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Sociedade Brasileira de Geoquímica - SBGq

XIII International Geochemical Exploration Symposium

RIO 89 II Brazilian Geochemical Congress

Excursions

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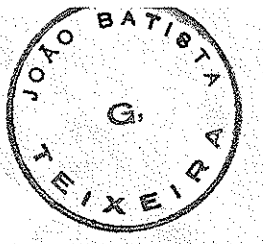

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RIO 89 II Brazilian Geochemical Congress

ESCOLA DE MINAS - DEGEO / UFOP
BIBLIOTECA

Excursions

PRELIMINARY EDITION

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ESCOLA DE MINAS - DEGEO / UFOP
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1. MINERAL PROVINCE OF CARAJÁS

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INTRODUCTION

The excursion to the mineral province of Carajás will consist of visits to mines and deposits as well as observations of outcrops and profiles of the main geological sequences that comprise the stratigraphy of the region.

The N4 Iron Mine, the Azul Manganese Mine, the N-5 Bauxite Deposit, the 3A Salobo copper deposit (Au, Ag, Mo) and the body number four copper (Zn) deposit at Pojuca will be visited. Also, representative outcrops of the Xingu Complex, Grão Pará Group, Rio Fresco Group and intrusive granites will be visited.

Geological data about the locations to be visited are presented here in the form of a summary. Discussions on the geology of these locations and on the stratigraphy of the province will be made during the excursion (fig. 1.1).

THE 3A SALOBO ORE DEPOSIT Cu (Au, Ag, Mo)

Location. The polymetallic deposit of Cu (Au, Ag, Mo) of the 3A Salobo is located on the right bank of the Igarapé Salobo, a left-bank tributary of the River Itacaiúnas, about 60km to the NW of the N4 Iron Mine, in the Serra dos Carajás (fig. 1.2).

History. The discovery of the 3A Salobo copper deposit occurred during a systematic programme of geochemical, geophysical and geological exploration of the Carajás Region, by DOCEGEO/CVRD at the end of 1984.

In 1977 copper anomalies of up to 2,700ppm were detected in stream sediments, collected in the Igarapé Salobo tributaries, which led to successive geological, geochemical and geophysical mapping of the prospect. In 1978, the first exploratory borehole in the area revealed the presence of copper sulphides associated with a body of magnetic shales. A detailed pattern of soundings and the opening of two research galleries permitted DOCEGEO, in 1971, to present a first evaluation of the deposit with a geological reserve of around 1.1 billion tons of mineral, having 0.8% of copper. In the period from 1985 to 1987, the research activities were carried out to characterize the various types of mineral content, to define the geometry of the workings, and to treat the mineral content at a pilot-plant level. Up to now, 38 thousand metres of surface and underground drilling have been carried out and 2,111 metres of galleries have been excavated.

Geology of the Deposit. The workings are constituted by a volcanic-sedimentary sequence called the Salobo Group. This unit encompasses poly-deformed rocks of the Archaen Age, sheared and metamorphosed in amphibolite facies with associated retrograde metamorphism. The assemblage has an elongated form in a WNW-ESE trend and shows a subvertical attitude. Diabasic bodies and granite cut the sequence.

The Salobo Group comprises two formations: the Três Alfa Formation and the Cinzento Formation (fig. 1.2).

Três Alfa Formation: This is a unit with Cu-Au-Ag-Mo mineralization. It has a mean thickness of around 250m and is mainly comprised of metasediments with subordinate volcanic contributions of a basic and intermediate nature. The

mineralization is hosted in ferrous siliceous oxide formations, constituted mainly of magnetite, with variable proportions of grunerite, phayalite, almandine and biotite. The most common sulphates are those of calcite, bornite and chalcopyrite. Based on the variation in the mineralogical constituents, textural aspects and chemical analyses, it was possible to characterize five of the most common lithological associations in the workings - schists 1 to 5. In table 1, description of the textural characteristics, mineralogical composition and chemical content of copper in the five lithological groups are found. Schist types 1 to 3 contain the main types of minerals present in the workings, and are ferriferous formations containing high proportions of magnetite (fig. 1.3).

The base of the Três Alfa Formation is comprised of gneisses with a light-grey colour and a fine to medium grain, composed of plagioclase (albite-oligoclase), quartz, chlorite and rare K-feldspar. They show occasional insertions of amphibolites, hornblendes, and metapelites.

Cinzento Formation: This unit represents the top of the Salobo Group, with a length of tens of kilometers and a mean thickness of around 200 metres. It is predominantly composed of medium-grain light-grey quartzites, occasionally containing a small proportion of k-feldspar. Sericite and chlorite are the most common accessories. The underlying contact with the Três Alfa Formation is marked by the presence of mostly mylonitic rocks hydrothermally transformed.

Reserves. The detailed geological work carried out between the period 1985 and 1987 permitted the ore evaluation reserves to be ascertained to be 157 million tons of ore sulphate, with an average of 1.21% Cu and 0.579g/t of Au, as well as marginal reserves of 485 million tons with 0.45% Cu and 0.199g/t of Au. Such reserves refer to the B and C bodies of the mine workings up to the O-level.

THE CORPO QUATRO ORE DEPOSIT Cu (Zn)

Location. The Cu (Zn) workings known as Corpo Quatro are located in the Pojuca area, about 25km to the SE of the Salobo 3A copper workings and 30km NW of the N4 Iron Mine (fig. 1.1).

History. The first indication of copper in the Pojuca prospect (the old MM1) were detected at the end of 1975, by Amazônia Mineração S.A. (AMZA), through soil geochemistry, the of which results divided the area into 4 anomalous bodies (C-1, 2, 3 and 4). Detailed and semi-detailed works consisting of geological mapping, geophysical and geochemical surveys, as well as excavations of shafts, led to the drilling programmes, which permitted a better understanding of the prospect. Since 1982, the research work was concentrated on the Corpo Quatro, where 14,000m of drillings and 225m of gallery excavations have been carried out up to now.

Geology. The deposit of Cu (Zn) of the Corpo Quatro seems to be part of the volcanic-sedimentary sequence known as the Pojuca Group, which is consituted by clastochemical sedimentary rocks forming the Corpo Quatro Formation enclosed in basic intermediate volcanic rocks (fig. 1.4). The assemblage is metamorphosed into amphibolite facies and has a strike of N45°W, wth dips of 60°SW to vertical.

Corpo Quatro Formation: The Corpo Quatro Formation is constituted by two lithological groupings: banded rocks, the mineralization hosts of Cu (Zn), and rocks with fragments (fig. 1.4).

- Banded Rocks: these are chemical sediments mainly composed of quartz, iron amphibolite, and sulphides. The rocks are at times magnetic, arranged in millimetric and centimetric bands, and frequently contain almandine and/or biotite. The sulphates are of pyrite, chalcopyrite and sphalerite, which occur either in fine bands or are dispersed. Occasional layers of chert and ferriferous bands are also found.

- Rocks With Fragments: the principal characteristic of this group is the existence of quartz in millimetric and centimetric agglomerates, frequently with angular outlines, immersed in an overtly hornblende matrix or with variable proportions of amphibolites, quartz, almandine, plagioclase and/or cordierite. They commonly present pyritic/chalcopyritic diffusions, at times sphaleritic. Such rocks are interpreted to be the reworked products of the underlying banded rocks.

- Metavolcanics: metavolcanic rocks with a basic-intermediate composition, frequently exhibiting hydrothermal alteration (assemblages of cordierite-anthophyllite, albite) host the Corpo Quatro Formation.

Reserves. The geological reserves of the Corpo Quatro are 48 million tonnes of ore with 0.9% Cu and 8.5 million tons of ore with 1% Zn, and traces of Cd (up to 300ppm), Ag (5-10ppm), Mo (30-70ppm) and, rarely, Au (1ppm) occur.

THE N4E IRON MINE - SERRA DOS CARAJÁS

The N4E iron mine, owned by Companhia Vale do Rio Doce, is located in the Serra dos Carajás in the State of Pará. The workings form part of the complex of iron ore bodies of the Mineral Province of Carajás.

In operation since January, 1986, the N4E ore body is until now the only one being mined by CVRD within the Mineral Province of Carajás. Its reserve was estimated at 1.2 billion tons of iron ore, with an average of 66% Iron.

The lithotypes occurring in the N4 workings in the Carajás Formation belong to the Grão Pará Group. The Carajás Formation is locally comprised of a banded iron formation which is associated with the iron ore bodies, positioned between two sequences of paleovolcanic rocks. Until now it has not been possible to detect the presence of the Upper Paleovolcanic Sequence within the confines of the workings.

For practical purposes the N4 workings were divided into two areas known as Aba Norte and Aba Sul. These are adopted nowadays for the classification of the mining of the hematitic ores, which exist in the workings in two main types, crumbly hematite and compact hematite. These are divided into sub-types in accordance with their physical and chemical characteristics. The mining method used in the N4 workings is open pit, distributed in benches 15 metres high, mined by BUCYRUS excavators, of 9-cubic -yard capacity (40 tons) and transported by 170-ton HAULPACK trucks. In the compact ore the conventional blasting method is used.

The production of the workings has evolved over a long period. In 1986, 15 million tonnes were produced, in 1987, the production reached 23 million tons, and for 1988, a total of 30 million tons was expected.

THE AZUL MANGANESE MINE

The Azul Manganese Mine is 28km from the N4 Iron Mine, of Carajás. It was discovered in September, 1971, during a geological survey by Amazônia Mineração S.A.

In 1985, Vale do Rio Doce initiated the ore production together with the installation of an ore mill unit within the area of Azul.

On the surface, the mineralized area appears as an elongated body with a width of 50 to 300 metres and 4.300 metres in strike. From the drilling data, Bernardelli and Beiseigel (1978) presented the following stratigraphic column for the area, interpreted as belonging to the upper pelitic package of the Rio Fresco Group:

- at the base, about 65 metres of siltites and light-grey to black argillites, with less than 40% Mn.
- lower manganiferous unit (18 to 40 metres) with 21 to 26% Mn.
- dark grey to black carbonaceous siltites (±50 metres), with 4% Mn.
- light and dark grey, and violet siltites (17 to 40 m), with less than 5% Mn.

Upper manganiferous unit (33 to 54 metres), with about 15% Mn.

- At the top, a brownish to redish coloured siltites (70 metres) with 6% Mn.

Three types of manganese ore are classified for the Azul deposit: Protore, Surface Deposits and Subsurface Deposits.

The subsurface ore are classified as: Manganiferous Pelites, granulated Manganiferous Material, high-density Manganiferous Material, Siltites impregnated with Manganese, and siltites enriched with manganese. Of these, the manganiferous pelites, the granulated manganiferous material, which contains electrolitic ore, and the dense manganiferous material have economic importance. The last two are used only when they occur in close proximity to the other two.

The surface deposits are represented by pisolites, blocks, plates and manganiferous breccias. These are structural materials and their formation was affected by weathering action, topographical conditions and variations in the water table.

Table nº 2 represents the geological reserves and the exploitation ratio, by type of ore.

BAUXITE N5 - CARAJÁS

The Carajás aluminium deposit stretches over part of a plateau that becomes the N5 clearing. The bauxite-forming process occurs over the basic rocks (mafics) of the Lower Paleovolcanic Formation of the Grão-Pará Group.

Based on the prospecting drill-holes, a reserve of 48 million tonnes of ore has been calculated, with an average of 35% Al_2O_3, 1.7% reactive SiO_2, 25% Fe_2O_3 and 4% TiO_2. The layer has a thickness of 4.5 metres.

The N5 Bauxite Deposit is situated 2.5 km away from the end of the Carajás railway. As well as this advantage, this ore deposit has a thin overburden with a favourable stripping ratio, and low reactive silica.

XINGU COMPLEX

At the edye of highway PA-275, 15 km away from Rio Verde, the Xingu Complex rocks crop out.

These rocks vary from homogeneous gneissic rocks, with slightly developed bands and foliation marked by the direction of mafic minerals, to gneissic rocks with an accentuated degree of migmatization with varying compositions of mafic and felsic rocks.

The petrographic study reveals a variation from inequigranular granoblastic to porphyroblastic texture. In the portions richest in mafic ores the texture becomes granolepidoblastic. It is basically composed of plagioclase, alkaline feldspar, quartz, mica and greenish prismatic minerals (amphibolite). The plagioclase normally shows an alteration to serecite and epidote. The amphibolite, of the hornblende variety, exhibits partial transformation to epidote.

RIO FRESCO GROUP

A sand pit, located on the access road to the Carajás stone quarry (see fig. 1.1), permits part of the psammitic sequence of the Rio Fresco Group to be exhibited. The sandstones are slightly metamorphosed, predominantly coarse to medium-grained with subordinate fine siltite inserts. Their colour pattern varies from cream to yellowish to reddish (layers with the highest percentage of iron oxides).

The rocks are essentially constituted of quartzite grains in a micro-crystalline quartz matrix, sericite (locally recrystrallized to muscovite), and iron oxides in various proportions. In general, they present a low degree of selectivity. The quartz grains show a roundness from very angular to sub-angular with diameters ranging from 0.15 to 1.00 mm. Microscopical-

ly, the quartz presents normal extinction to rarely undulate. The most conspicuous sedimentary structure is the cross-bedding layers.

DOCEGEO (1988) considers that the Rio Fresco Group was deposited between ±2,600 to ±1,800 M.Y., or more probably, between ±2,000 and 1,800 m.y.

GRÃO PARÁ GROUP (RAILWAY TERMINAL)

In the northern part of the N4 Iron Mine, on the Carajás Pará Railway, there is a typical outcrop of metavolcanic mafics of the lower sequence of the Grão-Pará Group.

There, the mafic metavolcanic rocks show textural variations from dense rocks, with plagioclase phenocrysts and clinopyroxene in a phaneritic matrix, to a less porphyritic mafic rock with vesicles. Foliation is not seen, at least in hand samples, but a high degree of fracturing is visible.

In sheets, these rocks vary from less than 1 mm to medium (1-3 mm) granulation, in the majority of cases exhibiting a hypocrystalline texture. Relatively equivalent quantities of plagioclase and euhedral clinopyroxenes occur with a lesser quantity of intergranular clinopyroxenes. The finest varieties, brown-greenish interstitial alteration minerals, occur as interstitial volcanic glass. In addition, oxides, titanite and apatite occur. Vesicles of various sizes are generally filled with zoned assemblages of chlorite, quartz, calcite, epidote and amphibolite. In some samples, scapolite occurs in association with chlorite and biotite.

CIGANO GRANITE

A massive granite named "Cigano Granite", situated to the northeast of Serra dos Carajás, is a batholith with a stock shape (20 x 15 km). The granite is intrusive into Archaean units (Xingu Complex and Pojuca Group) and the Lower Proterozoic (Rio Fresco Formation). The granite body is constituted of monzogranites with subordinate syenite-granites. Five petrographic facies were identified (Gonçalez, G.B., 1988), of which the essential paragenesis is formed of quartz, plagioclase and K-feldspar. The ferromanganiferous minerals in the two earliest facies are represented by biotite and hornblende. In the rest of the facies, the only significant mafic is biotite. The effects of hydrothermal processes on these facies are extremely intense, frequently resulting in quartz veins associated with epidote, sericite, chlorite, carbonates and sulphides, with small occurrences of greisen. Geochronological data obtained by Machado et alii (1988) by the U/Pb method in zircons indicate an age of 1,885 m.y.

CARAJÁS GRANITE

The granite batholith of Carajás has an elongated body with approximate dimensions of 22 x 12 km. It is well exposed in the "CINCOP stone quarry" on the Serra Sul road (fig. 1). Its essential constituents are alkali-feldspar, plagioclase, quartz, biotite and hornblende. In general it shows a coarse-grained hypidiomorphic, porphyritic (subordinately) texture. Rapakivi texture is also common.

One of the main petrographic features of the granite is the predominance of alkali-feldspar (up to 60% of the whole rock), represented by orthoclase crystals, normally altered and rarely generated according to the low of Carlsbad (Alemeida, R.C.C., 1988). Plagioclase (orthoclase) is less abundant than the quartz and feldspar, and is visible as subhedral crystals, normally altered to epidote, sericite and, sometimes, carbonates (Alemeida, R.C.C., op. cit.)). Apatite, zircon, opaques, fluorite, epidote, calcite and alanite are the most frequently encountered additions.

Field work, carried out by DOCEGEO geologists, clearly defined the intrusive character of the Carajás granite metarenites of the Rio Fresco Group. Gibbs et al. (1988) dated this granite as 1820±49 m.y., using the U/Pb method on zircons.

Table nº 3 shows the chemical composition and granite sample norms from Carajás (Alemeida, R.C.C., op cit.).

GRÃO-PARÁ GROUP

In this profile there is a good exhibition of saprolites of the Lower Metavolcanic Sequence of the Grão-Pará Group. Mafic metavolcanic rocks with various textures can be seen, together with metavolcanics and felsic tuffs and intermediate and volcanic breccias.

Wirth, K.R. (1986) described in detail the geology and geochemistry of the Grão-Pará Group in this locality. The metavolcanic mafic mainly consists of dense flows. Two texture predominate in the mafic volcanic rocks. The first type is common in dense flows, and is characterized by plagioclase phenocrysts in a phaneritic matrix. The second type of texture is less porphyritic and has an altered aphanitic matrix. This texture is common in the vesicular portions of the flow and is characteristic of the edges of the flow units.

According to Wirth, K.R. (op. cit.), the felsic volcanic rocks form approximately 10-15% of the Grão-Pará Group. They include felsitic flows and volcanic tuffs and breccias. Layered felsic tuffaceous volcanoclastic rocks are well represented by the sapolites exposed in this profile. One can observe tuffs of lithic crystalline layers with 2-5 cm thicknesses and filled with fragments of volcanic felsites generally of less than 1 cm in diameter. Some sublet quartz phenocryst is also present. The layered tuffs range from coarse volcanic breccias with fragments of volcanic and felsitic rocks, typically angular, irregular and with diameters of up to 20-30 cm. Altered massive volcanic mafics are also represented in this profile. In thin-sections and in the hand samples collected a long way from the drainages, the rock composition is about 10-20% of quartz and feldspar phenocrysts and lesser quantities of ferromanganese ores. [illegible]ddition zirconite, alanite and opaque ores occur. The matrix is typically composed of quartz and feldspar, with a lesser quantity of amphiboles, biotite and chlorite, all fine-grained. Zircons from these felsic rocks were dated by Gibbs and Wirth (19[illegible]7) by the U/Pb method as being 2,700 m.y.

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Table 1 – Classification of the Schists of Salobo 3A.

Lithology	Mineralogy		Structure	Copper
	Principal	Subordinate		
1	Magnetite ≥ 50%	Garnet, biotite, fayalite, grunetite, grafite, fluorite	Derse in general (eventually banded)	≥1,5%
2	Garnet, grunerite	Biotite, quartz, ≤10% magnetite	Isotrope and partially foleated	Generally less than
3	Biotite, garnet, magnetite (10/50%)	Fayalite, quartz, grunerite (plagioclase)	Foliated/banded	0,5 a 1,5%
4	Biotite, garnet	Grunerite, quartz ± fayalite ± plagioclase, <10% magnatite	Foliated, banded	Generally less than 0,5%
5	Quartz, plagioclase, biotite, amphibolite	± Garnet	Laminated; fine granulation	Less than 0,5%

Table 2 – Azul Manganese Reserves (x 1.000t)

Ore Type	Geologic Reserves	Workable Reserves	Mean Mn Chemical Reserves
Detric	26.078	22.090	36,91%
Electrolitic	11.488	10.875	46,36%
Peltic	27.662	27.204	28,51%
Total	65.248	60.169	35,00%

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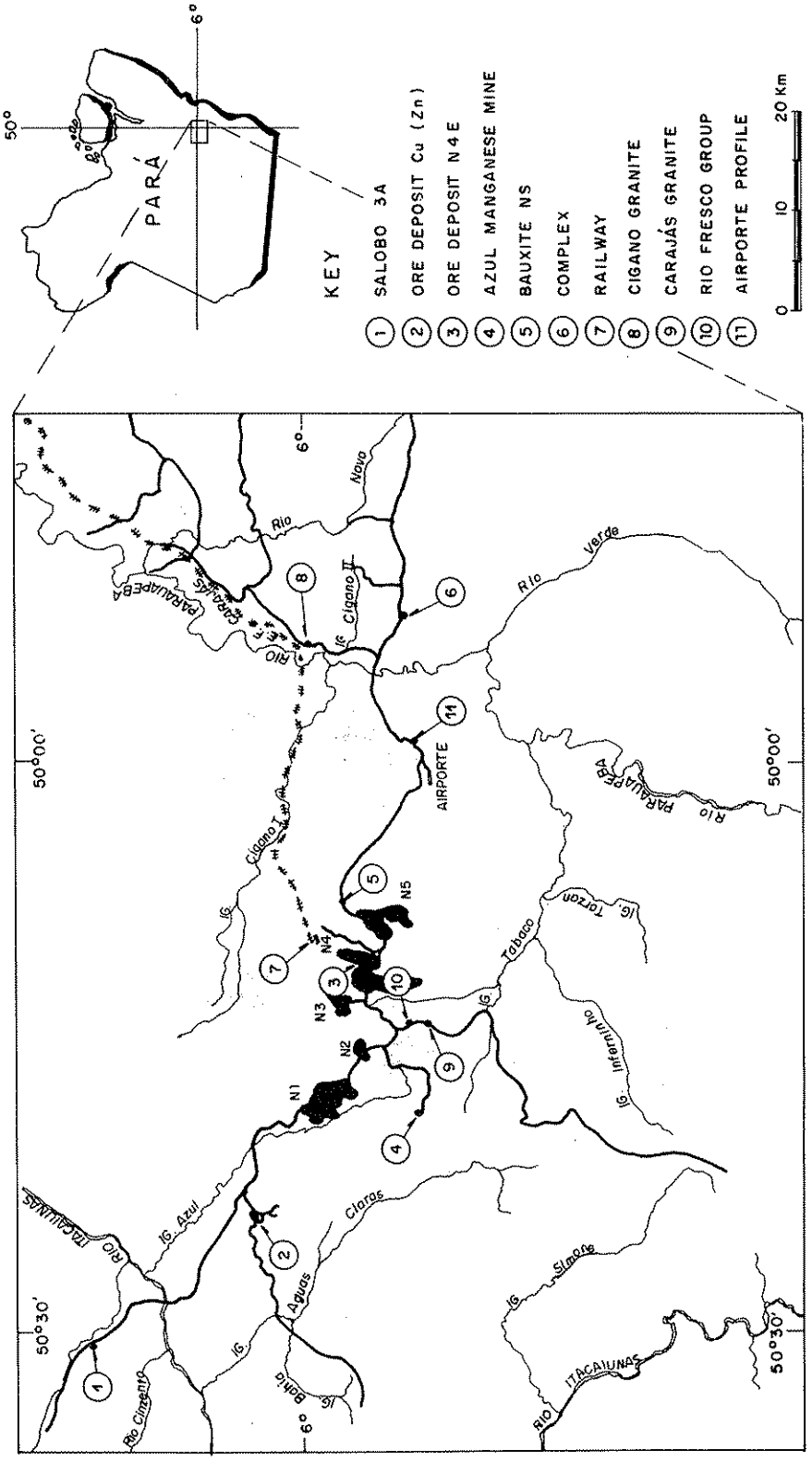
BIBLIOTECA

Table 3 – Chemical and Normative Sample Composition of the Carajás Granite.

	11	20	45	43
SiO_2	67,20	73,72	71,00	67,40
TiO_2	0,54	0,13	0,21	0,81
Al_2O_3	11,36	11,43	12,20	11,50
Fe_2O_3	2,06	1,53	0,92	3,09
FeO	5,30	1,47	1,99	5,08
MnO	0,05	0,03	0 ,03	0,05
MgO	0,62	0,20	0,38	0,80
CaO	2,80	1,36	1,64	3,04
Na_2O	1,69	2,02	2,36	3,71
K_2O	5,07	5,52	6,30	2,28
P_2O_5	0,29	0,27	0,30	0,37
H_2O^+	1,94	1,35	1,45	1,46
H_2O^-	0,24	0,18	0,34	0,46
Total	99,16	99,21	99,12	100,05
Standards				
Q	29,17	36,91	28,47	28,11
Or	32,05	34,30	39,00	14,15
Ab	16,20	19,05	22,15	34,85
An	9,00	5,25	4,22	8,35
C	–	0,33	–	–
Di	3,08	–	1,28	3,96
Hy	6,72	1,66	2,46	5,22
Mt	2,29	1,68	1,00	3,37
Il	0,80	0,18	0,30	0,18
Hm	–	–	–	–
Ap	0,64	0,59	0,64	0,80



EXCURSION Nº 1 - THE MINERAL PROVINCE OF CARAJÁS (LOCATION AND ROUTE)

Fig - 1.1

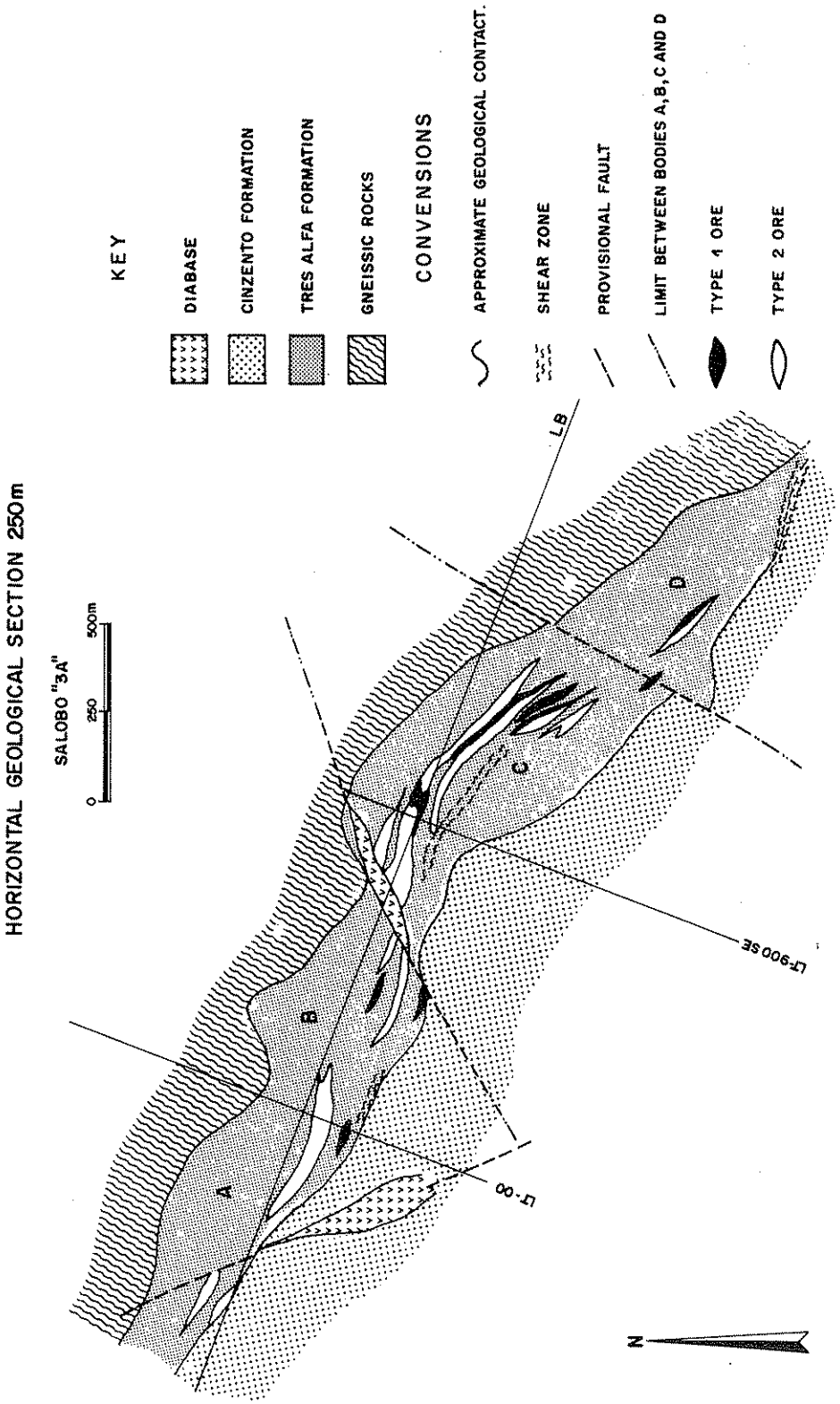

HORIZONTAL GEOLOGICAL SECTION 250m
SALOBO "3A"
0
250
500m
KEY
DIABASE
CINZENTO FORMATION
TRES ALFA FORMATION
GNEISSIC ROCKS
CONVENSIONS
APPROXIMATE GEOLOGICAL CONTACT.
SHEAR ZONE
PROVISIONAL FAULT
LIMIT BETWEEN BODIES A,B,C AND D
TYPE 1 ORE
TYPE 2 ORE
LB
LT-00
LT-900 SE
A
B
C
D
N

Fig-1.2

VERTICAL GEOLOGICAL SECTION 900 SE

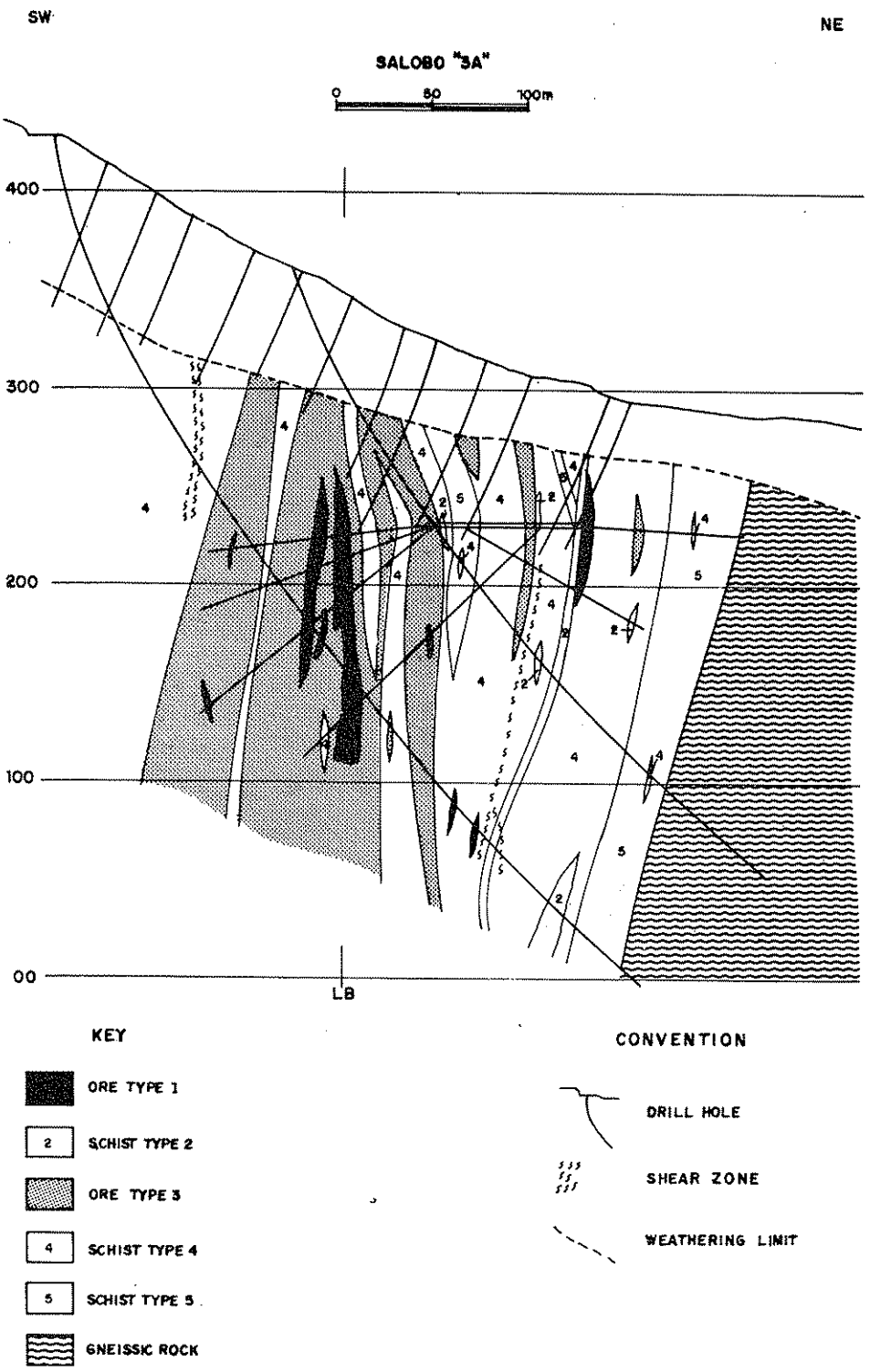


Fig-1.3

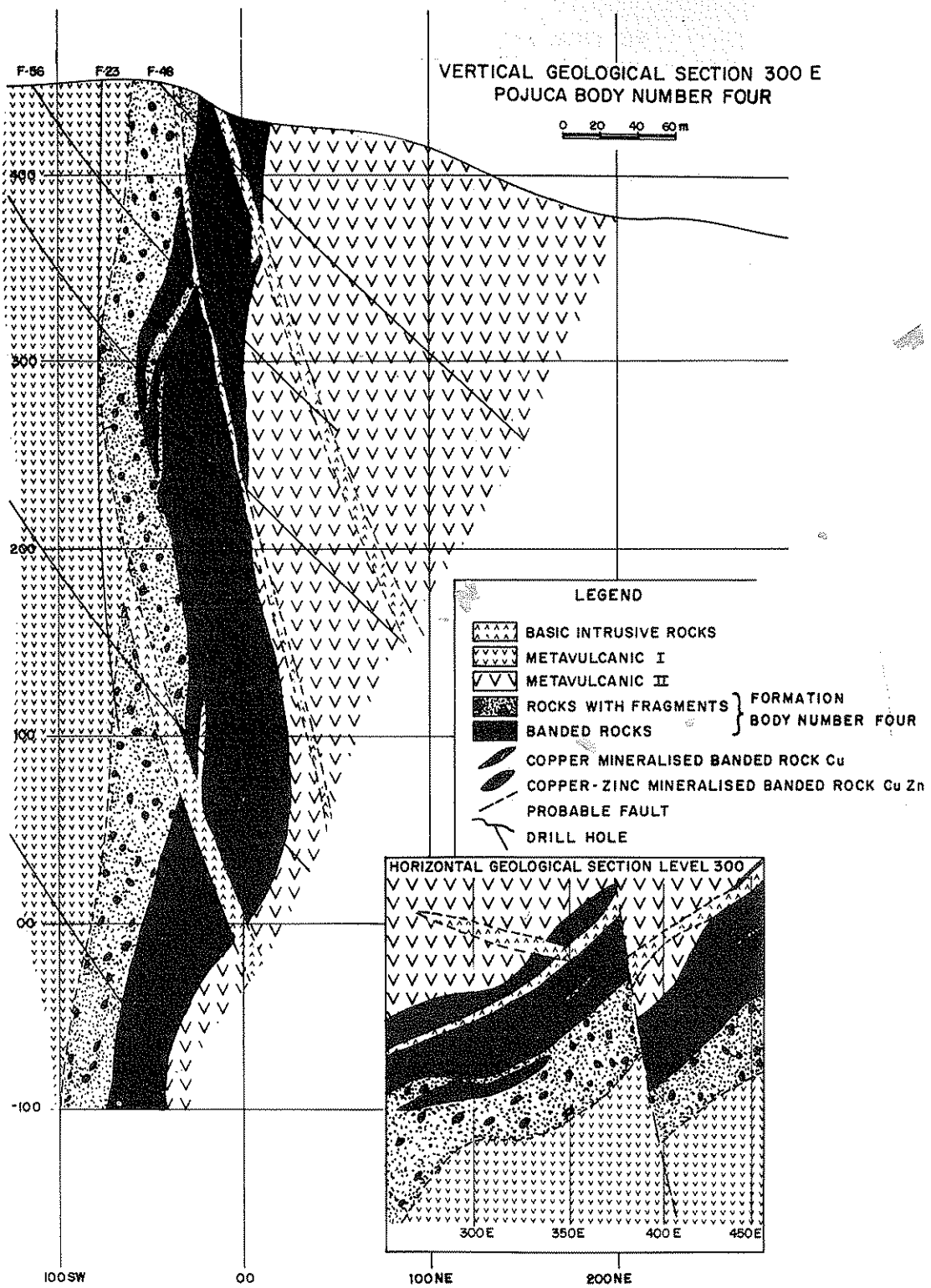

VERTICAL GEOLOGICAL SECTION 300 E
POJUCA BODY NUMBER FOUR
0 20 40 60 m
F-56
F-23
F-46
300
200
100
00
-100
100SW
00
100NE
200NE
LEGEND
BASIC INTRUSIVE ROCKS
METAVULCANIC I
METAVULCANIC III
ROCKS WITH FRAGMENTS
BANDED ROCKS
FORMATION
BODY NUMBER FOUR
COPPER MINERALISED BANDED ROCK Cu
COPPER-ZINC MINERALISED BANDED ROCK Cu Zn
PROBABLE FAULT
DRILL HOLE
HORIZONTAL GEOLOGICAL SECTION LEVEL 300
300E
350E
400E
450E

Fig- 1.4

2. "QUADRILÁTERO FERRÍFERO"

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INTRODUCTION

The Quadrilátero Ferrífero (Fig. 2.1) is situated in the center of the State of Minas Gerais. Its area covers about 7,000^2. Its name is derived from its configuration, a quadrilateral, and from its enormous iron ore reserves. This "quadrilateral" is approximately limited by the coordinates:

44°W - 43°22'30"W

19°45'S - 20°37'30"S

Only some small areas, especially one near Itabira, fall outside these limits. Belo Horizonte, the capital of the State of Minas Gerais is situated in the NW of the quadrilateral, and today it has about three million inhabitants. The old capital, Ouro Preto is at its southern extremity. These two cities are the largest ones within the Quadrilátero Ferrífero. The priciple state industries are concentrated in Belo Horizonte, amongst which steelworks and the automobile industries stand out. Iron ore extraction is carried out in innumerable mines spanning the Quadrilátero Ferrífero. Tourism is a highly developed activity in the historic cities of Ouro Preto, Mariana, Sabara and Congonhas.

The region has a moderate subtropical climate, with an

06.10.89 - Friday - Evening, leave Rio de Janeiro for the airport of Confins. Overnight stay in Belo Horizonte.

07.10.89 - Saturday - Belo Horizonte - Itabirito

Excursion A — The Quadrilátero Ferrífero, tectonics, stratigraphy, petrography, and lithogeochemistry. Visit to the Iron Mine of Capanema. (Overnight stay in Belo Horizonte.)

08.10.89 - Sunday: Belo Horizonte-Ouro Preto

Morning: Free to visit the historic city of Ouro Preto which was declared a historic monument by UNESCO in 1980.

Afternoon: Visit to the Mineralogy Museum of the School of Mines. Visit to the old library of the School of Mines and later a visit to a Topaz Mine. (Overnight stay in Belo Horizonte.)

09.10.89 - Monday - Belo Horizonte - Ponte Nova

Excursion B — The transition between the "Quadrilátero Ferrífero" (Craton São Francisco) and the mobile belt of East Brazil.

Metamorphic rocks of various types from low to high degree. Visit to a soapstone mine. Aspects of geochemical prospection for gold. (Overnight stay in Belo Horizonte.)

10.10.89 - Tuesday: Belo Horizonte-Sta. Bárbara.

Morning: Visit to the gold mine at São Bento.

Afertnoon: Return to Rio de Janeiro.

average annual temperature of 20°C; the summer average being 22°C and that in winter being 18°C. The range between daytime and nightime temperatures can be large. The absolute temperatures vary from around 5°C in winter to 35°C in summer. Temperatures lower than this are rare. The year fundamentally divides into two climatic phases, a dry, cold season from April to September, and a rainy, hotter season from October to March. The rainfall average in Belo Horizonte is about 1,600mm and in Ouro Preto it is about 2,100mm.

The topography of the area is heterogeneous. The metasediments of the supergroups, Rio das Velhas and Minas, especially the quartzites, form outstanding mountains, while the gneisses of the basement constitute a rounded hill morphology. The highest altitude is that of the Serra do Caraça (2,070 meters NN) and the lowest point is the city of Mariana, at 650 meters NN. An important morphological separation structure, which cuts the Quadrilátero Ferrífero in the NW - Se sense is the Serra Geral, which also represents the main watershed of the region.

GENERALITIES

The Quadrilátero Ferrífero in the center of the State of Minas Gerais can today be considered as one of the classic areas of Pre-Cambrian geology in Brazil and of the world. The area has been well known since the second half of the eighteenth century, because of its occurrences of gold, diamonds and other precious stones. As an example the works of Castro Sarmento (1973) about gold and diamonds can be mentioned, and also that of Bruckmann (1784): Über einen biegsamen elastischen Stein".

The iniciation of more accurated geological studies can be put in the first half of the nineteenth century. As such, one can consider Von Eschwege (1833) as the first in the detailed geology in Minas Gerais.

A series of geologic works about Minas Gerais were published in the following years. In relation to this, Harder and Chamberlin (1915) presented a basic concept of the geological evolution of the Pre-Cambrian in central Brazil. As other authors of this time Gorceix, Riman, Freyberg and Derby must also be mentioned. In 1906, the latter created the "Series - Minas".

A very complete summary of the situation of the geological research in Minas Gerais up to the start of the thirties was made by Von Freyberg (1932) in his work: "Ergebnisse geologischer Forschungen in Minas Gerais, Brasilien" - Geological Reseach Results in Minas Gerais, Brazil.

Valuable contributions to the geology, and especially to petrology of the area were made by the various works of Guimarães (as examples: 1931, 1933, 1951, 1966).

More recently the "Quadrilátero Ferrífero" region has been the object of studies in depth, especially by a group of american geologists, who, in cooperation with brazilian geologists (DNPM: USGS Convention) created the basic maps of the region to a scale of 1:25,000. The immense iron ore reserves of the region which were estimated by Eichler (1970) to be 50 billion tonnes of iron-rich ore, was descisive for the detailed investigation of the area. It was exactly these iron occurrences which gave origin to the name "Quadrilátero Ferrífero".

A summary of the work of this group is given by Dorr (1969). A general view of the petrography is given in Herz (1970, 1978).

In the last fifteen years many works have been published about geology, the petrology and the geochemistry of the Quadrilátero Ferrífero area. Many of them were carried out as the result of an agreement between the Federal University of Ouro Preto and the Technical University of Clausthal, RFA.

One can consider the large number of works cited above as the most recent (including the Synthesis of Ladeira, 1982, Ladeira, et al., 1982, 1983; Roeser et al., 1982). Today one has the following geological situtation.

The Quadrilátero Ferrífero is the meridional extension of the Serra do Espinhaço and is formed from two supergroups, the Rio das Velhas and the Minas, metasedimentary bodies and various gneissic-migmatitic complexes which surround it or which are found within it, such as the Bação Complex, geologically studies by Gomes, C.J.S. (1985) and petrologically and geochemically by Gomes, N.S. (1985).

These complexes contain some of the oldest rocks in the Brazilian Shield, being dated at 2.7 Ga (Herz, 1970, Cordani et al., 1980).

Ladeira (1976, 1980) and Roeser (1977) considered part of these granitoid complexes as remobilized basement.

This basement is composed of gneissic-tonalitic rocks and migmatites (Roeser et al., 1981), as well as amphybollites, granulitic rocks (Jordt Evangelista, 1984, 1986), metaultramafics in the form of metakomatiites (Ladeira et al., 1983), serpentinites and steatites. The petrological and geochemical evolution of these latter ones was described by Roeser, U. et al., 1979, 1980; and Roeser et al., 1987).

Above the basement two supergroups of supercrustal rocks occur: the Rio das Velhas Supergroup, of Archaen Age, and the Minas Supergroup (including the Itacolomi Group) of Proterozoic Age.

Although the Minas Supergroup is a mainly metasedimentary sequence with quartzites, phyllites, itabirites, dolomites and a iron formation of the "Lake Superior" type, the Rio das Velhas Supergroup is at present considered to be a "greenstone belt" as suggested by Almeida (1976) and documented by Ladeira (1980, 1981) and Ladeira et al. (1983a,b). This greenstone belt includes a banded Iron Formation of the "algoman" type. Compilations by Schorscher (1982) maintained such a concept until the registration of the map of Brazil on a scale of 1:2,500,000 by Schobenhaus et al., in 1981.

Herz (1970), Almeida et al. (1972), Cordani et al. (1973, 1980), Thorpe et al. (1984) and Teixeira et al. (1987) verified the area of the Quadrilátero Ferrífero and the gnaissic complexes closely surrouding them as basically having three geological ages:

The age of 2,700 m.y. (Jequié Cycle) is linked by many authors to a Archaen Age metamorphism of the Rio das Velhas Supergroup. Herz (op. cit.) determined an age of 2,790 m.y. in mica-schists of the low degree of the Rio das Velha Supergroup, and Thorpe et al. (1984) obtained 2,710 m.y. in galenas of the stratiform gold deposits of the Nova

Lima Group in the neighbourhood of the Morro Velho mine. Because of their polymetamorphic evolution, Schorscher & Guimarães (1976) postulated a much older age for the gnaisses than for the green schists of the Rio das Velhas Supergroup. Consequently the ages of 2,700 m.y. as have been determined various times in the gneisses of the region, are perhaps representative of their true ages, and are only a homogenization of the isotopes of Sr during the Rio das Velhas Cycle.

The age of about 2,000 m.y., which is well known in various parts of Brazil, represents, in the region of the Quadrilátero Ferrífero, the metamorphism of the Minas Supergroup (Transamazonic Cycle). Perhaps in the basement rocks between Mariana and Abre Campo, on the excursion B, the transamazonic age is well documented (for example, in the granulitic complex of Acaiaca, and in gneisses and amphybolites near Ribeirão de Carmo), thus demonstrating that there was an important metamorphic recrystallization of archaen rocks approximately 2,000 million years ago (Cordani et. al., 1980; Teixeira et al., 1987). As well as this, one can verify a generalised rejuvenation of the Argon isotope in the rocks of the 540 - 580 m.a. period, contemporarily with the cooling of the Brazilian orogeny cycle.

PETROGRAPHY AND METAMORPHISM OF THE "QUADRILÁTERO FERRÍFERO"

Basement. The granitoid rocks which occur in the Quadrilátero Ferrífero (Complexo Bação) and at its borders (Complexo do Bonfim, to the West; Domo de Caeté, to the North; Complexo de Santa Rita, to the South; Complexo Gnáissico-Migmatítico, to the East) form the basement of the Supergroups Rio das Velhas and Minas, though some authors have interpreted them as "intrusive granites" (Dorr, 1969; Herz, 1978). Gneisses of a granodiorite/tonalite composition predominate, and are at times granitic, variably banded and migmatized, and whose main parageneses were formed in conditions of the upper amphybolite facies, though there is evidence of retromorphic events in conditions of the green schist facies (Schorscher, 1976; Roeser, 1977; Jordt Evangelista & Müller, 1986; Gomes, 1985; Lauenstein, 1985).

In this gneissic-migmatitic complex other types of subordinate lithologies are found, some of which, by their characteristic of displaying unconformity are much younger. Orthoamphybolites (Roeser & Müller, 1977) exhibiting granonematoblastic textures form elongated lenticular bodies with a variable thickness (normally a few meters), concordant with the metamorphic banding of the gneisses. The typical paragenesis is that of tschermakitic hornblend (70 - 80% in volume), plagioclase, quartz, titanite and ilmenite, which corresponds to the amphybolite facies. There is evidence of retromorphism in the form of uralitization and chloritization of the hornblend and saussuritization of the plagioclases (Roeser, 1977; Jordt Evangelista, 1984; Gomes, 1985). There are dikes of metadiabasics called diabasoid amphybolites by Guimarães (1986) cutting the basement and also the adjacent overlaying rocks, and which have relictic igneous textures and variable degrees of uralitization of the pyroxenes and saussuritization of the plagioclases. Schistocity is absent, or is restricted to the borders of the thickest bodies (Evangelista, 1984; Alkmin, 1988).

Spacially associated with the amphybolites or in isolated lenticular bodies metaultrabasic rocks occur, such as talc schists, serpentinites and steatites, which can exhibit petrographic zoning (Roeser et al., 1980), with zones of massive steatite in the center of the body, passing to rocks with talc and carbonate, rocks with amphybolite and talc, and finally to chloritic rocks at the border. The degree of metamorphism of these rocks is normally low, but in the basement in the Southeast of the Quadrilátero Ferrífero steatites carrying anthophyllite occur with a medium degree of metamorphism (Roeser, 1977).

In the Bação Complex lenticular bodies of metasedimentary rocks of the upper amphybolite facies were described, such as calciossilicates with tremolite, plagioclase, epidote/clinozoisite, quartz, carbonate, diopside and garnet, metapelitic rocks with cordierite, garnet and sillimanite or with quartz, garnet and sillimanite, as well as with cummingtonite, garnet and feldspar (Gomes, 1985).

The Rio Das Velhas Supergroup. The Rio das Velhas Supergroup was originally subdivided into two Groups, the Nova Lima with a metavolcanic/metasediment origin, and the Maquiné, with a detrital origin (Dorr, 1969). The metavolcanic rocks are steatite talc schists, serpentinites, chlorite schists, green schists and amphybolites, with variable contents of serpentine, talc, chlorite, tremolite - actinolite, dolomite (or magnesite) and pyrite. Its igneous origin is proved by geochemical data (Roeser, 1977; Ladeira, 1980) and the volcanic character is indicated by relict textures of the spinifex type found in some metakomatiites in the base of the Nova Lima Group, as well as by structures of pillow lava (Ladeira, 1981). The peridotitic metakomatiites in the base of the Nova Lima Group, whose discovery contributed greatly to characterize of the Rio das Velhas Supergroup as a greenstone belt.

The name Quebra Osso Group was given by Schorscher (1978). The chemical metasedimentary rocks of the Nova Lima Group make up a banded iron formation (BIF) of the Algoman type, interfinger with schists and thin banded phyllites which are frequently composed of alternate bands rich in phyllosilicates (mainly chlorite and/or sericite), banded carbonates, and banded quartzites. The clastic metasediments form the top of the Nova Lima Group and are represented mainly by quartzites, quartz-schists and quartz-phyllites, whose the main minerals are quartz, white mica, chlorite and plagioclase. Staurolite and garnet appear locally, indicating a higher grade of metamorphism.

The Maquiné Group is mainly composed of sericitic quartzites, and at times of conglomerates and phyllites or schists. As well as these, quartz, white mica and chlorite appear at times, also kianite and chloritoid, all being indicative of the green schist facies of barrovian metamorphism.

The metamorphism of the rocks of the Rio das Velhas Supergroup is basically to greenschist facies, although locally it becomes lower amphybolite facies.

Minas Supergroup. The stratigraphic column of the Minas Supergroup was divided into three Groups by Dorr

Minas Supergroup was divided into three Groups by Dorr (1969): Caraça, Itabira and Piracicaba.

The Caraça Group is composed of sericite-quartzites and subordinately metaconglomerates of the Moeda Formation, which forms part of the Tamandauá and Itacolomi Groups of Dorr (1969) according to Alkmin et al., 1988, and by greyish coloured sericite-phyllites, at times graphitic and at others carbonatic, of the Batatal Formation. Sedimentological and stratigraphical studies of the rocks of the Moeda Formation and of the Itacolomi Group were carried out by Guerra (1979), Glockner (1981), and Alkmim (1985). According to Guerra (1979), a mineral paragenesis which is very common in the most phyllitic horizons of the Moeda quartizites is that of kianite-muscovite-chlorite, which in turn is typical of green schist facies. In the Serra do Itacolomi region to the SE of Ouro Preto, Glockner (1981) cited the occurrence of staurolite (indicative of the amphybolite facies according to Winkler, 1979) and kianite. Considering the Holdaway diagram (1971) of the Al_2SiO_5 polymorph and knowing that staurolite forms at a temperature of 550 ± 25°C (Hoschek, 1969), one can conclude that the metamorphic pressure in the region of the Serra do Itacolomi was at least 4.5 kbar.

The Itabira Group is constituted of chemical metasediments and is subdivided into two Formations, one, basal, called Cauê, and the other, upper, called Gandarela. The rocks of the Cauê Formation are mainly banded itabirites of the "Lake Superior" type, with a rhythmic alternance of thin dark bands of hematite, and with some magnetite and/or martite and light bands of quartz. At times the facies is carbonatic, as when the light bands are composed of dolomite. Amphybolitic itabirites, manganiferous horizons and ferrigenous phyllites are subordinate. Rich ore bodies appear locally, sometimes compact and sometimes crumbly (this latter called "Blue Dust"), with a high iron content (greater than 63% by weight of iron), and which are intensily mined in the region. Geochemical and mineralogical studies of the ore of the Quadrilátero Ferrífero were carried out by Greiffo (1985).

Geothermometric data based on the oxygen isotopes of the iron ores of the Quadrilátero Ferrífero (Muller et al., 1982) permit to characterize in two metamorphic regions: a western sector of greater size, in which the temperatures reached puts it in the green schist facies, and an eastern sector, smaller, of amphibolite facies. In this area to the East one also finds higher temperatures of around 800°C (Muller et al., 1982; Lauenstein, 1984), which corresponds to the granulite facies. According to the interpretation of the aforesaid authors, these high temperature rocks at the eastern border of the Quadrilátero Ferrífero are relict, that is to say, they were saved from the metamorphic recrystallization during the Minas tectono-metamorphic event (2.1 - 2.0 b.a.), of a retrograde character, or they are allochthonous.

The Gandarela Formation is mainly composed of dolomitic and calcitic marbles. Carbonatic itabirites, schists, phyllites and metaconglomerates occur subordinately. Geothermometric calculations bases on the distribution of $MgCO_3$ in calcite crystals coexistent with dolomite carried out by Souza and Müller (1988) indicate metamorphic conditions of the green schist facies to be lower (T = 310 ± 45°C) in marbles from the southwest portion of the Gandarela syncline situated in the central region of the Quadrilátero Ferrífero. These marbles show a good preservation of the sedimentary structures such as stromatolites and parallel stratification (Souza and Müller, 1988). In the central-south portion of the Quadrilátero Ferrífero, in the region of the Funil viaduct, the temperatures calculated (500 ± 25°C) were greater, indicating the transition of the green schist facies to amphybolite facies. In the extreme Southeast of the Quadrilátero Ferrífero, in the Ribeirão do Carmo region, temperatures less than 544 ± 35°C were obtained for the amphybolite facies.

The Piracicaba Group is composed of a sequence of quartzitic metasediments and phyllites. Dorr (1969) divided it into five Formations, of which some have only a local thickness. From the bottom to the top they are the Cercadinho Formation (greyish phyllites, ferrugenous quartzites), the Fecho do Funil Formation (Silvered carbonatic phyllites), the Tabõoes Formation (quartzites), the Barreiro Formation (Graphitic phyllites), and the Sabará Formation (schists and phyllites, whose thickness is greatest, and of more than 1,000 meters).

SUMMARY OF THE METAMORPHISM IN THE QUADRILÁTERO FERRÍFERO

The basement of the Quadrilátero Ferrífero, formed in conditions of the lower amphybolite facies, is composed of gneisses and migmatites. Over this basement occurs the Rio das Velhas Supergroup, a greenstone belt, composed of metavolcanic rocks, and chemical or clastic metasediments. Its grade of metamorphic indicated by the paragenesis, is that of green schist facies of the barrovian type metamorphism or locally (especially at the southeast border) is that of lower amphybolite facies. The Minas Supergroup, in which the Itacolomi Group is also included, is mainly composed of quartzites, phyllites, marbles and itabirites. The mineral parageneses, as well as the geothermometric calculations, indicate recrystalization in the green schist facies and, at the eastern border, of the amphybolite facies also.

Therefore one is able to asceratain a certain tendency of increase, not very regular, in the degree of metamorphism of the supercrustal rocks of the Quadrilátero Ferrífero from the West to the East.

Although the Minas and Rio das Velhas rocks are situated over the gneissic-migmatitic basement and are mostly of green schist facies, the basement shows only weak evidence of retrograde metamorphism events.

MINERAL OCCURRENCES

Gold

Gold has been known and explored in they Quadrilátero Ferrífero since the XVIII century. The prospecting works from this epoch are numerous, as much in the alluvials as in the open galleries of quartz veins.

Amongst the main studies of the geology and of the auriferous deposits of the Quadrilátero Ferrífero are those of

Henwood (1871), Eschwege (1883), Monchot (1884), Ferrand (1894), Von Freyberg (1932), Gair (1962), Dorr (1969), Guimarães (1970), Fleischer (1971), Torres (1975), Moreschi (1972) and Ladeira (1985a,b).

The primary gold deposits are traditionally well known and explored in the Archaen horizons (Nova Lima Group. Lapa Seca Formation of Ladeira, 1985a,b) in which the mines of Morro Velho are located and in the "Banda Ferrífera" Raposos Formation where the Depósitos de Ramos and São Bento are located; and in the Lower Proterozoic level of the Batatal Formation of the Caraça Group in which the mine of Passagem de Mariana is located (Fleischer, 1971).

The genetic conceptions of the gold in the Greenstone of the Rio das Velhas has varied with time, from the first investigators until the present. Ladeira (1985) noted that Lindren (1933) considered the Morro Velho ore deposit as a hydrothermal model hypothermal ore deposit formed by the metasomatic substitution of a diabasic dike represented by the "Lapa Seca". The hydrothermal hypotheses predominate between authors. Matheson (1956), Gair (1958 and 1962), Tolbert (1962 and 1964) accept a hydrothermal epigenetic origin, relating the gold accumulation to the deformation and metamorphism. Ladeira (1980 and 1985a,b) suggests the volcano-exhalative model for the Morro Velho gold. Fyfe & Henly (1973) suggest a Shear Zone Model for the same deposit.

Recent works have corceived a genesis related to the planar zones of intensely deformed rocks with important gold concentrations as the result of the circulation of the mineralized solutions: the gold Shear Zones, which in the Quadrilátero Ferrífero appear to be the rule rather than the exception, are based more on being a type of ore deposit than a particular case of gold mineralization (Menezes, 1988).

Iron Ore

The iron ore of the Quadrilátero Ferrífero has for a long time atracted the researchers of the whole world. At the start of the century, around 1913, Harder and Chamberlin, english geologists, began the first research into the iron ore of the Quadrilátero Ferrífero with the opening of shafts and galleries with a view to their explotation. The work published by these authors in the 1915 Journal of Geology is important.

The iron ore of the Quadrilátero Ferrífero is in the Cauê Formation of the Itabira Group - Minas Supergroup (Lower Proterozoic). The ferriferous formation is constituted of itabirites and hematite, the latter occurring in massive concentrations or in lenticular structures parallel to the foliation. The contact of the ferriferous formation with the surrounding rocks is usually short. The occurrence of basic and ultrabasic intrusives, and of quartz veins crosscutting the ferriferous formations is frequently common.

Within the possibilities for the iron ore formation, the following genetic hypotheses can be proposed:

- Chemical sedimentary deposition;
- Metamorphic-deformational enrichment;
- Supergenic enrichment.

Various authors have defended one or more of these suggested hypotheses. Nevertheless, it is supposed that the genesis of the ore bodies found in the Quadrilátero Ferrífero is polygenic. The oldest known mineral, as much in the ore as in the itabirites is magnetite. It most frequently occurs as relicts within the martite (pre-metamorphic) and within the hematite and sphalerite crystals. These latter being constituted as products of deformational metamorphic recrystallization.

The supergenic enrichment is constituted in the final phase of the mineralizing processes of the iron ore. It is in this way responsible for the oxidation and hydration of the iron, first accompained by the dissolution and leaching of the silica, then by the dissolution of the carbonates.

The previously cited processes nowadays constitute the main hypotheses for the explanation of the iron ore of the Quadrilátero Ferrífero.

Topaz

In the SE of the Quadrilátero Ferrífero in the State of Minas Gerais, Brazil, various topaz occurrences are known. As well as the gemologic characteristics shown by these topazes, they are found in hydrothermal veins, predominantly surrounded by carbonatic phyllites or in dolomitic marbles, and in sub-vertical fault-controlled zones whose the main direction is N60°W. The occurrences in Ouro Preto are similar to those deposits of the Gundan foothills of Pakistan as well as to those of the Serra das Éguas - Brumado, Bahia.

It is believed that the topaz has been prospected in the Ouro Preto region since 1750. In the epoch of colony, the ministries of the Government Chamber made reference to the activities of the prospectors in the leasings of Saramenha and Rodrigo Silva.

The prospecting activities have developed for more than two centuries, at first activity and then were abandoned. At present, in the principal prospects of the region, geological research is becoming part of the work, permitting the adoption of more advanced mining techniques, and thus allowing a systematic and economic production to be acheived.

The main areas of the workings is in the following regions: Saramenha, Boa Vista, Capão do Lana, Fundão, Caxambú, Trino, Morro do Gabriel and Antônio Pereira. The alluvials of the streams Falcão and Maracajá also deserve mention.

Location and Geology. The region of the Imperial topaz is located in the central part of Minas Gerais, some 80 km, to the south of Belo Horizonte, in the southern part of the Quadrilátero Ferrífero and between the localities of Saramenha and Miguel Burnier in the municipality of Ouro Preto. The primary occurrences are situated in the syncline of Dom Bosco, and E-W band approximately 28 km long and 6 km wide. Only the workings of Antônio Pereira form an exception, being situated to the North of the eastern extremity of the band. All the primary occurrences of topaz in the region of Ouro Preto are contained in the rocks of the Minas Supergroup.

The metamorphic rocks of the area of the topaz-bearing province are quartzite phyllites and dolomites of the Piracicaba Group, and are sub-divided into four levels:

Level I - Chlorite-phyllite, hematitic-phyllitic-sericite, and graphitic-phyllite.

Level II - Sericitic-quartzite and hematitic phyllite.

Level III - Dolomite-phyllite, dolomite-marble and hematite-quartz-dolomite-marble.

Cutting the volcanic rocks and/or the dolomitic rocks is a brecciated zone due to normal faults where there are occurrences of dispersed veins containing topaz. These veins are called the "mineralized zone", and have a regional direction of N60°W and a plunge with a vertical tendency.

The thickness of the mineralized zone varies from a few meters to tens of meters, and in some cases are continuous through the different levels previously described, due to strong structural control. All the rocks, as much the volcanics as the metamorphics or the veins, show an intense degree of alteration. Only some minerals such as quartz, hematite, topaz, pyrophyllite, rutilite, euclase, and more rarely, fluorencite and xenotime are preserved.

Recent studies in the region under discussion show that the topaz occurrences are closely linked to the dolomite rocks and to the last regional volcanic event (Ferreira, 1983). Preliminary microthermic data indicates a temperature of 310°C for topaz, thus indicating the existence of a hydrothermal event. The relationship of this veins with their enclosing rocks indicate that the aforesaid hydrothermal event is linked to the final phase of the volcanic activity mentioned previously.

Emerald

Nowdays Brazil is considered to be one of the great emerald producers of the world, perhaps the most important if we consider the total sum of the production and the quality of the stones.

The Itabira emerald deposit, of Belmonte Mine, is situated outside, but near to the boundary of the mapping work carried out by DNPM-USGS in the central part of Minas Gerais. According to Mendes, J.C. et al. (1985) and Souza, J.L. et al. (1987), it is a deposit which fits into a regional geological context which can be sub-divided into various important lithostratigraphic and lithostructural units. They can be identified on a large scale in the meridional part of the São Francisco Craton.

These large lithological units are represented by the archaen cratonic basement, composed of gneissic-migmatitic terrains with a polymetamorphic and polygenetic character, and includes granitic rocks of the "Rubber Granite" type; by the large belt of green archean rocks (Greenstone Belt) of the Rio das Velhas Supergroup; by metasediments of the Lower Proterozoic Age belonging to the Minas Supergroup; and finally by the metasediments of the Middle Proterozoic Age, essentially quartzites, belonging to the Espinhaço Supergroup.

According to Souza, J.L. (1988), the local geology where the mine is situated is characterized by its presentation of two distinct lithological structural arrangements, respectively represented by gneissic rocks with a granitic composition, belonging to the Basal Complex, and by a strong weathered volcano-sedimentary sequence basically constituted of successive interfingers of schists and metapelitic gneisses, various amphybolites, metaultramafic derived schists and quartzites. Subordinately quartz veins and pegmatoid veins from centimetric to metric dimensions appear, and fill the faults and fissures, in especially close contact with the gneissic rocks. Still according to Souza, J.L. (1988), the Itabira deposit is located in the contact between the volcano-sedimentary sequence and the granite gneisses (Rubber Granites) in an area of faulting, where the dominantly concentrated emerald bearing mineralization occurs in decimetric or metric ultramafic rocks represented by chromite-biotite/phlogopite schists (or biotites).

The aforesaid authors agree that the genesis of these emeralds is closely related to the fault contacts between the two lithostructural arrangements already referred to. The chemical interaction took place between the beryl bearing pegmatitic phase, represented by the pegmatoid veins originating from the gneissic lithologies, and the ultramafic rocks carrying the chromiferous elements (Chromium, iron and vanadium), fostered the crystallization of the emeralds in the aureoles of metasomatic alteration, represented here by the chromite-biotite/phlogopite schists which surround them. A hybrid process evolving the pneumatolitic and hydrothermal stages is suggested for the formation of this deposit, by virtue of the nature of the pegmatoid concentrations and the large number of fluid inclusions in the emeralds.

Bauxites

The Quadrilátero Ferrífero bauxites ore evaluation are estimated to be about 10 million tons, and are distributed in 24 small deposits which range in size from 150 to 150,000 thousand tons (Fig. 2.2). Most of the deposits belong to ALCAN - Aluminium do Brasil S.A., which has a plant located at Saramenha (Ouro Preto) with an alumina production of about 150,000 tons/year and 60,000 tons/year of aluminium.

The genesis of these deposits is a matter of controversy: according to Fleischer & Oliveira (1969), bauxite deposits of the Quadrilátero Ferrífero result from two different controls. First, that a great part of them are related to the Itabira Group of the Minas Supergroup (geological control), and second, they are supposed to be related to karstic traps, which exist in the plantation surfaces (paleogeographical control). Some other authors (Pomerene, 1964; Bucht et al., 1982) also mention lacustrine sediments as the protore for bauxite deposits.

An evolution from "in situ" protore, from phyllites, dolomitic phyllites and schists was considered by many authors (Vaz, 1931; Guimarães, 1945; Guimarães & Coelho, 1945; Lacourt, 1947; Moore, 1969; Door, 1969; Maxwell, 1972; Ferreira, 1983, and Varajão, 1988).

A classification according to the chemical and morphological characteristics have been proposed by Varajão et al., 1988 (Fig. 2.3). Such classification is based on a strong correlation between the deposits distribution pattern within a

triangle and its morphological setting: (I) The Fraga type (slope), (II) Batatal and (III) Macaquinho (plateau), and (IV) Vargem dos Óculos (depression).

The distribution of the deposits, as a function of altitude, shows that the different types described are not related to only one altimetric level (Fig. 2.4). Thus, considering that deposits of the same type are formed at the same age, these different altimetric levels were already present at that time.

Finally, Varajão (1988) and Varajão et al. (1988) have concluded that the Eocene Age is the maximum age for the Quadrilátero Ferrífero bauxites due to the eocenic age for the Fonseca Formation sediments (substratum of the Macaquinho deposit).

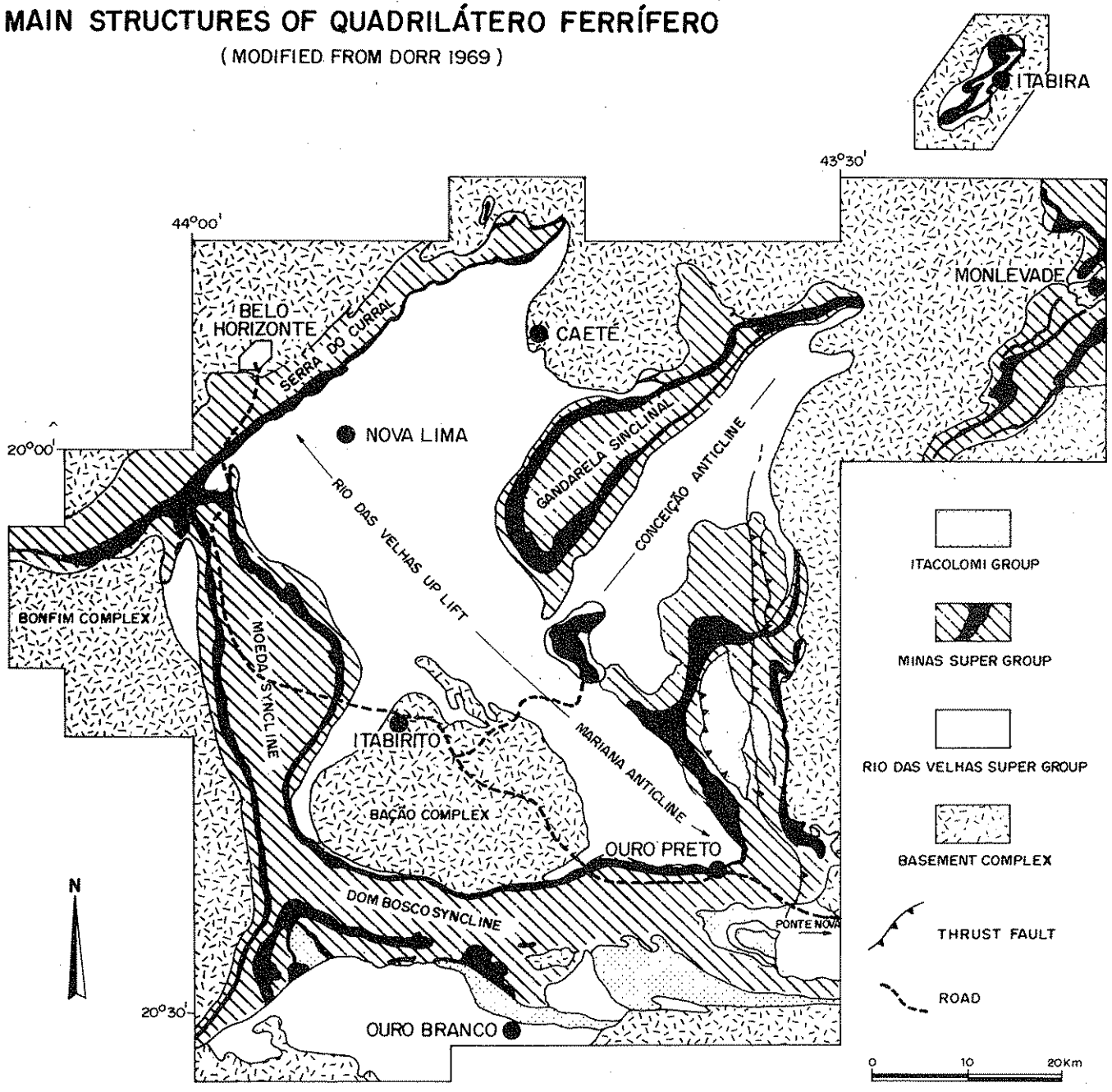
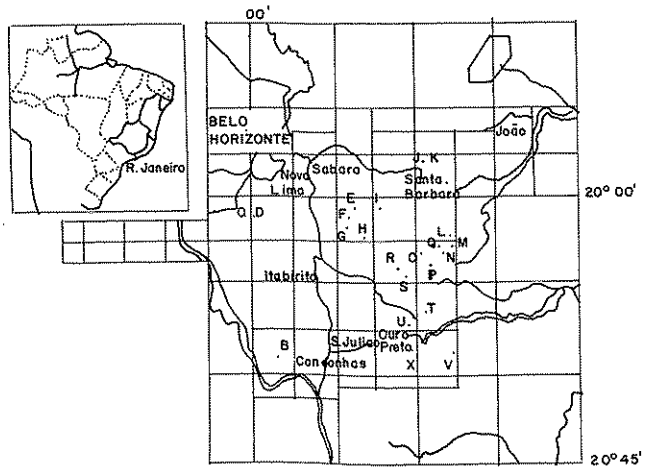


FIG 2.1



A – CASA DE PEDRA
B – SERRA DA BANDEIRA
C – JARDIM CANADA
D – VARGEM DOS OCULOS
E – FAZENDA DO LOPES
F – MAQUINE
G – GARDARELA
H – VIGARIO DA VARA
I – FAZENDA DA VARGEM
J – DOIS IRMAOS
K – FAZENDA SAPE
L – FARIA
M – MACAQUINHO
N – FAZENDAO
O – ARATACA
P – FRAGA
Q – CATA PRETA
R – BATATAL
S – CONTA HISTORIA
T – ANTONIO PEREIRA
U – BRIGIDA
V – MORRO DO CRUZ
X – TESOUREIRO
Y – MONJOLO

FIGURE-2.2 – INDEX MAP OF THE QUADRILATERO FERRIFERO SHOWING THE LOCALIZATION BAUXITE DEPOSITS.

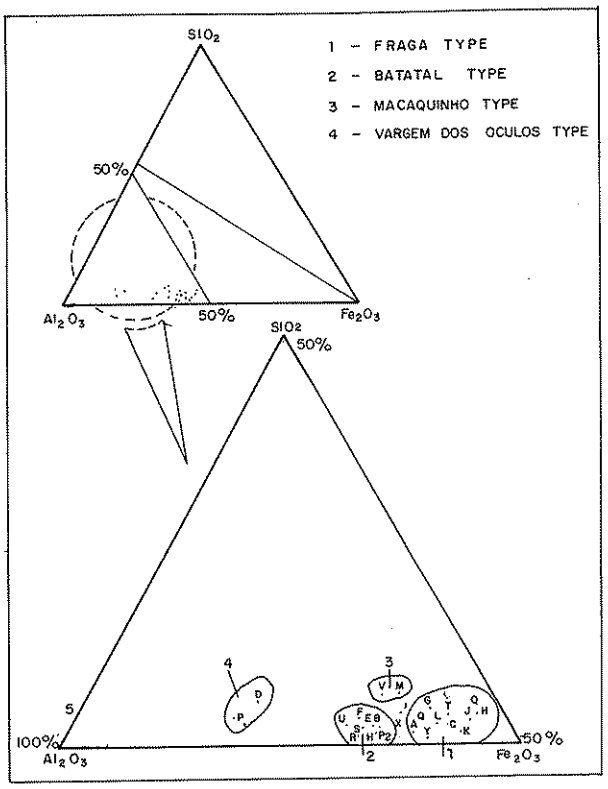


FIGURE-2.3 Triangular diagram showing the behavior of quadrilatero ferrifero bauxite deposits in function of its main chemical components.

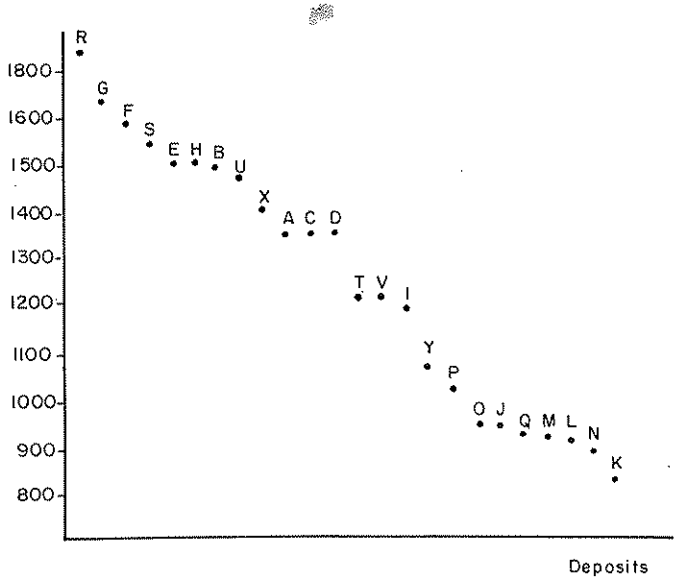


Figure-2.4 Height distribution of the quadrilatero ferrifero bauxite deposits.

2 a) Belo Horizonte to Ouro Preto geologic excursion, passing the Capanema Mine, with special focus on the stratigraphic and tectonic aspects of the Quadrilátero Ferrífero

INTRODUCTION

The central region of Minas Gerais known as the Quadrilátero Ferrífero covers around 7,700k^2 and is identified by heights and mountains tracing an approximately rectangular line within which thick packages of iron formations and quartzites are found. It possesses iron ore rserves of around 13 billion tons, and there are also significant reserves of gold, manganese, bauxite and uranium.

The most frequent altitudes found in the region are between 800 and 1,100 meters, with extremes of 600 and 2,040 meters. Varajão (1988) said that the parameters which most closely influenced the morphologic evolution of the area were those of structure and lithologic association. As well as this, according to the same author, the present relief was sculptured by the various climatic actions and tectonic reactivation which raised the South Atlantic event. It is possible to distinguish the following morphologic units (which were already interpreted as planing surfaces; see, for example, King, 1956):

- Small plateaus or flat tooped mountains with "shadows" of quartzites and/or iron formation; lateritic covering of ferrogeneous crust developed from the Cretaceous to Miocene; altitudes of around 1,450 meters.

- Assymetrically sloping hills of aligned crests, developed over schists and phyllites in the interior of the great structures of the region (for the most part being synclines in an inverted relief); altitudes of around 1,100 meters.

- Symmetrical hills, in the foothills, over rocks of the basement complex; altitudes of approximately 900 meters.

From the geotectonic viewpoint the "Quadrilátero Ferrífero" is part of the São Francisco Province, which is situated at the extreme South of the area occupied by the harmonious craton (Almeida, 1977; Almeida & Hasui, 1984) (Fig. 2.5).

The geological investigations in the region were initiated by the pioneer works of Von Eschwege (1822, 1832, 1833). There have been significant advances at the end of the XIX century and in the first half of this century. In the fifties and sixties an agreement was established between the USGS and the DNPM which resulted in the integrated mapping of the whole region on a scale of 1:25,000 and in geologic evolution compiled by DORR (1969). That established by Dorr and his collaborator has served as the base for all the later works.

This route was chosen with the objective of drawing attention to the topics of stratigraphy, structural geology and tectonism, and to the controls of some of the mineralization of the region.

STRATIGRAPHY

On general lines one can say that the following major units compose the cronostratigraphic units of the Quadrilátero Ferrífero Gneissic tonalitic/trondhjemitic to granodioritic basement, a greenstone belt (Rio das Velhas Supergroup), plataformal sedimentary succession (Minas Supergroup), basic to intermediate intrusives, lateritic coverings (Cretaceous or Miocene) and fluvial sediments/lake dwellers, eocenics (Lima & Salard-Cheboldaeff, 1981), in two small isolated basins (Gandarela and Fonseca).

With the exception of the position of the gneissic and granitoid rocks and to the thicknesses of the quartzite packages, the column established by Dorr (1969) has been confirmed and is still in routine use.

Roeser (1977), Ladeira (1980), Cordani et al. (1980), Ladeira et al. (1983), and Gomes (1985) demonstrated that

the majority of the "granite intrusives" of Dorr (1969) composed the local Basement Complex.

Almeida (1977), Schorscher (1975, 1978, 1980), Pires (1977), Ladeira (1980, 1981), and Ladeira et al. (1983) established that the Rio das Velhas "series" of Dorr (1969) corresponded to a greenstone belt. Ladeira (1980) proposed a sub-division of the Nova Lima Group (Fig. 2.6) which increased with the works of the mentioned authors before can be showed on following (Fig. 2.7).

