include biotite, magnetite, apatite, and pyrite. Tinguaita is mineralogically similar, with more nepheline and less pyroxene. Its color is medium to dark green with strictly aphanitic texture. Phonolite and tinguaita may grade into one another along the trend of a single dike and are not mapped separately. In that phonolite also occurs as fragments in carbonatite more than one generation is indicated.

VOLCANIC BRECCIA Well-exposed in the northernmost trench at Clugger near mine coordinates 10125N, 10075E (Fig. 3), volcanic breccia there represents a pipe with a diameter of about 60 m. Smaller pipes occur to the south and west. Volcanic breccia is a somewhat porous, light brown rock composed of pyrite cubes, broken feldspar laths and fragmental debris in a matrix of glass shards. Fragment materials include violet fluorite, granite, quartzite, and phyllite and range to 15 cm in maximum dimension. Fragments are mostly subrounded to rounded, possibly in response to assimilation. The volcanic breccia pipes are thought to be the result of near-surface explosive activity. In that they appear to cut all other rock types and contain fragments of fluorite, they are certainly late in the intrusion-mineralization sequence.

ORE BRECCIAS Most of the ores at Clugger are brecciated to greater or lesser degree. Ores fall into four general types, disseminated, banded, massive, and recrystallized, each with its distinct style of brecciation. Banded and massive ores constitute about 85% of the orebody and recrystallized most of the remainder. Disseminated ores are volumetrically unimportant.

Disseminated material occurs in carbonatite host below the zone of laterization. It consists of single cubes and fine to medium-granular fluorite which most often replace calcite on the rims of fragments in breccia. Disseminated material is not

considered economic at the present time.

Paulo Adib Engenharia (1986a) calls attention to the banded nature of much surface ore. These breccias appear to be a product of inter-mineral movement on the Morro Agudo fault zone. Banding is manifested by subparallel alignment of breccia fragments, vugs, iron oxide-stained fractures, and post-fluorite quartz-chalcedony veinlets. Oriented layers have a few centimeters in thickness, and their trend is N50-70E with steep northwesterly or vertical dip. Breccias are largely matrix-supported, fragments comprising 10-70 vol% of the ore but averaging about 30%. Fragment size averages approximately 5 cm. The matrix is more or less completely replaced by fine to coarse-granular fluorite.

Banded material grades over distances of 1 m or less into massive breccia ores. These are very similar in character but lack preferred orientation. Fragment size may also range up to several meters, and vugs are somewhat more abundant. In some locations, notably the underground workings (mine coordinates: 10030N, 10080E, (Fig. 3), fluorite fragments occur in the fluorite-replaced matrix.

Adjacent to the large volcanic breccia pipe previously described, fluorite ore has been fractured into a coarse crackle breccia. Randomly oriented and crumpled fracture planes are spaced 10 cm to 1 m apart, and fragmentation extends up to 80 m from the central pipe. The crackle breccia localizes recrystallization in the ores and is particularly abundant north and east of mine coordinates, 10050N, 10100E (Fig. 3). The recrystallized ores consist of veins and veinlets of coarse to very coarse-grained fluorite which follow breakage planes in the crackle breccia. The veins range up to 1.5 m in thickness and frequently open into crystal-lined vugs, 5 to 15 cm in diameter. Fragments from the earlier breccias are rare to absent.

MINERALOGY Clugger ore is mineralogically complex (Tab. 2) with about 60 species now known from the ores, breccias, and altered wall rocks (Jenkins *et al.* 1984, Paulo Adib Engenharia 1986b, Nuclebrás, oral comm. 1986). This is

