International Conference "Geochemical Evolution of the Continental Crust"

Poços de Caldas, Brazil
11-16 July, 1988

Guidebook

NE QUADRILATERO FERRIFERO AND ADJACENT AREAS

H.D. Schorscher

June 1988
Prof. Dr. H.D. Schorscher
U.S.P.-I.G.-D.M.P.
Cx.P. 20899
São Paulo, Brasil

TABLE OF CONTENTS

1. INTRODUCTION - LOCATION AND IMPORTANCE OF THE AREA

The Quadrilátero Ferrífero (Q.F.), "Iron Quadrangle", in Eastern Brazil, State of Minas Gerais, is the classical area of the Precambrian Geology of this country. The name is owing to the impressive development and geometric arrangement of the major itabiritic (bif) units, as is spectacularly visible on air photographs and satellite imagery (figs. 1, 2).

The Q.F. is, in geographic terms, part of the southernmost Serra do Espinhaço, "Espinhaço (means backbone) Range" (E.R.). This predominantly quartzitic mountain chain was named by Eschwege (1832) and extends for more than 2.000 km in a general N-S direction, almost parallel to the East-Brazilian coast. The geology of both, the Q.F. and the E.R., however, are quite different. They represent two distinct Proterozoic Supergroups, termed Minas and Espinhaço, respectively.

The scope region of this field trip encompasses Northern and Eastern parts of the Q.F., the southernmost foot-hills of the E.R. and, in the E and NE, the neighbouring districts of Sta. Barbara (-Florália), Piçarrão and Itabira (fig. 1).

The Q.F. and southern E.R. are still Brazil's most important mineral producing province. Iron ore, gold and diamonds are the principal products. Besides these, manganese ores, chromitites, platinum, vanadium-rich magnetite-ilmenite iron formations, uranium, bauxite and even one stibnite and one mercury occurrence are being, or were mined/intermittently mined in past times.

Further importance is due to gemstones and technical minerals. Famous are the occurrences of imperial topaz near Ouro Preto, the 1979/1980 discovery of emeralds near Itabira (<Belmont Mine>), most recently (1986/87), the discovery of alexandrites near Hematita and, of course, the diamonds from Proterozoic metaconglomerates of the E.R., known and in production since historical times (fig. 1). Other pegmatite-gemstones produced in the area include tourmaline, aquamarine, topaz among others. The most important technical minerals are: beryl, columbite, micas, alkalifeldspars / kaolin-kaolinite and quartz from pegmatites, quartz and kyanite from "veins" in quartzitic sequences and talc, steatite and asbestos from ultramafic bodies.

A review of the mineral occurrences of Minas Gerais was given by Freyberg (1934) and of the Q.F., more recently, by Dorr and co-workers (Dorr 1969).

2. REGIONAL GEOLOGY

The area shown in fig. 1 can be subdivided into several large scale lithostratigraphic and lithostructural units:

- The Granitic ("Basement") Complex of mainly Archaean, polymetamorphic and polygenetic migmatites and gneisses including the "Borrachudos Granite" type rocks,
- the Archaean Rio das Velhas Greenstone Belt (Supergroup),
- the Q.F. sensu stricto of Lower Proterozoic, mainly ferriferous (itabiritic) metasediments (Minas Supergroup),
- the E.R. of Lower to Medium Proterozoic, mainly quartzitic metasediments (Espinhaço Supergroup),
- the Itabira Iron-Ore District with granitoids, gneisses, migmatites and Minas SGr. rocks,
- the easternmost domains of high grade gneisses and migmatites, including the Piçarrão Iron Ore District,
- the São Francisco Basin with Medium to Upper Proterozoic (meta-) sediments.

2.1 The Granitic ("Basement") Complex

areal distribution, terminology and lithologies

The Archaean parts of the Granitic Complex can be well individualized in the western and central portions of the area, since they were only affected by low to medium grade younger regional metamorphic overprintings (fig.3, domain W of isograde 2: "staurolite in" reactions). The continuation into the eastern parts, although recognized in individual cases, is not yet mapped in detail. This part suffered high grade regional metamorphism and intensive tectonics, especially in the course of the youngest Proterozoic, Minas/Espinhaço, orogeny. In consequence, the eastern areas became characterized by structurally complex, intimate associations of different high grade gneisses and migmatites. Some of them resulted from metamorphic and structural reworking of Archaean migmatites and gneisses, others, possibly from Rio das Velhas and/or similar supracrustal sequences, and still others from Minas Supergroup rocks, most probably of the Paragneiss Sequence and of lateral facies equivalents of the Piracicaba Group. In fig. 1, as a compromise, all these different high grade gneisses and migmatites were labeled with one symbol. Fig. 3 shows an outline of the younger Minas/Espinhaço regional metamorphism, with subdivisions into lowermost grade (W of isograde 1: "stilpnomelane out"), low to medium grade (E of isograde 1 - until 2: "staurolite in"), medium to high grade (E of isograde 2 until 3: "2nd sillimanite isograde") and very high grade - upper amphibolite and granulite facies (E of isograde 3).

According to the latest edition of the geologic map of Brazil, the Granitic Complex includes the high grade gneisses and migmatites of the eastern regions and is a part of the "Complexo Migmatito-Granulitico de

Minas Gerais" - Migmatitic Granulitic Complex of Minas Gerais (Inda et al. 1984).

The Granitic Complex is thus composed of rocks of different types and ages. The quantitatively predominant constituents possess granitic compositions sensu lato (s.l.). Besides, there occur metabasic, metaultramafic, metasedimentary and basaltic rocks. The lithologic constituents of the Complex can be subdivided into two groups according to their "primary" or "secondary" origin. To the first group belong high grade metamorphic/polymetamorphic gneisses, migmatites, rare amphibolites as well as igneous meta-granitoids considered to be of Archaean age. The second group comprises younger metamorphic, metasomatic, metaigneous and igneous rocks with or without defined lithostratigraphic and/or age relationships with the major regional units (i.e. Rio das Velhas, Minas, or Espinhaço Supergroups) and, except for local cases, the eastern portions of the Granitic Complex subjected to high and very high grade younger regional metamorphic reworking in the course of Proterozoic events.

2.1.1 "Primary" constituents of the Granitic Complex

The bulk of the "primary" constituents are granitic rocks s.l.. "Primary" amphibolites were only found in less than 1% of the total of more than 3.000 outcrops studied.

2.1.1.1 The s.l. granitic rocks

These granitic rocks are in their large majority metatectic gneisses and anatectic migmatites, i.e. originally high grade metamorphic rocks. Igneous, s.l. granitic intrusives are rare.

Among the *gneisses* leucocratic homogeneous types predominate; well banded heterogenous types are scarce. The predominant *migmatites* are also more homogeneous plutonic rocks with nebulitic, "Schlieren" and stromatic macro- and mesoscopic structures. However, folded ophthalmic, surreitic, ptygmatic and patch structures occur as well (figs 4 and 5).

The *intrusive granitic rocks s.l.* form smaller, irregular and/or round shaped bodies (of one to hundreds of meters of major dimensions) or dikes, cutting the gneisses and migmatites with intrusive contacts (figs. 4 and 6). However, effects of contact metamorphism could not be observed and some outcrop features suggest that at least in some cases the solidification of the migmatites and gneisses may not have been completed at the time of intrusion.

All the "primary" granitic constituents s.l. of the "Basement" Complex, gneisses, migmatites and intrusives, possess quartz-dioritic (tonalitic) and the most leucocratic types, trondhjemitic modal compositions. Plagioclase and quartz are the principal minerals with about 40 Vol.% each, K-feldspar is normally less than 10 Vol.%, and the mafics, in general biotite, rarely hastingsitic-tschermakitic amphibole and very rarely garnet, commonly total less than 15 Vol.%.

Some 200 samples of granitic rocks s.l. were analysed for major and some minor elements by various authors (Schneiderhöhn 1935, Herz 1970, Roeser 1977, Schorscher and Leterrier 1980). The overwhelming majority have $Na_2O:K_2O$ ratios >1.5 and not uncommonly values >2.5. If the $Na_2O:K_2O$ ratio is <1, the petrographic studies always show that "secondary" processes of metasomatic K-feldspathization acted and modified the "primary" rock composition. Comparative mean values, mainly of the well preserved Archaean portions of the Granitic Complex, are given in table 1. Fig. 7 shows "primary" and "secondary" granitic rocks s.l. in a representation relevant to the Na:K and feldspar proportions.

In an attempt to obtain more precise information on the high-grade P-T conditions of the formation of the migmatites and gneisses, two-feldspar geothermometry was applied to microprobe data obtained from relics of antiperthitic "primary" (unsaussuritized) plagioclases. They indicated temperatures of about 600 to 720°C for assumed pressures in the range of 3 to 5 kb.

All the "primary" granitic rocks s.l. of the "Basement" Complex suffered younger metamorphic readjustments. P-T conditions of these processes varied from the lower greenschist to the lower amphibolite facies in the western and central parts of the Complex (fig. 3). Throughout this area they caused partial to total saussuritization of plagioclases, sagenitization and chloritization of biotites, chloritization of and actinolite overgrowth on amphiboles, chloritization of garnet, polygonal recrystallization of quartz. The "primary", microscopically non-perthitic microclines are without visible signs of retrometamorphism. However, microprobe data revealed regular variations of their Na-contents, as being always higher in the cores of the individuals, with 10 to 15 mol.% Ab, and lower in the border zones with less than 5 mol.% Ab, probably a result of partial readjustment by the younger low-grade metamorphic events.

2.1.1.2 The "primary" amphibolites

These rocks (not indicated in fig. 1) belong to two different genetic groups, derived from basic and ultramafic igneous rocks respectively. Both types are intensely foliated, gneissose textured medium-grained rocks with foliations concordant with the enclosing country migmatites/gneisses. The amphibolites are deeply weathered, more than their granitic surroundings s.l.. A few aritificial outcrops, however, expose the direct contact between "primary" amphibolites and migmatites/gneisses in fresh rock preservation. They show the amphibolites "welded" to the granitic constituents s.l. and thus, that they were also fully involved in the high-grade metamorphism from which originated the quantitatively predominant constituents, gneisses and migmatites, of the Granitic Complex. The *basic amphibolites* occur preferentially as concordant and/or pseudoconcordant layers/transposed dikes. Their maximum thickness is in the order of 50 m. Serially arranged lenticular bodies are most probably disrupted/boudinated layers/dikes, and range from one to tens of meters dimensions. Irregular or rounded larger masses are very rare and may represent original intrusive bodies.

Principal minerals and modal compositions are: tschermakitic amphibole ≅ 60 Vol.%, plagioclase ≅ 30 Vol.% with ≅ 65 mol.% An normative composition, quartz ≅ 6 Vol.%, accessory sphene and opaques totaling <4 Vol.%. The original high-grade metamorphism and tectonics caused some metamorphic differentiation, bringing about millimetrical alternations of amphibole and plagioclase-quartz-rich layers, giving the rocks a typical dark and light coloured, striped aspect. No relics of primary igneous textures survived.

Rockchemical studies of the basic amphibolites are still scarce. Roeser (1977) reported analyses of the major and some minor elements of 15 rocks he termed "Pre-Minas Amphibolites". The rocks were collected in a relatively small area, situated NE of Ouro Preto (fig. 1, in the southeastern corner of the Q.F.) and correspond, from the petrographic description, to the above discussed basic amphibolites of the "Basement" Complex. Roeser concluded on chemical grounds, that the premetamorphic parents of his rocks were probably tholeiitic basalts.

The basic amphibolites also suffered younger low-grade metamorphic reequilibrations causing advanced to total saussuritization of plagioclases, actinolite overgrowths on primary amphiboles, leucoxenic transformation of opaques and polygonal recrystallization of the quartz.

The *ultramafic amphibolites* predominantly occur as lenticular and irregularly shaped bodies of different sizes, some exceeding several hundred meter dimensions. They only rarely form concordant and/or pseudoconcordant layers/dikes.

The ultramafic amphibolites are nearly pure amphibole rocks, >95 Vol.% being light greenish coloured clinoamphiboles with chromite as an accessory constituent and the other minerals, tremolite (as overgrowth on greenish amphibole), talc (in isolated flakes), clinozoisite-epidote (individual grains), magnetite, representing products of retrometamorphism due to the younger low-grade regional metamorphic readjustments.

One larger occurrence of metaultramafics (located NW of the city of Congonhas, fig. 1) preserved in its internal parts non-retrometamorphic nuclei. Interestingly enough, these show dry, granulite facies parageneses composed mainly of orthopyroxene (bronzite), forsterite-rich olivine, olive spinel (hercynite) and relictic chromite. The parageneses are considred to be of progressive metamorphic origin, due to armoured relics of magnesian amphiboles and talc, preserved exclusively in the poikilitic orthopyroxenes. Towards the contacts with the migmatites and gneisses of the Granitic Complex, hydration and retrometamorphism occur, causing the formation of low grade minerals (amphiboles, serpentine, talc, chlorite) and finally, the total destruction of the high grade parageneses. The surrounding gneisses and migmatites are equally retrometamorphic at low grade (greenschist facies) P-T conditions.

Two samples of ultramafic amphibolites were analysed for major and some minor elements. They possess peridotitic compositions and high Cr ≅ 2.000 ppm and Ni ≅ 1.500 ppm contents.

2.1.2 "Secondary" constituents of the Granitic Complex

The "secondary" constituents are metamorphic and non-metamorphic igneous, metasomatic and metasedimentary rocks. Their contacts with the "primary" lithologies are either tectonic or intrusive, as distinct younger dikes, stocks, plugs and, less frequently, as irregular bodies. The intrusive contacts are marked by low-grade hydrothermal mobilisates and/or by hydrothermal alteration of the wall rocks.

Among the "secondary" constituents again the granitic lithologies s.l. predominate, represented by rocks of the Borrachudos Granite type (fig. 1) and by minor pegmatoid dikes and irregularly shaped bodies (not indicated in fig. 1). Metaultramafic, metabasic, metasedimentary and basaltic rocks form small bodies, too small as to be individualized in fig. 1, except for some metaultramafics.