A compilation of the results of the most recent works dealing with the aspects of sedimentology and stratigraphy of the Minas and Itacolomi Sequences (Eichler, 1968; Guerra, 1979; Glockner, 1981; Vilaça, 1981; Viveiros et al., 1983; Souza & Müller, 1984; Tessari & Amorim, 1984; Moraes, 1985; Garcia & Bernardi, 1986; Alkmim, 1985, 1987; Viel et al., 1987; Rosseto et al., 1987) permits a verified column of Door to be made by Alkmim et al., 1989 (Fig. 2.7).

The absolute datings for the region are few, and refer to the basement complex rocks (Herz et al., 1961; Herz, 1970; Cordani et al., 1980; Teixeira, 1985). The modal ages obtained are of 2,7 billion years, 2,1 to 2,0 billion years and 0,6 to 0,5 billion years, and have been respectively interpreted as:

- a metamorphic event of a high degree, accompanied by migmatization (Cordani, et al., 1980; Roeser et al., (1982);

- a synformational metamorphic event, Minas diastrophism, during the Transamazonian Cycle (Cordani et al., 1980; Roeser et al, 1982; Teixeira, 1985);

- a thermo-tectonic event, Brasiliano Cycle (same authors).

TECTONISM

In a regional perspective, the dominant structures of the Quadrilátero Ferrífero correspond to the great synclinals (Moeda, Dom Bosco and Gandarela) (Fig. 2.8), from which evolved all the supracrustal units and which were moulded to the structures with a domic aspect of the Basement Complex. Apart from this fact they constitute the overturned syncline of the Serra do Curral, the Uplift of the Rio das Velhas/Anticline of Mariana, in the central region and the eastern border, where reverse faults and thrust faults predominate on a N-S line.

Already in the first works about the tectonism of the region two aspects became evident: the polyphasic character of the deformation and the great complexity of the small and large structures. With the work of USGS-DNPM came the first ideas of the tectonic evolution of the whole area (see Barbosa, 1961, 1968, and Dorr, 1969). Many works of detailed structural analysis were carried out in isolated areas, mainly in Mines, from the seventies onwards. These permitted the development of new evolutionary models of the deformations (see Ladeira & Viveiros, 1984; Quade, 1985; Alkmim et al., 1989). More recently, a revision of the previous works and complementary studies led Marshak & Alkmim (1989) to postulate that the deformation of the rocks of Mines and Itacolomi have been given four main pulses, which are as follows:

- Event D1: of a compressional character, it was responsible for the generation of the folds of all sizes, shear zones and the generalized transport from SE to the NW along the thrust faults and the slip surfaces. Heterogeneous and progressive deformation is characterized by an accompanied progressive metamorphism which touches upon the start of the amphybolitic facies. The most evident structures on a regional scale are related to it, in outocroppings and hand samples, as a foliation observable in the whole area. There is no evidence that the basement has been formed by deformation. During the subsequent events the D1 structures were parcially obliterated and rotated. Examples of structures which still retain their original position are then Synclinal do Gandarela, the trend of the Serra do Curral, the Synclinorium de Itabira and the Monlevade band (Fig. 2.8).

- Event D2: reverse faults and shear zones were generated in response to a N-S compressive field in the southern portion of the Quadrilátero Ferrífero together with macro and meso open folds having an East to West line. The Moeda and the Dom Bosco Sinclines may have been nucleated as drape folds associated with the movement of the Bação block, becomming a tableau of the Colorado Plateau block movement style (Davis, 1978).

- Event DE: stretching event which expresses itself in the Quadrilátero Ferrífero as normal faults with a WNW-ESE direction accompained by basic to intermediate intrusives. Reactivation of old faults and accentuation of basement structures are other phenomena associated with this event.

- Event D3: characterized by folding and thrust faults, this may be the result of an East to West comppressive field. The most conspicuous structures are the thrust faults at the eastern border and the systematic N-S orientation. During this event the high Bação block may have evolved in the deformation, modifying those already iniciated synclines of Moeda and Dom Bosco. For this same reason the Rio das Velhas Uplift/Mariana Anticline are able to be interpreted as a fold nappe installed over a large nucleated thrust by the basement.

In addition, should be mentioned that Barbosa (1961, 1968), Dorr (1969), Ladeira & Viveiros (1984) and Ladeira (1982) postulate the existence of a deformation episode which would have exclusively affected the rocks of the Rio das Velhas Supergroup, bu they lack data and detailed descriptions which would serve for the base of a kinematic interpretation.

As well as the events described, the Quadrilátero Ferrífero was evolved during the reactivation of the South Atlantic ridge, as attested to by the faults in the surfaces of

canga, desintegration of the planing surfaces and the existence of miocenic basins in many elevated areas.

The points to be visited in the course of this excursion are situated along the BR-040 (Brasília-Rio de Janeiro) and the BR-356 (Rodovia dos Inconfidentes) highways, on the access road to the Capanema Mine and in the area of the mine, and finally in the Ouro Preto neighbourhood (Fig. 2.8). As references for the localization of the points the kilometer markers on the rocks will be used.

- km 0, BR-356 - The start point of the BR-356 is the corner of Av. do Contorno and Av. N.S. do Carmo in Belo Horizonte.

The north and northeast sector of the city is built over gneissic and migmatic terrains of the basement complex. The south and southeast half is built on the rocks of the top of the Minas Supergroup (Piracicaba Group).

- km 1.6 to Km 2.5, BR-356 - Along this stretch the rocks of the Sabará Formation of the Piracicaba Group outcrop in a reverse position. This structural positioning which will be able to be seen along the next 10km reflects the great structure of the Serra do Curral, a reversed homocline.

- km 2.5 to Km 4.0, BR-356 - In successive cuts the rocks of the Piracicaba Group outcrop: graphitic phyllites of the Barreiro Formation, quartzites of the Tobões Formation, hematite-sericite-dolomite-quartz phyllites of the Fecho do Funil Formation and, finally sericitic quartzites with interlayers of phyllites of the Cercadinho Formation.

- km 4.0, BR-356 - Normal fault in quartzites of the Cercadinho Formation.

- km 5.4, BR-356 - BH-Shopping Center, constructed over dolomites and dolomitic phyllites of the Gandarela Formation. At the left and upwards, the Serra do Curral.

- km 6.0, BR-356 - Contact zone between the altered dolomites of the Gandarela Formation and the Cauê Ferriferous Formation (carbonate facies, oxide and silicate, this last inferred by the occurrence of manganese), the excavations were made for the extraction of ferro-manganese ore.

- km 8.4, BR-356 - Interchange of the BR-356 with the BR-040.

- km 539 - BR-040 - From the point on the two roads have the same aspect.

- km 539.8, BR-040 - Crossing of the Sera do Curral. In the cuts on either side of the road the intensely deformed oxide and carbonated facies of the Cauê Iron Formation outcrop.

- km 540.7, BR-040 - Mutuca Viaduct.

- km 545, BR-040 - From this point on until km 43 on the BR-356 (see Stop nº 1) the road is located over the moeda Plateau, which developed over the trough of the homonymous syncline (compare Fig. 2.8). Along this stretch one can verify, from East to West respectively, the occurrence of the A and B morphological units described in the first stop on to this route.

- km 546.6, BR-040 - To the right, the bauxite and Kaolin deposit of the Vargem dos Óculos. In a depression developed over the rocks of the Cauê Iron Formation one has a covering of Laterite some 20 meters thick, capped by detrial sediments. The deposit shows zoning, essentially being kaolinite to the South, and bauxites to the North.

- km 533, BR-040 - Ferruginous cover over the Cauê Formation. Two types of cover can be observed: goethitic/limonitic cement breccia, containing compact blocks of hematite and itabirites; goethitic and limonite crust.

- km 367.7, BR-040 - Access stretch to Ouro Preto by way.

- km 27, BR-356 - Of the Rodovia dos Inconfidentes (BR-356).

- km 27.3, BR-356 - Highway Police Station.

- km 29, BR-356 to Km 40, BR-040 - In the successive cuts dolomitic phyllites, hematitic phyllites and graphites of the Fecho do Funil Formation outcrop, as also do sericitic quartzites of the Cercadinho Formation.

- km 35.9, Br-356 - Bridge over the Ribeirão das Codornas. To the left, the Codornas reservoir.

- km 39.8, BR-356 - Highway Police Station. To the right, the Summit of Itabirito, constituted of a single block of compact hematite.

- km 40, BR-356 - Itabirites of the Cauê Formation.

- km 40.4, BR-356 - Start of the descent of the Moeda Plateau, by the Serra de Itabirito, in the direction of the Serra das Velhas. In this stretch the road cuts the reverse flank of the Synclinal da Moeda.

Successively outcropping are: The Cauê Formation, Batatal Formation, Moeda Formation and schists of the Nova Lima Group.

- km 41.1, BR-356 - Phyllites of the Batatal Formation.

- km 42, BR-356 - Batatal - Moeda Contact.

km 43, BR-356 - Stop no. 1.

Panoramic view of the Quadrilátero Ferrífero and the Valley of the Rio das Velhas, Serra de Itabirito, in the locality known as Santa. Here the Moeda Formation can be subdivided into three levels which show their greatest thicknesses. The basal level and the top are meta-arenites and fine meta-coglomerates. The intermediate encompasses phyllites and fine sericitic quartzites. In this area Dorr (1969) characterized an angular unconformity between the schists of the Nova Lima Group and the Moeda Quartzite, the base of the Minas Supergroup.

km 44.3, BR-356 - Stop no. 2.

Morphologic expression of the Cata Branca Fault in the valley to the South of the BR-356 highway. In the area of influence semingly domic structure of the Bação (Fig. 4), one can characterize various within these that of the Cata Branca, asinistral fault with a horizontal separation of about 500 meters, which affects the rocks of the Bação Complex, of the Rio das Velhas Supergroup and of the base of the Minas Super Group. In the portion which cuts the Moeda Quartzites there are quartz veins which are gold mineralized. Freiberg (1932) and Guimarães (1933) described in addition to pyrite, antimony and bismuth sulphides (antimonite, bismuthite) as components of the mineralized zone. In colonial times this area was mined and considered exhausted. In 1840, the works were reopened by the English, and were definitely closed down in 1844 when the roof-fall of a large lateral block caused the death of about thirty workers.

- km 44.3, BR-356 to Km 49.3, BR-356 - In the cuts of the highway schists and altered phyllites of the Rio das Velhas

Supergroup outcrop.

- km 50, BR-356 - Bridge over the Rio das Velhas.

From this point on until km 78.4 the BR-356 highway remains over gneissic-granite terrains of the Bação Complex.

- km 56, BR-356 - Access stretch to the city of Itabirito.

- km 62.8, BR-356 - Access stretch to the Capanema Mine (Minas da Serra Geral S/A, CVRD). From this point on one can take the paved road to the left which goes to the Capanema Mine (km 0 RMC of the stretch).

In addition to emphasising some lithological and stratigraphical aspects of the greenstone belt of Rio das Velhas, one can characteristics of the Fundão System. Originally defined and interpreted as a large rip fault by Dorr (1969), the Fundão System is today interpreted as a fan of anchored faults, connected to a slipped surface with a regional expression. It has as a frontal ramp, the Fundão Fault in the sector which cuts the Gandarela Syncline (see Fig. 2.8 and 2.9).

- km 0, RMC to Km 4, RMC - Gneissic-granite terrains of the Bação Complex.

- km 6.3, RMC - Bridge over the Rio das Velhas.

km 9.2, RMC - Stop no. 3.

Quartz-chlorite-schist of the basal sequence of the Nova Lima Group.

It corresponds to the mafic section of the greenstone sequence, possibly meta-basalts. Note the intense silicification and the sulfidization. The dominant foliation (s_1 = 030/40) is parallel to the compositional banding.

There is development of the s-c surfaces and refraction of the main foliation, indicative of tectonic transportation to the NW.

km 12.4, RMC - Stop no. 4.

Chlorite-sericite-quartzite of the Nova Lima Group, in a zone with high magnitudes of deformation. Originally interpreted by Dorr (1969) as meta-sediments. Rocks such as these can also be acid volcanic protolites or prematurely silicified mafics (Menezes, 1988). Data about this outcrop is not available, but in adjacent areas similar quartzites exhibit high contents of Ni, Co and Cr.

km 14.5, RMC - Stop no. 5.

Siderite-chloritoid-sericite-quartzite of the base of the Maquiné Group, of the Palmital Formation, in the area of influence of the Fundão System.

The quartzites appear as S-L-tectonites and in a cut normal to the lineation they look like a meta-conglomerate.

This appearence is noticeable when the material is altered: the dissolution of the siderite stains the iron oxide matrix, emphasising the linear pieces.

The dominat structures are: the milonitic foliation s_m = 020/50 and the lineation 1_m = 100/15. A large number of the gold mineralized zones of the Maquiné Formation are like this.

According to Menezes (1988), shear zones found in acid protolites (metasediments or metavolcanics) are frequently accompanied by sulfidization, carbonation, silicification, and at times, gold mineralization.

km 15.4, RMC - Stop no. 6.

S-L-Tectonites of the Maquiné Group, in a zone of intense sulfidization. With the exception of the sulphides and micas with high chromium content, the quartzites are identical to the observations of the previous point. The greater part of the sulphides is of pyrite and minerals of its group: ullmanite (NiSbS), Cobaltite (CoAsS), Gersdorfite (NiAsS). Moreover, chalcopyrite and the sulphosalt tetraedrite, a variety of freibergite ($(AgCu)_{12})Sb_4S_{13}$)occur (Menezes, 1988). Observe the assymetry of the foliation trajectory and the pressure shadows of the quartzite bodies, indicating movement to the NNW (s_m = 045/45, 1_m = 115/30).

km 18, RMC - Stop no. 7.

Gateway to the Capanema Mine.

The Capanema Mine is situated in the Serra do Ouro Fino and, geologically speaking, in the southeast extension of a complex synclinal structure, the Ouro Fino Syncline. Taking part in this structure are the rocks of the Nova Lima and Maquiné Groups and of the Moeda, Batatal and Caué Formations (Fig. 2.10). Nucleated in the aloctone block of the top of the Fundão System and progressively dragged towards the lateral line of the same system, the syncline in question was in addition affected by the previous folding.

The following types of iron ore are extracted from the Capanema Mine (compare Table 1) (Massahud, 1988):

Hematite A (HA): ore formed from the leaching of silica from itabirites.

Goethitization and infiltration of clays are observable. Reserves (1987): 127,808 x 10^3 ton.

Hematite B (HB): rich itabirites by parcial leaching of silica. Infiltration of clays is not found. Reserves (1987): 60,740 x 10^3 ton.

Crumbly Itabirite (SI): crumbly itabirites with considerable leaching of silica. Reserves (1987): 22,624 x 10^3 ton.

Stop no. 7a. Valley of the Flechas Stream (Fig. 2.11)

Meta-sandstones and meta-conglomerates of the Moeda Formation in the east flank, inverted from the Ouro Fino Syncline. The sedimentary structures, the body geometry and the vertical succession are indicative of deposits made in braided fluvial systems. On the normal west flank of this same structure and in this same level of stratigraphy occurs gold and uranium mineralization which has been classified as being of the Witwatersrand type (e.g. Renger et al., 1988).

It is noticeable in these areas that there is a great tectonic influence in the spacial distribution of the mineralized bodies.

Stop no. 7b.

Left bank of the Córrego das Flechas. Batatal formation. Sericite (+ illite)-quartz-phyllite, in a zone of low magnitude deformation where the schistosity S_1 cuts the surface S_0 at a sharp angle.

Stop no. 7c.

Workface of the Capanema Mine. The Caué Iron Formation is represented by two facies: silicate (amphybolitic silicate) and oxide (itabirite). As has already been observed in other mines of the region, there are great volumes of altered iron formation completely free of silica and residues which can also correspond to carbonate facies. In this mine its occurrence never was verified. The supergene ores, hematite A, hematite B and crumbly hematite, are encased in fresh itabirites, amphybolitic itabirites, intrusives and phyllites of the Batatal Formation. Tectonic elements of various stages of the formation can be seen here.

Stop no. 7d.

Mirante do Pico do Monge.

The Pico do Monge is one of the highest points of the Quadrilátero Ferrífero, and is at an altitude of 1,754 meters. Panoramic view of the region, and return.

- km 62.8, BR-356 - Access stretch to the Capanema Mine.

- km 78.4, BR-356 - Access on the left of a dirt road to the locality of the Serra do Siqueira. Leaving the Serra do Siqueira to take a dirt road in a line for the South which leads to the Vitória-Minas Railway at km 131.

- km 131, Vitória-Minas Railway - Bação Complex and its petrographic phases. In the points of the following description the various phases which compose the Bação Complex will be seen together with their spacial and temporal relationships.

Stop no. 8a.

Migmatitic gneiss showing magmatic structure (Tab. 2). Blocks of up to two meters in diameter of greyish gneiss, tonalitic-trondhjemitic to granodioritic, are evolved by leucossoma and are cut by aplites and pegmatite. Aplites and pegmatites show an identical mineralogical composition: quartz, tourmaline, feldspars, moscovite, epidote and garnet.

Stop 8b.

Migmatitic gneiss of the same composition as the previous point, cut by an amphybolite dike (compare table 3). These two rocks are in their own turn traversed by the previously observed non-foliated pegmatites.

Stop no. 8c.

Contact between the intrusive granitoid body and migmatitic gneiss. The granitoid rock does not exhibit foliation and possesses the same mineralogy as the aplites and the pegmatites (compare table 4). Based on the descriptions of outcrops, petrological studies and geobarometric calculations, Gomes (1985) postulated the following evolution of the rocks of the Bação Complex:

1 – Partial migmatization to their ortho-derivatives at temperatures of the order of 700°C. Such rocks (migmatitic gneisses of a greyish colour) constitute the basement itself in the region of the Quadrilátero Ferrífero.

2 – Retrograde metamorphism of the migmatitic gneisses and the intrusion of basic rocks (amphybolites).

3 – Intrusion of granitoids and pegmatites and the diaphtoresis of the surroundings.

The same author attributed ages, respectively, Jequie (greater then 2.7 billion years), Transamazonic (2.0 billion years) and Braziliana to these evolutionary steps.

km 78.5, BR-356 - Stop nº 9.

Funil Viaduct (Viaduct of the Vitória-Minas Railway over the BR-356).

Chlorite schists of the Nova Lima Group in contact with quartzites of the Moeda Formation (in this case, quartz-milonites). Over the quartzites occurs the Caué Iron Formation, with silicate, oxide and carbonate in its facies. Along the south and north flanks of the Dom Bosco Syncline (Fig. 2.1) the contacts between the Moeda Formation and the schists of the Nova Lima Group are of a tectonic nature and everything indicates that they would have been connected to the slipping of the base of the Fundão System.

- km 79, BR-356 - Deformed dolomites and dolomitic limestones of the Gandarela Formation.

- km 81.7, BR-356 - Quartzites of the Cercadinho Formation.

- km 83.2, BR-356 - Hematite-sericite-quartzites interfingers with phyllites and with dolomitic marble lenses of the Cercadinho Formation. In the lower portion of the Piracicaba Group, Garcia & Bernardi (1986) described plataformal deposits of the following types:

Top: Terrigenous - deltaic plataform bar constructions. deltaic front turbidites and deep water.

Carbonates, laminites, algalites - carbonatic plataform (shows continuity)

Base: Bitotites, pelites - . with Gandarela Formation.

- km 86, BR-356 - Zone of tectonic contact between the base of the Moeda Formation and the top of the Caué Formation, marked by the occurence of specularite-schist lenses (the product of milonitization of the iron formation) and of moscovite-quartz-schist.

km 90, BR-356 - Stop no. 10.

Access stretch to the city of Ouro Preto. Quartzites interfingers with sericite-hematite phyllites of the basal portion of the Piracicaba Group, represented by deltaic front turbidite deposits. High magnitudes of deformation obliterate the original structures in a way that the dominant foliation is parallel to the compositional banding. Intrafoliate folds with creases parallel to the stretch line and crenulation lineations are other observable elements.

km 92, BR-356 - Stop no. 11.

Meta-diamictites and meta-conglomerates supported by a matrix, Sabará Formation (altered). Clastics of gneissic rocks quartzites and quartz veins folting in a clayey matrix (phyl-

lite). The rock foliation is anastomatic in relation to the clastics, which are stretched. The assymetry of the foliation trajectories in the neighbourhood of the clastics indicate a general movement from SE to NW. Looking to the right, one can see in the background the Morro Saramenha and the Topazios Vermelho Mine.

A fault system in a WNW-ESE direction cuts carbonate phyllites of the lower portion of the Piracicaba Group. In this zone the topaz mineralization is found and it is accompanied by intense quartz veining, breccias of the surroundings and extremely weathered rocks of a varigated aspect (intrusive?).

The topazes occur in various colours: light brownish - yellow to honey, red, lilacs and violets (rare), and also colourless. As well as fluid inclusions, they also show crystalline inclusions of carbonate, rutile, goethite, specularite, topaz and pyrophyllite (Ferreira, 1987).

km 96.7, BR-356 - Stop no. 12.

Chlorite and graphite phyllites of the Sabará Formation are cut by an intermediate rock dike, which marks the extensional event DE (see introduction). The foliation pattern of the surrounding rocks on both sides of the intrusive body indicate normal movement. One can observe that only the borders of the intrusive body are foliated. To the Southeast, one sees the Pico do Itacolomi, at the point culminating in the Nappe do Itacolomi (in the sense of Gloecker, 1981).

From this point on one leaves the BR-356 and takes the road to the left in the direction of the Bairro Bauxita of the city of Ouro Preto and from there to the Morro do Cruzeiro.

Morro do Cruzeiro - Stop no. 13.

Morro do Cruzeiro bauxite ore deposit. Over dolomitic phyllites, basic intrusives, quartzites and the iron formation of the Piracicaba Group base, a lateritic covering of up to 7 meters thick is developed on the Morro do Cruzeiro (a flat-topped hill with peakes between 1,210 and 1, 220 meters). In the east-southeast portion of the hill it is of bauxite and was totally mined, leaving only a single outcrop as evidence. In this outcrop one is able to characterize the following facies from the bottom to the top in the laterite: soft bauxite, soft alumino-ferrugenous laterite, and soft ferro-aluminous laterite (Varejão, 1988).

Tabela 1 – Capanema Mine Ore – Chemical Analyses

Hematite A						
Fractions	**%**	**Fe**	**SiO_2**	**Al_2O_3**	**P**	**PPC**
+ 1/4"	45,31	64,49	1,42	1,77	0,062	4,28
- 1/4" + 100	33,06	64,50	2,33	1,33	0,061	3,98
- 100	21,63	64,05	4,34	0,96	0,056	2,89
Global	100,00	64,40	2,35	1,45	0,060	3,88
Hematite B						
Fractions	**%**	**Fe**	**SiO_2**	**Al_2O_3**	**P**	**PPC**
+ 1/4"	41,65	65,09	2,38	0,93	0,073	3,40
- 1/4" + 100	32,39	62,06	6,75	0,90	0,078	3,34
- 100	25,96	55,31	16,55	0,72	0,062	2,40
Global	100,00	61,57	7,47	0,87	0,072	3,12
Friable Itaberite (GI)						
Fractions	**%**	**Fe**	**SiO_2**	**Al_2O_3**	**P**	**PPC**
+ 1/4"	33,99	63,34	6,00	0,30	0,047	2,29
- 1/4" + 100	33,65	57,85	14,17	0,56	0,056	2,32
- 100	32,36	45,19	33,09	0,64	0,044	1,53
Global	100,00	55,62	17,52	0,50	0,049	2,05

Table 2

Migmatitic-Gneisses Mineralogical Composition
(181 Modal Analises)

Quartz	29,65%
Plagioclase	44,15%
K-feldspato	8,00%
Biotite	10,45%
Muscovite	3,25%
Epidote	3,40%
Sphem	0,85%
Apatite	0,10%
Zircon	Tr.
Anphibole	Tr.
Garnet	0,10%
Turmaline	Tr.
Clorite	Tr.
Carbonate	Tr.
Rutile	Tr.
Alofana	Tr.
Opaques	Tr.
Total	99,95%

Migmatitic-Gneisses Chemical Composition
(13 Chemical Analises)

SiO_2	72,88%
TiO_2	0,26%
Al_2O_3	14,61%
Fe_2O_3	1,85%
MnO	0,02%
MgO	0,47%
CaO	1,82%
Na_2O	4,94%
K_2O	2,27%
P.F.	0,67%
Total	99,79%
Rb	146ppm
Sr	314ppm

Table 3

Basic Rocks – Mineralogical Composition
(54 Modal Analises)

Anphibole	60,7%
Plagioclase	16,1%
Biotite	3,2%
Sphem	3,7%
Quartz	3,1%
Epidote	8,8%
Clorite	1,9%
Carbonate	0,3%
Apatite	0,2%
Opaques	1,9%
Turmaline	Tr.
Rutile	Tr.

Basic Rocks – Chemical Composition
(12 Analises)

SiO_2	48,45%
TiO_2	2,29%
Al_2O_3	13,61%
Fe_2O_3	15,31%
MnO	0,21%
MgO	6,13%
CaO	10,28%
Na_2O	1,98%
K_2O	0,85%
P.F.	0,88%
Total	99,98%
Rb	17ppm
Sr	189ppm

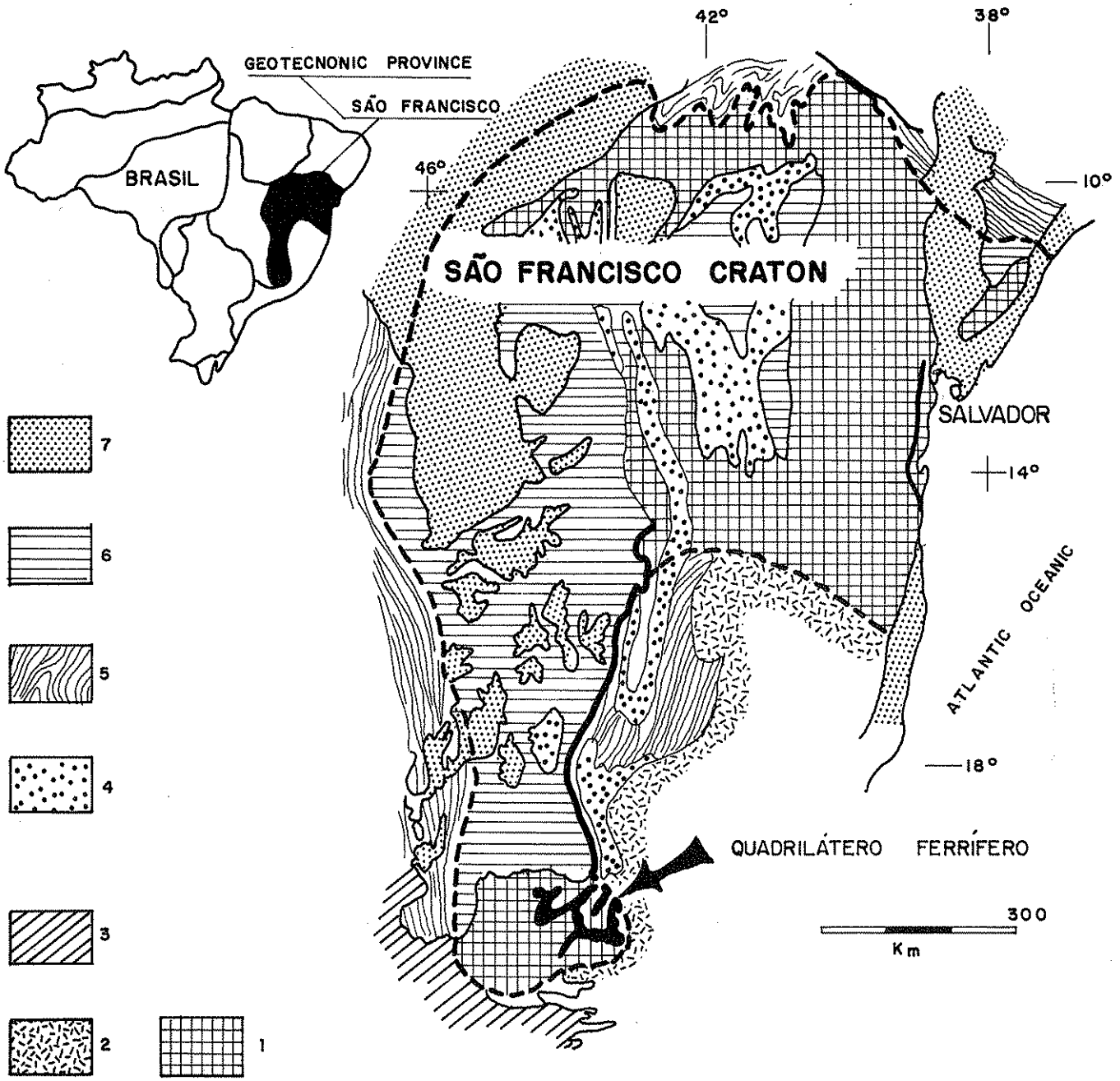
Table 4

Granitoids – Mineralogical Composition

Quartz	28,00%
Plagioclase	45,9%
K-feldspato	17,4%
Muscovite	2,2%
Turmaline	5,0%
Carbonate	1,5%
Zircon	Tr.
Epidote	Tr.
Apatite	Tr.
Opaques	Tr.

Granitoids – Chemical Composition

SiO_2	75,09%
TiO_2	0,02%
Al_2O_3	14,40%
Fe_2O_3	0,22%
MnO	0,01%
MgO	0,08%
CaO	0,69%
Na_2O	4,50%
K_2O	3,93%
P.F.	1,05%
Rb	124ppm
Sr	117ppm



GEOTECTONIC LOCATION OF QUADRILÁTERO FERRÍFERO

1: PRETRANSAMAZONICO AND TRANSAMAZONICOS TERRAINS 2: UNITS MODIFIED DURING THE BRASILIANO CYCLE 3: URUAÇUANA BELT 4: MIDDLE PROTEROZOIC UNIT (ESPINHAÇO SUPER GROUP). 5: BRASILIANO UNITS 7: FANEROZOIC COVER. MODIFIED FROM INDA ET AL 1984 E ALMEIDA HASUI 1984)

FIG. 2.5

ID.	S.	GR.	FORMATION	LITHOLOGY	ENVIRONMENT
CRET./T.			-	Canga, sandies, lakes and fluvials claies	contin.
			FLORÁLIA	Lakes and fluvials sediments, lignite	contin.
				(1)	
PRE - CAMBRIAN	ITACOLOMI		UNDIVIDED	Orthoquartzite, protoquartzite, conglomerade, grit. Sto Antonio Facies: quartizite, phyllite, conglomerate	Parolic Molasse ?
				(1)	
	MINAS	PIRACICABA	SABARÁ	Chlorite-schist and phyllite metatuff, graywacke, conglomerade, quartzite, iron formation	Eugeos. Flysch
				(2)	
			BARREIRO	Phyllite and graphitose phyllite	Plat.
			TABOÕES	Orthoquarzite	Plat.
			FECHO DO FUNIL	Phyllite,dolomitic phyllite, dolomite	Plat.
			CERCADI-NHO	Ferruginous quartizite, grit, phyllite, conglome-rate, dolomite	Plat.
				(2)	
		ITABIRA	GANDARELA	Dolomite, calcareous, dolom. itabirite dolomitic phyllite	Plat.
			CAUÊ	Itabirite, dolomitic itabirite, phyllite dolomite	Plat.
		CARAÇA	BATATAL	Phyllite graphitose phyllite, metachert, iron formation, sericitic phyllite	Plat.
			MOEDA	Orthoquartizite, conclomerate, phyllite, sericitic quartzite	Plat.
				(2)	
		TAMANDUÁ	-	Dolomitic phyllite, iron formation, dolomite	Plat.
			CAMBOTAS	Orthoquartzite, conglomerate, grit, conglomeratic quartizite, phyllite	Prisma-tic, pa ralic
				(1)	
	RIO DAS VELHAS	MAQUINÉ	CASA FORTE	Protoquartzite, conglomerate, subgraywacke.	Molasse
			PALMITAL	Phyllite, protoquartzite, graywacke, basal conglomerate, phyllite quartz.	Molasse
				(?) (?)	
		NOVA LIMA	UNDIVISED	Chloritic phyllite, graywacke, iron formation, meta-vulcanics, quartzite, conglomerate, dolomite	Eugeos. Flysch
	There isn't basement outcrop. The granitic rocks are intrusives.				

STRAIGRAPHIC COLUMN TO THE QUADRILÁTERO FERRÍFERO BY DORR (1969).
1: ANGULAR DISCORDANCE 2: UNCONFORMITY

Figura-2.6

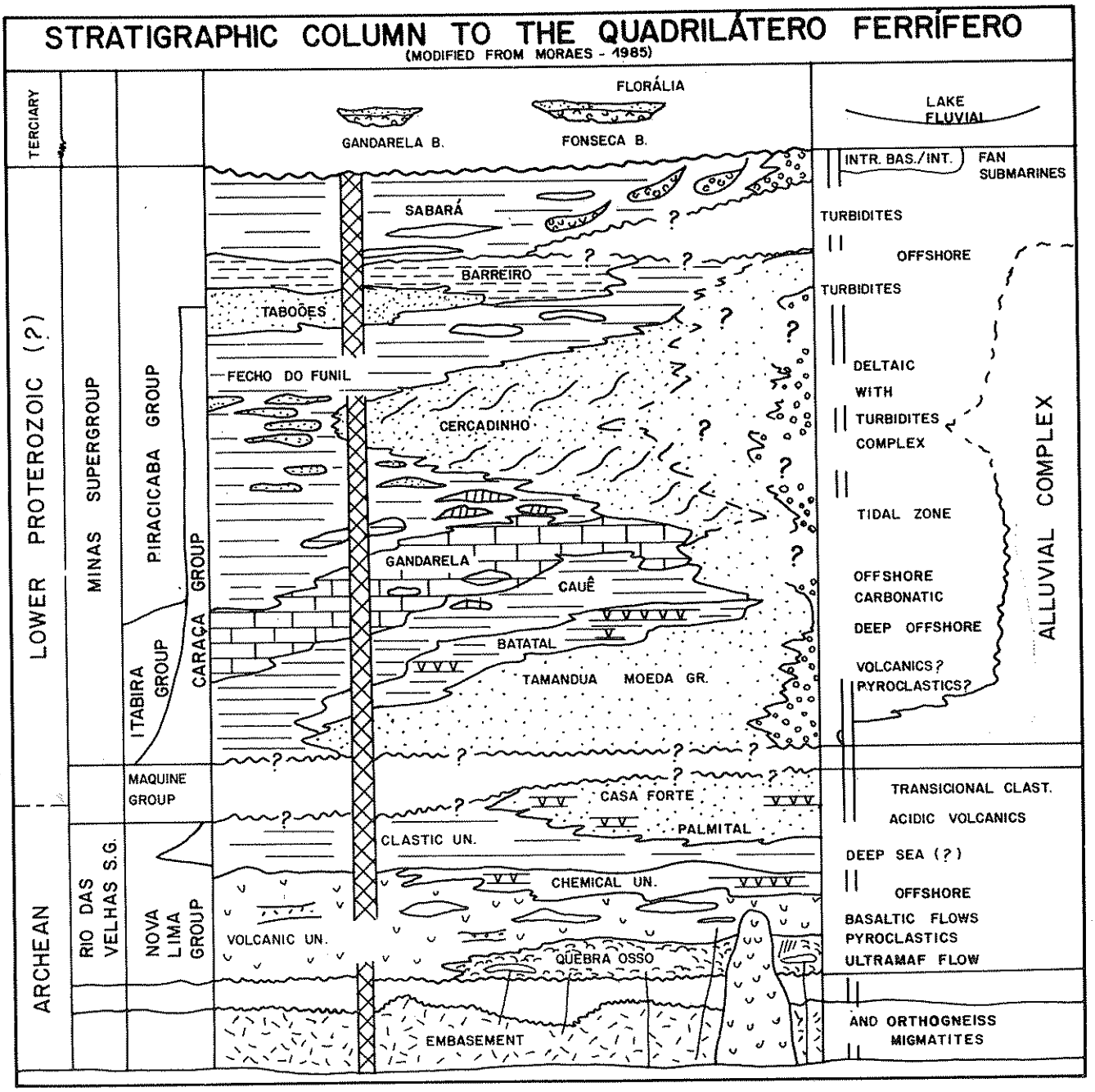

STRATIGRAPHIC COLUMN TO THE QUADRILÁTERO FERRÍFERO
(MODIFIED FROM MORAES - 1985)
TERCIARY
LOWER PROTEROZOIC (?)
ARCHEAN
MINAS SUPERGROUP
RIO DAS VELHAS S.G.
PIRACICABA GROUP
ITABIRA GROUP
CARAÇA GROUP
MAQUINE GROUP
NOVA LIMA GROUP
FLORÁLIA
GANDARELA B.
FONSECA B.
SABARÁ
BARREIRO
TABOÕES
FECHO DO FUNIL
CERCADINHO
GANDARELA
CAUÊ
BATATAL
TAMANDUA MOEDA GR.
CASA FORTE
PALMITAL
CLASTIC UN.
CHEMICAL UN.
VOLCANIC UN.
QUEBRA OSSO
EMBASEMENT
LAKE
FLUVIAL
INTR. BAS./INT.
FAN
SUBMARINES
TURBIDITES
OFFSHORE
TURBIDITES
DELTAIC
WITH
TURBIDITES
COMPLEX
TIDAL ZONE
OFFSHORE
CARBONATIC
DEEP OFFSHORE
VOLCANICS?
PYROCLASTICS?
ALLUVIAL COMPLEX
TRANSICIONAL CLAST.
ACIDIC VOLCANICS
DEEP SEA (?)
OFFSHORE
BASALTIC FLOWS
PYROCLASTICS
ULTRAMAF FLOW
AND ORTHOGNEISS
MIGMATITES

Fig. 2.7

MAIN STRUCTURES OF QUADRILÁTERO FERRÍFERO

(MODIFIED FROM DORR 1969)

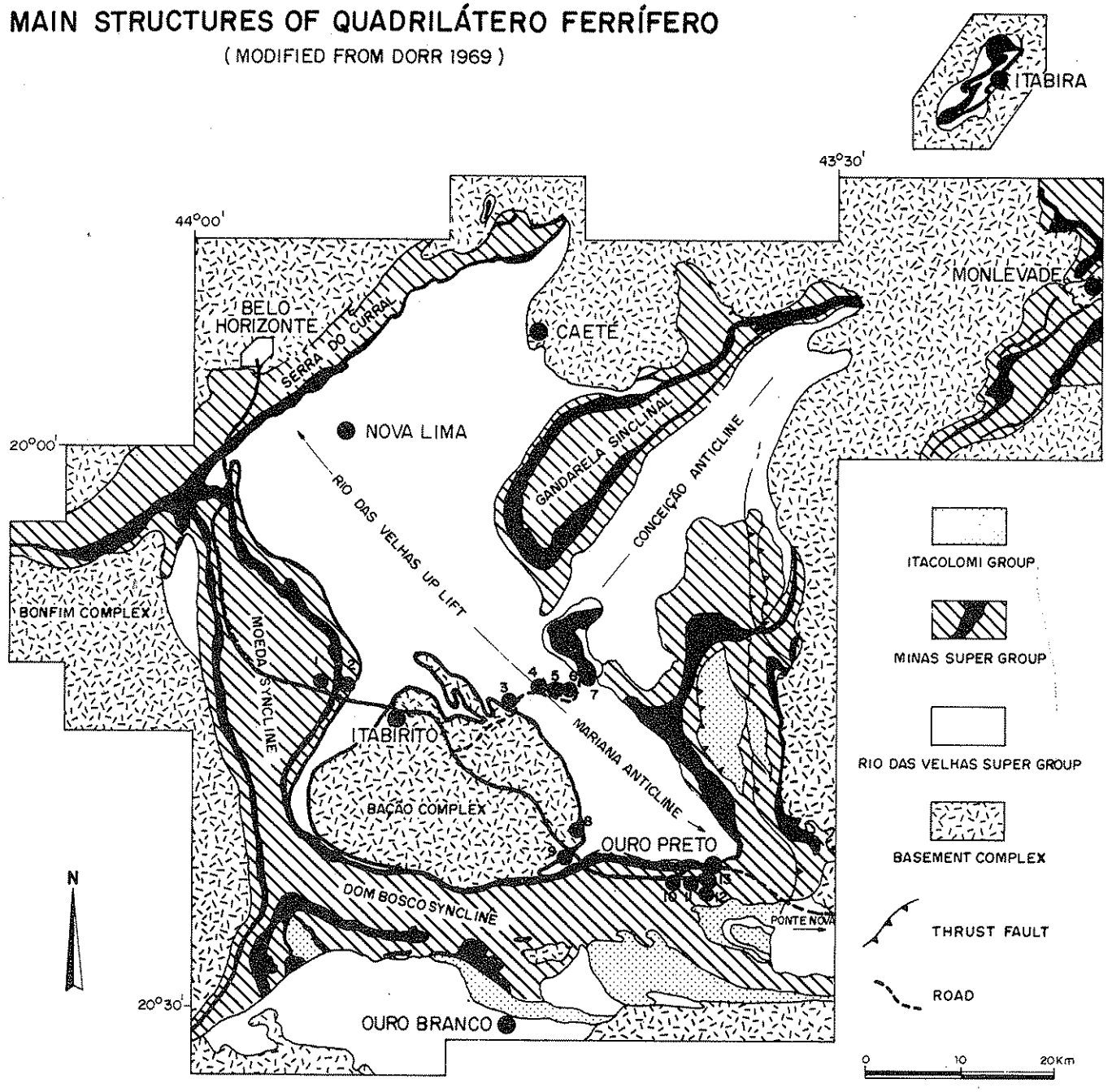


FIG 2.8

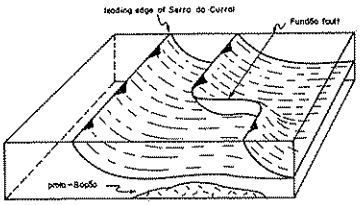
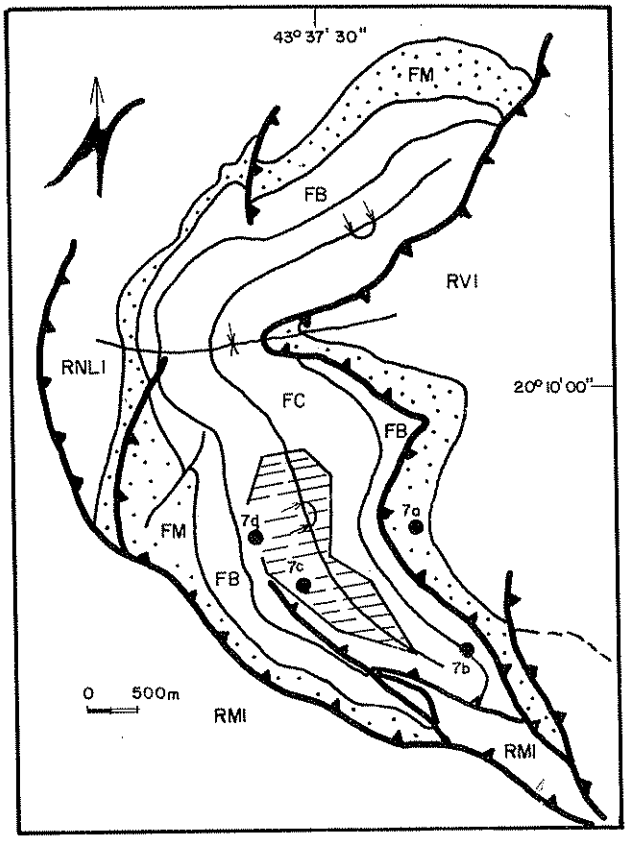


Fig-2.9-SCHEMATIC REBUILD OF FUNDÃO SYSTEM, BY MARSHAK & ALKMIM (1969)



SCHEMATIC GEOLOGICAL MAP OF OURO FINO SYNCLINE (FONSECA 1989)

Fig-2.11

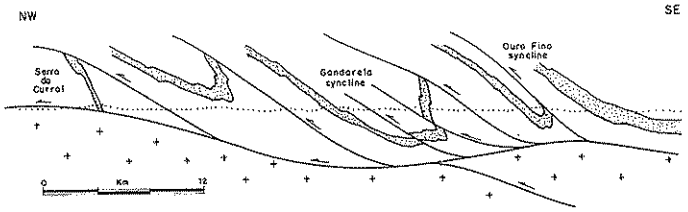
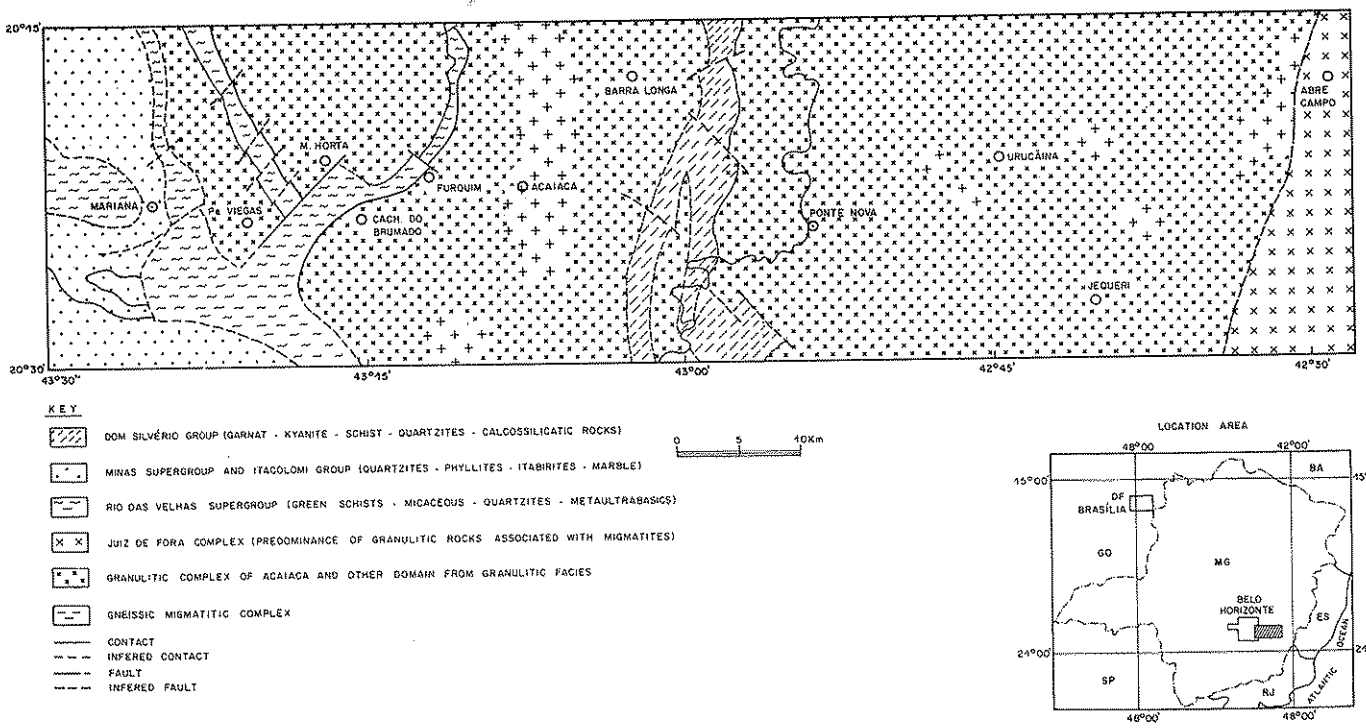


Fig-2.10 SCHEMATIC GEOLOGICAL CROSS-SECTION BETWEEN SERRA DO CURRAL AND OURO FINO SYNCLINE SHOWING THE GEOMETRY OF COMPONENTS FROM FUNDÃO SYSTEM BY MARSHAK & ALKIMIN (1989).



GEOLOGICAL SKETCH OF THE REGION BETWEEN MARIANA AND ABRE CAMPO

ADAPTADED FROM: LIMA ET ALLI (1974), BARBOSA (1969), JONAR EVANGELISTA (1984), SCHULZ-KUHNT (1985), MAPA GEOLOGICO DO ESTADO DE MINAS GERAIS - 1 : 1.000.000, DNPM (1976)

Fig. 2.12

2 b) Petrology and geochemistry of low to high grade metamorphic rocks in the east of the Quadrilátero Ferrífero

(Stretch: Mariana–Ponte Nova–Abre Campo)

INTRODUCTION

The area covered by this excursion (see Fig. 2.12) represents a profile which reaches, from West to East, the transition between the proterozoic metasediments of the Minas supergroup as well as the archean greenstone belt of the Rio das Velhas (in the West) the gneissic-migmatitic basement of the Quarilátero Ferrífero and the granulitic belt of East Brazil (in the East).

Lithologic Units

The east corner of Figure 2.12 forms the southeast border of the Quadrilátero Ferrífero. Here occur rocks of the Minas Supergroup (e.g. the silvered phyllites) with a low degree of metamorphism, and those of the Rio das Velhas Supergroup with a low to medium degree of metamorphism. The basement of this latter Supergroup is formed of granodioritic and tonalitic gneisses, predominantly biotitic and variably migmatized and which constitutes a gneissic-migmatitic complex (also called gneissic-granitic). This complex of archean age, which must have the greatest distributed area in figure 1, possibly corresponds to the Barbacena Complex, which occurs more to the south, even though, according to Hasui & Oliveira (1984, p. 137), the extension of the Barbacena Complex to the North, as well as being parallel to the Viçosa (20° 45'), is problematical, as its relationship with the gneissic-granitic complex is not known.

In the eastern sector (to the West of Acaiaca) of figure 2.12, the petrology is more homogeneous and the weakly migmatized biotite-gneisses predominate (points 8 and 10) and at times it also carries of some amphybolite or epidote. The amphybolite dikes are relatively frequent associated or not with steatite bodies. In the region of Acaiaca, in an area of approximately 5Km in width and which extends to the North and to the South, rocks with a granulitic facies predominate and they are associate with gneissic rocks of medium grade, which form the granulitic complex of Acaiaca (Jordt Evangelista, 1985b). In the central sector of figure 212 occurs a band composed of various schists of the amphybolitic facies and some quartzites, which on the map of Lima et al. (1974) take the name of the Dom Silvério Group. According to HASUI & OLIVEIRA (1984, p. 312), these rocks belong to the S.J. del Rei and Andrelândia Group whose age is still uncertain (middle or upper Proterozoic, HASUI et al., p. 315).

In the Eastern sector (to the East of the Dom Silvério Group) biotite - (amphibolite - epidote) - gneisses predominate, which are at times strongly banded. Locally bodies reduced from orthopyroxene carrying rocks occur. The migmatization is at times very intense. In the eastern extremity of Fig. 2.12 near Abre Campo, the granulitic facies becomes predominant and here is the probable limit between the migmatic gneissic complex and the Juiz de Fora complex. According to HASUI et al. (1984) the Juiz de Fora complex constitutes a band stopped by the Barbacena complex and is only differentiated from it by the predominance of white granulitic rocks which are in transicional limits. Its age is unknown, but its metamorphism is probably Transamazonian, with isotopic rejuvenate during the Brasiliano. Other authors join all these rocks with a predominance of granulitc facies together in the "Atlantic Belt" (FYFE & LEONARDOS Jr., 1974).

Assurely in the area in question it is difficult to establish the limit between the migmatitic - gneissic complex and the Juiz de fora complex. For many authors the rocks with a high degree of metamorphism represent deep segments which were reworked and brought to the supercrustal level by a tectonism of blocks in the mobile belt during the proterozoic cycles.

Metamorphism

In the eastern extremity of Figure 2.12 (Mariana) the metamorphism is of a low degree (green schist facies), in accordance with those found in the phyllites of point 3. The presence of staurolite and kyanite in the metapelites of the Rio das Velhas Supergroup which is situated between Mariana and Cachoeira do Brumado/Furquim, indicates a recrystallization at temperatures and pressures correspond-

ing to the start of the medium degree of Barrovian metamorphism. The still elevated quantity of Mg-Fe-chlorite and the large presence of chloritoid relicts in garnets (see point 5 and 7) indicate that the metamorphism must have been of lower amphybolitic facies, for in metamorphic conditions somewhat more elevated, these minerals are unstable (only the Mg - clorites are stable in the amphybolitic facies, those which contain Fe decompose to give the green schist facies (see WINKLER, 1979). There is evidence of multiple deformation events and metamorphic recrysallization in these schists, showing that the paragenesis of the amphybolitic facies was the last formed.

In the migmatitic-gneisses of the eastern basement the paragenesis also indicates recrystalization of the amphybolitic facies with a low degree of metamorphism. Although the plagioclase (oligoclase/andesine) indicates a higher grade of metamorphism than the green schist facies (TURNER, 1982), their frequent association with epidote restricted the metamorphism to the lower amphybolitic facies. As a consequence one can deduce that the rocks are polymetamorphics, and that the paragenesis encountered represents a retrograde metamorphism in relation to the metamorphic event of the upper amphybolite facies which later would have occasioned an incipient migmatization in these gneisses.

In the neighobourhood of Acaiaca, however, one can find various bodies of granulitic facies in this migmatitic-gneisses complex, where mafic varieties behave as orthopyroxenes, and which shows a retrograde metamorphism in green schist facies conditions. Furthemore, in this neighbourhood migmatitic gneisses also occur which are similar to those described in the previos paragraph.

In the center of Figure 1 appears a set of predominantly metapelitic and quartzitic rocks which take the name of the Dom Silvério Group. Their metamorphism is of a low degree. The schists here differ from those of the Rio das Velhas Supergroup which occurs more to the West (Mariana-Cachoeira do Brumado/Furquim) by the abscence of Mg-Fe-chlorites (except as secondary), by the much corser granulometry and by the higher chemical content of garnet and cianite. The occurrence of staurolite in these metapelites and diopside in calcosilicatic horizons indicate amphybolitic facies. Their degree of metamorphism is also more elevated than that of the schists to the West and they present evidence of multiple deformation events.

To the East of the Dom Silvério Group appear new migmatitic-gneissic rocks of the amphybolitic facies. The degree of migmatization increases to the East and in the surrounding of Abre Campo they appear migmatized with a great strucutural variety, such as flebitic, stromalitic, ptigmatic, "Schlieren" and nebulitic.

Resuming, one can observe that there is a generalized increase in the degree of metamorphism from West to East, though this is not in the form of a gradual and continuous change, but tending to be, for example, isolated bodies of granulitic rocks which are seen to be distributed in the gneissic-migmatitic terrains. Perhaps* at least some were preserved from a retrograde event which reached the gneissic terrains in an unequal manner. There are strong indications for an irregular diaphtoresis in accordance with what one can see in certain outcrops (see, for example, point nº 15). As well as this there exists the possibility that the migmatitic-gneissic terrains with lenses of orthopyroxene rock correspond to a critical depth of the crustal level in which the migmatitic rocks would have been generated, by the access of sufficient quantities of H_2O or granulitic rocks in the case of little H_2O or the dilution of the fluid phase by CO_2.

According to FYFE & LEONARDOS JR. (1974) the charnockitic rocks associated to the migmatites in the Atlantic Belt are considered as the residue of anatase.

Geotectonic Units

The tectonic-metamorphic evolution of the region in Figure 2.12 and its surrounding area was polycyclic, as demonstrated by the varied geochronological results and the petrographic observations.

A block structure, indentified by gravimetric data, developed in the Archean and is attributed to the Jequié cycle (2.7 billion years, HARALYI & HASUI, 1982). In the immediate surroundings of Campo Abre (Fig. 2.12) a remarkable gravimetric anomaly occurs in a approximately N-S direction, which indicates discontinuities in the crust thickness. To the West of this discontinuity one can find the migmatitic-gneissic terrains which correspond to a thckening of the crust. To the East one finds the belt with a high degree of metamorphism which correspond to the lower portions of a slightly lifted block (HARALYI & HASUI, 1982). The gneissic-migmatitic terrains form part of the old Paramirim Crater which is a geotectonic unit of pre-transamazonian age intensely affected by the Jequié event, as also perhaps were the belts that surround them (ALMEIDA, 1981). In the Lower Proterozoic (Transamazionian or Minas Cycle, - 2.0 billion years) and the Upper Proterozoic (Brasiliano Cycle, 0.5 billion years) there was intense tectono-metamorphic reworking in the areas encircling the Paramirim Craton and including its own borders, although the effects are much more attenuated in them than in the mobile belts (ALMEIDA, 1981). The repetition of the incidence of the intense tectono-metamorphic reworking events characterise the so called mobile belts (mobile belts in the sense of ANHAEUSSER et al., 1969) which surround craterized areas. It appears that the region under discussion (the Eastern sector) was qualified as belonging to a coastal mobile belt by ALMEIDA, in 1981. Those Archean areas composed of gneissic-migmatitic terrains, the "Greenstone Belts" (Rio das Velhas Supergroup) and recovered by supercrustals with a low degree of metamorphism of the Lower Proterozoic (Minas Supergroup), and which did not suffer, except at its borders, the effects of the Brasiliano Cycle (-0.5 billion years) form part of the São Francisco Craton (ALMEIDA, 1977). The eastern limit of this crater in the region under discussion is characterized, according to ALMEIDA, in 1977, by a fault system in an approximately N-S direction and by a movement direction of E-W, that borders the Quadrilátero Ferrífero and was developed during the Brasiliano Cycle. In Figure 2.12, in the western sector this limit would be where various thrust fault systems occur.

Summarizing, at the western extremity of figure 2.12 the

Craton of São Francisco is shown, and to the East (Abre Campo neighbourhood) the Coastal Belt (sometimes called Ribeira Belt or Band, Atlantic Belt, Granulitic Belt, Coastal Belt) which was intensely reworked in the Braziliano. Between these two geotectonic units occur the gneissic-migmatitic terrains with isolated bodies of granulitic rocks in with a metasedimentary cover of an unidentified age and stratigraphic position (the Dom Silvério Group) in the central portion. These terrains form a transition between the São Francisco Craton, to the West, and the mobile Coastal Belt, to the East, and forms part of the old Paramirim Craton.

Based on geochronologic data that indicates tectono-metamorphic reworking in the Transamazonian and rejuvenating in the Brasiliano in the area under discussion, TEIXEIRA et al., in 1987, noted modifications in the eastern borders of the São Francisco Craton, but the previously adopted belts based on lithologies and faultings are strongly subjective. The above mentioned authors extend the mobile belt to Mariana and call attention to the difficulty of tracing the precise limit between the crater and the adjacent fold, by virtue of the differential reworking which occurred in the Brasiliano on a paleocrust of considerable dimensions.

EXCURSION ROUTE

For the convenience of the participants, the kilometer markers at the edge of the MG-262 highway are used as reference points, when journeying from Mariana to Ponte Nova. The starting point for the excursion is at the entrance to the city of Mariana - km 0 - on the MG-262.

Stop 1: km 2.2, MG-262

Silvered Phyllites

Outcropping of phyllites of the Minas Supergroup.

Silvered phyllites mainly composed of white mica, opaques (hematite and magnetite), garnet, quartz and kyanite. Occurrence of kyanite in macrocrystals (of up to 15cm in size), at times folded, together with quartz and white micas mainly in fractures.

Bands of manganese oxide of up to 10cms thickness, products of mineral weathering of Mn. Low degree of metamorphism in the rocks.

Stop 2: km 6.0, MG-262 - North of the road on the old part of the road.

Amphybolites

Quartz schists of the Rio das Velhas supergroup.

Main Composition: Quartz magnesium chlorite, biotite, dolomite, amphybolite (member of the actinolite - tremolite series 7/c 15°, 2Vx = 85°)

Acessory minerals: Titanite, apatite, clinozoisite, zircon, ilmenite, albite, rutlite.

Strongly folded rocks still showing altered sequences which show the sedimentary bands. A transversal increase of the amphybolites indicates a survival of the metamorphic thermal flows over the tectonic forces. The rocks show graywacke chemistry with an elevated chemical content of Ni and Cr, which has been interpreted as being their original material (premetamorphic) and as Archean Graywackes formed from volcanic material (Tab. 5).

Stop 3: km 3 on the Ribeirão de Carmo road. The enterance to this road is at km 7 on the MG-262. The road goes in a northern direction. See the mape of Mariana, 1:50,000 IBGE, 1976.

Amphybolites

Main composition: Amphybolites of the actinolite series (Z/c = 13°, 2Vx = 80°), plagioclase (average chemical content of anortite is between 20 and 40%), quartz (Tab. 6).

Stop 4: On the Ribeirão de Carmo road 1.2km from the junction with the MG-262.

Steatite

Main Composition: Talc, magnesium chlorite, dolomites orthosteatite with elevated values of Ni and Cr (1,000ppm), metasomatic rock formed from ultramafic/ultrabasic rock.

Stop 5: On the Ribeirão do Carmo road 2.5km from the junction with the MG-262, directly to the side of the bridge over the Rio do Carmo. See the mape of Mariana, 1:50,000 IBGE, 1976.

Greenschist

Schist of the "Nova Lima" type (Rio das Velhas Supergroup) mainly composed of white mica, quartz and garnet. The formation of these rocks were probably in conditions of the start of the medium degree of metamorphism because it has already staurolite in it, which forms crystals of chlorite or chloritoid at 550° ± 30°C at a pressure of 4 to 7 kbar (HOESCHECK, 1969). The choritoid which also exists in this schist is distinctly relectic and invariably included in the garnet (Tab. 7).

Stop 6 - km 13, MG-262

Steatite

Main Composition: Talc, dolomite, anthophyllite, magnesium chlorite.

One of the possible formations of orthoamphibole anthophyllite happens from the reaction of talc + magnesite according to JOHANNES (1969) and indicates medium degree of metamorphic conditions (for pessures Pf = 2 kbar, temperatures of around 500 - 550°C). One condition for this reaction is a high modal fraction of CO_2.

The paragenesis in this rock (dolomite instead of magnetite) does not occur in exactly the same way for the formation of anthophyllite, which in this case must be the product of similar conditions. One can therefore conclude that here we have a rock of in the transitional phase between the low and medium degree of metamorphism. This hypothesis is re-enforced by the occurrence of staurolite schists very close to these rocks.

It can be treated as a meta-ultramafic rock formed from ultrabasic rocks which were metamorphosed and influenced by metasomatic processes that totally changed their main

chemical composition (ROESER, U. et al., 1980; ROESER et al., 1897). Chemical Analysis (by electron microprobe) of the steatite mineral (Tab. 8).

Stop 7 - km 13.2, MG-262

Staurolite - garnet schist of the Nova Lima Group (Rio das Velhas Supergroup).

Main Composition: White mica, staurolite, chlorite (Mg), garnet, quartz.

The Paragenesis: Staurolite-chlorite-white mica-quartz indicate metamorphic conditions at the start of the medium degree. The rock is the product of the metamorphism of argillitic sediments. The high values of Al_2O_3 combined with the relatively low chemical content of CaO indicate, according to RONOV, 1966, a sedimentary process near the coast. The elevated values of the Ni and Cr traces show the influence of the participation of basic material, which is typical of rocks of the Greenstone Belts, and which are related to ultramafic/ultrabasic occurrences. Other charactreristics which combine with the ages of these rocks is the relationship Ni/Cr lesser than 1, and which is generally greater than 1 in more recent sediments (Tab. 9).

Stop 8 - km 14.9, MG-262 (Santo Antônio)

Biotite-gneiss with incipient migmatization Main Composition: quartz, alkaline feldspar, plagioclase, biotite, white mica.

The rock, extremely folded, shows the signs of the start of a migmatization process. The rock is a polymetamorphic product; it was originally formed under elevated conditions of a metamorphism which occasioned a partial migmatization. It later suffered an almost total recrystalization in lower metamorphic conditions. From its old composition there only remain some orthoclase blasts. At time one also finds two generations of plagioclasics. The rock age is 2,700 million years as determined by CORDANI et al. in 1980 using the Rb/Sr method. A biotite of the same rock showed 507 million years, reflecting the Brasiliano thermal event already mentioned (see the introduction). The rock is an Archean orthogneiss, which is derived from a migmatite of the granite-tonalite type (Na/K greater than 1). (Tab. 10).

Stop 9 - km 16.3 - MG-262. Turning to Cachoeira do Brumado and stopping 4km along this road one sees an outcrop of soapstone in the quarry.

Steatite

Main Composition: talc, actinolite, magnesium chlorite.

Accessory minerals: pyrite, ilmenite, magnetite, biotite, serpentine.

The rock is a product of a metamorphism/metasomatism of a low degree. Due to its metasomatic formation the rock shows a very heterogeneous appearence. One can see in the outcrop a steatite body in the following form: massive steatite - rock from amphybolite - chloritic rock. The transitional zone are gradual with the exception of the chloritic rock which moulds the lenses of the steatites forming distinctly limited borders.

Stop 10 - km 31 - Mg-262, after the bridge over the Rio Gualaxo, at a cut in the road.

Biotite-gneiss.

With biotitic melanocratics and mesocratic bands of very fine granulometrics, with biotite, garnet, pyrrhotite and felsic minerals. Intensely folded quartz veins with boudins (Tab. 11).

Stop 11 - km 31.1 - MG-252

Amphybolite-gneiss.

Composed of melanocratic and mesocratic amphybolite horizons, at times lenticular, sometimes of fine graisn and sometimes course and with leucocratic veins; aplitic. Rocks with a medium degree of metamorphism (Tab. 12).

Stop 12 - km 37 - Mg-262

Soapstone Quarry.

Steatite.

Relatively homogeneous rock, rich in amphybolites (actinolite-tremolite series); rock with a low/high grade of metamorphism.

Main Composition: talc, amphybolite, magnesium chlorite

Accessory minerals: ilmenite, hematite, pyrite, magnetite.

Stop 13 - km 43.5 of the MG-262, entering road to the North and following it for about 3km.

Abandonned quarry of rocks with a high degree of metamorphism, belonging to the granulitic complex of Acaiaca. The outcrop is constituted of and alterance of leucocratic bands (plagio granulitics = granulitic rocks constituted of quartz greater than 10, plagioclase orthoclase, clinopyroxene, amphybolitem and plagioclase), whose plunge is sub-vertical. The arrangement is venulated by course granitoids, sometimes concordant and sometimes discordant. Basaltic dykes, of approximately one meter thickness, cut the whole complex (Tab. 13).

Stop 14 - km 47.2, MG-262

50 meter long cutting along the MG-252 road Transition kianite - garnet schists/amphybolite-schists/biotite-gneiss.

Along the road cutting walking towards the East, one can observe a graditional lithologic variation within the Dom Silvério Group. Mica-schists with porphyroblasts of garnet and of a burgundy colour, changing to amphybolitic schists which cut the calcosilicatic horizons. These amphybolite-schists become more biotitic as they become a finely banded biotite-gneiss (Tab. 14).

Geothermometric calculations based on the biotite-garnet pair following the models of PERRY & SPEAR (1978), THOMPSON (1976) and PERCHUK et al. (1981) resulted in recrystallization temperatures of the borders varying between 510 and 540°C which correspond to the start of the medium degree of metamorphism. The presence of staurolite and of diopside also indicated the medium grade of metamorphism.

Stop 15 - Outcrop in the city of Ponte Nova, in the road which borders the Rio Piranga beyond house number 61. Metanorite, massive and homogeneous, with a greyish colour and fine to medium grain. One can observe some incipient schistosity in the locality (Tab. 15).

In accordance with what one can observe in the modal analysis, the rock suffered considerable retrograde transformation, which is more accentuated in the schists samples, because in these there is a greater ease of percolation for the fluid phase necessary for the formation of the secondary Hydrated minerals (amphybolites, talc, biotite). Therefore, the uneven diaphtoresis in this case, results from the different degrees of development of the schistosity in the rock body.

The origin of this rocks appears to be magmatic, that is to say, before the regional metamorphism it must have been derived from a norite.

Stop 16 - MG-359 highaway at the exit from Ponte Nova at a gneiss quarry.

The gneisses are strongly banded. The bands have variable thicknesses but in general are centimetric or decimetric. The contacts are gradational. The following petrographical types are common: biotite-gneiss, amphybolite gneiss, amphibole gneiss, diopside gneiss, epidote gneisse and bands with more than one of these mafics (e.g. amphybole-diopside-gneisse, biotite-amphybole-gneiss, amphybole-diopside-epidote-gneiss, etc.).

The felsic minerals, which chemical content is very variable from sample to sample, are quartz, plagioclase (oligoclase-andesine) and microline. The latter restricts itself to the leucocratic horizons of the biotite-gneisses.

The amphybole of the calco-silicatic horizons, which one associates with the diopside and some carbonate, is a very light green in thin leaves. Its composition is tremolitic. Those amphyboles of the amphybole-gneisses or of the biotite-amphybole-epidote-gneisses show a strong pleocroism in tones of olive green, green-blue, yellowish. One can treat it as a hornblende which center is Tschermakitic and whose borders are ferroárgastic (See the microprobe analysis below).

The chemical content of anortite of the plagioclase associated with this hornblendes varies from 35 to 50 mol. % (microprobe analysis in JORDT EVANGELISTA, 1985a) within the same crystal. The variation is irregular and can reflect a situtation of inequilibrium. A sharp variation of the chemical content of An is frequent within crystals of plagioclase which have been recrystalized in the lower amphybolite facies (see for example, BRAUN & MÜLLER, 1975; FREY, 1974). Only at more elevated temperatures there is a tendancy towards a greater homogenization of the composition. Geothermalbarometric calculations based on the plagioclase-hornblende pair (PLUSNINA, 1982) of this run resulted in a recrystallization temperature of 560°C to 570°C at a pressure of 4 - 5 kbar, for the border of these crystals (JORDT EVANGELISTA, 1984 and 1985a).

The large quantity of epidote rich in Fe in these gneisses is interesting. Generally epidote decomposes in the low degree to medium degree transition, supplying the calcium to the albite to plagioclase transformation with more calcium (An greater than 17). This transformation characterizes the start of the medium degree of metamorphism according to TURNER (1981), though it does not occur at a fixed temperatures. In some thin sections there are indications of this transformation, in the form of aureoles of plagioclase enveloping relicts of epidote.

Microprobe Analysis

By the classification of the amphyboles according to LEAKE (1978) the center of the crystals (analyses I and II) have the composition of a tschermakitic and at the border (analyses II and IV) that of a Ferropargitic hornblende.

Tabela 5

Modal Analysis:

Actinolite:	28 – 29.3		Extras
Quartz:	37.8 – 40.9		
Dolomite:	6.8 – 30.2	Apatite:	Albite

Biotite:
0 – 15.4
Titanite
Clinozoisite

Chlorite:	7.3 – 20.9	Ilmenite	Rùtile
Extras:	1.5 – 2.3		

Chemical Analysis:

Main Chemical (% by weight)		Traces (ppm)			
SiO_2	64.33	Ba	428	Sc	17.4
TiO_2	0.76	Co	36	La	20.4
Al_2O_3	14.29	Cr	715	Ce	44.7
Fe_2O_3 (tot)	6.88	Cu	69	Sm	2.7
MnO	0.07	Ni	289	Eu	1.0
MgO	4.80	Sr	143	Tb	0.6
CaO_2	2.06	V	143	Lu	0.2
Na_2O	2.58			Hf	2.5
PF	2.08				
Total	99.61				

Standard CIPW:

qz:	31.14	c:	4.43	or: 10.44	ab: 21.92
an:	10.26	en:	12.00	hm: 6.91	il: 0.15
ru:	0.68				
salic.	78.17				
femica:	19.74				
total:	97.91				

Tabela 6

Approximate Modal Analysis:

Main Chemical (% by weight)		Traces (ppm)
Amphybolite:	65 – 80%	Extras
Plagioclasic.	10 – 25%	Titanite
Quartz:	5 – 10%	Ilmenite
Extras:	0.05 – 8%	

Manin Chemical (% by weight)		Traces (ppm)	
SiO_2	49.00	Ba	68
TiO_2	3.33	Co	63
$Al_2O_3$275	15.03	14.29	
Fe_2O_3 (tot)	3.79	Cu	103
MnO	0.33	Ni	185
MgO	7.01	Sr	184
CaO_2	10.45	V	313
Na_2O	3.89		
K_2O	0.24		
PF	0.79		
Total	99.53		

Standard CIPW:

qz:	11.89	or:	1.24	ab:	13.04	ab:	32.26
wo:	8.06	en:	17.79	hm:	12.13	il:	0.45
in:	2.07						
salic.	58.43						
femic:	40.50						
total:	97.91						

Tabela 7

Modal Analysis:

White Mica	86%
Extras	
Garnet	6%
Opaques	
Quartz	4%
Chlorite	
Extras	4%
Staurolite	
Chloritoid	
Toumaline	

SiO_2	49.68	Ba	1250
TiO_2	0.97	Co	24
Al_2O_3	26.53	Cr	246
Fe_2O_3 (tot)	9.83	Cu	10
MnO	0.06	Ni	89
MgO	1.13	Sr	246
CaO_2	0.01	V	186
Na_2O	1.70		
K_2O	5.57		
PF	4.65		
Total	100.11		

Standard CIPW:

qz:	36.33	or:	17.68	or:	32.92	ab:	14.39
an:	0.05	en:	2.81	hm:	9.81	il:	0.13
ru:	0.90						
salic.	81.81						
femic:	13.66						
total:	95.47						

Tabela 8

oxides	amphybolite	talc	chlorite
SiO_2	56.68	62.71	30.60
TiO_2	0.03	0.03	0.06
Al_2O_3	2.09	0.52	19.61
Fe_2O_3 (tot)	13.22	0.38	9.37
MgO	25.42	28.82	28.87
MnO	0.38	0.02	0.03
CaO_2	0.29	0.03	0.02
Na_2O	0.05	0.05	0.04
K_2O	0.01	0.03	0.03
H_2O (calc	2.17	5.17	12.36
Total	100.34	103.37	99.38

Tabela 9

Modal Analysis: (% by volume)

White mica	41.2 – 57.2
Staurolite	0 – 47.7
Garnet	0 – 19.3
Chlorite	4.5 – 10.5
Quartz	0.8 – 5.7
Opaques	0 – 7.9
Tourmaline	0 – 3.9
Apatite	+

Chemical Analysis:

Main Chemical (% by weight) Traces (ppm)

	SiO_2	55.12	Ba	910
	TiO_2	0.76	Co	34
Al	Al_2O_3	22.48	Cr	204
	Fe_2O_3 (tot)	9.52	Cu	27
	MnO	0.11	Ni	125
	MgO	2.35	Sr	143
Ca	CaO_2	0.01	V	158
	Na_2O	1.21		
	$K_{22}O$	3.89		
	PF	3.86		
Total		99.31		

Standard CIPW:

qz: 29.88 o: 16.37 or: 23.15 ab: 10.31
an: 0.05 en: 5.89 hm: 9.59 il: 0.24
ru: 0.64
salic. 79.76
femica: 16.63
total: 96.12

Tabela 10

Modal Analysis: (% by volume)

Plagioclase	35.1		Access.
Quartz	26.6		Epidote
K-feldspar	22.9		Chlorite
White mica	9.1		Zircon
Extras	0.5		Apatite
		Carbonate	

Chemical Analysis:

Main Chemical (% by weight) Traces (ppm)

SiO_2	73.34	Ba	516
TiO_2	0.25	Co	18
Al_2O_3	13.37	Cr	87
Fe_2O_3 (tot)	2.45	Cu	10
MnO	0.05	Ni	45
MgO	1.57	Sr	97
CaO	2.13	V	15
Na_2O	4.05		
K_2O	1,91		
PF	0.53		
Total	99.65		

Standard CIPW:

qz: 35.69 : 0.77 or: 11.33 ab: 34.39
an: 10.60 en: 3.92 hm: 2.46 il: 0.11
ru: 0.19
salic. 92.79
femica: 6.68
total: 99.47

Tabela 11

Average Modal Composition:

Quartz	26	Extras
Plagioclase	47	Epidote
Biotite	13	Tibatite
Garnet	1	Apatite
Extras	1	Chlorite
		Zircon

Chemical content of An in the plagioclase 25.

Chemical Analysis (% by weight) by microprobe.

SiO_2	37.76		34.49
TiO_2	n/a	3.03	
Al_2O_3	20.75		18.24
FeO (tot)	24.76		24.06
MgO	0.42		7.68
MnO	5.88		n/a
CaO	12.97		0.07
Na_2O	n/a		0.39
$K_{22}O$	n/a		9.93
Total	99.54		99.97

Components:

Almandine:	55.0
Grossularite:	36.9
Pyrope:	1.7
Spessartite	6.4

Tabela 12

Modal Analysis: (% by weight)

	Amphybolitic horizons	aplitic horizons
Quartz	0 – 9	36
Plagioclase	36 – 53	64
Amphybolite	31 – 54	+
Biotite	0 – 9	+
Clinopyroxene	+ – 10	–
Epidote	+ – 4	+
Titanite	+ – 5	–

Extras: Epidote, carbonate, scapolite, opaque, opatite, chlorite.

Tabela 13

Average Modal Analysis:
Plaggr. = Plagiogranulite, Pyribol. = Pyribolite

Mineral	Plaggr.	Plaggr.	Plaggr.	Pyribol.
Quartz	29.4	23.1	22.7	–
Plgioclase	50.1*	40.4	33.4	39.0**
Alkaline F/spar	14.1	16.6	23.7	–
Biotite	3.2	19.8	12.1	2.6
Garnet	2.9	+	7.3	–
Opaque	0.2	0.1	0.8	1.0
Apatite	0.1	–	–	–
Zircon	+	+	+	+
Epidote	+	0.1	–	–
Amphybolite	–	–	–	31.5
Clinopyroxene	–	–	–	19.2
Orthpyroxene	–	–	–	6.7
Carbonate	–	+	–	+

* = An = 27, ** = An = 55

Chemical Analysis
Main Composition (% by weith)

	Plaggr.1	Plaggr.2	Plaggr.3	Pyibol.
SiO_2	71.30	67.80	64.00	49.40
TiO_2	0.20	0.46	0.73	1.40
Al_2O_3	15.30	15.00	15.80	13.10
Fe_2O_3 (tot)	0.14	< 0.10	1.40	4.90
FeO	1.85	3.99	4.99	10.42
MnO	0.07	0.07	0.09	0.25
MnO	0.73	1.20	2.40	6.50
CaO	2.80	1.80	2.10	10.70
Na_2O	4.41	3.49	3.18	3.08
K_2O	2.54	5.26	4.55	0.31
H_2O	0.27	0.38	0.35	0.30
P_2O_5	0.07	0.06	0.06	0.13
CO_2	0.15	0.29	0.098	0.25
S	0.02	0.03	0.08	0.27
Total	99.85	99.82	99.828	100.01

Tabela 14

	Kyanite-garnet schists	Amphybolite schists	calcosilicatic bands
Quartz	35.8	8.5	0 – 5.1
Plagioclase	13.6	46.9An40	–
K-felspar	–	2.6	–
Riotite*	20.7	6.6	0 – 53.7**
Moscovite	13.8	–	–
Cianite	10.9	–	–
Garnet***	4.0	–	5.1 – 69.4***
Amphybilite	–	32.2	***
	–	–	0 – 34
Carbonate	+	1.3	16.6 – 81.5
Extras	1.2	1.9	< 1.0
	Staurolite Rutite Zircon Cartonate Epidote	Titanite Opaques Apatites	Epidote Chlorite Tourmaline

* See electro microprobe analysis
** phloggophite
*** tremotile-actinolite

Electron microprobe analysis of cianite a- garnet schist minerals

	Centre Garnet	Border Garnet	Biotite
SiO_2	37.43	37.11	36.12
TiO_2	n/a	n/a	2.57
Al_2O_3	23.21	23.20	20.84
FeO (tot)	31.47	32.11	18.32
MnO	3.41	2.75	0.09
MgO	1.69	2.61	10.29
CaO	5.89	4.58	0.01
Na_2O	n/a	n/a	1.27
$K_{22}O$	n/a	n/a	9.29
Total	103.1	102.36	98.80

Tabela 15

	Sample 1 without Schistosity	Sample 2 with weak Schistosity
Plagioclase	58.3 (An 65)	55.1 (An 60)
Orthopyroxene	7.7	–
Clinopyroxene	0.5	–
Amphybolite* (Actolinite & Cummingtonite)	31.8	41.6
Biotite*	1.4	1.5
Talc*	0.3	1.8
Carbonate*	+	+
Apatite	+	–
Opaque	+	+
Mg chlorite	–	+

* = secondary minerals, formed by the retrograde alteration of the mafic rocks.