Table 2 – Mineralogy of the Clugger orebody

Aegirine-augite	1 R	Ilmenite	1 VR
Albite	1 C	Ilmenorutile	3 VR
Anatase	3 VR	Kaolinite	3 VC
Anglesite	3 VR	Maghemite (?)	3 R
Ankerite	1 C	Magnetite	3 C
Aragonite	3 C	Malachite	3 VR
Arfvedsonite	1 R	Molybdenite	2 VR
Barite	2 C	Monazite	2 R
Bastnaesite	2 R	Montmorillonite	3 VC
Biotite	3 VC	Nepheline	2 R
Calcite	1 VC	Opal	3 VR
Celestite	2 VR	Perovskite	1 R
Cerussite	3 VR	Phlogopite	1 C
Chalcopryrite	2 VR	Pyrite	2 VC
Chlorite	2 R	Pyrolusite (?)	3 R
"Crandallite"	3 R	Pyrrhotite	2 R
Diopside	2 R	Quartz	2 R
Dolomite	1 R	Rhabdophane (?)	2 VR
Epidote	2 VC	Rutile	3 VR
Ferrimolybdenite	3 VR	Sanidine	1 C
Fluorapatite	1 C	Scheelite	2 VR
Fluorite	2 VC	Siderite	1 R
Galena	2 VR	Sphalerite	2 R
Gearksutite	3 VR	Strontianite	3 VR
Goethite	3 C	Talc	3 VR
Grossular	2 R	Titanite	2 R
Gypsum	3 R	Tremolite	2 R
Hematite	3 C	Vanadinite (?)	3 VR
Hydrogrossular	2 VR	Wollastonite	2 R
Hydromica	2 C	Zircon	1 R

1 = wall rock; 2 = ore + hydrothermal alteration; 3 = soil + late alteration. VC = very common; C = common; R = rare; VR = very rare.

a function not only of the mineralization process but of the variety of host rocks. Replacement of each of the latter has produced overlapping but mineralogically and geochemically distinct suites. Weathering of each has added to the complexity.

At least, three generations of fluorite are present at Clugger. From oldest to youngest these are violet (disseminated and some massive), colorless to brown (massive and banded), and colorless-recrystallized.

Violet material occurs in the nepheline syenite area and in carbonatite below the zone of surface weathering. In the former case, it is medium to coarse-grained and is associated with barite, apatite, iron oxides, very minor pyrite, a crandallite, and other minerals. In carbonatite, it is fine to medium grained and associated largely with pyrite and epidote. In breccias containing fragmented fluorite the clasts are violet, the matrix colorless to brown. In drill holes DB-44 and DB-46 (mine coordinates: 10054N, 9931E, Fig. 3), carbonatite containing abundant violet fluorite is cut by large veins of brown material.

Colorless to brown massive or banded fluorite is abundant in the central and southern portions of the orebody. It is associated with apatite, monazite, bastnaesite, small quantities of pyrite, quartz, and other minerals. Vugs are partially filled with kaolinite, gerssutite, strontianite, aragonite etc. Similar vug fillings are present in openings in the recrystallized veins. Quantity of fluorite present varies with ore type (Tab. 3).

ALTERATION Hydrothermal alteration accompanying mineralization at Clugger has been obscured by surface processes. Any attempt at deciphering the alteration type and sequence must thus be largely confined to the carbonatites and ores cut by drill cores below 70 m.

The most prominent alteration types include replacement of calcite by silica $\pm$ fluorite $\pm$ pyrite and replacement of silicate minerals by epidote $\pm$ albite $\pm$ chlorite $\pm$ calcite. Kaolinization of feldspars in carbonatite may at least in part be related to hydrothermal processes.

Silicification accompanied by weak fluoritization and pyritization, well displayed at Mato Preto 1 and elsewhere at Mato Preto 2, probably represents a deuteric process within the igneous complex, perhaps unrelated to the activity which formed the Clugger orebody. Silicified carbonatite has only been observed in outcrop at elevations above 510 m. It may thus form an outer alteration shell within the carbonatite intrusion(s) of the complex. Late silicification has been described from many carbonatite complexes (Heinrich 1966) both as large irregular masses (Temple & Grogan 1965) and as planar zones controlled by fractures (Olson *et al.* 1954).

No temporal relationship has been firmly established between silicification and epidote alteration. Silicified carbonatite is cut by dike rocks in Clugger trenches, but the latter have been altered to montmorillonite and other minerals during weathering, obscuring any effect of epidotization. Silicified carbonatites are also cut by massive and banded ores which themselves contain sparse grains of epidote veined and embayed by fluorite. Silicification and epidotization may thus be contemporaneous, but it appears likely that the latter is somewhat younger.