2.1.2.1 The Borrachudos Granite type granitic rocks

These rocks form three large sized masses, located N, S and SE of Itabira respectively (fig. 1). The occurrence S of Itabira was first mentioned and partially mapped by Freyberg (1932,p. 236-237, fig. 38) and petrographic descriptions were given by Schneiderhöhn (1935, p. 165, sample No. 19). Freyberg (1932) described the rocks as granite, Schneiderhöhn (op.cit.) as cataclastic and metamorphic granitic rocks with "Flasergneis" aspect. Dorr and Barbosa (1963) described the occurrence of Itabira, named the rocks "Borrachudos Granite" and considered them (op.cit., p. C 45) "... a late stage potassic, igneous granite..." in the sense of Read (1955), i.e., as non-metamorphic igneous rocks younger than the Minas Series. Herz (1970) studied petrologic aspects of the occurrences N and S of Itabira. He maintained an igneous, non-metamorphic origin, concerning the crystallization conditions he concluded, however, that these were more similar to those of a pegmatite than to a true igneous granite. The Borrachudos Granite type rocks are light coloured, coarse-grained (2 to >10 mm) of granitoid aspect, and are characterized by linear aggregates of mafic minerals, mainly biotite (fig. 8). The mafic mineral lineation is constantly E throughout the three bodies, with gentle dips around 15 to 25°. Foliation is less pronounced in the bodies N and S, and better developed by flattening of the mafic aggregates in the one SE of Itabira. Foliation parallels the major outlines of the rock bodies, dipping 25 to 40° in general eastward directions (SE, E, NE) in occurrences N and S of Itabira and with similar values towards NW in the one situated SE of Itabira (fig. 1). Parallel to the foliation intercalations of mainly mylonite gneisses and mylonite (quartz-phengitic muscovite-) schists occur. Extensions of the intercalations vary from several meters to more than 1 km, with thicknesses ranging from a few cm to more than 200 m. The major intercalations form deep "septae" subdividing the granitoid bodies into "mega-foliae" of variable thicknesses in the order of several tens to more than 200 m, according to the spacing of the intercalations. The contacts between the individual granitoid bodies and migmatites (fig. 1) are tectonic, as evidenced by bilaterally increasing mylonitization of the latter. Indications of contact metamorphism are absent. The bordering zones of cataclastic gneisses reach more than

1.000 m thickness, and their (cataclastic) foliation is parallel to the foliation of the granitoids and of the contained intercalations. The contacts between the granitoid and the cataclastic rocks, independent of their occurrence as intercalations or along the outer borders, are gradational, by progressive alkali feldspar blastesis towards the granitoids. Widths of blastesis zones vary from a few cm to >100 m, depending on the rock compositions. Generally, the mylonite gneisses are more strongly affected than mylonite schists, and, in both rock groups, higher contents of sheet silicates reduce the intensity and the range of alkali feldspar blastesis.

The Borrachudos Granite type rocks are composed of perthitic alkali feldspar (≅ 55 Vol.%) and quartz (≅ 38 Vol.%) as major minerals, biotite is normally <5 and fluorite <2 Vol.%. Other minor and trace constituents include relics of saussuritized plagioclase mainly as inclusions in perthites, zircon, allanite, opaque minerals (mainly titano-magnetite), partially transformed into leucoxene, carbonate, chlorite, muscovite, epidote-clinozoisite, and bluish (riebeckitic) amphibole.

Of special interest are the perthitic alkali feldspars. They are replacement perthites, always containing relics of saussuritized plagioclases and quartz, with micro-textures indicating syncataclastic growth (fig. 9). The K-feldspar phase of the perthites contains as much as 20 Vol.% of triphasic (hydrothermal liquid - liquid CO_2 - gas) fluid inclusions in the form of negative crystals (fig. 10). Dimensions of fluid inclusions are in the order of 5 to 10μ. The replacement perthites formed by the invasion of preexisting saussuritized plagioclases, by K-feldspar, with accompanying reorganisation of the albite phase and remotion of saussurite minerals. The K-feldspar phase is structurally intermediate between orthoclase and microcline, without microcline twinning, and with triclinicities around 0.8. The replacement perthites tend to develop hypidiomorphic habits and may be best described as porphyroclastic porphyroblasts. Along their borders, the perthites recrystallize into small polygonal individuals of twinned microcline and albite and the fluid inclusions are healed to disappear by post-cataclastic periods of regional metamorphism.

The linear aggregates resulted from concentration of the mafic minerals, not suitable for substitution, within major interstices between parallel and subparallel oriented perthites in response to dynamometamorphic differentiation and syncataclastic perthite-blastesis. They are composed mainly of biotite and also contain clinozoisite-epidote, opaques partially substituted by leucoxene, zircon, allanite and bluish riebeckitic amphibole. Again, post-tectonic periods of regional metamorphism are evidenced by biotites and the bluish amphiboles grown across the main microscopic foliation (and lineation) of the mafic aggregates. Quartz in polygonal individuals concentrates also in interstices between perthites and composes quartz-richer portions of the granitoids. These may contain disseminated carbonate and fluorite.

A less frequent variety of granitoids occurs in the direct contact with mylonite (quartz-phengitic muscovite-) schists. Differences mainly concern the porphyroclastic alkali feldspar porphyroblasts, being, in this case, non-perthitic, without relics of saussuritized plagioclase but containing relics of mainly quartz and white mica. Biotite, clinozoisite-epidote, chlorite and amphiboles are also absent. Throughout the granitoids, fluxion texture is predominant and relictic rock portions of mylonite gneisses and schists, unaffected by alkali feldspar blastesis are frequent.

The above observations were described by Schorscher (1975a), Schorscher and Müller (1977) and Schorscher and Leterrier (1980). They concluded that the Borrachudos Granite type rocks were formed by syncataclastic K-feldspar infiltration metasomatism in early, syntectonic, periods of the Minas/Espinhaço regional metamorphism. Sites of the granitoid formation were deeper levels of tectonically active large-scale regional high angle thrust faults, which reach into the deep crust. The faults were interpreted as thrusts caused by obduction of sialic crust from eastern towards western regions. Pre-metasomatic parents of the granitoids were predominantly mylonite gneisses derived from the Granitic Complex, mylonite schists and possibly Minas Supergroup rocks of the Paragneiss Sequence. P-T conditions of the granitoid formation were estimated from regional metamorphic, perthitic two-feldspar and fluid inclusion data, applying a combined model of infiltration metasomatism, cataclastic and regional metamorphism (open system), in the order: $T \cong 350 - 420°$, $P_s \cong 4 - 6$ kb, $P_f \cong 1.5 - 2.5$ kb.

Postcataclastic periods of the Minas/Espinhaço regional metamorphism at increasing grades progressively extinguished the genetically significant features and transformed the eastern parts of the granitoids into leucocratic medium- to coarse-grained "Flasergneisses", composed of microcline (without fluid inclusions), oligoclase, quartz, biotite, amphibole and accessories. It is important to note that the Borrachudos Granite type granitoids suffered one phase of regional progressive metamorphism. Only their mylonite-gneiss parents, originally primary constituents of the "Basement" Complex, were retrograde metamorphic rocks.

Over 160 samples of granitoids, partially feldspathized mylonite gneisses and mylonite schists, and corresponding non-feldspathized cataclastic and non-cataclastic rocks were analysed for major and trace elements, in order to obtain information on the chemical characteristics of the metasomatic process. The analyses were briefly discussed by Schorscher and Leterrier (1980). The granitoids are SiO_2- and K_2O-rich rocks with 75-82 and 5 - 7 wt% respectively, $F \cong 0.3 - 0.5\%$, depleted in Sr (<50 ppm) and enriched in Zr, Y, Rb, La, Ce and others (fig. 7, table 1).

2.1.2.2 The Emerald Deposit <Belmont Mine>

The emerald deposit of the <Belmont Mine> near Itabira (fig. 1, outcrop No. 15) is genetically related to the Borrachudos granitoid body SE of Itabira. Borrachudos granitoids and the emerald hosting rocks are in the medium amphibolite facies of Minas/Espinhaço (Proterozoic) regional metamorphism (fig. 3). At the site of the deposit (fig. 11), the granitoid is in direct tectonic and metasomatically altered metamorphic contact with metaultramafics of a series of gneissified remnants of vulcano-sedimentary (greenstone belt) nature, considered of Archaean age. The metaultramafics with associated amphibolites, pelitic gneisses and mica-quartzites were mapped previously as a sequence of paragneisses (Schorscher 1975a), and some petrological considerations with respect to the peculiarities and the attained grade of regional metamorphism were made by Braun and Schorscher (1977).

The emeralds occur in the biotitized metaultramafics, within a contact zone extending not more than a few tens of meters away from the direct boundary of the granitoids. Particularly rich mineralisations were formed were the biotitized metaultramafics are additionally cut by a major quartz vein, varying, due to pinch and swell phenomenons, from a few decimeters to several meters of thickness and running, to all appearances, parallel/subparallel to the contact with the granitoids. Emeralds are most frequent at the direct contact plane between the quartz vein and the biotitized metaultramafics. Their growth structures are parallel or discordant to this plane. In the discordant case the emeralds are partially ingrown in both, the vein quartz and the biotitite. However, emeralds fully enclosed within internal portions of the quartz vein were not observed but do occur entirely within the biotitite. Minor quartz veins, discordant to the cataclastic foliation of the biotitized metaultramafics and, in general, to the direction of the tectonic contact with the granitoids, occur as well, but show no related emerald mineralisation.

The major characteristics of the Borrachudos granitoids, as being formed in the environment of active thrust faults by synmetamorphic-metasomatic and syntectonic processes, from infiltrated, K_2O- and related incompatible minor and trace element-rich fluids, were already stressed. Chemical data about the Be-contents do not exist up to now, but positive anomalies may be expected. It is though that these characteristics of the granitoids and their direct contact with metaultramafics as well as the "right" grade of syngenetic amphibolite facies regional metamorphism were the controlling factors for the emerald deposit formation, which is clearly not related to igneous granitic intrusions.

A recent description essentially of mineralogical properties of the emeralds from the <Belmont Mine> was published by Hänni et al. (1987).

2.1.2.3 Pegmatoids

Pegmatoids (not indicated in fig. 1) are less important secondary constituents of the Granitic Complex. They occur as small (≅ tens of meters dimensioned) intrusive dikes and irregularly shaped bodies. They are hololeucocratic coarse-grained rocks composed essentially of microcline, quartz and minor albite. Black tourmaline is abundant in individual occurrences. The pegmatoids possess some geotectonic significance in the round shaped uplift of Granitic Complex rocks, located in the south central part of the Q.F. (fig. 1, Bação Complex). They occur as radial exposed dikes and veins in the marginal part of the uplifted block. The uplift and pegmatoids respectively deformed and intruded both Rio das Velhas and Minas rocks, and some pegmatoids are without signs of regional metamorphism and tectonic deformation. They may be related to the Brasiliano Tectono-Thermal Event (≅ 500 m.y.).

The analysis of one pegmatoid dike sample was represented for comparison in fig. 7, together with the other "Basement" Complex granitic rocks

2.1.2.4 Metaultramafics

Metaultramafic, secondary constituents (fig. 1, symbol "u") occur with tectonic, cataclastic contacts within the Granitic Complex. Additional common contact features are quartz-mobilisates and talc veins. Evidences of thermal metamorphism are absent. The metaultramafics form elongated oval and lenticular shaped bodies, preferentially oriented in N-S and NE directions.

Most of the known occurrences have maximum extensions of less than 1 km and could not be represented in fig. 1.

From the regional distribution the metaultramafics are more frequent along the southern and eastern bordering areas of the Q.F., apparently preferring in this case a closer spacial association with Rio das Velhas, in the Itabira District with Minas, and along the eastern borders of the E.R. with Espinhaço and Minas rocks.

They are characteristically schistose, low-grade metamorphic rocks, ranging from serpentinites to chloritites and talc schists. More frequently, there are mixed types containing the above mentioned minerals and also varying amounts of tremolite and magnesite. Accessory chromite is common in all the types, and up to cm-sized magnetite porphyroblasts of regional metamorphic and/or metasomatic origin occur preferentially in chloritites and chlorite-rich varieties ("black wall" alterations).

Accessory chromite octaedrons (<1 mm sized) are the only primary magmatic relic minerals. They also suffered partial reequilibration in the course of greenschist facies metamorphism, as indicated by higher reflecting ferrit-chromite transformations along borders and fractures.

Relictic textures, pseudomorphs after olivine, could be found in a few occurrences of the Itabira district. Pseudomorphs possess elongated forms and are aggregates of cross hatched serpentine bordered by fine-grained, secondary oxide mineral (magnetite) seams. The pseudomorphosed textures resemble rather the imbricated olivine textures of alpine type peridotites than pseudomorphosed and subsequently deformed cumulus textured peridotites.

Some of the metaultramafic occurrences contain deformed bodies of massive or disseminated chromitites. The chromite individuals are eu- to subhedral and finer grained than in typical alpine type chromitites, with medium grain sizes of about 0.5 mm. The chromites contain oriented inclusions according to (100) and (111), of ilmenite and rutile and droplike inclusions of Ni-sulfides. They also show ferrit-chromite transformation along the borders and fractures (fig. 12). Silicate minerals in the chromitites are the same as in the ultramafic rocks.

More than 60 rocks and some chromitite samples were analysed for major and some minor elements. Rocks show peridotitic compositions with characteristic high Cr and Ni contents (both >2.000 ppm). Surprising were anomalous Zn contents in the rocks (100 - 400 ppm) and chromitites (700 -

1.700 ppm). Microprobe and microscopic studies showed the Zn to be bound in the chromites' spinel structure (fig. 12). Highest contents found in individual chromites reach 4 wt% Zn. These chromites are optically anisotropic (Wiedemann and Schorscher 1978, Schorscher 1980b).

The genetic context of the ultramafics is not clear. Most probably they belong to different groups. Apparently, they are all younger than the "primary" constituents of the Granitic Complex. Some may be related to the evolution of the Rio das Velhas Greenstone Belt and thus, Archaean rocks. Others, however, occur as tectonic intercalations within Minas, and still others thrust over Espinhaço Supergroup rocks. These may represent tectonically intruded "alpine type" peridotites, related to the Minas/Espinhaço orogeny. From regions with abundant ultramafic rocks, E of the E.R. platinum occurrences were described (Hussak 1906, Belezkij and Guimarães 1959).

2.1.2.5 Metasediments

Metasedimentary secondary constituents (not represented in fig. 1) are quartz-(phengitic) muscovite mylonite schists. They always occur in cataclastic zones cutting the Granitic Complex, preferentially in N - S trending directions and dipping with high angles to the E. Major extensions may reach several hundred meters with thicknesses generally less than 50 m. They are mineralogically and texturally identical with the mylonite schist intercalations of the Borrachudos granitoids.

Major minerals are quartz and white mica. The proportions may vary, from mica-poor quartzitic to quartz-poor schistose compositions. Some occurrences contain abundant magnetite octaedrons as additional constituents. Minute (detrital?) zircons are always present.

Textures are cataclastic, of mylonite schists, however, variations exist and are due to different habits of the quartz. Some of the schists are laminated, composed of regularly alternating quartz- and mica-rich millimetric layers. Others contain coarse-grained up to 5 mm dimensioned, disk-shaped, bluish quartz. These quartzes contain abundant fluid inclusions and extremely fine rutile needles. They give the schists an eyed texture.

On the genesis of the mylonite quartz - white mica schists different opinions exist. One author considers them as products of dynamometamorphism of the Granitic Complex gneisses and migmatites, another as regional metamorphic and mylonitized acid volcanics. Here, a metasedimentary origin is favoured, essentially since most of them occur in structural continuation with the also N - S trending quartzitic Espinhaço metasediments, however, without excluding different origins for individual occurrences.