Chemical Analysis of a sample without schistosity.

	Main Chemical (% by weight)		Traces (ppm)
SiO_2	52.50	F	800
TiO_2	0.11	Sc	22
Al_2O_3	19.20	V	130
FeO (tot)	1.2	Cr	600
FeO	3.99	Co	22
MnO	0.11	Ni	122
MgO	9.10	Cu	51
CaO	10.30	Zn	890
Na_2O	2.56	Ga	22
$K_{22}O$	0.33	Rb	30
H_2	0.25	Sr	475
P_2O_O	0.06	Zr	21
CO_2	0.15	Nb	20
S	0.06	Mo	5
Total	99.92	Sn	5
		Ba	140
		Pb	54

Chemical Analysis by Microprobe (% by weight)

Clinopyroxnene (Diopside)		Orthopyroxene (bronzite)
SiO_2	54.38	55.03
TiO_2	0.14	0.06
Al_2O_3	1.77	0.91
FeO (tot)	5.19	16.95
MnO	0.22	0.38
MgO	16.00	27.18
CaO	23.38	0.17
Na_2O	0.33	0.00
Total	101.41	100.68

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3. GOLD MINERALIZATIONS OF NORTHEASTERN BAHIA

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THEME OF FIELD TRIP

The purpose of the field trip is to illustrate the geology of the two main gold provinces of Bahia and the geologicsl control of gold mineralizations of the northeastern margin of the São Francisco craton.

The four days excursion will begin and end in Salvador. On the first day the excursion will visit the Fazenda Brasileiro gold mine where exposures of high-grade gold orebodies will be shown. On the second day the trip passes through the Rio Itapicuru greenstone belt where a section will cross other gold occurrences, including a small mine. The setting of these deposits, and associate hydrothermally altered rocks and shear zones, will form the discussion topic. During the third day, the route passes through gneissic and granulitic terrains. Further west, in the Jacobina Range, gold occurs in Proterozoic clastic sediments deposited on Archaean basement. During the fourth day, a section will cross the Jacobina sequence and its eastern basement. Sedimentary models and tectonic relations between the Jacobina sequence and the basement rocks will be the subject for discussion.

ACKNOWLEDGMENTS

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GEOLOGICAL SETTING

The main geological features of the São Francisco craton in the State of Bahia are shown in figure 3.1. The major Archaean to Proterozoic geotectonic units presently accepted are:

1 – The Archaean Jequié block, with its associated mobile belts (Mascarenhas, 1973), extending for more than 700 km from north to south and divided into the Salvador-Curaçá and the Atlantic Coast or Itabuna granulitic belt;

2 – a medium grade gneiss-migmatite complex, which forms the borders of these older terrains and is separated into a large western belt and a northeastern, oval-shaped nucleous in the Itapicuru river region;

3 – supracrustal sequences, metamorphosed to greenschist - amphibolite facies grades, associated with the gneiss migmatitic complex are intruded by several types of granitoids. These sequences are mainly represented by the Jacobina and Itapicuru volcanosedimentary belts, which will be described in more detail in the following text.

Part 1
The Rio Itapicuru Greenstone Belt with the Weber Gold District

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THE RIO ITAPICURU GREENSTONE BELT

INTRODUCTION

The granite-greenstone terrains of Itapicuru extends for more than 4,000 km on the eastern margin of the São Francisco craton, NE of Bahia (figs. 3.1 and 3.2). The first attempt to compare this geological environment with Archaean greenstone belts elsewhere was made by Mascarenhas (1973). Later, a regional map with lithogeochemical descriptions was presented by Kishida (1979) and Kishida & Riccio (1980). Subsequently, the so-called Rio Itapicuru greenstone belt has been the focus of intense geological and geochemical exploration because of its attractive potential for gold and base metal mineralization.

THE SUPRACRUSTAL SEQUENCE

The volcanosedimentary rocks have been grouped into three lithostratigraphic domains (Teixeira et al., 1982; Silva, 1984; Davison et al., 1988), from base to the top:

1 – Mafic volcanic domain (MVD); a 5,5 km thick sequence of dominantly tholeiitic metabasalts comprising massive, porphyritic, variolitic and pillowed lavas, the latter often associated with flow-breccias. Gabbroic sills, carbonaceous metapelites, chert and banded iron formations common within this domain.

2 – Felsic volcanic domain (FVD); a 3,5 km thick sequence of calcalkaline andesite to dacitic lavas and pyroclastics, intruded by subvolcanic diorites.

3 – Sedimentary domain (SD); a 0,5 to 1,0 km thick sequence of epiclastic metasediments (sandstones and siltstones), metaconglomerates and metagreywackes, carbonaceous phyllites and chemical metasediments (BIF, chert, marble, jaspilite and gondite).

INTRUSIVE ROCKS

Several types of intrusions have been described by Kishida & Riccio (1980), Teixeira (1985) and Matos & Davison (1987), as follows:

1 – Large granite-gneiss domes, consisting of weakly deformed granitic cores with highly deformed margins containing granodioritic to tonalitic gneisses associated with quartzo feldspathic pegmatites. The transition from granitic to gneissic rocks can be gradational, indicating increasing, or abrupt, where granite has intruded banded gneisses and incorporated them as xenoliths.

2 – small to large isotropic granitoids, composed mainly of granodiorite showing homogeneous aspect, absence of enclaves and lack of pegmatitic activity. These rocks intrude mainly the MVD;

2 – small to large isotropic granitoids, composed mainly of granodiorite showing homogeneous aspect, absence of enclaves and lack of pegmatitic activity. These rocks intrude mainly the MVD;

3 – small subvolcanic intrusions, consisting of stocks and dykes of porphyritic diorite and quartz-diorite which intrude both the supracrustals and the granite-gneiss domes;

4 – narrow gabbroic sills which can be differentiated or not and frequently intrude the MVD or the MVD-SD and FVD-SD interfaces;

5 – very small ultramafic bodies, represented by two oval-shaped metaperidotites localized at the NW portion of the area, within the FVD. These rocks show relict cumulus texture with olivine crystals replaced by serpentine, talc and carbonate.

METAMORPHISM

Greenschists facies of metamorphism predominates. According to Silva (1984; 1987), three distinct metamorphic events affected the supracrustal sequence: (a) the M, sea-floor hydrothermal alteration which produced spilites and keratophyres on part of the volcanic rocks; (b) the M_2 dynamothermal event, related to the intrusion of the large granite-gneiss domes - this resulted in a metamorphic zoning within the supracrustals, grading from greenschist to amphibolite facies and (c) a thermal event M_3 which produced hornfels in contact aureoles around the late-tectonic intrusives.

GEOCHRONOLOGY

The first age determinations for felsic metavolcanics in the southern part of the belt were published by Brito Neves et al (1980), with a five point Rb-Sr whole rock isochron where $T = 2080 \pm 90$ Ma and $R_o = 0.7017 \pm 0.0014$.

The authors also presented a 13 point whole rock isochron for gneissic granite and migmatite from the western and southern parts of the belt where $T = 2090 \pm 27$ Ma and $R_o = 0.704 \pm 0.0008$. A similar age was reported by Gaál et al. (1987) for zircons extracted from syntectonic granitoids at the western part of the belt, with an intercept at 2170 ± 23 Ma in an U-Pb concordia diagram. These authors also presented an U-Pb diagram for zircons from a highly deformed xenolith of banded gneiss in the marginal zone of the Ambrosio Dome (see fig. 3.2), with a intercept at 2930 ± 32 Ma (fig. 3.3).

Although conclusive isotopic analyses for metabasalts are not available, the geochronological data point to a Proterozoic age for development of the Itapicuru granite-greenstone terrane, with deposition of the volcanosedimentary sequence on an Archaean gneiss basement, followed by metamorphism, deformation and plutonism.

STRUCTURE

The Rio Itapicuru greenstone belt is considered to be a remnant of an Early Proterozoic lava flow and volcanoclastic filled ensialic basin (Davison et al., 1988) or the remnant of a back-arc rift system developed to the east side of a major Early Proterozoic continental collision zone (Silva, 1987; Gaál et al., 1987).

The deformation pattern of the central-north arm of the belt is characterized by a penetrative bedding-parallel compaction cleavage which was locally sheared, metamorphosed and then folded during an EW compression. These produced large F_1 folds with NS axial planes which dip consistently towards the west. The F_2 folding phase produced non-penetrative crenulations in the fine-grained metasediments, with maximum fold amplitude and wavelengths up to 30.0 cm (Davison et al., 1988). The structural pattern appears to be more complicated in the southern sector of the belt, with superposition of four ductile deformations. The F_1 event, described by Teixeira (1985) in the Fazenda Brasileiro gold mine, was a strong shearing locally accompained by isoclinal folding. During this phase a penetrative ductile fabric destroyed most of the primary textures in sediments and igneous rocks. The F_2 deformation was regionally more important and produced EW oriented tight folds with axial planes dipping consistently to the south. A penetrative axial planar foliation S_2 is the most evident structural feature in the southern area. The F_3 phase generated subvertical, EW trending folds which are open, asymmetric monoclines with a spaced axial crenulation cleavage (Gaál and Teixeira, 1988). Northward-direction of thrusting, correlated with the F_2-F_3 events was reported in the Fazenda Brasileiro gold mine (Reinhardt, 1988). The fourth folding phase caused undulations with subvertical NE-SW oriented axial planes, presenting a locally pronounced crenulation cleavage S_4.

The last deformation process in the region developed under a brittle regime a NE-SW and NW-SE faulting sistems which produced kilometer scale horizontal offsets of lithological contacts (Davison et al., 1988).

Structural correlations between the northern and southern domains are still not clear and a change in the principal shortening direction from EW in the north to NS in the south is poorly understood (Davison et al., 1988).

GEOCHEMISTRY AND VOLCANIC PETROGENESIS

The metabasalts of the Itapicuru River section are low-K tholeiites with compositional analogy with MORB (Kishida & Riccio, 1980). According to Silva (1987) these rocks can be geochemically classified into three distinct groups:

1 – predominant ferrobasalts, with total iron higher than 12.0%;

2 – subordinated normal basalts, with total iron ranging from 10.0% to 12.0% and with MgO lower than 8.5%; and

3 – rare magnesian basalts, with MgO higher than 8.5%.

The positive correlations of Zr and Y with total Fe (fig. 3.4) suggest that fractional crystallization played an important role during the generation of these magmas. Based on the interpretation of REE patterns, Silva (1987) recognized two types of tholeitic lavas: a) slightly depleted LREE basalts, with normalized La/Sm ratios varying from 0.75 to 0.99 and (b) enriched LREE basalts, with normalized La/Sm ratios from 1.58 to 2.10, both the two groups exhbiting a flat to gentle inclined HREE pattern (fig. 3.5). After numerical modelling the same author concluded that the two types of lavas were derived from distinct parental liquids, certainly generated at different depths and from different proportions of mantle melting.

The felsic metavolcanics have compositions within the dacite/andesite field and present a calc-alkaline differentiation trend with affinity to calc-alkaline suites from younger continental margins (Kishida & Riccio, 1980). These rocks suffered a pervasive post-magmatic alteration which caused K and Na mobilization and a relative addition of Al, while the SiO_2 contents vary from 60 up to 74%. The REE pattern for Itapicuru andesites show a strong LREE depletion, with La/Sm ratios of 1.30 to 1.60 and with Gd/Yb ratios around 0.50 (fig. 3.6).

The comparison of REE patterns from mafic and felsic extrusives indicates that these two groups of rocks were not derived from a single parental liquid by fractional crystallization and the distinction between the tholeiitic and the calc-alkaline differentiation trends is clearly shown in the diagram TiO_2: [MgO/(MgO + FeO)] of figure 3.7.

Alternatively, the generation of the Itapicuru felsic lavas by anatexis of the sialic crust is constrained by the low Sr-isotope initial ratios and an eclogitic source for these melts is not discarded (Silva, 1987).

GOLD MINERALIZATION

Gold has been sporadically panned in alluvial deposits on the Itapicuru River banks, at least since the thirties. Two gold mines are presently in production: the Fazenda Brasileiro, in the southern sector of the greenstone belt and the Maria Preta gold mine, near the Itapicuru River. Although the host rocks are different from one deposit to the other, gold deposition is always associated with hydrothermal alteration processes which overprinted greenschist facies metamorphism in a regional scale and the main orebodies are often related to pervasive small-scale fracturing, normally in shear zones, where fluid wall-rock reactions have been more effective.

Based on available data already published (Teixeira, 1985; Marimon et al., 1986; Gaál & Teixeira, 1988), the metallogeny of gold in the Rio Itapicuru greenstone belt can be regarded as very similar to that of the Yilgarn Block, Western Australia, described by Groves et al. (1984).

THE WEBER BELT GOLD DISTRICT

INTRODUCTION

Fazenda Brasileiro is the most important gold deposit localized on the Weber belt which is a 8.0 km long gold district at the southern sector of the Rio Itapicuru greenstone belt (fig. 3.8). The district was discovered in 1976 by DOCEGEO during a regional prospecting project which involved geological, geophysical and geochemical methods.

The major orebodies of the Weber belt are found at the borders of a metamorphosed and hydrothermally altered mafic sill, where gold is associated with quartz veins containing albite, calcite, arsenopyrite and pyrite (Teixeira, 1985; Marimon et al., 1986).

PHYSICAL FEATURES

The region around the Weber belt exhibits a relief of low hills with gentle slopes that rise to a maximum of 50 m above narrow alluvial plans. The hills are covered by residual soils which vary in thickness from more than 1.0 m close to the valleys to just a few centimeters deep at the tops. Nevertheless, a deep oxidation zone developed in the area, sometimes extending deeper than 30.0 m (Vasconcelos, 1987).

The climate is tropical semi-arid, with an average annual precipitation of about 300 mm. The average annual temperature is around 24°C, with minima and maxima of 12°C and 40°C, respectively. The region is drained by seasonal streamlets and the vegetation is dominated by xerophytes of medium to small port.

DETAILED EXPLORATION

Although the first boreholes at Fazenda Brasileiro were drilled to check geophysical anomalies, a stream sediment survey was his survey detected a gold anomaly grossly outlined by counts of gold particles in the heavy mineral fraction (fig. 3.9). A follow-up soil geochemical survey was carried out using a 100 x 25 m grid over the eastern portion of the area. The samples were collected in the depth interval of 10-30 cm and the -30 # fractions and were analysed for gold by AAS, after an aqua-regia digestion. The result was only partially successful, since only the strongest anomalies related to orebodies covered by a thin soil blanket were detected. Later, an As soil survey was carried out using a 200 x 50 m grid, with analysis of the -80 # fraction by the Gutzeit method. The outer limit of soil anomaly is bounded by the 30 ppm As contour line and the 120 ppm As contour defines the dispersion halo around arsenopyrite-rich mineralizations.

Subsequently, a more rapid and cheaper follow-up soil sampling method was employed, consisting of: (a) sampling of 5 liters of the surface material, using a 200 x 25 m soil grid; (b) sieving at -10 # grain size; (c) wet defloculation of clayey components by rotary churning with addition of small amounts of lime and (d) sluicing, panning and counting the visible gold particles in the heavy concentrates. This process was considered to be efficient for detection of both high and

low-grade mineralized zones in the Weber belt (fig. 3.9), and counting of Au particles in equal-volume of soil samples has been successfully applied as a detailed exploration tool throughout the greenstone belt (Teixeira, 1981).

GEOLOGY OF THE WEBER BELT

The geology of the Weber belt has been reported by Marques (1979), Teixeira & Kishida (1980), Monte Lopes (1982) and Teixeira (1985). Based on surface mapping and drill-core data, Marques (1979) has grouped the local lithologies into three main units, from south to the north: Riacho do Incó unit, Fazenda Brasileiro unit and Fazenda Canto unit (fig. 3.10).

The Riacho do Incó unit is composed of greenschists with interlayered metasediments and metagrabbro sills. Petrographic and geochemical studies indicate that the greenschists are metamorphosed and deformed tholeiitic basalt flows (Monte Lopes, 1982; Teixeira, 1985).

The Fazenda Brasileiro unit was divided into four lithological sub-units: (a) "marker horizon"; (b) "magnetic schist"; (c) quartzofeldspathic breccia" and (d) "intermediary sub-unit".

The "marker horizon" is a continuous metasedimentary bed composed of carbonaceous metapelite and chert layers, occurring at the hanging wall of the main orebodies. The "magnetic schist" is a dark-green chlorite schist which becames reddish under weathering. Normally, it is composed of Fe-chlorite, calcite, quartz, albite, magnetite, ilmenite and sulfides, but in the vicinity of the orebodies this rock shows a remarkable variation in mineral composition because of hydrothermal alteration (Marimon et al., 1986). The "quartzofeldspathic breccia" comprises most of the high-grade ore, forming discontinuous, lenticular-shaped bodies within the "magnetic schist". This "breccia" is composed of quartz, albite and oligoclase, in varying relative proportions. The remaining minerals are calcite, chlorite, biotite, white mica, apatite and tourmaline. The opaque assemblage includes arsenopyrite, pyrite, pyrrhotite, ilmenite and lesser chalcopyrite, sphalerite, galena and gold. The "intermediary sub-unit" is a massive to foliated metagabbro with a few metasedimentary intercalations. The metagrabbo shows locally preserved ophitic texture and is composed of albite, andesine, Mg-chlorite, calcite, clinozoisite, sphene, apatite, white mica and quartz. Hornblende, rutile and ilmenite are rare constituents.The Fazenda Canto unit is a turbidite sequence composed of fine-grained carbonaceous metasediments, with alternating well-laminated metargillite and metasiltstone layers. The sequence also includes black chert and metagreywacke. Primary sedimentary features are rarely preserved, but bedding-parallel cleavage, convolute lamination and slump structures can be locally recognized.

GEOCHEMISTRY OF IGNEOUS ROCKS

The low-K tholeiitic metabasalts of the Weber belt show a continuous variation between the low Fe-Ti (and higher MgO) and high Fe-Ti (and lower MgO) types encountered further north, in the Itapicuru River section (fig. 3.11). Observed trends of incompatible element behaviour can be explained by partial melting, followed by low-pressure fractional crystallization. Multi-element variation diagrams for less altered metabasalts (fig. 3.12) reveal a pattern with a prominent declivity from Nb to P, different from that reported for some normal MORBs (Pearce, 1983), but similar to that encountered in anomalous ridge segments or within intra-plate environments. Hydrothermally altered metabasalts show widely varying LIL element concentrations and two-element rations.

The REE pattern for metabasalts (fig. 3.13A) is ~~weak;~~ flat with slight HREE depletion and no significant Eu anomaly, which could be original features. However, the REE pattern for metagabbros strongly indicates that they have crystallized from a more differentiated magma (fig. 3.13A). Less altered "magnetic schist" has a REE pattern parallel to the basalt pattern, but with a negative Eu anomaly. This is compatible with an igneous rock derived from a residual liquid formed by low-pressure fractionation of a parent basalt with a flat or slightly LREE enriched pattern. The REE pattern for the "quartzofeldspathic breccia" resembles to those of the "magnetic schists" (fig. 3.13B), confirming that it should represent a hydrothermal alteration product.

The metagabbro together with the "magnetic schist" shows a trace element variations compatible with igneous differentiation (fig. 3.14).

Part 2
The Serra de Jacobina auriferous metasedimentary sequence

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INTRODUCTION

The geological sequence of Serra de Jacobina (Jacobina Range) is comprised of metamorphic rocks represented mainly by metaconglomerates and quartzites which form a series of parallel ridges over a distance of about 200 km, with a width between 6 and 14 km, and maximum elevations up to 1,300 m. The ridges are separated by valleys occupied by ultramafic and mafic rocks, as well as schists, in which exuberant vegetation usually grows.

The economic importance of this geological environment is related mainly to gold, chromium and emerald deposits and, secondarily to amethyst, guait 3 and manganese mineralization. The city of Jacobina, located at about 330 km southwest of Salvador, is a traditional center for "garimpagem" and gold mining. The Morro Velho Mining Company, after dedicating many years to research, is now the owner of a mine located about 12 km to the south of Jacobina and which will be visited, an addition to a number of outcrops of the Jacobina sequence.

HISTORICAL

The first geological references to the Serra de Jacobina date from the beginning of this century, when Branner (1910) described the serra as being formed by four NS oriented, easterly dipping longitudinal blocks, separated by transverse faults.

Williams (1930) and Kegel (1959) presented profiles showing the relatioship between the Serra da Jacobina and the Chapada Diamantina to the west. Oliveira & Leonardos (1940) also described the Serra da Jacobina and correlated it with the Minas Series as defined by Derby (1906), in the State of Minas Gerais.

It was only after the studies of Leo et al. (1964) that the Jacobina region could be analysed in lithostratigraphic, metamorphic and structural aspects. Based on a thematic mapping of the region between the cities of Jacobina in the north and Miguel Calmon in the south, the authors presented a stratigraphic sequence divided into four formations, from the base to the top, as follows:

Bananeira Formation: schists with garnet, andalusite and sillimanite porphyroblasts; quartz-schists and micaceous quartzites; total thickness around 1,000 m.

Serra do Córrego Formation: interstratified quartzites and gold-bearing conglomerates with quartz-muscovite schists at the base; thickness between 1,800 and 2,000 m.

Rio do Ouro Formation: green and white quartzites, with a 20 m-thick bed of pelitic schist about 350 m below the top; thickness between 2,000 and 2,300 m.

Cruz das Almas Formation: schists with andalusite and garnet porphyroblasts; micaceous quartzites with a subordinate conglomerates; thickness about 2,100 m.

With a total thickness around 8,000 m, the sequence is limited to the west by the reverse, easterly-dipping Jacobina fault and to the east by the nearly vertical Itaitu fault.

Metamorphosed ultramafic rocks occur in the form of sills, in places slightly discordant and usually aligned along the serra.

With the exception of the Bananeira formation, this basic stratigraphy is still accepted by the staff of the Jacobina gold mine (see Horscroft et al., this guide). Nevertheless, new investigations led to different stratigraphic sub-divisions and structural interpretations. Griffon (1964; 1965; 1966 and 1967) established new stratigraphical sub-divisions, and described an isoclinal structural style, formed by a combination of folding and faulting. Griffon's ideas have been corroborated by Mascarenhas (1969a;b) and further modifications have been proposed by Jordan (1972) and Couto et al. (1978). More recently, the isoclinal style and westerly vergence of tectonic transport were confirmed by Sabaté at al. (1987).

Attention has been given to the peraluminous nature of the granite plutonism, whose origin is thought to be related to the crustal thickening along the Jacobina range and its extensions (Sabaté and McReath, 1987; McReath and Sabaté, 1988. Additionally, Rudowski et al. (1987a;b), Giuliani et al. (1988) and Rudowski (1989) extended the definition of the chemical nature of this plutonism, to which they related the hydrothermal phenomena responsible for beryl (emerald), molybdenite and scheelite mineralization.

Basically, the regional geology can be described in terms of three fundamental elements: the Jacobina group and its western and eastern basements (fig. 3.15).

THE BASEMENT ROCKS

The western basement forms a morphological domain with a pediplaned zone broken by smoothly rounded hills. It is composed of extensive occurrences of diatexites and metatexites with amphibolite intercalations and rare calc-silicate and quartzite lenses. It has been postulated that these rocks are of Archaean age (Mascarenhas, 1979). They host the stratiform chromitiferous basic/ultrabasic complex of Campo Formoso as well as the peraluminous, biotite and muscovite-bearing granites with a geochronological age of about 1,96 Ga (Torquato et al., 1978; Mascarenhas, 1987; Sabaté et al., 1989).

Near the city of Jacobina, the eastern basement is characterized by a volcanosedimentary sequence of arkosic and greywacke gneisses metamorphosed to medium metamorphic grade. This sequence comprises intercalations of quartzites, cherts, calc-silicates, BIF, quartz-schists, serpentinized ultramafics (locally chromitiferous), as well as amphibolites and metabasites. By its depositional characteristics, the sequence is considered to represent a proximal paraplatformal deposit. Further to the east, in the direction of Capim Grosso, the eastern basement is composed of metatexites and diatexites which grade into granulite facies metamorphic rocks.

The tectonic interface between the eastern basement and the Jacobina sequence was also the focus for peraluminous granitic activity, represented by two-mica leucogranites, such as the Flamengo and Jaguarari granites, to the north, and the Cachoeira Grande granite further to the south and cut by the BR-324 highway between Capim Grosso and Jacobina. The age of these granites is thought to be similar to that of the Campo Formoso granite and they form part of a meridional alignment with an extension of around 500 km between two Archaean blocks within the São Francisco craton (Sabaté et al., 1989). They have a crustal origin and are suggestive of continental collision dynamics, which follow subduction/obduction processes characterized by their own specific magmatic activity and mark the end of the Transamazônico tectonic cycle.

THE JACOBINA GROUP

The three-fold division of the Jacobina group into Serra do Córrego, Rio do Ouro and Cruz das Almas formations is accepted here (fig. 3.16 - 3.16A). The interpretation of the Bananeira formation at the base of the group is controverted. It could be part of what has been termed "basement".

The following is a preliminary analysis of the depositional system during the formation of the sedimentary sequence, and of the evolution of sedimentation within the basin. It must be emphasized that subsequent metamorphism and tectonism overprint some details of the sedimentary register, and may have obliterated the primary characteristics of significant segments of the original units.

The Serra do Córrego Formation

The gold-bearing zones in the Jacobina mine area are described in more detail by Horscroff et al., in this paper. In the present discussion, the basic features noted by the authors include the subdivision of the formation into two upward-fining sequences, deposited in alluvial fans or fluvial channels with W paleocurrent directions. Throughout the serra, evidence for WSW current direction also exists and storm periods or generally higher energy conditions were responsible for the deposition of more extensive conglomerate beds which is poorly-sorted, with disorganized internal characterist and which is associated with sygmoidal or tangencial cross-beds in quartzites. Towards to the top of the formation, the cross-beds are smaller, forming festooned sets. This suggests that ripple marks with locally sinuous crests developed in sand layers with later migration.

The Rio do Ouro Formation

The basal quartzites of these formation commonly have plane-parallel stratification. Symmetric to asymmetric, small ripple or current marks are frequently at the top of the beds. Fish-bone cross-bedding was produced by paleocurrents having E, N or S directions, and occurs in 10-20 cm thick beds, alternating with subordinate plane-parallel beds.

Quartzites having fish-bone cross-bedding and abundant current or ripple marks forming interference patterns, signify an association typical of a transitional, shallow littoral environment of tide-dominated deltas, or of the upper foreshore where paleocurrents suffered constant direction changes although generally remaining parallel to the coast.

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At the top of the Rio do Ouro formation, a facies with andalusite schists shows cross-bedding in metre scale quartzite layers formed by large ripples. This type of hummocky cross-bedding is probably a result of oscillatory movement associated with storm waves which reworked the sandy sediments down to depths of about 20 m below the calm-weather wave base.

The faciological association of quartzites and schists, together with the sedimentary structures present in the former, may be interpreted as having formed in a lower foreshore environment, with the pelitic and plane-parallel beds marking normal weather sedimentation, and the hummocky beds, characterizing the stormy periods.

The Cruz das Almas Formation

This upper unit is composed of phyllites, andalusite schists and recrystrallized quartzites. The schists and quartzites have conspicous plane-parallel stratification and show rhythmic intercalations with the sediments becoming less quartzoze upwards.

Just below the central part of the formation, manganesiferous banded iron formation occurs intercalated with phyllites and andalusite schists. Together, these rocks form a sequence with a thickness of around 50 m, locally intruded by small bodies.

In terms of sedimentary environment, this formation could be related to a paraplatform in rather deep water, below the storm wave base (fig. 3.17). This environment is characterized by the predominance of pelitic sediments originally transported in suspension, probably by turbidity currents. The arenaceous basal facies shows plane-parallel stratification as the most conspicous sedimentary feature, while areno-argillaceous beds show local graded-bedding, which must have formed in response to a change in the hydrodynamic conditions. This may have occurred when currents associated with the upper flow regime during storms succeeded in reaching the deeper platformal domains of the basin.

STRUCTURE

Structural elements between Campo Formoso and the BR-324 highway show a folding style interpreted as a result of two main phases of continuous deformation followed by a third less intense phase. The first phase is characterized by a set of meso-scale, overturned isoclinal folds, developed in response to a NS compression, which is tentatively assigned to the Archaean. $Sn_1//S_o$ biotite foliation assigned to this phase, has no expression in the rocks of the Jacobina sequence.

The second phase of deformation corresponds to intense EW shortening and has its expression in pre-Jacobina rocks, both as isoclinal folds with vertical axial planes and subhorizontal axes, and as asymmetric folds having near vertical western limbs, large amplitudes and short wavelenghts. Vergence of these folds is to the west, as is also the direction of tectonic transport, shown by incompletely obliterated mineral stretching lineations. The folds of this phase are associated with a system of shears and faults which form slices with overall thrusting to the west. The slices are seen in the field at meso- and mega-scales and are represented at map scale. It should be noted that the thrust faults which form the eastern limit to the Jacobina sequence (the Itaitu and Pindobaçu faults), together with the group of longitudinal faults in the region of Itaberaba (Couto et al., 1978), result from the same compressive process. As well as controlling the regional structures, this phase of deformation generated a regional, approximately NS-trending foliation.

The resulting unit has a homoclinal structure, with dips varying from horizontal near the contact with the western basement, just to the vertical at the eastern limit of the serra. The average dip is between 55° and 70° towards the east. As far as the longitudinal evolution of the sequence is concerned, a transition from vertically inclined structures in the south to less-inclined structures in the north leads to the development of dome structures formed by forcefull intrusions of the Carnaíba, Campo Formoso and Flamengo plutons.

This deformational event, which varied from continuous to move discontinuous conditions, affected the Jacobina sequence. It may have been also responsible for the system of low-angle faults of probable sub-crustal origin which is parallel to the Serra da Jacobina, and provided planes of weakness along which ultramafic bodies intruded in an aligned series as described by Leo et al. (1964). The preferential erosion of the less-resistant ultramafic rocks controls the position of valleys within the serra. Although these bodies are vertically inclined between Pindobaçu and the area to the north of Miguel Calmon, further north they have shallower dips, and are clearly affected by tangential deformation associated with the second folding phase. They follow the anticlinal structure of Carnaíba, indicating that they intruded before the folding.

This deformation, which is part of the Transamazônico geotectonic cycle, is linked to the formation of the Atlantic coast mobile belt, with granulite facies metamorphism.

The Jacobina group has folded sectors exhibiting synclines and anticlines (eg. Miguel Calmon-Sapucaia, Pindobaçu-Carnaíba and the region west of Juacema), whilst others have a homocline structure (eg. Jacobina and Campo Formoso regions). Although this variation in style may be related to the differential action of compression, which also produced the transverse faults, the small structural details are not sufficiently well documented. It is known however, that, the deformation in the Jacobina area is more intense towards the east, near the Itaitu-Pindobaçu thrust, becoming progressively less intense westwards. No stretching is seen in pebbles of the Serra do Córrego conglomerates, and fluvial sedimentary structures in this formation, together with the marine sedimentary structures of the Rio do Ouro formation, are perfectly preserved, suggesting that the deformation was not penetrative in the quartzites and conglomerates. Adjustment of blocks along the longitudinal faults and their association with ultramafic intrusions appears to have occurred. Local internal shearing in the quartzites is indicated by breakage of kyanite crystals and their reorientation along the foliation as in the area west of Juacema (Mascarenhas, 1987).

The metamorphic peak is clearly late to post-tectonic,

since aluminosilicates and garnet porphyroblasts are usually preserved.

DEPOSITIONAL MODEL

In the southern part of the serra, an alluvial plain system (Serra do Córrego fm.) is related to a littoral system (Rio do Ouro fm.) which is in turn related to a marine platform system (Cruz das Almas fm.) (fig. 3.17).

The last two upward sequences of the Serra do Córrego fm. are probably concordant, and were deposited during a strongly transgressive sedimentation at a passive continental margin, with distal facies with a progressive progradation over proximal facies.

Facies changes which occur both at a scale of lateral discontinuities within the formations and also at the large scale, indicating discontinuity of the entire sequence, suggest that the basin occurred within a rift system formed during an episode of crustal thinning. Following onset of crustal extension, continental alluvial fan and fluvial sediments of the Serra do Córrego fm. filled the basin.

As subsidence advanced, the basin was invaded by the sea, submerging deltas and causing the deposition of the transitional and shallow marine sediments of the Rio do Ouro fm., and the deeper platform deposits of the Cruz das Almas fm.

Part 3
Field Trip Manual

Day 1: Fazenda Brasileiro gold mine

Directions: from salvador drive along highway BR-324 to Feira de Santana. Turn right (north) onto BR-116 to Teofilândia. From Teofilândia turn left (west) onto the 12 km long gravel road which leads to the mine (fig. 3.18).

THE FAZENDA BRASILEIRO GOLD MINE

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INTRODUCTION

The Fazenda Brasileiro gold mine is currently owned by Companhia Vale do Rio Doce (CVRD), a state controlled company. Production started in 1984, with open-pit mining and heap leaching of the weathered ore. About 2,000 kg of gold bullion were produced up to December'88. Recently the operation changed from open-pit to underground mining on a selected ore block with reserves estimated at 13×10^6 tonnes of ore at an average grade of 7,74 g Au per tonne.

MINE GEOLOGY

The mine stratigraphy has been simplified below with the lithological units described without petrogenetic connotation, from south towards north:

1 – The Riacho do Incó unit, composed mainly of a fine-grained grey-greenish carbonate-chlorite schist (CCX), with lenses of carbonaceous schist (GRX). Consistent actinolite schist layers are locally found. The basal contact of the sequence is marked by a continuous carbonaceous schist layer (GRX). Discordant and conformable quartz-carbonate veins (CAP) appear within this unit.

2 – The Fazenda Brasileiro unit, which has been divided into four distinct lithological groups:

a) quartz-chlorite schist (CLX), with a dark-green color. This medium-grained rock is composed mainly of Fe-chlorite and contains greyish-blue quartz porphyroblasts (blue quartz-eyes). Irregular magnetite-rich lenses, with about 10% magnetite porphyroblasts are common within the CLX. This unit frequently hosts mineralizations with arsenopyrite, pyrite, pyrrhotite and gold;

b) sulfide-bearing quartz-plagioclase rock (SUF), consisting of several generations of cross-cutting veins in hydrothermal alteration zones developed within the CLX. Opaque minerals perform more than 5% of SUF and include arsenopyrite, pyrite, pyrrhotite, ilmenite and gold;

c) chlorite-carbonate schist (CAX), is light-green to greyish in color. This fine to medium-grained rock shows granolepidoblastic to lepidoblastic texture and contains biotite as a minor constituent. CAX can host gold-rich quartz veins, usually at the footwall position;

d plagioclase-actinolite rock (PAX), has a granoblastic texture and showing varying degrees of epidotization.

3 – The Canto unit, composed of chlorite-carbonate schist interlayered with carbonaceous schists (GRX). Potassic alteration with the formation of white mica-rich zones and free-gold-bearing quartz veins are found within this unit.

CLX and SUF have commonly been described as a single lithological unit with apparent transitional relationships. Systematic studies of the hydrothermal alteration zones allowed Marimon et al. (1986) to recognize gradational mineralogical changes from unaltered CLX towards SUF and quartz vein cores. Observed textural and mineralogical variations are shown in figures 3.19 and 3.20.

A less important mineralization type is represented by sulfide-poor quartz veins hosted by CAX.

ORE DESCRIPTION

The primary ore at Fazenda Brasileiro is though to have been deposited from reactions between hot mineralizing fluids coming in contact with suitable reactive host rocks, after the main period of metamorphism and tectonic deformation (Marimon et al., 1986; Xavier, 1987).

The high-grade mineralizations (SUF) form a stratabound, network vein pattern within the CLX. In the central part of the area, the orebodies are lenticular to cylindrical-shaped and plunge 11° towards 095°.

Gold occurs in a grain size range from submicrometric up to 300 μm and can occur in the following forms:

1 – native gold attached to sulfide surfaces (by far the most important type);

2 – native gold as fracture fillings in pyrite and arsenopyrite;

3 – native gold as minute crystals (smaller than 20 μm) included within euhedral arsenopyrite;

4 – native gold inclusions in quartz.

Secondary ore refers to the surface oxidized orebodies where gold has been separated and remobilized away from individual sulfide grains by weathering-related supergene processes.

OPEN-PIT MINING

This operation is restricted to the upper, weathered portions of orebodies and therefore extends to only 15-25 m depth.

Annual production to date has been in the order of 240,000 tonnes of ore at an average grade of 2.5 g/t. Gold is extracted from crushed ROM material by heapleaching cyanidation and recovered by adsorption on activated carbon during filtering of the cyanide solution. Metal recoveries of up to 80% on average have been achieved. At present, the secondary (oxide) ore reserves at Fazenda Brasileiro have been exhausted and open-pit mining proceeds around in the Weber belt.

UNDERGROUND MINING

A sublevel-shrinkage-caving method is currently being applied. Underground exploration is carried out during ascendant fan-drilling. Blasted ore is mucked and hauled from the face. Most of the mining work is performed by using electrical equipment, however haulage of the blasted ore is performed by diesel trucks.

The mine access ramp of the "C" orebody has been excavated down to a depth of 160 m below the surface. Sublevels had been driven down to a depth of 100 m below the surface, and are vertically spaced at 10 m intervals.

Initial ROM production is forecasted at 252.000 t/year with an expected dilution rate of about 10%.

METALLURGICAL PROCESS

The Fazenda Brasileiro gold plant was planned to recover gold from "primary ore" by the hydrometallurgical carbon-in-pulp (C.I.P.) process with an expected recovery index of 90%.

The first-stage gravimetric cycle comprises crushing and milling followed by cycloning and jigging. After this stage the mill product (80% of bulk volume) is directed to the thickener and its underflow (50% solids) is pumped to pre-aeration and cyanide solution addition tanks. The gold in solution and the pulp resulting from leaching are pumped to carbon tanks for the gold adsorption stage.

Au-enriched carbon goes to a desorption (elution) unit. The impregnate solution is then pumped to electrolytic cells and gold is electro-deposited on steel wool cathodes which are removed from the cells when saturated.

Saturated cathodes are acid washed in order to dissolve impurities. The concentrate obtained is filtered, dried and melted in induction furnaces. The gold bullion is afterwards sent to refineries.

ENVIRONMENTAL CONTROL

Some of the measures taken by CVRD in controlling the environmental impact of the operation are:

1 – an environmental impact report was compiled to elaborate on social, biological and physical aspects and identification of those aspects most affected by mine and plant operation;

2 – delimitation of appropriate areas for ore stock piles and waste storage;

3 – construction of the tailings dam for plant waste containnent, using a PVC lining to prevent any leakage of cyanide solution.

4 – the treated ore stock piles, heap leach areas, and solution and emergency tanks are all lined with PVC sheets;

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5 – leached piles and residual sodium cyanide are washed and neutralized by alkaline chloration;

6 – soil, water and air quality are systematically monitored within the CVRD property;

7 – protection of fauna and flora and planting of a number of varieties of fruitful and decorative trees inside CVRD property;

8 – environmental education by means of signs, videocassette projections, lectures, contests, etc. is practised.

Day 1: SCHEDULE

October 7, 1989
07:00 hs - Departure from Salvador.
10:00 hs - Arrival at Fazenda Brasileiro: reception and general presentation.
11:00 hs - Underground mine section.
13:00 hs - Lunch.
14:00 hs - Open-pit section.
15:00 hs - Visit to carbon-in-pulp plant.
16:00 hs - Discussion.
17:00 hs - Return to Teofilandia.
(Overnight in Teofilandia)

Day 2: Itapirucu river geological profile

Directions: from Teofilândia drive south to Serrinha. Turn right (west) on the road to Conceição do Coité, Retirolândia, Valente and Santa Luz. From Santa Luz turn right (northeaast) onto the dirt road which leads to Stop nº 1 at the margin of the Itapicuru river (fig. 3.21).

THE CROSS-SECTION (fig. 3.22)

Stop nº 1 - Mafic volcanic domain
Basaltic flow breccias with lapilli size fragments along with blocks of massive basalt in an aphanitic basalt matrix.

Stop nº 2 - Felsic volcanic domain
Grey-greenish, weakly deformed meta-andesites. Fluidal texture suggested the preferred orientation of prismatic plagioclase and hornblende phenocrysts, can be observed. Autoclastic andesites occurs locally, with lava fragments set in a microcrystalline matrix of similar composition.

Stop nº 3 - Felsic volcanic domain
Dacitic volcanic agglomerates with predominantly bomb-size and lesser lapilli-size fragments in a lapilli tuff matrix. Chilled margins and preferred tectonic orientation can be observed, particularly in the coarser pyroclasts.

Stop nº 4 - Sedimentary domain
Turbiditic psammites and pelites composed of sandstones, siltstones and shales, with lenses of carbonaceous phyllite. This sequence shows a greenschist facies paragenesis and in place has preserved graded bedding. The deformation produced tight metric-scale folds with steeply dipping axial surfaces, besides kink and chevron folds.

Stop nº 5 - Center of the Ambrósio Dome
Weakly deformed greyish granodiorite with fine granoblastic texture, composed mainly of quartz and oligoclase and less microcline and biotite.

Stop nº 6 - Margin of the Ambrósio Dome
Strongly deformed banded gneiss with a granodioritic to tonalitic composition. Centimetric to millimetric-size biotite and/or hornblende-rich layers, alternating with coarse grained quartzofeldspathic bands. Less deformed pegmatite veins are also present.

Stop nº 7 - The Maria Preta gold deposits
The gold mineralization at Fazenda Maria Preta are associated with NS-trending shears zones which affected metasediments and intrusive rocks in the north-central sector of the Rio Itapicuru greenstone belt.

Gold occurs in both quartz veins and silicified brecciated zones within carbonaceous schists, metadacite, meta-andesite and metagabbro. Sulfides are rare and comprise less than 1% of the ore volume.

Since February 1987 a small open-pit mine is being operated on the northern deposits by Rio Salitre Mineração and about 310 kg of gold bullion has been produced to date. The southern deposits lie within the Companhia Vale do Rio Doce property where a new mining project is under consideration.

The reserves of the CVRD property, down to a depth of 100 m, are estimated at 1,5 x 10^5 tonnes of ore, with an average grade of 5,70 g Au per tonne. These reserves will be exploited open-pit minning during the first 5 years operation followed by underground mining. Gold will be recovered by crushing, milling and gravimetric concentration processes followed by a hydrometallurgical C.I.P. (carbon-in-pulp) circuit. An annual production of 700 kg of gold is expected.

Day 2: SCHEDULE

October 8, 1989
06:00 hs - Breakfast.
07:00 hs - Departure from Teofilândia.
09:00 hs - Stop nº 1.
09:20 hs - Stop nº 2.
09:40 hs - Stop nº 3.
10:00 hs - Stop nº 4.
10:25 hs - Stop nº 5.
10:40 hs - Stop nº 6.
11:15 hs - Stop nº 7: Maria Preta gold deposits.
11:30 hs - Lunch.
12:30 hs - Explanations.
13:00 hs - Visit to outcrops and mining operations.
15:30 hs - Discussion.
16:00 hs - Return to Teofilândia.
(Overnight in Teofilandia)

Day 3: Eastern basement and the Jacobina gold mine.

Directions: from Teofilândia drive south to Serrinha, Santa Bárbara and proceed until intersection with highway BR-324. Turn right (northwest) to Riachão do Jacuípe, Vila de Fátima and Capim Grosso. From Capim Grosso proceed onto the road which leads to Jacobina (fig. 3.21).

THE EASTERN BASEMENT

Stop nº 1 - Granulites of the Salvador - Curaçá mobile belt. The outcrop is near the bus-stop at the Nova Fátima crossroads.

The outcrop shows one of the granulite types, which is homogeneous and rather constant throughout the region. The granulite has northerly-trending banding commonly having a regular alternation of orthopyroxene-bearing basic and felsic bands. The granulites possibly represent a plutonic precursor which underwent subsequent intense deformation as indicated by folds in the mafic zones (previous dykes or lenses), and advanced transposition in the felsic facies. Shearing is developed, and indicated plastic deformation conditions, with some axamples of transitional viscoplastic behaviour under granulite facies conditions.

A family of conjugate tension gashes, filled by felsic material, formed during deformation which was coincident in timing with the main phase of metamorphism, and resulted in the minerals having an orientation parallel to the gneissic banding. Later tension gashes are filled by similar material, and are oriented perpendicular to the banding and lack a preferred mineral orientation.

Petrographic data obtained by CPRM give the following compositional range:

Quartz1932%
Microcline2921%
Sodic plagiclase4238%
Biotite3%
Orthopyxorene76%
Opaquestraces
Apatite, zircontraces

The granulite texture is granoblastic having only weakly preserved preferred mineral orientation, observable only at a microscopic scale having been partly obliterated by the subsequent granulite grade metamorphic recrystallization. Clinopyroxene is replaced by a retrograde assemblage of tremolite-actinolite, biotite and iron oxides. In addition late chlorite is also present.

On a regional scale, this rock type is associated with folded volcanic assemblages which are also metamorphosed to a granulitic facies.

THE JACOBINA GOLD MINE

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INTRODUCTION

Since the 17th century, gold has been recovered along the Serra de Jacobina. Production started from shallow excavations and in organized small-scale ("garimpos") mining.

The total gold production was around 20,000 kg to the end of the sixties. The Jacobina Gold Mine started up in November 1982 as an underground operation with a treatment capacity of 1,000 t/day of ROM to recover 1,300 kg of gold per year.

A general description of the Serra and the Jacobina Group has already been given by Mascarenhas et al. in this guide. In the mine area, the total thickness is between 4,500 to 5,000 m. The lowermost beds on the west side overlie gneiss with a sheared contact.

Gold is present in quartzite-hosted veins, and in association with the ultramafic rocks. But the economically important deposits are in pyritic quartz-pebble conglomerates of the Serra do Córrego Formation (See figures 3.23, 3.24).

THE SERRA DO CÓRREGO FORMATION

This Formation has a thickness varying between 260 and 1,000 m, being formed by two major sedimentary cycles termed the lower and an upper members. Both members are composed of conglomerate at the base, grading upwards through alternations of conglomerate and quartzite in the middle to quartzite at the top. Lateral and vertical facies changes are common with individual beds having strike lengths of tens to hundreds or meters. The basal sediments were deposited unconformable on an uneven basement surface having vertical reliefs of up to 80 m.

The lower member attains a maximum thickness of 600 m of which the basal 200 m is composed of medium to coarse-grained conglomerate with minor interbedded quartzite. The upper member has a maximum thickness of 570 m with varying proportions of conglomerate and quartzite along strike. Individual conglomerate beds are commonly 1-6 m thick and up to a maximum of 15 m.

The conglomerates of the Formation are oligomictic, with a predominance of rounded quartz pebbles, with the coarser fraction commonly of medium to large grain size (3.2-6.4 cm). The texture ranges from well-packed, pebble-supported to matrix supported pebble quartzite. The matrix is composed of quartz grains, sericite and commonly fuchsite, with variable quantities of pyrite. It shows an advanced degree of recrystallization and is locally silicified. The color varies from pale grey to green or reddish with the latter resulting of the oxidation of pyrite.

Quartzite from individual beds and the conglomerate matrix are similar in appearance and normally composed of

recrystallized quartz grains with minor sericite, muscovite, fuchsite, pyrite, rutile, zircon and tourmaline.

Cross-bedding indicates a western paleocurrent direction which persisted throughout the deposition of the Formation. In each of the two major depositional cycles, the lower boundaries of the conglomerates show scour channel structures which eroded or reworked the underlying material. Discontinuity of individual beds along strike reflects multichannel sediment accumulation with deposition occurring in both main river channel or in flood channels. Trough cross-bedding in quartzite, unimodal distribution of pebble sizes, and lens-like channel-fill conglomerates confirm that the environment was fluvial and that deposition probably occurred in a braided channel system. The uniformity of the particle assemblage throughout the sequence suggests that the provenance area remained the same throughout the deposition of the Formation.

THE GOLD OCCURRENCE

Gold occurs in a member of the conglomerate in each of the two main depositional cycles, and old workings are spread throughout the 30 km lateral extent of the formation. Not all conglomerates contain gold, and most gold occurrences are small local concentrations. The principal gold deposits occur in three different fluvial environments:

The Basal Reef at Cuscuz is in the Lower Conglomerate Member, 15 m above the basement contact. It is part of a broad channel-fill of predominantly coarse sediment deposited under flood conditions. The main payshoot is 300 m wide, and is comprised two reefs. The richer lower is 4-5 m thick and composed of small to medium close-packed pebbles in a pyritic matrix. Gold concentrations occur in both the upper and lower portions. The lower reef of the unit is separated from the upper reef by 5 m of quartzite and pebble quartzite. The upper reef comprises coarser pebbles and is charactized by more erratic gold values.

The Main Reef at Morro do Vento is at a higher level bu still within the Lower Conglomerate Member, 60-90 m above the basement contact. It is a well-washed and reworked fluvial sand rich accumulation approximately 3 km wide and 16 m thick which was deposited between periods of coarser gravel deposition. Gold is present in conglomerate zones comprising lenticular, overlapping gravel lenses ranging from lines of small pebbles to coarse conglomerate 3 m thick. The most persistent concentration of gold is in close-packed, pyritic conglomerate. The gold mineralization can be concentrated the top or base as occur throughout the conglomerate. There is also an enrichment of gold in quartzite associated with distal lag gravel. The most widespread gold occurrences in the Upper Conglomerate Member, which contains deposits at Serra do Córrego, Morro do Vento and João Belo in the lower sub-zone, and at Canavieiras in the middle sub-zone. The reefs are medium- to coarse-pebble conglomerates, with lengths of up to a few hundred meters and thickness of between 1-18 m, alternating with quartzite. These commonly is overlapping or "stacking" of reefs, with the lowermost tending to have the greatest gold concentrations. Characteristic of many occurrences is a reduction in the pebble size towards the top of the reef. Coincident there is a tendency to become a well-packed and well-sorted, small- to medium-peblle conglomerate with pyritic matrix. High gold values occur along the upper surface, especially where overlain by crossbedded quartzite.

The zones of highest concentration are thin and may be discontinuous, extending along strike for only a few meters to several hundred meters. The conglomerate are multi-channel deposits which formed semi-continuously over several kilometers during the period of flood, alternating with sand that accumulated during periods of reduced stream flow.

MINERALOGY OF THE REEFS

The reefs are comprised of pebbles in a matrix of quartz felted masses of sericite and muscovite, and fuchsite. Pyrite forms up to 30% of the matrix, occurring as angular grains, with less abundant rounded, nodular grains, 1-3 mm in diameter. Other sulfides occurring together with, or interstitial to, pyrite and chalcosite, bornite, chalcopyrite, covellite, digenite, sphalerite, galena, and molybdenite.

Uranium oxide is present as rounded detrital grains, angular interstitial grains, rims enveloping pyrite, and as small inclusions in hydrocarbon. Evidence suggests that the main uranium mineral is pitchblende.

Gold occurs as rounded to irregular grains, 0.03-0,3 mm in diameter.

Most grains occur in or alongside quartz, or as rounded, drop-like inclusions in pyrite and chlorite. A minor proportion is enclosed in hydrocarbon. Plates of secondary gold are commonly developed on joints and fractures. After crushing most of the gold reports as free gold. Carbon occur in small concetration as grains with irregular outlines. Rutile is ubiquitous, occurring with tourmaline, zircon, spinel, thorite, monazite, magnetite and chromite.

It is planned to visit the following points:

1 – Contact of basement with sediments of the Jacobina Group.

2 – Main Reef in the João Belo block.

3 – Outcrop of the schist guide level.

4 – LMPC at the base of the upper reef.

5 – Basic rock intrusive in the Jacobina Group.

6 – Quartzite of the Rio do Ouro Formation.

7 – Section across the Cruz das Almas Formation.

Day 3: SCHEDULE

October 9, 1989.

06:00 hs - Breakfast.
07:00 hs - Departure from Teofilândia.
08:00 hs - BR-116/BR-324 intersection.
09:10 hs - Stop nº 1.
09:30 hs - Stop nº 2.
10:50 hs - Capim Grosso cross-road.
11:05 hs - Stop nº 3.
11:35 hs - Stop nº 4.
12:30 hs - Jacobina gold mine: reception and lunch.
13:30 hs - Visit to the mine.
17:30 hs - Discussion (Overnight in Jacobina.)

Day 4: The Jacobina metasedimentary sequence and its eastern basement.

Directions: from Jacobina drive eastwards on highway BR-324 until reaching a cross-road, 12,9 km from Jacobina. Turn left (north) onto the road which leads to Saude (see fig. 4.18).

Stop nº 1 - From this point, we follow the upper conglomerate of the Rio do Ouro Formation. While some sedimentary features can be seen in this outcrop, others are obscured by faulting, fracturing and weathering. Dips are not sharply defined, but are seen locally (up to 70°E).

Stop nº 2 - Rio do Ouro fm: Asymmetric ripple-marks with interferences.

Stop nº 3 - Rio do Ouro, fm: Fish-bone cross-bedding.

Stop nº 4 - Contact between Rio do Ouro and Cruz das Almas formations. Mapping to the north of the road shows that an ultramafic sill occurs on the contact. Very altered quartzites of the Cruz das Almas fm. occurs at this stop. They are brownish-yellow with a secondary iron oxide crust. Porphyroblasts of andalusite up to 0,7 cm in diameter are seen in the vertically-foliated schist.

Stop nº 5 - Cruz das Almas fm.: fine-grained quartzites with planeparallel stratification. They have a vertical attitude and tend to grade upwards into bleached schist. The schist turn upwards into ferruginous quartzites and reddish phyllites. The latter become banded though a process of supergene concentration, forming Algoma-type BIF and pyrolusite deposits. About 2 km to the south of this point a secondary Mn deposit used to be worked commercially.

Stop nº 6 - The outcrop is formed of a verticalized BIF cut by a intensely weathered mafic rock, showing spheroidal exfoliation.

Stop nº 7 - Fault zone in the basement. The fault has a trend of N10°E and is situated under the bridge over the Itapicuru river. The movement direction on the fault is almost exclusivelly horizontal and sinistral. The fault mainly affects quartz-rich biobite gneiss. It is partly calc-silicatic and its main expression as shear planes developed in the flanks of P_1 folds whose axes oriented vertical.

The displacement is sinistral and movement resulted in stretching along the S_1 planes, as well as in intense transposition, parallel to the fault, both of S_1 and of S_o within the folds limbs. Synthetic Riedel faults have a direction N30 to N40 (fig. 3.25) and develop drag folds with sub-vertical axes plunging to the northwest. Mineral stretching lineations are oriented sub-horizontal. To the east of the fault zone, well-recrystallized quartzites with magnetite beds are seen. These have spectacular similar folds with sub-vertical oriented axes and sinistral stretching of the limbs along faults developed under ductile to rigid conditions. Mini drag folds are present.

In both the eastern and western blocks of the fault zone, fold hinges comprise deformed, recrystallized quartz veins. An underformed discordant coarse-grained pegmatite vein having an approximate width of 45 cm. A number of undeformed quartz veins occur in the western block. Elsewhere other pegmatites are clearly earlier than the final part of the stretching, since they have boudins and tension gashes filled by quartz.

Stop nº 8 - Calc-silicate rocks having tremolite-actinolite crystals up to 3 cm long and 1 cm wide occurring in rosettes. Quartz and diopside are the main mineralogical constituents. The calc-silicate rocks are associated very fine-grained with/quartzite intercalations, gradding onto cherts over a distance of about 10 m. The rocks are verticalized.

These rocks belong to an extensive group of paragneisses which include meta-arkoses, tremolitites and biotitites which are repeated in centimetric to metric bands, and outcrop in a road cut about 300 m to the south of the present outcrop. In this locality, the rocks are also included subvertically and are very altered.

Stop nº 9 - The road cut shows a sequence of calc-silicate rocks having an easterly dip of about 40°. This sequence has undergone two folding phases. The axes of the first phase being seen in tight anticlinal/synclinal pairs, with dips parallel to the plunges of the limbs. Mineral lineations are seen in a sinclinorial formed in a thin decimetric calc-silicate band. These lineations are believed to follow the axial plane of the first fold phase.

On the other hand, frictionally-induced lineations which occur in quartzites must have formed during the second phase, which produced asymetric folds. In their present situation, the rocks occupy the eastern limb of a larger antiform, the previous outcrop occupying the western limb.

Stop nº 10 - Migmatitic biotite gneisses having intercalations of biotite schist and amphibolite and small-scale, vertical isoclinal folds whose axes plunges at 20 - 25°S, developed during the second phase. The gneisses bands have vertical-

ized biotite lineations which result from intersection of the beds with the axial plane foliation developed during the first phase. The gneissic folitation is also vertical.

Stop nº 11 - In a low, 1 m high cut at the east side of the road, a sequence of biotite gneiss with intercalations of biotite schists and amphibolite in repeated bands is similar to that observed at the last stop. Here, however, there are numerous smaller isoclinal folds with sub-horizontal axial plunges, seen at a ground level in a horizontal plane (fig. 3.26). In a vertical section at the road side, an antiformal hinge of the second deformation phase is seen. The fold axes are also horizontal with northerly plunge. Internal gneiss bands have parasitic first phase folds with sub-vertical axes (fig. 3.27).

SCHEDULE

October 10, 1989

07:00 hs - Breakfast
07:45 hs - Stop nº 1
08:00 hs - Stop nº 2
08:20 hs - Stop nº 3
08:50 hs - Stop nº 4
09:15 hs - Stop nº 5
09:40 hs - Stop nº 6
10:00 hs - Stop nº 7
10:30 hs - Stop nº 8
10:50 hs - Stop nº 9
11:15 hs - Stop nº 10
11:40 hs - Stop nº 11
12:00 hs - Lunch and return to Salvador

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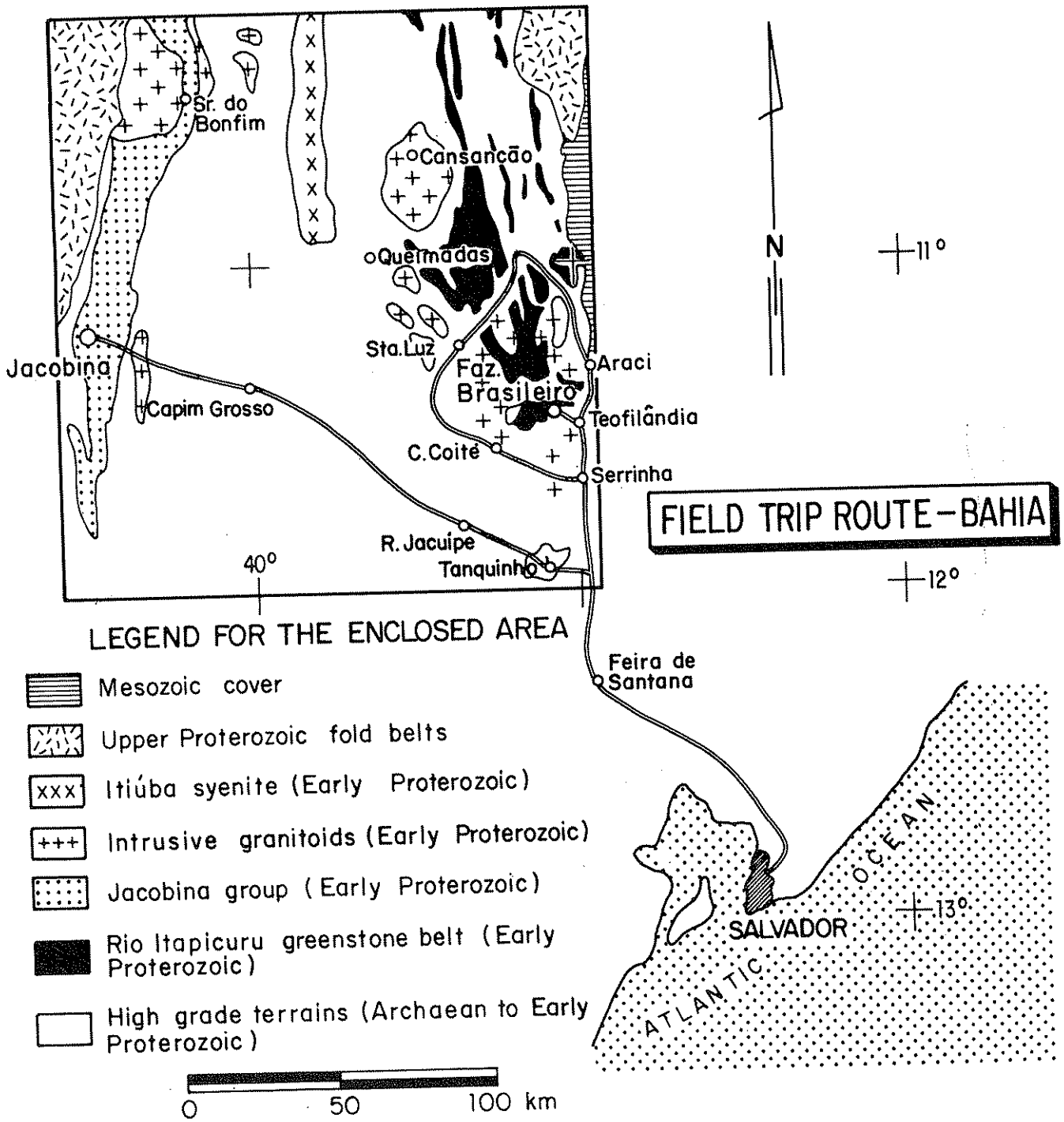

Sr. do Bonfim
Cansancão
Queimadas
Sta.Luz
Faz. Brasileiro
Araci
Teofilândia
Serrinha
Jacobina
Capim Grosso
C.Coité
R. Jacuipe
Tanquinho
40°
N
11°
12°
13°
FIELD TRIP ROUTE – BAHIA
Feira de Santana
SALVADOR
ATLANTIC OCEAN
LEGEND FOR THE ENCLOSED AREA
Mesozoic cover
Upper Proterozoic fold belts
Itiúba syenite (Early Proterozoic)
Intrusive granitoids (Early Proterozoic)
Jacobina group (Early Proterozoic)
Rio Itapicuru greenstone belt (Early Proterozoic)
High grade terrains (Archaean to Early Proterozoic)
0
50
100 km

Fig - 3.1

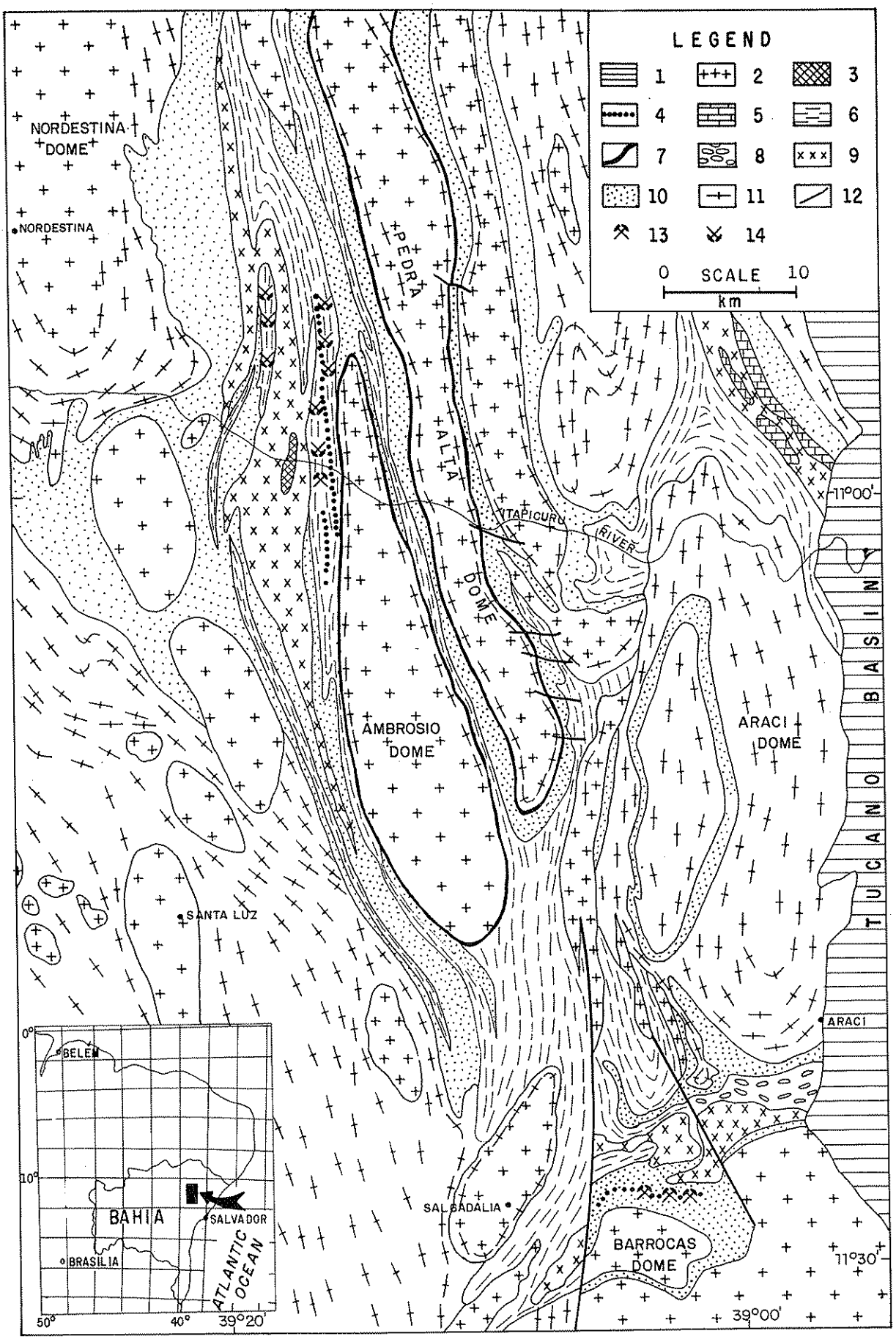


Fig- 3.2 - GEOLOGICAL SETTING

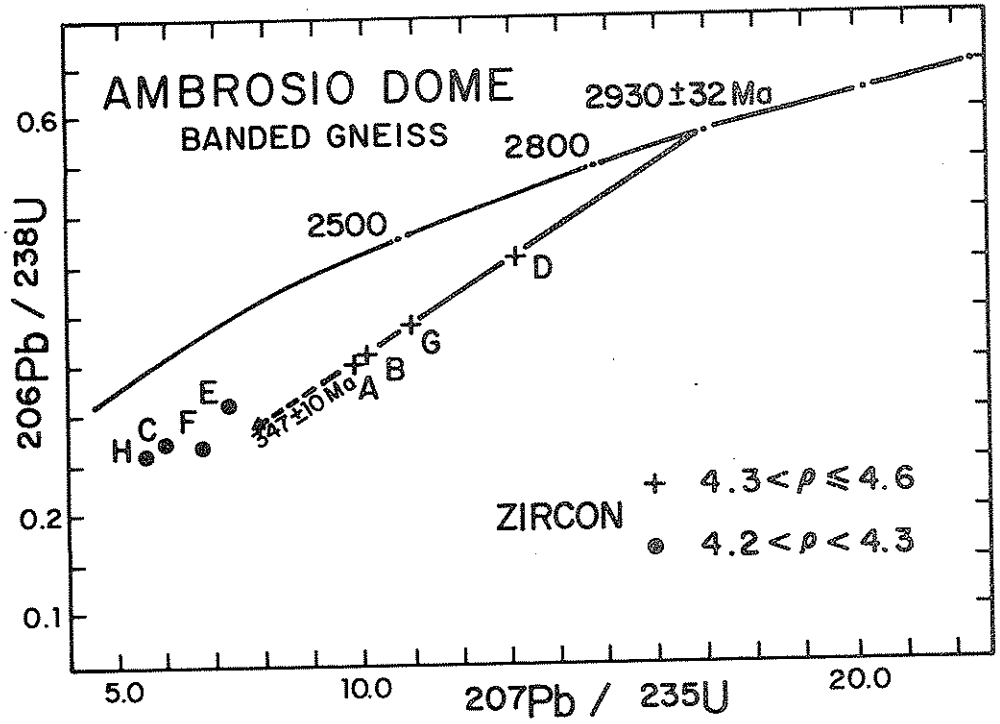


Fig- 3.3 AGE DETERMINATTION (BANDED. GNEISS)

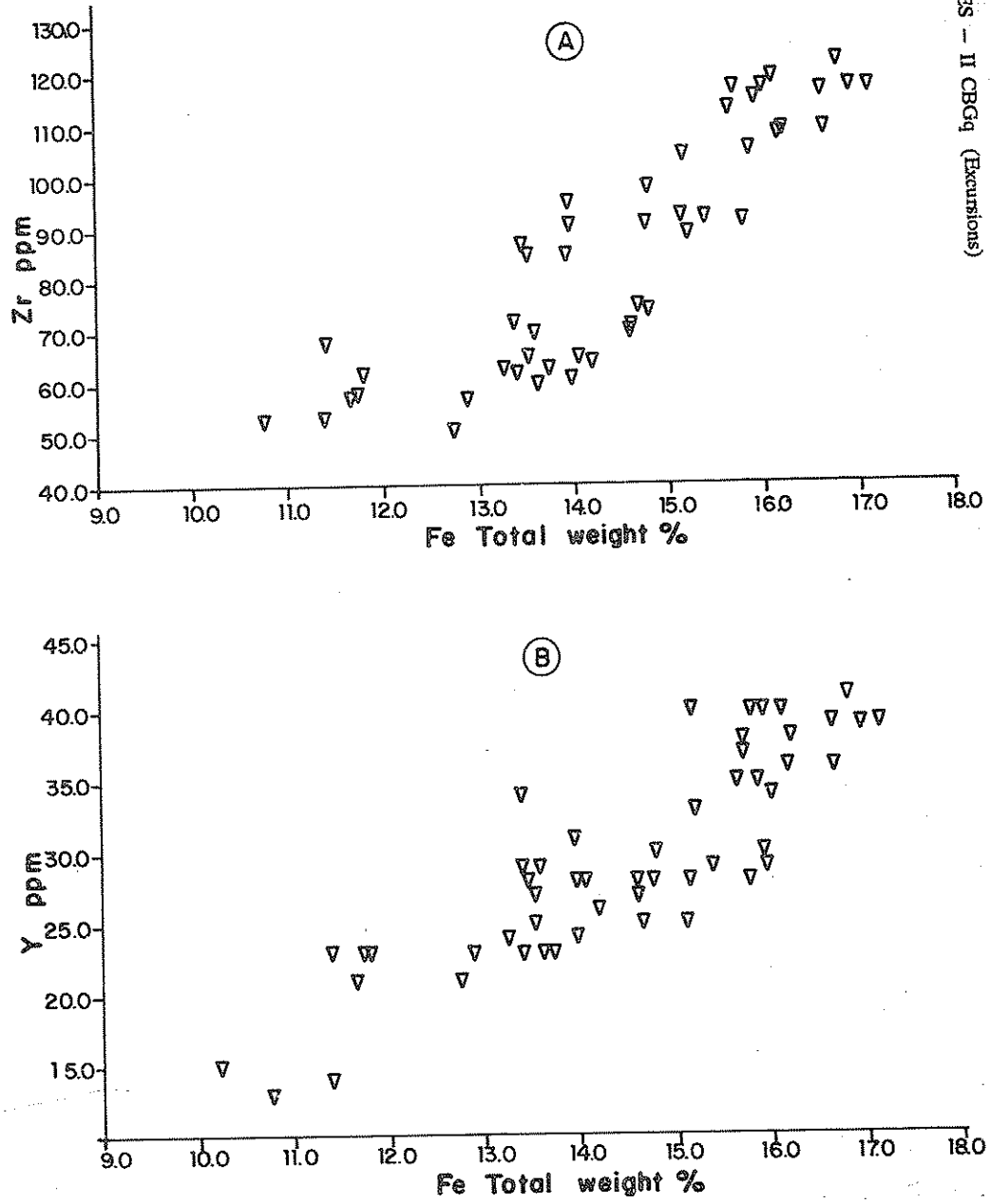


Fig- 3.4

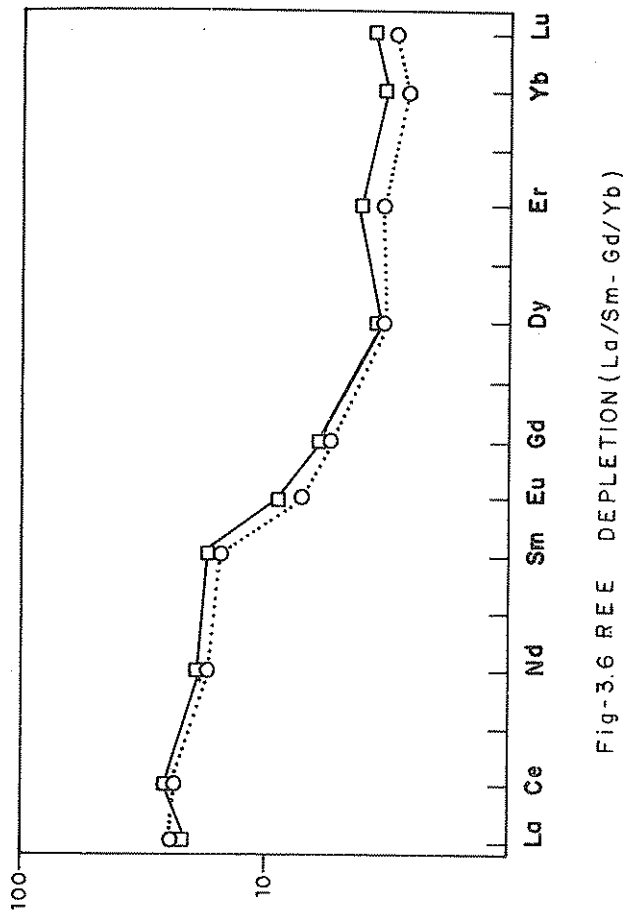


Fig-3.6 REE DEPLETION (La/Sm-Gd/Yb)

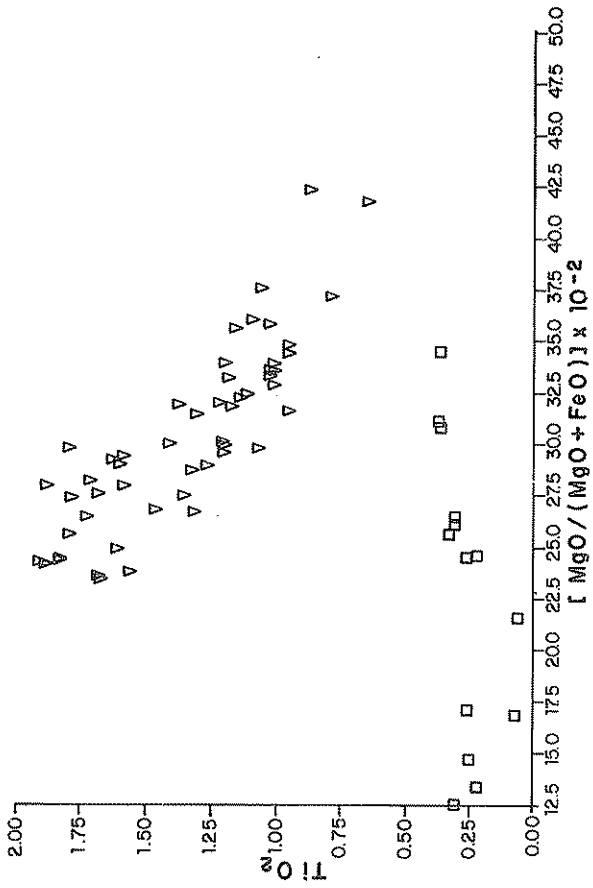
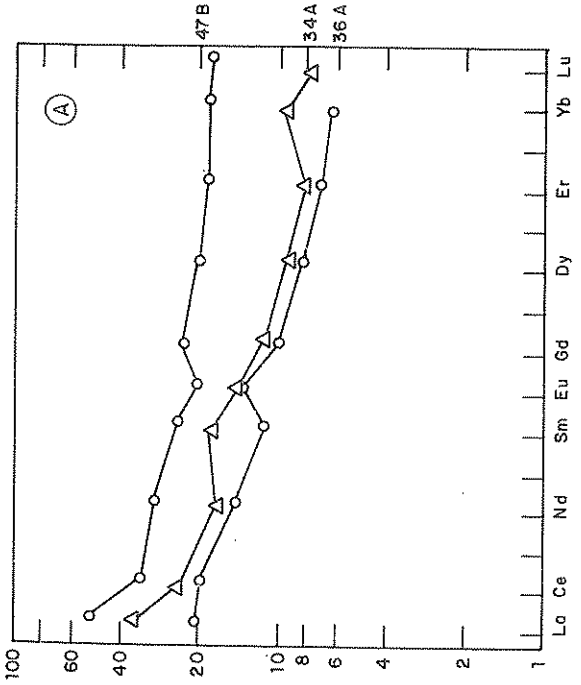
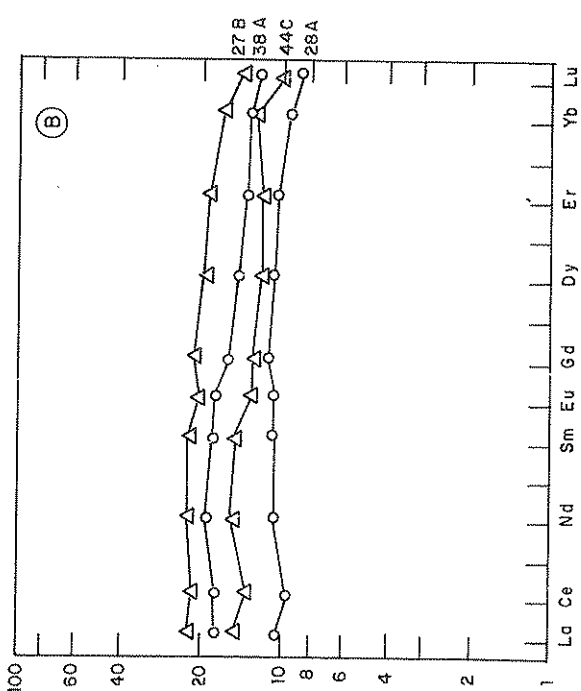