Epidotization is a fracture-controlled alteration type, restricted to the vicinity of dikes. Its intensity falls rapidly within a few meters of an intrusion. Introduced fluorite and pyrite, both of which are later, occur well beyond the boundaries of epidote alteration, though in diminishing quantity (Fig. 5). Epidotization affects precursor minerals in the order: feldspar, pyroxene, nepheline, calcite. Quartz remains unaffected, and biotite is usually chloritized. Intense epidotization appears to be restricted to elevations below about 450 m, although this may be an effect of surface laterization. Epidote alteration occurs, however, with chlorite

and violet fluorite in brecciated phonolite porphyry and ijolite within 10 m of the surface at an elevation of 425 m about 0.7 km southwest from Clugger. This location is within the Morro Agudo fault zone.

Figure 5 – Mineralogic changes across epidote alteration zone, drill hole DB45, 10037N, 9954 E, Elev. = 524 m (Cc = calcite; Fl = fluorite; Py = pyrite; Ep = epidote; Di + Gr = diopside + grossular)

PARAGENESIS AND AGE OF MINERALIZATION Clugger mineralization is temporally divisible into three main stages (Fig. 6). They are easily distinguished based on color of fluorite, style of mineralization as well as trace mineralogy. Only the major phases are shown on the diagram.

Early violet fluorite was in part contemporaneous and in part later than epidotization and pyritization of the host rocks (A-B of diagram). Significant Ba-Sr mineralization was formed with the fluorite, particularly in the nepheline syenite. Apatite from the host rocks was incorporated in the ores.

Middle stage, colorless to brown, banded and massive ores were introduced during and after shearing and brecciation (B-C of diagram). Somewhat more pyrite and barite appear to have formed at this time, and fluorite deposition was succeeded by small quantities of quartz in cross-cutting veinlets and coatings. Some of these may be related to weathering.

Following explosive venting of the system fluorite in crackle breccia adjacent to vent(s) was recrystallized into a network of monomineralic veinlets (to right of C on diagram). It is unclear whether further fluorite was introduced at this time, but preexisting trace minerals appear to have been

Figure 6 – Paragenesis among major minerals of the Clugger orebody (A = emplacement of phonolite-tinguaitite dikes; B = intermineral shearing and brecciation; C = formation of volcanic and crackle breccias)

removed from the mineralization.

Subsequent weathering of the orebody area resulted in thorough leaching of carbonate minerals to depths up to 70 m, conversion of rock-forming silicates to clays, quartz, and iron oxide minerals and formation of new titanium and rare earth-containing phases. Except for oxidation of accompanying sulfides and deposition of late carbonate and oxide phases in vugs, fluorite was largely unaffected by surface processes.

Phonolite dike rocks from Clugger have been dated at 65.2 ± 3.3 Ma and 67.0 ± 3.4 Ma by whole rock K-Ar methods (Cordani & Hasui 1968). In that these rocks have been both epidotized and fluoritized these data provide a maximum age for mineralization. The volcanic breccias are undated but likely represent part of the same cycle of igneous activity. The Clugger deposit is thus considered to be late Cretaceous to early Paleocene in age.

GENESIS The intimate spatial and temporal association of the Clugger orebody with magmatic rocks, with rare earth, phosphate, and titanium-niobium mineralization suggest that the deposit is hydrothermal in origin. Figures 7a-d therefore illustrate one possible scheme for its evolution.

Figure 7 – Schematic cross-sections showing the evolution of the Clugger orebody (ns = nepheline syenite; p = phonolite; cb = carbonatite; pt = phonolite-tinguaite; ep = epidote alteration and low grade mineralization; vb = volcanic breccia, solid black denotes high-grade mineralization)

Figure 7a depicts injection of a central core plug of calcite carbonatite into nepheline syenite and phonolite (with small quantities of ijolite). Intrusive breccias are formed at the margins of the carbonatite body, and the latter is silicified above elevations corresponding to the present 520 m. Fluids

responsible for silicification deposit only minor fluorite and sulfides.