2.1.2.6 Metabasic rocks ("anfibolitos diabasóides", amphibolites, Minas-amphibolites, etc.)

Metabasic rocks (not represented in fig. 1) cut throughout the Granitic Complex, as frequent younger dikes, sills and plugs, ranging from several tens to more than 1.000 m of major extensions. They were described in the literature under different names. Guimarães (1933) termed them "anfibolitos diabasóides" (diabasic amphibolites), Dorr and co-workers (in Dorr 1969, plate 1) as diabase, gabbro and amphibolite, Herz (1970) diabase, gabbro, metadiabase, metagabbro and amphibolite, Renger (1970) metabasalt, Gorlt (1972) metabasalt and basalt, Schorscher (1975a) amphibolites, Roeser (1977) Minas-amphibolites, etc.

Much confusion exists in the literature and concerns these rocks and their nomenclature: to identical rocks different names were given, and different rocks included under the same denomination. Probably the best descriptive term was the one adopted by Guimarães (op.cit.). The name diabasic amphibolite stressed at the same time the metamorphic nature and the relictic igneous texture of the rocks. And it is in this manner that they occur throughout the western and central parts of the Granitic Complex (fig. 1), where the younger metamorphic overprintings did not exceed low- to medium-grade P-T conditions (fig. 3, W of isograde 2: "stau.-in"). In this domain, they intruded not only the Granitic Complex, but also the Rio das Velhas and Espinhaço Supergroups. Exceptions are the Minas Supergroup rocks of the Q.F.: they possess tectonic contacts with these rocks. Metabasics are not known from the São Francisco Supergroup. Most probably the metabasics are older than the (meta-)sediments of the São Francisco Supergroup.

The metabasics are, in the western and central parts of the Granitic Complex greenschist facies, regional metamorphic rocks. Relictic igneous textures are always preserved and range from diabasic (holocrystalline coarse-grained ophitic) to ophitic and porphyritic. Relictic igneous pyroxenes are generally preserved in occurrences lying to the W of 43°30' (fig. 1).

The intensity of the regional metamorphic and tectonic process affecting the metabasics increased continuously, generally from the W to the E. Thus, in the western lower greenschist facies occurrences (fig. 3), with relictic magmatic minerals and textures, schistosity is absent or very weak and mostly confined to the borders of the meta-igneous bodies. Local cases of stronger tectonic deformation occur as a result of shearing and mylonitization caused by individual thrust faults.

Towards the E, the magmatic pyroxenes are progressively and finally totally replaced/pseudomorphosed by microcrystalline aggregates of fibrous actinolitic amphibole and some not definitively identified brownish coloured chlorite-serpentinite minerals (medium greenschist facies). Igneous textures are still preserved by the pseudomorphs after pyroxene and the typical laths of igneous, however saussuritized, plagioclase. Regional, but weak schistosity becomes evident. As from the inset of upper greenschist facies P-T conditions (fig. 3), the metabasics suffered more intense regional schistosity. Relictic igneous textures become rare. Pseudomorphs after pyroxenes are deformed and recrystallize to coarser grained poikiloblastic actinolitic amphibole. The saussuritized igneous plagioclases recrystallize as well, to metamorphic albite-oligoclase and finally, East of isograde 2: "stau-in" (fig. 3), the metabasics pass gradatively to typical amphibolites. Actinolitic amphibole is converted to tschermakite, and albite-oligoclase to andesine. Both reactions cause the consumption of clinozoisite formed by saussuritization. The rock fabrics become gneissose, relics of igneous textures are totally destroyed and the amphibolites from metabasics are undistinguishable under macroscopic and microscopic aspects from possible Rio das Velhas or polymetamorphic "Basement" amphibolites of the same region.

The main age of intrusion of the igneous parents of the metabasics was posterior to the sedimentation of the lower and medium Espinhaço Supergroup but prior to the deposition of the highest formations and to the culmination of the Minas/Espinhaço orogeny.

The composition of the igneous parents as indicated by the modal mineralogy of the least metamorphic types ranges from gabbro-diorite over diorite to quartzdiorite. However, more probably they were effusive rocks and the actually observed coarse-grained massive textures are due to the present erosional surface, exposing subvolcanic levels.

Chemical studies of the metabasics were made by Herz (1970), Roeser (1977), Biondi (1979) and this author (unpublished data). Rocks may be classified generally as continental tholeiites and follow, as plotted in the FP_y^*-FG_i^* diagram of La Roche and Ohnenstetter (1980), a trend intermediate between "normal" and "abyssal" tholeiitic series.

2.1.2.7 Metajacupirangite and metalamprophyres

Metajacupirangitic rocks are known only from one occurrence, located about 120 km N of Ferros within the "Basement" Complex, E of the E.R. (outside fig. 1). Contact relations with the "Basement" migmatites and gneisses are obliterated by thorough weathering, but supposed to be intrusive. The metajacupirangitic body is elongated, oval shaped, exceeding several hundred meters of major extension. Rocks are inhomogeneous, predominantly dark greenish to black coloured and contain subordinated leucocratic "Schlieren".

The dark coloured major rock portions are composed of green hedenbergitic pyroxene, plagioclase, abundant sphene and apatite, relictic reddish brown biotite, minor free (magmatic) carbonate and, possibly secondary, quartz. Regional metamorphic minerals within these rock portions are dark green amphibole partially substituting pyroxene, poikiloblastic garnet, clinozoisite and at least some of the quartz.

Leucocratic "Schlieren" are of retrograde saussuritized plagioclase, recrystallized metamorphic plagioclase, microcline, quartz, totally decomposed inferred former feldspathoids and also contain considerable amounts of apatite, sphene, minor carbonate in well defined grains, perfectly fitted into the general rock texture and individual pyroxene/amphibole, garnet and clinozoisite crystals.

The apatites are of special interest. They concentrate in globular shaped aggregates of up to 1 mm in size and are optically anomalous positive. The rock chemical composition is given in table 2.

Among the minor elements (wt%): Th = 0.21; Y = 0.13 and Sr = 0.25 are especially high. Thorium occurs in orangite, a decomposition product of thorianite. Yttrium, as found by microprobe studies, concentrates up to 1.2wt% in the apatites.

The rocks were affected only by the youngest Minas/Espinhaço regional metamorphism, under upper greenschist facies P-T conditions.

They were considered by this author (1975a) as members of the jacupirangite-carbonatite rock suite in spite of their relatively high SiO_2 contents, since some of the microcline and quartz could be of secondary metasomatic origin, as textural features indicate. The rocks could be genetically related to the diamond producing early Espinhaço magmatism.

Metalamprophyres were found in the southern part of the Floralia District and identified by field and mesoscopic petrographic criteria (fig.1, outcrop No. 9). They occur as several centimeter to half a meter thin dikes cutting migmatites of the "Basement" Complex. Rocks are black coloured, schistose and sprinkled with fine-grained light coloured minerals. Microscopic studies show the existence of two distinct groups of mafic dike rocks. The one (A) has as major constituents: green biotite, quartz and carbonates, the carbonate being grown as porphyroblasts with poikilitic inclusions. Minor and trace constituents are: clinozoisite-epidote s.s., titanite, blue-greenish amphibole (replacing biotite) little untwinned, fine-grained "matrix" plagioclase and opaque ore minerals, orientedly distributed along the schistosity. Polished sections revealed the ore minerals as deformed sulfides: pyrite and calcopyrite. The second group (B) has as major minerals dark brown biotite, quartz, carbonate and plagioclase, the latter two being developed as porphyroblasts with poikilitic inclusions. Minor and trace constituents are clinozoisite-epidote s.s., titanite and little untwinned, fine-grained "matrix" plagioclase. Blue-green amphiboles and opaque ore minerals are extremely rare to totally absent. Average chemical compositions of the two groups are listed in table 2. In both groups, the poikiloblastic carbonates are considered as recrystallized from originally magmatic equivalents, not of allochemical origin, the enclosing rocks being free of carbonates. The plagioclase poikiloblasts of group (B) rocks are also of isochemical, metamorphic origin. They formed by a reaction of quartz with clinozoisite-epidote s.s. and carbonate, as can be observed under the microscope.

These rocks too show only the effects of one phase of tectonic deformation and regional metamorphism (upper greenschist facies P-T conditions). They are considered to belong to the incipient magmatic activity of the Minas/Espinhaço cycle and may be genetically related to the diamond producing early Espinhaço magmatism.

2.1.2.8 Basaltic rocks

Basaltic rocks of two different age and compositional groups occur most commonly as dikes, cutting the Granitic Complex or in smaller intrusive bodies near the discordances with Minas and Espinhaço Supergroup rocks. Due to scale problems, they could not be represented in fig. 1. In areas extensively covered by Proterozoic units, including the São Francisco Basin, these rocks are apparently less frequent, absent or at least little known.

The basaltic rocks of both groups form plugs, sills and dikes and occur sometimes in close regional association, preferentially along N-S, NE and NW trending younger fracture zones. They are unfoliated throughout the area (fig. 11).

The older group (A) of basalts are holocrystalline coarse-grained, ophitic textured rocks. They possess tholeiitic mineral composition with: orthopyroxene (hypersthene), pigeonite, plagioclase, basaltic hornblende, apatite and opaques. More mafic types contain additional olivine and the more acid ones (without olivine) may bear little free quartz, sometimes in granophyric textures with late, sodic plagioclase. Their pyroxene content also diminishes.

The older basaltic rocks show evidence of a regional thermal metamorphism not accompanied by orogenetic tectonics. They developed polymict coronas between the mafic minerals and plagioclases. Compositions of the coronitic paragenesis, for instance the presence or not of garnet, and the state of conservation of the plagioclases, ranging from slightly clouded to polygonally recrystallized, indicates regional variations in the intensity of the thermometamorphic event (figs. 13, 14). These variations, however, show no relationship with the grade of the progressive regional Minas/Espinhaço metamorphism (fig. 3).

The intrusion of the older basaltic rocks must be posterior to the youngest (Minas/Espinhaço) orogeny, since they are neither progressively regional metamorphic nor foliated/schistose rocks. Their thermal metamorphism is attributed to the about 500 m.y. old Brasiliano tectono-thermal event.

The younger group (B) of basaltic rocks are olivine bearing or olivine free augite basalts with pilotaxitic, porphyritic, intersertal and subophitic textures. Excepting the plagioclase phenocrysts, they are much finer grained than the older basalts. They show no evidences of thermal metamorphism or deformation. The younger basalts are considered post-Precambrian in age and may be related to the Mesozoic basaltic magmatism that affected the Brazilian continent.

Comparative analyses of the two groups of basalts are listed in table 3. The rather primitive composition of the older group (A) and the well specialised geochemical characteristics of the younger group (B) of basalts become evident mainly through the elements Ti, Mg, K, P, Ba, Sr, Rb, and Cr.

2.1.3 Interpretation of the Granitic ("Basement") Complex

The Granitic Complex is in its "primary", largely predominant parts the oldest Archaean lithostructural unit of the area.

Petrographic and petrochemical characteristics indicate analogies to the other Archaean "grey-gneiss" complexes. An origin from deep crustal, already homogenized material rather than from suprastructural rocks is here preferred for the bulk of the "primary" granitic rocks, i.e for the more homogeneous quartzdioritic (tonalitic) rocks, migmatites with predominant plutonic structures and metatectic gneisses. The intrusive "primary" granitic rocks, also of tonalitic composition, may have been derived by more advanced crustal anatexis, from the same gneisses and migmatites, in slightly deeper crustal levels. In this case, the gross of "primary" constituents of the "Basement" Complex would provide insight into compositions and geotectonic processes that acted in early Archaean times in deep seated levels of a more primitive crust and finally led to the formation of the oldest Archaean high-grade metamorphic and igneous rocks known from this part of the Brazilian Shield.

The "primary" high-grade metamorphic mafic and ultramafic amphibolites are subordinated constituents of the "Basement" Complex and also considered to be derived in early Archaean times, but from subcrustal mantle levels. They intruded the crust as dikes and minor intrusive bodies. In their now exposed level they also experienced the high-grade metamorphic, deep crustal process that originated the enclosing "primary" granitic rocks in their pre-retrograde metamorphic form. An explanation as direct relics (igneous residues) of a hypothetic older Archaean crust, of mafic-ultramafic composition, subjected to repeated processes of partial fusions seems difficult not only on account of the quantitative relationships but also on petrological grounds related to the compositions of the mafic amphibolites.

Primary gneisses and migmatites of older supracrustal origin, if present at all, are rare. They could be represented by the scarce occurrences of well banded heterogenous gneisses composed of more than two distinctly different lithotypes. However, rocks as calcsilicate or aluminous gneisses, commonly accepted as of supracrustal origin, could not be confirmed within the well individualized, typical parts of the Granitic Complex, i.e. in the regions affected only by low-grade younger reworkings (figs. 1, 3).

Secondary constituents and the younger tectonic, metamorphic and metasomatic overprintings of the complex are important keys to the understanding of the upper Archaean to post-Precambrian processes in the crustal evolution of the region considered (fig. 1). Some of them are related to the formation of important pegmatite and gemstone deposits, among these the Emerald deposit of the <Belmont> Mine near Itabira.

2.2 The Archaean Rio das Velhas Greenstone Belt (Rio das Velhas Supergroup)

2.2.1 Areal Distribution and Definitions

The Rio das Velhas Supergroup forms, together with the Granitic Complex, the infrastructure of Minas and Espinhaço sequences within the area of the Q.F.. Occurrences underlying the westernmost extremety of the prominent northwestern itabiric Q.F. structure (Serra do Curral Syncline) have apparantly no physical continuity with the principal Rio das Velhas domain (fig. 1).

Dorr and Barbosa (1963) correlated schistose rocks of the Itabira District (fig. 1) with the Rio das Velhas rocks of the the Q.F. type area, based on lithological similarities, in spite of occurrences being non-continuous. The present author (1973, 1975a) included the schistose rocks of the Itabira District within the Minas Supergroup as an additional unit termed Greenschist Sequence, since the unconformity described by Dorr and Barbosa (op.cit.) as separating them from the Minas Series, was found to be unconvincing (fig. 29).

Schöll and Fogaça (1979) described schistose sequences containing banded iron formations and quartzitic units, occurring some 150 km to the N of the Q.F., within the central anticline of the E.R., as well as pertaining to the Rio das Velhas Supergroup (N outside fig. 1). Again physical continuity is inexistent, but lithological and structural similarities exist as far as the contacts with the adjacent migmatite-gneisses and the Espinhaço cover rocks are concerned.