Fig-3.7





REE PATTERNS

Fig-3.5

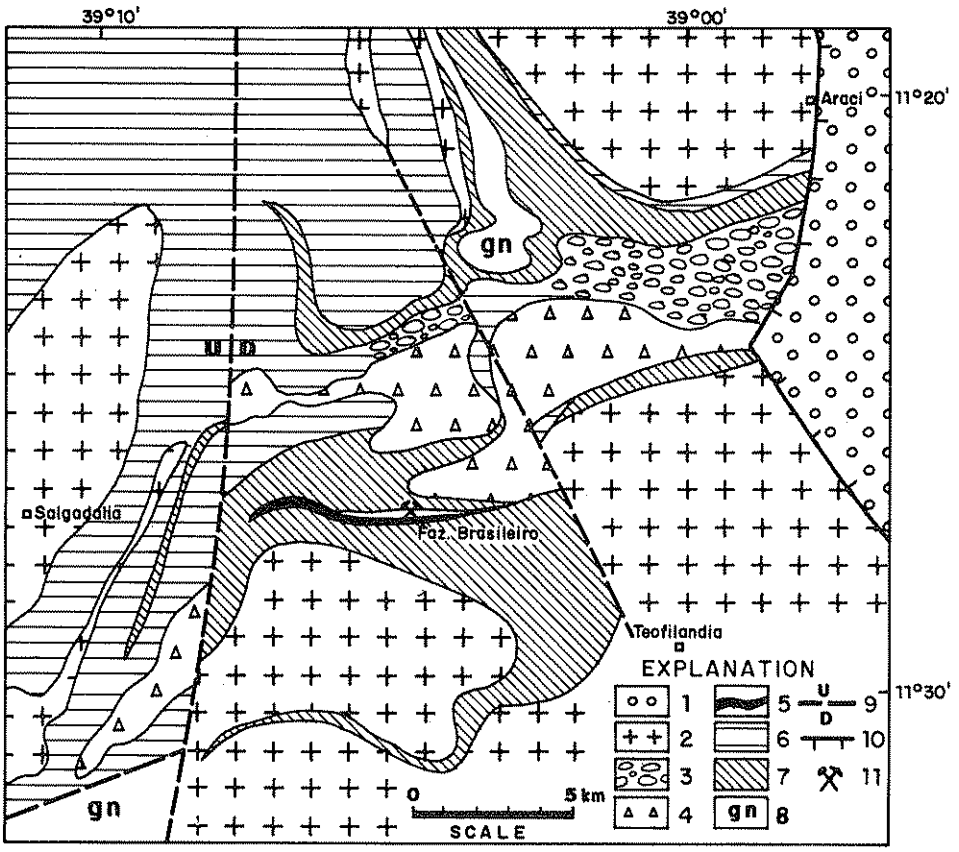


Fig-3.8 - Fazenda Brasileiro Location Map
(With Geolocical Setting)

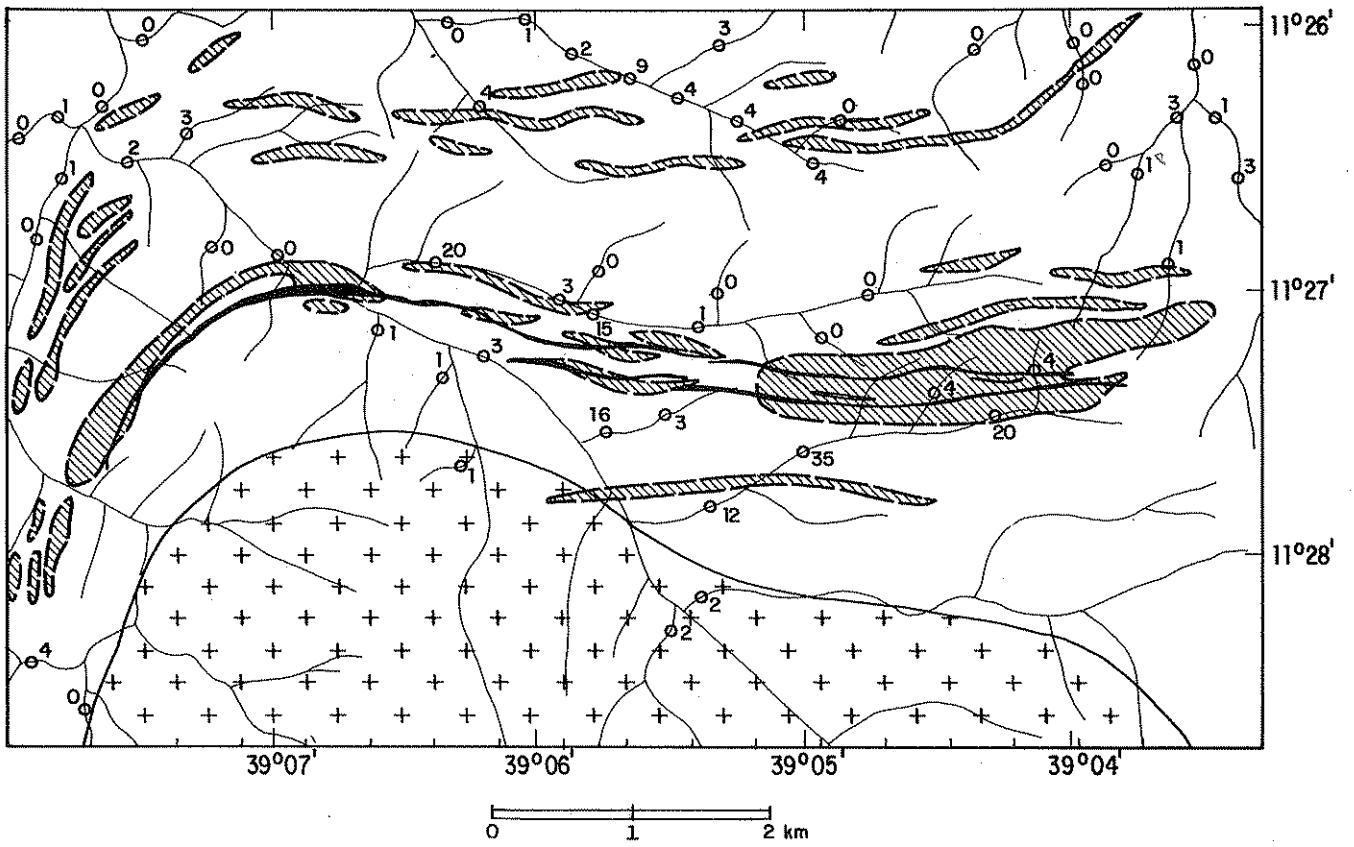
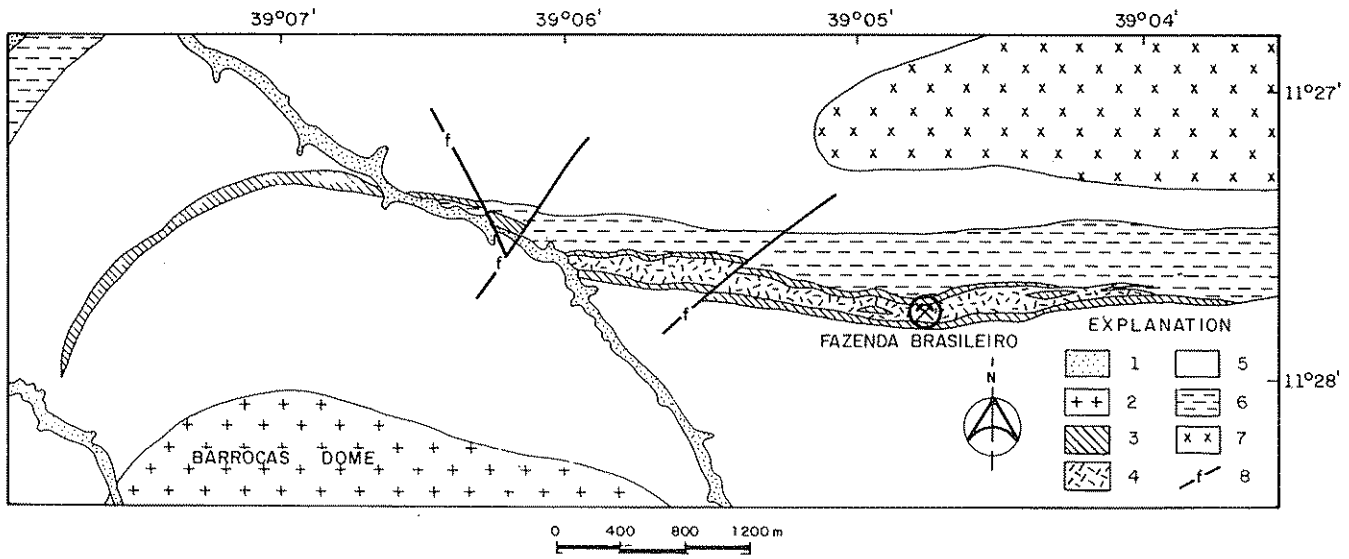


Fig-3.9 Stream Sediments Survey (PAN COLOURS)



Fig·3.10 Weber Belt Geology

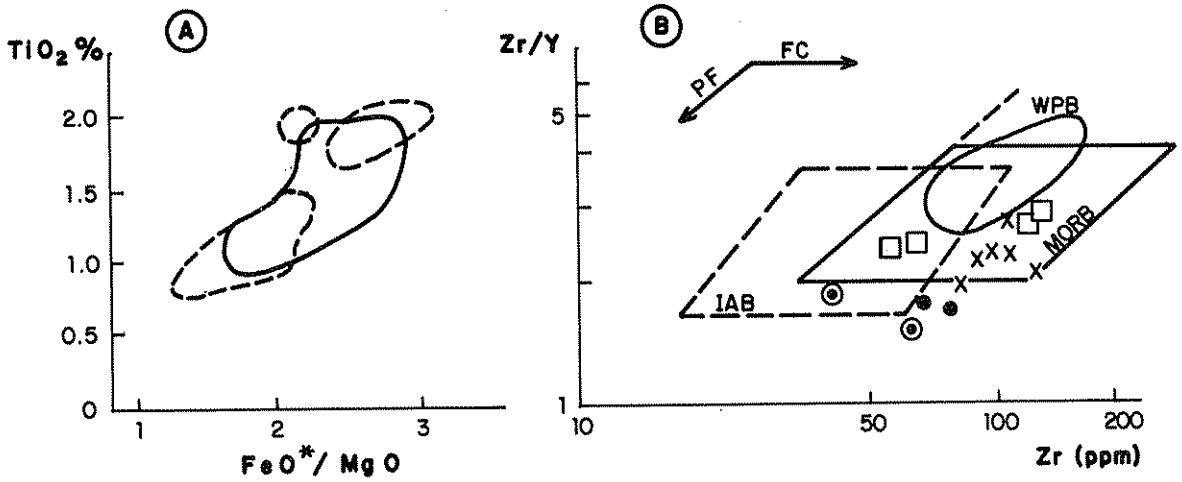


Fig-3.11- Correlations Between T_cO_2 - FeO/MgO - And Za/y /y

(METABA SALTS - WEBER BELT)

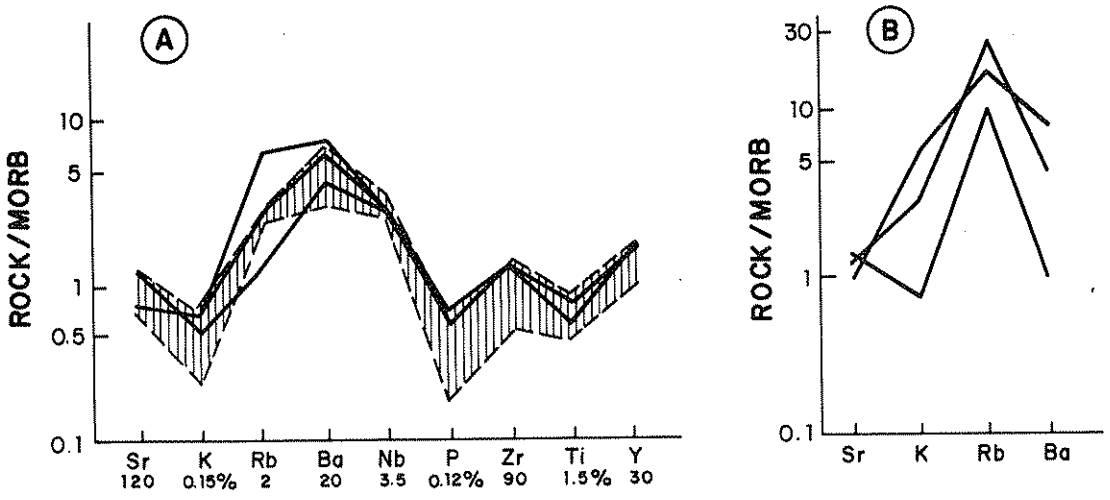


Fig- 3.12 - Mult-Element Variston Diagrams

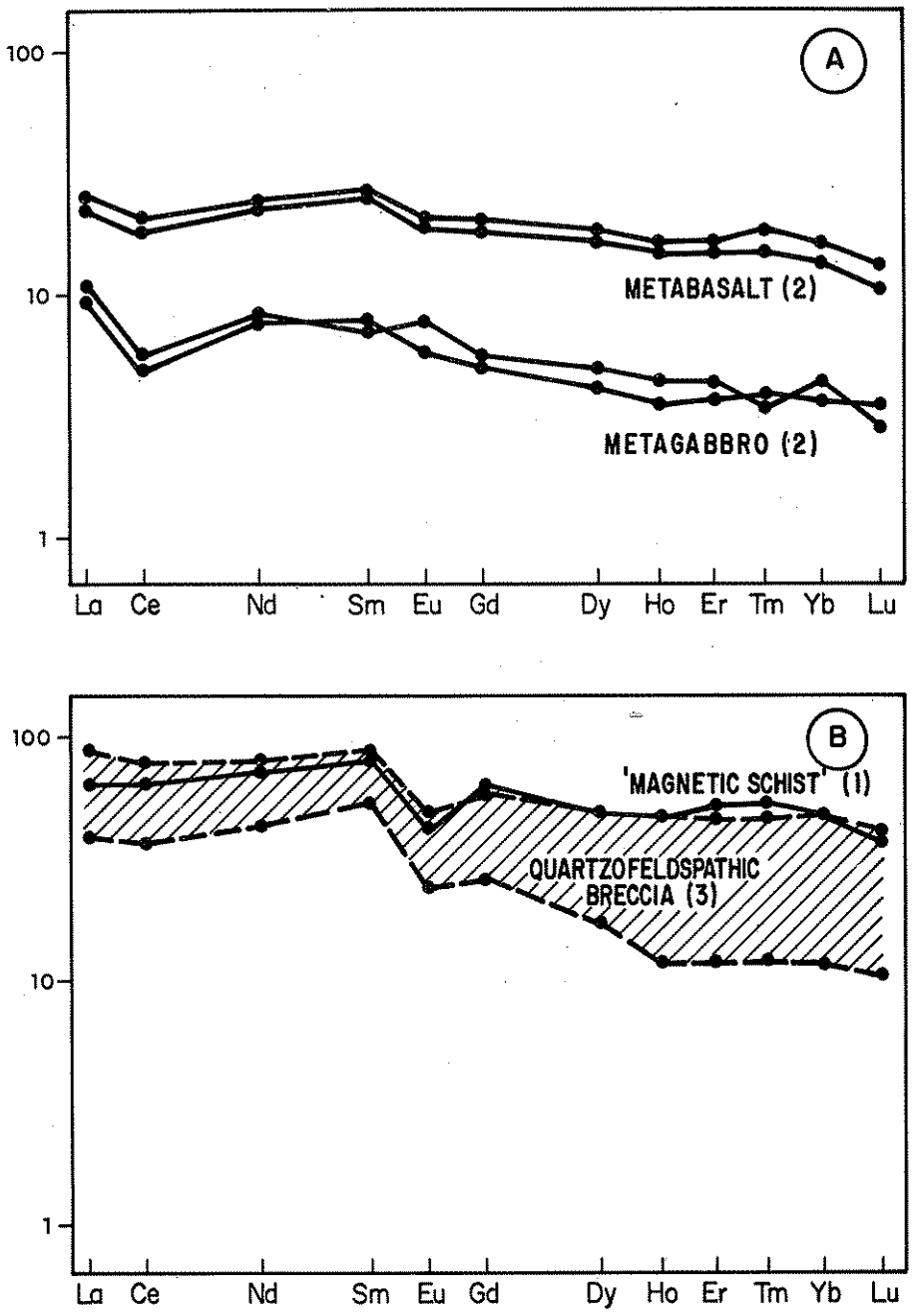


Fig- 3.13 REE PATTENS (META BASALTS)

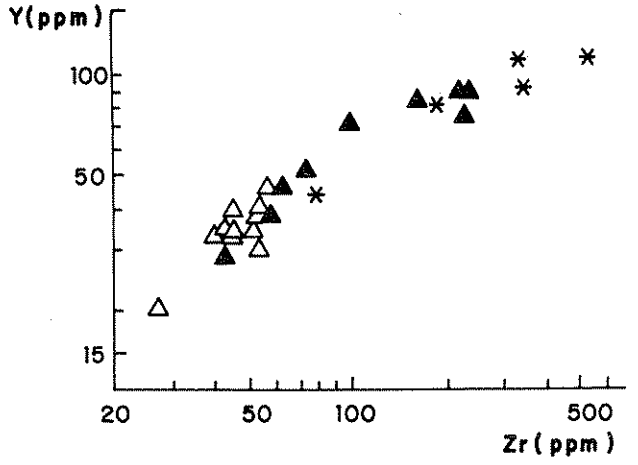


Fig- 3.14 Trace Elements Variations

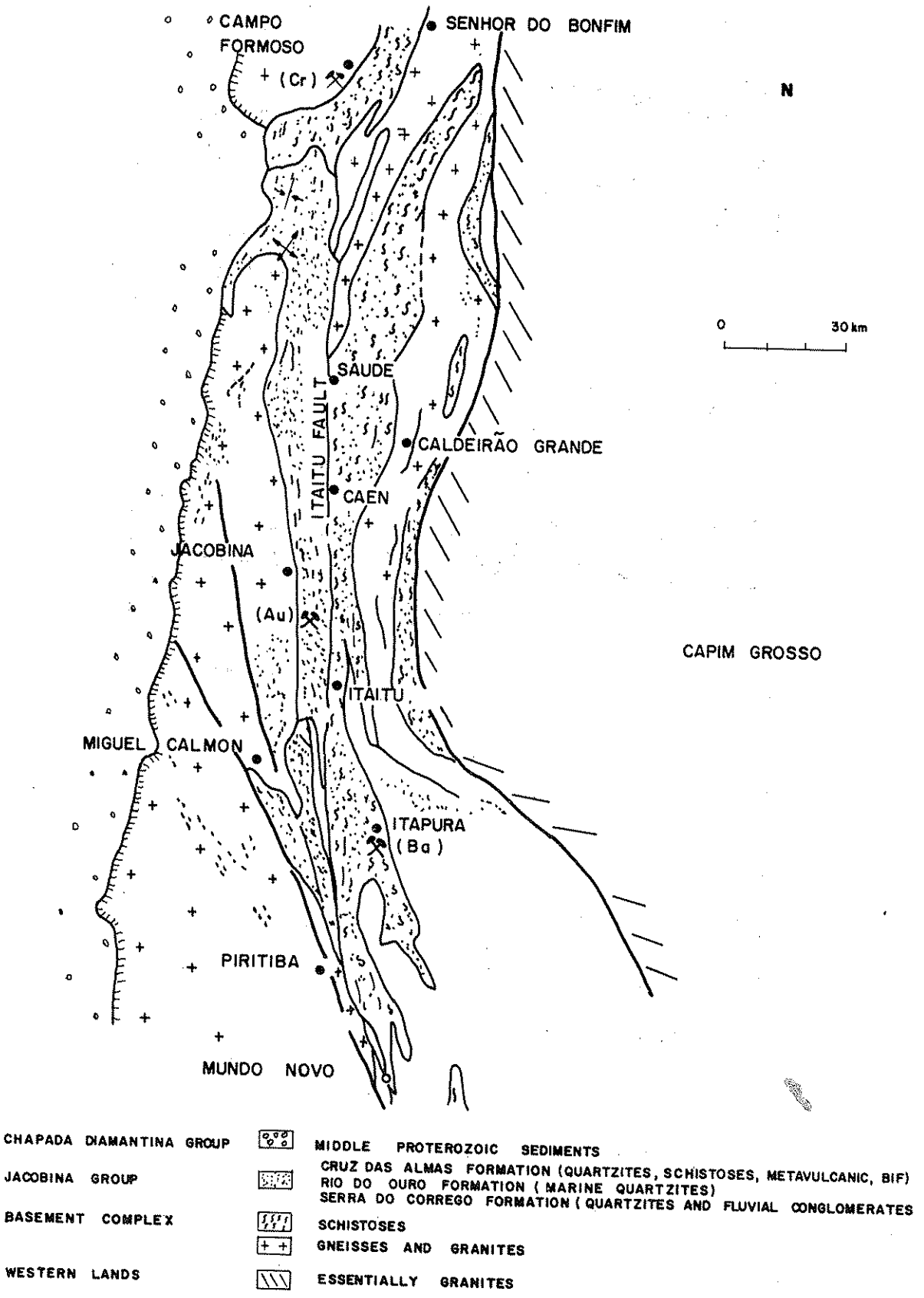


FIG.3.15 - REGIONAL GEOLOGY OF THE JACOBINA REGION

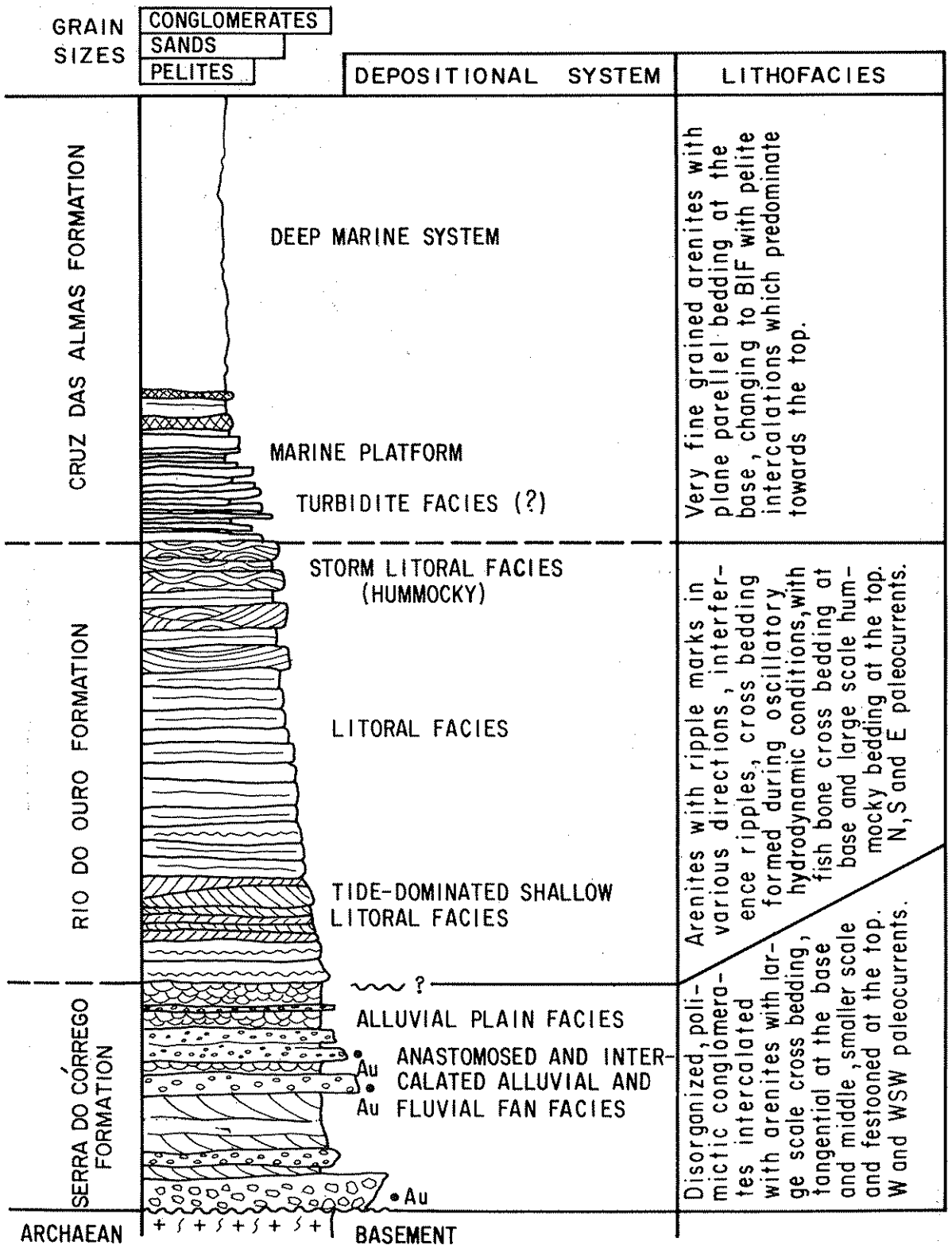

GRAIN SIZES
CONGLOMERATES
SANDS
PELITES
DEPOSITIONAL SYSTEM
LITHOFACIES
CRUZ DAS ALMAS FORMATION
DEEP MARINE SYSTEM
MARINE PLATFORM
TURBIDITE FACIES (?)
Very fine grained arenites with plane parellel bedding at the base, changing to BIF with pelite intercalations which predominate towards the top.
RIO DO OURO FORMATION
STORM LITORAL FACIES (HUMMOCKY)
LITORAL FACIES
TIDE-DOMINATED SHALLOW LITORAL FACIES
Arenites with ripple marks in various directions, interference ripples, cross bedding formed during oscillatory hydrodynamic conditions, with fish bone cross bedding at base and large scale hummocky bedding at the top. N, S and E paleocurrents.
SERRA DO CÓRREGO FORMATION
?
ALLUVIAL PLAIN FACIES
Au
ANASTOMOSED AND INTERCALATED ALLUVIAL AND
Au
FLUVIAL FAN FACIES
Disorganized, polimictic conglomerates intercalated with arenites with large scale cross bedding, tangential at the base and middle, smaller scale and festooned at the top. W and WSW paleocurrents.
Au
ARCHAEAN
BASEMENT

Fig. 3.16

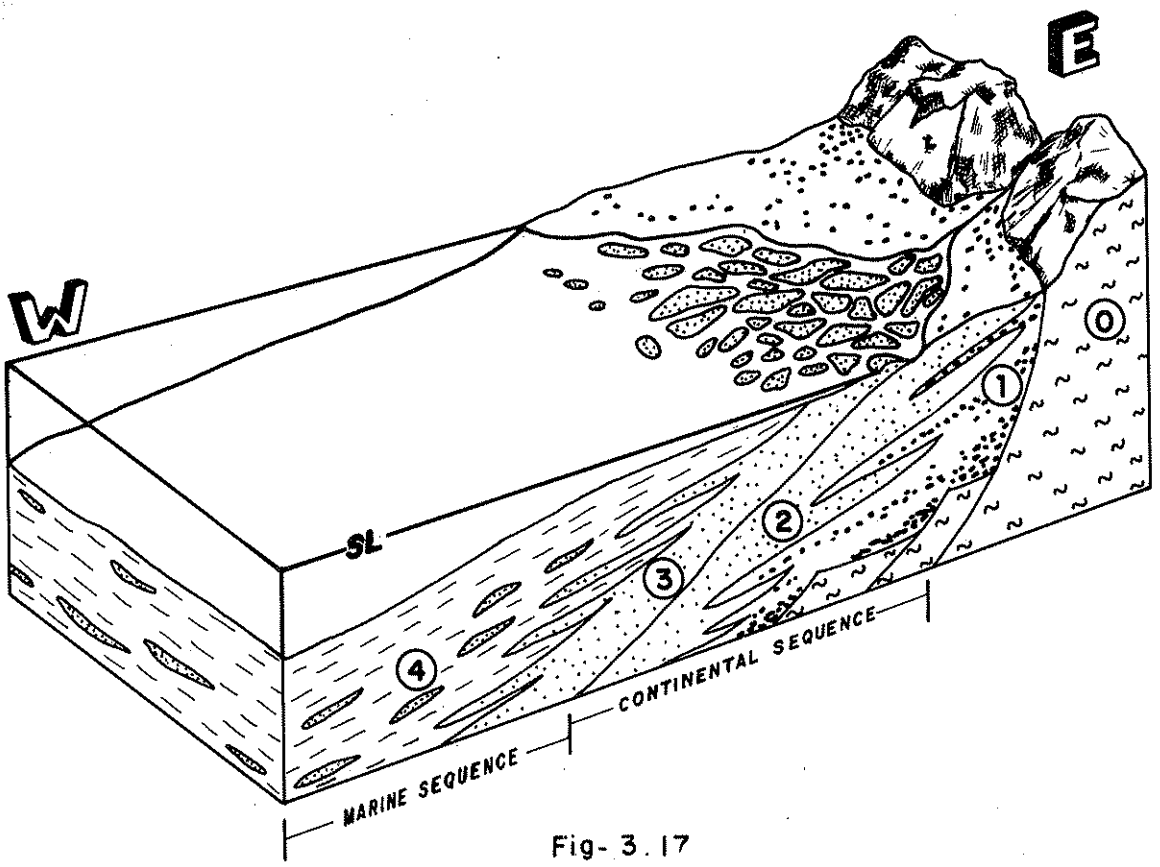


Fig- 3.17

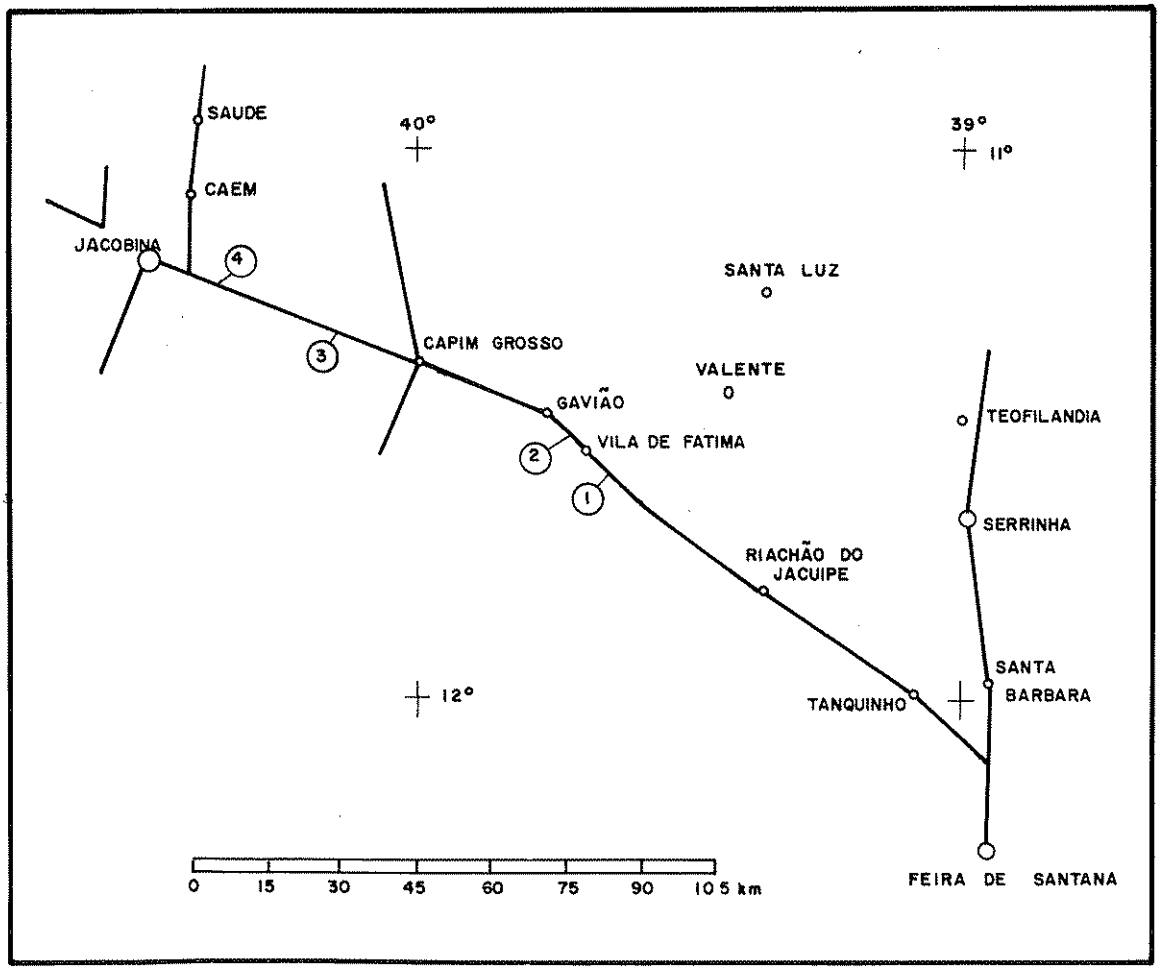


Fig- 3.18

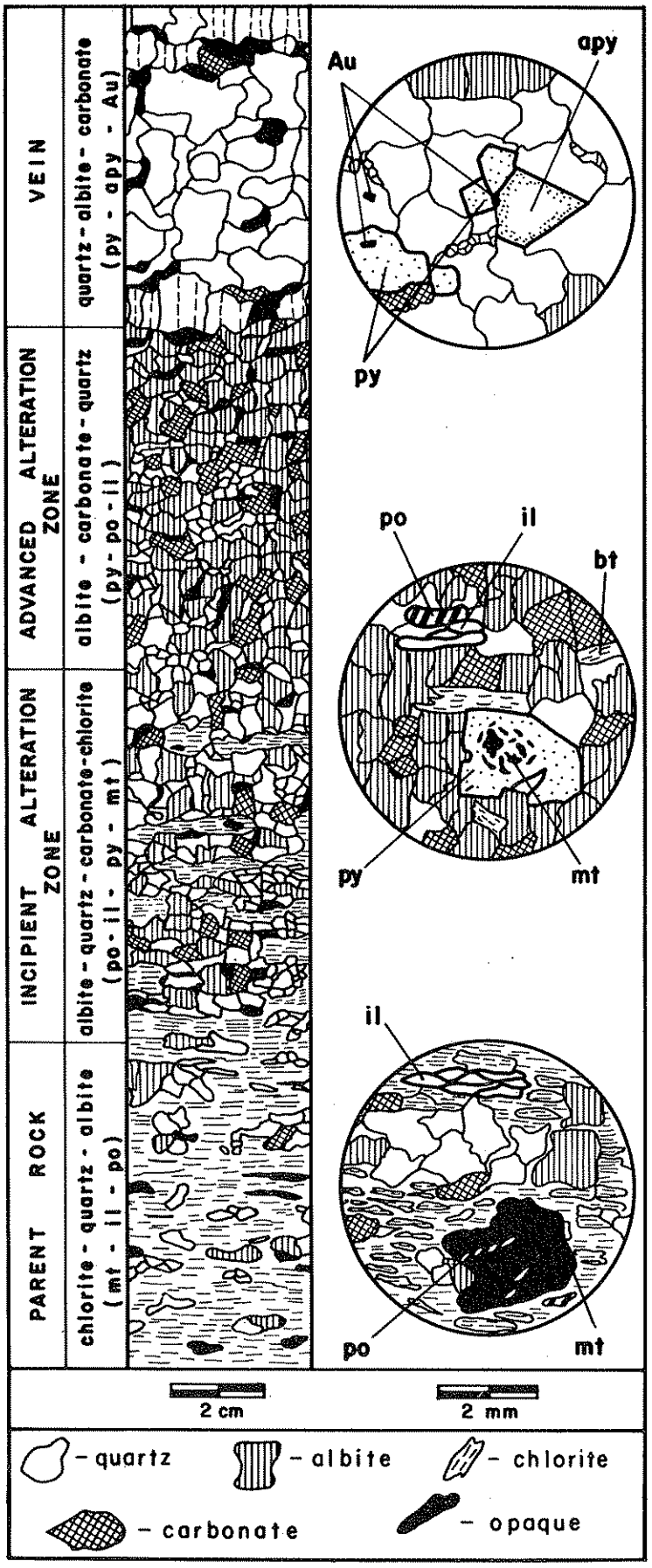

VEIN
quartz - albite - carbonate
(py - apy - Au)
ADVANCED ALTERATION ZONE
albite - carbonate - quartz
(py - po - il)
INCIPIENT ALTERATION ZONE
albite - quartz - carbonate - chlorite
(po - il - py - mt)
PARENT ROCK
chlorite - quartz - albite
(mt - il - po)
Au
apy
py
po
il
bt
py
mt
il
po
mt
2 cm
2 mm
- quartz
- albite
- chlorite
- carbonate
- opaque

Fig- 3,19

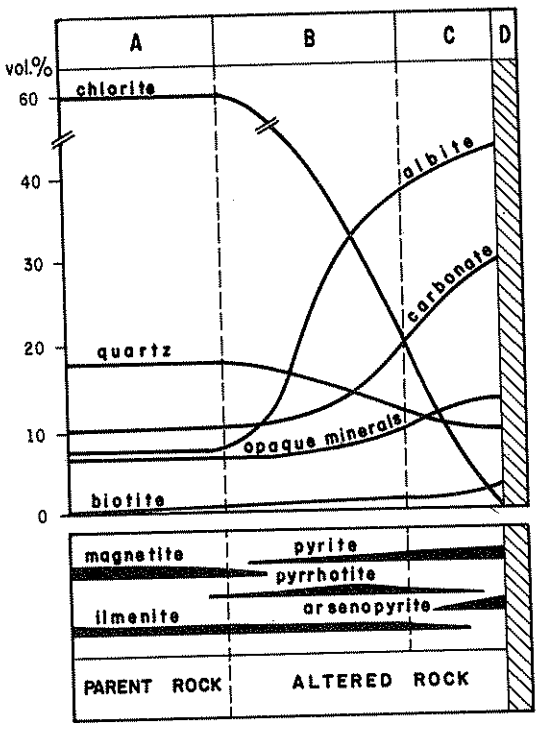


Fig-3.20

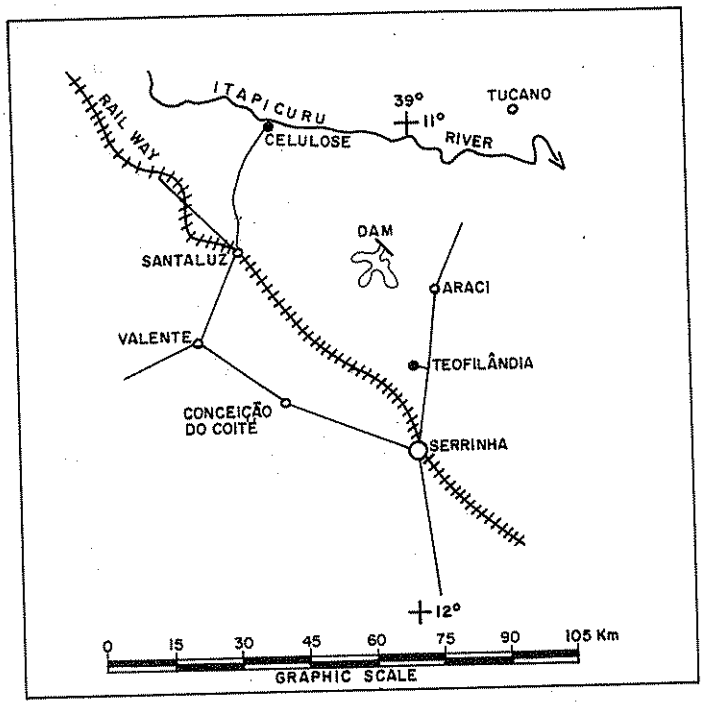


Fig-3.21- LOCATION MAP

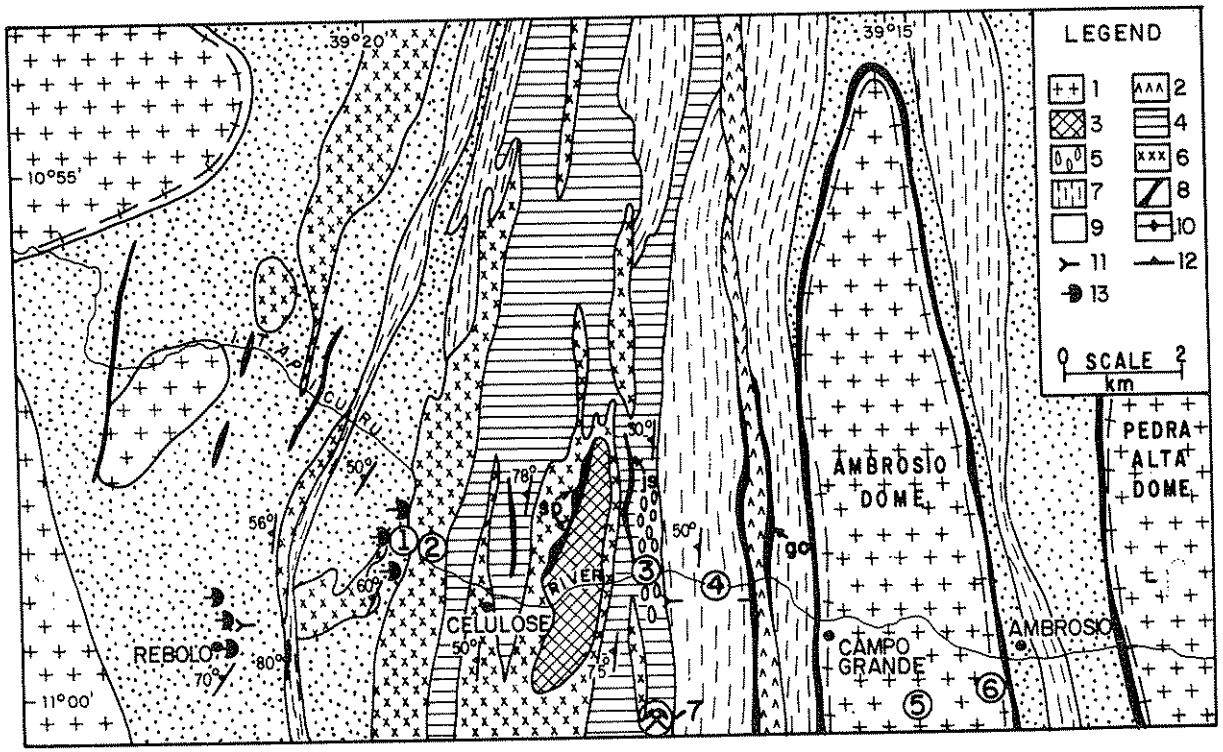


Fig. 3.22 - GEOLOGICAL SETTING
(ITAPICURU RIVER GEOLOGICAL PROFILE)

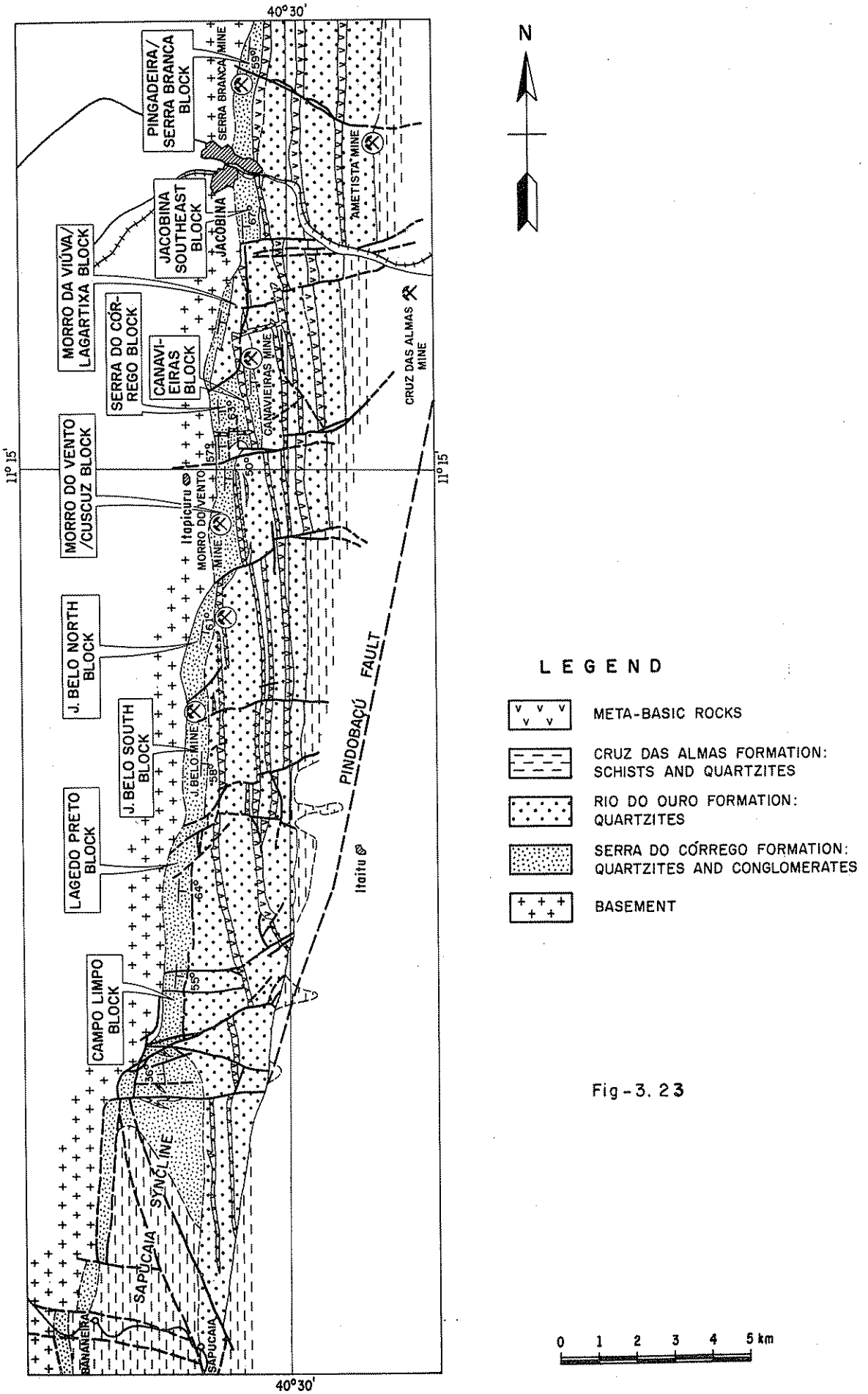

40°30'
11°15'
PINGADEIRA/ SERRA BRANCA BLOCK
JACOBINA SOUTHEAST BLOCK
MORRO DA VIÚVA/ LAGARTIXA BLOCK
SERRA DO CÓR-REGO BLOCK
CANAVI-EIRAS BLOCK
MORRO DO VENTO /CUSCUZ BLOCK
J. BELO NORTH BLOCK
J. BELO SOUTH BLOCK
LAGEDO PRETO BLOCK
CAMPO LIMPO BLOCK
SERRA BRANCA MINE
AMETISTA MINE
JACOBINA
CANAVIEIRAS MINE
CRUZ DAS ALMAS MINE
MORRO DO VENTO MINE
J. BELO MINE
Itapicuru
Itaitu
PINDOBAÇU FAULT
SAPUCAIA SYNCLINE
BANANEIRA
SAPUCAIA
N
LEGEND
META-BASIC ROCKS
CRUZ DAS ALMAS FORMATION: SCHISTS AND QUARTZITES
RIO DO OURO FORMATION: QUARTZITES
SERRA DO CÓRREGO FORMATION: QUARTZITES AND CONGLOMERATES
BASEMENT
0 1 2 3 4 5 km

Fig-3.23

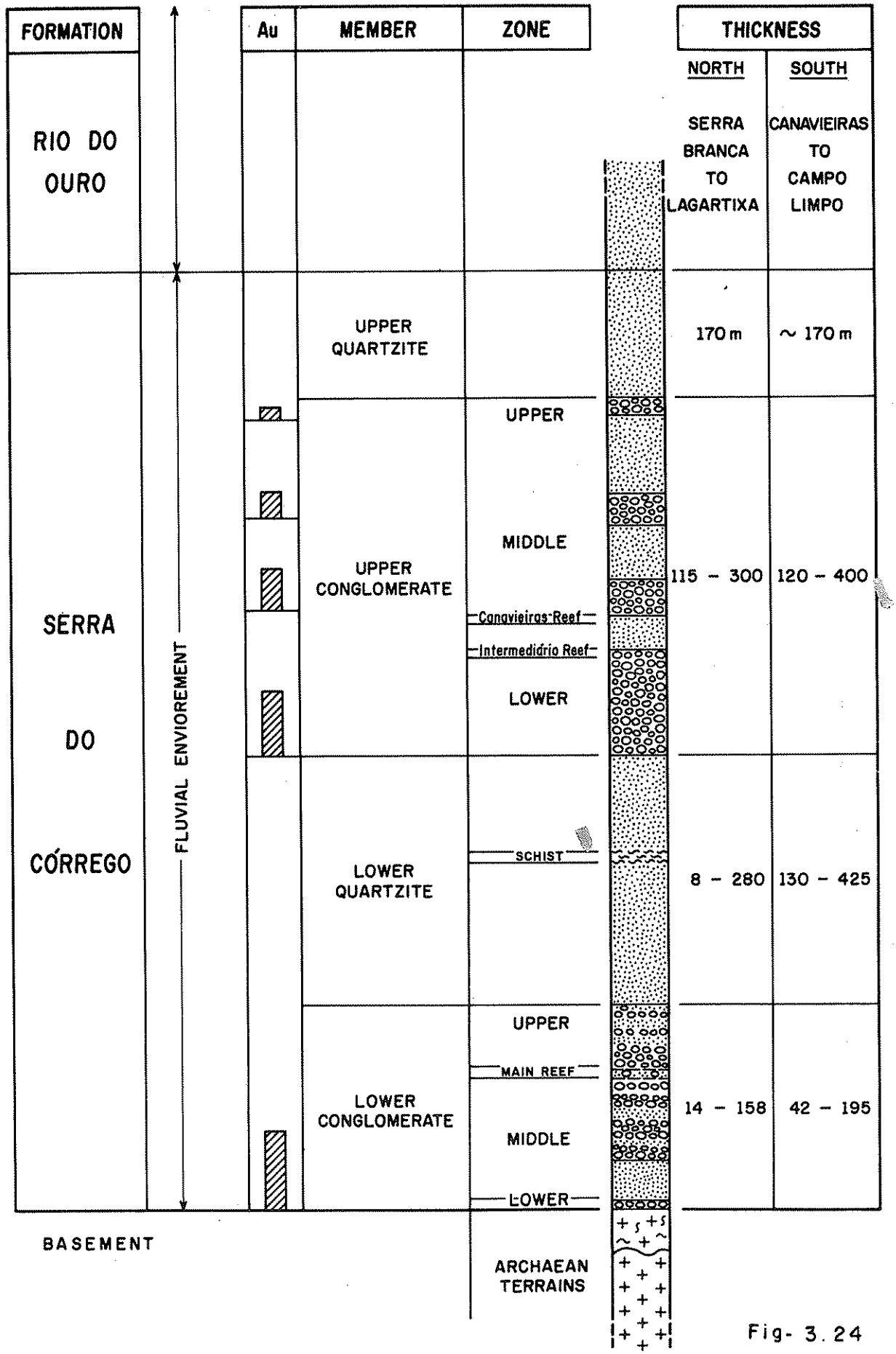

FORMATION
Au
MEMBER
ZONE
THICKNESS
NORTH
SOUTH
RIO DO OURO
SERRA BRANCA TO LAGARTIXA
CANAVIEIRAS TO CAMPO LIMPO
SERRA DO CÓRREGO
FLUVIAL ENVIOREMENT
UPPER QUARTZITE
170 m
~ 170 m
UPPER CONGLOMERATE
UPPER
MIDDLE
LOWER
115 – 300
120 – 400
Canavieiras Reef
Intermediário Reef
LOWER QUARTZITE
SCHIST
8 – 280
130 – 425
LOWER CONGLOMERATE
UPPER
MAIN REEF
MIDDLE
LOWER
14 – 158
42 – 195
BASEMENT
ARCHAEAN TERRAINS

Fig- 3.24

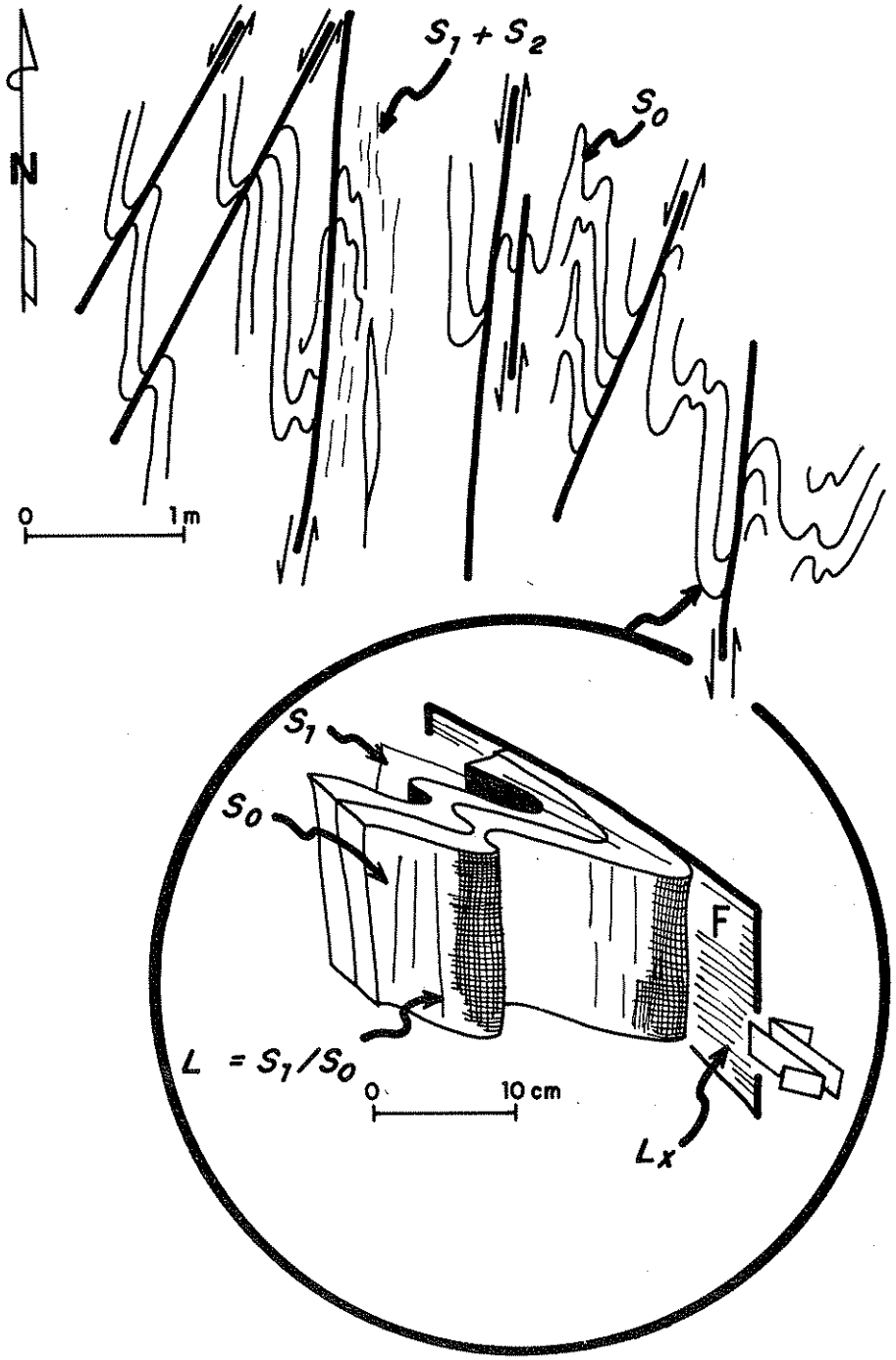


Fig- 3.25 FAULT PLANES

ESCOLA DE MINAS - DEGEO / DEMIN
BIBLIOTECA

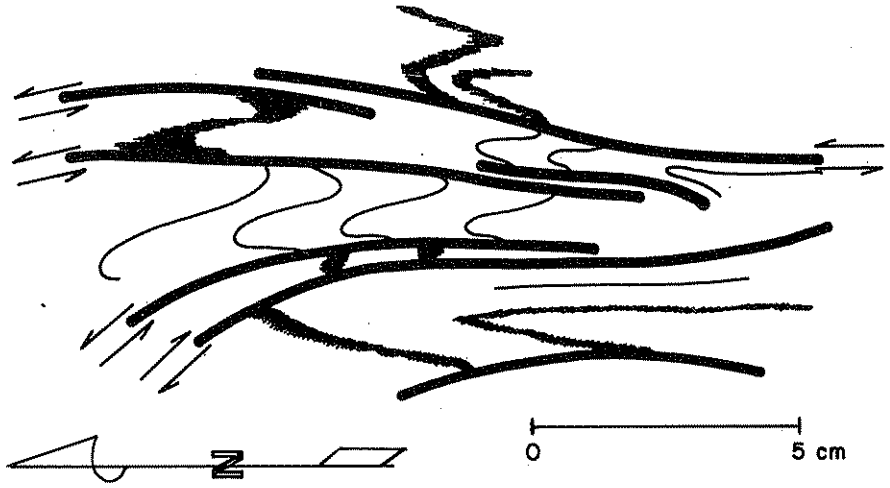


Fig - 3.26

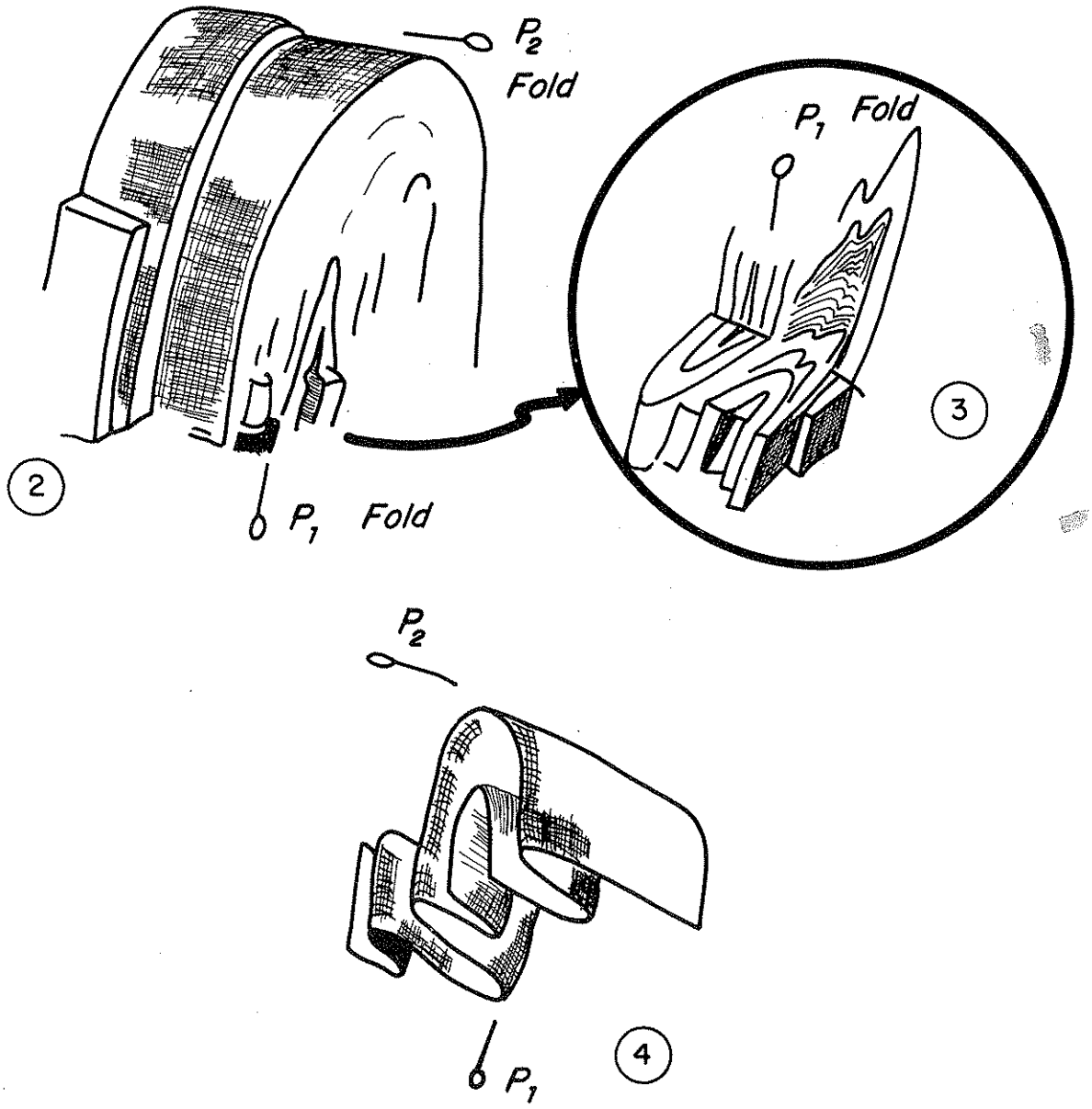


Fig - 3.27

4. PRESENT STATE OF KNOWLEDGE OF THE ORGANIC GEOCHEMISTRY OF THE CAMPOS AND ESPÍRITO SANTO BASINS

Paulo César Gaglianone
Luiz Antonio Freitas Trindade
PETROBRÁS/CENPES

The Campos and Espírito Santo basins display several similar geochemical aspects.

The main sources rocks in both basins are the shales from the Jiquiá stage. Shales from the Buracica and Alagoas stage also show some hydrocarbon source potential in these areas (fig. 4.1).

The microbial and other degradation processes caused changes in the composition of the oils in the reservoir rocks. The oils are biodegraded at different temperatures, with the reservoir temperature performing an important role in the control of the biodegradation process.

The migration pathway model is similar for Campos and Espírito Santo basins, involving upward secondary migration through windows in the evaporitic seals.

The oils migrated into the marine sequence where migration and accumulation were controlled by faults, regional unconformities and by reservoirs.

INTRODUCTION

The organic geochemistry of the Campos and Espírito Santo basins has been the theme of papers published (ESTRELLA et al. MEISTER and PEREIRA et al.) and PETROBRÁS unpublished reports (FIGUEIREDO et al, MEISTER, PEREIRA and WOLFF et al).

PETROBRÁS continues to study the geochemical behaviour of the two basins, updating information as new wells are drilled.

CENPES and the PETROBRÁS Exploration Department are in the final phase of a project whose aim is a map of several geochemical and geological parameters on a regional scale. The Lagoa Feia Formation is sub-divided into four units, encompassing Buracica, Lower Jiquiá, Upper Jiquiá and Alagoas stages

CHARACTERIZATION OF SOURCE ROCKS

Such rocks are rich in organic matter suitable for the generation of ore and must have been subjected to appropriate thermochemical conditions within the oil window.

The quantity of organic material is estimated by total organic carbon analysis. "Rock-Eval" pyrolysis evaluates the hydrocarbon source potential in the rock and the type or kerogen it contains. The stage of maturation of the organic matter is determined by the vitrinite reflectance.

In the Campos basin, the best hydrocarbon potential yield is found in shales and marls of the Lagoa Feia Formation, corresponding to the Jequiá and Buracica stage (fig. 4.2). In this section, the hydrocarbon source potential is usually situated between 10 and 14 kg HC/t of rock, with types I and II kerogens predominating, which are suitable for the generation of liquid hydrocarbons (fig. 4.2).

The Lagoa Feia Formation is mature practically throughout the Campos Basin except in the São Tomé Low where the top of the mature zone is positioned at the base of the Jiquiá stage.

Shales associated with evaporites of the Alagoas stage (Lagoa Feia Formation) are also considered locally as source rocks, although they occur in thin bands.

The shales and marls of the Cenomanian/Turonian age at the top of the Macaé Formation, although they show a high

hydrocarbon source potential for liquid hydrocarbon in some wells, are considered non-sources because they are immature (figure 4.1).

The top of the overmature zone was not reached in any well in the Campos Basin, and extrapolation of vitrinite reflectance data suggest that it lies below 6,000 metres. According to Pereira (1982), the Lagoa Feia Formation reached adequate conditions for generation of hydrocarbons from the Eocene/Oligocene, when intense subsidence started during the Tertiary.

The principal source rocks in the Espírito Santo basin are shales from the Maririocu Formation/Mucuri Member, pre-Jiquiá and Jiquiá stages (fig. 4.3).

At the open mine Tertiary to Upper Cretaceous sediments show no potential as a source section.

The source rocks of the Mucuri unit are within the oil window between Nativo High and the western edge of the basin (fig. 4.4). The rocks in the east of Nativo High, although not drilled are in the overmature zone.

The thin shale levels of the Alagoas stage, corresponding to the Itaúnas Member of the Mariricu Formation, contain geochemical conditions locally for the generation of small quantities of hydrocarbons.

According to Kiang et al (1983), the Jiquiá section of the Espírito Santo Basin reached adequate conditions for oil generation from the upper Cretaceous to the beginning of the Tertiary.

CHARACTERIZATION OF OILS

The geochemical analyses of oils were carried out by liquid and gas chromatography carbon isotopes and gas chromatography-mass spectrometry (steranes and terpanes).

Three types of oils were found in the Espírito Santo basin:

- type A: light, very mature, found in the turbidites of Cretaceous/Tertiary in the Regência and Fazenda Cedro paleocanyons and in the Albian reservoirs of the Regência Platform (fig. 4.5);

- type B: thermochemically less developed than type A, usually at an advanced stage of biodegradation. Its occurrence is restricted to Alagoas reservoir rocks in the São Mateus Platform (fig. 4.5);

- type C: mixed, generated from organic mather deposited in a salt-water environment, influenced by fresh-water continental organic matter. It is found only in Alagoas reservoir rocks in stratigraphic traps (fig. 4.5).

In general, all oils in the Campos basin are geochemically similar, whatever the age of the reservoir rocks in which they are accumulated. However, they show evidence of being at different stages of biodegradation (fig. 4.6). They are derived from lipidic algal material, deposited in a restricted salt lake environment, not influenced by organic matter of continental origin. The carbon isotopic ratios are around - 25.0%; however, two oils from the Badejo and Enchova fields have even more negative carbon isotopic ratios.

OIL - SOURCE ROCK CORRELATION

In the Campos basin there is a good correlation between oils and organic extracts from the Lagoa Feia Formation in terms of gas chromotography, biomarkers and carbon isotopes. The best correlation among oils and organic extracts is that of extracts from Jiquiá and Alagoas stages (fig. 4.7). Organic extracts from Buracica stage tend to show a more negative ratio, suggesting a greater influence of organic material deposited in a fresh water continental environment. However, the shales from the Buracica stage may contribute to a lower proportion of oil generated, mixed with a high proportion of petroleums generated by the Jiquiá source rocks.

Geochemical parameters in the Espírito Santo basin show that type A oil has a better correlation with organic extracts from the Jiquiá stage, while type B oils are a mixture of petroleums generated from the Jiquiá and Alagoas source shales. Type C oils show a contribution from Jiquiá and pre-Jiquiá source rocks.

Biological markers play an important part in the oil/oil and oil/source rock correlation, due to the degradation shown by some oils.

CENPES is at present engaged in a detailed study of biomarkers from the Jiquiá and pre-Jiquiá section of the Espírito Santo basin. The correlation between oils and source rocks can be more precisely defined by means of this study.

OIL ALTERATION PROCESSES

Problems related to the different stages of alteration of petroleums exist in the two basins. Altering processes make the oil heavier due to its relative enrichment in resins and asphaltenes.

Biodegradation is the predominant process in the alteration of hydrocarbons, followed by the water-washing process. This process results in a loss of normal paraffins, first those of lower molecular weight and then the removal of isoparaffins.

In advanced stages of biodegradation, the compound demethylated hopane appears; this appearance is interpreted as a result of the removal of a methyl of triterpane hopane by bacterial action.

Innumerable geological factors control biodegradation, which can inhibit or enhance this process. Apparently, temperature is the factor which above all shows good correlation with biodegradation. Temperatures from 65° to 75°C are acknowledged to be the maximum limit for effective bacteriological activity (Philippi, 1977).

In the Espírito Santo basin, more specifically at the São Mateus platform, there is a good correlation between the 25° API curve and the 65°C isotherm (fig. 4.8). Oils accumulated in reservoirs at a temperature below 65°C tend to have a lower API degree, showing more severe stages of biodegradation.

In the Campos basin, to a depth of 2000m of deptth the temperature is around 65°C, which promotes an advanced stage of biodegradation of some oils at shallower depths.

GENERATION, MIGRATION AND ACCUMULATION MODEL OF OILS

In the two basins, oil was generated in the Jiquiá and pre-Jiquiá section with some contribution from the Alagoas stage shales Migration and accumulation of oil in the presalt sediments were directed basically by faults and by the beds of coquinas and conglomerates.

Once they reached the windows in the evaporites created by halokinetic tectonics, the oil migrated to the marine section, where its migration and accumulation were controlled by reservoirs, faults and unconformities (fig. 4.9).

The migration of hydrocarbons is being studied principally in the Campos basin, by CENPES.

CONCLUSIONS

- The principal hydrocarbon source rocks in the Espírito Santo basin are the shales from the Jiquiá stage. Secondly, the shales of pre-Jiquiá and Alagoas stages have some potential for generating hydrocarbons;

- the source rocks in the Campos basin are the shales of the Lagoa Feia Formation (Alagoas, Jequiá and Buracica stages). The shales from the Jiquiá stage are responsible for the generation of the majority of the accumulations in the basin;

- the oils of the two basins are biodegraded in different stages. Apparently, the temperature of the reservoir is one of the foremost factors in controlling biodegradation;

- the model of generation, migration and oil accumulation is applied in exploration of the Campos and Espírito Santo basins, for the purpose of orienting prospection to the most favourable areas for drilling new wells.