With renewal of shearing and brecciation along the Morro Agudo fault zone a swarm of NE-trending phonolite-tinguaite dikes is emplaced near the carbonatite-syenite contact (Fig. 7b) with subsequent epidote alteration and mineralization (Figs. 7b, c). Fluids affecting the later follow the planar conduits of the dike-host rock contacts and deposit ore minerals as envelopes about the dikes. The dikes themselves are to some extent fluoritized. Fluids introduce fluorite, epidote, sulfide minerals, barite, and some quartz. Apatite and monazite from the host rocks remain in the replacement ore.

At or near the close of activity explosive venting of the system forms pipes of volcanic breccia, resulting in development of coarse crackle breccias in ore adjacent. Fluids related to this activity or developing later utilize crackle breccia as channelways and effect recrystallization and enrichment of the ore (Fig. 7d). Present erosional level of the deposit is shown on figure 7d.

Any hypothesis for origin of the deposit is hampered by the current lack of fluid inclusion or isotopic data. Proximity of porphyritic-aphanitic to glassy igneous rocks suggests a relatively shallow depth of formation. Projection of elevations from the Primeiro Planalto Paranaense (Almeida 1952) indicates 400-500 m of post-Pliocene erosion, but further quantification is not possible. Similarly, association of fluorite with rather low intensity epidote alteration would seem to indicate a low temperature of formation, but no definitive estimation can be made.

Table 3 – Variations in CaF_2 content with ore type (values in wt%)

	Range		Average
	Low	High	
Disseminated (Violet)	< 0.1	40	28
Massive (Violet)	47	65	52
Massive and banded (Colorless)	55	70	61
Recrystallized	75	94.5	85

The circular structures outlining elements of the Mato Preto Igneous Complex, the pipes of volcanic breccia and the flat-lying phonolitic tuff-agglomerates all suggest the existence of a volcanic edifice at Mato Preto during the late Cretaceous with formation of the Clugger orebody in one of the vents. This edifice was possibly similar to the Napak, Kenya volcano studied by King (1949), but very limited outcrop and drill data outside of the orebodies make substantiation of a Mato Preto volcano difficult.

CONCLUSIONS With the exception of Barra do Itapirapuã, the fluorite deposits of northern Paraná align in a prominent E-W direction (Fig. 1). At Mato Preto and westward this lineation coincides with a belt of dikes, plugs, and small stocks, mostly of phonolitic composition. The alignment may be happenstance, in that genesis of different deposits appears to range from low temperature sedimentary replacement (Sete Barras, Lopes *et al.* 1980; Volta Grande, Ronchi 1986 to that of Mato Preto, but it may also relate to a Precambrian(?) source for Mato Preto fluorine.

The distribution of aeromagnetic and aeroradiometric anomalies show similar patterns. Ferreira & Algarte (1979) propose the existence of an alkaline magma chamber of approximately 400 km² extent, elongated E-W and underlying the general vicinity of Cerro Azul. The Mato Preto locale represents the intersection of the NE-trending Morro Agudo fault zone with this deeper crustal magma source.

The 2.65 million tonnes reserve of the Clugger orebody places it among the "world class" fluorite deposits. Nearly all of these exceptionally large deposits, notably those of Coahuila and Guanajuato, Mexico (Van Alstine *et al.* 1962), are associated with silicic-alkalic igneous rocks. Although other carbonatite-affiliated deposits are known (Heinrich 1966), Clugger is unusual both for its size and for its relatively high grade of mineralization.

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MANUSCRITO 444

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O desenvolvimento científico e tecnológico deve ser norteado pelos seguintes princípios: Proporcionar as condições necessárias para que o desenvolvimento econômico e social se faça de forma autônoma, de tal modo que se possa superar a dependência tecnológica do país e alcançar a melhoria das condições de vida da população. Propiciar garantias efetivas à autonomia da pesquisa científica... A pesquisa de materiais e de fontes de energia será orientada pela busca de alternativas à exploração de recursos naturais não renováveis, bem como da preservação dos recursos minerais estratégicos.

SBPC, 1987, proposta para a Constituinte