Dorr et al. (1957) originally defined the Rio das Velhas Series "as comprising those schistose metasedimentary and metavolcanic rocks in the Quadrilátero Ferrífero older than the Minas Series" (Dorr 1969, p. A-15). They subdivided the Rio das Velhas Series into two groups, the older termed Nova Lima and the younger Maquiné. The Maquiné Group again was subdivided into two Formations, the lower termed Palmital and the upper Casa Forte (in: Dorr 1969).

Simmons and Maxwell (1961) defined an additional, still younger group, termed Tamanduá and included it in the Rio das Velhas Series. However, already Moore (1969) noted that the Tamanduá Group refers mostly to quartzitic rocks of the Espinhaço Range. In fact, the Tamanduà Group has to be excluded from the Rio das Velhas (Simmons and Maxwell 1961) and Minas (Dorr 1969) stratigraphic columns, since it is essentially composed of Espinhaço Supergroup quartzitic sequences. The Cambotas Quartzite Formation of Simmons and Maxwell includes rocks of the lowermost three formations of the Espinhaço Supergroup (= Minas Series as defined by Pflug 1968) indiscriminately, and the upper, unnamed formation of Simmons and Maxwell is an upthrusted sheet of Nova Lima schists (Schorscher 1980a).

The present author (1978) could show the existence of and define an additional group underlying the Nova Lima, almost exclusively composed of ultramafic effusive rocks, among them spinifex textured (peridotitic) komatiites. For this unit, the term Quebra Osso Group was introduced. Thus, it could be shown that the Rio das Velhas comprises a complete greenstone belt succession. This, and a possible larger regional distribution than presently confirmed, justified its elevation to Supergroup rank. The stratigraphy of the Rio das Velhas SG., after Dorr (1969), with modifications, is shown in table 4.

It is of certain historical, bibliographic and, last but not least economic interest to note that from the Quadrilátero Ferrífero - classical region of Brazilian Precambrian geology - for the first time in this country, the occurrence of spinifex textured peridotitic komatiites and of a complete greenstone belt succession could be definitely evidenced. Under these aspects, the economic geology of the Archaean supracrustal sequences of the Q.F. needs fundamental review too.

2.2.2 Contacts with the Granitic Complex, areal distribution of Groups and specific litho-stratigraphic characteristics

Contacts of the Rio das Velhas Supergroup with the Granitic Complex are tectonic, characterized by mylonitization of the adjoining lithologies. Mylonitization is more evident in the migmatites and gneisses of the Granitic Complex than in the predominantly schistose, low-grade metamorphic and strongly weathered Rio das Velhas rocks. In certain areas thermo-metamorphic aureoles developed within the Rio das Velhas (Wallace 1965, Dorr 1969, Herz 1978), along the tectonic contacts, and pegmatoid mobilizates (chapter 2.1.2.3) used them as sites of ascent intruding both the Granitic Complex and Rio das Velhas rocks.

The majority of contacts are between the Nova Lima Group and Granitic Complex rocks. Only in the Santa Bárbara and, perhaps Congonhas regions (fig. 1, see also Guild 1957) do rocks of the Quebra Osso Group occur in direct tectonic contact with the Granitic Complex.

Quebra Osso Group type occurrence is, in surface outcrops, limited to a 1.5 km wide belt at the most, extending for more than 16 km along the northeastern borders of the Rio das Velhas synclinorium (fig. 1, Santa Bárbara region, fig. 15, table 4). These rocks were previously mentioned by Harder and Chamberlin (1915) as a thrust-sheet of mafic lavas. Dorr and co-workers (in: Herz 1970, plate 1) mapped them as "greenstone and chlorite schist; metamorphosed mafic rocks, probably post-Minas in age" and Maxwell (1972), who detailed parts of the area in the scale 1:25'000, included them (op. cit., p. 32) <...under the general field term "greenstone sequence">. He observed that the greenstone sequence is composed of <...mafic and ultramafic intrusive and extrusive rocks, and mafic dike rocks similar to those mapped separately in adjacent...> areas (op. cit., p. 32), that sedimentary rocks may occur as well, and contributed some mineralogical and petrographical details. However, the separation of rock types proved impractical and the age question also remained unanswered.

The predominant rocks are ultramafic lavas, (peridotitic) komatiites. Primary igneous textures are best preserved in the southern, wider part of the belt, and best exposed in the Quebra Osso river valley (fig. 15). The northern, finer parts of the ultramafic belt are strongly tectonically deformed and now serpentine-chlorite-talc-tremolite-magnesite-schists. Mafic, metaigneous intrusive and/or dike rocks could not be confirmed.

Predominant ultramafic extrusives with igneous textures are from massive flows, exhibiting polyhedral jointing and rare spinifex textured "garlands" and "veins" (figs. 16, 17). They may grade laterally or vertically (or both) into pillow lavas. Second in abundance are brecciated lavas. They occur either as individual flows or as top and bottom zones of other flows. Rare rock types comprise aphanitic, originally cryptocrystalline or vitreous ultramafics and ultramafic tuffs and agglomerates (fig. 18).

The mineralogical composition of the ultramafics is of typical greenschist facies assemblages. They are mixtures of serpentine, chlorite, talc, tremolite and magnesite. In spinifex textured rocks the skeletal olivines are replaced by serpentine and minute opaques and the vitreous ground-mass by chlorite (fig. 19). The only primary magmatic minerals are accessory chromites. However, they show the ferritchromite transformation along the borders and thus incipient metamorphic reequilibration. In the eastern stratigraphically lower and central parts of the Quebra Osso ultramafics, intercalations of detrital metasediments are absent. The only metasediments are of chemical origin, banded iron formations, gradational with ferruginous metacherts (fig. 15). In the western parts, towards the contact with the Nova Lima Group, intercalations of mafic (tuffitic) schists occur, become more frequent and finally predominant. They characterize, together with mafic metavolcanics, the gradational (≅ 70 m wide) contact zone between the stratigraphically lowest ultramafic Quebra Osso Group and the medium, mafic Nova Lima Group of the Rio das Velhas greenstone belt.

About forty samples of ultramafic rocks with and without preserved igneous textures of the Quebra Osso Group were analyzed for major and some trace elements. Major elements indicated peridotitic (komatiite) composition. Trace elements characteristically show light Cr and Ni contents (both ≅ 2,000 ppm). Quebra Osso ultramafics also show anomalously high Zn contents in the range of 100 - 400 ppm. Again, Zn is located in the crystal structure of accessory chromites as indicated by microprobe tests.

Nova Lima Group rocks occupy by far the major part of the presently exposed area of the Rio das Velhas greenstone belt. Lithologies (table 4) are badly weathered in natural outcrops. Only the levels of banded iron formations and ferruginous metacherts (fig. 15) appear as morphological positive ridges and crests, easily recognized on air photographs. Best petrographic descriptions of Nova Lima lithologies are from sample material saved in underground mines (Gair 1962, Tolbert 1964, Ladeira 1980). Therefore, the Nova Lima Group, in spite of its (at least apparent) thickness of more than 4,000 m (Dorr 1969, here table 4) and large areal distribution, could not yet be regionally subdivided into formations. Efforts by Ladeira (op. cit.) still depend on correlation with additional underground mine profiles, and still more, on surface mapping.

In general, one can state that the mafic, clastic, volcaniclastic and igneous rocks predominate. The bulk of the schistose to graywacke rock types are chlorite-rich, and the predominant igneous effusives and subvolcanics of basic to intermediate composition. Acid volcanics are not yet definitely known, but possibly represented by some of the occurring sericite and sericite-quartz schists and phyllites.

Chemical meta-sediments abrange low (in Fe) grade banded iron formations grading to almost pure quartzitic rocks (metacherts) and banded ferro-manganesiferous and manganesiferous formations. Fresh banded iron formations described from underground mines are oxide (magnetite), carbonate and sulfide facies. From surface outcrops mixed carbonate-silicate and silicate facies are known as well.

Ferro-manganesiferous and manganesiferous formations are known from natural outcrops, badly weathered and not studied any further.

The chemical Fe and Mn sediments apparently show a regular distribution throughout the Rio das Velhas greenstone belt. In its northern and northeastern parts the Fe formations predominate by far, Fe-Mn formations are more abundant in the western (including the westernmost continuation) and southern parts. Of biogenic or partly biogenic origin may be some dolomites and graphite-rich schists. Clastic quartzites and quartz-rich schists are very rare and possibly confined to the stratigraphic upper part of the Nova Lima Group. Conglomerates are rare but important rock types as indicators of the depositional environment. Dorr(1969) described one occurrence as "paraconglomerate" or "tilloid" (in the sense of Pettijohn 1957) and attributed its origin to "subaqueous density currents". Further occurrences of such conglomerates are known from the Nova Lima District (Gair 1962, plate 1) and from the Santa Bárbara region. The latter occurrence is, as the one described by Dorr (1969), extremely bimodal, with up to half a meter sized subangular to rounded boulders, cobbles and pebbles of banded iron formation (to metachert), in fine-grained phyllitic matrix (fig. 20). Pebbles of Granitic Complex rocks are not known from the Nova Lima conglomerates.

Additional features of synsedimentary gravitational deformation (slumping, sliding) may be suspected from some surface outcrops and are known from bore cores.

The Nova Lima Group is the major gold producing unit of the Q.F. area. Gold is bound in sulfide mineralizations previously considered in the Nova Lima District by Gair (1962) and Dorr (1969) as hypothermal replacement deposits. Similar mineralizations in the Santa Bárbara and Florália regions (São Bento and Pari Mines respectively) were studied by the author and interpreted as syngenetic volcano-sedimentary deposits (Schorscher 1979a, b), i.e. carbonate-sulfide and sulfide facies banded Fe-formations. Major sulfides are pyrrhotite, pyrite, arsenopyrite and chalcopyrite. Microscopically visible gold occurs predominantly as inclusions in arsenopyrite. Studies by Ladeira (1980) of the gold mineralizations of the Nova Lima District yielded similar results. Secondary, remobilized gold occurs in gold-quartz veins cutting the Nova Lima Group (Dorr 1969) and in carbonate veins cutting the Quebra Osso Group (fig. 21).

Maquiné Group undivided forms the stratigraphically upper clastic unit of the Rio das Velhas greenstone belt. Rocks of this group (table 4) occur in two noncontinuous structures. One is a narrow syncline starting about 16 km NNW of Ouro Petro, extending and broadening into NW direction, and terminating about 18 km SE of Belo Horizonte (fig. 1). The second underlies the Caraça range of Espinhaço quartzite located in the eastern part of the Q.F. (fig. 1, outcrop No. 12, fig. 15).

The Maquiné Group is separated from the Nova Lima Group by at least local erosional unconformity, and represents a drastic change in the type of sediments and by means of their source areas. Previously described groups have ultramafic respectively mafic overall composition, quartz being absent or a little frequent mineral. The Maquiné Group is, at least in parts, of orthoquartzitic composition.

In the occurrence located in the eastern part of the Q.F., the basal portions of the Maquiné are coarse-grained to microconglomeratic quartzites and conglomerates. They are greenish coloured due to some chlorite and chloritoid in the matrix. Decimeter sized cross stratification of frequently varying directions is common in the quartzites. Pebbles in microconglomeratic quartzites are of vein quartz, 0.5 - 1.0 cm in size and normally well rounded. Various conglomeratic levels/lenses occur intraformationally inclosed within the lower portion. Pebbles are predominantly of banded iron formation to metachert of the Nova Lima Group and of intraformationally reworked Maquiné quartzites and conglomerates. Vein quartz, greenschists (metabasics of the Nova Lima Group) and meta-ultramafics of the Quebra Osso Group are quite rare. Granitic pebbles could not be found. Matrices of the conglomerates are light or greenish coloured depending on the presence of mainly chloritoid and subordinately chlorite. The occurrence of abundant detrital pyrite in quartzites, microconglomerates and conglomerates is important (fig. 22). Higher stratigraphic portions of the Maquiné consist of coarse- to medium-grained, light coloured and normally mica-poor quartzites.

2.2.3 Structure and Metamorphism

The Rio das Velhas greenstone belt may be referred to as a regional sized complex synclinorial structure, preserved in between, and penetrated by round shaped uplifted masses of Granitic Complex rocks. No granitic igneous intrusions are known from the Rio das Velhas belt, except for younger pegmatoid veins.

Three major phases of deformation affected the Rio das Velhas rocks. The principal schistosity is parallel to the one of the adjacent Minas and Espinhaço Supergroup rocks and produced by the Minas/Espinhaço orogeny. Locally, however, especially finer layers of competent rocks such as dolomite, banded iron formation, quartz veins, exhibit polycyclic structures indicating an intensive older folding phase with subvertical axis. This folding phase may be attributed to the about 2.800 m.y. old (Herz 1970) Rio das Velhas orogeny.

The youngest deformations were caused by a latest phase of uplifts of granitic rocks. They affected not only the Rio das Velhas but also Minas and Espinhaço rocks, as well evidenced by the Bação Complex (figs. 1, 2; uplifted mass of Granitic Complex rocks located in the south-central part of the Q.F., piercing through Rio das Velhas and deforming adjacent Minas structures). Uplifts cut through and produced cataclastic deformation of the Rio das Velhas Supergroup rocks.

The Rio das Velhas rocks must be considered polymetamorphic rocks. In the northeastern and eastern parts of the Rio das Velhas belt, however, they reveal only one phase of regional metamorphism, identical in grade, and with the same relations between deformation and metamorphic recrystallization as exhibited by the overlying younger Minas and Espinhaço rocks (middle to upper greenschist facies). This metamorphic event must be attributed to the Minas/Espinhaço orogeny. The western and southern parts of the Rio das Velhas belt were not systematically studied by the author and the literature contains no data suggesting polyphasic regional metamorphic or retrograde metamorphic phenomenons from these areas. It must be concluded that, if a regional metamorphism of Rio das Velhas age existed, as is indicated by the radiometric age of 2.800 m.y., obtained by Herz (1970), and as is generally admitted, it must have been lower in grade than the younger Minas/Espinhaço event. On the other hand, the younger event was not as intense as to readjust the Rb-Sr system of muscovite formed in the course of the older Rio das Velhas metamorphism about 2.800 m.y. b.p. (Herz op.cit.).

Thermal-metamorphic parageneses occur superimposed upon the regional metamorphic ones in Nova Lima Group rocks along the contacts with Granitic Complex uplifts. Wallace (1965) and Herz (1978) described and mapped zones of thermal metamorphism around the Bação Complex (fig. 1).

Paragenesis with staurolite and possibly cordierite characterize the maximum of grades reached. The thermal metamorphic events affected not only Rio das Velhas rocks, but, as the uplift related tectonics , also previously regional metamorphic Minas rocks. Gair (1962), for instance, described thermal metamorphic Sabará Formation (table 5) schists occuring in the Nova Lima District in direct tectonic contact with granitic rocks (fig. 1, outcrop No. 1). This author (1975a), Herz (1978) and Schorscher et al. (1982) described thermal metamorphic paragenesis superimposed on regional metamorphic dolomitic itabirite (hematite ± magnetite + dolomite + quartz) of the Itabira Group (table 5) from the NW flank of the Serra do Curral syncline (fig. 1).