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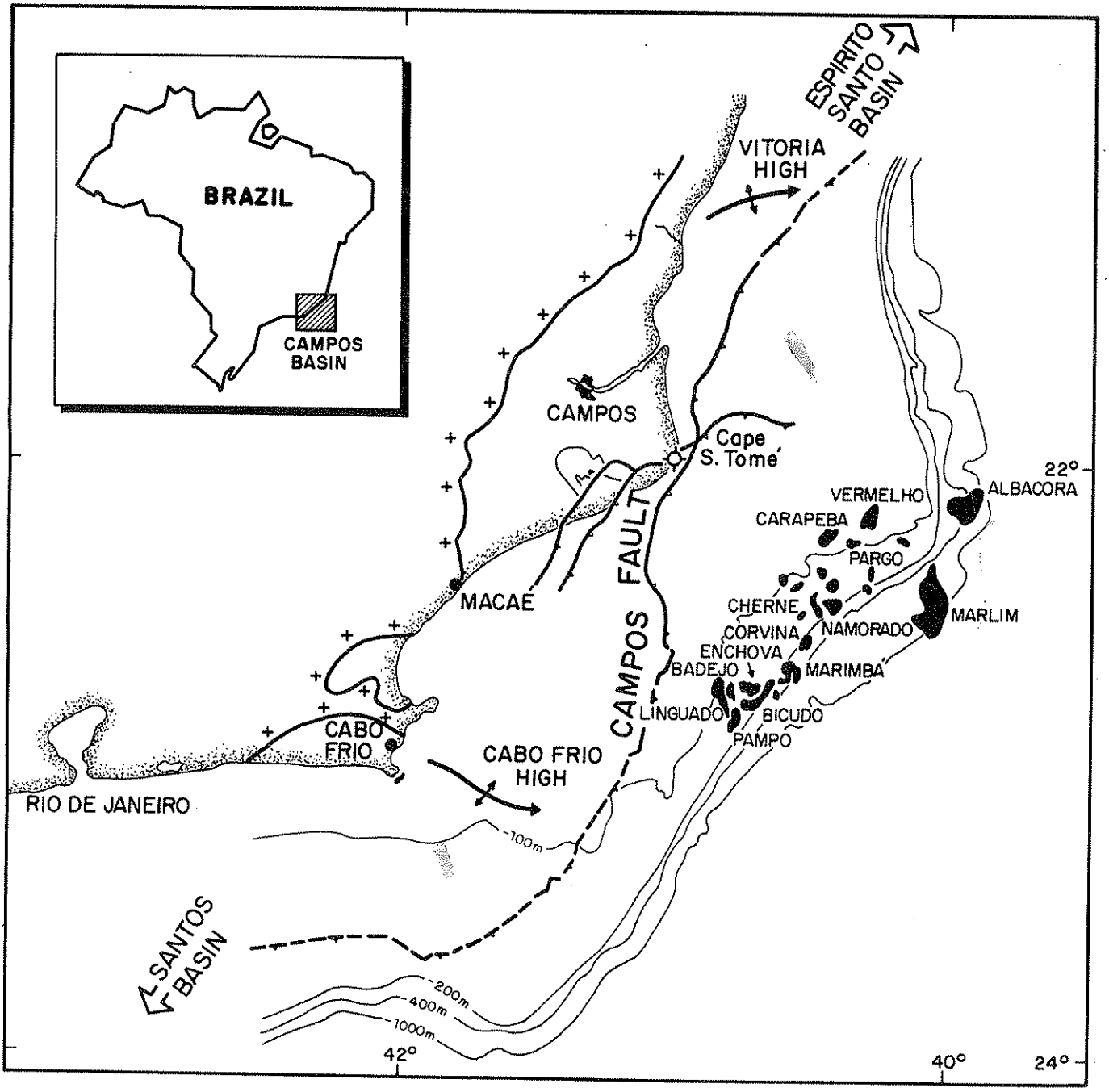
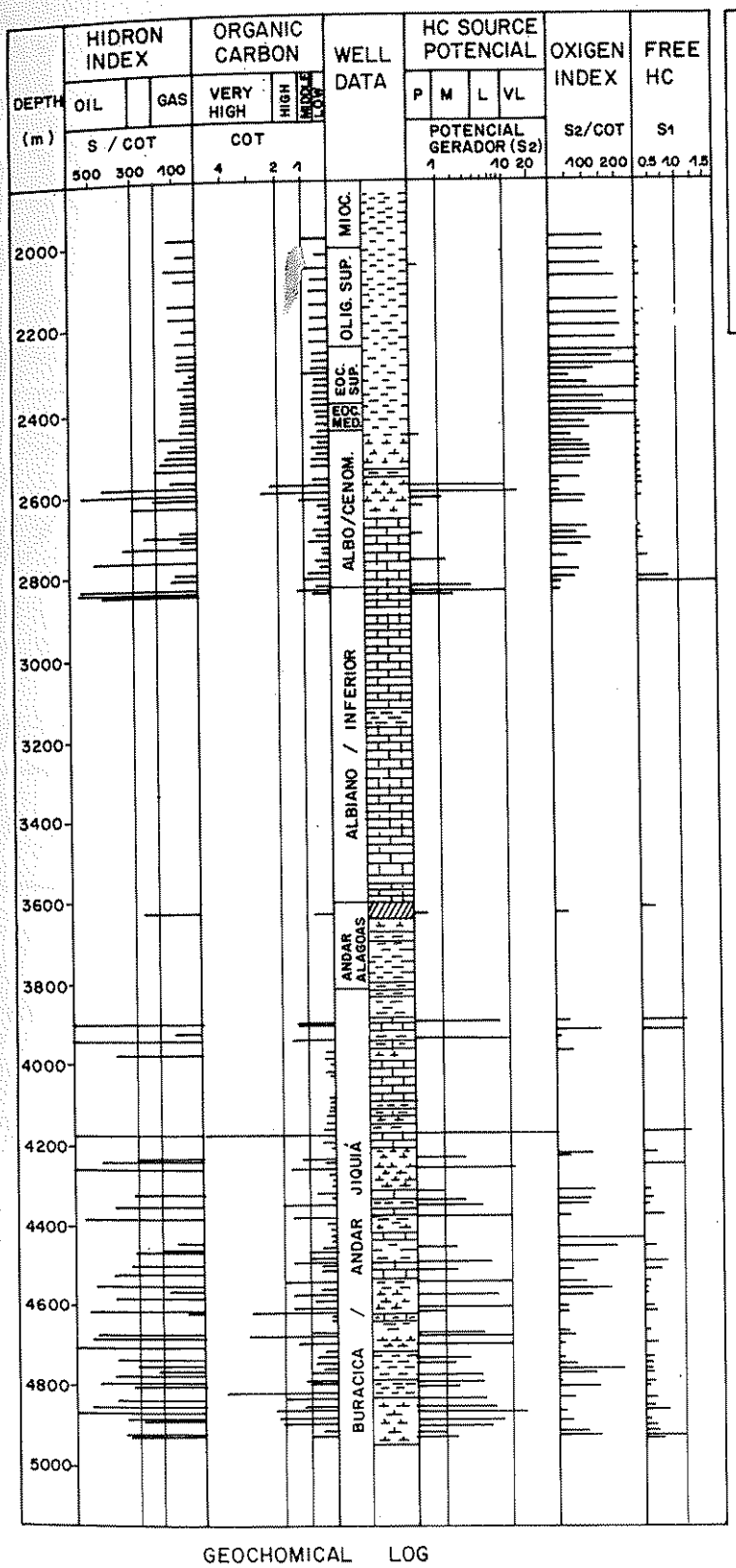
GEOCHEMICAL EVALUTION OF CAMPOS BASIN, BRAZIL
FIELD TRIP Nº 7

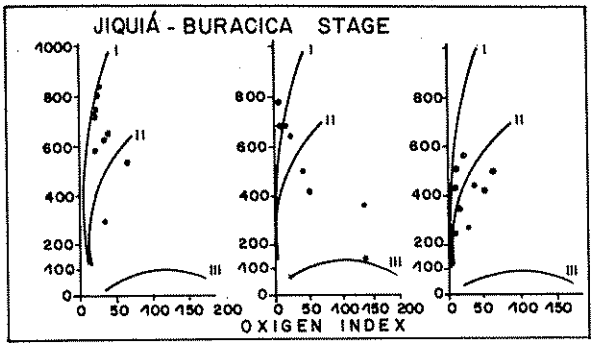


(FROM PETROBRAS' EXPLORATION DEPARTMENT)

FIG. 4.1 - CAMPOS AND ESPIRITO SANTO BASINS



GEOCHOMICAL LOG



VAN KROVELEN TYPE DIAGRAMS
JIQUIÁ - BURACICA STAGE

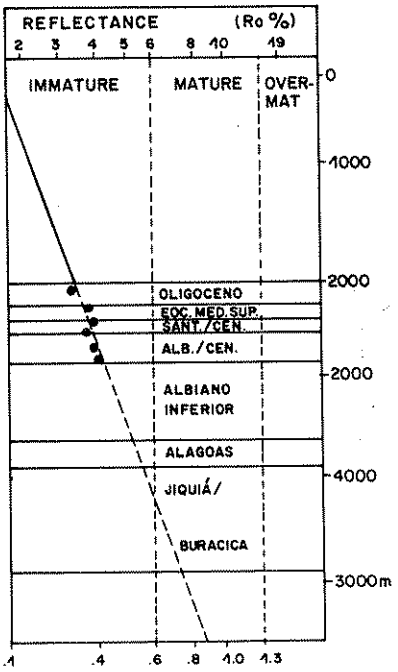


FIG.4.2 - GEOCHOMICAL DATA FROM ONE WELL OF CAMPOS BASIN
(ADAPTED FROM PEREIRA ET AL, 1984)

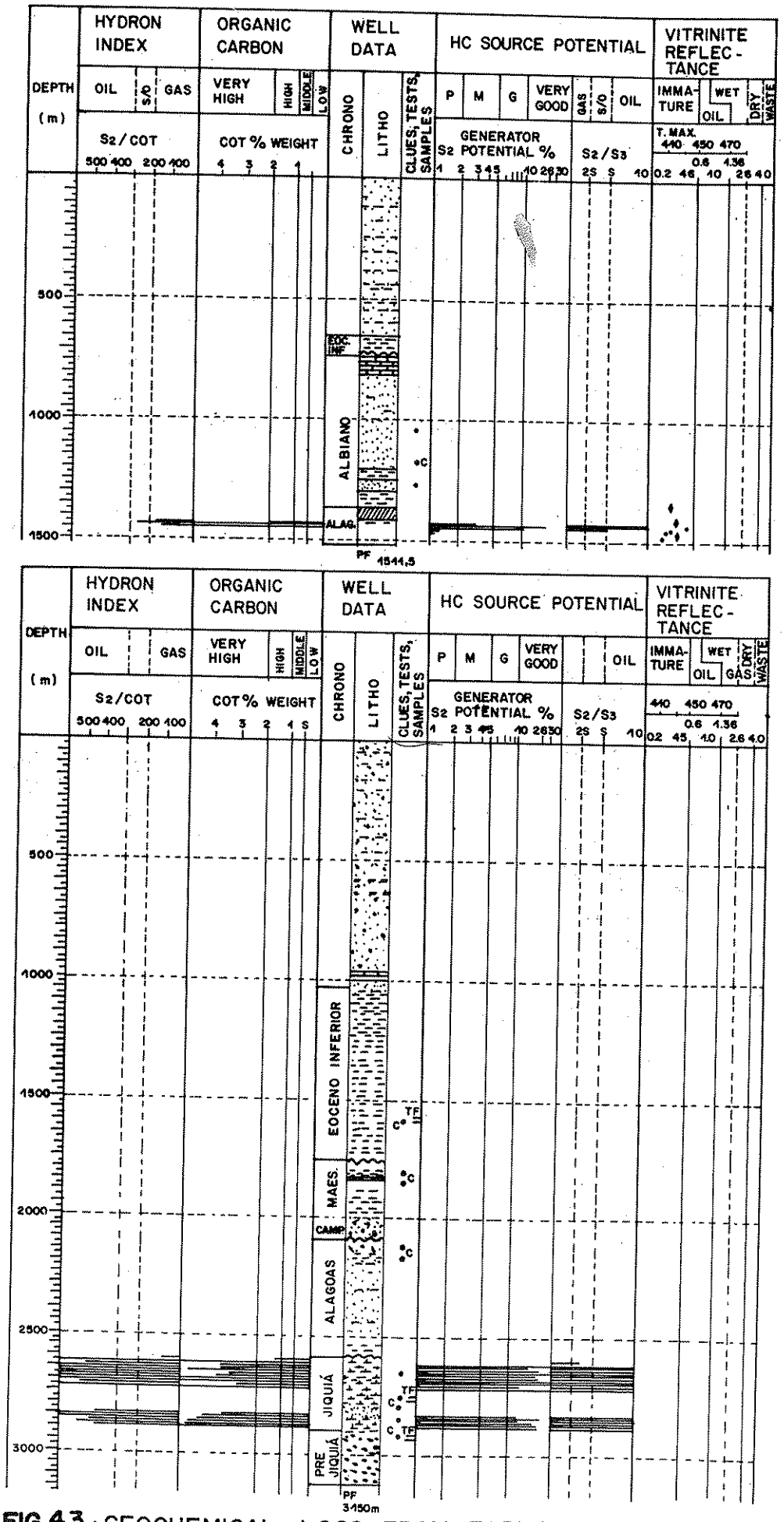
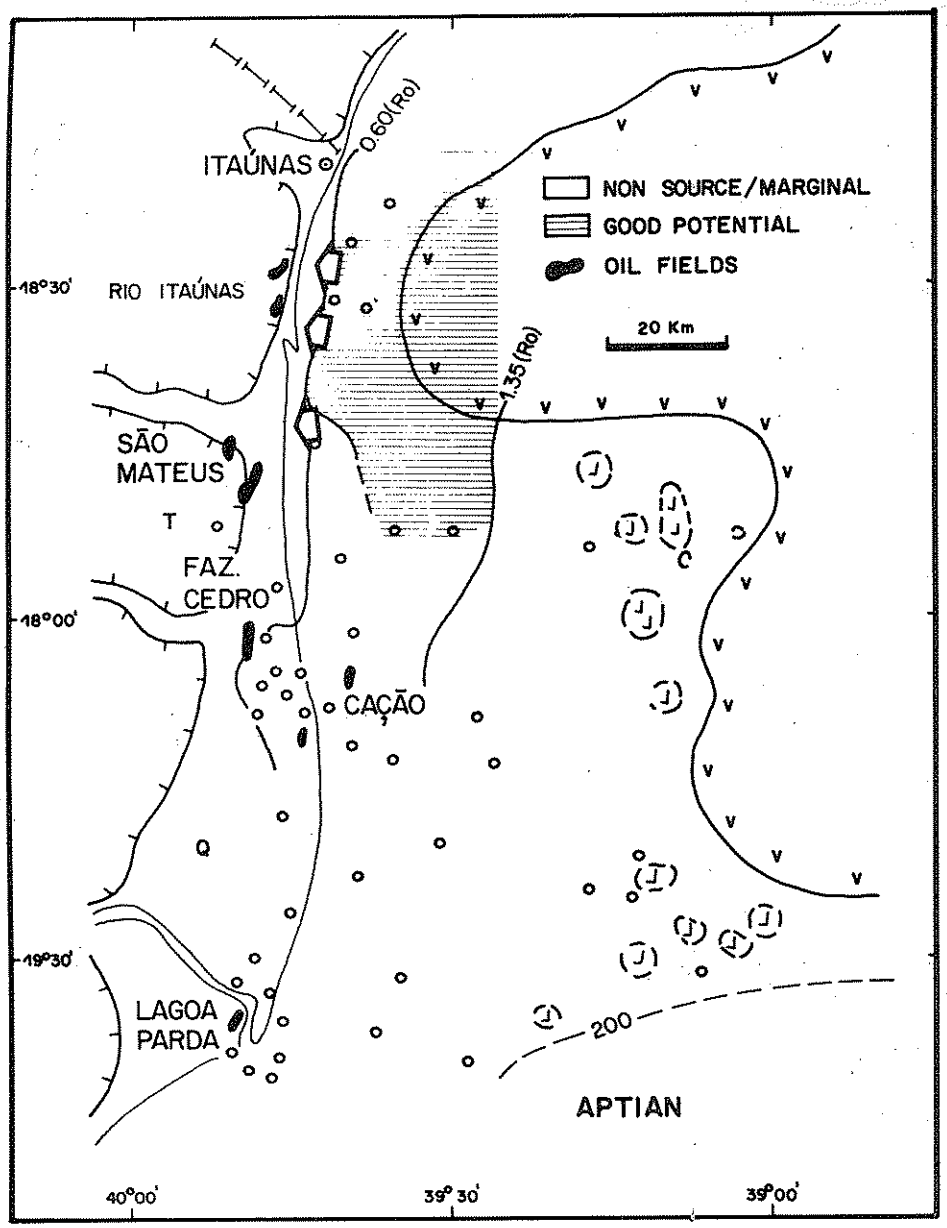


FIG. 4.3 - GEOCHEMICAL LOGS FROM ESPIRITO SANTO BASIN
(ADAPTED FROM ESTRELLA ET AL 1983)



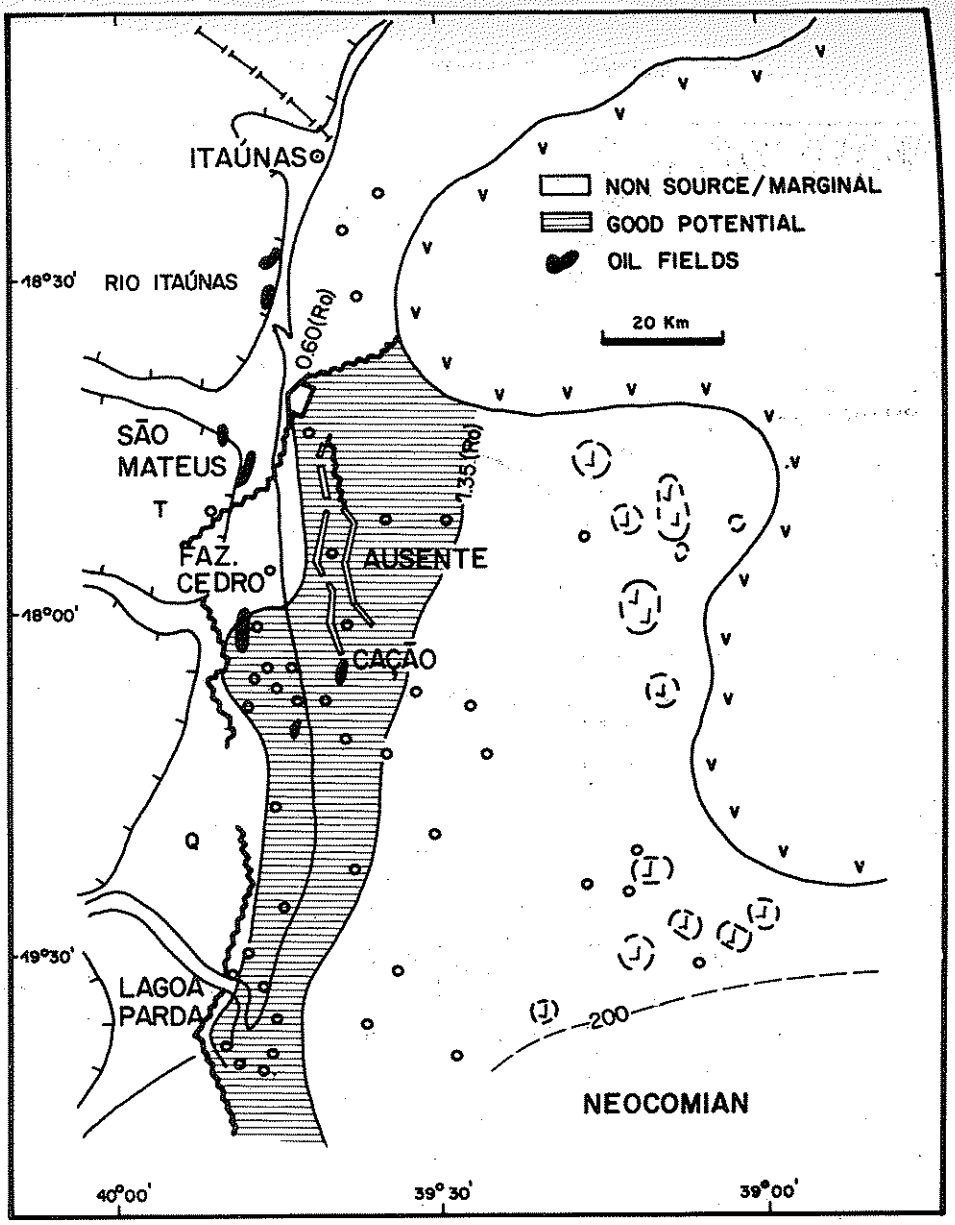


Fig-4.4 - AREAS OF HYDROCARBON GENERATION IN ESPÍRITO SANTO BASIN.
(ADAPTED FROM ESTRELLA ET AL, 1983)

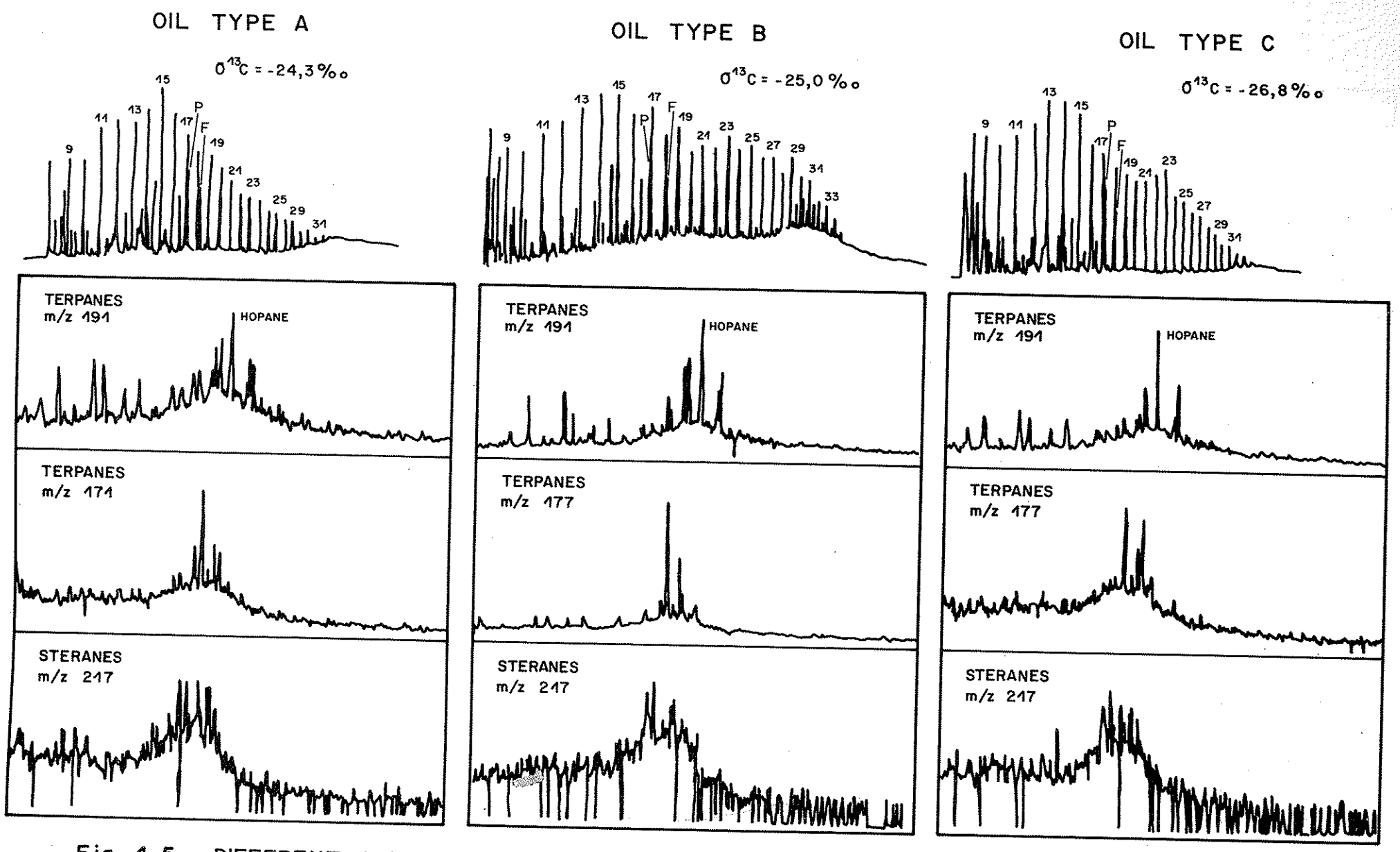


Fig-4.5. DIFFERENT TYPES OF OILS NON BIODEGRADED FROM ESPÍRITO SANTO BASIN.
(ADAPTED FROM WOLFF ET AL, 1986)

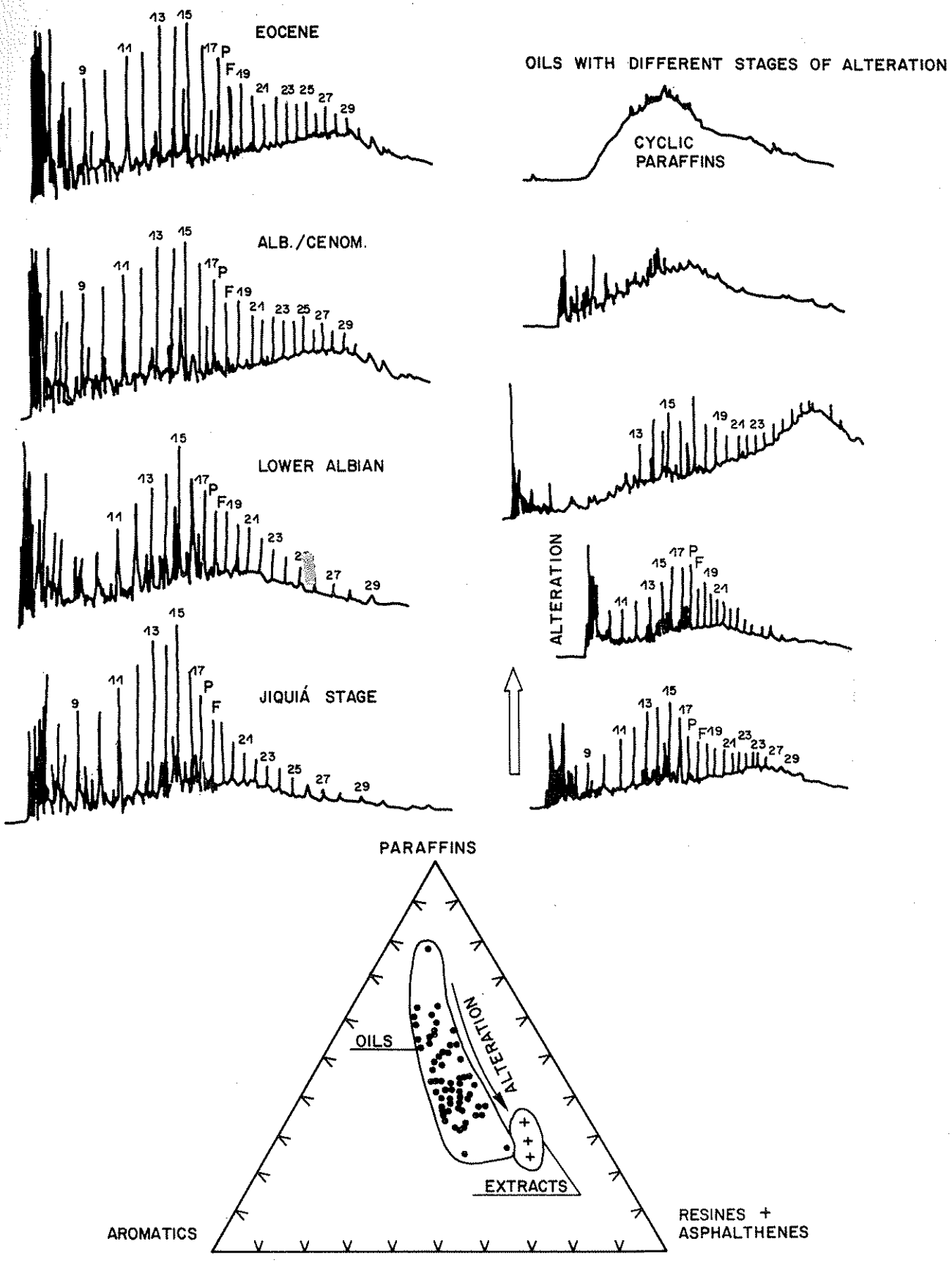


Fig 4.6 LIQUID AND GAS CHROMATOGRAPHY OF OILS FROM DIFFERENT RESERVOIRS, CAMPOS BASIN. (ADAPTED FROM PEREIRA ET AL, 1984)

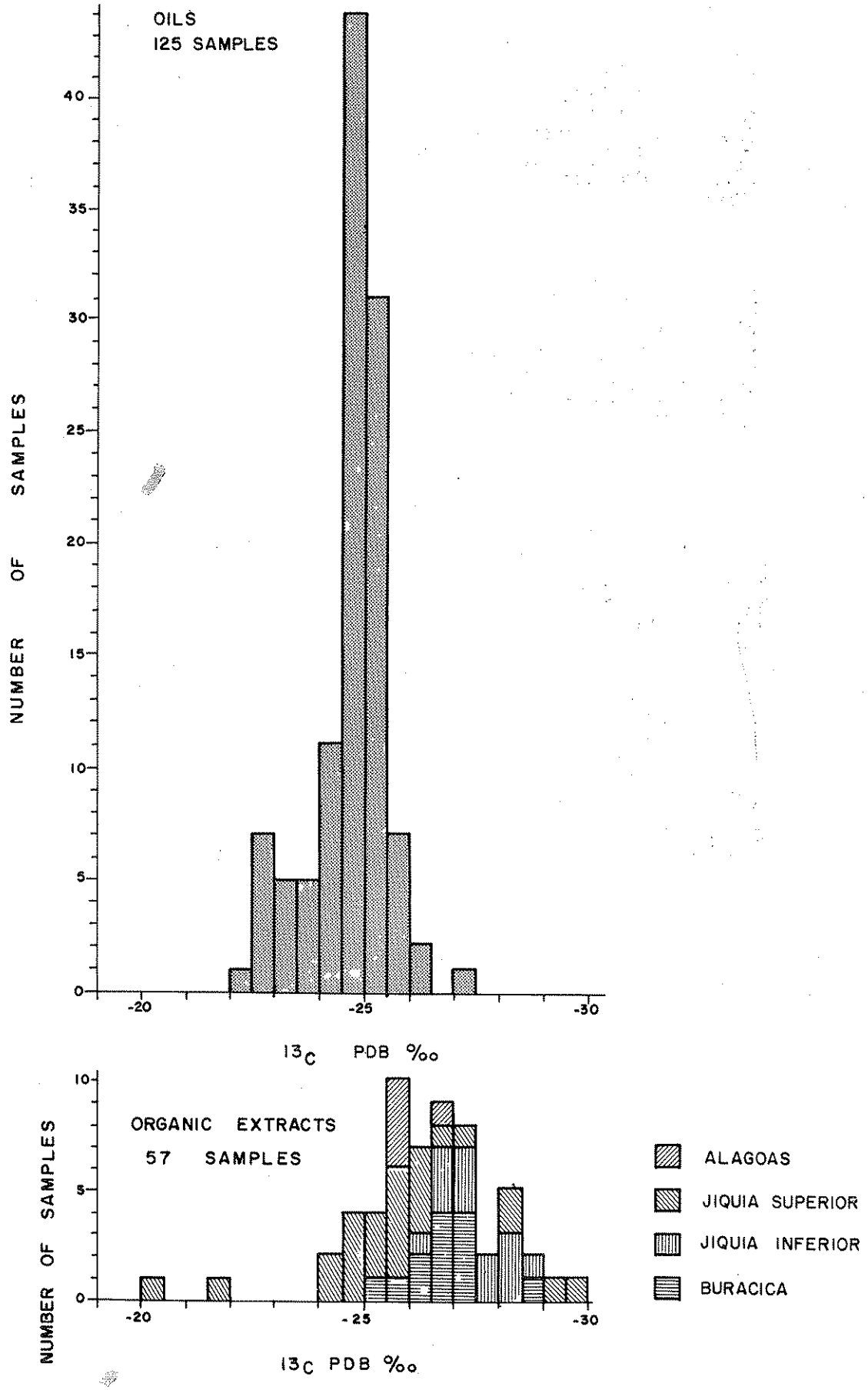


Fig 4.7 - CARBON ISOTOPIC RATIOS OF OILS AND ORGANIC EXTRACTS CAMPOS BASIN

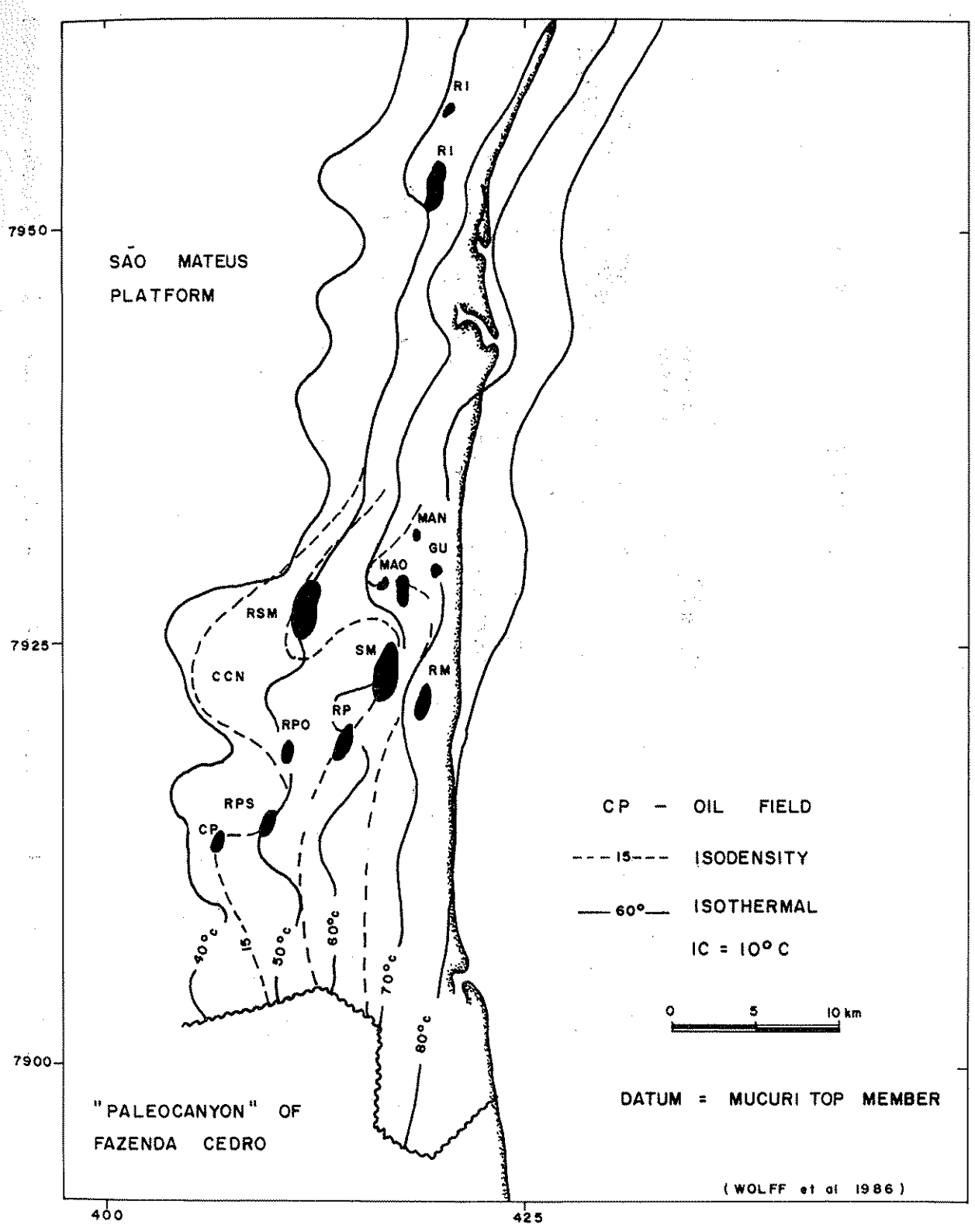
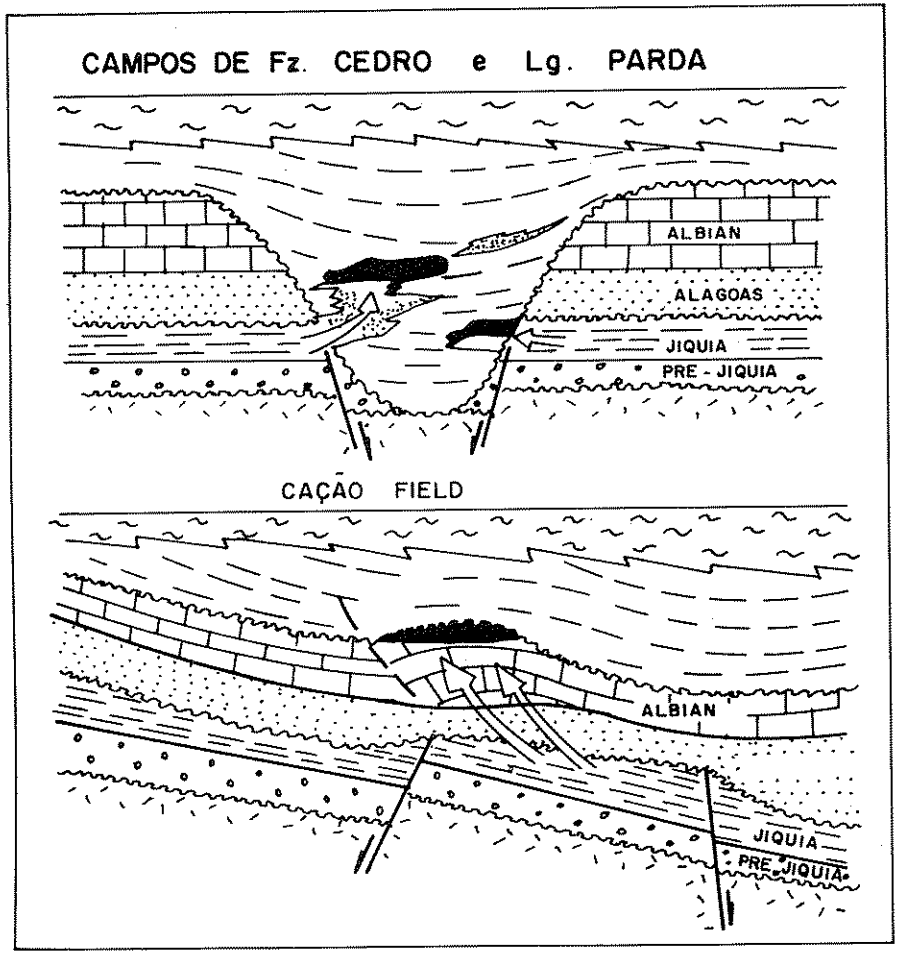


Fig 4.8 - ISOTHERMAL AND ISODENSITY MAP, SAO MATEUS PLATFORM, ESPIRITO SANTO BASIN

ESPIRITO SANTO BASIN



CAMPOS BASIN

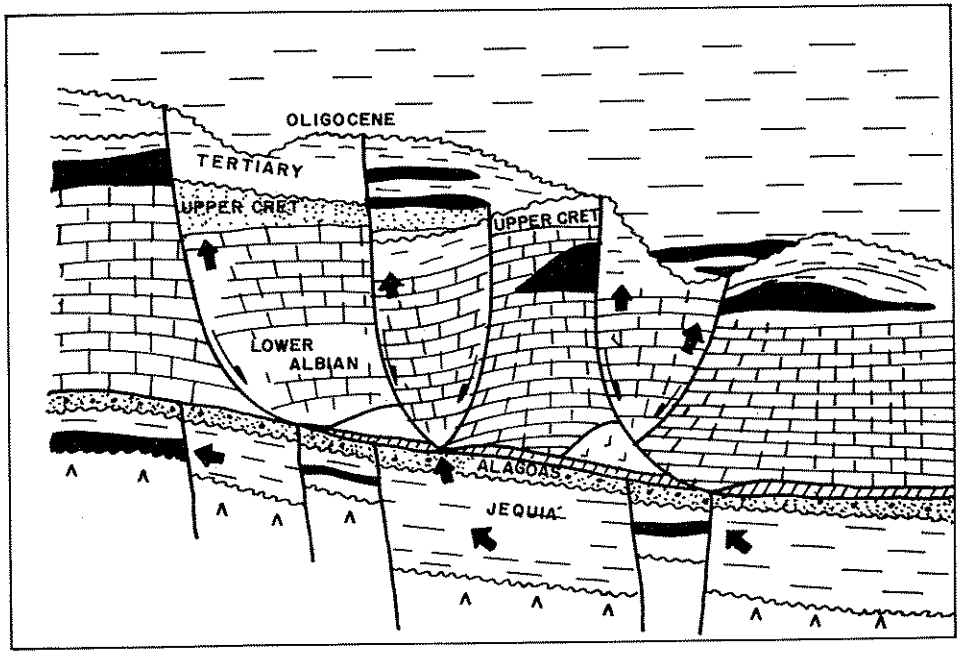


Fig.4.9- SCHEMATIC MODELS OF MIGRATION AND ACCUMULATION OF HYDROCARBONS

5.a THE GOLD DEPOSIT OF "MEIA-PATACA", CRIXÁS - GOIÁS

Luiz Fernando Magalhães
Ricardo Luiz de Morais Lobo
Luiz Carlos Adjuto Botelho
Rommel da Costa Pereira

Metais de Goiás S.A. - METAGO

The ore body of Meia-Pataca is situated in the Crixás region(fig. 5.1) of Goiás State, a historic gold exploration area. It occurs in the upper unit (Ribeirão das Antas Formation) of the Greenstone Belt of Crixás. The pyrite, pyrrhotite, arsenopyrite and gold mineralization that constitute the ore body M1 is located in a graphitic-carbonate horizon with feldspatic zones. This mineralization is probably the product of exhalative (syngenetic), hydrothermal and structural (shear zone) associated processes.

The ore reserves are around 160,000 tonnes of altered rock ore and about 460,000 tonnes of fresh rock with grades of 2.55 and 2.20 ppm Au respectively. In fact, it is the altered rock body that is being exploited by an open-pit mine and gravimetric concentration.

The mineral survey consisted of geological mapping, geochemical sampling of stream sediments and soil, excavations and drilling.

INTRODUCTION

This work treats the ore body M_1, of the Meia-Pataca Gold Deposit in the context of the geology in which it is inserted, its lithostratigraphic positioning, its structural and metamorphic aspects and the data referring to its cubic content and reserves. In the final part, the prospection methods, the mining and the mineral treatment methods was carried out by Metais de Goiás S/A.

The chert of the lower zone varies from less than one metre to more than 20 metres in thickness. Locally, it shows various chert horizons, which are probably caused by repetitive folding of the same layer. Where the chert is thick or where there is the presence of multiple horizons of chert, the ore is frequently bifurcated, accompanying the upper and/or lower contact with one or more chert horizons.

In all the ore horizons of the "Mina" III the gold mineralization predominantly occurs as visible filaments of native gold. In the chert horizons, the gold filaments are up to 3mm in size and, frequently, appear jointed along the small graphite schist inclusions.

In the graphite schists adjacent to the chert horizons and in the upper and middle ore zones, the gold appears more commonly as small filaments at the boundaries between the arsenopyrite crystals and the surrounding crystals of pyrrhotite, chalcopyrite or pyrite. It also appears as thin filme with arsenopyrite filling fractures.

GENETIC AND MINERALIZATION CONTROL

The mineralization of the "Mina" III is characterized as being of the stratiform type and of evaporate singenetic origin. The gold in "Mina" III is associated with massive sulphides and diseminations of arsenopyrite and pyrrhotite, followed by chalcopyrite, pyrite, sphalerite, digenite and covellite, within three defined stratigraphic horizons, and known as, from the bottom to the top, the upper, middle and lower zones, with a subzone garnet.

The upper zone is characterized by gold mineralizations associated with sulphides and is disseminated in the sericite

tuffs within the carbonate sequence. It is an extremely irregular mineralization, probably caused by the strong facies changes, as demonstrated by the drilling evidence. The lithologies and the sedimentation indicate the existence of micro-basins, possibly of a reefal environment, and which formed a subaquatic environment suiting the formation of arsenopyrite, pyrrhotite, chalcopyrite, pyrite and other sulphides associated with gold, as well as a little silver.

The ore of the middle zone is similar to that of the upper zone, however it is situated in contact with the carbonate and graphitic sequences or within the graphites. The mineralization is also extremely irregular, and, in this case, possibly caused by the strong changes in the facies that are observed, as well as in the sericitic and chloritic tuffs, which are their principal host rocks. Just as in the upper zone, the gold and sulphide mineralization must have been formed by mineral-bearing solutions originating from volcanic events, which circulated through volcanic vents and sediments of the carbonate and graphitic sequences.

The lower zone is characterized by gold mineralization associated with disseminated sulphides in the graphitic band, and intimately associated with the concordant metamorphic chert levels or with the silicious horizon. The layer occurs within a biotite and graphite schist unit and its thickness can attain 20 metres. The thickness of this chert layer may be due to the compacting of folds. The mineralization sometimes occurs within the chert, and one can see a greater concentration near the upper and lower contacts of the immediately adjacent graphitic schists.

These mineralized zones have a WNW direction with a plunge of around 15 degrees, coincident with the predominant lineation of the "Mina" III. This orientation indicates the existence of folds whose force could have effected the ore horizons and the surrounding rocks, easing the mobility of the gold and sulphides in the crests of the isoclinal style folds.

RESERVES

The drilling work carried out up to now in the "Mina" III permits are to divide the geological ore evaluation into three stratigraphic horizons known as the upper, middle and lower zones. The total geological reserve is 5,288,268 tonnes of ore with an average gold content of 12.72 g/t, resulting in a gold content of 67,252 tonnes.

TECHNICAL STUDIES

The first technical studies of the ore in Crixás were carried out by drill sampling with the purpose of studying the best ore treatment processes and to determine the operational parameters for the future plant. his study arrangement led to the conclusion that the gold extraction could be carried out with the usual technology, with an average recovery of at least 91.9%.

The studies are continuing to optimize the process.

LOCATION

The M-ore body is situated in the division between th Geral stream to the South and the Meia-Pataca stream to th North, in the county of Crixás, in the Micro-region of Alt Tocantinn, Goiás State. It is approximately 300 (thre hundred) km from Goiás to the south of Goiás.(fig. 5.1).

HISTORY

Since the XVIII century gold has been the object of exploration and exploitation in the central portion of Goiás, a region which today includes the town of Goiás, Crixás, Pilar, Muquém, etc.

Domingos Rodrigues Prado was one of the armed adventurers who, in that century, penetrated and hid in the hinterlands of Goiânia, and, around 1734, discovered the "Crixás Workings". They were so rich that to secure their capture two years later, a reward of eight and a half Reis* and a slave were offered. (Palacin, 1979).

This potential gold production was writter about by Cunha Mattos on a visit to the region, a century later, when he referred to the size of the mineral remains: the excavations, the removal of earth, the diversion of waters, to give the impression that it was the work of a cyclops (Palacin, 1979).

The region had about 30,000 inhabitants, of which 10,000 worked at the mine. In Crixás, the number of slaves was about 2,500.

The estimated gold production for the region, based on the gold taxes gathered and the delivery contracts, from 1728 to 1750 (Palacin, 1979) were as follows:

Notwithstanding the "Eldorado" years of production, at the end of the XVIII century, Crixás would have found itself in the decadence leading to the spoiling of the City of Gold, and in face of the reality of a bad geographical location, constituting the most setentrional hamlet within the Valley of Araguaia, isolated, for fear of Indian attack, with malarial epidemics and poor and hopeless agricultural terrains.

Only at the start of the XX century, between 1918 and 1922, did a return to the activity of mining take place with the implementation and exploitation of the Chapéu do Sol Mine. However, this activity was short-lived and once again the extraction of gold at Crixás was interrupted.

Although not favourable for the mining activities in these different epochs, Crixás continued to be the target of an investigation campaign and of geological and prospecting studies on the part of national and international governmental institutions, state and national private companies, as well as international ones, not only for gold, but also for other metals amongst which the basic metals (Ni, Cu and Zn) stand out. In the seventies, METAGO and the mining subsidiaries of the international companies, Shell and the International Nickel Corporation (INCO), from their regional exploration activities, offhed for and held exploration targets on the lithological assemblage, in which the works of METAGO

Reis - Name of Brazilian currency unit in the XVIII century.

were developed and made it possible for Saboia (1979) to identify and define a volcanic-sedimentary belt of the Archaean Age known as the Crixás Greenstone Belt of Crixás - Crixás Band.

METAGO initiated the exploration work to obtain an evaluation for the areas in respect of basic metals. These works presented data and evidence that justified the re-orientation of the exploration priority to that of gold. From then on, the results in one of the selected targets led to the identification of a gold reserve in the altered rock zone of the M_1 ore body of Meia-Pataca, which is being developed today.

REGIONAL GEOLOGY

THE GREENSTONE BELT OF CRIXÁS

The Greenstone Belt of Crixás (fig. 5.2) is represented by a volcanic-sedimentary sequence interbedded in granite-gneissic terrains, and is unconformably overlain by metamorphics related to the Araxá Group, which occur in the mid-north region of Goiás. After being treated as an Archaean terrain of the Greenstone Belt type by Danni & Ribeiro (1978) and Ribeiro Filho et al. (1978), it was described and defined by Saboia (1979). In his work, he called the volcanic-sedimentary compartments of the Crixás Greenstone Belt: Crixás Band, Guarinos Band and the Pilar Band. The granite-gneissic terrains were called: Anta Block, Muquém Block, Hidrolina Block and the Guarinos Dome.

The Guarinos and Pilar de Goiás bands described and named by Danni & Ribeiro (1978) of the Pilar de Goiás Group are lithologically associated with ultramafic volcanic rocks (talc schists and amphybolites) and serpentized periodotic intrusions. Overlaying these rocks are ferrugenous quartzites that shows a vertical gradation through marble metachert and calcsilicates. Over these sediments occurs a set of rocks described as metavolcanic mafic feldspars associated with detrital quartzites and mica schists. At the top, clayey metapelites occur with fine interlayering of graphitic phyllites, ferromanganiferous quartzites and talc schist lenses. According to Danni & Ribeiro (1978), the entire sequence is covered by the mica schist unconformity of the Araxá Group. On the other hand, this sequence is controlled by the sialistic domes of Caiamar, of Muquém, of Cedrolina and Hidrolina.

The Crixás Band, correlated to the Pilar de Goiás Group (fig. 5.3), was divided into three units by Sabóia (1979), and which he described and defined from the bottom to the top as: a) the Córrego Alagadinho Formation, predominantly constituted of extrusive ultramafics, serpentinites and magnesium schists with metasediment interlayering, as well as intrusions in the form of sills of pyroxene and metagabro; b) the Rio Vermelho Formation, constituted of mafic pillow lava with interlayering of ultramafic diffusions and metasediments; c) the Ribeirão das Antas Formation, constituted of graphite schists, chlorite schists and chemical strata with interlayering of extrusive ultramafics, mafics and intermediate tuffs and volcanics. This band is limited by the domes of Caiamar to the east and to the south and by the Dome of Anta to the northwest, west and southwest. To the northwest, there is a metasedimentary sequence correlated to the Araxá Group.

Later, Castro & Magalhães (1983) proposed the subdivision of the Ribeirão das Antas Formation into three units known as the Manganiferous Graphitic Unit, the Carbonate Graphitic Unit and the Graywacke Unit, taking the mafic and ultramafic stratas of the Ribeirão das Antas Formation previously noted by Sabóia (1978) and correlating them with the Córrego Alagadinho Formation of the same author, as well as a pronounced faciological variation mainly in the Carbonate and Manganiferous Granitic Units (fig. 5.4).

The regional metamorphism that affected the sequence is low grade, characterized as greenschists facies and, very rarely, attaining amphibolite facies, such as observed in the region of Pilar de Goiás. Structurally, the bands of Guarinos and Pilar de Goiás are found interbedded in gneissic rocks, according to Danni & Ribeiro (1978), following elongated bands in a N20 - 40W direction. They show the form of troughs behaving as open isoclinal folds with sub-parallel axes to the borders of the bands and with a tectonic vergence to the East. The Crixás Band shows the configuration of a syncline with the west flank overturned with a vergence to the east, whose axis is roughly north-south. In the central portion can be observed the development of the important shear zone, which shows a well -defined relationship to the auriferous mineralizations (fig. 5.3).

GRANITIC: GNEISSIC DOMES

The domes that represent the sialic terrains in which the volcanic-sedimentary bands are embedded are constituted of gneisses of mainly tonalitic and granodioritic composition, with its mineralogy constituted mainly of quartz, oligoclase, biotite, muscovite, epidote and chlorite, generally metamorphosed to green-schist facies. Near the contacts with the sequence they are normally foliated and, at times, migmatitic, giving rise to some centimetric bands of mafics with leucocratic bands, also centimetrical. In these domes are found various gabroic intrusive bodies with ameboid or dyke forms. Pyroxenite dykes are also common.

ARAXÁ GROUP

To the north, setting in unconformity on the Crixás Band is a muscovite-chlorite-biotite-quartz-schist unit with interlayering of middle quartzite, which is crumbly, with fine-grained banded quartz and, sometimes, a graphitic matrix. Such a sequence is correlated to the Araxá Group according to Sabóia et al. (1979).

It shows a structural style defined by two phases of folding, the first being represented by isoclines with a horizontal axial plane and a plunge axis approximately N45W. A second phase created crenulation with a verticalized axial plane.

LOCAL GEOLOGY

Highly detailed work carried out in the central and NE portions of the Crixás Band made it possible to review the

geological knowledge of the lithological, stratigraphical and structural aspects of this area.

This review covered:

a – Identifying the shear zone with the lithological products of associated hydrothermal alteration;

b – Reformulating the litho-stratigraphic sequence of the Pilar de Goiás in the Crixás Band;

c – Structural evolution showing generalized deformations of a fragile-ductile character.

STRATIGRAPHY

Highly detailed geological mapping carried out in the NE portion of the Crixás Band made it possible for Castro & Magalhães (1983) to reform the work of Sabóia et al. (1979). The proposed sequence is based on evidence of a variation of the lithologic facies, in the context of the Corrego and Ribeirão das Antas Formations, as well as the dislocation of the Rio Vermelho Formation. The reformulated hypothesis referred to is discussed below.

Lithologically, the Córrego Alagadinho formation has its southern part characterized by a predominance of ultrabasic, pyroxenite and peridotic lavas, nowadays transformed into talc-tremolite-schists, tremolite-schists, tremolite-serpetine-schist, talc-chlorite-schist, talc-schist and serpentine, with subordinate interlayering of metasediments. In a northerly direction, these diffusions intertwine and become a predominantly detrital and chemical set, fundamentally represented by quartz-chlorite-schist with interlayering of ferriferous formation and of volcanics of an ultrabasic (talc-chlorite-schist, tremolite-chlorite-schist, talc-schist, etc.) and basic nature. Volcanic structures occur with spinifex, polihedral disjunction and breccia flow.

The Rio Vermelho Formation is constituted by mainly basic lavas with pillow lava structures, variolites and amygdals. The area of the occurrence is fundamentally situated to the south of Crixás, forming a "V" over the Córrego Aladinho Formation. In the portion north of the Band (the Meia-Pataca Region), it is shown by some rare and limited outcrops. In some drill-holes in this region amphybolitic-schists were described, correlated to this formation, as well as interlayering with ultrabasic horizons. The thickness here is not more than some tens of metres.

The identification and characterization of the diffusions and structures which occur in this region has, since Gebrim's work (1977), been the object of studies and works by various authors, of whom Sabóia & Teixeira (1980) and Teixeira et al. (1981) stand out.

The Ribeirão das Antas Formation, which forms the top of the Pilar de Goiás Group in Crixás, is mainly of a detrital and chemical nature, shown in its lower portion as a significant and representative variation of facies, defined by the interlocking of lithological units, known as the Carbonate Graphitic Unit and the Manganiferous Graphitic Unit. Overlying these units there is a lithological unit known as the Graywacke Unit.

The Manganiferous Graphitic Unit is mainly constituted by garnet-graphite-schist, garnet quartzite and graphitic and garnet quartzite. The alteration of garnet in this context leads to the formation of a manganese crust of variable size, chemical content and thickness, which characterize the outcropping terrains of the unit.

The Carbonate Graphitic Unit is characterised by the alteration of horizons, which the predomited composition leads to the distinction of definite intervals of graphite-schists, dolomites, graphitic metacherts and magnetite-garnet-chloritoid-chlorite-schists, as well as an irregular presence of a calciferous nature in all of them. This alteration characterizes an interlocking and a faciological variation, also found within the environments of this unit.

The Graywacke Unit, which forms the top of the Ribeirão das Antas Formation, is represented by lithic, feldspatic and quartzitic metagraywacke, slightly calcitic, and of a pronounced graphitic nature. In outcrops, it appears slightly altered, normally with yellow and lilac colours, rarely grey and greenish, with dark intervals. It is predominately fine-grained. In fresh samples obtained from drilling evidence, this lithology shows a greyish colour and is characterized by the regular alteration of light and dark layers of centimetric and decimetric size. The light layers are constituted by a fine psamitic fraction of a quartzo-feldspatic nature in which rock fragments (graphite-schist) of some centimetric size are found. In these layers, graded bedding can be observed. The dark layers represent the pelitic fraction, whose nature is essentially graphitic. Within the context of this formation, a limited occurrence of intermediate to acidic metatuffs is found.

The lithologic characterization, its compacting and the faciological variation were better defined from examination of the drilling evidence, given that the outcrops are not very frequent on the surface and are highly altered.

The gold potential of these units has been noted since the time of the early explorers. The old working, together with local geochemical anomalies of gold and arsenic, are restricted to the lithologic levels belonging to the Carbonate Graphitic Unit and Ribeirão das Antas Formation over which a shear zone developed. The discovery of the M_1 ore bodies in the Meia-Pataca target and in the CGI and CGIII bodies of the Córrego Geral target confirm the theory.

STRUCTURAL GEOLOGY

Most of the regional aspects of the tectonic evolution of the Crixás Band, the works of Sabóia (1979), Sabóia et al. (1979), Castro (1981), Kuyumjian (1981), Castro & Magalhães (1984) and Kuyumjian & Araújo Filho (1984), are well known. In the present work the data obtained during the research work on the Crixás Project and the Crixás - CMP (Companhia de Mineração e Participação) are described for the Mine of Meia-Pataca and environs.

The Greenstone Belt of Crixás in the domain of the Meia-Pataca Mine shows a complex structural evolution, as shown by the generalised deformations in the sequence of rocks exposed there.

In this domain, a milonitic foliation can be seen, which

passes over and masks all the previous structures, generating a stretched out lineation (X), which is well shown by a mineral lineation. The milonitic foliation shows a near EW direction, with a low inclination angle to the north. The recumbent character of this foliation and the form of the structure observed here are interpreted as being the consequences of thrust faults with a north-south movement, which fixes the correlated sequence to the Araxá Group in contact with the Archaean rocks.

The stretch lineation shows subhorizontal plunges of up to 15° to the west.

Events of a ductile-fragile behaviour are represented by folds with millimetric to metric crenulation with subvertical axial planes in a N-S direction. This phase, of low intensity, caused only undulations of the milonitic foliation.

The block diagrams of figure 5.5 show the interpretaion of the evolution and structural configuration of the Crixás Band.

MINERALIZATION

Until now the mineralization has proved to be of interest in the Crixás Band, and it has been the object of intense exploration for gold.

The lithographic units which show occurrences of this element, some of which were exhaustively mined, are the Córrego Alagadinho Formation (Chapéu do Sol Mine) and the Ribeirão das Antas Formation (Fazenda do Prefeito Mine).

For Kuyumjian (1981), the Chapéu do Sol Mine is stratigraphically positioned in what is known as the Upper Ultramafic Unit. The occurrence of talc and chloritised ultramafic rocks, with volcanic and metasedimentary interlayered, predominantly of metachert and iron formation, at times graphitic, can be traced in this mine. To account for the elevated gold chemical content in the depths of the mine in the talc-chlorite-schist and in the interbedded metachert of this unit, the author suggests that such enrichment possibly originated from the percolation "per ascenbun" of fluids. These would have "washed" metals from the volcanic-sedimentary pile already deposited, during their convecutive flow at depth. Thus the major gold concentrations are products of remobilization from these rich levels, relocated n the axial zones of the isoclinal folds on N30°E axis, where they are associated with bars of quartz, sulphides and oxides, such as arsenopyrite, pyrite, magnetite, hematite, limonite and ilmenite.The Fazenda do Prefeito Mine, Mina III (Kuyumjian, 1981), would be situated in the Lower Sedimentary Unit. It is admitted that the mineralization, also as the result of percolation by ascansion of fluids, would have the iron formations as surrounding rocks, such as graphite schists and chloritoid-quartz-magnetite-garnet-muscovite-chlorite-schi sts whose major concentrations would also be the product of remobilizations situated in isoclinal axial fold zones, having a N60°W axis, and associated with carbonate and/or quartz, pyrite, arsenopyrite, pyrrhotite and, rarely, chalcopyrite and gold.

For Thomson (1986), Mina III was composed of two mineralized horizons, one upper, the other lower. The upper zone consists of ferrugenous dolomitic schists and schists of chlorite and sericite, where the major gold concentrations are associated with arsenopyrite, pyrrhotite and chalcopyrite lenses. The lower zone is a breccia of graphitic-pelite, cemented together by quartz, and containing gold associated with arsenopyrite, pyrrhotite and chalcopyrite at the borders and in the interior of the graphitic-pelitic fragments. The gold mineralization is a product of a hydrothermal lateration which produced the present lithology from foliated amphibolite and graphitic-pelite. The mineral assemblages of the altered rocks indicate that the hydrothermal alteration consisted of carbonate, sericitization and silicification. The hydrothermal fluid containing CO_2 transported Fe, K, B_2 and As as well as gold.In the region of the Meia-Pataca and Geral streams, the gold occurrences (gold beds) were evaluated as well as other work, which led to the discovery of the ore bodies M_1, CG1 and CG-III.These occurrences are situated along a ductile shear zone contained in a lithologic unit known as the Carbonate Graphitic Unit, and belongs to the Ribeirão das Antas Formation. Lithostratigraphically speaking, the Meia-Pataca occurrences are correlated with the lower mineralized level of Mina III. From the structural point of view, they show the same trend, following the stretching lineation (X) with subhorizontal plunge (0 - 15°) to the west. The gold in these contexts appears free and/or associated with arsenopyrite, pyrrhotite and pyrite.

DEPOSIT DESCRIPTION

The M1 ore body is located approximately 9km to the SE of the town of Crixás, in the division between the streams of Geral to the south, and Meia-Pataca to the north.

The body geometry is approximately elipsoid, having a E-W extension of 480 metres, with an average width of 130 metres (N-S) and a thickness of 2 to 3 meters. It is stratigraphically positioned in the upper portion of the Carbonate Graphitic Unit of the Ribeirão das Antas Formation.

The mineralization occurs in the lithologic context described as calciferous graphite schist, which makes contact with the garnet-chloritoid-chlorite-schist horizon. The mineralized horizon shows an orientation following the foliation and the mylonitic lineation. The foliation has an approximately E-W direction with an inclination of a low angle (10 - 15°) to the north. The lineation shows a plunge of up to 15° to the west.

The thickness of this lithological bed is as variable in the south-north direction as it is in the lateral sense. Such verification of these bed has led to the thought that as well as a variation of lithological facies, they are associated with the configuration of the structural component of the body.

In these beds the intervals and zones of intense feldspatization and carbonatization reflecting the effects of the hydrothermal process, can also be observed. The mineralized horizons contain pyrite, arsenopyrite and pyrrhotite, which occur preferentially along the mylonitic foliation. The gold occurs in association with these sulphides and free in smaller proportions.

The chemical content of the gold also shows a variation that is as much related to the lithologic variation (the presence of carbonates) as to the greater or lesser quantities

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The chemical content of the gold also shows a variation that is as much related to the lithologic variation (the presence of carbonates) as to the greater or lesser quantities

of sulphides present, principally that of pyrrhotite. It is this variation that defines the potential of the ore body, and which must be the result of exhaustive processes (singenetic), and of associated hydrothermal and structural processes.

The weaker alteration stage of the rocks, and of the mineral components which constitute the M1 ore body, led to the identification of two modules which were called the Altered Rock Module and the Fresh Rock Module. The characteristics of the ore in the Fresh Rock Module is the presence of pyrrhotite and arsenopyrite. In this context, the gold occurs free as much as in association with sulphides, which it was proved in the treatment tests.

The ore of the Altered Rock Module was the object of gravimetric concentration and leaching. When viewed through a binocular microscope, it shows the following characteristics: - Fresh and semi-altered schist fragments (mica-schists and graphite-schists) dispersed throughout all the granulometric fractions studied (from 1/2" to 150 mesh, Tyler); ilmenite; quartz and mica grains. It was verified that sulphides exist only as traces, i.e. in extremely small quantities, and only one sulphide, pyrrhotite, was obtained in significant concentrations. The gold appears much more as free grains than aggregated with micas, quartz and/or ilmenite, in a granulometry, on average, between 100 and 400 mesh.

The available reserves of the M1 ore body were calculated by the conventional cross-section method in which the altered rock and fresh rock modules were distinguished (figs. 5.6 and 5.7).

Tables 1 and 2 synthetize the gold reserves in the altered and fresh rock modules, respectively, in accordance with the Final Exploration Report presented to the DNPM.

PROSPECTING AND EXPLORATION SURVEY

The gold prospecting and exploration survey used for the M1 ore body block of Meia-Pataca and other targets currently being evaluated in the Greenstone Belt of Crixás - Crixás Band consisted of geological mapping, geochemical surveys, heavy mineral prospecting (counting the gold colours), evaluation of old workings, excavations and drilling.

The characteristics of each target were the subject of these developement activities to define and delineate the Archaean volcanic-sedimentary sequence. Whether they were initially made by detailed geological survey, or by prospecting for heavy minerals or by prospecting for heavy minerals or by evaluation of old workings, they were always in an integrated form.

MAPPING AND GEOLOGICAL ACCOMPANIMENT

The geological mapping carried out was assisted by the additional support of the interpretation and evaluation of data obtained during exploration.

Geological mapping was carried out on the scales of 1:250,000, 1:50,000; 1:20,000; 1:15,000; 1:100 and for pits "garimp" workings and trenches, 1:50.

HEAVY MINERAL EXPLORATION - GEOCHEMISTRY

Heavy mineral prospecting through the counting of gold colours in concentrated pan was the most important exploration method used for gold in the Crixás Band, and was extensively used in various stages and scales.

The geochemical survey for As was used, and together with the heavy mineral exploration represented one more method for the selection and evaluation of targets.

Stages of sweeping through stream sediments with the support of geologists were made, and later, for selected targets, soil survey were carried out.

Each one of these stages was preceded by orientation studies in pilot areas in order to determine the best method of sampling, analysis, etc.

DRAINAGE SEDIMENT (As/Au), SILT SAMPLING PROGRAMME

The first survey was carried out for As and Au in stream sediments in a small area of 10km^2. Due to the small number of samples, this survey was not subjected to statistical treatment. The results obtained in the gold colours cause the Crixás Band to stand out.

In a later phase, a linear sampling at 500-metre intervals was carried out in a selected area of 0.5km^2.

The results obtained here statistically define two populations for As, with a threshold of 41ppm. The gold colour count, on the other hand, shows values that grouped them into three populations, having as their threshold of 15 colour values.

In the case of the gold colour count, after the field check, some of the anomalies were defined as dislocated anomalies (anomalies in the granite-gneissic terrains and of the Araxá Group). Some other high values were also checked and it was ascertained that they should be treated as a concentration of near background values.

The joint analysis of the gold colour count and the As showed a coincidence, amongst others, of an anomalous area of both the elements, in the context of the Ribeirão das Antas Formation, but more specifically in its eastern portion. This area, known as the Meia-Pataca Target, where the old workings occur in rock, was the subject of complementary exploration works, which was responsible for the definition of the M1 ore body in Meia-Pataca.

Some other sampling was carried out at some selected targets with the objective of better restricting the area to be covered by a regular pattern of soil sampling. The former sampling was carried out in the drainage beds at 100-metre intervals, and the samples were collected in a linear fashion.

The results obtained did not fullfil the objective.

SOIL (As/Au)

In the anomalous targets, selected as a result of the surveys in stream sediments, soil sampling guides were establihed, using gold colour counting by panning and chemical analysis for As. The pattern was 160 x 80 x 20 metres. The

sampling method established for this work, with the objective of analyzing for As, consisted of the collection of 300 grams of material from a depth of 15 to 20cm. Such samples were analysed by X-ray (fig. 5.7).

For the gold colour count, the best level of soil and the best volume of the sample were established after carrying out an orientation study. From this it was established that a volume of 5 litres from a depth of 10 to 20cm would be collected at each point.

Soil sampling at 100 metres was carried out along the margin of some selected drainages for tests before employing a survey on a regular grid. The results obtained enabled the definition of an area with high values, in which it would be better to carry out the regular grid soil sampling. It was concluded that this same result could be reached at less cost with expeditious profiles of sampling perpendicular to the strikes.

The results obtained from the 160 x 80-metre pattern carried out in the eastern region of the Crixás Band from the gold colour count and from the As in the soil, defined statiscally, a threshold of 37 colours, for the gold colour count and 90ppm for arsenic. The anomalous trends of the gold colours are quite continuous and coincident with a band of workings in rock, although the arsenic showed dicontinuity. In the comparison of the two surveys with the line of old workings, it was concluded that the greatest anomalies corresponded to them, where the superimposition of the two elements occurred. It can be seen that some As anomalies neither coincide with the workings nor with the gold colour anomalies. The anomaly of As/Au initially selected for detailing at 80 x 20 metres was the subtarget 1 of the Meia-Pataca Target. Here, although the gold colour count obeyed the pattern for As was 80 x 40 meters (fig. 5.7). The results led to the conclusion that excavations and later, drilling in this subtarget would be necessary. The results subsequently, as mentioned before, ended up defining the definition of the M1 ore body of Meia-Pataca.

EXCAVATIONS

These activities compared the evaluation of old workings, and the opening, description and sampling of trenches and of pits, all of which were located at the selected targets.

A programme of pits was carried out to estimate the volume of the ore bodies, in addition to the evaluation of the anomalous values in the geochemical and colour count surveys and to investigate the extent of the mineralized horizons.

In these excavations the sampling system adopted was to collect the sample in a channel, each sample being collected at an interval of 1 metre and having a weight of between 2 and 3kg. The pattern initially used for these excavations was 80 x 20 metres.

DRILLING

The drilling activities by METAGO in gold exploration at Crixás have been carried out, until now, at those targets which were identified and defined as being mineralized on the surface (Fig. 5). Its objective was to define the limits and to supply surface data on the mineralization. This data was used in determining the extent of the M1 body.

To achieve the proposed objective the investigation pattern was implemented on the basis of data supplied by previous exploration activities. This pattern was modified as the programme procedure and as new parameters became available. The holes were in a NW-SW direction.

The sampling consisted of half of the drill core at intervals of one metre. This sampling, in the case of the M1 body, followed lithological limits. The overall zone sampled was limited by the contacts with the basic/ultrabasic rocks (Córrego Alagadinho Formation and Rio Vermelho Formation) and with the Metagraywacke Unit (Ribeirão das Antas Formation).

MINING AND TREATMENT & MINING METHOD

The exploitation of the M1 ore body, which was initially defined as having an average minable gold grade of 2.04 g/t, and a 0.5 g/t as a cut-off was carried out by an open-pit method, having 7-metre high benches on the flank of the hill. In the ore zone the bench height varied with the thickness of the body.

At the bottom of the ore body, the open-pit has benches whose width is 4.5 metres and whose height is 8.5 metres and whose general slope angle is 55°.

For the treatment of the altered rock, the removal of the overburden and ore is carried out by Caterpillar bulldozer and without the use of explosives. The removal of the overburden is topographically controlled by the use of geological profile information, through the observation of lithologies and the taking of samples at the workface.

The spacial configuration of the ore body has led to a mining dilution in the order of 60%, and as a result of this, the grade of the ore supplied to the plant is reduced, but permits a high recovery in the workings.

The loading of the overburden and the ore is made by rubber-tyred loader (Michegan 55) and is transported by dumper trucks (1313).

The overburden is deposited in an waste daw with an average distance of 200 meters away.

The overburden is deposited at waste heal 200 metres away.

TREATMENT

The concentration plant is about 600 metres away from the workface and the concentration method is gravimetric. The ore is unloaded from the trucks and stocked on a pad near the supply piles. From this deposit the ore is removed by a rubber-tyred loader (michegan 45C) and is put on concrete pads where it is disaggregated with a hydraulic monitor and fed to an open-circuit crusher (42 x 30 face) and rod mill (Furlan-Rosensweig 1.4 x 3.3 metres). The mill discharges the pulp directly in the "Ourocone" model M-30, where the principal concentration takes place. The overflow from the "Ourocone" is supplied to a 12" hydrocyclone classifier. The

coarse fraction (greater than 100 microm) returns to the mill and the fine fraction passes through rifled troughs and cloth filters before being deposited in the reject pond. The gravimetric concentrates are subjected to cyanide treatment in a tank and the gold contained in the solution is recuperated in the form of bullion after electrolysis and cathodic fusion. The complete gravimetric concentration plant flow diagram is shown in figures 8.8 and 8.9.

The bullion is sent to Goiânia to be refined at the Mineral Technology Center - CTM instalations of METAGO, to separate the silver and to obtain gold of 99.9% purity. The gold is moulded into ingots of 1,000 grams (One Thousand Grammes).

The yields reached in the various concentration stages are summarised as follows:

- Recovery by gravimetric concentration = 70%

- Recovery by cyanide and refining = 97%

- Total recovery = 66.5%

Because of the environmental problems created by the use of mercury in the recovery of the gold from the concentrates, METAGO has substituted the amalgamation by intense cyanation followed by electrolysis and cathodic fusion. By doing so, the worker's health and nature are preserved.

ACKNOWLEDGEMENTS

To Metais de Goiás S/A - METAGO, for the unrestricted freedom of access to data; to colleagues of the Geochemical, Geophysical, Petrographical, Drilling and Mine Treatment Co-ordination Sections, as well as geologist colleagues and technicians in mining, who participated and contributed, at different stages and times, in the exploration at Crixás, to obtain this data.

To colleagues in the Support and Technical Drawing Section for typing, drawing, revision and presentation.

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Table 5.1 – Syntehsis of the Reserves of the Altered Rock Module of the M1 Body Meia Pataca Target.

Reserve Category Sections	Measurements	Chemical Content in ppm	Indicated	Chemical Content in ppm	Measured and Indicated	Chemical Content in ppm
72W	40980	0,85			40980	0,85
80W	13516	0,55			13516	0,55
88W	2458	2,98	22426	2,98	24884	2,98
96W	53683	4,55			53683	4,55
104W	27418	2,62			27418	2,62
112W	19245	2,25			19245	2,25
120W	7296	1,44			7296	1,44
Total	164596	2,55	22426	2,98	187022	2,60

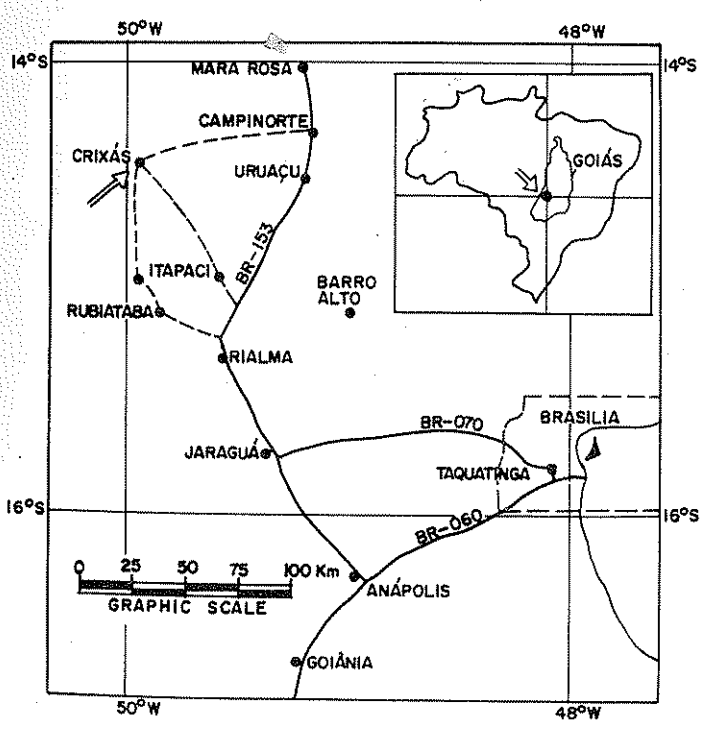


Fig 5.1 - LOCATION MAP

Table 5.2 – Syntehsis of the Reserves of the Fresh Rock Module of the M1 Body Meia Pataca Target.

Reserve Category Sections	Measurements	Chemical Content in ppm
72W	102291	0,86
80W	80770	5,67
88W	40680	1,61
96W	73954	1,19
104W	817920,83	
112W	55891	3,01
120W	31149	2,94
120W	31149	2,94
–	–	–
Total	466527	2,20

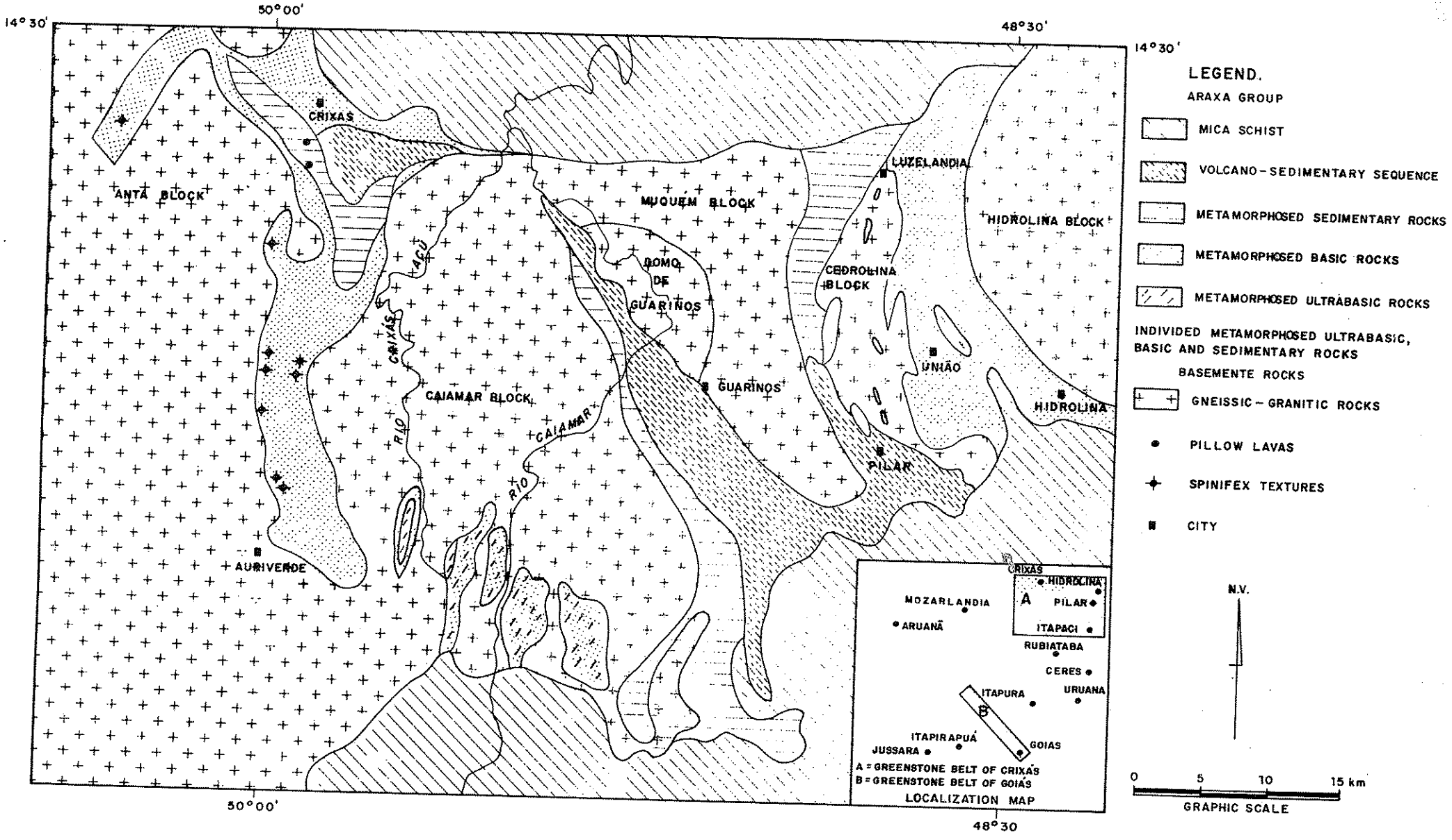


Fig 5.2 GEOLOGICAL SKETCH OF THE CRIXAS GREENSTONE BELT MODIFIED FROM DANNI & RIBEIRO (1978) ANEL RIBEIRO FILHO ET AL (1978).

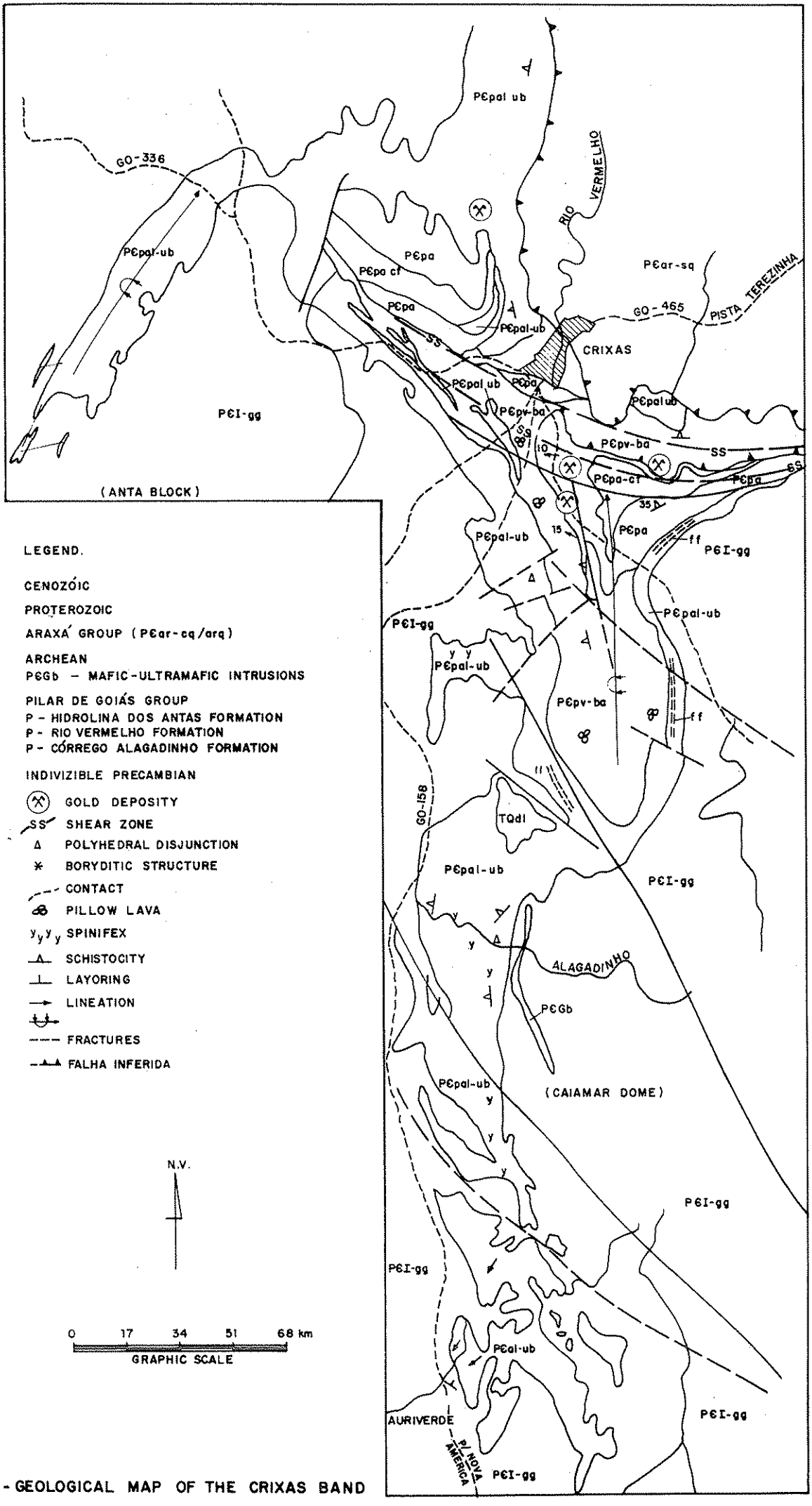


Fig .5.3 - GEOLOGICAL MAP OF THE CRIXAS BAND

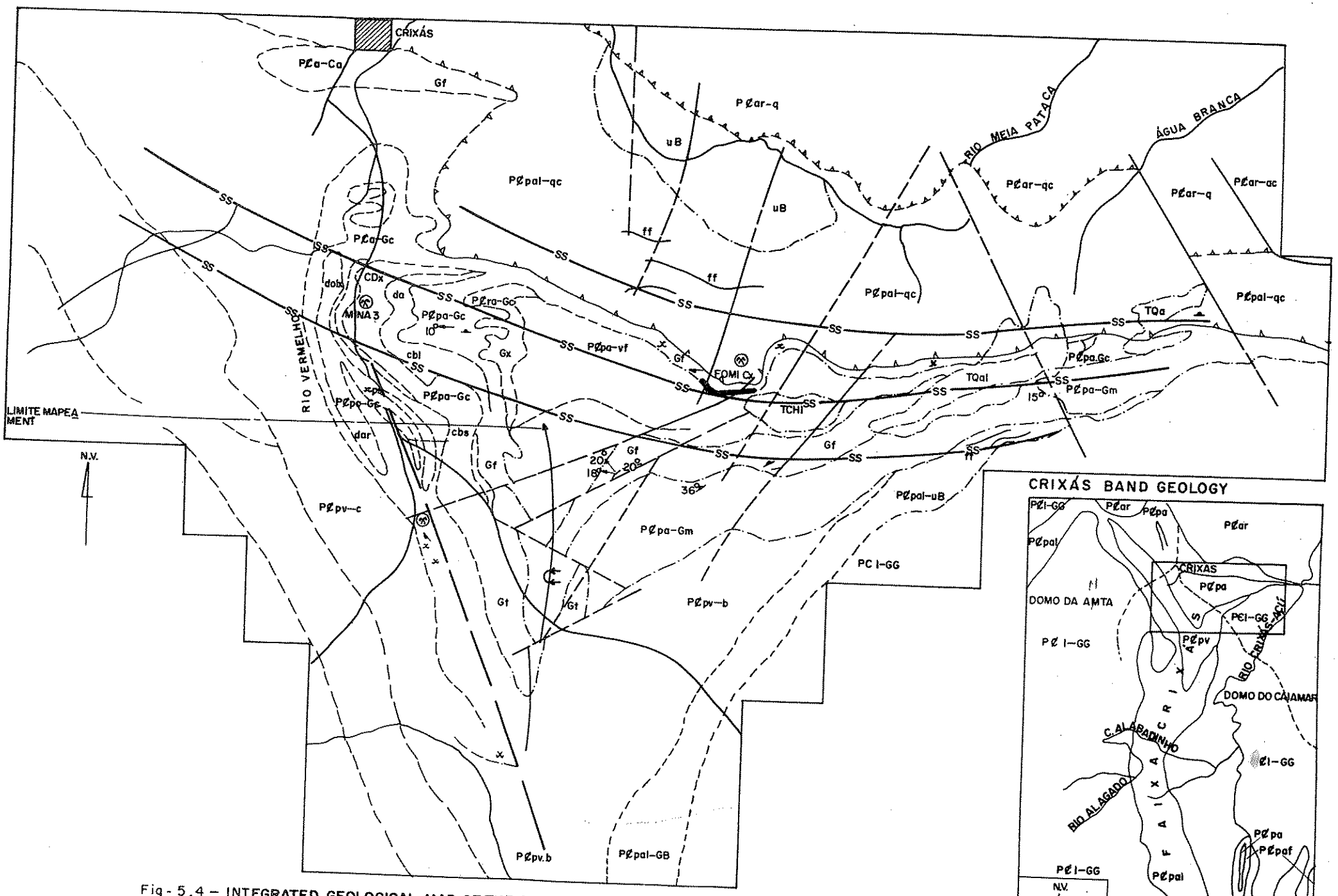
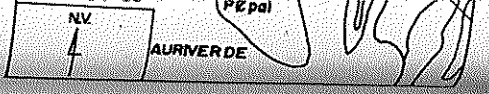


Fig - 5.4 – INTEGRATED GEOLOGICAL MAP OF THE CENTRAL POSION OF THE CRIXÁS BAND

Fig - 5.4 – INTEGRATED GEOLOGICAL MAP OF THE CENTRAL POSION OF THE CRIXÁS BAND



STRATIGRAPHIC COLUMN FROM FIG. 5.4

CENO-ZOIC		TQdl	dl – Detritic – Lateritic Cover
PROTEROZOIC	A R A X A GROUP	PEar – aq -PEar-q PEar-q	cq – Chlorite – Quartz-Schist q – Medium-Grained Crumly Quartzite and fine-Quartzite qc – Quartz-Chlorite-Schist
A R C H E A N	PILAR DE GOIÁS GROUP – RIBEIRÃO DAS ANTAS FORMATION	DISCORDANCIA PEpa-W Gx PEpa-Gc dol Gf cbx	W – Graywacke Unit (Psamitic) metagraywacke ilitic, feldspatic, quartzose. Gc – Carbonated Graphitic Unit (Chemical Pelite) Graphitic Schist (SF-X) garnet-Chloritoid-Chlorite Schist (cx) Graphitic Quartzite (metachert), Sericite Schists; Magnetite-Chloritoid Schist; Dolomite-Chlorite-Serecite Schist (Dol/cbx/dolx);with Mineralizations of gold, Pyrrhotite, Arsenopyrite, Pyrite.
	PILAR DE GOIÁS GROUP – RIO VERMELHO FORMATION	PEpa-Gm dolx PEpal-uB	G – Manganesiferous Graphitic Unit (Pelite Chemical); Garnet-Quartz--Schist, garnatiferous quartzite. b – Mafic to intermediary lava Flows interlayering with ultrabasics rocks and sediments
	PILAR DE GOIÁS GROUP – CÓRREGO ALAGADINHO FORMATION	PEpal-qc ff uBs PEpal-uB ff	uB – Peridotitic and Pyroxenitic lavas Mg Schists (talc schist; chlorite-tremolite-talc-schist, etc) and serpentites. qc – Quartz-Chlorite-Schist interlayering with ultrabasic and basic lavas. uBs – Predominant zone of ultrabasic lavas ff – oxide and Sulphide iron formation facies with gold and arsenopyrite mineralization.
	PRECAMBRIAN (NOT-DIVIDED)	PEX-GG	GRANODIORITES E TONALITES;

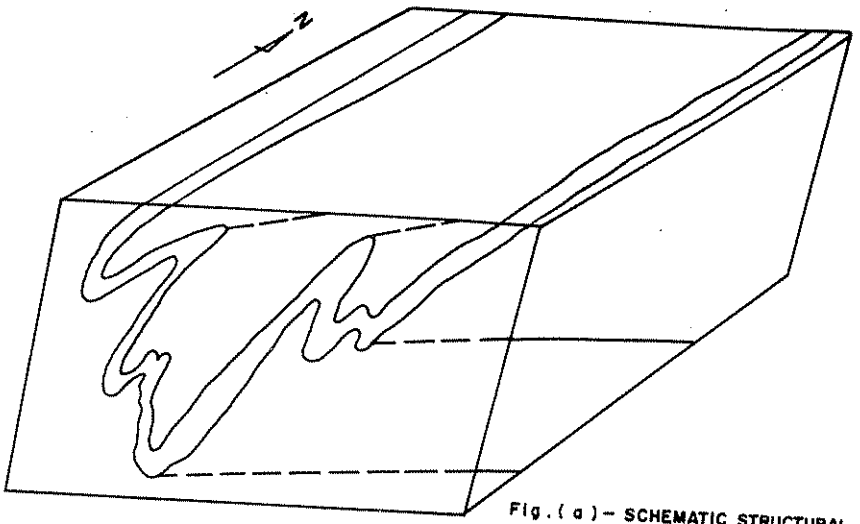


Fig. (a) – SCHEMATIC STRUCTURAL CONFIGURATION OF THE F_1 AND F_2 FOLDS (ISOCLINAL)

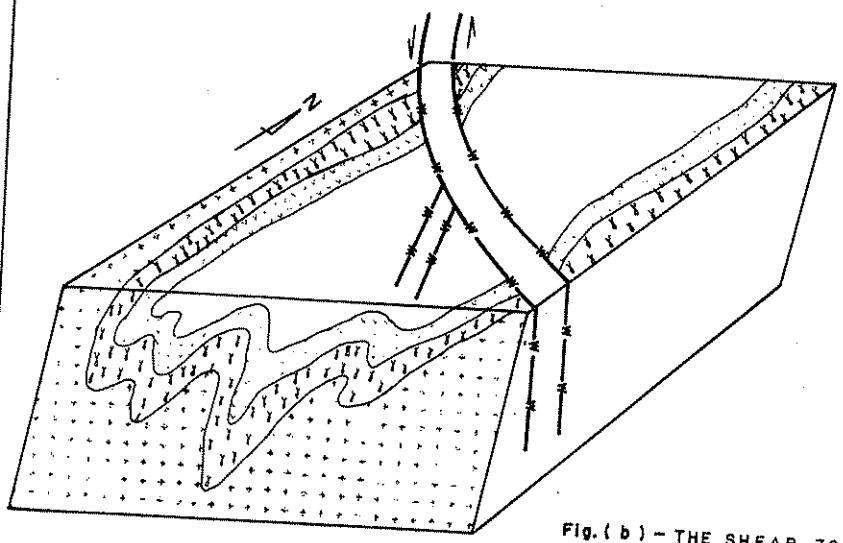


Fig. (b) – THE SHEAR ZONES IN THE COMPLEX OF THE CRIXÁS BAND.

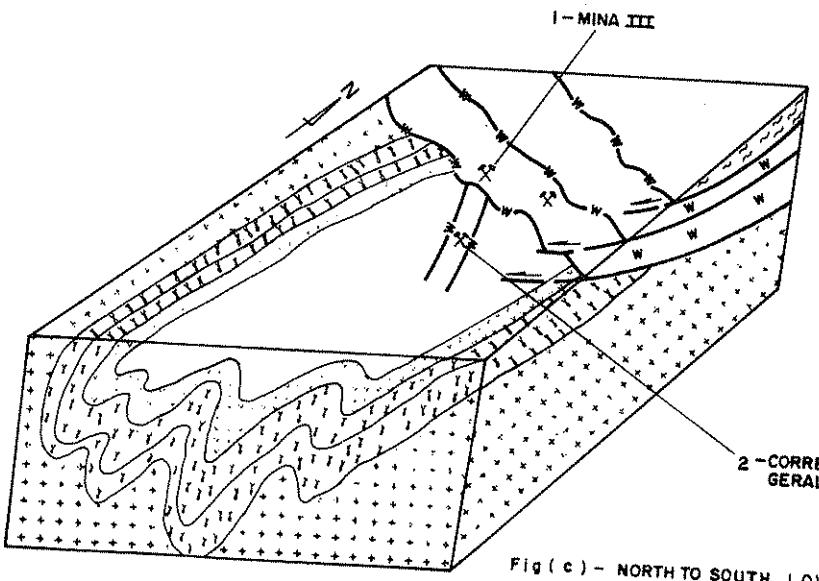
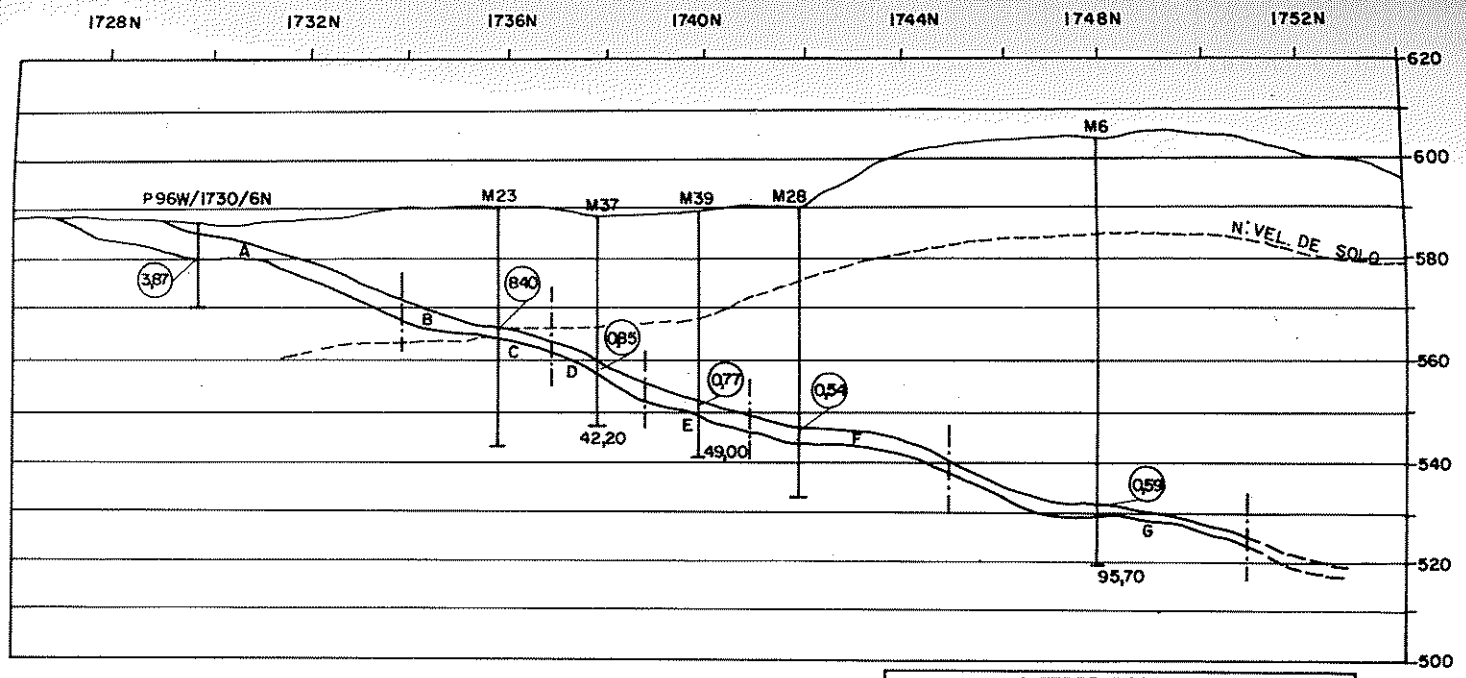


Fig (c) – NORTH TO SOUTH LOW EUTENSITY PHASE

Fig. 5.5 – SIMPLIED SCHEMATIC OF THE STRUCTURAL E VOLUTION OF THE CRIXÁS BANCH



DRILL HOLE

PIT

MINERALIZED ZONE

AREA OF INFLUENCE

A.B.C.D MINERALIZED BODIES

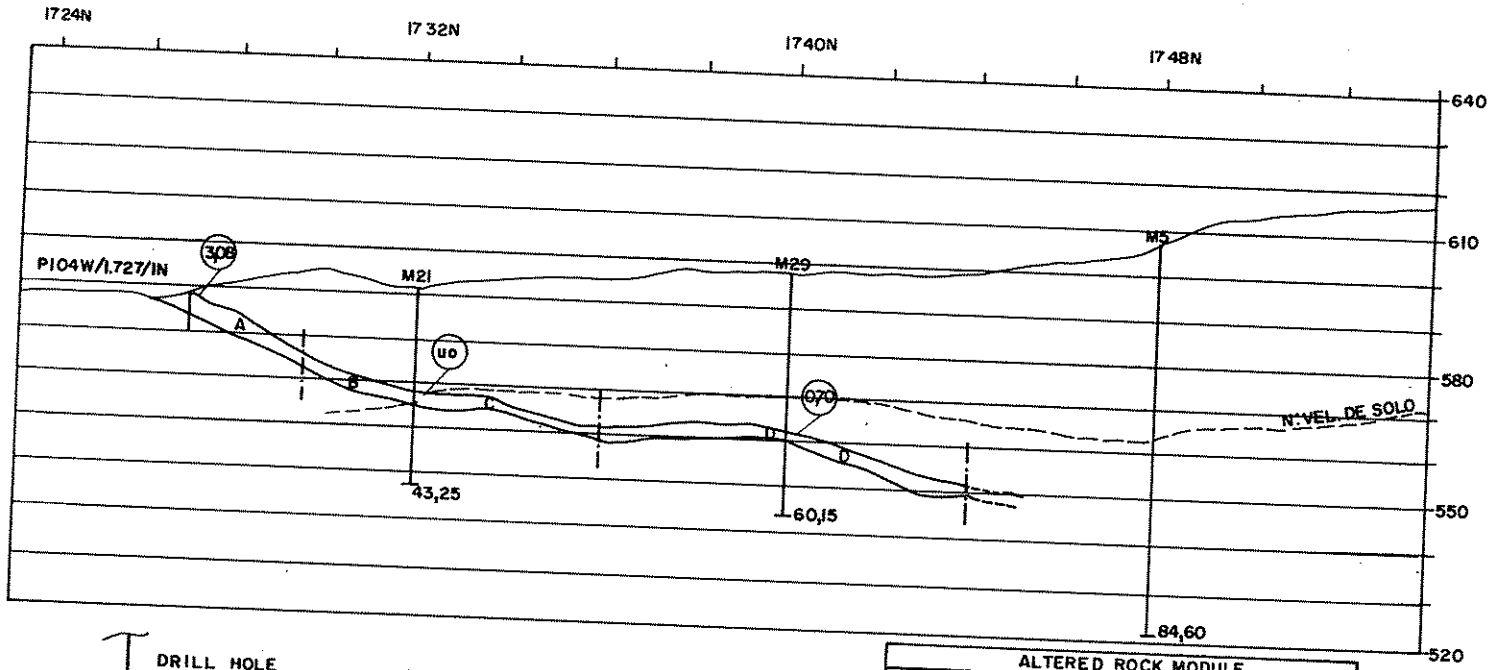
(Au) CHEMICAL CONTEND IN ppm

N.V.

ALTERED ROCK MODULE					
ORE RESERVE	BODY	THICLC-NESS	V(m^3)	T(ton)	CHERU-CAL PER CENT (Au-ppm)
AVEAGE	A	5,0	20.400	39.168	3,87
	B	3,0	7.560	14.515	6,40
	TOTAL			53.683	4,05

ALTERED ROCK MODULE					
ORE RESERVE	BODY	THICLC-NESS	V(m^3)	T(ton)	CHERU-CAL PER CENT (Au-ppm)
AVEAGE	C	3,0	2.520	7.157	6,40
	D	1,0	1.680	4.771	0,85
	E	3,0	5.040	14.314	0,77
	F	2,0	6.720	19.095	0,54
	G	2,0	10.080	28.627	0,59
	TOTAL			73.954	1,19

Fig. 5.6. EVALUTION OF THE GOLD RESERVES OF THE MI BODY - SECTION 104 W/PROFILE-10



ALTERED ROCK MODULE					
ORE RESERVE	BODY	THICKNESS	V(m³)	T(ton)	CHEMICAL PER CENT (Au - ppm)
AVEAGE	A	3,0	7.900	14.976	3,00
	B	3,0	6.480	12.442	1,10
	TOTAL			27.418	2,62

ALTERED ROCK MODULE					
ORE RESERVE	BODY	THICK - NESS	V(m³)	T(ton)	CHEMICAL PER CENT (Au - ppm)
AVEAGE	C	3,0	9,600	27,284	1,10
	D	3,0	19,200	54,528	0,70
	TOTAL			81,792	0,83

THICKNESS

Fig. 5.7 - EVALUATION OF THE GOLD RESERVES OF THE MI BODY - SECTION 104W/PROFILE - 10

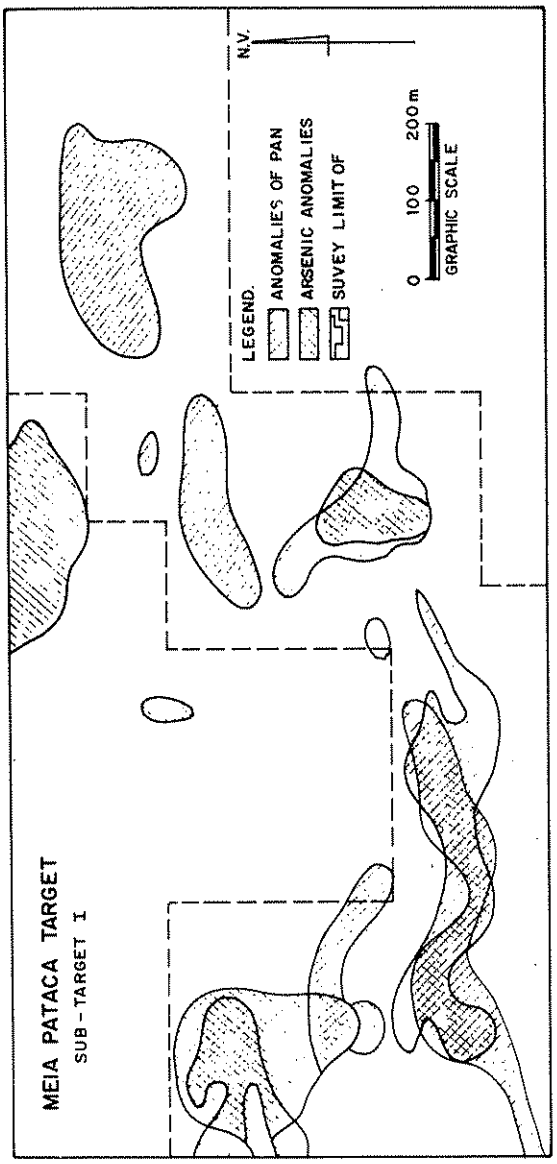


Fig. 5.8 SOIL GEOCHEMISTRY— GOLD COLOURS AND AS ANOMALIES

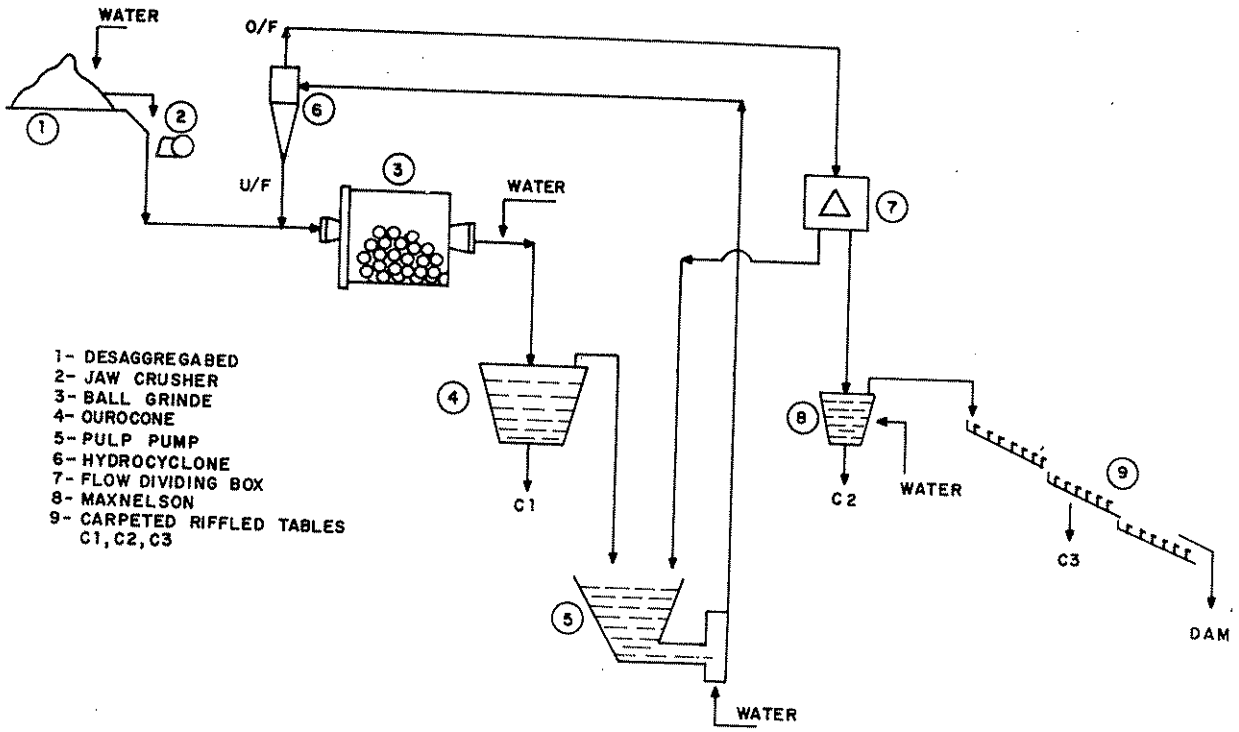


FIG.5.9– FLOW DIAGRAM
GRAVIMETRY

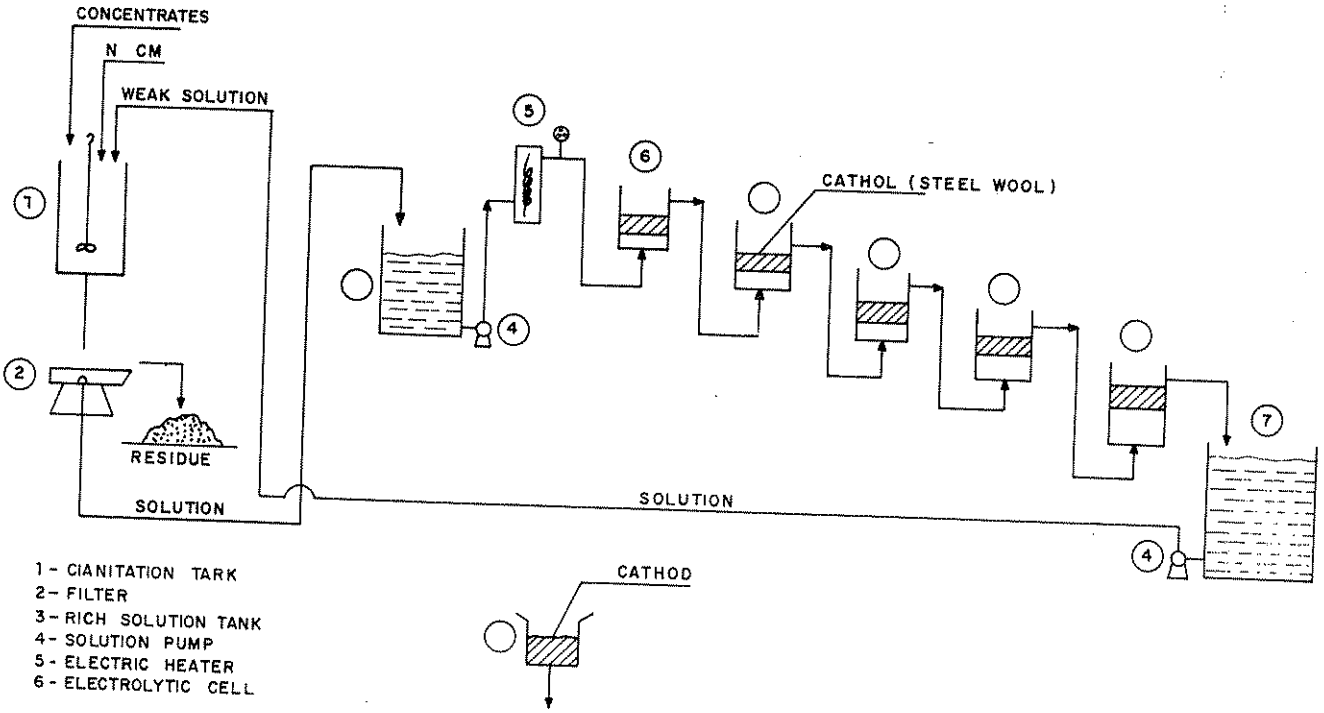


FIG. 5.10– CIANETATION AND FUSION FLOW DIAGRAM

5.b THE GOLD DEPOSIT OF "MINA" III, CRIXÁS, - GO

Walter Norbumasa Yamaoka
Edijarbas Martins Araujo
MINERASUL

The gold deposit in Crixás, known as "Mina" III, occurs within a metasedimentary volcanic sequence belonging to the Ribeirão das Antas Formation, a sub-division of the Pilar de Goiás Group of Archaean-Early Proterozoic age.

The stratiform type of gold mineralization occurs in layers consisting essentially of intercalated chemical and pelitic sediments. Minor volcanic contributions such as cherts, basaltic lava flows and felsic tuffs are interspersed in the sedimentary sequences.

These rocks underwent low to medium grade greenschist facies metamorphism, resulting in well-foliated schists essentially composed of chlorite, biotite, graphite, carbonates, quartz, sericite, feldspars and lesser amounts of chloritoids and garnets. It has been suggested that the sedimentary environment must be reefal (Bulmer, 1982), following the tentative identification of stromatolites in calcareous rocks.

Gold in the "Mina" III deposit is associated with massive and disseminated arsenopyrite and pyrrhotite and is concentrated in three separate zones, referred as to the upper, intermediate and lower zones. The latter also includes a garnet sub-zone. The three approximately superimposed zones are aligned in a WNW direction with a plunge of 15°. Approximately 60 metres of barren formation separates the upper from the intermediate zone and similarly the intermediate from the lower zone.

The strike of the main axis of the mineralized bodies has the same direction of the lineation in "Mina" III. Narrow isoclinal folds with a WNW plunge direction, parallel to the major axis of the deposit, have been observed. This folding possibly affected the mineralized horizons, resulting in the remobilization of gold and sulphides along the lines of the isoclinal folds (Kuymijian, 1985).

A drilling programme carried out at "Mina" III between 1980 and 1985, estimated a geological reserve of 5.2 million tons of ore with an average gold grade of 12.7g/ton.

INTRODUCTION

All the data about the gold mineralization in the "Mina" III (Crixás) is related in this work. The deposit was developed by the company, Mineração Serra Grande Ltda., and worked by the association of Inco and Kennecott. The area studied is located in the geomorphological context of the Brazilian Central-West, characterized by the domain of the undulating relief. Belonging to the hydrographic basin of the Rio Araguaia, it is drained by the Rio Vermelho, the Rio das Antas and others.

The prospecting and reseach works essentially consisted of regional and detailed geochemistry, geological mapping, geophysical surveys, aerial photogrametry, drilling and ore dressing studies on a laboratory scale.

This work is based on the data obtained from the reseach in Crixás, plus the information of many geologists who work or have worked in the area.

HISTORY

Since the middle of the seventies, the Minerasul Group has been developing geological exploration in the State of Goiás, searching for new gold and base metals targets.

The "Mina" III gold deposit is situated to the south of the town of Crixás.

The geological photo-interpretation and bibliographic research about the geology were initiated in 1973, selecting the areas with geological potential for base metals mineralization.

A large campaign was initiated with the intention of sampling stream sediments, at a reconnaissance level, over the area, with a sampling density of 10 to 20 km per sample.

The presence of volcanic and metamorphic rocks was observed at this field stage, later called the volcanic-sedimen-

ESCOLA DE MINAS - DEGEO / DEMIN
BIBLIOTECA

tary Sequence of the Pilar de Goiás Group by Danni, in 1979. It was because of this geological sequence, potentially favourable for base metals and precious metals, and the occurrence of alluvial and eluvial auriferous deposits along Rio Vermelho, that the research for the base metal changed its objectives, changing to looking for gold anomalies.

At the end of 1974, some alluvial gravels from Rio Vermelho and its tributaries were tested, and whose results led to targets in the "Mina" I, II, III, Extended-III and IV. The initial work on these targets involved geological mapping, detailing the old works, channel sampling, and the altered outcrops sampling in the old excavation. In this phase, the presence of arsenopyrite mineralization and gold in many samples permitted selection of many targets for exploration drilling.

Gold mineralization associated with arsenopyrite and pyrrhotite was encountered in the drill holes made at the selected targets, but in view of the difficulty of determining the continuity of the mineralization, allied to the complexity of the structure, the drilling programme was interrupted.

A systematic drilling programme started at the begining of 1980, to delineate the target known as "Minas" III. A total of 248 holes with a depth varying from 20 metres to more than 600 metres, corresponding to 41,832.89 total drilled metres were made. From 1983, the exploration work was intensified, and the main results were the delineation of "Mina" III and its evaluation.

At the end of this phase, a new evaluation of the data was initiated, which consisted of a new ore evaluation, mineral treatment, geotechnical survey and preliminary studies of the economic feasibility.

At present, an access ramp is being opened and will permit access to the mineralized zones, to confirm in detail the information obtained in the geological exploration phase by drilling. It will be also possible to redefine the mining methods and to re-evaluate the mineral dressing.

LOCATION AND ACCESS

The area, located near the town of Crixás, in the State of Goiás, and whose co-ordinates are 14°32'03" latitude south and 50°56'18" longitude west, covers a surface area of 80km^2 (fig. 5.1).

The access from the city of Goiânia is by paved roads, GO-080, BR-153 and GO-336, just to Itapaci, passing through the towns of Nerópolis, Petrolina de Goiás, São Francisco de Goiás, Jaraguá, Ceres and Jardim Paulista; and then taking the dirt road, GO-336, to the town of Crixás. The total distance from Goiânia to Crixás is 308 km.

SYNTHESIS OF THE REGIONAL GEOLOGY

The region of Crixás is characterized by the presence of elongated volcanic-sedimentary features with a predominantly NW-SE direction, folded in open isoclines with a plunge to the SW. These features constitute large barren belts known as the Guarinos and Pilar de Goiás, separated by gneissic-granitic bodies of the Basal Goiano Complex, locally known as the blocks of Caiamar, Muquem and Hidrolina (Danni & Ribeiro, 1978) and Bloco da Anta (Sabóia, 1979).

The volcanic-sedimentary sequence of the Crixás band is in concordant contact in the west with the Caiamar Block and in the west-northwest with the Anta Block (Kuyumijian 1981) and is in unconformable contact in the northeast with the Araxá Group. This sequence is characterized by the presence of intrusive and extrusive ultramafic rocks, panelled extrusive mafics and chemical and pelitic sediments, which Sabóia (1979) divided into three units, respectively called the Córrego Alagadinho Formation, the Rio Vermelho Formation and the Ribeiro das Antas Formation. These formations, defined by Sabóia (1979), fit in with the Pilar de Goiás Group and defined in Pilar de Goiás and Guarinos by Danni & Ribeiro (1978) (fig. 5.11).

The three volcanic-sedimentary features are manifested in the form of troughs, behaving as open isoclinal folds (Danni & Ribeiro, 1978, apud Kuyumijian, 1981).

The Araxá group is basically composed of mica-schists, lying in unconformity contact with the volcanic-sedimentary sequence. A tectonic contact is suggested by the changes in direction of the observed sequences, as much in Crixás (Sabóia, 1979) as in Pilar de Goiás and Guarinos (Danni, 1979), and in Crixás by the greater deformation nearer the contact where drag folds are seen and transposition indicates possible metasediments riding over the volcanic-sediments. Therefore, there is the possibility highlighted by Kuyumijian (1979) of gradual contact of the upper ultramafic sequence with the acid volcanic and ferrugenous quartzite sequence (Araxá). This upper ultramafic sequence is interpreted as being an ultramafic unit at the base of the sequence, positioned "in loco" by the folding in a tight isocline with an inverted flank.

Stratigraphically, the lower unit of the column is the Goiano Complex, represented by the gneissic-granitic bodies of the blocks of Anta, Caiamar-Muquém and Hidrolina, formed in the Early Pre-Cambrian (Archaean), with a volcanic-sedimentary band of the Pilar de Goiás Group.

In relation to the metamorphic belt of the Middle Pre-Cambrian (Proterozoic), there are the metasediments of the Araxá Group.

LOCAL GEOLOGY

Locally in the gold mineralization area called "Mina" III by Mineralsul (1975) and, later, by Kuyumijian (1981), the "Fazenda do Prefeito" occurrence, the geology is constituted by a metamorphic volcano-sedimentary sequence belonging to the Pilar de Goiás Group, partially covered in the north-northeast area by pelitic metasediments of the Araxá Group.

The volcanic-sedimentary sequence was subdivided, from bottom to top, into three lithological units constituted of ultrabasics, basics and sediments, all of which were metamorphosed.

The metamorphosed ultrabasic rocks, known as the Córrego Alagadinho Formation (Sabóia, 1979), generally outcrop in elevations with a N20-50W orientation and characterized by the high content of talc. These rocks are generally foliated with thin films, strongly deformed, showing kinks

and crenulate cleavage. The main metamorphic transformation in the ultrabasic rocks was the talcification, shown as the following lithologies: talc-schist, talc-chlorite-schist, serpentinite, talc-tremolite-schist and talc-magnetite-schist. There are frequently lenticular insertions of metasediments composed of iron formation, metachert, and quartzite-graphite-schist, as well as a not very well-defined sequence of chlorite-chloritoid-schist. Ultrabasics with a spinfex texture or polyhedral disjunction structure were not identified in the area, as occur more to the south (Sabóia, 1979); therefore, the talcification may have obliterated this feature.

The metamorphosed basic rocks, known as the Rio Vermelho Formation, mainly crop out along the Rio Vermelho and the Crixás-Auriverde road. This unit shows itself to be well
-foliated, with pillow lava type structures and vesicular type textures and still preserved amygdales. The lithological types identified macroscopically were carbonate-chlorite-actinolite-schist, actinolite-feldspar-schist, quartz-amphybolite-schist and chlorite-schist.

The metamorphosed metasedimentary rocks, known as the Ribeirão das Antas Formation, show great thicknesses. This unit is identified by a variable lithology, constituted by pelitic sediments and volcanics with lenticular insertions of schists of tuffaceous origin.

The pelitic sediments, for the most part constituted by graphitic horizons, form a complex unit with sedimentary afinites and with volcanic contributions, and are charcteristically black due to the variable carbonaceous content.

A intense change of facies can still be observed, formed of lenses, and, at times, layers of dolomite and chlorite-carbonate-schist.

One of the zones with gold mineralization detected in the area is enclosed within this pelitic sedimentary sequence in close contact with rocks of volcanic origin represented here by metamorphosed chert. This gold mineralized zone was called the lower zone and is constituted by sulphides (pyrrhotite and arsenopyrite) disseminated in graphitic schist near the metachert horizons.

The fragmental aspect, including various mixtures of chloritic, carbonatic and feldspatic and fesdspatic material in a graphitic matrix, suggest a volcanoclastic environment near to the volcanic centre.

Within this sequence, interlinked with the pelitic sediments, two dolomite layers of the pure and impure crystalline types are seen, with contributions of pelitic sediments, as well as of dolomite with a stromatolitic and oolitic structure, indicating a shallow marine environment.

Fragmentation of the dolomites is common, as well as the outcrop of the primary sedimentation, when the outcrop is tectonic, that makes the observation of the stromatolitic structures identified by Bulmer, 1982, difficult.

Associated with the carbonate sequence, at least two volcanic events are observed. Their more acid character (tuffs) with gold mineralization are called the upper and intermediate zone of the "Mina" III.

The two ore zones are predominantly constituted by dense disseminated suphides, containing pyrrhotite, arsenopyrite and traces of chalcopyrite, as well as of magnetite surrounded by sericite-chlorite-schist, chlorite-chloritoid-garnet-schist in the carbonate facies.

Above this sequence occur more coarsed pelitic metasediments, such as chlorit-carnet-schist and chlorite-chloritoid-garnet schist with some free gold mineralization and associate with disseminated pyrrhotite and arsenopyrite.

At the top of the sequence occurs pelitic metasediments which are thin and laminated, represented by metagraywacke, where one can observe graded and cross bedding, indicating calm sedimentation without the next volcanic disturbance.

The position of the graded and cross bedding indicates the inversion of the layers in the locality of "Mina" III.

The lithology of the Araxá Goup is represented by the micaceous sediments which discordantly cover the volcano-sedimentary sequence. These metasediments are constituted by quartz-biotite-muscovite-schist-quartz-garnet-chlorite-biotite-schist, biotite-muscovite-schist and quartzite.

At the contact of the Araxá Group with the volcanic-sedimentary sequence small bodies of quartz-schist or quartz-muscovite schists can be found, as well as well-foliated biotite-gneiss. The contact between the rocks of the Araxá Group and the underlying ultrabasic and sedimentary rocks of the volcanic-sedimentary sequence is probably a reverse fault, as evidenced by the presence of drag folds associated with transposition faults approaching the contact.

The Araxá schists are in unconformity with the various rock sequences of the Pilar de Goiás Group.

Part of the metamorphosed ultrabasic rocks and of the metasediments were eroded, resulting in a transportation and sedimentary deposition by plainal waters and which was subsequently partly covered by lateritic detritous, silt and clay. Such sediments formed by diagenetic action formed the present terraces of lateritic canga.

Small recent alluvial deposits of clayey sandstone with layers of coarse gravel, including sub-angular and rounded pebbles, are found on the banks of Rio Vermelho and its tributary streams.

METAMORPHISM

The volcanic-sedimentary sequence of the Crixás band suffered mineralogical transformations as a result of deformational tectonic events.

In microscopic and macroscopic studies the following mineralogical assemblages were observed in the main lithological sets:

Meta-ultrabasics: Antigorite, talc, tremolite, carbonate, anthophyllite, quartz and magnetite.

Metabasics: Actinolite, chlorite, biotite, tremolite, carbonate, albite, clinozoisite and quartz.

Metasediments: Chlorite, biotite, garnet, muscovite, quartz, calcite, dolomite, chloritoid and magnetite.

The above mineral assemblages reflect low grade metamorphism corresponding to green-schist facies in the lowest temperature band (Turner, 1968). The presence of

actinolite, albite and glauc ophane give an indication of a relatively high pressure (Winkler, 1977).

STRUCTURAL GEOLOGY

The Archaean terrains are characterized by intense structural complexity resulting from the various tecto-orogenic cycles to which they were submitted.

The deformation styles present in the areas studied are mainly observed in chert and altered schist outcrops and, at times, in drill core.

The effects of at least two deformation phases are characterized in the areas under consideration here.

The first phase is characterized by foliation a N60-80°W direction and an inclination to the SW, reflecting an ample fold of NW-SE orientation and with an inverted flank in the "Mina" III area.. The flank inversion is evidenced by:

a) - truncating of the cross bedding in the inverted position in the biotite-feldspar-schist;

b) - inversion of the graded bedding in the schist-feldspatic laminated sediments;

c) - the inverted orientation of the pillows in the metavolcanics;

d) general position of the sequence, showing the ultrabasic and basic rocks above the sediments.

The second deformation phase is manifested by the open antiform on the axis WNW with a plunge of 10-15°W. This structure is well demonstrated by the configuration of the outcropping lithological units and by the "S" - folds. In them there are folds on a smaller scale, strongly deformed fragments of chlorite-biotite-schist in graphite-schist. They are aligned parallel to the fold axis and flattened in the foliation plane and in the axial planes of the smaller folds. There is also lineation of the minerals parallel to the fold axis. There further exists small scale crenulation in the foliation planes with a N-N10°E direction, with an inclination of 10° to the north. This type of deformation can be caused by diapiral movement in which the global movement is parallel to the axis of the small folds on the flanks of the diapir folds.

Therefore, there is a possibility of the deformation being linked to the event in which the rocks of the Araxá Group rode over the volcanic-sedimentary sequence.

Generally speaking, there is a reasonable proximity between the foliation and the layering. Therefore, in the "Mina" III, the foliation, which accompanies the smallest, but abundant, folds of the chevron style, camouflages the true direction of the layering due to the evidence scale in relation to that of the small outcrops. In this area, while the evidence of the visible foliation indicated an inclination to the north, the layering inclines to the south.

The present configuration of the mineralized zones suggests the remodelling of an initial syngenetic concentration by the folding geometry. The local presence of fracture cleavage filled by sulphides and concentrations of quartz veins in less suitable rocks in the expansion zones, such as the ascer of t folds, is evidence of the process of migration. This proce would be able to generate enriched pockets, and would ma a significant contribution to the formation of the mineraliz zones.

DESCRIPTION OF THE DEPOSIT

The "Mina" III deposit is in layers. The ore occurs i three horizontal stratigraphies, called the upper, inte mediate and lower zones, with a subzone of garnet. (fig. 5.12

The mineral bodies are markedly elongated in a WN direction, inclining in a WNW axis with a plung of about 15 conforming to the longitudinal section.

The mineral zone has a global dip to the southwest c aproximately 35°. Straight isoclinal folds that plunge to th WSW, parallel to the major axis of the deposit, and affecte the mineral horizons and the surrounding rocks, and exer cised the control over the mineral distribuition.

Geologically, the upper ore zone is complex. It include three types of ores:

1) Massive sulphide ore, composed of arsenopyrite pyrrhotite and magnetite, in a seritic gangue, chlorit and garnet.

2) Ore with chloritoid and Garnet with some ar senopyrite, and magnetite.

3) Sericitic ore constituted by fine sericitic schist, with a chamois-colour, (paleocre-brown) and with some arsenopyrite and pyrrhotite, both disseminated.

All of the three types of rock are be represented in the upper zone of ore in one particular drill-hole; though, where the ore is more compact and has a higher chemical content, the presence of massive sulphides of the ore occur. The fine seritic schist is interpreted as being metamorphosed felsic tuff. This rock is extremely fissile, and is predominantly composed of white mica, identified as muscovite by X-ray diffraction analysis. When the fine seritic schist and the chloritoid rocks with Garnet appear, in general, only one part of the schist contains gold ore of any value.

One the other hand, the massive sulphide indicates the gold mineralization of economic value. The lithologies of the upper ore zone are encountered within a thick mass of dolomitic rock, which occasionally shows structures similar to the stromatolites or may be simply clastic, caused by various tectonic events.

The intermediate ore zone is geologically very similar to the upper zone, being, therefore, encased in a graphitic unit including massive and disseminated ores. The ore of the intermediate zone is less continuous than that of the other zones, at times the mineralization of the graphitic zone being confused with that of the lower zone.

The lower ore zone with the recrystallized chert horizon was intercepted by the drilling in the direction of the incline up to a distance of 1.6km.

The chert occurs in a schistose unit of biotite-graphite

which contains distinct fragments of carbonate. There is an occurrence of auriferous mineralization within the chert, especially near the upper and lower contacts and within the immediately adjacent graphitic schists. In the graphitic schists, the chemical content of gold is directly porportional to the abundance of the arsenopyrite mineralization, which varies betweem 1 to 5% in volume. The graphitic schist also contains 1 to 3% in volume of pyrrhotite, which also appears to have a correlation with the gold content. Just as in the upper and intermediate zones, there occurs secondary mineralization of pyrite and chalcopyrite. Nevertheless, the combined content of pyrite and chalcopyrite in the lower ore zone generally does not exceed 1% in volume.

The chert in the lower zone varies from less than one metre to more than twenty metres in thickness. It presents various horizons of chert, possibly caused by repetitions of the same layer by folding. Where the chert is thick or where the presence of multiple horizons of chert exist, the ore is frequently bifurcated, accompanying the upper and/or lower contact of one or more horizons of chert.

In all the ore horizons of "Mina" III the gold mineralization occurs predominantly as visible filiments of native gold. In the chert horizons, the gold filiments are of up to 3mm. in size and, frequently, appear grouped along the small inclusions of graphitic schist.

In the graphitic schists adjacent to the chert horizons and in the upper and intermediate ore zones, the gold appears more commonly as small filiments between the crystals of arsenopyrite and the surrounding crystals of pyrrhotite, calcopyrite or pyrite. Is also appears as fine leaves between the fractures of arsenopyrite.

GENESIS AND CONTROL OF THE MINERALIZATION

The mineralization of "Mina" III is characterized as being of the stratiform type and evaporites of syngenetic origin. The gold in "Mina" III is associated with the massive sulphides and disseminations of arsenopyrite and pyrrhotite, followed by chlcopyrite, pyrite, spharelite, digenite and corellite, within the three stratigraphic horizons defined and called, from bottom to top, the upper, intermediate and lower zones, and the subzone of Garnet.

The upper zone is characterized by gold mineralizations associated with the sulphides and is disseminated in the seritic tuffs within the carbonated sequence. It is an extremely irregular mineralization, probably caused by the great changes of facies as shown in the drilling evidence. The lithologies and the manner of sedimentation indicate the presence of microbasins, possibly of a reefal environment which formed a subaqueous environment propitious to the formation of arsenopyrite, pyrrhotite, chlcopyrite, pyrite and other sulphides associated with gold, as well as a little silver.

The ore of the intermediate zone is similar to the upper zone; therefore, it is situated in contact with the carbonate and graphitic sequences or situated within the graphitic sequence. The mineralization is also extremely irregular, in this instance caused by the great changes in the facies, which are also seen in the seritic and chloritic tuffs, its main host rocks.

Just as in the upper zone, the mineralization of gold and sulphides must have been formed from mineralizing solutions originating from volcanic events, and which circulated by the volcanic and sedimentary conduits in the carbonate and graphitic sequence.

The lower zone is characterized by gold mineralization associated with the diffused sulphides in the graphitic band, intimately associated with the concordant levels of metamorphosed chert on the silicified horizon. The layer occurs within a schistose unit of biotite and graphite, and the thickness may be up to 20 metres. The thickness of this chert layer may be due to the packing action of folds.

At times, the mineralization occurs within the chert and a greater concentration is noted near the upper and lower contacts and within the graphitic schists immediately adjacent to them.

These ore zones have a WNW direction with a plunge of around 15°, coincident with the predominant line of "Mina" III. This orientation indicates the existence of folds whose force has affected the ore horizons and the surrounding rocks, facilitating the remobilization of the gold the sulphides in the hinges of the folds of isocline form.

RESERVE

The drilling work carried out to date in "Mina" III has permitted the geological ore reserves in the three stratigraphic horizons, known as the upper, intermediate and lower zones, to be concluded.

The "average" total geological reserve is 5,228,268 tons of ore with an average chemical content of 12.72gm/t, resulting in 67,252 tons of gold contained in "Mina" III.

TECHNOLOGICAL STUDIES

The preliminary technological studies of the ore in Crixás were carried out on the basis of drilling evidence to determine the best ore treatment process and the operational parameters for the future plant. This group of studies led to the conclusion that the extraction of gold can be carried out with usual technological methods, and with a final mean recuperation of at least 91.9%. The studies continue with the aim of optimizing the process.

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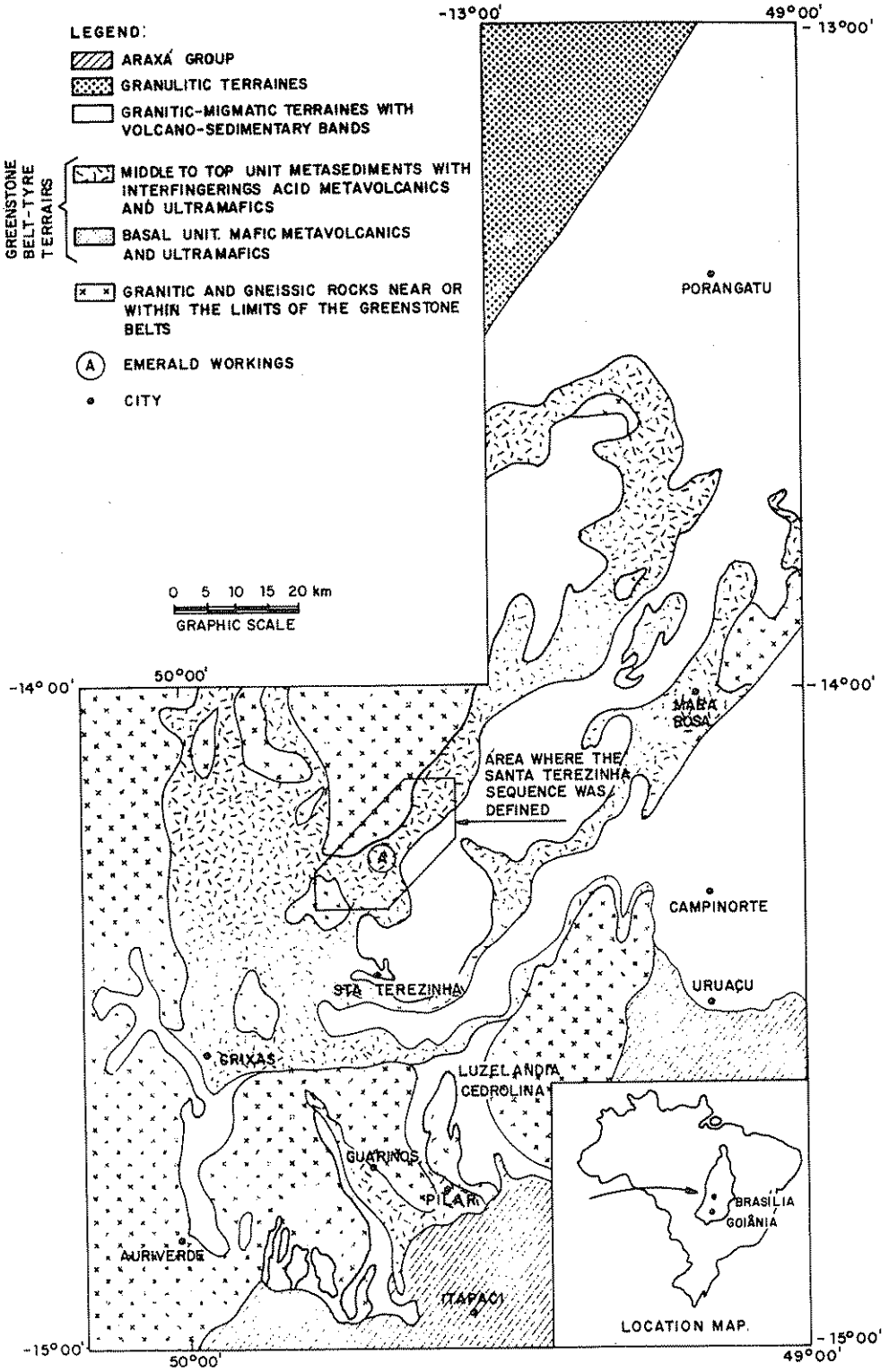

FIG.5.11 – GEOLOGICAL SKETCH SHOWING THE GREENSTONE BELT-TYPE TERRAIN DISTRIBUTION IN ACCORDANCE WITH THE SABÓIA (1981) PROPOSAL AND THEIR RELATIONSHIP TO THE LARGE GEOTECTONIC COMPARTMENTS OF THE PILAR / GUARINOS / CRIXAS – SANTA TEREZINHA – MARA ROSA – PORANGATU REGION.

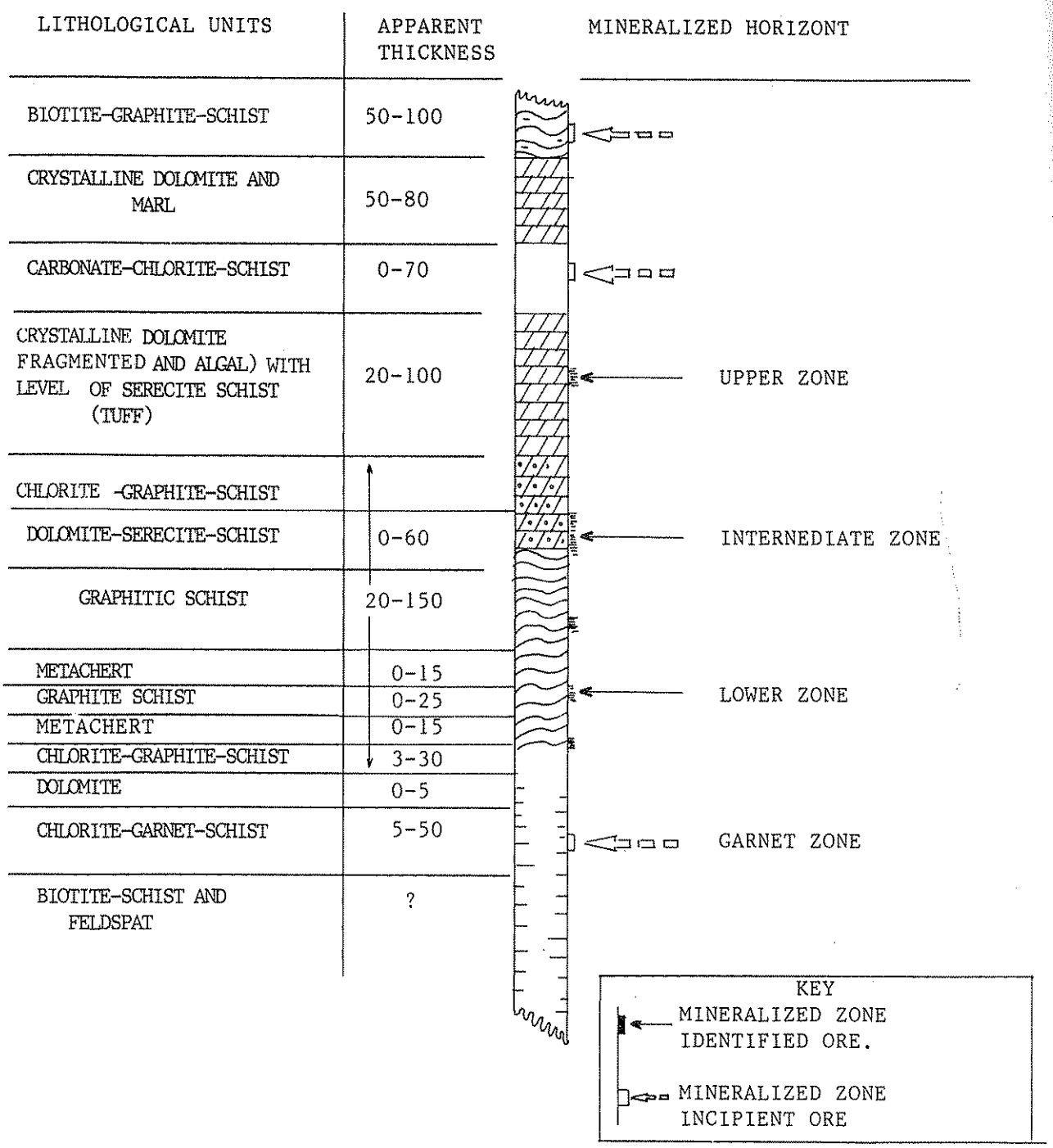

Fig. 5.12 – Illustrative Stratigraphic Column of the "Mina" III, with Mineralized zones.

5.c CORRELATION FOR THE EMERALD ENCASING SEQUENCE OF SANTA TEREZINHA DE GOIÁS WITH THE TERRAINS OF THE GREENSTONE BELT TYPE OF CRIXÁS AND THE TYPOLOGY OF THE DEPOSITS

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The continuity to the North of the greenstone belt of Pilar-Guarinos-Crixás has been assumed on bases related to bigger features. The works developed by the Gold Project (GO) brought into evidence that the volcanic-sedimentary sequences of Santa Terezinha and Crixás are located in the same evolutive geotectonic context. The main evidences are: A) The ultramafic rocks of Santa Terezinha are metakomatites according to chemical composition and relics of layers analogous to spinifex textured rocks; B) there is a notable lithologic resemblance between facies at the top of the Crixás belt and the Santa Terezinha sequence; C) the structural development of both sequences are similar; D) both sequences show manifestation of compatible granite plutonism.

The emerald deposits at Santa Terezinha de Goiás can be fitted into the non-pegmatitic type of Be mineral concentrations. The gems occur disseminately or form aggregates in talc carbonate schists with aureoles of metasomatic alteration rich in potash-micas. The mineralization may be persistent for another 450 metres with a concentrated average of 1kg/m^3 of emeralds, of which around 10% are considered polishable by international standards.

INTRODUCTION

This work is the result of the re-evaluation of studies carried out during the Gold Project - GO (Campos et al., 1984, 1985 and 1986), in the emerald-bearing region of Santa Terezinha de Goiás It is based on a great deal of information obtained from the geological mapping on a scale of 1:25,000 and 1:2,000, from the studies of drilling evidence, geological and subsurface surveys, geophysical surveys, and lithochemical surveys.

The area studied is about 300km from Goiânia, and is situated to the north of the city of Santa Terezinha de Goiás, in the central-west of the State, where one of the most impressive emerald deposits in the world occurs.

The studies and conclusions presented here are intended to improve to the geological understanding of one of the most potentially metallogenetic regions of the Brazilian Central-West, and describes the presence of economic concentrations of the mineral Be in metakomatites.

REGIONAL GEOLOGY

Machado, 1981, is the main reference which effectively confirms the continuity to the north of the Greenstone Belt type terrains of Crixás-Pilar-Guarinos. From the integration of the many works the author grouped the oldest rocks of the Pilar-Guarinos-Crixás-Santa Terezinha-Mara Rosa-Porangatu region together in the same geotectonic evolutionary context, with the following division: Greenstone Belt type terrains, Migmatitic-granite terrains and Granulitic terrains. In figure 5.11 the distribution of the Greestone Belt terrains can be seen in relation to the large regional tectonic units, in accordance with the MACHADO proposition. The Greenstone Belt terrains were divided into the Basal Unit, including the Volcanic-Sedimentary Sequence of Crixás (SABÓIA, 1979) and the Pilar de Goiás Group (DANNI & RIBEIRO, 1979), and the middle to the top Unit, including the Mara Rosa Sequence (RIBEIRO FILHO, 1981) and the rocks attributed to the Araxá Group (SABÓIA, 1979; DRAGO et al., 1981). The setentrional extension of these

terrains has been left open by some authors (SABÓIA, 1979; SABÓIA & TEIXEIRA, 1983; KUYUMIAN, 1981; SOUZA & LEÃO NETO, 1983) and contested by others (RIBEIRO FILHO, 1981; OLIVEIRA, 1982; CASTRO & MAGALHÃES, 1984). The opposing arguments, therefore, have little consistency, but would base themselves, principally, on structural paramenters, of dubious validity, when used in isolation (PARK, 1969) for the comparison of broad belt metamorphics, especially when confronting areas with different degrees of geological knowledge.

GEOLOGY OF THE SANTA TEREZINHA SEQUENCE

In 1983, SOUZA & LEÃO NETO classified the Santa Terezinha Sequence as a volcanic-sedimentary assembly with a low degree of metamorphism, positioned to the north of the city. It is inserted in a trough which has a NE-SW direction, and which has a bifurcation to the south and an average width of 6 km. It is balanced, to the southwest, by a "domino" structure in the form of large elipsoids, constituted of coarse gneisses (dome of the Serra de Santa Cruz). To the northwest, it is bounded by gneissic granitic rocks, where it is delineated by a body of porphyry granite (São José de Alegre granite). To the southeast, it meets a gneissic-amphybolitic-calcosilicatic association. Its longitudinal limits are: to the south, with the Mara Rosa Sequence of RIBEIRO FILHO, and to the north, with the Araxá Group (SABÓIA, DRAGO et al., and others). It forms part of the middle and top Unit of the Greenstone Belt terrains of MACHADO, and is correlated with the Pilar de Goiás Group of DANNI & RIBEIRO.

Lithologies

The area where the sequence occurs is very flat, with rare outcrops of the less resistant rocks, which allied with the complex structures, create great difficulty in establishing the effective control of the distribution, in relation to the thickness and stratigraphy of the different lithologies.

Therefore, without the neccessity to define the top and the base, one can observe an intermediate unit, rich in ultramafic rock metamorphites, acid metaclastics, cherts, ferriferous and manganiferous formations, carbonatic sediments and graphite sediments. Also one can observe a separate meridional arrangement, preferentially constituted of chlorite-quartz schist, sericite-quartz schist and seritic quartzites, and a setentrional set with continuous horizons of magnetite-quartz schists and feldspatic schists.

The quartz schists, the chlorite sericite and at times, the biotite are the predominant lithologies in the region: horizons rich in garnet (spessartites) are frequent. In the intermediate portion, quartz-chlorite and magnetite-quartz-chlorite-carbonate schists predominate.

Acid volcanoclastics are characteristically represented by sericite-quartz schists which are finely banded and contain feldspar or garnet porphyry. The analysis of a sample from the level in which hidden talc schists occur, near to the emerald beds, shows a potassium composition, with 0.88% Na_2O and 4.6% K_2O. A continuous horizon of magnetite-muscovite schists, with levels of black tourmaline, which extends in the north portion of the sequence, possibly corresponds to acid meta-volcanics.

Dolomite inserts with subordinate quantities of quartz, sericite and sulphides, as well as fuchsite quartz schists, were detected in drill-holes in the intermediate portion of the sequence.

Chert levels, almost exclusively constituted by recrystallized quartz or with subordinate quantities of iron oxide, banded manganiferous horizon formations, inserted with centimetric to decimetric levels of manganese oxide in cryptocrystalline form and with insertions of fine milky quartz, are well-represented in the northeast of the area. Magnetite iron formations are also found.

Graphitic schists rarely crop out, and always occur in lesser quantities in the sequence, sometimes as interfoliated laminar levels, rich in pyrite and pyrrhotite.

Rocks constituted by aggregated quartz grains, with 50% calcite, and, at times, with garnet, feldspar and iron oxide lenticular forms in well-defined levels, interlayered in the set, have been interpreted as tuffaceous cherts.

Chloritoid-chlorite-calcite-quartz schists and muscovite-calcite feldspatic schists characteristically appear in the intermediate and setentrional portions of the sequence.

Basic rocks rarely occur. They are associated with ultramafic levels and are represented by calcite-chlorite-tremolite-actinolite feldspatic schists. The occurrence of the ultramafic rocks will be discussed later, due to its geological and economic importance.

Metamorphism

The mineral paragenesis of the Santa Terezinha Sequence is represented by the presence of low temperature hydrated minerals, a characteristic of green schist facies (TURNER, 1960) or low grade metamorphism (WINKLER, 1976).

The garnet present in the region is of the spessartite type compatible with the chlorite zone, consequently not characterizing the weak-grained amphybolite facies (WINKLER, 1976) nor the transition between the green schist and the amphybolite, in zones of medium to high pressure (TURNER, 1960).

The distribution of biotite in coexistence with the paragenesis of the ultramafic rocks is restricted to the surrounding of the zones with concentrated deformation, where a significant amount of potassium is found.

Structures

The most predominant tectonic aspects are north-northwest foliations that accommodate the contours of the adjacent granite and gneissic terrains.

Three penetrative foliation development phases are found in the area and they document the structural evolution of the rock arrangement in plastic or metamorphic and tectonic conditions.

The foliation related to the oldest deformation (D_1), is in evidence in the crests of the later fold deformation phase (D_2), where the neocrystallization of micaceous minerals can be seen, developing a slip cleavage over the previous schistosity (S_1). The S_1 foliation is observed by the presence of inclusions arranged in parallel milky layers and with helitical

folds at the edges, which occur in garnet porphyry, distinctly developed along the neoschistosity (S_2).

The second deformation phase (D_2) is well shown in the rocks of the region, with its most prominent element being the schistocity known as S_2. It shows a preferential direction of N45°-60°E with an inclination equal or less than 30° to the NW. Closed to isoclinal mesoscopic folds with axial planes in a direction of around N50° - 60°E are found with plunges of about 30°NW. Recrystallization of quartz micaceous minerals and garnet porphyry develpoment is apparent, and corresponds to the region where the metamorphosim was greater.

The S_2 refolding gave rise to the third deformation event (D_3) and is well demonstrated in a notable, almost isoclinal, closed synform structure which extends from the river Peixe to the northern region of the emerald occurrence.

A typical crenulation cleavage S_3 is developed in the schistosity forms of the mesofold environs which have axial planes in a N13°-15°W preferential direction and an inclination of 70° to 80°SW and plunge axes of 15° to 25°NW.

Showing intimate association with D_3 are the shear zones whose maximum elongation is in a N5°-15°W direction, conditioning the deformation of the layers with an increase in the amounts of micaceous minerals.

Smooth folds or warping, with preferential axes of N60°-70°W are characterized by the absence of associated penetrative foliation.

They probably represent the final undulations of a not very deep tectonism in conditions of predominant rigidity (drag folds and faults also developed), and which are dissasociated from the evolutionary process, as demonstrated by the deformations in conditions of regional metamorphism. Locally these can be seen as D_4 etc.

Plutonism

Direct evidence of plutonism affecting the Santa Terezinha Sequence is provided by a small offshoot with a granitic and granodiorite composition surrounded by chlorite-talc schists, which occurs in the northeast of the area. It shows medium granulation, hardly folded, with a porphyritic texture, and mainly constituted by quartz, muscovite, plagioclase and potassium feldspars.

In the contact with the Santa Terezinha Sequence the São José do Alegre Granite suffered a mylonitization process, although the contact relationship has not been observed. It is predominantly constituted by quartz, plagioclase, phenocrysts, microline and biotite. Chemical analysis of two samples from this intrusive body revealed the following average chemical contents: Na_2O = 4.15%, K_2O = 4.3% (Na_2O/K_2O = 0.96), which permits them to be compared with the potassic granites which characterize the youngest intrusives associated with the Greenstone Belt of Crixás (KUYUMIJIAN, 1981).

The Granite Dome of the Serra da Santa Terezinha is apparently linked to the evolution and deformation of the volcanic-sedimentary belt, which makes an inflection to the south of the Santa Terezinha Sequence. The macroscopic aspect of these rocks is that of coarse gneisses, but, as yet, no petrographical or geochemical data exist to characterize them.

META-ULTRAMAFIC ROCKS

These are characterized by chemical contents of MgO greater than 20% and high Cr and Ni, and which are found in different faciological transformations. They define the metamorphic and specific metasomatic domains and may, therefore, be grouped as follows:

a Talc-tremolite, talc-chlorite-tremolite and chlorite-tremolite schists, locally occurring in the middle of talcified rocks with apparently well preserved primary structures.

b Chlorite-talc, chlorite-carbonate-talc, carbonate-talc, quartz-carbonate and talc schists, which constitute the predominant lithologies with a regional distribution. The faciological variations are apparently conditioned by the differing actions of SiO_2 and CO_2 as metamorphic or metasomatic agents. The talc schists are possibly related to the introduction of SiO_2 from the surrounding silicate rocks, and the carbonate facies metasomatized by carbon dioxide. Dolomite was the only carbonate identified by the use of X-ray.

c Phlogopite-talc-carbonate, talc-biotite-carbonate and carbonate-biotite schists ("biotitites"), which have a restricted distribution controlled by zones of more intensive deformation where potassium occurs. They constitute the host rocks with the most enriched layers of emeralds in their mineralized horizons, but trenches rich in potassic micas may be sterile or have only uneconomic occurrences of the gem. Biotite and phlogopite are generally more common, nevertheless, the presence of ferric muscovite was also identified. The name biotitite here refers to the rocks which are essentially constituted by biotite, pyrite, and, at times, carbonate, though they show a well developed schistocity.

d Magnetite-chlorite and chlorite schists ("chloritites"). These are rocks essentially constituted by chlorite, at times, with levels rich in magnetite porphyry, and with subordinate quantities of carbonate. Regionally, they shows the limits of the ultramafic layers and rarely occur in the internal portions.

These metamorphic assemblages are intimately associated within the well-defined milky beds and are interlayered within the metasediments of the sequence. The meta-ultramafic rock layers are relatively thin and continuous, occurring in apparent thicknesses of up to 20 metres.

Ultramafic Schists with Spinifex-Type Texture

These are represented by talc-chlorite-tremolite schists with a dense aspect and with tremolite prophyry, and which do not show visible schistocity to the naked eye. They occur in the form of small lenses relictually in the middle of talc schist.

The mineral paragenesis indicates less intense metamorphic or metasomatic conditions in relation to the rest of the set, although allochemical reactions with the introduction of SiO_2 appear to show that a weak talciferous formation occurred. The only surface exhibition of this was detected within the prospector settlement.

The porphyritoid texture is characterized by an association of tabular tremolite crystals whose dimensions are at least 1 cm in size, randomly arranged or forming radial aggregates, in the middle of a fine matrix of talc-chlorite-tremolite or talc, with subordinate magnetite. The apparent presence of two generations of tremolite appear to correspond in reality to two generations of pseudomorphs of olivine or clinopyroxene.

The nature of the occurrence gives the initial idea that the texture was the first. Later, the petrographical studies confirmed that its characteristics are similar to the spinifex textures of metamorphic rocks in the greenschist facies, according to LEWIS, 1971, who defined them as "a distinct association of minerals in which tremolite, chlorite or serpentine form long tabular crystals, aggregated or not, in the middle of a granular matrix of chlorite or tremolite".

A type of metamorphic texture, similar to spinifex, has recently been described in literature under the name, of "jack-straw" (in DONALDSON, 1982). It is diagnosed as secondary, because it shows neoblasts of tremolite cutting the milky folded beds. In the rocks of Santa Terezinha, therefore, the blades of tremolite show twists and fracturing and a lack of inclusions in the matrix, which permits them to be considered as more representative of olivine or clinopyrixene pseudomorphs of porphrys.

On the other hand, the chemical composition of the ultramafic shcists of Santa Terezinha will be in accordance with the following approach, and are compatible with komatites, where the spinifex textures typically occur. As well as the komatitic chemistry as a whole, the quantity of MgO is within the limits verified in ultramafic lavas, where these textures occur, i.e. MgO less than 30% (BESWICK, 1982).

Geochemistry

The ultramafic rocks of Santa Terezinha were particularly susceptible to alterations induced by metamorphic or metasomatic processes, due to the nature of their occurrence in the form of thin layers interlayered between sediments and acid volcanics. The mineral parageneses indicate an allochemical reaction process and the introduction, at minimum, of H_2O and CO_2, which between them are not necessarily able to make the modifications in the relationship between the original constituents.

The analytical results demonstrate, nevertheless, that almost all the ultramafics of Santa Terezinha were, to different degrees, affected by the redistribution or the introduction of major elements, which produced geochemical relationships incompatible with any kind of ultramafic rock class.

Only the ultramafic schists, with textures of the spinifex type preserved in them, show chemistry which can be directly compared with the differentiated ultramafics, but the high chemical content of SiO_2, the same as komatite, appears to indicate the addition of SiO_2.

Not only the tremolite schists, but all the ultramafics of Santa Terezinha appear to be enriched with silicon dioxide, although the normalized values of SiO_2 and MgO (together with CaO, Al_2O_3 and FeO show the SiO2 following a trend compatible with magmatic fractionation). In figure 5.13, the komatites of Crixás are compared with the richest rock in SiO2 of Santa Terezinha, and all the non-carbonate talc schists show analogous chemical contents.

An internal distribution of Al and Fe inside the ultramafic layers covered by chloritites appear to have occurred. In Table 5.3 the contrast between the aluminium and iron chemical content of the chloritites and the other rocks can be seen. Furthermore, it can be noted that the extremely high values of aluminium (Al_2O_3 greater than 16%), as well as the very low chemical content (Al_2O_3 less than 1%), are uncommon in ultramafic suites.

Comming to K, Al, and on a lesser scale Na, together with the minor elements of Be and some Ba, they occur in restricted trenches and are well controlled structurally, where one finds the emplacement of emerald mineralizations (table 5.3). In the areas adjacent to these zones (in lower facies), relatively high chemical contents of Na_2O and Be (table 3) can occur.

The behaviour of MgO, always greater than 20%, is compatible with the fractionation of ultramafic magmas and its variation with SiO_2 in less altered rocks, demark a well defined trend. The redistribution of Mg from the original silicates top form talc and dolomite does not appear to have altered regionally in relation to the chemistry. Recalculating the chemical contents of table 3 without the volatiles (P.F.), two samples show a content of 46% MgO, indicating that localized concentrations occur.

In accordance with the broad observations, CaO shows a negative correlation with MgO, which is compatible with the magmatic differentiations. Some extremely low values of CaO are, however, indicative of the CaO being least locally mobile.

The values of TiO_2, P_2O_5 and MnO are characteristally low, with their chemical contents only increasing in the covering chloritites, where chemical changes to the surroudings may have occurred.

The chemical content of Cr, with an average value of 1,750 ppm and of Ni with an average of 1,240 ppm (not including the emerald mineralized rocks and the chloritites) are substantially high, but the lack of analytical results, principally of the less magnesitic rocks, do not permit conclusions to be made about the distribution of these metals in relation to MgO.

Chemical Comparison with the Komatites of Crixás

Through chemical changes induced by the metamorphic and/or metasomatic processes, the analytical results of the ultramafic rocks of Santa Terezinha show that they evolved from a fractioned ultramafic suite in terms of the MgO less than 25% and MgO greater than 30% respectively, similar to the Crixás suite (Kuyumijian, 1981).

The ultramafic schists with the spinifex-type texture retain sufficient geochemical indications to permit their direct comparison with the komatites. The chemical content of MgO, greater than 20%, Na_2O and K_2O, less than 0.9%, and TiO_2

less than 0.9% in relation to CaO/Al_2O_3, greater than 1 and high Cr and Ni, indicate a chemistry similar to the komatites of Crixás (Kuyuminian, 1981; Montalvão, 1984) and to other regions of the world (Brookes & Hart, 1974; Arndt & Nisbet, 1982). In accordance with the Pearton, 1982 projection to characterize the talc-carbonate komatites of Murchison, it is unlikely that the metamorphic or metasomatic processes have produced chemical changes of major and minor elements which would reproduce the well-established rocks of this chemical class.

In the other variety those parameters became modified to different degrees as a function of specific metamorphism domains, but the indices of MgO greater than 20%, $Na_2O + K_2O$ lesser than 0.9%, TiO_2, less than 0.9%, and high Cr and Ni, are persistent in the less transformed lithologies.

In table 5.4 the normalized compositions of the principle oxides (SiO_2, Al_2O_3, FeO_2, CaO and MgO) are shown for the less altered ultramafics of Santa Terezinha, for the komatites of Crixás and the talc-carbonated komatites of the Greenstone Belt of Murchison - South Africa (Pearton, 19820, which permits a more effective comparison of the geochemical behaviour of the major elements in those sequences. The comparison with Murchison is due to the presence in the region of komatites with a metamorphic paragenesis similar to that of Santa Terezinha.

In figure 5.13, the normalized chemical contents of MgO and SiO_2 are plotted (normalized with the principal oxides noted in table 5.4) for the rocks of Santa Terezinha and Crixás. It can been that both sets show trends of differentiation, which are parallel and partially coincident with the two well-established magnesian fields. The SiO_2 enrichment in the Santa Terezinha suite appears to have an apparent regional environment linked to the stratification process. The talcified komatiites of Murchison (Pearton, 1982) are also enriched with SiO_2, in accordance with that which can be seen in figure 8.11, where the average of 21 samples from that sequence are in the same field as that defined by the Santa Terezinha rocks.

In the diagram CaO - Al_2O_3 - MgO, it can be seen that both the sequences lie in the komatites field and define sub-fields of the very near magnesian, and with the same inflexion in relation to the CaO - MgO side. The inclination observed is not compatible with the fractionating of the ultramafics and appears to reflect modifications in the original composition, also seen in the rocks of Crixás. The somewhat irregular behaviour of the differentials, whose subfields ore inverted in position, is apparently linked to the mobility of Al in Santa Terezinha.

In the diagram of Jensen (1976) one can see similar behaviour for the ultramafics of Santa Terezinha and Crixás. The less magnesian sub-fields terms of Crixás can be seen, in part, curiously situated in the basalt komatite field, and the trend of the fractionation is parallel to the $FeO + Fe_2O_3 + TiO_2$ + Mgo side, which appears to be an indication of an alteration in the primary geochemical relationships that need to be better analysed. The Santa Terezinha samples are well-defined in the komatiite field, although the most magnesian sub-fields are in a little frequented position, due to the depletion of Al and some Fe in the most metamorphically altered facies.

Conclusion about the Original Nature of the Meta-Ultramafics

In accordance with the redefinition of Arndt & Nisbet (1982), the term komatiite, refers to the lavas or volcanoclastic rocks of ultramafic composition. They are rocks characterized by an MgO content of greater than 18% (in an anhydrous base) and a texture that effectively proves that they are extrusive in character.

The meta-ultramafics of Santa Terezinha have a volcanic nature. Therefore, the set of various characteristics, such as spinifex-type texture, the nature of the occurrences in thin layers interlayered in metasediments, chemistry compatible with the komatiites of Crixás and the presence of emeralds with silica melt inclusions (Barros, 1984), are very significant evidence that permits the diagnosis, with great certainty, that these are metakomatiites.

NATURE OF THE EMERALD DEPOSITS

The discovery of emeralds at Santa Terezinha occurred in April 1981, in the locality known today as Trecho Velho. It was due to the prospector, Antonio Gusmão, who was searching for gold in the region and identified some "green stones" as emeralds, that an access road was opened (Ribeiro de Sá, 1983).

From then on, more than three emerald occurrences were found, known as Trecho Novo, Trecho do Netinho and Trecho dos Barbudos, of which the latter has not shown economically viable concentrations up to now. Through drilling of exploratory excavations, four new mineralized bodies were discovered, which are: Norte do Trecho Velho, Cieba do Trecho Novo, Trecho Loteado, and Trecho do Jacob (this and the previous one are known through drilling).

They are positioned on the flanks of a synform structure by the River Peixe, and have a preferential direction of NNW. They are metalgenetically controlled by the carbonatic talc schist horizons of the ultramafic suite. They have the configuration of doubled strata, whose morphology reflects the local structural position in relation to the deformation events that took place in the region and which is complicated by the plasticity of the talc-carbonates and the heating produced by metasomatic reactions. Throughout the stratiform distribution one finds mineralization, not only in the vertical extensions of the carbonatic talc schists, but also, more frequently, in the emerald-bearing levels, which form horizons of submetric thickness next to the contact with the surroundings and in the internal meso-folded creases.

The mineralization discovered up to this moment (Trecho Novo) persists longitudinally in a NNW direction for a distance of 450 metres, with a width of 40 to 60 metres. The thickness is variable, and can attain 12 metres at the thick borders of the tectonicism (canoe) although, in the interior of the mineralized zone, the layers of talc schists (preferentially mineralized in the mantle) have an average thickness of around 1.5 to 2 metres and are repeated, folding two or three times (weaves) within a vertical interval of 20 metres. Apparently, this is related to the old fold creases which are rotated, refolded and woven by the D_3 phase of shearing. It shows a mean plunge of around 15°/NNW, except in the

northern part, dropped by fault, where it plunges at up to 35°.

The mineralization of the Cieba do Trecho Novo appears to represent a lower position of a megasigmoid related to the shearing of D_3, whose upper part would be represented by the Trecho Novo body.

In the Trecho Velho and the Norte do Trecho Velho the behaviour is similar to vein-layers, repeated by folding and moved to follow the direction of the major elongation of the shearing (N13°-15°W) of the D_3 metamorphic event.

In the Trecho do Netinho bunches form with dimensions of a few metres and are related to the meso-fold creases of the second deformation event (D_2), and which were drawn out by the D_3 shearing.

The gems occur in well-formed crystals, either scattered or together, and have an average size, as measured along their major axis, of 0.5 to 2.0 cm. They occur in concentrations of around 1 kg/m^3 of which about 10% are considered suitable for cutting to international standards.

Through microprobe analysis, Barros (1984) characterized the inclusions and chromophores responsible for the colour of the emeralds of Santa Terezinha, which are:

a) Solid inclusions: biotite, phlogopite, talc, tremolite/actinolite, pyrite, chalcopyrite, quartz, feldspar, dolomite, chromite, pentlandite, beryl, garnet, apatite, unidentified pyroxene and silica melt.

b) Fluid inclusions: normally rich in CO_2 and accompanied by halite, sylvite and carbonate.

c) Chromophores: Chrome and vanadium having an analysed chemical content of Cr_2O_3 greater than 1% with the amount of chromium accompanying the variation in colour.

The emerald mineralizations are typically epigenetic and can be grouped in the non-pragmatic type of Be mineral concentrations (Griffiths, 1973). They show favourable structural control in a NNW direction and which are related to the most intense deformation levels of the shear zones. The carbonated talc schists in the locality of the tectonic thickening probably functioned as conductors of mineralized fluids.

The metasomatic solutions that carried Be were rich in CO_2, Cl, Na and K, in accordance with the fluid inclusions found in the emeralds (Barros, 1984). Al, V and some Ba enrichment is also associated here, in accordance with what can be observed in the analytical results of table 8. Sulphur appears to have been introduced at the same time, and constitutes the pyritic gangue of the biotites.