Thermal metamorphism caused reactions of dolomite + quartz, in the highest grade reached, to diopside and, more commonly, to tremolite. Calcsilicate reactions did not occur under the high total pressure and relatively low temperature conditions of the regional Minas/Espinhaço metamorphism in this part of the area.

Finally, it has to be remembered that even the non-deformed, older groups of basaltic dike rocks (of post-Minas/Espinhaço Precambrian age) show evidences of thermal metamorphic coronitisation (chapter 2.1.2.8). Thus, there are no doubts about the existence of the youngest, post-Minas/Espinhaço period of uplift and thermal metamorphic processes. Nevertheless, an older, Archaean period, at least of important uplifts, of post-Rio das Velhas (and pre-Minas/Espinhaço) age must be admitted too, because of the stratigraphic and structural configuration of the Archaean and Proterozoic units (fig. 1). The relationship of this older period of uplifts with Archaean metamorphic processes however, continues to be uncertain.

2.2.4 Some Considerations on the Evolution of the Rio das Velhas Greenstone Belt.

Different matters invariably arise when the evolution of Archaean greenstone belts is discussed, among them: age relations between the greenstone belt and adjacent migmatite-gneiss complexes, environment of greenstone belt generation and relations with sialic continental domains, depositional environments in greenstone belts - deep versus shallow water conditions, horizontal versus vertical tectonic regimes during orogenesis of greenstone belts, and many others.

The Rio das Velhas greenstone belt sequence is considered younger than the surrounding migmatite-gneiss domains. As arguments may hold the high metamorphic grade of the surroundings, not experienced by the Rio das Velhas and probably more important, the lack of granitic intrusions s.l. within the belt, in spite of their occurrence in neighbouring parts of the "Basement" Complex. However, not a single case of normal contacts, merely tectonic contacts are known between Granitic Complex and Rio das Velhas rocks.

If one accepts the Granitic Complex rocks as being older and the place of generation of the greenstone belt, the question about the palaeo-geographic context arises, more precisely: whether the granitic rocks s.l. represented continental or submerged sialic crust when the greenstone belt formation was initiated. As for the lack of sediments derived from granitic terrains, within the two lower groups of the Rio das Velhas greenstone belt, the conclusions should be that the belt formation was initiated in an environment of submerged sialic crust (cf. Hargraves 1976). Further, that during the deposition of the lower two groups (Quebra Osso and Nova Lima) no considerable sialic continental masses existed within distances able to pour appreciable amounts of quartzitic, or in a more general way, granitic terrain derived clastics, within the belt. Only with the beginning of the coarse clastic quartzitic Maquiné sedimentation such landmasses came into being and became very important furnishers of sediments.

Little information exists about the subaquatic environment during the deposition of the Quebra Osso ultramafic Group. The ultramafic pillow lavas, however, may indicate that water depth of several hundred meters existed at least locally, when judging from the predominant cases known by actual geologic observation of oceans.

The Nova Lima Group was considered by Dorr (1969) as composed of eugeosynclinal flysch deep water deposits. Turbidite type conglomerates and slumping and sliding features sustain this interpretation. At the same time, arguments imply that morphologically higher domains, possible even subaerial, must have existed within the Nova Lima trough maybe as mafic volcanic islands/seamounts, producing the sediments and being starting places for turbidity currents.

The Maquiné environment was identified by Dorr (1969) as a eugeosynclinal molasse basin: for the occurrence in the eastern part of the Q.F. (figs. 1, 15) shallow water high energy sedimentary conditions must be assumed at least during the deposition of lower coarse quartzitic and conglomeratic rocks. This is further supported by the type and rapid direction changes of crossbedding. Detrital pyrites in this unit (fig. 22) may signify more reducing atmospheric and shallow oceanic conditions.

Structural evidences regarding the tectonic regime during the Rio das Velhas orogenesis are equivocal. Prominent structures are the tectonic contacts between the Rio das Velhas units and adjacent uplifted parts of the Granitic Complex. These are no doubt results of vertical tectonic regimes but they are, at least in some cases, younger than the Minas/Espinhaço orogeny and can be attributed to the 500 m.y. old Brasiliano tectono-thermal event. As discussed above, a series of stratigraphic and structural observations indicate that the now visible structures are of older Archaean origin and, in part, reactivated, an adequate structural analysis of this question, however, is lacking.

Horizontal tectonic regime is indicated by the Rio das Velhas rocks in places where they are squeezed and dragged along the basal low angle thrust faults of the Minas allochthonous units (nappes) constituting the Q.F.. Such structures were probably the grounds for the plate tectonic model, as the allochthonous part of an ophiolitic complex, proposed by Drake and Morgan (1980) for the Rio das Velhas. However, horizontal structures in the Rio das Velhas are not always clearly results of Proterozoic Minas/Espinhaço tectonics. Some of the oldest recognized structures of the Rio das Velhas rocks (not observed in the Maquiné Group) are tight folds with subvertical axes. Only in rare cases are they well preserved in actual outcrops and their meaning is as yet incompletely studied, but (Archaean) horizontal shear, probably parallel/subparallel to major synclinorial axes, must have been important for their development.

Thermometamorphic aureoles in the Rio das Velhas rocks were considered to be evidences for an intrusive igneous origin of the adjacent granitic rocks s.l.. Dorr (1969) and Herz (1970), for example, considered all the gneisses and migmatites of the Granitic Complex to be igneous intrusions, younger than the Rio das Velhas and Minas Series. Alternatively, the tectono-thermal uplift of hotter but rigid granitic rocks, from deeper crustal environments, can cause contact metamorphism in the tectonically juxtaposed, cooler rocks of higher crustal levels, when the velocity of tectonic ascent is higher than the cooling of the ascending (uplifted) blocks. This model is preferred here in order to explain the thermo-metamorphic aureoles exhibited by Rio das Velhas rocks. It is considered in better agreement than the igneous model with some major geologic features, i.e. the Granitic Complex rocks are largely predominant high-grade metamorphic gneisses and migmatites; contacts with the Rio das Velhas rocks are always tectonic, characterized by intense mylonitization of contiguous lithologies but only locally thermo-metamorphic, and the grade of thermal metamorphism varies over km distances even along the contact with one individual uplifted block as from non-observable (absent) to medium (staurolite) grade, in spite of the overall quite homogeneous quartzdioritic composition of the uplift.

2.3 The Quadrilátero Ferrífero (Q.F.) Sensu Strictu (s.s.)

2.3.1 Areal Distribution and Local Nomenclature

The Quadrilátero Ferrífero s.s. is composed of four major synclinal structures of inferred lower Proterozoic age (figs. 1 and 2). Two of them possess northeastern directions. The western one, near Belo Horizonte, is named Serra do Curral syncline and the eastern one, near B. (Barão) de Cocais city, Gandarela syncline. The third major syncline, named Moeda, possesses N-S direction, forms the western, and the fourth, E-W trending Dom Bosco syncline, the southern border of the Q.F. s.s.. The eastern parts of the Q.F. s.s. (fig. 1, E and N of Ouro Preto city, located in the SE corner of the Q.F.) are structurally less continuous due to more intense deformation. They turn from E-W into N and NW directions. Northernmost continuations conform tectonically to the southern and eastern borders of the prominent mass of Espinhaço quartzites, named Serra do Caraça (figs. 1 and 2). Northwesternmost extensions reach nearly physical continuity with the SW termination of the Gandarela syncline (fig. 1). It must be stressed that ferriferous Minas units occur/continue to the W and SW of the Q.F. s.s., outside fig. 1 (Pires 1977) and that the eastern and northeastern Minas SG. iron-ore districts of Monlevade and Itabira respectively (fig. 1), are not considered parts of the Q.F. s.s., due to structural and stratigraphical differences.

2.3.2 Stratigraphy and Lithology

The still valid outlines of the stratigraphy of the Minas Supergroup in the Q.F. s.s. date back to Eschwege (1817, 1822, 1832), Pissis (1842), Derby (1906) and Harder and Chamberlin (1915). Most detailed stratigraphic work has been done by Dorr and co-workers (in: Dorr 1969). The stratigraphic subdivision of the Minas Supergroup in the Q.F. s.s., according to these authors, is shown in table 5, with minor modifications. The Tamanduá Group (Simmons and Maxwell 1961) considered by Dorr (op.cit.) as stratigraphically the lowest Minas unit, is omitted in the table, since it is composed of Espinhaço Supergroup rocks. Other minor modifications contained in table 5 refer to additional lithologies, tuffogenous greenschists occurring as concordant intercalations within Cauê and Gandarela Formations, and to somewhat differing interpretations of unconformities, below the Sabará Fm. and the Itacolomi Group. Dorr and co-workers considered Itacolomi as individual series, the here adopted interpretation is the one of the stratigraphically highest Group of the Minas Supergroup. Alternatively, there exist, since Derby's work, correlations with quartzitic sequences of the upper Espinhaço Supergroup. As to the rest, table 6 is selfexplanatory and also contains the principal lithologies and depositional environments of the individual stratigraphic units.

2.3.3 Specific Lithologic and Faciologic Observations

2.3.3.1 Caraça Group

The Moeda Formation varies regionally in thickness and lithologic composition from about 1.100 m (table 5) to absence and from coarse conglomerates through quartzites to quartz-poor muscovite schists. Variations in thickness are locally due to tectonic reasons (ex.: Gandarela syncline), but the regional variations depend essentially on the primary sedimentary environment. Of special interest is the occurrence of detrital pyrite within conglomerates and conglomeratic quartzites (Maranhão 1979). However, larger sized conglomerate occurrences are rare. Some of them show radiometric anomalies (Andrade Ramos and Fraenkel 1974) and were studied under economic viewpoints by the <NUCLEBRAS> company. Uranium contents proved uninteresting, but in the case of one occurrence, located in the SW termination of the Gandarela syncline (figs. 1 and 23), gold was found in amounts that stimulated a renewed uptake of exploration activities, now underway through the <Minas Novas> company. Regional heavy mineral studies of Moeda Formation quartzites were made by Guerra (1979) and revealed rutile as an additional, very characteristic component.

The Batatal Formation is regionally non-continuous and quite often lacking, for both primary sedimentary and tectonic reasons. Of special interest are the important occurrences of graphitic schists and phyllites, the generally very fine-grained nature of Batatal epiclastics and the incipient sedimentation of oxide facies iron formation and metachert (see table 5). Batatal Formation rocks characterize the transition to the principal period of chemical deposition of ferriferous sediments in the Minas Supergroup.

2.3.3.2 Itabira Group

The Cauê Formation (table 5) is economically the most important unit of the Q.F. due to the itabiric iron ores. Itabirites are metamorphosed oxide facies iron formations (fig. 24). Hematite and/or magnetite are the principal Fe minerals. Gangue minerals are quartz and/or dolomite. Rare constituents are seritic white mica, chlorite, talc, albite, tourmaline, tremolite, diopside, garnet.

Important is the occurrence of levels of synsedimentary reworking as indicated by sharpstone conglomerates (Kehrer 1972, Paternoster 1979).

Itabirites may grade over enriched itabirites or pass abruptly into high Fe-grade almost pure hematite ores (fig. 25). Enrichment processes were considered by Dorr (1973) as post-Minas regional metamorphism in age and metasomatic, due to the intrusion of overall granitic gneiss. Schorscher (1975b) and Schorscher and Guimarães (1976) considered a syndiagenetic (sedimentary) origin of these ores on stratigraphic and faciologic grounds. The conclusion of Hoefs et al. (1980) and Müller et al. (1982) are similar. However, the presented oxygen - isotope data are all of metamorphic origin. They only indicate the pre- to syn-metamorphic formation and/or reequilibration of the high-grade ores but are non-specific for a sedimentary or diagenetic process.

Itabirites are gold bearing and were mined previously to the "iron-ore epoch" for the noble metal. Gold is typically palladium alloyed. The origins of gold and palladium are unknown, possibly syngenetic. They were secondary, enriched in specific tectonically fractured zones. During recent years the economic evaluation of the itabirite gold was retaken in the Itabira District through the <VALE DO RIO DOCE> company (CVRD) with best results obtained in tectonic zones of the <Conceição> iron deposit (fig. 1, outcrop No. 18, fig. 29, 38, 39).

The Gandarela Formation lithologies and overall characteristics are shown in table 5. However, as originally defined in the area of the Gandarela syncline, the unit became again open to question. In this syncline, dolomitic "Gandarela itabirites" are not separable from their Cauê equivalents. Dolomites form oval or round shaped massive bodies of up to km extension but normally less, sometimes exceeding 100 m of thickness. The lenticular carbonate bodies interdigitate and pass laterally over short distances into laminated rocks (dolomitic itabirites and dolomitic phyllites) and are totally enclosed in either dolomitic itabirites and itabirites, dolomitic phyllites, or both. They do not form a continuous horizon within the Itabira Group but occur at different levels of its stratigraphically higher portion. Typical are sharpstone conglomerates occurring in the peripheric parts of the carbonate bodies. They are best explained as bioherms, patch reefs, in spite of the undetectability or lack of preservation of stromatolites in the type area.

From the Dom Bosco southern syncline of the Q.F. s.s., Dorr (1969, p. A-53) described a similar carbonate rock body well exposed in "Cumbi's" quarry. He considered this and morphologically similar occurrences of carbonate rocks as bioherms, but stratigraphically as Fêcho do Funil Formation (Piracicaba Group). More recently, stromatolites, unsatisfactorily preserved for precise classification, became known from "Cumbi's" quarry and a review of the local lithostratigraphic context showed the dolomite body totally enclosed in the Itabira Group iron formation. It seems more convenient to consider the Gandarela rocks as a facies within the stratigraphic higher portion of the Itabira Group than as an individual formation. Thus, in places Gandarela rocks may be entirely absent without any evidence of erosional unconformity between the Cauê and directly overlying Cercadinho Formation or, as in the Itabira District, reduced to a few centimetric horizons of dolomitic itabirites enclosed within the Cauê Formation.

2.3.3.3 Piracicaba Group

The Cercadinho Formation is one of the most constantly represented units of the Q.F.. Typical lithologies are silvery, fine-grained sericite-quartz schists and phyllites. Besides, there occur quartzites, ferruginous quartzites, metacherts and other minor lithologies (table 5). This formation characterizes the end of the main period of chemical Fe-sedimentation in the Minas Basin and the renewed access of coarser epiclastic sediments to palaeogeographic realms almost exclusively reserved to chemical sedimentation during Itabira Group times.

The Fêcho do Funil, Tabões and Barreiro Formations are of rather limited distribution and often absent, due to both, non-deposition and subsequent errosion. Lithologies and some other properties are listed in table 5.