The source of the Be and associated elements can be related as much to the pneumatolitic solutions of the subjacent granites as to the transference of material by differential deformation of neighbouring surrounding rocks (acid volcanics etc.). a mixed source can also be considered, being residual solutions of granite associated with the fluid phase of metamorphism.

As far as the purely metamorphic process is concerned, it is important to point out the close association of the mineralized levels with the acid tuff layers, rocks that can be rich in Be. Vernon (1976) described the enrichment of K in shear zones and the creases of folds by the action of differential deformation. Griffiths (1982) reported that the Be dispersed in the middle of rocks could have taken place during metamorphic events and carried to sites favourable to their fixation.

CORRELATION OF THE VOLCANIC-SEDIMENTARY SEQUENCES OF SANTA TEREZINHA AND CRIXÁS

Major field reports led Machado (1981) to propose the continuation of the predominantly sedimentary portion that occurs on the top of the terrains, known as the Greenstone Belt of Crixás - Pilar - Guarinos, to the north. The study of the Santa Terezinha Sequence permits the establishment of important geological and geochemical characteristics which permits it to be considered as being developed in the same geotectonic evolution as the Crixás belt, therefore proving his hypothesis. The main evidence is:

a) Through the chemical changes induced by the metamorphic and/or metasomatic processes the geochemistry of the major elements of the magnesian schists of Santa Terezinha show that they evolved from a differentiated ultramafic suite of komatiite chemistry (MgO greater than 20%, $K_2O + Na_2O$ less than 0.9%, TiO_2 less than 0.9%, CaO/Al_2O_3 greater than 1 and high Cr and Ni) similar to the ultrabasic suite of Crixás (Kuyumijian, 1981; Montalvão et al., 1981).

In Santa Terezinha, the presence of thin and continuous levels of magnesian schists with spinifex-type textures and containing emeralds with silica melt inclusions constituted complementary indications that suggest these rocks to be effectively metakomatiites.

b) The lithological set of the Santa Terezinha Sequence shows, in different proportions, mineral assemblage similar to those encountered at the top of the volcanic-sedimentary sequence of Crixás.

More specifically, they show a similarity to the lithologies of the Lower and Upper Metasedimentary Units of Kuyumijian, 1981, and the Ribeiro da Anta Formation/Araxá Group of Castro & Magalhães, 1984, i.e. quartz-chlorite schists, graphite schists, chlorite-chloritoid schists, ferrugenous metacherts, iron formation, feldspatic schists, sericitic quartzites, magnesium schists (ultramafic diffusion), actinolite-tremolite schists (basic diffusions), acidic metavolcanic-clastics etc.

c) The two sequences show the same style of structural evolution in conditions of regional metamorphism, as characterized by three phases of penetrative foliation development.

The last foliation (S_3 (Castro & Magalhães, 1984) of

the two suites is represented by a typical crenulation cleavage with a coincident NNW direction.

Final deformation events of non-metamorphic tectonism (D_4 (Castro & Magalhães, 1984) affected the two sets to produce undulations, localized folds and faulting. The S_1 and S_2 foliations, referred to by Castro & Magalhães (1984), known as the Araxá Group, appear to correspond respectively, in fact, to the penultimate and ultimate foliations of Crixás and Santa Terezinha.

d) Potassic granites as characterized by the relationship Na_2/K_2O a. 1, are found associated with both the sequences and were considered as the youngest intrusions of the Crixás band by Kuyumijian, 1981.

A much older phase of granite plutonism of a sodic nature were identified by Kuyumijian (1981) in Crixás, and they are represented by domed structures related to the inflexions in the volcanic-sedimentary sequence. In Santa Terezinha, the positioning of the Dome of Santa Cruz, to which the deformation effect on the bifurcation to the south of the Volcano-Sedimentary Sequence is linked, is similar, and may be, at minimum, structurally correlatable to the domes of Crixás.

CONCLUSIONS

The Santa Terezinha Sequence has a correlation with the Greenstone Belt type of terrain at Crixás because of their lithological, metamorphic and structural characteristics, and because of the associated plutonism. The least transformed ultramafic rocks of Santa Terezinha show relict levels with spinifex-type textures, and compatible chemical indices with differentiated komatiites at Crixás and in other regions of the world (MgO greater than 20%, $Na_2O + K_2O$ less than 0.9%, TiO_2 less than 0.9%, CaO/Al_2O_3 greater than 1, and high Cr and Ni).

On the basis of what is asserted above, it can be proposed that the name of the Pilar de Goiás Group (Danni & Ribeiro, 1978) employed for the rocks of the Greenstone Belt of Pilar de Goiás - Guarinos should be maintained for the volcanic-sedimentary belt of Santa Terezinha, and then extended for the Crixás Belt (Sabóia et al., 1979).

The extension of the Pilar de Goiás Group to the north contained in the hypothesis of Machado (1981) was more or less partly confirmed in Santa Terezinha, showing the confidence in the regional criteria used by this author and the viability of the hypothesis as whole. Neverthless, it must be emphasized that only a detailed mapping will it be possible to define the limits of this compartmentation with certainty.

The characterization of emerald deposits in komatiites increases the economic prospects for the Greenstone Belt type terrains of the region and are of important geological significance, for recognizing the presence of economic concentrations of beryl mineral in that class of rock.

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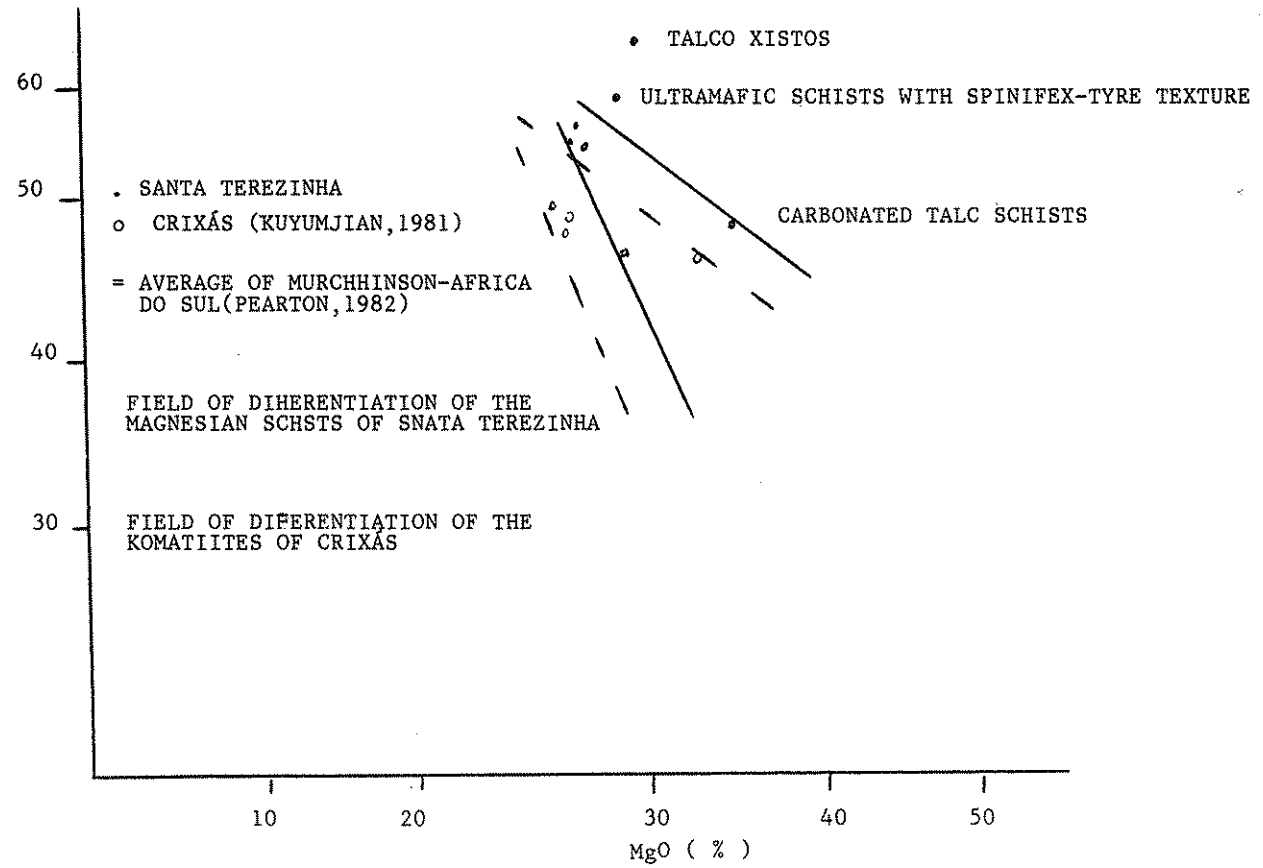

Fig. 5.13 MgOvs SiO2 com valores normalizados para os principais óxidos (SiO2,Al2O3,FeO,CaO,MgO de xistos magnesianos de Santa Terezinha,Komatiitos de Crixás(Kuyumjian,1981 e valor médio de 21 amostras de Metakomatiitos de Muchinson Africa do Sul (Pearton,1982).

TABLE 5.3 – ANALYTICAL RESULTS OF MAJOR AND MINOR ELEMENTS OF THE MAGNESIAN SCHITS A SANTA TEREZINHA DE GOIÁS

		STEMILE ROCKS														ENERALCE MINERALIZED			
		Not Adjacent to the Mineralized Zones							Adjacent to The Mineralized Zones										
		Talc – Clorite Schists With Spirifex Texture			"Clorites"		Talc Schists		Carbonatic Talc Schists							Talc, Flogophgte, Biotite, Carbonatic Schists			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
SiO_2	(%)	53,00	53,20	51,49	31,30	27,90	59,10	54,41	29,70	36,40	32,90	39,20	41,97	35,53	37,28	41,48	38,88	33,10	44,43
TiO_2		0,03	0,17	0,18	0,48	0,25	0,01	0,19	0,01	0,02	N	0,01	0,22	0,17	0,20	0,20	0,23	0,19	0,18
AL_2O_3		3,80	2,72	4,60	18,00	19,40	0,94	4,33	0,94	1,90	0,94	0,94	0,46	0,50	0,52	5,43	10,43	2,54	1,22
Fe_2O_3		3,20	6,15	5,80	4,80	1,10	2,93	1,90	1,90	1,80	1,60	0,84	3,42	1,97	2,46	1,32	3,00	3,15	2,85
FeO		4,50	3,15	3,50	9,50	10,50	4,10	2,84	4,50	4,50	4,00	4,60	1,91	3,87	2,43	2,57	3,04	3,36	1,79
MnO		0,27	0,19	0,25	0,06	0,10	0,05	0,04	0,10	0,45	0,09	0,08	0,11	0,15	0,07	0,05	0,03	0,14	0,10
MgO		21,10	20,04	21,56	22,50	25,70	28,40	25,91	33,20	31,90	34,40	32,50	28,37	29,84	28,58	25,00	20,40	27,45	29,00
CaO		10,50	9,89	6,45	0,56	0,14	0,21	0,58	1,50	2,00	0,14	0,84	2,41	1,34	2,56	4,16	1,50	2,97	0,70
Na_2O		0,20	0,15	0,12	0,04	0,03	0,03	0,96	0,04	0,02	0,03	0,05	0,95	1,06	0,82	0,85	1,40	1,07	1,21
K_2		0,02	0,02	0,02	0,01	0,01	0,01	0,02	0,01	0,01	0,01	0,01	0,06	0,02	0,02	3,85	6,26	1,82	0,69
P_2O_5		0,15	0,10	0,10	0,62	0,27	0,10	0,05	0,13	0,15	0,12	0,05	0,04	0,04	0,03	0,04	0,07	0,04	0,14
P.F.		2,40	3,40	4,85	11,20	10,90	4,80	6,80	25,00	20,80	24,40	19,90	18,70	24,75	23,90	14,27	14,00	24,25	16,94
Total		**99,17**	**99,18**	**98,82**	**99,05**	**99,80**	**98,85**	**99,06**	**98,02**	**99,94**	**98,62**	**98,96**	**98,62**	**99,24**	**98,87**	**99,22**	**99,24**	**100,08**	**99,25**
Cr	(ppm)	1500	–	–	1000	200	1000	2000	2000	1000	2000	1000	2000	2000	3000	1500	3000	5000	1000
Ni		1000	–	–	300	70	1500	700	1000	700	1500	1500	1000	1500	2000	700	300	1000	1000
Co		70	–	–	70	20	70	70	30	20	50	50	70	100	100	100	50	70	100
Be		N	–	–	N	N	N	N	N	N	N	N	150	N	N	200	1000	20	50
Ba		20	–	–	20	20	20	N	20	20	20	20	N	20	N	100	200	50	100
V		20	–	–	100	70	10	70	10	10	10	10	10	10	15	50	150	50	30

OBS.: The Samples (1) SC-111-E; (4) PLN-194,10M; (5) TT-949 E-150N; (6) TT-2671; (B) LP-18-66,40M; (9) LP-11-43,60M; (10) TT-2622 e (11) SC-100 Analysed at were LAMIN-CPRM

The Samples (2) SC-111-0; (3) TT-2632; (7) TC-3544; (12) TN- (13) TN-213; (14) TN-129; (15) TN-080; (16) TV-045; (17) TN-132 e (18) TN-167 Analysed were AT METAGO.

TABLE 5.4 Conteúdos normalizados de SiO_2, Al_2O_3, FeO, CaO e MgO de xistos ultramáficos e talco xistos carbonatados de Santa Terezinha, Komatiitos de Crixás e talco-carbonato e talco-clorita xistos (metakomatiitos) do Greenstone Belt de Murchinson-Africa do Sul.

		SANTA TEREZINHA		CRIXÁS		MURCHINSON
		1	2	3	4	5
SiO_2	%	55,8	49,8	52,4	43,9	49,5
Al_2O_3		3,9	1,1	1,9	4,2	5,7
FeO*		8,6	7,0	13,8	10,5	8,6
CaO		9,5	2,4	7,6	2,4	4,5
MgO		22,2	39,7	24,3	39,0	31,7
TOTAL		**100,0**	**100,0**	**100,0**	**100,0**	**100,0**

(1) Média de 3 amostras de xistos ultramáficos com textura do tipo Spinfex de Santa Terezinha com MgO 25%.

(2) Média de 5 amostras de Talco Xistos Carbonatados de Santa Terezinha com MgO 30%

(3) Média de 4 amostras de Komatiitos de Crixás com MgO 25% (KUYUMJIAN, 1981)

(4) Média de 10 amostras de Komatiitos de Crixás com MgO 30% (KUYUMJIAN, 1981)

(5) Média de 21 amostras de Metakomatiios (Talco Carbonato e Talco-Clorita Xistos) do Greenstone Belt de Murchinson - Africa do Sul (Pearton, 1982)

FeO* TOTAL DE FERRO EXPRESSO COMO FeO.

6. GOLD AND ZINC-LEAD DEPOSITS OF PARACATU AND VAZANTE

Dardenne, M.A.
UnB
Madalosso, A

INTRODUCTION

Field trip n. 6 entails the visit to three mineral deposits located in the northwest of Minas Gerais state, southeast of Brasília, central-east part of Brazil. The deposits to be visited are the Morro Agudo (Zn/Pb), the Morro do Ouro (Au), and the Vazante (Zn) mines. During this trip some typical surface rock outcrops will also be inspected.

Details on the local geology, stratigraphy and mineralization of each deposit are presented in appended papers.

The main aspects on the regiopnal geology, including stratigaphy and sedimentation plus some evailable date on geochemistry are presented here.

REGIONAL GEOLOGY

The Zn/Pb Morro Agudo and Vazante deposits are hosted by carbonate rocks of the Vazante Formation, formerly equated to the Bambui Group and now considered as belonged to the Paranoá Group (Dardenne, 1979). The Vazante formation consists of middle to upper Proterozoic carbonate and terrigeneous sediments deposited in a shallow marine and terrigeneous sediments deposited in a shallow marine and tidal flat environment (Madalosso, 1979, 1980). A distinct feature of the Vazante formation is the presence of an algal barrier reef that extends N-S for some 200km. The development of this reef created an isolated laggonal-tidal flat environment of deposition to the west (figs. 6.3, 6.4).

The Morro do Ouro Au deposit at Paracatu is hosted by te overlyng Paracatu formation which consists essentially of blaxk shades with minor quartzit interbeds.

The sedimentary rock units in the region (fig. 6.2) are elongated N-S consisting the Brasília belt. Extensive thrust faulting and more localized overturned folding, originated by a strong eastward compression against the São Francisco craton are characteristic of the region. The reactivation of old N-S faults that had affected the basement would have created the condition for deposition of the various rock units (Campos Neto-1979). Growth faults exist in the area and in places seem to control the Pb/Zn mineralizations. An upper greenschist facies regional metamorphism affected the rocks of the Brasília belt. The grade of metamorphism increases westward.

To the east of the Brasília belb carbonate and terrigeneous sediments of the upper Proterozoic Bambui Group ("sensu strictu") were deposited on the São Francisco craton and are essentially flat lying.

GEOCHEMISTRY/GEOCHEMICAL EXPLORATION

Extensive soil and drainage geochemical exploration, mainly for Zn/Pb was carried out by various companies. Most of these data are however not published and are considered confidential by these companies.

Some data on soil geochemistry south of Paracatu were presented by Alecrim and Pinto (1980). They include analisys of Co, Cu, Pb, Zn, and Mn.

Bez (1979, 1980) studied the geochemistry of Morro Agudo deposit.

A regional drainage survey (including pan concentrates), soil and rock geochemical surveys was carried out by Heineck et all (1980) (tables 6.1 and 6.2).

TABLE 6.1 – SUMARY OF STATISTICS – STREAM SEDIMENT (AFTER HEINECK ET ALL – 1980)

PARÂMETRO	ELEMENTO (ppm)	ÁREA TOTAL (N = 2711)		SEQÜÊNCIA CARBONÁTICA (R = 501)		SEQÜÊNCIA CARBONÁTICA – DOLOMITOS (H = 273)		SEQÜÊNCIA CARBONÁTICA – CALCÁRIOS (N = 228)		SEQÜÊNCIA CLASTICA (N = 2210)		INFLUÊNCIA DE ARENITOS (N = 140)		INFLUÊNCIA DE QUARTZITOS (N = 113)		INFLUÊNCIA DE TUFOS (K = 60)	
TESTES DE DISTRIBUIÇÃO	Cu – AA Fb – AA Zn – AA P – Col P – EIE Fe – AA Mn – AA																
VARIAÇÃO	Cu – AA	L (3)	95	N (3)	50	L (3)	50	N (3)	50	N (3)	95	N (3)	10	3	21	30	170
	Pb – AA	N (3)	680	L (3)	680	L (3)	680	L (3)	90	N (3)	250	N (3)	18	L (3)	22	8	95
	Zn – AA	L (3)	470	4	460	4	460	6	110	L (3)	470	L (3)	24	3	40	7	100
	P – Col	25	2900	50	2400	50	2400	50	1100	25	2900	25	800	50	1100	225	1600
	P – EIE	25	2250	50	2200	100	2200	50	900	25	2250	25	1000	25	900	25	1400
	Fe – AA	0,08	G (10)	0,6	G (10)	0,8	G (10)	0,6	7,6	0,08	G (10)	0,03	2	0,2	6,3	1,1	G (10)
	Mn – AA	L (3)	G (10000)	28	G (10000)	40	G (10000)	28	2800	L (3)	G (10000)	L (3)	440	7	1100		7900
$\bar{X}$ – S	Cu – AA	26,5	15,1	23,8	11,8	24,9	11,6	22,5	11,7	27,1	15,8	4,2	4,0	9,4	4,4	7,6	27,2
	Pb – AA	23,5	51,2	29,2	19,8	30,3	23,3	27,8	16,0	22,3	13,9	4,7	3,9	7,3	4,6	20,7	10,5
	Zn – AA	45,7	31,8	55,6	39,7	65,9	51,0	44,5	25,7	43,4	29,6	9,7	8,6	15,3	8,7	64,6	25,6
	P – Col	455,1	305,7	475,8	286,6	566,2	388,1	377,1	162,4	487,2	310,1	246,1	256,1	254,1	185,5	1461,2	979,0
	P – EIE	499,2	289,0	583,7	302,3	671,4	336,3	479,9	224,2	479,6	278,9	95,2	87,7	165,2	136,3	703,4	409,6
	Fe – AA5	4,3	2,6	4,1	1,7	4,4	1,8	3,8	1,5	4,4	2,8	0,7	0,5	1,6	0,9	7,5	3,3
	Mn – AA	597,3	897,6	693,3	752,5	595,7	677,6	796,7	743,7	567,6	888,0	169,7	194,8	130,1	133,5	1287,8	920,6
G – DG	Cu – AA	23,1	1,700	21,4	1,598	22,6	1,556	19,9	1,615	23,4	1,720	3,0	2.243	8,5	1,567	65,9	1,452
	Pb – AA	19,8	1,805	24,1	1,858	24,1	1,978	24,1	1,711	18,9	1,776	3,6	2,069	6,1	1,799	18,5	1,623
	Zn – AA	37,5	1,876	45,4	1,897	52,1	1,987	38,7	1,711	35,8	1,856	7,2	2,153	13,4	1,696	60,1	1,405
	P – Col	410,4	1,783	407,6	1,745	466,9	1,863	346,4	1,511	411,1	1,792	169,7	2,378	237,8	1,822	1213,1	1,850
	P – EIE	432,1	1,712	518,4	1,629	600,3	1,606	434,8	1,561	414,6	1,716	69,8	2,205	127,2	2,069	607,8	1,724
	Fe – AA	3,7	1,756	3,8	1,500	4,1	1,479	3,4	1,492	3,7	1,809	0,6	1,959	1,4	1,717	6,9	1,519
	Mn – AA	230,6	2,968	469,2	2,423	392,2	2,501	581,4	2,217	305,4	3,046	110,8	2,520	90,3	2,361	1045,4	1,916
PARÂMETROS GRÁFICOS	Cu – AA	24,1	51,5	22,1	43,2	23,4	43,2	20,8	45,8	24,6	51,5	3,6	14,9	8,2	21,7	63,6	136,9
	Pb – AA	20,2	56,3	25,7	76,1	26,0	88,5	24,6	64,1	27,4	60,1	4,1	20,2	6,9	30,5	17,2	55,5
	Zn – AA	38,9	106,5	46,4	129,8	53,3	139,3	41,2	87,4	37,1	96,8	7,9	28,9	13,6	42,7	59,4	103,4
	P – Col	398,6	1238,9	407,0	1258,9	470,6	1552,6	358,7	691,9	408,1	1329,9	168,2	1294,6	246,9	895,2	1317,7	5916,1
G – VL	P – EIE	444,5	906,3	515,7	1134,5	606,8	1348,6	447,6	827,2	432,1	901,8	78,8	351,1	125,4	558,1	636,5	1472,2
	Fe – AA6	3,88	8,89	3,92	7,27	4,21	7,76	3,55	6,55	3,88	9,28	0,61	2,01	1,41	5,15	7,0	15,3
	Mn – AA	405,8	1888,4	553,9	1946,2	378,5	2029,3	638,9	2059,8	323,2	1748,9	128,5	776,6	95,5	572,4	1105,5	2750,1
CURTOSE – ASSIMETRIA	Cu – AA	10,232	– 1,840	9,424	– 1,892	11,606	– 2,224	7,891	– 1,593	10,365	– 1,800	2,153	– 0,398	2,650	– 0,148	2,651	0,316
	Pb – AA	6,400	– 0,472	6,508	0,246	6,368	0,605	5,518	– 0,653	6,212	– 0,746	2,008	– 0,162	3.152	– 0,739	4,020	0,609
	Zn – AA	5,736	– 0,830	5,051	– 0,507	5,529	– 0,620	3,878	– 0,910	5,934	– 0,966	3,176	– 0,814	2,902	– 0,339	15,038	– 2,536
	P – Col	4,470	– 0,249	4,347	– 0,194	3,628	– 0,348	6,636	– 1,096	4,484	– 0,261	2,115	– 0,191	2,787	0,209	2,594	– 0,668
	P – EIE	8,059	– 1,572	5,083	– 0,914	5,339	– 1,015	5,900	– 1,317	8,468	– 1,718	2,373	0,073	3,136	– 0,267	17,893	– 2,806
	Fe – AA5	8,959	– 1,601	5,941	– 0,998	7,180	– 1,027	5,088	– 1,096	8,587	– 1,592	4.900	– 0,975	4,945	– 0,561	6,858	– 0,863
	Mn – AA	3,789	– 0,725	3,658	– 0,498	3,550	0,093	5,566	– 1,416	3,654	– 0,700	8,289	– 1,800	3,792	– 0,011	17,790	– 2,453
COEFICIENTE DE VARIAÇÃO – GRAU DE PETLOÇÃO	Cu – AA	0,169	98	0,153	100	0,142	100	0,164	100	0,172	99	0,726	63	0,210	100	0,089	100
	Pb – AA	0,198	98	0,195	100	0,214	100	0,169	100	0,195	99	0,565	69	0,324	93	0,166	100
	Zn – AA	0,174	99	0,168	100	0,174	100	0,147	100	0,173	100	0,388	89	0,204	113	0,094	100
	P – Col	0,096	100	0,093	100	0,101	100	0,071	100	0,097	100	0,169	97	0,110	113	0,087	100
	P – EIE	0,089	96	0,078	100	0,074	100	0,073	100	0,090	99	0,186	70	0,085	93	0,085	99
	Fe – AA6	0,432	99	0,305	100	0,276	99	0,325	100	0,457	99	– 1,205	100	0,594	100	0,217	91
	Mn – AA	0,188	100	0,144	100	0,153	100	0,125	100	0,195	100	0,197	99	0,191	100	0,093	100

K – S (Teste de KOLMOGOROV – SMIRNOV)
Teste CHI–QUADRADO
L,N ou G ( ) Valor Qualificado
(Ver texto sobre definições e estatística)

ACEITA

$\bar{X}$ = Média aritimética
S = Desvio padrão
G = Média geométrica

ética
ão
trica

DG = Desvio geométrico
VL = Valor limiar

TABLE 6.2 – SUMMARY OF STATISTICS
PAN CONCENTRATES
AFTER HEINECK. ET ALL – 1980

PARÂMETRO	ELEMENTO (ppm)	ÁREA TOTAL (N = 448)		SEQUÊNCIA CARBONÁTICA (N=81)		SEQUÊNCIA CLÁUSTICA (N=364)	
TESTES DE DISTRIBUIÇÃO LOG-NORMAL	Cu – AA Pb – AA Zn – AA Au – AA P – Col						
VARIAÇÃO MIN – MAX	Cu – AA	L (3)	500	6,0	90	3	500
	Pb – AA	L (3)	1200	L (3)	610	L (3)	680
	Zn – AA	6,0	1900	8,0	770	6,0	1200
	Au – AA	N (0,05)	24	N (0,05)	5	N (0,05)	24
	P – Col	100	G (10000)	100	G (10000)	100	G (10000)
$\bar{X}$ – S	Cu – AA	38,5	36,5	36,8	24,4	38,9	38,5
	Pb – AA	81,0	124,0	90,9	145,5	76,7	112,3
	Zn – AA	118,4	128,8	142,8	158,2	109,3	113,4
	Au – AA	0,04	0,09	0,07	0,18	0,04	0,07
	P – Col	1772,9	2441,1	1613,3	2070,3	1806,6	2487,9
G – DG	Cu – AA	28,0	2,229	30,7	1,838	27,6	2,292
	Pb – AA	44,1	3,019	46,9	3,196	43,1	2,934
	Zn – AA	80,0	2,427	94,7	2,496	75,8	2,358
	Au – AA	0,02	3,659	0,02	4,408	0,02	3,410
	P – Col	1038,5	2,818	977,9	2,746	1057,3	2,822
PARÂMETROS GRÁFICOS G – DG	Cu – AA	31,7	1,787	31,2	1,670	30,9	1,854
	Pb – AA	53,0	2,121	58,0	2,093	51,8	2,016
	Zn – AA	94,7	1,888	117,0	1,839	84,9	1,855
	Au – AA	0,05	21,064	0,01	9,028	0,05	5,165
	P – Col	1080,5	2,753	933,6	2,696	1103,3	2,840
CURTOSE – ASSIMETRIA	Cu – AA	4,520	– 0,796	– 2,722	– 0,626	4,482	– 0,760
	Pb – AA	3,680	– 0,614	3,007	– 0,616	3,814	– 0,704
	Zn – AA	3,365	– 0,347	2,359	– 0,263	3,341	– 0,524
	Au – AA	10,009	2,598	6,171	1,947	11,756	2,821
	P – Col	3,315	0,011	2,790	0,105	3,421	0,008
COEFICIENTE DE VARIAÇÃO – GRAU DE DETECÇÃO	Cu – AA	0,241	99	0,178	100	0,250	99
	Pb – AA	0,292	98	0,302	99	0,286	98
	Zn – AA	0,202	100	0,201	100	0,198	100
	Au – AA	– 0,326	13	– 0,399	21	– 0,304	11
	P – Col	0,149	98	0,147	99	0,149	97

ACEITA
REJEITA

$\bar{X}$ = Média aritimética
S = Desvio padrão
G = Média geométrica
DG = Desvio geométrico
VL = Valor limiar

K – S (Teste de KOLMOGOROV – SMIRNOV)
Teste CHI–QUADRADO
L,N ou G ( ) Valor Qualificado
(Ver texto sobre definições e estatística)

TRAVEL ITINERARY

A travel itinerary which will by follow as closely as possible is appended.

Detailed description of the various stops, including detailed maps for the Morro Agudo and Morro do Ouro mines are also appended.

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SUMMARY DESCRIPTION OF SITES TO BE VISITED

STOP 1 - N Orebody

This is the uppermost orebody of the mine extending from surface until the 150 level. The host rocks are dolarenites (grainstones) and dolorudites which are interbedded with the argillaceous dolomitic sequence (SAD).

The orebody consists of fina bands of light vrown sphalerite, bands of silica, fina galena and pyrite. Spharelite predominates at the base, pyrite in the intermediate position and galena at the top.

The orebody is 2,0 to 6,0m thick and the average grade grade is around 10-12% Zn and 3-4% Pb.
Minor normal faulting is frequent.

STOP 2 - Footwal N orebody

Argillaceous dolonmitic sequence (SAD). Slightly carbonaceous laminated argillaceous dolostone with very fine pyrite usually in sub-milimetric laminae.

Sphalerite and galena occur at the contact with the mineralized dolarenites (grainstones) but the grades are not economic.

STOP 3 - Hanging wall SAD and barren dolarenite (grainstone).

Concordant contact betweem the two main rock units in the mine. The strike is N 30° E and the dip 20° NW.

The contact in places seems to be gradational. The dolarenite (grainstone) is barren at this position.

STOP 4 - J-K orebody

The mineralization consists of pale yellow sphalerite predominating at the base with galena more abundant at the stop. Some pyrite is widespread. The host rocks are dolarenites (grainstones) and dolorudites with dolarenite matrix, the latter showing usually better grades.

At the botton of the drive there is a contact with a barren dolorudite (fine grained matrix). The grade is better at the top of the orebody and averages 6-7% Zn and 3-4% Pb.

STOP 5 - J-K orebody

At the top the mineralization is in the dolarenite (grainstone) with fine grained sphalerite and galena as disseminated cement. At the botom a similar mineralization occurs in dolorudite but some coarse grained fracture filling mineralization occurs as well.

Pyrite is less abundant.

The orebody is 13,0m thinck at this position and the grade averages 7-9% Zn and 3-5%Pb.

STOP 6 - L orebody

The mineralization is finely disseminated galena and sphalerite cement in a dolarenite (grainstone). Pyrite is rare.

Lenses of black chert, centimetres thick, are enclosed in the orebody.

The orebody is 9m thick and grade averages 5-6% Zn and 2-3% Pb.

STOP 7 - Lower unit. Dolorudite with micritic matrix

This dolorudite is not mineralized, almost certainly due to lack of original porosity. It is the base of the J-K orebody, wich can be examined at this site (mineralized dolarenite (grainstone) 4-5% Zn).

Big dolostone clasts (tens of centimetres) occur in the dolorudite. Algal stromatolite boundstone clasts can be observed.

STOP 8 - Surface Outcrop

This outcrop at the southernmost part of the mine consists of dolarenite (grainstone) with dissiminated galena and minor sphalerite. Some coarse grained fracture filling

mineralization o ccurs as well.

Underlyng dolorudites are locally mineralized. Metric planar cross-bedding can be obsered in the dolarenite (grainstone).

STOP 9 - Fault at surface

A growth-fault that forms the eastern border of the Morro Agudo mineralization. The fault strike N15°W and dips 75°SW. Narrow (cm) veins of galena occur in a weathered dolarenite (grainstone).

STOP 10 - Drill core inspection

A typical drill hole showing the stratigraphy and various orebodies at Morro Agudo will be inspected.

TRAVEL ITINERARY

Oct. 6 - Friday (evening): Fly Rio-Brasília, overnight in Brasília, accomodation to be arraged.

Oct. 7 - Sat. Early morning - Bus drive Brasília to Morro Agudo Zn/Pb Mine (290km) Mineração Morro Agudo S.A

Arrive at mine site by 11:00 a.m
Presentation Mine geologist
Lunch at the mine cafeteria
Underground Mine Visit
Outcrop examination
Drill core inspection
Evening drive Morro Agudo - Paracatu (40km) overnight at Paracatu - Hotel Veredas.

Oct. 8 - Sun. Early morning drive Hotel-Morro do Ouro Au mine (3km). Rio Paracatu Mineração S/A.

Presentation Mine geologist.
Visit to an exploration pit and old workings.
Visit to an exploration trench.
Visit to an open pit mining bench.
Lunch at the mine cafeteria.
Afternoon visit to individual manual alluvial mining sites ("Garimpos") and outcrops.
Overnight at Paracatu. Hotel Veredas.

Oct. 9- Mon. Early morning drive Paracatu - Vazante Zn Mine (116km). Cia Mineira de Metais.

Presentation - Mine geologist.
Lunch at the mine cafeteria.
Visit the open pit mining.
Visit dlostone outcrops.
Visit the underground mine - (if possible).
Inspect outcrops of dolostones with algal stramotolites.
Evening drive do Paracatu - Hotel Veredas.

Oct. 10 - Tue. Morning drive Paracatu - Brasília airport (250km)

Fly Brasília-Rio or other destinations.

6 a) THE MORRO DO OURO GOLD DEPOSIT, PARACATU, MINAS GERAIS

Antônio Zini
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Alexandre de Souza
RTZ Mineração Ltda.

The Morro do Ouro Project started up in 1980 when Riofinex do Brasil Geologia e Pesquisas Ltda (succeeded by RTZ Mineração Ltda) created an exploration division for low-grade large-tonnage gold deposits, with possibilities of being mined by open-pit methods at low operational costs.

Within the above characteristics, the Morro do Ouro Project developed pioneer techniques during its evaluation stage. Thousands of assays were carried out with intense geostatistical treatment to obtain average grades of the order of 0.64 grammes of gold per ton, which placed Morro do Ouro as one of the lowest grade deposits in the world and the lowest grade hard-rock deposit in Brazil. In addition, innovations were introduced in the treatment unit during the pilot plant stage which processed 4,000 tons of rock during one year of operation to optimize the process.

This present paper is a compilation of the Final Exploration Report presented to the DNPM in 1984. It is, therefore, a non-academic work aimed at quantifying the Morro do Ouro *deposit and developing a technology for the treatment of low grade ore.*

INTRODUCTION

The present work was based on the Final Exploration Report presented to DNPM in August, 1984, condensing the information produced during the years, 1981 to 1984, and represents the state of knowledge of the deposit up to May, 1984. This work was carried out with the objective of determining the reserves and chemical content, having, as its principal point, the sampling and mineral analysis which gave an overall average grade of 0.66 grams per ton of gold.

There this work is to be treated as descriptive only, consideration being given to the relationship of the geology and the genesis of the deposit to the level of knowledge in the literature of the region and not to the more profound objec-

tive functions of the Morro do Ouro Project.

With the effective implantation of the Project in 1986, and the development of the reserves, an ample opportunity opened up for work in the areas of geology, mineralogy, petrology and the origin of the mineralization.

These further studies were able to be carried out to an academic level, with important contributions to the knowledge of this type of deposit.

HISTORY

Gold was discovered in Paracatu by pioneers in 1734, simultaneously, in two locations: the streams of Rico and São Domingos.

Since that year until the abolition of slavery in 1888, intense manual work was made as much for gold in the rocks as in the alluvials. Consequently, almost all the alluvial drainages that radiate from the Morro do Ouro and all the flood areas near them were stirred up and mined, as well as the surface cap of weathered rock which covers the Morro do Ouro. These works continue today, principally based on a rudimentary system of sluices and panning.

In the period, 1977/1978, non-systematic investigations were carried out by Enjex Mineração Ltda with the objective of testing the chemical content and distribution of gold. This company was a subsidiary of New Jersey Zinc and the work was carried out under the permit issued to cover the central-west portion of the Morro do Ouro. The work consisted of sampling the walls of old open-cuts and old adits old pits.

The results obtained did not encourage the company to proceed with the work.

Later, in 1980, the area was the object of an application by Mineração Rio Xingu Ltda, in reality Billiton Metais S/A, after they had carried out re-sampling in pits, old walls and adits.

During 1980, RTZ Mineração Ltda carried out surveys of the gold occurrences in central Brazil in a search for targets of this metal. The attention of RTZ was drawn to Morro do Ouro by the numerous old workings that are scattered in an area approximately 6km wide by tens of kilometres long, and also by the existence of preliminary studies made by the above mentioned companies.

LOCATION

The area of the Project is located on the hills immediately north of the city of Paracatu, in the county of Paracatu, Minas Gerais, and it is located by the co-ordinates 17°13'01" South and 46°52'17" West, in the locality known as the Morro do Ouro (fig. 6.1).

The site of the Paracatu county is situated beside the BR-040 Belo Horizonte-Brasília highway, 239km from Brasília and 500km from Belo Horizonte. It can be reached by car in about three hours from Brasília and in about six hours from Belo Horizonte.

There are various commercial bus services from Paracatu to the two capitals and vice-versa.

The access to the exploration area is made by turning at an intersective on the BR-040, which is 2km from the area.

Paracatu has an airstrip with a thin asphalt surface which is licensed by the Air Ministry, and which permits aircraft of the Bandeirante type to land. There are no scheduled flights.

PHYSIOGRAPHIC ASPECTS

The climate of the region is the Tropical Altitude type, encompassed in the Aw classification of Koppen, where the dry period is in winter, from April to September, and the rainy period occurs in summer, October to March. The average annual temperature is around 22°C. The average rainfall varies, approximately, between 900mm and 1,350mm.

The town of Paracatu is at an altitude of 688 metres and the deposit is at altitudes varying between 645 and 837 metres. The regional relief is of plains and smoothly undulating hills, with altitudes varying from 500 to 1,000 metres. To the west of the area the hills, orientated north/south, stand out, and the Morro do Ouro is found in these hills.

The area is drained by streams which originate in the Morro do Ouro itself and in other hills to the west and north. Of the streams that flow to the south towards the town, the streams of Rico and Praia dos Macacos stand out. To the north are the streams of Eustáquio, Bandeirinha, Santo Antônio, São Domingos and Ribeirão Santa Rita. All these streams are tributaries of the River Paracatu, which flows into the São Francisco River.

The predominant vegetation of the region is of the shrub type, typical of Central Brazil. This vegetation is characterized by the presence of three distinct forms: arboreal, bush and herbaceous. The bushes and trees have deep roots which reach the water table 15 to 20 metres below. Thick woods also occur in the form of patches along the valleys formed by the water courses.

REGIONAL GEOLOGY

Within a broad geological context, lithologies belonging to the Vazante and Paracatu Formations (Dardenne, 1978) predominate in the Paracatu region.

These lithologic types, considered as belonging to the Bambui Group, are charactrerized by miogeosynclinal deposits bordering the São Francisco Craton (Costa et al., 1970), and suffered various stratigraphic distributions since Braun (1968) until the present day, as shown in Table 1, presented by Costa and Romagna (in this volume).

As it is not our objective to discuss each of the classifications, we will mention that adopted by Dardenne (1978) and detailed by Madalosso (1979).

As well as this, chemical-terrigenous rocks from a shallow marine environment predominate in the region in the depths of the Vazante and Paracatu Formations (figs. 6.2 and 6.3).

Vazante formation

This formation is distributed to the west of the Paracatu city and forms a north-south band of approximately 10 to

15km wide, which extends to the south as far as Coromandel, passing by Vazante, and to the north as far as Unai, with a total length of more than 200km.

The Vazante Formation is composed of a range of varied carbonate/terrigenous rocks developed in a shallow water environment. Reefal stromatolitic dolomites, in lateral facies, in which important deposits of zinc and lead are found, also occur. Summarising, it includes clayey carbonates, slates, metasiltites and sandstones. It is estimated that the thickness is greater than 2,000 metres.

To the south of Paracatu, the Vazante Formation has been divided into the following facies, from west to east:

- Morro Agudo facies;
- Serra do Landim facies;
- Serra da Lapa facies;
- Serra do Velosinho facies;
- Morro do Calcário facies;
- Serra do Garrote facies;

Though having longitudinal persistence facies, one of the characteristics marking the Vazante Formation is the great change of facies, laterally and vertically, with the same detail, the more usual form of change being that of interdigitation.

The rocks have a general direction between N30°E and N30°W, with a regional plunge of 15 to 30° to the northwest and southwest, respectively (fig. 6.2).

The age of the Vazante Formation rocks has been determined by radiometric methods and by stratigraphic correlation based on stromatolitic structures of the Conophyton type. It is concluded as being of the Middle to Upper Proterozoic Period (600-1,900Ma).

Paracatu formation

This formation is distributed to the north and west of Paracatu and follows an approximately north-south direction (fig. 6.2).

The Paracatu Formation is essentially composed of a thick sequence of graphitic phyllites with interbedded layers and lenses of impure quartz sandstones, generally quartzitic. This overlays the Vazante Formation, particularly the lithologies of the Serra do Landim Facies, whether by reverse faults and slips or through normal and transitional contact.

There is a lack of regional studies to determine the type of depositional marine environment of these rocks, but they appear to have been deposited in a shallow to moderately deep marine environment. Locally, it denotes a calm, rhythmic terrigenous and chemical deposition.

The facies changes, therefore, are less frequent than in the Vazante Formation, but are common on smaller scale.

The Paracatu Formation can be informally subdivided in to the followyng regions, from bottom to top:

- Morro do Ouro facies, of a restricted marine environment, and
- Serra da Anta facies, of an open sea environment.

Tectonically, the Paracatu Formation exhibits less intense rigid deformations than the overlarying formation, enabling its deposition to have occurred after then, with the deposition polarity changes in its sediments. West to east and much younger east to west forces affected the Vazante Formation and the Paracatu Formation, creating a complex system of fractures and longitudinal and transverse folds.

Regionally, the rocks follow the same directions as the Vazante Formation, with similar plunges (fig. 6.2).

LOCAL GEOLOGY

Locally, the rocks of the Morro do Ouro area are at the base of the Paracatu Formation, whose sequence is informally called the Morro do Ouro facies. This sequence shows the following lithostratigraphic units from the base to the top (fig. 6.4):

T1 - This is the transition unit between the Serra do Landim facies of the Vazante Formation and the Morro do Ouro facies of the Paracatu Formation. Except for the foot of the Morro do Ouro to the north, northwest, east and southeast (fig.6.3), it is made up of slates and graphitic phyllites with interbedded horizons at quartzitc and impure quartzitic clayey lenses. The coarse sediments, generally discontinuous but persistent, are able to form three or more horizons or a single thicker horizon of up to 5 metres thick.

They are generally cut by veins of coarse quartz with pyrite and a little carbonate.

A) This is the basal unit of the Morro do Ouro facies itself and constitutes the footwall of the mineralized horizon.

It occurs on the north flank, the northeast and southeast of the Morro do Ouro structure and in the lowest part of the streams which cut them to the south (fig. 6.4).

As with the previous unit, it is made up of lightly carbonate, graphitic, clayey-siltic phyllites with thin interbedding of impure clayey quartz sandstones, generally quartzitic and, at times, recrystallized.

The rock can show rare boudins of quartz, which are concordant with the principal foliation, discordant quartz veins also being common.

The phyllite is mainly constituted by muscovite, quartz and chlorite. The common sulphide his pyrite, at times arranged in a rhythmic configuration, and rarely arsenopyrite.

Geochemically, the facies are slightly anomalous in arsenic and the gold content is lower than 2.20ppm. Its thickness is about 30 metres and its passage through the upper unit is more or less abrupt.

B + C) These are the upper units carrying the gold. Originally, they were separated in the mapping, as

they were thought to be different lithological units. The division was maintained after the correction of the error because of its use in the technological classification of the material for the future treatment plant.

The units dominate the Morro do Ouro outcrop in the area, with the B-unit predominantly occurring in the north, northeast and southeast of the Morro do Ouro structure and the C-unit extending from the northweast to the southeast, always occupying the most elevated positions (fig. 6.4).

In reality, it is treated as a sandy clay-silt graphitic phyllite with a rhythmic aspect in the alternation of the light sandy-silt plates and those dark clayey graphitic ones, with boudins of quartz. On the surface, or when little weathered, their colour is dark grey with clear plates (Unit B); but when weathered is of a grey-yellow/lilac colour, sericitic and oxidized (Unit C). In its upper part, a persistent quartz sandy level occurs and this has been used as a marker horizon (Ar 2). It is composed of quartz (97%), sericite (3%), opaques (less than 1%) and traces of leucoxene, zirconite, apatite, tourmaline and epidote, and it is sometimes massive and boudinaged or banded to lenticular, in alternation with the phyllite. When massive, it presents lenses and layers of up to 2.8 metres thick with interbedded phyllite, it can reach thicknesses of up to 5 metres, with individual layers of from 1 to 35cm.

When it is massive it is common for it to be cut by centimetric quartz veins. Concentrations of arseno-pyrite and/or pyrite are common when the rock is fresh.

The phyllite is mainly constituted by muscovite (50%) and quartz (45%); in addition carbonates (2%), plagioclase (1%), tourmaline, leucoxene and epidote occur. The opaques are represented by pyrite, arsenopyrite, pyrrhotite, tetrahedrite, galena, sphalerite, chalcopyrite, gold, magnetite, ilmenite and hematite.

In the weathered portion the sulphides and the carbonates are very rare, and are represented by ferruginous boxworks filled or coated by hydrated iron oxides.

The boudins of quartz are distributed in an irregular pattern, but locally form concentrations. Their size varies from millimetres to metres. Geochemically, the B + C unit is the gold-bearer (0.20 to 24.00 ppm) and is also anomalous in arsenic (from 200 to 4,500 ppm).

The thickness of the B + C Unit is about 200 metres in the northeast of the Morro do Ouro structure, and may be more than 100 metres thick in the southeast, giving an average of 70 metres.

The thickness of Unit C varies with the topographical position and the intensity of fracturing and may be from a few metres to 50 metres with an average of 35 to 40m.

The passage from B to C is transitional, with all the graduations between oxidised to non-oxidised materials. Its thickness is variable from one metre to more than 10 metres and it may be outcropping or sub-outcropping.

Laterite/Lateritic Metapellite - In the most elevated parts of the Morro do Ouro, mainly in its central-north portion, there is a cap of concretional laterite, at times, massive and extremely hard (fig. 6.4). It is discontinuous, and in one place it was removed by previous works, and its thickness is very irregular, varying from a few centimetres to 3 metres. The greatest thicknesses occur where the quartz outcrops.

In the northeastern portion of the Morro do Ouro, concretional laterite is found in thicknesses of 1 metre. The laterised phyllite is commonly found in the area, mainly to the southeast of the Morro do Ouro.

D) This unit is the cap of the mineralized sequence, and occurs to the west of the Rico stream, the area being shown in figure 6.4.

It can be considered as a graphitic phyllite with little rhythm and more homogenous than the previous types, with thin lenses of quartzitic sandstone. It is commonly to be cut by quartz veins of a few centimetres to 20 centimetres thickness, concordant or discordant with the main foliation. It is mainly composed of quartz and sericite, and rarely, of pyrite.

On the surface, its alteration gives rise to an extremely red soil, which is lateritic and rich in opaque magnetic minerals. Its thickness was not determined, but it may be of hundreds of metres.

Alluvial Sediments - Four main drainages radiate from the Morro do Ouro: the streams Estáquio, Santo Antônio, São Domingos and Rico. Near to the Morro do Ouro, all them show an excavated profile with coarse sediments and few alluvials.

The alluvials in the work area are found in the headwaters of the Rico stream and its principal tributary, the Praia dos Macacos, chiefly to the north of the BR-040. They are predominantly coarse sediments, mainly made up of sand and pebbles, and blocks of quartz, laterite and quartzitic sands. Decimetric clayey levels are also seen. While in the Praia dos Macacos and the tributaries that emenate from the Morro do Ouro, there alluvials which are encased, reduced and coarse, the Rico stream locally shows an assymetric polarised alluvial plain, which can reach a width of 250 metres, more clayey and less coarse than its present bed.

The transverse profile is very variable and irregular, and, in the actual location where it is found, the thickness of the bed may reach some 3 metres.

At the locality where gold was historically discovered in Pracatu, the active alluvials of the Rico stream are still worked by tens of prospectors.

Soils - The soils that cover the mineralized rocks of the Morro do Ouro structure occupy a less important place. Almost always lateritic, they show reduced thicknesses, are generally transported and without differentiation.

Only over the rocks of the Basal Transition Unit, and mainly over the cap unit is there a significant soil, where, to the west of the Rico stream, it reaches a thickness of 4 metres. It is clayey and very sandy, and it is common to find ferruginous concretions (fig. 6.4).

TECTONICS

Generally speaking, the tectonism of the Morro do Ouro area is very discrete.

A detailed analysis, however, permits the distirotiur of at

least four main fracture systems, some of which overlap and are:

- N10-30°W/50°-60°NE
- N10-30°W/50°-60°SW
- N10-70°E/50°-60°NW
- N-S to N10°E/70°W to NW

The first system appears to be the oldest, and is represented by steep folds of millimetric and centimetric size. The force was from the northeast to the southwest.

The second system is characterized by forces from the southwest to the northeast and made well-defined zones in the previous system and produced mainly reverse faults.

The third system was also due to compressive differentials, producing transverse faults of the reverse and trailing type.

The fourth system, the most discrete, is characterized by stretching forces, producing fractures with planes to the southwest, which are filled with quartz.

The plastic tectonism is evident in the small isoclinal folds lying or a northeast/southeast axis, and in step folds. Syn-sedimentary structures of the slumping type are relatively common, mainly at the borders of the structure, denoting slippage in the deposition basin.

The behaviour of the rock layering is somewhat peculiar, but in overale terms, varies from the subhorizontal to 10° in the northwest and central portions, and more than 30° in the southwest portion, near the Rico stream.

The peculiarities are linked to the paleogeography, and, at the borders of the structure, the directions vary from the NE, in the southeast of the Morro do Ouro, charying to the N-S, E-W and NW.

The main rock foliation, S_1, is parallel to the layering S_0. In a few rare cases, schistosity S_2, containing the main foliation and layering, was observed.

The rocks show a low degree of metamorphism, but locally they have a schistose aspect due to the local concentrations of quartz boudins and intense shear zones.

PALEO-ENVIRONMENTAL DEPOSITION

The Paracatu Formation, near the four of the same name, forms an appendi to the east-northeast, which is somewhat abnormal to the general direction of its rocks and to the adjacent sequences.

During the fieldwork, special attention was given to this detail, and the configuration of the structure in a trough, with a SW-NE axis, open, and plunging to the southwest.

It does not appear to be a tectonic structure, but a structure developed as a result of a paleogeographic element, such as a paleobasin or inlet.

This paleogeographical situation must be responsible for the special physico-chemical conditions, characteristic of a restricted marine environment, creating favourable conditions for the deposition and formation of particular lithological facies, and the deposition of metallic elements in suspension, amongst others, gold.

Therefore, the factor that first controlled, and may be the most important, the deposition of the auriferous sediments of the Morro do Ouro, was the paleogeography.

THE AURIFEROUS MINERALIZATION

The gold occurs in three different forms in the rocks of Morro do Ouro.

- Free gold, in silica concentration, such as boudins of quartz;
- Residual gold, the result of the decomposition of sulphides mainly those of pyrite and arsenopyrite; and
- Gold in sulphides, distributed in the structures or in the microfractures of the iron or arsenic sulphides.

Based on the geostatistical treatment of samples, it is evident that there is no preferential gold distribution in accordance with any considered orientation. The facts demonstrate that, locally, the gold is diffused throughout the rocks in a more or less regular manner. In detail, however, it can be verified that the major concentrations of gold are in the boudins of quartz (treatment of the samples demonstrated that 90% of the total contained in the rock was found in these structures). More recent observations confirm, furthermore, great concentrations of gold linked to the limonite box works derived from the weathering of carbonates.

With respect to the grain size, the gold is extremely fine and difficult to see with the naked eye. Nevertheless, when compared with certain deposits of the Carlin type, the gold of the Morro do Ouro would be considered coarse. Microscope studies reveal that the granulometry of the gold varies from 1 micron to 800 microns, with an average of:

- Table concentrate = 160 microns
- Flotation concentrate = 3-7 microns

Testing for trace elements in the primary gold of the Morro do Ouro, two samples of gold showed the presence of elements in accordance with the following table:

ELEMENT / SAMPLE Nº	Ag	Pt	Pd	Cu
33,534(B)	0.59	0.05	0.01	0.020
33,533(C)	0.38	0.05	0.01	0.004

CONTROLS

In respect of the mineralization controls, the work carried out up to now permits one to visualize two main controls:

- Paleogeographical control - The paleogeography

created favourable micro-environmental conditions for restricted and calm deposition. At the borders of the structure the chemical content tends to be lower, increasing in the direction of the axis, from northeast to southwest;

- Lithostratigraphical - In the micro-environment, lithologic type particles were deposited together with gold. It is in this form that the gold is found in Units B and C, which reflects a low energy deposition in not very deep waters, with Eh and pH conditions favourable to the syngenetic precipitation of gold.

The tectonism was not sufficiently intense to provoke a gold concentration in the boudins of quartz, nor in the deformation zones.

GENESIS

At present, there is nothing conclusive concerning the genesis of the gold at Morro do Ouro, as there is a lack of studies carried out to this end. What do exist are ideas and hypotheses supported by field work and general observations which must be taken with many restrictions, since more conclusive data has not yet been produced.

As a preliminary, some general observations can help in the understanding of the genesis of the auriferous deposit:

- Magmatic sources near the Morro do Ouro, outcropping or not, are not known;

- There is no evidence of the gold being detrital, as the coarse sediments are very poor in this element and the gold is distributed isotropically in the deposit, as well as not having the sedimentary structures that show a detrital transportation;

- There is no evidence of intense hydrothermal activity, as there are no common veins of quartz, and gold concentrations along the junction of the veins, or fractures do not exist.

One possible hypothesis is that the gold migrated to the marine sedimentary environment through deep fractures which would have permitted the demonstration of distant magmatic activity, as supported by the tectonic miogeosynclinal sedimentary behaviour in which the Morro do Ouro is encased.

With notable paleogeographical control, the gold, in the form of complexions, would have met physical/chemical conditions favourable to precipitation, together with Cu, Pb, Zn, Fe, in chemical/terregineous sediments. Thus, gold would have deposited syngenetically, with submicroscopic grain sizes.

In the diagenetic phase, tectonic forces from east to west induced the migration of silica saturated solutions, resulting in the formation of the silica boudins. In this short silicate solution migration, Fe, As, Cu, Pb, An, carbonates and gold would have been carried and deposited with the silica. In this phase, the first concentration of gold, together with the boudins, would have occurred, as the first increase of the sub-microscopic origins of gold. The tectonic deformations which followed were not capable of mobilizing and concentrating gold along the fractures or in the shear zones.

A supergene enrichment has continued over the years until today by the decomposition and leading of the mineral components of the auriferous rocks, thus concentrating the gold.

COMPARISON WITH OTHER DEPOSITS

Compared with the recent classifications of low grade gold deposits, it is easy to see that the geological characteristics of the Morro do Ouro do not fit into any of the categories that have been described.

However the geological characteristics of the Morro do Ouro, as presently known, are not so fundamentally different from the low grade gold deposits in sedimentary rocks, mainly in the United States and Australia

Three main characteristics stand out as exceptions:

- Proterozoic Age;

- Absence of magmatism;

- Absence of conspicuous hydrothermal activity

With respect to the age, the fact that the low-grade gold deposits, known until now, were restricted to the Phanerozoic Era and appear to be the result of limited research dedicated to the older low-content deposits. There is no good geological reason to justify the absence of gold deposits in rocks older than the Cambrian.

At first sight, the tendency is to compare the Morro do Ouro with the Carlin Mine deposits, which are similar to those such as Telfer (Australia), Haile (South Carolina, U.S.A.), Alligator (Nevada, U.S.A.), and Ortiz (New Mexico, U.S.A.), but serious restrictions are immediately evident, not only the geological age, but mainly the genesis, transport and deposition of the gold. In all, it is clear a direct or indirect action of magmatic bodies occurred in the present surroundings of the gold mineralization.

PROSPECTING METHODS

Preliminary Geological/geochemical Survey

The preliminary sampling of the Morro do Ouro consisted of a geological/geochemical reconnaissance of the top and part of the east of it along the Cachoeira stream, by a non-systematic collection of rock samples.

The rocks were analyzed for gold using fire assay (the crucible method) and for copper, lead, zinc and arsenic, atomic absorption. The content of gold varied from 0.10 to 22.76ppm, and that of arsenic, from 25 to 7,000ppm.

This work gave a preliminary idea of the gold content and permitted not only the establishment of the stratigraphy but

also the preparation of the first geological/geochemical profiles.

Regional Geological/geochemical Survey

The regional geological/geochemical survey was carried out with the objective of defining and discovering possible targets of gold mineralizations similar to that of the Morro do Ouro in the areas to the north and south of Paracatu.

These works resulted in the discovery of a gold occurrence to the west of the Canto mountain, locally known as the Fazenda Lavras. The area of occurrence had already been the object of old prospecting work. For a more detailed survey, the occurrence was subjected to topographical, geological (1:5,00) and geochemical work on the surface rocks, shafts and trenches.

The work showed a gold occurrence linked to the rocks of the same type as those of the Morro do Ouro, but with an outocropping area too small to justify any additional work.

Soil Sampling

The soil sampling, which had already been used for the regional work covering the areas to the north and west of the Morro do Ouro, was also used in the southern portion over rocks already known to be mineralized.

This was carried out following an east to west profile at spacings of 250 metres, and along the roads. Whenever an outcropping rock was found it was sampled too. The soil samples were analyzed for arsenic, although the rocks were analyzed for arsenic and gold. In this programe, the arsenic content reached 5,000ppm in the rocks and between 250 and 500ppm in the soils. In the latter, it was common to find arsenic values of 1,000ppm. This work and the subsequent exercise of comparing the chemical contents of arsenic and gold in the rocks permitted the observation that there is not a straight correlation between arsenic and gold. As a consequence of this, not only was the soil sampling abandoned, but also the arsenic analysis.

Rock Sampling

Sampling Tests

As a consequence of the decision to take only rock samples, various sampling tests were prepared in different standard channels and sample volumes.

Thus the sampling channels for test were:

15cm. wide x 5cm. deep x 200cm. long, giving a sample of 30 to 35kg;

15cm wide x 5cm. deep x 100cm. long, giving a sample of 15 to 20kg;

5cm. wide x 5cm. deep x 200cm. long, giving a sample of 10 to 12kg.

5cm. wide x 5cm. deep x 100cm. long, giving a sample of 5 to 6kg.

The results of the analysis for gold were compiled and compared, and the sampling that proved to be both practical and representative from the statistical viewpoint was the channel of 5cm. wide 5cm. deep x 100cm. long, giving a sample weight of 5 +- 6kg.

All the geochemical sampling of the rocks of the Morro do Ouro in all the different patterns used, followed this standard.

Gold Analysis Tests

The test that preceeded the systematic sampling work of the Morro do Ouro was that of the comparison of the methods of gold analysis: Fire assay and atomic absorption.

The results showed that atomic absorption, as well as giving erratic results, would also show chemical contents of up to 30% lower than those of fire assay, because of problems probably due to the type of opening used and the small quantity of the sample used in the analysis.

It was because of this that, at the start, the fire assay method was adopted for it permitted the use of a larger quantity of the sample and thus became more representative.

As well as this, samples were, at the beginning of the work, analysed by the crucible method at Brazilian laboratories and overseas. In Brazil, the UNIGEO laboratory was used, and overseas the samples was sent to South Africa and Zimbabwe.

However, the volume of the samples together with their large number and the cost of their transport made the company aware, quite early on, of the need to have a laboratory in the vicinity of the project. Therefore, a fire assay equipment was installed at Paracatu, with checking being carried out in the laboratories of the RIO ZINC MANAGEMENT SERVICES in Johannesburg, South Africa. Even today, 10% of the samples analysed in Paracatu are re-analysed by the RIO ZINC MANAGEMENT SERVICES for checking and control.

Systematic Sampling In Surface Rocks

A programme of rock sampling in a regular grid was carried out in the southern portion of the Morro do Ouro, and later extended to the east and north-northeastern portion. By the end of 1982, all the Morro do Ouro had been sampled.

The following was used for the sampling criteria:

- Only samples of rocks;
- Channels perpendicular and vertical to the layering;
- Rock description and visual estimation of the boudins of quartz.

The initially adopted grid was 300 metres x 50 metres to the south of the Morro do Ouro and 200 metres x 50 metres to the east and the north-northeast. Later, intermediate sampling lines were intercalated with sampling at 100-metres spacing. In the central area of the Morro do Ouro, the sampling was of 100 meters by 100 metres, with a later reduction to 50 metres where the content of gold showed

itself to be better. The content of gold in the samples varied from 0.04 to 24.31ppm. The average, however, was 0.518ppm. with the best values situated in the central-southwest of Morro do Ouro.

In the central-northeast, the values were less, with erratic and anomolous results. Based on the rock geochemistry it can be seen overall that the values tend to diminish towards the borders of Morro do Ouro. It was also possible to observe that the coarseness in values tended to be progressively better than the average as they approached an imaginary axis, a SW-SE.

The major part of the detailed work that followed was concentrated on the central-southwest area where the best values were found.

Laterites

In the topographically more elevated parts of the Morro do Ouro there occurs a cap of laterite or lateritic phyllite.

With the objective of sampling the distribution, thickness and gold content, 1-metre channels were dug. The shafts were sparsely distributed in a manner that covered the main area of the occurrence.

Nº of trenches	7
Total linear cut	11,696 meters
Volume excavated	4,296 cubic meters
Nº of samples	2,806
Weighted average of gold	0.6289 g/t

Shallow Trenches

The gold content was less than that expected (0.48 gm/t), possibly because most of the covered area is situated over rocks with much lower gold values.

Galleries

Five galleries were sampled, positioned in the various units of Morro do Ouro. All of them were situated in the southeastern part of the hill. The samples were collected from vertical channels of 100cms. x 15 cms. at 5-metres intervals, and were analysed for gold and arsenic.

Summary of the work and its results:
Shallow Trenches

Trenches were made with the purposes of better exposing the rocks to be studied, collect rocks samples and to test vertically and laterally the gold distribution. The trenches were dug in the more sloping points of the Morro do Ouro near the drainages, in a manner that made it easy for their construction and for the interception, as much as possible, of the stratigraphic thickness. The first trenches were sampled in vertical channels measuring 100cm x 15cm x 5cm; the later ones were sampled completely with horizontal or vertical channels, generally of 100cm. size and, rarely, 200cm.

With the object of defining and testing for possible concentrations of gold close to the fracture zones, some trenches were opened in the main fracture and micro-fold zones of the area. These shallow trenches followed an E-W and N-S direction over the area of the best gold chemical content, and were sampled in a continuous manner with horizontal or vertical channels 400cm long x 7 cm wide x 3cm deep, which resulted in a sample of 20kg average weight. The summary of this work is shown in the Table below:

Nº of sampled galleries	5
Total leaght	281m
Nº of samples	106
Average grade (gold)	0,405 g/t
As grade	de 300ppm a 4.500ppm

At intervals, where the gold value approached 1 g/t, trenches were deepened to 2.80 metres for the purpose of testing the chemical content at depth. In all the cases tested it was confirmed that the chemical contents of 1 g/t were restricted to the surface and were caused by supergene enrichment. The work of sampling and analysis was followed by mapping, counting and classification of the fractures along the trenches, and their correlation with the chemical content of gold. The studies show that there is not a strong correlation between these chemical contents and the tectonic deformations of the rocks.

Drilling

The first drilling work carried out at Morro do Ouro had the objective of obtaining the parameters of the physical characteristics of the rocks and gold recovery, as well as a preliminary knowledge of the distribution of the mineralized rocks and their gold values at depth. Three bore-holes were made, and the core were analysed for gold at one-metre intervals. As a result of this first programme it was possible to see the recovery problems and those of core contamination, as well as, in spite of the drill diameter used (HX and NX), a weak representation of the rock. As for the content of gold, it was proved that it extended some 38 metres with an average of 0.29 grammes per ton.

The subsequent drilling campaign made a systematic grid of bore-holes along the two E-W lines (19 bore-holes) with a spacing of 200 to 400 metres between the them. The depth of the bore-holes varied from 17.50 metres in the East of the area, to 90 metres in the west, and the cores were sampled at 2-metres intervals. Parameters of weathering and hardening of the rock were also observed.

The whole analysis of the 2,200 metres of drilling gave the following conclusions listed below.

- The mineralized rocks of Morro do Ouro are distributed to the north-northeast, in the same facies as known to the west-southwest; their actual thickness varies from 22 metres to the east-northeast to more than 140 metres in the extreme west-southwest.

- The unit which constitutes the base of the mineralized facies was cut at 22 metres to the north-northeast/east and at 90 metres depth in the central portion of the

Morro do Ouro structure.

- A quartzitic layer, with a thickness varying from a few decimeters to 3 metres, was identified almost at the top of the mineralized sequence, and used as a "marker layer".

- There was no evidence of any gold enrichment at depth. Average isocontent curves from the bore-holes confirmed semi-elipses open to the sothwest, with the best content following a SW-NE axis, possibly an appearence of the paleogeographic structure which controlled the sedimentation and gold concentration.

- The preserved thickness of the weathered rock is a function of its stratigraphic position and of the topography, and it varies from a few metres to more than 50 metres, having an average of between 35 and 40 metres.

- As it shows that "C" is the weathered facies of "B", its thickness in bore-holes, when projected, is shown to be more reduced than on the surface.

Pit Excavations

The limitation of information supplied by drill-cores, as well as the necessity for not only more significant samples for chemical analysis, but also for samples of a larger volume for treatment in the pilot plant, gave reasons to begin a programme of manual pit excavations. The objective of this was to have a more accurate decription, study, rock sampling and the correlation of all these parameters with the derivatives of the volumetric samples in the pilot plant, as well as to supply good information for the ore evaluation.

Preceeding the programme of shafts in a grid in the area of the best gold content, sampling of rocks in deep trenches was carried out with the object of obtaining a variogram, which would determine the optimum spacing between the shafts without prejudicing confidence in the average content of gold. The location of the deep trenches, with a view to detailed sampling for statistical treatment, required the two following parameters:

- an area free of deep excavations to allow the sampling along the same stratigraphic horizon;

- an area with good gold values. The trenches were opened to a depth of 3 metres. The sampling was made as follows:

- surface free of the lateritic cap;

- sample level 1 metre below the surface;

- vertical samples from both the walls in horizontal channels of 500 cm x 5 cm x 5 cm in between and linked to the vertical samples.

In the laboratory, the samples underwent preparation and routine analysis, with four fusions of 75 gm from each sample.

The tabulated gold content and their statistical processing gave a variogram which indicated an optimum spacing of 100 metres. From this, the programme of shafts was based in a grid of 100 x 100 metres, covering the area with the best gold content, based on the previous work or drilling and surface sampling. Initially, 150 shafts were programmed with the idea of dividing them into blocks of 30m for the formation of lots and for the approval of the excavated rock in terms of its processing in the pilot plant. The following system was adopted for the excavation of samples from the shafts and for the storage of the excavated material:

- circular shaft of 80 cm diameter;

- manual excavation with shovels;

- removal of the excavated material with one-metre intervals near the collar of the shaft, stored and protected by plastic covers;

- taking of samples from the four diametrically opposite faces. Samples of 100 x 5 cm size.

Based on the chemical content obtained in the sweeping phase it was programmed to reduce the grid from 100 x 100 to 50 x 50 metres, covering a small area having the highest gold values. In total, 199 bore-holes were made in the 100 x 100-metre grid (equivalent t0 2,169 metres cut), with an average depth of 11 metres and an average overall weight content of 0.630 gm/t. In the 50 x 50-metre grid, 81 bore-holes were made (1,087 metres), with an average overall wight gold content of 0.759 g/t.

RESERVES

Preliminary Considerations

All the geological/geochemical data generated, as previously catalogued and codified, were treated by a specially developed computer programme which enabled the integration of homogeneous information systems and the comparison/correlation of heterogeneous systems.

From the analysis of the directional variograms that determined the optimum distancing of the research shafts, to the calculation of the reserves, including the distribution of the various lithologies of Morro do Ouro, as well as the integration of such data as a percentage of the quartz boudins, carbonates, fractures, and their correlation with the content of the gold, the computer analysis was extremely valid. The Kriging method of computer-modelling was used for the mining blocks.

Generally speaking, the geostatistical data supplied from the computer greatly helped the interpretation of the area and helped to confirm the ideas and concepts developed until then.

Measured Reserve

The reserves presented in this study represent the present stage of ore evaluation, but its geological potential is still open. The sum total of these reserves, mainly the measured category, is limited in depth by the method used and by the area tested up to May, 1984. The reserves were calculated on the basis of 199 bore-holes in a regular grid of 100 metres and 55 shafts in a regular grid of 50 metres. For the calculation of the average reserves the cross-section method was employed, using east-west sections. The following points were considered:

a) the dry-base density of 2.15 used is the average of 20 determinations with samples of more or less 8 litres, taken from different depths of 0 to 21 metres;

b) the volume is the product of the section area and the zone of influence (Zi), intersections of 50 metres to the north and to the south and of 25 metres in the marginal sections. The sections were divided into intervals limited laterally by the shaft line, and at the bottom of the trace joining the bottom of the shafts, and at the top, by the topographical profile configuring the area of the interval (a) above; the zone of influence in the eastern and western extremities of each section were limited to 25 metres by the cut, as much by the measurement of the area at the respective intervals.

c) the gold content at each interval is the wighted average of the contents of the shafts limited by their depth; and for each section the weighted average of the chemical content of each interval with its tonnage;

d) the total tonnage is the sum of the section tonnages whose final content is the weighted average of the section content with their respective tonnages.

The Table below shows the total average reserves in each section with a cut-off grade of 0.50 g/t of gold:

Relation of Reserves by Sections

a) Reserves with a cut-off of 0.50 g/t:
(table bellow)

Below the cut-off of 0.5 g/t of gold, the average reserve is 3,199,431 tons and 0.417 g/tonne.

Indicated Reserves

The indicated reserve calculation is based on 18 bore-holes distributed in the area of the shafts and their neighbourhood and on the lithogeochemical data of the surface and on lithologies, which they amplify by the similarity of their characteristics and behaviour, and the area utilized for the calculation of the average reserves.

For the indicated reserves, "Unit C" was used below to the cut line of the shaft bases used for the calculation of the mesured reserves, just to the lower limit of the unit B. It is sufficiently weathered to be scarified and used for treatment following the flowsheet adopted for the treatment plant.

The cut-off grade used was the same as the measured reserve, the bore-holes or their lower portion having been excluded from the depth from which the arithmetic mean of the chemical contents no longer had a value of 0.50g/t of gold.

The final grade adopted was the weighted average of the grades of the contents of the interval at the base of each shaft, coincident with the bore-hole, or from the surface when non-coincident, just to the lower limit of the "Unit B Hole", with its size: (see table bellow)

Section	Tonnage	Grade
1	1300N 533,090	0.690
2.	1200N 1,349,970	0.578
3.	1100N 3,183,717	0.662
4.	1000N 3,963,175	0.695
5.	900N 4,140,038	0.728
6.	800N 3,470,664	0.680
7.	700N 3,070,696	0.636
8.	600N 2,225,249	0.609
9.	500N 2,802,316	0.676
10.	400N 2,984,578	0.551
11.	300N 4,851,377	0.689
12.	200N 3,495,158	0.658
13.	100N 3,245,123	0.661
14.	00N 2,864,470	0.595
15.	100N 134,570	0.591
	42,314,191	0.656

Area: 1.862.500m^2;
Density: 2,15;
Average Depth: 12,73m;
Grade: 0,60g/t;
Ore Reserve: 52.617.487 ton.

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SUMMARY DESCRIPTION OF SITES TO BE VISITED

STOP 1 - Unit A

Black shale with minor quartz boudins. The Boudins are normally along a foliation which cross-cut the bedding. Au is minor and restricted to the boudins.

STOP 2 - Unit B_2 at the base consisting of pyrite and arsenopyrite rich black shales.

Unite B_1 black shale at the top with littel sulfide. Carbon makes up to 4% of the rock.

STOP 3 - Exploration pit and old workings.

Four channels in each side of the pit were sampled to get a representative bulk sample for analysis. A fifth channel was collected to stablish the "Graphite-index", which is acolor standard used for mining purposes. A graphite-index above 15 causes problems in the Au recovery. An old working shows typical Morro do Ouro ore.

STOP 4 - Mining front

Partly weathered black shale with abundant quartz boudinage. The sulphides (usually oxidized) are the following (in order of abundance): pyrite, arsenopyrite, pyrrotite, galena, sphalerite, chalcopyrite and bornite.

Au is 90% concentrated in the quartz boundins, predominantly as free Au and in sulphide fractures. The sulphides tend to concentrate close to the margine of the boudins. The average Au grade of the mine is 0.63 g/t Au and of the boundins is 2.5 g/t Au. The Au:Ag ratio is 5:1.

STOP 5 - Manual alluvial mining (garimpo) at Corrego Rico creek.

The alluvial gravels are crushed and then passed through sluices for gravity recovery. The concentrates are usually amalgamated and then the Au recovered by healing the amalgam.

STOP 6 - Outcrops along the highway

Dolomitic siltstone of the Serra da Landim facies (top of the Vazante Formation) locally with malachite and MnO_2 dendrites along the foliation plane.

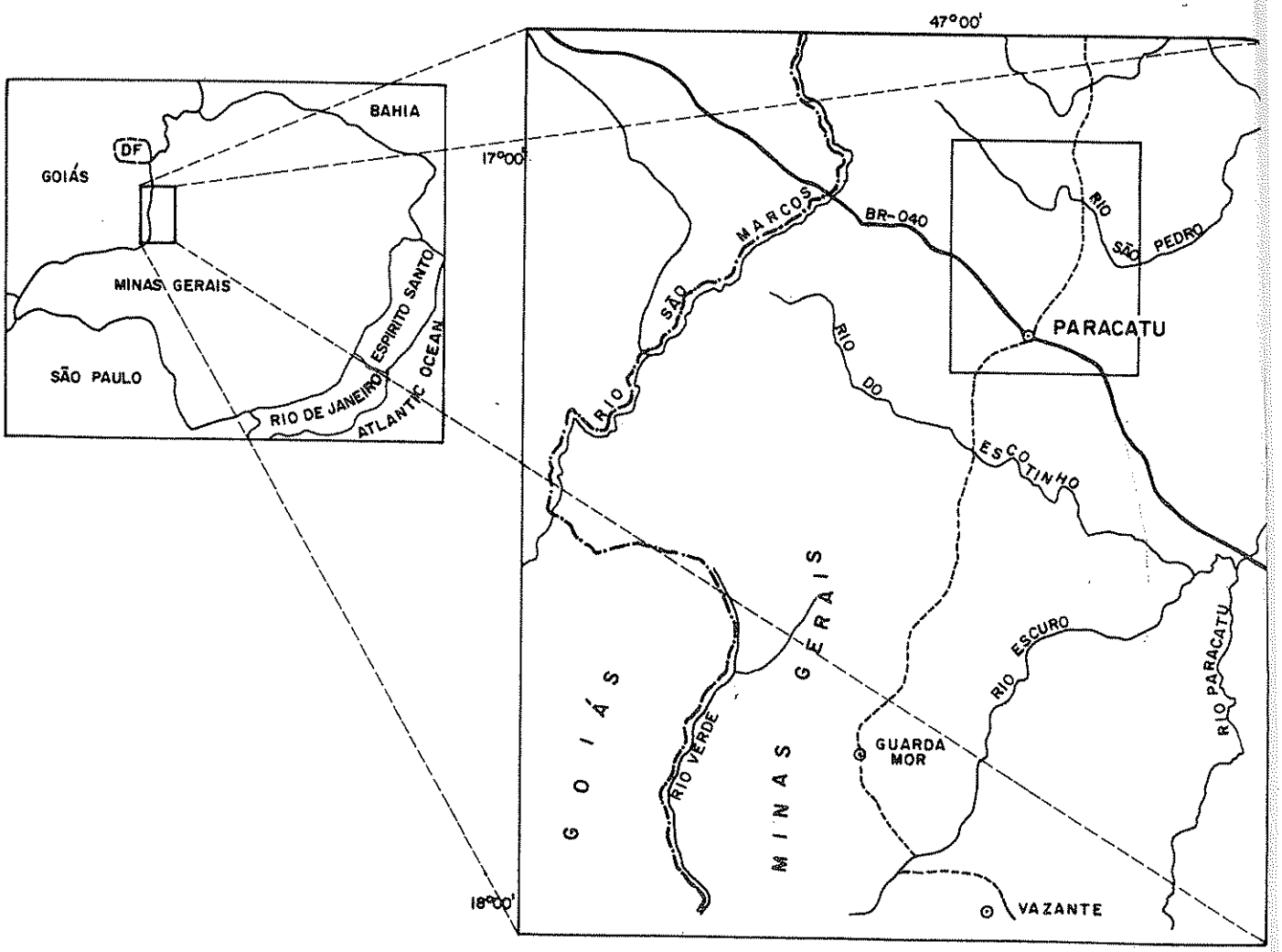
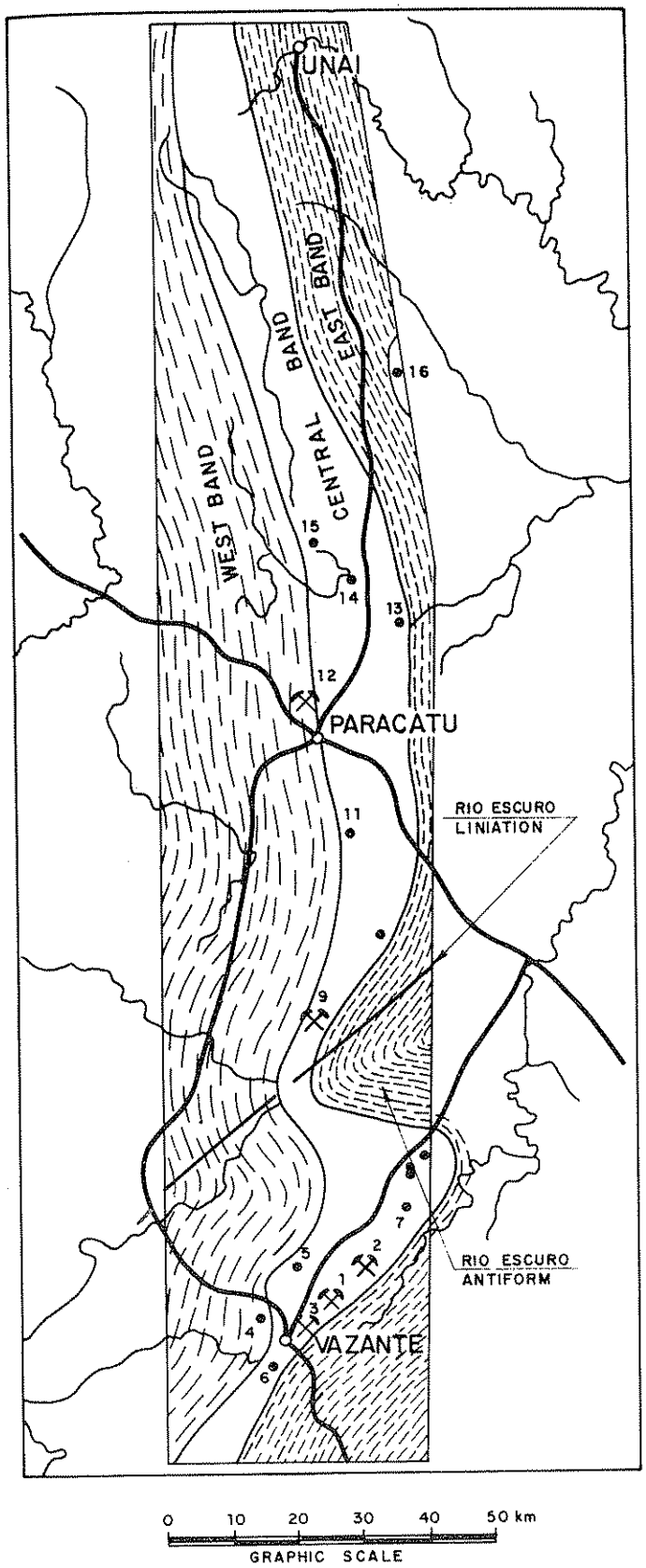


Fig. 6.1 – **LOCATION MAP**



LEGEND.