The Sabará Formation is widespread in the Q.F. s.s. (Dorr 1969) and represents a radical change in sediments and sedimentary environment when compared with the above described shelf and, in a general way, shallow water deposits of the Minas Supergroup. The Sabará Formation (table 5) is of eugeosynclinal, deep water origin (Dorr op.cit.). The erosional unconformity separating the Sabará Formation from the underlying ones is locally profound. Sabará rocks, in certain places (Gandarela syncline, for example, fig. 1), rest directly on the Cercadinho Formation, contain tilloid conglomerates with pebbles of Granitic Complex rocks (Dorr 1969, fig. 17), are, in general, of the flysch type, with turbiditic sedimentary character and contain abundant mafic igneous material (table 5). They document a drastic downsinking of parts of the Minas shelf from originally shallow to a deeper water environment. At the same time, an uprise of other areas took place, their profound erosion reaching, at least locally, the Basement level still during Sabará deposition, and furnishing the granitic pebbles of the tilloid conglomerates. This tectonically very active period was also a time of widespread mafic volcanism, as inferred from chlorite- (and biotite-) rich greenstones (Dorr op.cit., p. 56).

The Sabará Formation should be elevated to group rank and separated, since it is totally different from the formerly described older portions of the Piracicaba Group.

In more recent work, Ladeira (1980) questioned the existence of the Sabará Formation, based on structural reinterpretations. At the type locality (Gair 1958, 1962) in fact, doubts may arise as to the existence and/or precise delimitation of the unit since it is an area of intense shearing and the Sabará schists (if at all present) may be thoroughly mixed with lithologically similar Nova Lima schists, due to tectonic intercalation (fig. 1, outcrop No. 1). However, this local aspect should not invalidate the Sabará Formation regionally, especially not in areas where Sabará rocks occur as fillings of closed synclinal structures as, for example, in the Gandarela syncline (fig. 1).

2.3.3.4 Itacolomi Group

Originally recognized and separated as "Upper Series" from the Minas Series by Derby (1881a, b, 1884, 1906), on grounds of a discordance inferred from conglomeratic beds containing pebbles of Minas units, the Itacolomi rocks were again included within that series by Harder and Chamberlin (1915). Guimarães (1931) separated them again as "Itacolomi Series" based on Derby's discordance. The phyllitic facies was recognized by Barbosa (1949) and named Santo Antônio Formation, but included in the Minas Series. Guild (1957) correlated the type Itacolomi with, and separated the Santo Antônio facies from the Minas Series. Itacolomi rocks are identical in metamorphic grade with adjacent Minas rocks, and their sedimentary molasse characteristics well permit an inclusion within the general Minas development (table 5). In the latest edition of the geological map of Brazil, the Itacolomi rocks are included within the Minas Supergroup as stratigraphically the highest unit of group rank (Inda et al. 1984).

2.3.4 Structure and Metamorphism

Minas Supergroup rocks have tectonic contacts with all the other Precambrian regional metamorphic rocks throughout the Q.F. s.s.. Tectonic contacts are by low angle thrust faults and are characterized by intense mylonitization of the adjoining lithologies. The low angle faults may be verticalized to varying degrees when secondarily deformed by uplifts of adjacent Granitic Complex blocks.

Evidences of mylonitization are best preserved by the more competent lithologies, particularly of the Granitic Complex, quartzites from the Moeda Formation and late Espinhaço metabasics (when in fresh preservation at the contact or in its vicinity), in spite of the post-cataclastic Minas/Espinhaço regional metamorphic overprinting. Macroscopically less evident is the cataclastic deformation in low-grade metamorphic schistose lithologies as, for example, of the Nova Lima Group and Sabará Formation. Observation is rendered additionally difficult by the thorough weathering of these rocks in natural outcrops. Yet, whenever sample material suitable for microscopic studies is obtainable, cataclastic deformation becomes evident by mylonite schist fabrics and also by dynamometamorphic differentiation, again in spite of postcataclastic regional metamorphic overprinting. Itabirites behaved as an apparently more plastic phase of the cataclastic deformation (fig. 24). However, there exist accentuated differences in folding intensity and folding type depening on proximity to the tectonic contacts.

The tectonic nature of the contacts along the NW border of the Serra do Curral syncline is very evident in the field and even on satelite images (figs. 1 and 2).

The syncline (fig. 1) is, in fact, a NW-wards overturned mega-fold lacking the structurally lower (normal) flank over most of its about 100km of total extension. The flank is tectonically suppressed (squeezed off) as an effect of low angle thrusting over considerable distances. Sabará Formation rocks are in direct tectonic contact with those of the Granitic Complex, except for the SW extremity of the structure, where Rio das Velhas rocks occur (Gair 1958, 1962, Dorr 1969). Rio das Velhas, Nova Lima Group schists may also occur in other places along this contact zone, with thrust along the principal movement plane. Such occurrences, however, were not yet individually detailed due to the lithologic similarities between Nova Lima and Sabará schists, especially when intensely mylonitized and, as in most cases, badly weathered. Cataclastic deformation is most intense in the direct contact zone and diminishes gradually away from it within both units. In one place, exposing the direct contact zone (fig. 1, outcrop No. 1), the mylonite schists mapped as Sabará Formation by Gair (1962), contain tens of meters sized facoidal shaped bodies of cataclastic Granitic Complex rocks as tectonic xenoliths, oriented in the cataclastic foliation, with major axis in the direction of the tectonic transport.

At the northeastern extremity of the same structure, itabirites of the Itabira Group come near the tectonic contact with the Basement Complex (fig. 1, outcrop No. 2). There is a striking difference between their deformational state and the ones of the inverted flank further away from the tectonic contact. The first exhibit very complex patterns of macro-, meso- and micro-folds of the drag and chevron type, kink folds, box folds and others (fig. 24). The latter are even banded, in a general way little deformed rocks. These and similar observations may be repeated throughout the Q.F. s.s. within Minas Supergroup rocks along and near their tectonic contacts with other Precambrian lithologies.

A further structurally very important regional feature of the deformation of Minas Supergroup rocks in the Q.F. s.s. is that none of its megafolds (synclines) is imprinted in adjacent or underlying rocks of the other lithostructural units. The Espinhaço quartzitic structures N and S of B. de Cocais city may serve as a good example (fig. 1, outcrop Nos. 3, 5 and 13). The Gandarela NE trending, NW-wards overturned, nearly isoclinal megafold (syncline) overlies the Espinhaço quartzites with tectonic contacts (fig. 1, outcrop No. 5). In spite of underlying the isoclinal Gandarela fold, the Espinhaço rocks continue perfectly in their original N-S direction, without having been affected by the Minas folding. The same can be easily observed when following the fold axis of the Serra do Curral megafold to the NE in order to intersect the Espinhaço relics (fig. 1, located about 10km NE of outcrop No. 2). They are also perfectly N-S oriented, dipping constantly E-wards, without any sign of NW-wards overturned folding. The latter is valid for the adjacent and underlying Granitic Complex and Rio das Velhas rocks too.

It was concluded, that these fundamental deformation features of the Minas Supergroup rocks in the Q.F. s.s. may not be explained by autochthonous regional folding. They are the result of nappcrian transport and emplacement of the Minas structures into their present position. Minas structures of the Q.F. s.s. are thus considered erosional relics of a facies nappe system, i.e. of allochthonous origin (Schorscher 1975a, 1976a, c, 1980c). Nappe transport was generally directed from the E and SE to the W and NW and most probably occurred during two distinct periods. A minimum distance of tectonic transport can be reconstructed on palaeogeographic grounds, as from the easternmost relics of the Espinhaço Supergroup, about 10 km NE of Santa Barbara city, to the westernmost reaches of the Serra do Curral syncline, yielding more than 110km (fig. 1). The nappes suffered additional posterior deformations by uplifts of Granitic Complex blocks.

Regional metamorphism of the Minas Supergroup rocks of the Q.F. s.s. is identical in grade with Espinhaço and Rio das Velhas rocks of the same area, middle to upper greenschist facies. This, and the lack of intrusive metabasics (see part 2.1.2.6) allow a relative age estimation of the tectonic emplacement of the allochthonous Minas structures and, therefore, of the formation age of the Q.F. s.s.: it must have occurred posterior to the late-Espinhaço basic magmatism and prior to the Minas/Espinhaço regional metamorphism. Unfortunately, both events are so far only unsatisfactorily known by means of radiometric dating.

Thermometamorphic overprinting of the regional metamorphic assemblages can be observed in Itabira Group dolomitic itabirites and in rocks of the Sabará Formation along the border of the Serra do Curral syncline (Gair 1962, Schorscher 1975a, Herz 1978). This is considered an effect of the approximately 500 m.y. old Brasiliano regional thermal event.

2.4 The Serra do Espinhaço - Espinhaço Range (E.R.)

2.4.1 Regional Distribution and Stratigraphy

The E.R. forms an impressive, overall quartzitic mountain range extending over more than 2.000 km almost parallel to the east Brazilian coast, in general N-S directions (Harder and Chamberlin 1915). Maximum E-W widths reach about 150 km. In the area considered (fig. 1), the Espinhaço quartzites form a continuous mass occupying north-central parts and thinning out towards the S. N of and along the eastern and southern borders of the Q.F. s.s., the Espinhaço quartzites occur only in relictic, relatively small individual belts(fig. 1). Yet, even in these parts of the area, the overall E-W distribution of Espinhaço relics indicates that the original pre-tectonic and pre-erosional width of the Espinhaço Range was not less than in the northern parts. Continuation of the E.R., S of the Q.F. s.s. is not known.

The quartzitic sequences of the E.R. were included by Derby (1881a, b, 1884, 1906) partially in the Minas Series, and the predominant portion in the unit he referred to as the "Upper Series" of Palaeozoic age. Harder and Chamberlin (1915) included all the Espinhaço quartzites as Caraça

Group, within the Minas Series of Algonquian age. Guimarães (1931) attributed them partially to the Minas Series, to the younger Itacolomi Series and the still younger Lavras Series. However, at least in the Lavras Series, he also included rocks of the São Francisco Supergroup.

The Espinhaço lithologies were comprised in the latest edition of the geologic map of Brazil within the Espinhaço Supergroup (Inda et al. 1984). This term, however, since it was introduced by Draper (1920), was modified in meaning, definition and stratigraphic subdivision by various authors (for example: Moraes Rêgo 1931, DNPM/PROSPEC/CPRM 1975, Schobbenhaus et al. 1978, and many others). Subdivision of the Espinhaço Supergroup in the southern parts of the E.R., located in the central Minas Gerais state and abranging the area considered here (fig. 1), is after Pflug (1968) and was detailed and somewhat modified by Torquato and Fogaça (1979) and Schöll and Fogaça (1979).

Pflug (op.cit.) subdivided the Espinhaço Supergroup (considered by him as Minas Series) in the region around the town of Diamantina (outside fig. 1) into 8 formations. Kneidl and Schorscher (1972) introduced an additional basal formation termed "Greenschist Sequence", as essentially composed of metavolcanic and volcaniclastic basic to intermediate and minor acid material. This unit is locally lacking, either due to non-deposition or to subsequent erosion.

More recently, Torquato and Fogaça (1979) proposed the exclusion of the Rio Pardo Grande, stratigraphically the highest formation, and its inclusion within the São Francisco Supergroup. The stratigraphy and some depositional characteristics of the Espinhaço Supergroup in the central state of Mina Gerais (Pflug 1968, with minor modifications) are shown in table 6. From the E.R. area comprised in fig. 1, only the four lowermost formations are known, and, even so, only locally and not yet continuously mapped.

2.4.2 Specific Lithologic and Faciologic Observations

Greenschist Sequence rocks are apparently more frequent along the eastern border of the E.R., thinning or lacking in general western directions. Some of the metatuffitic greenschists are especially apatite-rich. The apatites are frequently optically anomalous positive. Similar anomalous apatites were described from the Luanza-Pipe in Congo/Zaire by Stutzer (1913) and also occur in the described meta-jacupirangitic rocks (part 2.1.2.7). They may provide a link to the yet unknown diamond bearing magmatites of the E.R.. Almost pure apatite heavy mineral layers occur as well in the higher quartzitic formations of the Espinhaço Supergroup and may be derived through synsedimentary reworking from the Greenschist Sequence.

The São João da Chapada, lowest quartzitic Espinhaço Formation may directly overlie Granitic Complex rocks where the Greenschist Sequence is lacking. In these cases, a reduced basal conglomeratic level occurs locally. Medium scale (decimetric) cross-stratification is frequent. Lithologies are as in table 6.

The Sopa Brumadinho Formation is of major economic importance among the Espinhaço Formations due to its diamond-bearing conglomerates. These form lenticular intraformational bodies of the shore-line type (Pflug 1965, 1967). Lenses extend for several kms in general N-S directions with width of normally less than 300 m.

Conglomerates are of the mono-, oligo- and poly-mictic type and contain reworked Espinhaço quartzite and abundant Itabira Group pebbles (fig. 26). Basement Complex pebbles are extremely rare and mostly absent. Itabira Group pebbles abrange itabirites, Fe-enriched itabirites, high Fe-grade hematite ores and metachert (fig. 27). Dolomite (Gandarela) pebbles could not be found. There are evidences indicating that carbonate pebbles were preferentially weathered. Under the microscope carbonatic micro-pebbles and detrital grains could be identified in silicified specimens.

Throughout the southern portion of the E.R. (fig. 1), facial variations of the conglomerates were mapped according to the pebble composition. They range from purely clastic quartzite-quartz pebble to purely chemical itabirite pebble conglomerates. Itabirite pebbles predominate by far in the eastern and easternmost occurrences (Schorscher 1975a). As a special variety, metachert pebble conglomerates were found in occurrences of the Serra do Caraça and adjacent Espinhaço relics (fig. 15).

Pseudomorphs after pyrite are frequent in the conglomerates and occur as well within São João da Chapada lower quartzitic unit. They were not encountered in the higher Galho do Miguel Formation. In spite of the unsatisfactory preservation for more detailed studies, a possible detrital origin of the pyrites must be considered.

The Galho do Miguel Formation is composed of very pure orthoquartzites. Megaripple stratification is characteristic. Individual megaripple bodies exhibit heights of 5 to 7 m and extensions of 100 to 150m (fig. 28). Schöll and Fogaça (1979) interpreted Galho do Miguel deposits as deeper shelf sediments (water depth >150m) and megaripples as a consequence of high energy coast-parallel currents.

Further lithological and stratigraphical information about the Espinhaço Supergroup are contained in table 6.

2.4.3 Sedimentary Environment, Structures and Metamorphism

Barbosa (1954) recognized the miogeosynclinal characteristics of the Espinhaço deposits, later confirmed by Pflug (1965, 1967, table 6). Sedimentary transport was generally from W to E. The Espinhaço Supergroup suffered in general little intense N-S trending folding and is cut by series of, also generally N-S trending, E-dipping high angle thrust echelon-faults. Intensity of folding and faulting increases throughout the Espinhaço occurrences from W to E and, in the particular area of fig. 1, also from N to S.

Regional metamorphism is, in general, of greenschist facies rank and exhibits systematic variations. Western-northwestern areas are of low and medium greenschist facies grade, whereas the easternmost occurrences, particularly NE of Santa Barbara city, attained the upper greenschist/lower amphibolite facies transition (fig. 3)

2.5 The Itabira Iron Ore District

The district (fig. 29) is considered additionally in part 3 of this excursion guide book. Therefore, only some conceptual stratigraphic and lithologic details will be anticipated here.

Differing from Dorr and Barbosa (1963) and Dorr (1969), Kneidl and Schorscher (1972), Schorscher (1973, 1975a) and Schorscher and Guimarães (1976) included the sequence of greenschists underlying the traditional Minas Series rocks in the Itabira District, within the Minas Supergroup (fig. 29, table 7). The unconformity inferred by Dorr and Barbosa (1963), as to separating them from the overlying Minas Series, could not be confirmed. In addition, underlying the greenschists, there occurs another metasedimentary unit composed mainly of texturally and compositionally immature metarenites. These, in turn, are separated from the Granitic Complex migmatites and gneisses by the principal unconformity as documented by the polymetamorphic and retrograde metamorphism of the latter and the progressive (mono-phase) regional metamorphic state of the former. The exact position and course of the unconformity is difficult to establish with accuracy in the field and in cartographic work, due to the overall intense and similar weathering behaviour of the adjoining lithologies (fig. 29).

The two additional units included within the Minas Supergroup in the Itabira District were considered to be of stratigraphic group rank and termed "Paragneiss Sequence" and "Greenschist Sequence" (table 7).

The Paragneiss Sequence is separated by the regionally inferred major unconformity from the Granitic Complex (fig. 29) and is of metarenites of metarkose to metagraywacke composition. Discontinuous intercalations of mica-quartzites and quartz-mica schists are frequent. Dorr (1969, p. 77, fig. 24) desribed these rocks as "Paragneiss forming from schist". The Paragneiss Sequence also contains concordant intercalations of calcsilicate rocks and of metamorphic mafic igneous products, although in minor amounts.

Upwards, the Paragneiss Sequence grades into a few meter thick level of quartzites and mica-quartzites. Contacts with the overlying Greenschist Sequence are gradational.

The Greenschist Sequence, considered by Dorr and Barbosa (1963) and Dorr (1969) as Nova Lima Group, may be subdivided into three horizons. The lowest, more arenitic, is transitional with the Paragneiss Sequence. The middle, major one is essentially of metatuff and metatuffite. The upper one is of carbonate bearing greenschists and metapelitic schists and is, in the uppermost portions, frequently graphitic.

The upper stratigraphic units of the Minas Supergroup in the Itabira District are presented in table 7, with additional comments in part 3. Of some regional faciological interest are the observations concerning the overall fine-grained mica-quartzitic and schistose development of the Moeda Formation, the frequent absence or very reduced development of the Batatal Formation and the entire absence of the Gandarela Formation.

2.6 The Easternmost Domains of High-Grade Gneisses including the Piçarrão Iron Ore District

These domains (figs. 1, 30) are as yet stratigraphically and structurally insufficiently known. A tentative stratigraphy was established by the present author (1975a) for the area shown in fig. 30.

Dark (regularly) banded gneisses originally named banded amphibolitic-granitic gneisses were considered stratigraphically the lowest. They correspond and are physically almost continuous with the unit termed Monlevade Gneiss by Reeves (1966) in the neighbouring area around João Monlevade (fig. 1) city. The banded gneisses contain concordant but fine and discontinuous layers of calc-silicate rocks, and scapolite-rich amphibole-plagioclase-quartz layers interpreted as of possible evaporitic origin.

Metapelitic (kinzigitic) gneisses with garnet - cordierite - sillimanite - biotite - antiperthitic plagioclase and quartz follow on top of the banded gneisses (fig. 30). Microscopic graphite is present. Varieties may contain cummingtonite and pargasitic amphibole as other and/or additional mafics. These are succeeded by quartzites (with garnet, alcali feldspar mobilisates, amphiboles, among others) forming a discontinuous level of less than 2 m thickness. Quartzites are overlain by banded oxide facies iron formation, itabirites, containing concordant lenses of hematite-rich ore. The pre-tectonic, almost pure hematite layers form the competent bodies of boudin structures and rods/mullions (fig. 31). Hematite-rich ore and itabirites are coarse-grained with millimetric hematite and centimetric magnetite crystals (fig. 32), and in the highest metamorphic grade attained, itabirites lose their well banded structure (fig. 33).

Homogeneous leucocratic granitic gneisses/migmatites were interpreted as the stratigraphically highest unit. They directly overlie the dark banded or the metapelitic gneisses if the other units are absent. In some places, leucocratic granitic gneisses/migmatites occur between and separate the dark banded gneisses from the metapelitic ones. It is likely that the homogeneous leucocratic granitic gneisses/migmatites are, at least in part, syntectonic granitic intrusions, thus not pertaining to the stratigraphic column.

The age of the high grade gneiss succession is under discussion. Reeves (1966) considered the Monlevade Gneiss pre-Minas in age and correlative with the Rio das Velhas Series. This author (1975a) preferred a Minas age tentatively correlating the dark banded gneisses with the Paragneiss, and the metapelitic gneisses with the Greenschist Sequence of the Itabira District as well as the high-grade metamorphic quartzites and iron formations with Caraça and Itabira Groups, respectively. Some leucocratic granitic gneisses were considered by Reeves (op.cit.) as possible equivalents of the Piracicaba Group. These could be present in the Piçarrão Iron Ore District too, among the leucocratic granitic migmatites/gneisses considered on top of the itabirites with enclosed hematite-rich ores.

Regional metamorphism throughout this domain is of high-grade upper amphibolite and hydrogranulite facies (fig. 3).

2.7 Age Relations and Development of Minas and Espinhaço Supergroups

Much controversy exists on this subject. Dorr (1969) and more recently Ladeira (1980) consider the Espinhaço as older than Minas Supergroup. From Derby (1881a, b, 1884) there exists the other opinion considering Espinhaço younger than Minas (Almeida et al. 1976, Almeida 1977) and from Harder and Chamberlin (1915) comes the third and last possible opinion considering Minas and Espinhaço Supergroups as, at least in part, contemporary facial equivalents, deposited in different palaeogeographic environments of the same sedimentary basin (Pflug 1965, 1967, 1968).

This author prefers the last model based on the following grounds:

- Units extend in two parallel N-S trending domains, the Minas Supergroup lying E of the Espinhaço Range (excepting the Q.F. s.s. for tectonic reasons).
- Normal contacts between units are unknown, contacts are always tectonic, Minas rocks being thrust towards the W, against and above Espinhaço rocks, with the Q.F. s.s. as the most prominent example.
- Itabirite pebble conglomerates (Sopa-Brumadinho Formation) are intraformational, Itabirite pebbles are, in their overwhelming majority, derived from the Itabira Group (Scheuch 1976) which commonly exhibits evidences of intraformational reworking.
- Itabirite pebble conglomerates (Sopa-Brumadinho Formation) grade laterally into continuous banded iron formations (Pflug 1965, 1967, Hoppe 1978, 1980, 1980 a).
- Itabirite pebbles show no signs of metamorphism prior to the conglomerate formation. They conform to the regional Minas/ Espinhaço metamorphism and, since they are occurring W of the major itabirite areas, are of lower metamorphic grade. Itabirite pebble conglomerates contain the least metamorphic iron formations (as pebbles) known from the area; sometimes diagenetic features survived (Schorscher 1975a, b).
- Minas and Espinhaço Supergroups suffered only one phase of progressive regional metamorphism in the course of the Minas/ Espinhaço orogeny, and they are of the same metamorphic grade, wherever they are in direct contact with each other.

Different models were proposed in order to explain the Minas/Espinhaço sedimentation. Harder and Chamberlin (1915) developed a delta model, Espinhaço quartzitic units ("Caraça Quartzite") representing the proximal and the finer clastic and chemical Minas deposits, the distal sediments.

Pflug (1965, 1967), Renger (1970), and Pflug and Renger (1973) proposed an orthogeosynclinal model, Espinhaço deposits representing the miogeosynclinal, Minas deposits the geoanticlinal and the high-grade gneiss domains the eugeosynclinal realms.

This author (1975a, 1980c) explained Minas/Espinhaço relations modeling a depositional environment that developed from an intra-continental rift to an active continental margin of the alpine type. Rift stages would be documented by the diamond bearing magmatism in the border parts of the structure and by the deposits of the Paragneiss Sequence (with immature arenites, schists and perhaps some evaporites) in internal parts. Shallow water stages are documented by Espinhaço-external and, except for the Sabará Formation, Minas-internal deposits. The Sabará Formation indicates the development of deep water realms and basic magmatism. At the same time Espinhaço domains were uplifted and partially eroded. The Minas/Espinhaço orogeny culminated later in the napperian emplacement of the allochthonous Minas structures of the Q.F. s.s. and westwards crustal obduction along the principal Granito Borrachudos high angle faults. These and similar structures of deep crustal thrusting, possibly located further to the E, are responsible for the Minas/Espinhaço regional metamorphism, its plurifacial character (higher pressure followed by higher temperature gradients, Schorscher 1975a, 1976a, b) and rapid increase E of the main Borrachudos fault: from higher greenschist facies near Itabira to hydrogranulite facies in Piçarrão, over approximately 25 km of E-W distance.

The absolute age, however, is still under discussion, at least from viewpoints of radiometric dating. The sedimentological characteristics of Minas and Espinhaço deposits well agree with the world wide properties of lower Proterozoic sedimentation through:

- large scale regional oxide facies banded iron formations of the Superior type: in the Minas SG.,
- large scale regional quartzitic deposits of "miogeosynclinal" type: Espinhaço SG., and
- the presence of detrital pyrites in some of the stratigraphically lower formations of both, Minas and Espinhaço SGs.

Radiometric age data (Herz 1970, 1978; Brito Neves et al. 1979; Cordani et al. 1980; Texeira 1982; Delhal and Demaiffe 1985, and others) were interpreted differently:

- as to sustain one lower Proterozoic age of regional metamorphism for both, Minas and Espinhaço SGs.,
- different metamorphic ages, i.e. lower Proterozoic for the Minas and middle Proterozoic for Espinhaço SGs., and
- again identical, but younger, middle Proterozoic metamorphic age of both SGs.

The major inconvenience of the radiometric data is, that most of them are from Granitic Complex, polymetamorphic rocks, not from Minas and/or Espinhaço lithologies. Exceptions are one zircon U/Pb age of metarhyolites, considered as Espinhaço SG. synsedimentary volcanics, and some K/Ar ages of metabasic rocks intruding the Espinhaço SG. (cf. part 2.1.2.6). Results are contradictory (Brito Neves et al., op.cit., Texeira, op.cit.): the zircon U/Pb age of 1.770 m.y. is considered to date a period of synsedimentary Espinhaço SG. volcanics, but the intrusive metabasic rocks yielded different, even older ages, up to 2.000 m.y.

2.8. The São Francisco Basin

Principal lithologies are limestones, shale and slate (fig. 1). Rocks are in diagenetic to anchimetamorphic state and only in close vicinity of the tectonic contact with the Espinhaço rocks of low-grade greenschist facies (fig. 34). The São Francisco Supergroup is considered of middle to upper Proterozoic age, contains stromatolites, and sedimentary structures are generally well preserved. Some diamond occurrences are known from the coarse-grained facies of Macaúbas Group metagraywackes. Comprehensive information and bibliography about the stratigraphic and faciologic evolution are contained in Schöll (1973) and Inda et al. (1984) and no further reference will be made here on these topics.

N-S trending, W-ward directed overthrusting, deformation (verticalisation to inversion) and metamorphism of São Francisco by Espinhaço SG. rocks, along their mutual contacts (figs. 1 and 34), poses some questions about the inferred middle to upper Proterozoic age of the São Francisco SG., and, similarly, about the equally inferred, lower to middle Proterozoic age of the Minas/Espinhaço evolution. In any case, up to now no evidence was found, neither of a younger period of N-S trending, W-wards directed, high-angle thrusting, posterior to the emplacement of the Minas SG. nappes of the Q.F. s.s., nor of regional thermo-dynamometamorphism which could explain the metamorphic relations observed in the São Francisco SG. independently from the main phase of Minas/Espinhaço regional metamorphism and tectogenesis (figs. 1 and 3).

3. CVRD-IRON ORE DEPOSITS FROM ITABIRA AND PIÇARRÃO

3.1 Iron Ore Deposits of the Itabira District

As previously stated, the metasedimentary and structural development of the Itabira District shows similarities and dissimilarities when compared with the Q.F. s.s. area. Similarities include the overall synclinorial structure of the metasedimentary belts, surrounded by indistinguishable migmatites and gneisses of the regionally continuous Granitic Complex. Dissimilarities regard local stratigraphics, in spite of some correlable units of the Minas Supergroup (tables 5 and 7). From the bottom to the top:

- The Paragneis Sequence of the Itabira District has no equivalent in the Q.F. s.s. area, neither in the Rio das Velhas nor in the Minas Supergroup;
- The Greenschist Sequence from Itabira is only similar to the Nova Lima Group of the Rio das Velhas Supergroup at first sight, however, not as far as details are concerned. The threefold subdivision of the former unit was not veryfied in the latter one of the Q.F. s.s. region;
- Moeda, Cauê and Cercadinho Formations, of Caraça, Itabira and Piracicaba Groups respectively (Minas Supergroup) are correlable, however, drastic facies changes exist.

Ultramafic and basic meta-igneous rocks of different ages are widespread throughout the Itabira District, cutting all the other rocks. They abrange a wide variety of types.

In general, the ultramafic rocks experienced greenschist facies metamorphism. They occur mainly as serpentinites, tremolite-talc-magnesite schists and talc schists, with tectonic contacts, within Granitic Complex migmatites and gneisses, within the Borrachudos type granitic rocks, and even within Minas metasediments, for example of the Paragneiss Sequence and Cauê Formation. Metaultramafics also occur in the Greenschist Sequence, but, to all appearance, with concordant contacts. Evidences of thermal metamorphism are absent in both cases: of tectonically intrusive and apparently concordant bodies. In two cases, the meta-ultramafics of the Greenschist Sequence proved chromite bearing, carrying disseminated ores, and these chromites too, showed anomalously high Zn-contents (Wiedemann and Schorscher 1978, Schorscher 1980b). The metabasic rocks include polymetamorphic amphibolites from the Granitic Complex, as described in part 2.1.1.2, metabasics grading into amphibolites with the progressive regional

Minas-Espinhço metamorphism (see part 2.1.2.6) and thermometamorphic, non-deformed basalts of inferred post-Minas/Espinhaço but pre-Brasiliano age (see part 2.1.2.8).