WEST BAND = PARACATU FORMATION (FP)

CENTRAL BAND { LAPA FORMATION (FL)
VAZANTE FORMATION (FV)

EAST BAND = SERRA DO GARROTE FORMATION

ORE DEPOSITS UNDER EXPLORATION

MINERAL OCORRENCES

Fig. 6.2 - REGIONAL GEOLOGY MAP

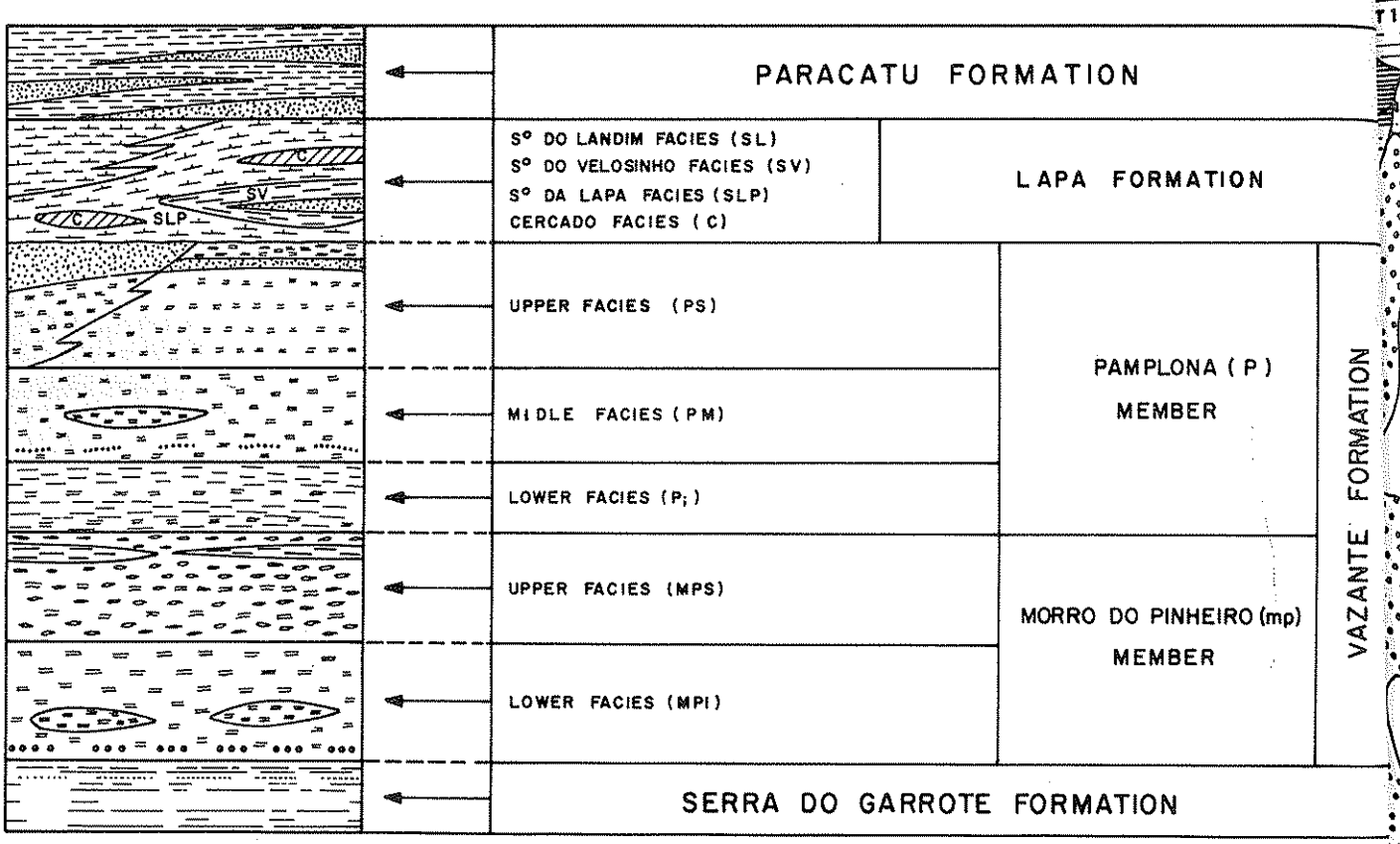
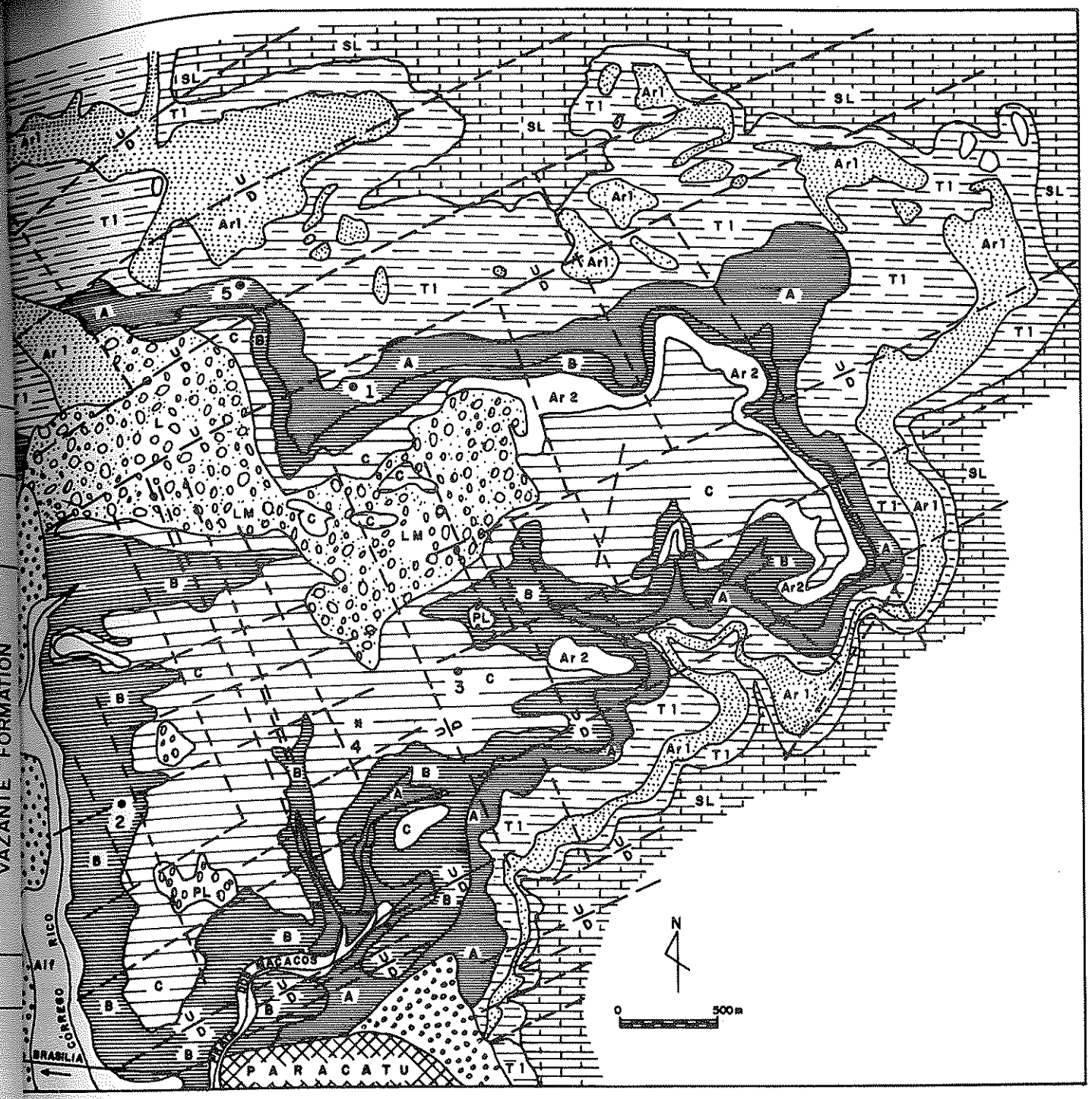


Fig. 6. 3 – STRATIGRAPHY OF VAZANTE FORMATION



LEGEND

Alf — Alluvium

S — Reddish lateritic eluvial / colluvial soil

PL / L / LM — Lateritized Pelite (PL), Laterite (small concretions) (L) Laterite (massive blocks) (LM)

PARACATU FM
MORRO DO OURO SEQUENCE

C / B / Ar2 — Auriferous Zone
- C - Sericitic silty-sandy shale with quartz boudins showing Fe oxide after sulphides
- B - Silty-sandy black shale with sulphides (Fe, As, Pb, Zn) and Au, locally calcareous/dolomitic
- Ar2 - Lenses of fine to medium grained sandstones (mostly quartzarenites) with arsenopyrite

A — Slightly calcareous dolomitic black shale with rare quartz boudins showing arsenopyrite and pyrite. Few sulphide rich sandy lenses

T1 / Ar1 — Transition Zone — Laminated black shale with fine to medium grained ferruginous orthoquartzites (Ar1) interbeds (cm/m).

SL — Vazante FM Serra de Landim Facies: greenish dolomitic / calcareous argillaceous metasiltstones

• 2 Outcrops to be inspected

After Zini et all

Fig - 6.4

6 b) THE MORRO AGUDO ZINC AND LEAD ORE DEPOSIT PARACATU, MINAS GERAIS

Glacir Romagna
Rubens Rulli Costa
Mineração Morro Agudo S/A.

The Morro Agudo zinc-lead sulphide ore deposit is located in the western-northwestern part of Minas Gerais, Brazil. The mineralization is hosted in late Proterozoic carbonatic rocks of the Vazante Formation of the Bambuí Group - and presents an example of a stratiform type deposit.

The ore minerals are sphalerite, galena and pyrite hosted in a medium to coarse-grained dolarenite and dolomite breccia of a reefal environment. The ore bodies, which strike NE and dip 20° to the NW, are intensively faulted. The strike length of the ore is about 1,000 metres, its width varies from 2 to 15 metres and the deepest ore layer is about 350 metres below the surface. With an outlined reserve of 11,700,000 tons, grading 6.4% zinc and 2.1% lead, the Mineração Morro Agudo S/A intends to produce 500,000 tons per year.

INTRODUCTION

The zinc and lead sulphide deposit of Mineração Morro Agudo S/A is situated in the extreme west-northwest of the state of Minas Gerais, and it is associated with carbonatic rocks of a reefal environment having a precambriam age, and which belong to the Vazante Formation of the Bambuí Group. Sphalerite and galena are the main minerals. The pyrite is of secondary importance and cadmium is a by-product locked in the crystalline structure of sphalerite. With the reserve calculated to be 11.7 millions tons of ore with average contents of 6.4% zinc and 2.1% lead, the company is prepared for a forecast production of 500,000 tons per year of ore, which after being submitted to the treatment process of selective flotation will result in 40,870 tons p.a. of zinc concentrate and 12,550 tons of lead concentrate. These products must be commercialized wholly within the internal market, thus allowing the country to substitute the imports of considerable value and to bring more socially benefits to this region.

In a condensed form, this work presents data about the regional and local geology, the research development and the present stage of the pre-operational mining work. Geological mapping, geochemical and geophysical work, and descriptions of about 30,000 metres of drill cores and geological detailing of about 10,000 metres of galleries and ramps gives support to the information given herein.

LOCATION

The ore deposit is situated in the locality known as Morro Agudo, some 38 km to the southeast of the town Paracatu, in the extreme west-northwest of the state of Minas Gerais (fig. 6.1). This town is crossed by the BR-040 highway, which links Brasília to Belo Horizonte. The distance between Brasília and Paracatu is 230 km and from Belo Horizonte to Paracatu, 500 km. The access to the area is made via the BR-040 highway, some 27 km from Paracatu in the Belo Horizonte direction and 16 km of gravel road to the area where the Mineração Morro Agudo is located.

HISTORY

The metallic sulphide occurrence in Fazenda Trairas, near the Morro Agudo locality, in the municipality of Paracatu, was discovered in 1961, by the prospector Mr. Ângelo Custódio Solis. The first company to carry out systematic geological research in the area was Compania Auxiliar de Empressa de Mineração S/A - AEMSA- linked to the Penarroya Group.

In September, 1973, through a private contract with the option of a promise of association and mining rights transfer,

there was an understanding between the assigne of these rights and the State Company of Metals de Minas Gerais S/A - METAMIG. This company set up an exploration project in the area, which consisted of geological mapping on a scale of 1 to 10,000, geochemical and geophysical studies and diamond drilling, all of which resulted in the definition of mineralization of the stratiform type in dolomitic rocks, positioned directly to the west of Morro do Calcário. In July, 1974, Mineração do Morro Agudo was founded with the mineral rights of the area being incorporated in its foundation.

Today, the control of the running of the company is exercised by three of the largest Brazilian companies in the zinc market: Companhia Mineira de Metais S/A, Companhia Mercantil e Industrial Ingá S/A and Companhia Paraibuna de Metais S/A.

REGIONAL GEOLOGY

In his work, "Stratigraphy and Sedimentation of the Bambuí Group in the Paracatu Region, MG, Brazil (1979)", Madalosso presented the stratigraphic division of the Bambuí Group in the Paracatu Region.

Some important points must be emphasized in this evolution:

1 – from 1968 until 1978 the rocks of the Paracatu region were all united within the Bambuí Group - the Paraopeba Formation, excepte in the work of Almeida (1968), in which the quartzites and phyllites, that occur to the west of the of Paracatu, are separate from the Paraopeba Formation and are known as the Paracatu Formation;

2 – the Paracatu Formation, name given by Almeida (1968) would only return to adoption by Dardenne in 1978, in substitution for the Unit A of the Paraopeba Formation, which consisted of phyllites and quartzites, and this continues until the present day;

3 – the sub-division of the Paraopeba Formation into Units A, B and C, with Unit A consisting of phyllites and quartzites; Unit B of carbonatic rocks and pelitics, and Unit C of slates, established by Dardenne (1976), remained in force until 1978, when the B and C units were united under the name of the Vazante Formation. This was divided, by Dardenne in 1978, into the Morro do Calcário Member and the Serra do Poço Verde Member corresponding to the Unit B, and the Serra do Garrote Member corresponding to the Unit C (slate);

4 – in 1978, Madalosso & Valle proposed the division of Unit B into the facies indicated in the Table. This division has been adopted in all the reports to the DNPM made by the geologists of Metais de Minas Gerais - METAMIG - Paracatu Center;

5 – at present, the geologists of the region have extensively adopted the names Serra do Garrote, Morro do Calcário, Serra do Velosinho, Serra da Lapa, Serra do Landim and Morro Agudo for the facies divisions of the Vazante Formation as presented by Madalosso in 1979.

The stratigraphic division of the Bambuí Group in the region of Paracatu has for the most part been adopted by the geologists that work there, as noted below:

All the rocks of the region belong to the Upper Precambrian Age of the Bambuí Group.

a) Vazante Formation

a.1) Morro Agudo Facies - sandy-phyllitic metarhytmics with insertions of locally carbonate phyllitic metasiltites. Carbonaceous slate phyllites is part graphitic black. Carbonaceous phyllites, black.

a.2) Serra do Landim Facies - phyllites and intercalated dolomites, phyllitic limestone and green slate phyllites.

a.3) Serra da Lapa Facies - sandy-phyllitic metarhytmics. Greenish phyllitic metasiltites, locally carbonate. Laminated dolomites, dark grey carbonaceous in part.

a.4) Serra do Velosinho Facies - Carbonaceous phyllites and in part black and graphitic.

a.5) Morro do Calcário - Dolarenitos, dolomites and intraformational breccias.

a.6) Serra do Garrote Facies - Slates.

b) Paracatu Formation

Stratigraphically above the Vazante Formation, the Paracatu Formation is essentially composed of black phyllites and quartz, which occur to the west of a line that includes the mountains of Araras, Horta and Muquém, and which extends to the north, passing to the west of the town of Paracatu.

In the "Geologia do Brasil" (Schobbenhaus et al., 1984), a stratigraphic connotation of the regional geology is given, which is a little different from that given here.

The Serra do Garrote is included in the Paracatu Formation of the Madalosso (1979) in a unit called the Vazante Formation, leaving doubt as to their position in relation to the Bambuí Group, putting forth the idea that this unit is in whole or in part related to a much older sequence than that of the Bambuí Group.

The Vazante Formation is divided into three distinct sequences from East to West:

- The slate sequence which corresponds to the Serra do Garrote of Madalosso;

- The clayey dolomitic sequence of Vazante which cor-

responds to the Morro do Calcário, Upper and Lower Serra do Velosinho, Serra da Lapa and Serra do Landim Facies of Madalosso; and

- the sandy clayey sequence of Paracatu which corresponds to the Paracatu Formation of Madalosso.

LOCAL GEOLOGY

The Morro Agudo mineralization is found in the Vazante Formation, hosted in dolarenites, dolarenitic breccias and dolomites belonging to the Morro do Calcário Facies, which takes in the reefal complex.

All the mining work, such as the geological investigations made by drilling in the mine clearly defined four lithologic types as described below:

a) Dolomitic Breccias (Dolorudites)

The base of the local stratigraphy is invariably occupied by Dolomitic Breccias, also known as dolorudites.

The dolomitic Breccias are interformational breccias constituted of angular and variable sized, from millimetric to metric, clastic rocks, of massive or laminated dolomitic rocks of a predominantly light grey, dark grey and subordinately of a pink colour.

In these breccias the presence of blocks of accumulated massive stromatolites is common. The cementing of these rocks is predominantly dolomitic and is extremely fine. Zinc and Lead occur in them in are increasing form of crystal, at times, centimetric, occupying dissolution spaces, porous rock spaces and even filling fractures. These occurrences define three known levels in the ore deposit, and show unconformities and make up the base bodies.

b) Dolarenitic Breccias

The dolarenitic breccias are constituted of fragments, the majority of which are less than 2 centimetres in size, of dolomites, such as those of the basal lithology, and which are of a dark grey, light grey colour, and which are embedded in a dolarenitic matrix. It has a varying thickness, which is, on average in the mine, around 5 metres thick, and it is this rock that is the host to the richest mineralizations of the Morro Agudo.

c) Dolarenites

These light and dark grey coloured rocks are constituted of dolomitic lithoclastis, with an average size of around 1.00 millimetres, and which are well rounded and at times with truncated borders, and are embedded in a fine dolomitic cement. It is common to observe the presence of intraclastics with irregular borders which were probably deposited in prelithification conditions with sizes of around 1.00 millimeter, such as colites which commonly show silica and sphalerite in their laminations, and not rarely with broken edges, which is evidence of an origin, in part, of erosion of rocks that were already lithified.

Dolomite is the predominant cement even though both quartz and chert also occur in smaller quantities. In the mineralized dolarenites, sphalerite and subordinately galena cement the dolomitic grains.

The average thickness of the dolarenitic package in the mine is approximately 30 metres thick.

d) The Dolomitic-Clay Sequence

The name Dolomitic-Clay Sequence (SAD) is used in the mine for the dark grey coloured packet of rocks with a laminated aspect, and which are composed of millimetric to centimetric sized insertions of predominent dark carbonous dolomite or clay. These rocks are positioned immediately over thje dolomites or interdigitated with them do the west of the Morro do Calcário. Submillimetrical levels of pyrites associated with rare points of sphalerite are seen in the dolomitic-clay sequence near the contacts with the dolarenites, which have no economic significance at this time.

Regionally this Dolomitic-Clayey Sequence is correlated with the Serra da Lapa Facies where they appear to have been deposited in a lagoonal environment. There is a dolarenitic dolarenite-breccia package situated above it and interlayered within the Dolomitic-Clay Sequence (SAD).

The Upper Ore Body - Corpo N - of the workings is interlayered in this. This package is vertically spaced from the main dolarenitic package by some 40-45 metres, and it has an average thickness of 10 metres, after which the dolomitic-clay sequence continues.

STRUCTURE

The structure is an important geological feature in the mine due to its influence on the ore extraction of the Morro Agudo. A very large quantity of reject faults and an unfavourable rock plunge make the exploitation of the proposed mining plan very difficult. The rock layers have a general NE direction (oscillating from N10-20E in the northern section to N40-50E in the southern sector) with a plunge of 20°NW on average. In their NE portion the workings are limited by a normal fault with a N15-20W direction and a plunge of 75°SW. This fault has a vertical reject near to 35 metters and it is the main element in the total fault system whose directions oscillate between N15 and N155E and which systematically lowers the SW block of the ore deposit.

The spacing between these faults is very close, with a common frequency of 4 to 5 faults each 10 metres near to the main fault, with vertical rejects being predominently centimetrical, however they can reach this every 5 or 6 metres at times.

This standards evidently imposes significant basculants and provokes an apparent N-S orientation on the layers and boddies of ore in platform. Definition of the faults by drilling is difficult because they generally show closed planes with insignificant alterarions. A careful and detailed mapping of the galleries, with identification of the fault with the most significant rejects, is a priority for a good understanding of the mine geological structure. A second system of faults, E-W, can be seen, but with a greater spacing between the

faults and less interference on the state of the ore body positioning.

There is no evidence of folding in the mineralized layers, which is clear evidence of a rhythmic reply to the tectonic evolution of the Morro do Agudo Facies. The southern portion of the workings, as a function of their separation from the main fault, shows a very much more simple structure, with greater spacing between the secondary faults and smoother dips of the layers, which are, on average, 18° to the NW.

DEPOSIT DESCRIPTION

Eight ore bodies were identified in the Morro do Agudo workings from the surface drilling studies, and are known as G, H, I, J, K, L, M and N. Of these, the main ones are J, K and L, which represent around 65% of the workings in terms of ore volume. The G, H and I bodies are hosted, in basic terms, in dolomitic breccias and form isolated and unconformity layers. The types of mineralization in these bodies is granularmetrically coarse, with crystals of blend and galena, at times of centimetrics size filling the dissolution spaces. This mineralization shows itselt to be discontinuous as much in the directional send as in the plunge, and it follows in a rough manner, the general structure of the layers, and locally forms pockets with economic chemical contents. The bodies are not very thick and for the most part are less than 4 metres at times. The J, K and L mineralizations are hosted in the dolarenitic breccias and the dolarenites positioned immediately above the dolomitic breccias. Their chemical content and thickness vary in all senses, with the best continuity of the ore being along the plunge. Accompanying the general structure of the mine sterile dolarenites with thickness of less than two metres each interleave in a package of 30 metres average thickness, and which forms a single or isolated body of up 15 metres thick. The J Body is found in a predominantly dolarenitic band and shows indications of fluid circulation and precipitation in the more favourable porous zones. The K Body is found in the transition zone of the dolarenitic breccias and the dolarenites, and aventually being able to be contained totally in the dolarenitic breccias or totally in the dolarenites. The mineralization has the same characteristics as were described for the J Body. The L Body, positioned above these other two, shows less substitution of the dolomitic grains, less lead present and the sphalerite basically being contained in the cement.

The M and N bodies are positioned in the Upper portions of the dolarenites, the M being in the dolarenite positioned over the L Body, and in its turn the N Body is found in the dolarenite package already interleaved in the dolomitic-clay sequence. The M Body has much less continuity and non-economic chemical content in its major part. The N Body has limited continuity in the upper levels of the mine and in its north portion, though with high observed chemical content.

All the ore bodies already studied have been submitted to faulting and they accompany the general behaviour of the layers. They have an extension of 1,100 metres in the mine and have a continuity along the plunge of around 500 metres.

MINERALOGY AND OF THE ORE ANALYSES

The zinc and lead deposit of Morro Agudo Shows a ve simple mineralogy, being composed of sphalerite, galen dolomite, pyrite, chert, quartz, a small quantity of barite an some rare fluorite.

Only the sphalerite and galena are considered to b mineral-ores. The cadmium quantified in the chemic analysis at 360 ppm is in the sphalerite structure, whilst silve in extremely low chemical content of 1.58 ppm, is linked t the galena structure.

Elements	Chemical Content
CaO	20.82
MgO	16.21%
Zn	5.06%
S	3.74%
Fe	3.19%
Pb	1.56%
Cd	360 ppm
Ti	20 ppm
In	20 ppm
Cu	13 ppm
Ga	4.37 ppm
Ag	1.58 ppm

TYPES AND ORIGIN OF THE ORE

The ore of the Morro Agudo workings is divided into three types for descriptive purposes:

1 – diffused ore: characterized by a fine dispersion of sulphides in the dolomitic clastics;

2 – Cement ore: showing the sulphides cementing the preserved dolomitic clastics;

3 – remobilized ore: filling fractures or spaces between the dolomitic clastics and the dolomitic cement.

The origin of the mineralization covers a formation period from the sedimentary phase to the later diagenesis phase.

The evolution of the knowledge of the ore deposit permitted the observation that the greatest volume of ore of the Morro Agudo is represented by reprecipitation of the sulphides in the most susceptible porous zones, together with an active process of substitution of the cement and dolomitic clastics during the diagenesis period through the circulation of fluids.

RESERVES AND CHEMICAL CONTENT

Since the termination of the research, from the surface drilling in 1976 until the end of 1982, various reserve calculations have been made using various techniques. This shows the fact that the reserve of an ore deposit is onlt static when considering the geology, i.e., only when one refers to the total quantity of metal contained in it; however, when economic

elements are inserted, it becomes dynamic as a function of the cut content to be adopted. Consequently, based on the various calculations of reserves for different chemical content cuts, one can construct a curve of the zinc metallic content versus the reserves, making it possible to see the metal reserve variations as a predetermined function of the chemical content of the cut, which forms important economic data for the economic study of the exploration of the deposit. Basically two basic methods were adopted for the calculations: the area of influence of the drill holes and the parallel sections through the profiles E-W, N-S and NW-SE made through the mine.

As an example, for a cut chemical content of 3.0% Zn and/or 4.0% Zn + Pb, the results where as follows:

Comparative Table of Reserves

Reserves	Areas of Influence			Parallel Sections		
	Tonnage	%Zn	%Pb	Tonnage	%Zn	%Pb
Average	13,530,603.90	5.18	1.49	13,880,400	5,06	1.39
Indicated	4,052,327.58	5.04	1.70	3,165,000	4,82	1.58
Inferred	–	–	–	1,339,500	5,32	1.63
Total	17,582,931.48	5.14	1.53	18,834,900	5,03	1.44

In order to gain greater support for the numbers, Paulo Abib Engenharia S/A carried out a reserve calculation using geostatistical methods. The numbers obtained in this work confirm those obtained by the previous method. During the detailing phase of the ore deposit, made by systematic mapping of the levels at every 33 metres vertically, the results obtained in the calculations were confirmed with significant distortions.

The numbers for the reserves and chemical content at present adopted by the Mineração Morro Agudo, after intense study of the economic viability of the deposit, are as follows:

Chemical Content of Cut: 4,4% Zn or 5.6% Zn+Pb
Reserves: 11,700,000 tons of ore
Average Chemical Content of Ore: 6,4% Zn 2.15% Pb

MINING METHOD AND TREATMENT

The experimental mining work carried out ended with the definition of a variant of the chamber and pilar method of mining which will be that used for the life of the mine. In accordance with the dimensions chosen for the chambers and pilars a recuperation of 75% of the cubic reserve will be effected by this method. The economic studies carried out defined the almost total mechanization of the mining as the best option, and therefore the main equipment for cutting will be pneumatic production vehicles, and those for the removal will be LHD dumper trucks. The work in the mine is in the final phase of fundemental structural development and the secondary phase of mining development, i.e., the conclusion of the access ramps, transport galleries, ventilation channels, ore/sterile passages, silos etc. The principle access ramp is a vertical shaft through which the ore will be discharged, in the same was as more than 9,000 metres of galleries have been made (fig. 9.5).

The ore treatment tests are finished, and the differential flotation method for both zinc and lead have already been defined. The forecast production of concentrates is 40,870 tonnes per year of zinc having a chemical content of 52.5% and 12,550 tonnes per year of lead having a chemical content of 54%.

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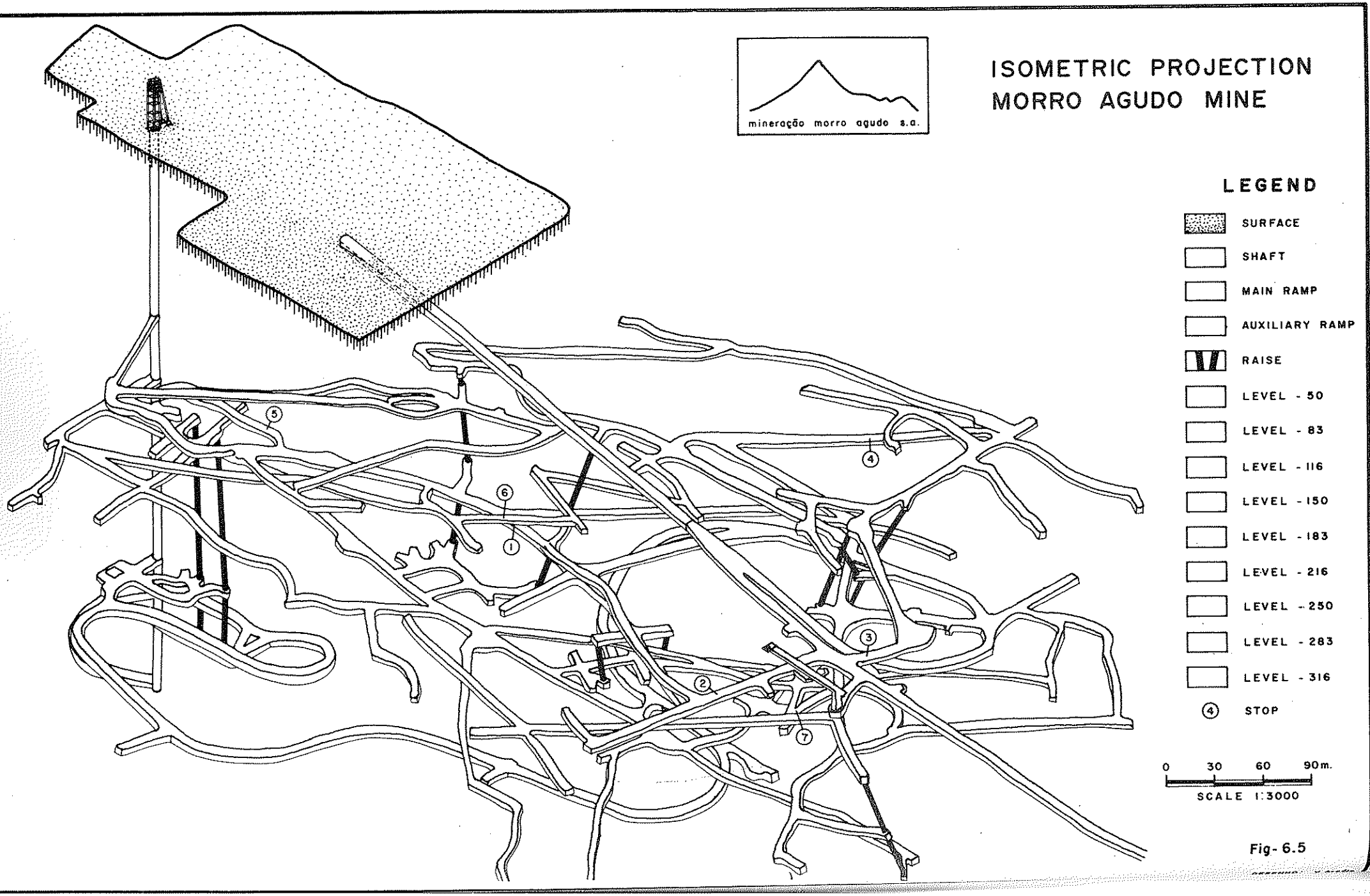
mineração morro agudo s.a.
ISOMETRIC PROJECTION
MORRO AGUDO MINE
LEGEND
SURFACE
SHAFT
MAIN RAMP
AUXILIARY RAMP
RAISE
LEVEL - 50
LEVEL - 83
LEVEL - 116
LEVEL - 150
LEVEL - 183
LEVEL - 216
LEVEL - 250
LEVEL - 283
LEVEL - 316
④ STOP
0 30 60 90m.
SCALE 1:3000
Fig- 6.5

Fig- 6.5

6.c) THE VAZANTE ZINC MINE, MINAS GERAIS

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Vazante is the largest zinc producer district in Brazil. The mineralization, is composed mainly of willemite and calamine, and is hosted by carbonate rocks of the Vazante Formation, which belongs to the late proterozoic (middle riphean) Paranoá Group.

The ore bodies are cross-cutting veins associated with a longitudinal fault of NE direction, dipping at 60° to 30°WNW. The ore is open-pit mined with an underground mine being developed.

Treatment of willemite consists of crushing, screening, separation in a heavy medium, and fine flotation. Calamine is volatized to zinc oxide in a "WAELZ" kiln. Zinc metal is produced in Três Marias via a hydrometallurgical process and electrolysis. Actual producing capacity is 70,000 t/yr of zinc, 5,000 t/yr of zinc oxide and 75 t/yr of cadmium.

Cia. Mineira de Metais is drill-testing the NE extension of the Vazante deposit and also carrying out an extensive programme of regional exploration in search of possible new deposits in the Vazante-Unaí belt.

INTRODUCTION

The Vazante region has many mines in operation and areas under research and constitutes the largst Zinc-bearing District in the country, and is the only one with large-scale production.

In this descriptive summary most emphasis will be given to the silicated deposits of vazante belonging to the Cia. Mineira de Metais (CCM).

This company carried out a research programme in the Unaí/Vazante region with a view to finding new occurrences, a research programme of reserve increase and detailing of working in its Vazante ore deposits, open-pit and underground mining and ore treatment. As well as this, it carries out metallurgical tests in Três Marias to produce electrolytic zinc with the benefit of cadmium as a byproduct.

HISTORY

Around 1952, when excavations in the Serra do Poço Verde were made, Mr. Angelo Solis, farmer and amateur prospector, and living in Vazante, found a material which after being examined by technicians of Ouro Preto and Belo Horizonte, was identified as being hemimorphite (calamine).

Only in 1954, did Mr. Solis reveal the location of the samples and permit a technician of Cia. Níquel Tocantins, a company helded by the Votorantim Group, to visit the occurrences.

In accordance with the mineral legislation of the time, this company aquired the priority rights, much later ceeded to Cia. Mineira de Metais, set up fot the research and exploration of ore deposits.

LOCATION

Vazante, is situated in the N-NW portion of the State of Minas Gerais, between the cities of Paracatu and Patos de Minas. Connections to Belo Horizonte can be made by the following routes (fig. 6.1).

– Vazante–Pontal (BR–040)	60km. dirt road
– Pontal–Belo horizonte	470km. BR.040 highway from Belo Horizonte/Braslia
	530km.

Note:– On this route, at 280km. from Vazante wil be found the Três Marias Metallurgical Plant.

– Vazante–Patos de Minas	121km., 25 being asphalted
– Patos de Minas–BR–262	141km., by the MG–354 Milho highway
– BR–262–Belo Horizonte	142km., by the BR–262 Uberaba/Belo Horizonte highway
	510km.

REGIONAL GEOLOGY

The Vazante/Unaí region is in the domain of the rocks of the Paranoá Group (Dardenne, 1979) which show a low degree of metamorphism.

The rock sequence is from a marine environment, with reefal facies that extend in a NS direction between these two cities, and has been extensively studied by various mining companies and government organizations, and the following lithofaciological divisions tend to have seen established (Dardenne, 1979; Madalosso & Vale, 1978; Madalosso, 1979):

East Band:

- Serra do Garrote Facies (Sard), constituted of black and green slates with sandstone levels.

Central Band:

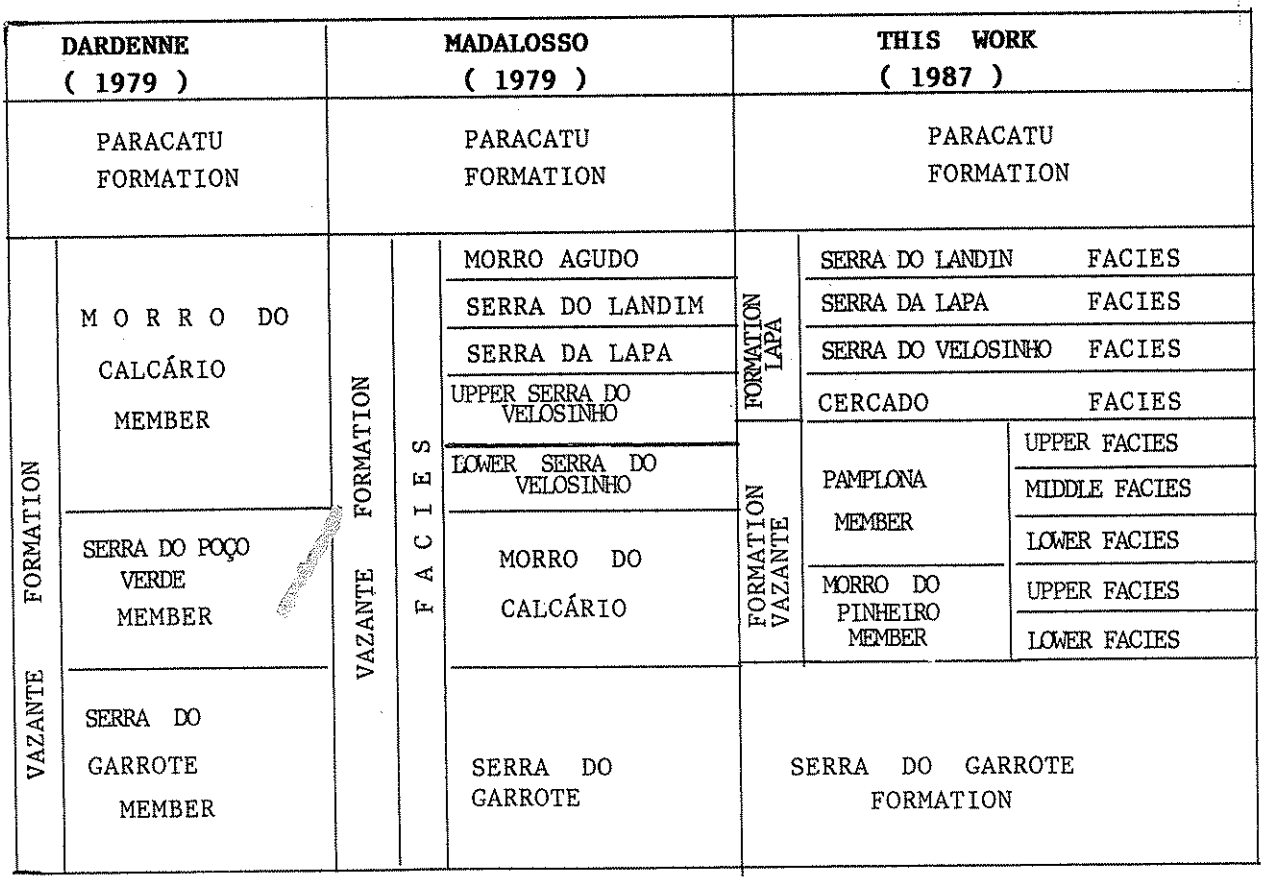
- Morro do Calcário Facies, constituted of stromatolithic dolomites, dolarenites and dolorudites.
- Serra do Velosinho Facies (SV), constituted of carbonous, pyritic schists and medium sandstones.
- Serra da Lapa Facies (SLP), constituted of schists and carbonatic, carbonous and pyritic siltites with lenses of dolomitic limestone.
- Serra do Landim Facies (SL), constituted of schists and sericit chloritous grey-greenish siltites with limestone insertions, also of a green and/or white colour.

Note: These two bands were grouped together in the Vazante Formation (Dardenne, 1979; Madalosso, 1979).

West Band

- Paracatu Formation (FP), carbonatis schists with metric lenses of quartzitic slates (fig. 6.3).

From the structural point of view there is a notable antiform in the vally of the Rio Escuro. To the north of this



Comparative Table of the latest stratigraphic divisions of the Vazante - Unaí Band.

structure one can observe a general NNW-SSE direction of the gold and longitudinal fault lines, which in the southern part (Vazante region) change to the NNE-SSW. In relation to the transverse faults (most recent) one can observe exactly the opposite, the SSW-NNW directions being predominant in the northern part and SSE-NNW in the south. Amongst the possible explanations for this fact are:

1 – the rotation about that structure; and

2 – the reactivation of a probable large zone of faults going in the NE direction (outline of the Rio Escuro) which aligns itself perfectly with the outline of São Francisco de Cassedanne (1972).

Figure 6.6 is a schematic geological profile which shows the stratigraphic position of the deposits and the mineral occurrences of the vazante-Unaí band.

GEOLOGY OF THE VAZANTE REGION

The three bands mentioned above are present in Vazantes, but, due to its importance from the economic viewpoint, the central band was the one studied in the most detail. Based on the field data obtained by CCM and its joint work with Rio Doce Geologia e Mineração S/A (DOCEGEO) it was possible to establish a new stratigraphic division (fig. 6.7).

The Vazante Formation of Dardenne (1979) was redefined, in that the Serra do Garrote member was raised to the category of a Formation. As well as this, the Serra do Landim Facies, Serra do Velosinho Facies and the Serra da Lapa Facies (Madalosso, 1979) were grouped together in the Lapa (the name was given because the predominance of this last facies).

The Vazante Formation, restricted in this work to the predominantly dolomitic sequence, was subdivided into the Morro do Pinheiro and the Pamplona members.

The Morro do Pinheiro Member is composed of two facies:

- Lower Facies (FVmp) = clay grey and rosy dolomites with algae carpets and subordinate levels of dolarenites, at times oncolithic and with lamellar breccia. Dolomite lenses occur with stromatolite columns. The thickness is approximately 500 metres.

- Upper Facies (FVmp) = Dolomites with a medium to dark grey colour with birds-eyes and plane and convoluted laminations, probably of algal origin Subordinate levels of dolarenite occur with lamellar breccias and, also, levels of a carbonous schists. The thickness is approximately 300 to 500 metres.

The Pamplona Member is characterized by three lithofacies:

- Lower Facies (FVp) = Clear grey, lilac and greenish carbonatic schists alternating with clear grey and rosy dolomite beds with algal carpetes. Small lenses of fine to conglomeratic slate occur, locally with colofane. It is important to emphasize that it is in this facies that the mining by Cia. Mineira de Metais is located. The approximate thickness is 100 to 200 metres.

- Middle Facies = Clear grey to rosy dolomites with algal carpetes. Rare lenses of black schists, lenses with stromatolithic columns and sporadic beds of dolarenite and lamellar breccias occur. The thickness is approximately 400 metres;

- Upper Facies (FVp) = Rosy to clear grey stromatolithic dolomites with convex algal laminations (Biostromes). Fine to course dolarenitic lenses and lenses of dolorudite occur with polygenetic metablocks in a red matrix, which are partially lateral (west side) to the biostromes. The thickness is approximately 200 to 300 metres.

Although there are numerous levels with indications of paleo-exhibition, the top of the Vazante Formation is characterized, regionally, by a main zone of strong oxidation, with the presence of jasper and iron oxide (hematite). The dolomites, of a red colour, stand out in contrast to the black pyritic schists of the Lapa Formation extremely reducing environment.

The Lapa Formation was not studied in depth. However, the descriptions found in the bibliographies mentioned herein and the data obtained by CCM permit the following placements to be made:

- the facies of the Serra do Velosinho, Serra da Lapa and the Serra do Landim are characterized by their predominantly carbonitic-clayey composition, by gradual contacts and by frequent reciprocal interdigitations;

- the predominant facies is that of the Serra da Lapa, in which one can regionally observe the occurrence of algal dolomite lenses and clastic rocks with colours varying from dark to rose light grey;

- due to the fact that the Cercado occurrence is surrounded by one of these lenses, this dolomitic facies was individualized by that place name.

GEOLOGY IN THE MINE AREA

The zinc silicate deposits of the Cia. Mineração de Metais are distributed along a set of highes which begin about 2 km to the NE of Vazante and extend for about 8 km in the NE direction.

Rocks of the Morro do Pinheiro (upper facies) and of the Pamplona (lower facies) occur and are orientated to follow a N-50°E direction, plunging about 60°NW near the deposits and 30°-15°NW more to the west.

This set of hights is landmarked by a large fault in the N-50°E direction, which shows a plunge of the order of 60°.

The mineralizations, in the form of willemite and calamine, are associated with a breccia fault, with an irregular distribution along it, but always in the lower facies and the

base of the middle facies of the Pamplona Member (fig. 6.8).

Small diabasic alkaline dykes are also found.

Structurally the deposit was divided into three domains (fig. 6.9).

Structural Domain I

This take in the west side of the pit and the extreme east of the mine, well outside the pit. The main strcuture of this domain is the banding which follows the fractures (N-50°W and N-56°E - Vertical). It is characterized by homoclines.

Structural Domain II

This domaid is between the willemite structure and the calamine structure. It is characterized by the presence of domes defined by the overlaying of two directions of folding, one of which has a NE subhorizontal axis, curvaceous axial planes, generally with the development of axial plane cleavages - these folds have a centimetric to metric magnitude, and the other shows a NW axis, also subhorizontal, but of greater scope, reaching some tens of metres. Lenticularization can be seen in the dolomites, of the order of a few metres, caused by the interseption between the curving axial plane faults (NE) and the banding.

Structural Domain III

In this domain the curvaceous faults are the main structures, whose intersections define intense lenticularization, which can be seen in hand samples up to full scale.

It is this domain which defines the geometry of the willemite bodies. This is the domain of the main deposit structure, the fault in the NE direction which controls the mineralizations of willemite and defines its geometry.

ORE TYPE

WILLEMITIC ORE

The willemite ore divided into two main segments, the south, outcropping, and the north without a surface occurrence.

The South Segment is in the from of various blocks dislocated by small slip transverse faults. It can be traced for 2,500 metres in the N-50°E direction. With a thickness varying from 1 to 10 metres, it has inserts of dolomite at times or separated in two or more narrow bodies.

The North Segment, non-outcropping, is separated from the South by a transverse fault. It can be traced for 1,500 metres in the N-50°E direction, and it has a thickness varying from 2 to 15 metres.

The datum of its top varies from 480 to 620 metres (100 to 200 metres below the surface) and the base varies between the datums of 440 and 250 meter.

The mineralogy of the bodies is simple. Willemite occurs with associated hematite and small concentrations of sphalerite, galena, cerussite and chalcocite. The sulphides correspond to a later phase of mineralization that cuts the willemite.

CALAMINIC ORE

This is located always to the west and together or near the willemite ore body.

It can be traced for 4,200 metres in a N-50°E direction, accompanying the main breccia in parallel, but showing various interuptions.

The mineralization occurs principally in the form of collapsed breccia schists and zinc enriched dolomites (fig. 6.10). The aspect is earthy and the most common minerals are hemimorphit and hydrozincite.

GENESIS

The most probable hypothesis for the origin of the deposit of Vazante is that of the Mississippi Valley model with later brecciation in fault zones and enrichment by oxidation. The deposits of the Mississippi type have a stratiform character concentrating themselves in a single or in few stratigraphic horizons. Therefore it is common for quantities of dispersed metal to occur in the whole carbonitic sequence. The main parametres for the occurrence of these deposits are:

a) carbonates from shallow marine waters;

b) basin edge or shallows;

c) unconformity above, below or within the host; and

d) proximity of limestone-dolomite interface.

In the ore deposit of CCM the presence of silicated ore can be ascertained (willemite) at great depths, of the order of 400 metres. One can also observe the occurrence of small concentrations of sphalerite and galena which cut the willemite. Because of this the previous hypothesis accepting the sulphide alteration through percolation "per descensum", in recent times, must be revised.

As was mentioned previously, there was a prolonged exhibition of the dolomites (red) of the Vazante Formation in the period preceeding the deposition of the pellitic-carbonatic facies of the Lapa Formation. It shows therefore, naturally the hypothesis of alternation of the sulphides in willemite during that period. Carvalho et al. (1962) evoked a phase of hydrothermal alteration, which would be responsible for the formation of the willemite. This hypothesis is tempting because of the great depth of the occurrence of silicated ore and the presence of diabasic bodies. In this case it would be fundamental also th the idea of Amaral (1968) which adimitted an association between the Cretaceous basic-alkaline volcanism and the mineralization of Vazante. Perhaps this association more properly applies to the late sulphides which cut the willeminite. With relation to the calamine ore, there does not appear ti be any doubt as to its supergenetic origin.

MINING

The mining operations at Vazante were initiated in 1968., with preparation of the mine, and production taking place

from 1969.. The mining situation at present is a follows:

- open-pit mining in the South Segment, producing 35,000 tonnes per month of willemite, which is taken for treatment together with the old stock;
- open-pit mining, producinf calamine ore at the rate of 15,00 tonnes per month to supply the volatilizing furnace;
- underground mining under development, to extract willemite from the depths of the North Segment.

TREATMENT

At Vazante, the two ore types pass through the following treatments:

WILLEMITIC ORE

Its treatment consists of crushing, screening and separation in a heavy medium with the flotation of the fines. The project for the flotation of the concentrate for separation is in the assembly phase.

CALAMINIC ORE

The volatilizing installation consists of a sector for the preparation of the raw material, where the ore and the coal are pounded and ground. After this stage, they are submitted to a process of being made into pellets and burn in a Waelz furnace, which is 4.5 metres in diasmeter and 70 metres long. It is the only installation in the word to produce Waelz oxide with vegetable coal.

The production capacity is 150 tons per day of oxide having 50% to 60% zinc content. It is able to treat ore of up to 10% or zinc.

METALLURGY

At Três Marias, also with its own process, the Cia. Mineira de Metais produces electrolytic zinc by hydrometallurgy.

The production capacity is 70,000 tons per year of electrolytic zinc as well as 5,000 tons per year of zinc oxide and 75 tons per year of cadmium.

From 6 to 10,000 tons per year is transformed into Zamac.

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SUMMARY DESCRIPTION OF SITES TO BE VISITED:

STOP 1 - Open pit - block 3N 14 level

Willemite ore (35% Zn). Willemite and hematite lenses ranging from cms to tens of metres in size in a fault zone cutting dolostones and dipping 30° to 60° westward. The willemite is light in color and the reddish tint is given by hematite.

STOP 2 - Calamine ore

Collapse breccia with open spaces filled by usually botryoidal calamine. The breccia consists of slates and dolostone fragments. Ore grade here is around 14% Zn. The presence of calaminacea bush indicates high zn content in the soil.

STOP 3 - View of the mill

Outcrops of Morro do Pinheiro facies basal dolostone.

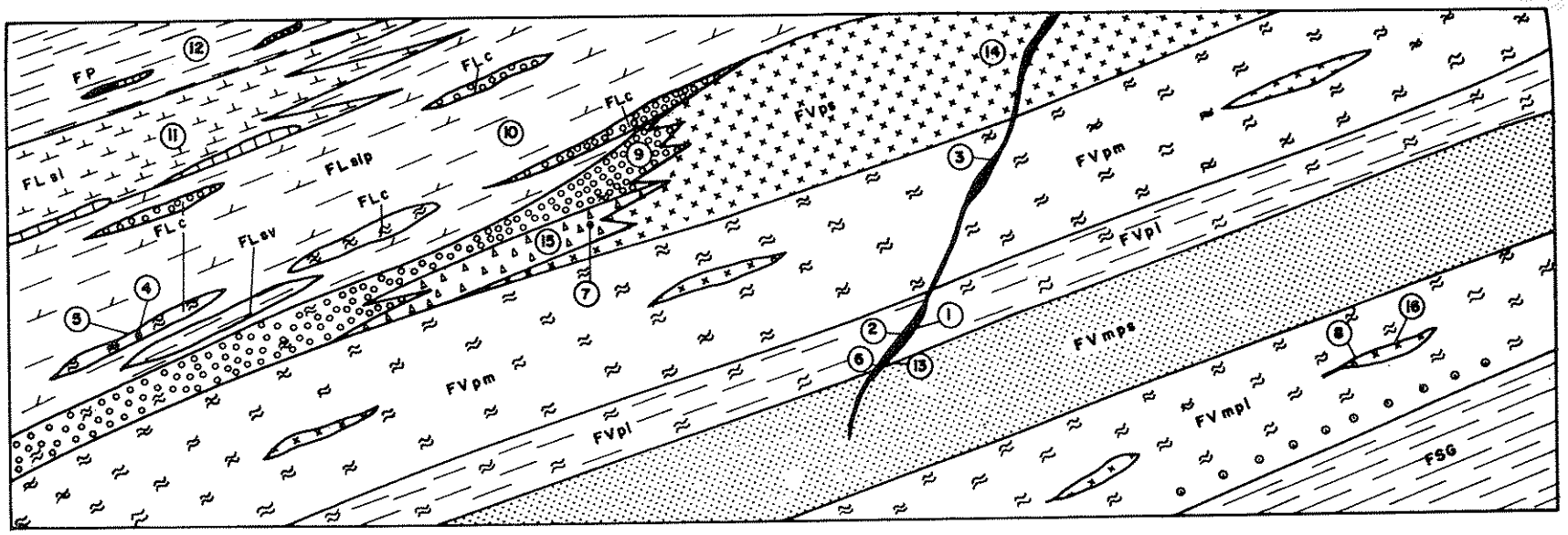
Laminated dolostone locally with probable birdseye structures and flat pebble congomerates.

STOP 4 - Morro da Usina

Typical rich calamine ore (35% Zn) with calamine and minor hydrozincite mineralization in breccia. Cross cutting fractures are mineralized only to the east, where the fractures cut clay rich rocks. The possible explanation is that the clay rich blocks were not dissolved, and therefore maintain interstetital porosity between them. This porosity was later filled by calamine.

STOP 5 - Typical algal dolostone (boundstone) outcrop.

This is part of a major alagal barrier reef developed in the



GROUP PARANOÁ			
FORMATION PARACATU Á (FP)			
FORMATION LAPA L (FL)		FACIES SERRA DO LANDIM (FL sl)	
		FACIES SERRA DA LAPA (FL slp)	
		FACIES SERRA DO VELOSINHO (FL sv)	
		FACIES CERCADO (FLc)	
FORMATION VAZANTE L (FV)	MEMBER PAMPLONA L (p)	FACIES UPPER (FVps)	
		FACIES IDDLE (FVpm)	
		FACIES LONOES (FVpl)	
	MEMBER DO PINHEIRO (mp)	FACIES UPPER (FVmps)	
		FACIES LONOES (FVmpl)	
FORMATION SERRA DO GARROTE L (FSG)			

DEPOSITS AND MINERAL OCCURRENCES

1. CIA MINEIRA DE METAIS
2. MINERAÇÃO AREIENSE
3. LAPA NOVA
4. CERCADO
5. OLHO D'ÁGUA
6. PAMPLONA
7. BIBOCA
8. CABELUDO
9. MORRO AGUDO
10. TAMANDUÁ
11. MARMELADA Cu
12. MORRO DO OURO Au
13. AMBRÓSIA
14. POÇÕES
15. FAGUNDES
16. PINDAÍBA

Fig 6.6 — STRATIGRAPHIC POSITION OF THE DEPOSITS AND MINERAL OCCURRENCES OF THE VAZANTE — URAÍ BAND

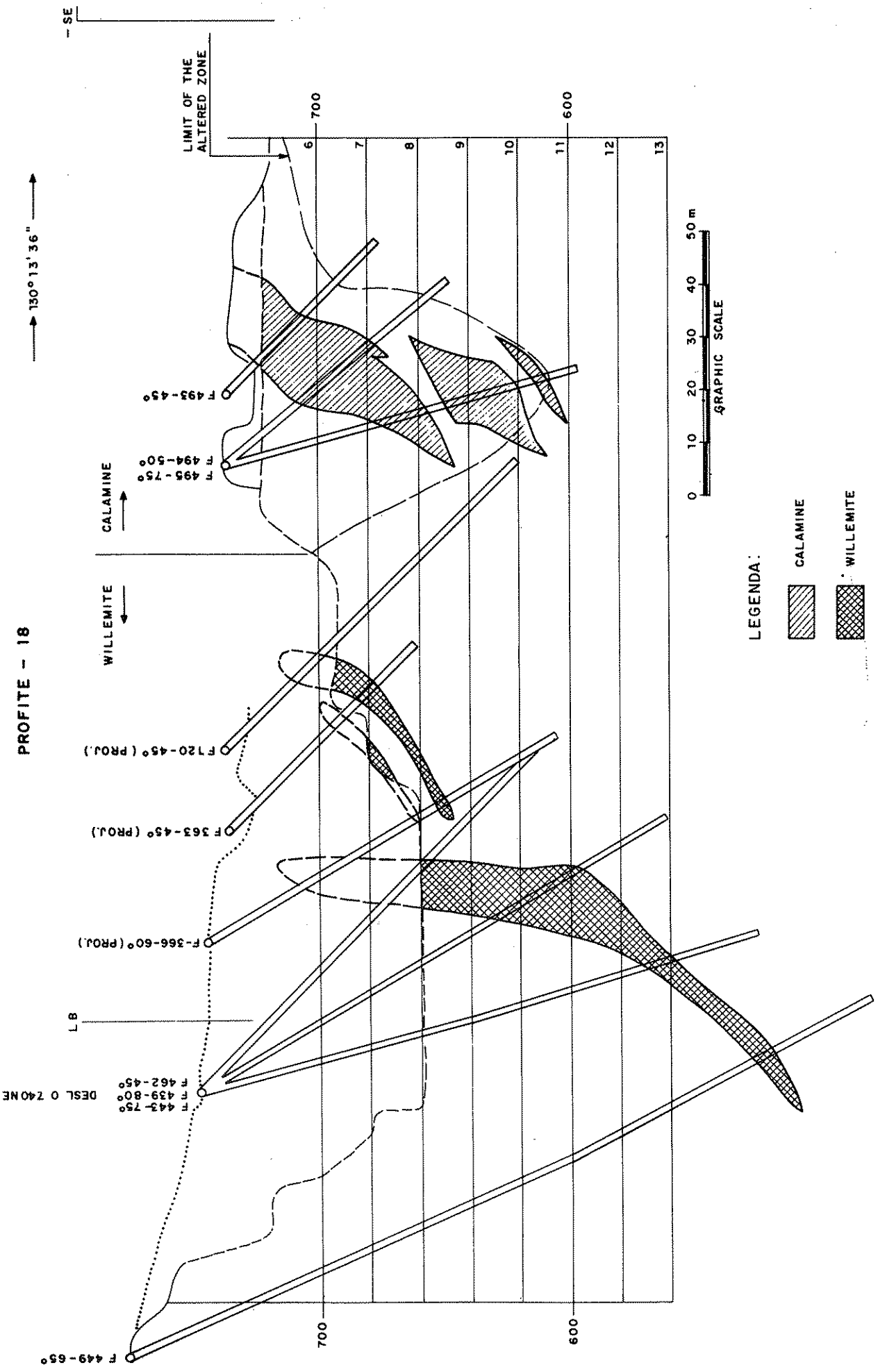


Fig-6.7 – GEOLOGY OF THE VAZANTE REGION – MINAS GERAIS

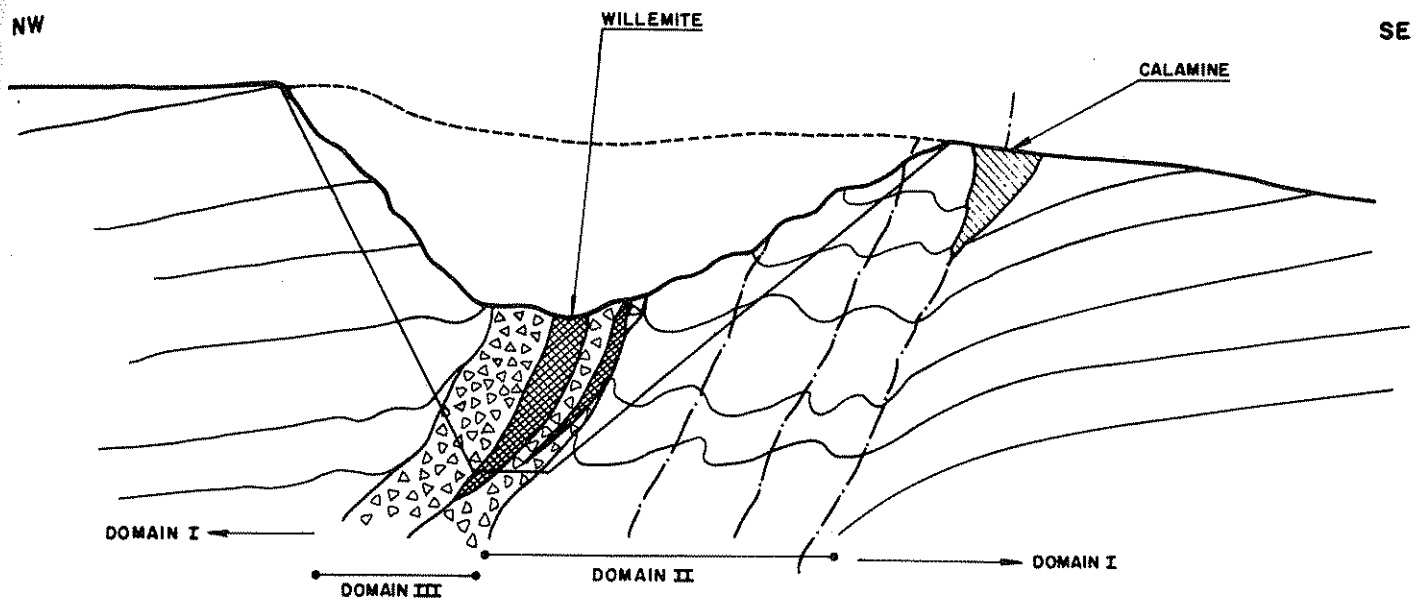


Fig- 6.8 SCHEMATIC PROFILE SHOWING THE THREE STRUCTURAL DOMAINS AND THEIR RELATIMP TO THE ZINC MINERALIZATION OF VAZANTE

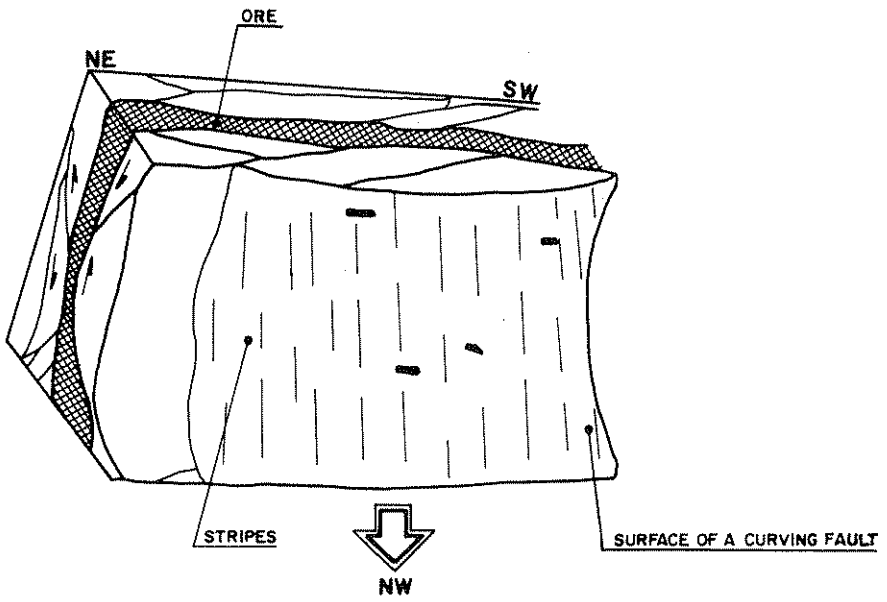


Fig - 6.9 SCHEMATIC DIAGRAN OF THE STRUCTURAL DOMAIN III

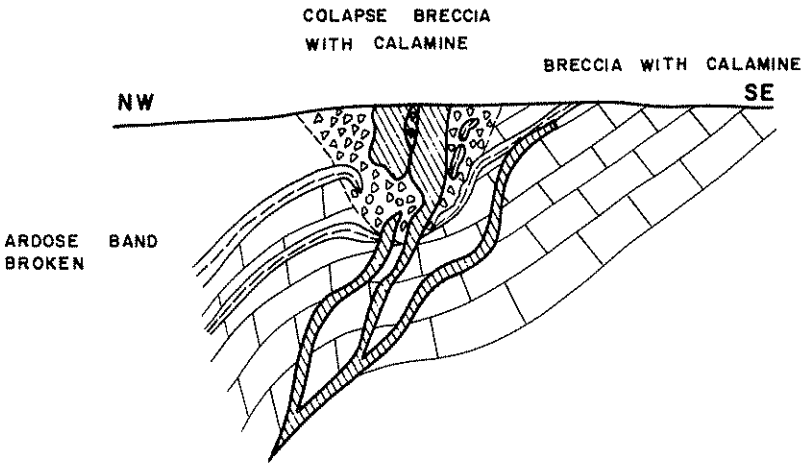


Fig- 6.10 SCHEDULE OF ONE CALAMINE MINING FRONT

Petrobrás Mineração S.A – PETROMISA

Em seus trabalhos de pesquisa, a *PETROBRÁS*, além dos dados essenciais à localização do petróleo, recolhe elementos de grande significação para a descoberta de outros minerais. Foi assim constituído acervo de dados de inestimável valor, cujo aproveitamento se tornou possível com a criação da subsidiária Petrobrás Mineração S.A - *PETROMISA*, dedicada, conforme estabelece seu Estatuto, à pesquisa e lavra de minerais nas bacias sedimentares brasileiras, área natural de atuação da *PETROBRÁS*, assim como beneficiamento e comercialização dessas substâncias e seus derivados.

A tarefa prioritária da *PETROMISA* foi a de iniciar a produção de cloreto de potássio fertilizante no Brasil, em razão da importância desse insumo e de nossa total dependência do exterior para sua obtenção. O Complexo Industrial de Taquari-Vassouras, localizado no município de Rosário do Catete - Sergipe, primeiro empreendimento da *PETROMISA*, constitui atualmente a única unidade destinada à extração e beneficiamento de minério de potássio em todo o Hemisfério Sul.

Desenvolve a *PETROMISA*, em paralelo, intenso esforço de pesquisa, voltado para várias substâncias minerais, num trabalho em que já foram obtidos resultados expressivos.

Do mesmo modo, destaca-se a preocupação da Companhia com a plena capacitação tecnológica, tendo a implantação de Taquari-Vassouras, assim como sua operação, proporcionado a absorção de avançada tecnologia de mineração a grande profundidade, que deverá ser aplicada em outros projetos.

O Complexo Industrial de Taquari-Vassouras, considerado de "Relevante Interesse Nacional", representa um marco no desenvolvimento da mineração no Brasil, por várias de suas características: pioneirismo, tecnologia avançada, e pela própria importância do potássio, um dos três macronutrientes básicos, juntamente com os fertilizantes nitrogenados e fosfatados.

As obras de implantação desse Empreendimento, dimensionado para a produção, à plena capacidade, a ser alcançada em 1991, de 500 ml toneladas/ano de cloreto de potássio, foram iniciadas em julho de 1979, com os primeiros trabalhos de terraplenagem e de escavação dos "shafts" de acesso à mina. Em sua execução a *PETROMISA* enfrentou, além da natural complexidade de um projeto de tamanho porte, uma série de dificuldades técnicas, e foi também necessária a implantação de todo um conjunto de instalações de apoio e obras de infra-estrutura.

Na obra de abertura dos "shafts", de quase 500m de profundidade, e 5m de diâmetro interno, através dos quais se faz a ligação entre a mina e a superfície, por elevadores de grande capacidade, o mais grave problema enfrentado foi a existência de camadas de arenitos, entre 330 e 380m abaixo do solo, impregnadas de água a grande pressão. Para criar barreira impermeável que evitasse a invasão da água, foram injetados na rocha aproximadamente 300 mil litros de resina epóxica, especialmente adaptada. A adoção dessa técnica, pioneira em termos mundiais, evitou a necessidade de congelamento da área, que iria retardar os trabalhos de forma imprevisível, além de implicar custos significativos mais elevados.

A mina conta atualmente com cerca de 40km de galerias de 7m de largura, em média, por 3m de altura, possibilitando a circulação livre de numerosa frota de veículos e equipamentos de mineração, especialmente fabricados para operação na presença de gases explosivos.

O método de lavra empregado em Taquari-Vassouras é o de câmaras e pilares alongados. As câmaras de lavra têm dimensões de 7m de largura por até 7m de altura, enquanto os pilares têm largura de até 12m. Cada painel de lavra possui dimensões ideais de 250m de largura de 500m de comprimento. No centro do painel passa uma galeria tripla, sendo a galeria central utilizada como retorno de ar e passagem de correia transportadora. Das galerias laterais partem as câmaras de lavra, em ângulo em torno de 60°, compondo a figura de "espinha de peixe".

O desmonte do minério é feito em duas etapas. Inicialmente um minerador contínuo escava em seção de 7m x 3,8m, e, numa segunda etapa, jumbos de perfuração aumentam a seção da câmara para até 7m x 7m. O transporte do minério desmontado pelos mineradores contínuos é feito por "Shuttle-cars", enquanto o minério obtido pela ação dos jumbos (desmonte a fogo) é transportado por "LHD's".

Dos painéis, o minério é levado ao poço de extração (Poço 1) por transportadores de correia, utilizando-se, ainda, um sistema de silos. Para trazê-lo à superfície, são empregados "skips" de 9 toneladas de capacidade, que se elevam à velocidade de 8m/s, significando capacidade de extração de 390t/h.

Concomitantemente à atividade de mineração, são

executadas sondagens no interior das galerias com a dupla finalidade de reconhecimento detalhado do corpo de minério e de segurança, objetivando a prévia identificação de fontes emanadoras de gases explosivos e de regiões potencialmente portadoras de água proveniente de bancos aqüíferos.

As reservas totais "in situ", consideradas as duas camadas de silvinita (superior + inferior), somam 810 milhões de toneladas, com teor médio de 24,8% de cloreto de potássio - KCl. Considerando imposições de ordem técnica e econômica, as reservas efetivamente mineráveis "in situ" reduzem-se a 133 milhões de toneladas de minério, com 32,3% de KCl (42 milhões de toneladas de KCl) para a "silvinita superior", e 225 milhões de toneladas de minério com 30,9% de KCl (70 milhões de toneladas de KCl) para a "silvinita inferior".

As duas camadas de silvinita da jazida de Taquari-Vassouras, situadas à profundidade média de 500m, estão separadas por aproximadamente 4m de halita (cloreto de sódio). A camada inferior assenta-se diretamente sobre taquidrita, rocha de baixa resistência mecânica e altamente higroscópica, não tendo havido ainda, no mundo, mineração em sua presença. O fato de estarem os evaporitos, classe de sais a que pertencem a silvinita, a halita e a taquidrita, sujeitos à fluência, confere características especiais à lavra e implica a realização de complexo trabalho de mecânica de rochas.

Dada a presença de metano (gás altamente explosivo), os equipamentos destinados a operar no interior da mina devem possuir características especiais, entre as quais motores blindados. A mina dispõe de sistema que corta automaticamente a energia elétrica das áreas onde houver emanação de gás, e aciona alarmes para desligamento de todos os equipamentos a diesel ou elétricos.

Devem ser ressaltados alguns cuidados, como o treinamento periódico de salvamento do pessoal e a existência de brigadas de resgate, devidamente equipadas para socorro em áreas com atmosfera perigosa.

A usina, localizada na superfície, projetada para processar 2,1 milhões de toneladas/ano de minério, que permitirão a obtenção de 500 mil toneladas/ano de cloreto de potássio, é composta de vários prédios, onde se realizam as diferentes etapas de beneficiamento: britagem, flotação, secagem, compactação e resfriamento, interligados todos esses edifícios por correias transportadoras. A usina conta com sistema de controle de processo por computadores e eficientes dispositivos antipoluição.

Para cada tonelada de cloreto de potássio são geradas aproximadamente, três toneladas de rejeito, constituído essencialmente por cloreto de sódio, o qual de acordo com o Projeto Básico, seria descartado no mar. Seu aproveitamento constitui expressivo êxito da Empresa, já que todo o sal obtido em Taquari-Vassouras é comercializado, destacando-se os fornecimentos, como matéria-prima, para a produção de barrilha, para preparação de lamas de perfuração e estimulação de poços de petróleo e também como arraçoamento animal. Além disso, com a instalação em breve do Pólo Cloroquímico de Sergipe, parte significativa da produção de sal-gema da *PETROMISA* irá destinar-se às indústrias integrantes do Pólo.

Diante da necessidade de acompanhamento contínuo dos trabalhos, desenvolvidos no interior da mina e na usina de beneficiamento, bem como das atividades de análise de amostras de rocha, bem como das atividades de análise de amostras de rocha, coletadas em várias regiões do País, além de testes referentes aos Projetos da Empresa, foram instalados, na área industrial, centro de pesquisas minerais e laboratórios químico e de mecânica de rocha, inteiramente aparelhados para o desenvolvimento desses trabalhos. O Complexo Mina-Usina de Taquari-Vassouras constitui-se assim em importante pólo de desenvolvimento e difusão de tecnologia.

Outros Projetos

Face à importância do potássio para o desenvolvimento da agricultura e ao reduzido número de países exportadores desse fertilizante, revestem-se de alto significado os projetos que a *PETROMISA* desenvolve na Bacia Amazônica, que se tem revelado extremamente promissora quanto à presença de depósitos minerais potassíveros.

Na região do Médio Amazonas, onde a *PETROBRÁS* em 1974 havia recolhido testemunhos de sondagem indicando a presença de minério de potássio, a *PETROMISA* perfurou 54 poços num total de cerca de 63.000m, dos quais 14.000m testemunhados. Como resultado desse trabalho, que envolveu investimentos em pesquisa de aproximadamente US$ 31 milhões, a *PETROMISA* delimitou dois grandes depósitos: Fazendinha, a 130km a sudeste de Manaus, com reserva da ordem de 540 milhões de toneladas de minério de potássio, e Arari, distante 40km de Fazendinha, junto à foz do rio Madeira, com 660 milhões de toneladas de minério.

Estudos de viabilidade já concluídos indicam a possibilidade de implantação de um complexo mina-usina em Fazendinha, dimensionadl para 1,5 milhão de toneladas/ano de fertilizante potássico, quantidade que poderia ser duplicada com a abertura de outra mina, de mesma capacidade, em Arari.

Ainda com relação a potássio, merecem referência a jazida de silvinita de Santa Rosa de Lima, em Sergipe, localizada a 18km de Taquari-Vassouras, cujo aproveitamento integrado com esse Complexo permitirá elevar sua produção para um milhão de toneladas/ano de cloreto de potássio, assim como os trabalhos que a Empresa vem realizando para implantação de uma planta-piloto, também naquele Estado, destinada à mineração por solução da carnalita, cloreto duplo de potássio e magnésio, e cujas reservas atingem 24 bilhões de toneladas. Nessa atividade, está sendo desenvolvida técnica pioneira, em conjunto com a estatal francesa Mines de Potasse d'Alsace (MDPA).

Sal-gema

No Estado do Espírito Santo, região de Conceição da Barra, as atenções voltam-se para a possibilidade de aproveitamento de importante depósito de sal-gema, com reservas avaliadas em 20 bilhões de toneladas.

Nos trabalhos de pesquisa, que envolveram investimento de US$ 1,8 milhão, foram executados 8 poços, num total de 12.700m, dos quais 1.000m foram testemunhados. Por sua localização, em terra, próxima ao litoral e dos principais centros consumidores desse insumo, dentre os quais o Pólo Petroquímico do Rio de Janeiro, projeta-se esse empreendimento como dos mais promissores da *PETROMISA.*

Enxofre

Na região de Castanhal, no Estado de Sergipe, a *PETROMISA* descobriu a primeira jazida de enxofre ativo do Brasil, tendo sido bloqueada reserva de 3,6 milhões de toneladas de enxofre "in situ". Uma vez verificado que a utilização do método tradicinnal "Frash" implicaria em custos energéticos elevados, a *PETROMISA* passou a examinar a possibilidade de extração do enxofre por processo alternativo, não intensivo no uso de energia.

A Empresa, além dos trabalhos em Sergipe, desenvolveu pesquisas com vistas a enxofre nativo na Bacia do Espírito Santo, onde foram executadas 19 sondagens, num total de 8.600m.

Barita

Na Bacia do Recôncavo a *PETROMISA* descobriu na região de Fazenda Barra, município de Aramari, depósito de barita (sulfato de bário) substância de grande consumo na preparação de lamas de perfuração, com reservas de minério que alcançam 856.000 toneladas.

Com a obtenção de resultados altamente animadores no estudo de viabilidade técnico-econômica, ficou decidido o início, já no próximo ano, da implantação de conjunto mina/usina para produção de aproximadamente 17.000 toneladas/ano de barita beneficiada.

Areias Especiais

Outra importante descoberta da *PETROMISA* aconteceu recentemente na Bacia do Parnaíba, em área próxima ao município de Carolina, no Maranhão. Trata-se de depósito de areias especiais utilizadas em estimulação de poços de petróleo, com reservas calculadas em 1,5 milhão de toneladas, o suficiente para atender ao consumo da *PETROBRÁS* por mais de um século.

Do mesmo modo que o projeto para a produção de barita, prevê-se que este também se inicie no próximo ano, em vista dos resultados positivos dos estudos realizados.

Outras Substâncias

A Empresa desenvolve, ainda, estudos de geologia e trabalhos de exploração mineral, como mapeamentos, sondagens, geoquímica, geofísica, com vistas, principalmente, a cobre, chumbo, zinco, fosfatos e minerais industriais, atualmente nas Bacias do Recôncavo, Tucano-Sul, Tucano-Jatobá, Sergipe-Alagoas, Parnaíba, Amazonas, Paraná, São Francisco e Potiguar.

Nessas atividades foram coletadas mais de 100.000 amostras geoquímicas, levantados 700km de linhas geofísicas e realizadas cerca de 220 sondagens verticais, tendo sido descobertas e cadastradas diversas ocorrências minerais.

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