Iron ore of the Cauê Formation is associated to a large synclinorium, some 11 kms long, and SW-NE oriented (fig. 29). The synclinorium north limb is quite regular, unlike the southern limb, which is tectonically missing or drastically thinned in various places. Major high grade ore deposits occur in the synclines: Cauê, Conceição, and Dois Córregos. However, hematite ore bodies are also present in anticlines. In these cases, deposits are smaller: Periquito and Chacrinha (fig. 29).
The most common iron ore type is itabirite, i.e. a banded, metamorphic oxide facies iron formation, composed of alternating layers of quartz and hematite. The high grade ores are almost pure hematite.

3.1.1 Cauê Mine

The Cauê mine (figs. 29, 35, 36, 37) is the CVRD's major producing site, in 1982 an open pit of 2 km length, 1.5 km width and 245 m below the original peak level. The 1981 output was 31 million tons of different iron ore types. Mining activities have continuously changed the topographic features of the surroundings, new drainage patterns appearing, original valleys becoming tailing deposits.

The lower sequence exposed at Cauê is made up of greenschists with quartz, plagioclase, actinolite, chlorite, biotite and muscovite, forming the about 250 m high, greenish coloured ultimate mine slope (fig. 35).
Quartzites and quartz-phyllites pertaining to the Caraça Group overlie the greenschists, the entire group being 25 m thick on an average.
The Caraça rocks grade into the Itabira Group, represented exclusively by the Cauê Formation, i.e. itabirites locally enriched to almost pure hematite bodies. Overlying rocks are ferruginous quartzites and phyllites of the Piracicaba Group (table 7).
Tectonically intercalated, green coloured meta-ultrmafic rocks are frequent in the mine, mainly along thrust faults, and are transformed by metamorphism into talc-chlorite or chlorite schists.

The major structure at Cauê mine is a disymmetrical syncline, its south and north limbs dipping 30°NE and 70°SE respectively. Plunge ranges from 30° to 15° SE (fig. 35).
The whole area experienced intense tectonic deformations, the result being a significant thickening of the iron formation caused principally by recumbent thrust faulting. Thicknesses of 500 m are usually observed. Piracicaba rocks, more competent, broke into blocks. Thrust movement was generally N50W oriented (figs. 35, 36, 37).

Brecciation is an ordinary feature in the mine, commonly associated with vein quartz, schistose and sometimes weathered metabasic and ultramafic rocks, slickensides, hard or soft hematite.

Recumbent folds are most frequent. They appear in itabirites and green rocks, also when enclosed in hematite ore. Folding is difficult to identify in the hematite ore bodies. Wherever visible, folds showed to be wide and of isoclinal type.

Three different lineations can be observed at the Cauê mine, they are oriented N-S to N30E, N70E to E-W, and S50E.

Iron Ores

All ores at the Cauê mine are derived from itabirite, by far the most relevant component of the Cauê Formation of the Itabira Group, Minas Supergroup, as described in the literature dealing with the Iron Quadrangle of Minas Gerais.

Hematite Ore

Hematite ore is generally high-grade ore with iron content over 64%. It formed from itabirite, either by replacement of hematite for silica or/and by removal of silica only. Epigenetic, hydrothermal-metasomatic, posttectonic-post(regional)-metamorphic (Dorr and Barbosa 1963) and diagenetic pretectonic-premetamorphic (Schorscher 1975b, Hoefs et al. 1980, Müller et al. 1982) processes are controversially discussed. Hematite ore occurs more significantly in the southern part of the deposit, i.e. it concentrates towards the lower portion of the Cauê Formation, mainly along the south limb, extending upwards to the nose of the syncline and thus obeying stratigraphic and superimposed structural controls (figs. 35, 36, 37).

With respect to the physical properties, the high-grade hematite ore ranges from hard, massive to powdery. Foliation may sometimes be recognized and is generally parallel to the foliation of the greenschists exposed on pit walls.

In the hematite ore bodies, tectonically enclosed or crossing meta-ultramafic and possibly metabasic rocks occur, which are practically always deeply decomposed. These rocks, generally referred to as intrusive, are folded into anticlines and synclines together with the ores (figs. 35, 36, 37).

Besides the main hematite ore bodies, minor lenses occur, associated with faulting zones, seldom also along folding cores.

Supergene enrichment of itabirite by leaching of silica may also take place on the surface, or in favourable sites at depth, producing hematite-grade ore bodies. Nevertheless, this type of ore is of minor significance.

Itabirite Ore

Itabirite makes up the bulk of the iron formation in the Itabira District. At the Cauê mine it distributes mainly in the north limb of the syncline.

Itabirite is a metamorphic rock made up of alternating layers or laminae of quartz and hematite. Bedding is sometimes intensely folded, the primary features being almost totally destroyed and replaced by a new banded layering.

Hard, low-grade itabirite is considered protore, whilst enriched itabirite is considered ore, since it is suitable for up-grading by magnetic concentration.

In the case of itabirite ore, the ore forming process comprises softening and iron enrichment by silica leaching. The iron content of itabirite ore ranges from 40 to 64%.

3.1.2 Conceição Mine

Conceição Mine (figs. 38, 39) is located in the southernmost extreme of the Itabira Synclinorium (fig. 29), ranking second among the CVRD's operating mines. In 1981 the output was 20 million tons of run-of-mine ore.

The Conceição deposit is again a disymmetrical syncline (figs. 29, 38, 39), with its southern limb largely deformed by folding and faulting. The southern limb was also the site of major concentrations of high-grade hematite ore. In the eastern part of the deposit, rocks of the Piracicaba Group appear, intercalated with the iron formation.

Almost all rock types described at the Itabira District are likely to occur in Conceição Mine.

The lower formation exposed comprises rocks of the green schist sequence, which generally appear highly decomposed. Next follow the conventional Minas Supergroup rocks divided into Caraça, Itabira and Piracicaba Groups.

The Caraça Group forms the footwall of the iron formation. The Group attains abnormal thickness, around 100 meters, which is a result of complex folding, as observed mainly in the southern limb. Phyllites and quartzites are the principal lithologies. Contact with the overlying iron formation is conformable and gradational over an interval of a few meters.

The Itabira Group comprises the itabiritic iron formation with local concentrations of hematite ore bodies.

Quartzite and sometimes graphitic and gray phyllites of the Piracicaba Group overlie the Itabira Group.

Meta-ultramafic and possibly metabasic rocks, generally referred to as intrusive rocks, appear within the metasedimentary sequence. The tectonic intrusives are generally weathered and may be conformable or not (figs. 38, 39).

Iron Ores: Weathering and Supergene Enrichment

Weathering acting on iron formation causes softening, generally due to quartz dissolution, accompanied by increase of the iron content and formation of canga. Canga is a conglomerate-like, detrital recent formation, composed of grains, fragments, pebbles and cobbles of hematite and itabirite, and, more rarely, of quartzites and greenschists, tied together by limonite and/or goethite cement. Canga forms a 2 to 3 m thick blanket, covering the iron formation and adjoining rocks. Not infrequently, limonite may compose the bulk of the canga; in this case, it appears as a brown uniform mass.

A second and economically much more important effect of the iron formation weathering is the supergene softening and enrichment by silica leaching. The enrichment effect is more pronounced in the case of protore itabirite which may become itabirite ore, physically and chemically amenable for final magnetic concentration. Hard hematite ore becomes friable, often very soft.

The weathering process is strongly controlled by the topographic surface, as well as by structural features like joints, fractures, shear and fault zones

3.1.3 Dois Córregos Mine

The Dois Córregos Mine is located between Conceição and Cauê mines (figs. 29, 40). The yearly output is around 5.2 million metric tons of run-of-mine ore.

The stratigraphic sequence at Dois Córregos is similar to that at Cauê and Conceição, the only remark being the lower thickness of the Caraça Group with a maximum of 20 meters.

The Dois Córregos deposit (fig. 40) is associated with a tied syncline, truncated by thrust faulting. Compared to Cauê and Conceição, the Dois Córregos syncline is in broad lines a disymmetrical structure too. The north limb dips 40° to the southeast. The south limb is almost vertical. Furthermore, contrasting with Cauê and Conceição structures, the Dois Córregos syncline shows a thickening of the south flank.

High-grade hematite ore occurs principally at the fold nose that plunges to the northeast (fig. 40).

3.2 Iron Ore Deposits from Piçarrão

The Piçarrão Iron Ore District pertains to the easternmost domains of high-grade gneisses (part 2.6). The iron ores at Piçarrão Mine form one of several regionally aligned discontinuous, lenticular occurrences, distributed over the area reaching from Nova Era to Ferros cities and further North (figs. 1, 30), always exhibiting similar general characteristics. The iron ore reserves of individual deposits are usually not very high and only exceptionally within economic range, but of high quality and easy treatment, due to the coarse grain size and friability, a combined result of the high-grade regional metamorphism and subrecent to recent weathering processes.

The iron ores at Piçarrão Mine are associated with banded gneisses exhibiting alternating amphibolitic and granitic layers with pelitic (kinzigitic) gneisses, quartzites and granitic gneisses. The banded amphibolitic-granitic gneisses are probably an extension of lithologically similar rocks, described as Monlevade Gneiss bei Reeves (1966).

Iron ores comprise hematite-rich ore bodies enclosed in hematite-quartz, hematite-magnetite-quartz and magnetite-quartz itabirites (figs. 41, 42). In the hematite-rich ores, magnetite porphyroblasts of up to 10cm max. dimensions may occur.

The stratigraphic position of the Piçarrão iron formation is still under investigation. The Monlevade Gneiss was considered by Reeves (op.cit.) of pre-Minas age, and tentatively correlated with the Nova Lima Group. Nevertheless, neither high-grade hematite ores nor hematitic itabirites are known to occur among the Nova Lima rocks (Dorr 1969). Alternatively, Davino (1974) and Schorscher (1975a, b) considered the Piçarrão rocks as being of Minas age and pertaining to the Cauê Group, based on regional airmagnetometric surveys and geologic mapping respectively. A stratigraphic succession for the rocks from Piçarrão and regionally related occurrences based on lithological similarities with true Minas successions has already been discussed (part 2.6).

At least two phases of folding and faulting took place at Piçarrão. One of the striking features at the mining benches is a medium to micro scale, isoclinal, recumbent fold system; fold axes are parallel, to some extent undulant, plunging 30° to the southwest. Another significant structure is a plani-axial foliation derived from the small scale folding (figs. 41, 42).

Faults may be grouped into two different sets. One associated to the isoclinal folding and a second, more relevant, associated to regional fault systems striking NNE and E-W, dipping 50°W and 70°N, respectively.

Boudinage and mullion structures are also frequent linear structures, other than fold axes. They occur in both iron formation and country rock, causing the rocks to look blocky. It is interesting to note that in both structure types the layers and levels of hematite-rich ores behaved tectonically competent when compared to the enclosing itabirites (fig. 31).

Iron Ores and Mining

Technologically, the iron ore may be defined as a friable itabirite suitable for upgrading, as to generate sinter feed type ore, i.e., ore sized between 6.350 mm (1/4") and 0.150 mm (100 mesh) with maximum 10% less than 0.150 mm.

Mining is done by open pitting through 10m high benches inclined 1% for drainage purposes.
The ore being friable, extraction is done by means of bulldozer, loading by front pay-loaders. Haulage is done by means of 35 ton off-road Euclid trucks. Ore dressing includes crushing, homogenization and gravitational upgrading by Humphrey's spirals.

4. ACKNOWLEDGEMENTS

This text is a revised version of an earlier Excursion Guide prepared by the author at the occasion of the <International Symposium on Archaean and early Proterozoic Geologic Evolution and Metallogenesis - ISAP>, held at Salvador Bahia from 3 - 11 September 1982, with the cooperative aid of C.V.R.D. geologists Marcos Tadeu Vaz de Mello, José Aluízio Vasconcelos, Fernando Carbonary Santana, José Carlos Polonia and José Maria Pereira Moreira. The latter three acted as invited co-authors and field-guides in the excursion part dedicated to C.V.R.D.'s Iron Ore Mines. Since then, the knowledge about the fascinating Precambrian Geology of the SE Minas Gerais state has broadened considerably, and some of the results of more recent work were incorporated in this text. The present guidebook, however, has benefited greatly from its previous edition, particularly with respect to the last chapter, where the data on the Iron Ore Mines ceded by the Vale do Rio Doce Company (C.V.R.D.) for the original publication could be used again without substantial modifications.
The present text was compiled during a research stay of the author at the Institute of Mineralogy and Petrology of the University of Bern, Switzerland. With the kind permission of Prof. Tj. Peters, Director of the Institute at Bern University, Jürg Megert, technician, Lina Bobade and Margrit Hug,secretaries, contributed considerably to the completion of this edition.

5. FIGURES

Fig. 1 Geologic Sketch map of the excursion area comprising: Quadrilátero Ferrífero, southern Serra do Espinhaço, São Francisco Basin and eastern gneiss domains (modified from Schorscher et al. 1982).

Fig. 2 Satellite view of the Quadrilatero Ferrífero, Serra do Espinhaço and adjacent areas (central parts of fig. 1 ca. 1,5 x linearly magnified).

Fig. 3 Metamorphic outline of the regional Minas/Espinhaço Proterozoic metamorphism.

Fig. 4 Stromatic, homogeneous migmatite intruded by minor tonalite body. Note felsic contact reaction rim locally destroyed by later shearing (fig. 1 outcrop point 10).

Fig. 5 Heterogeneous, complexly folded migmatite from the Itabira District (fig. 1).

Fig. 6 Tonalite dike (at hammers handle) cuts stromatic migmatite, both being intruded by a granodiorite dike (at hammers head). Youngest events are represented by fine felsic veins of different directions (fig. 1, outcrop point 10).

Fig. 7 "Primary" and "secondary" granitic rocks s.l. of the "Basement" Complex in a representation of Al/3-K vs. Al/3-Na (at.-proportions) proposed by La Roche (1968, 1972). Migmatites and Gneisses are Archaean rocks of low grade Proterozoic retrometamorphism; Meta-arkoses, Metagreywackes, Paragneisses are of the Paragneis Sequence (lowermost Minas SG); Mylonite gneisses are from both but predominantely from the Archaean rocks. Metasomatic (K-feldspathised) Mylonite gneisses, including as well rather weakly cataclastic Archaean migmatites and gneisses are transitional rock-types of the process of metasomatic formation of the Borrachudos Granite type rocks (Metasomatites - "Granito Borrachudos"). Similar relationships exist between Quartz-Muscovite/Phengite ± Magnetite Mylonite schists, their K-feldspathised equivalents (Metasomatic Myloniteschists) and Muscovite-rich Borrachudos Granite type rocks (Metasomatites-Mu-rich "Granito Borrachudos".

Fig. 8 Macroscopic aspect of Borrachudos Granite type rock. Note linear orientation of aggregates of mafic minerals.

Fig. 9 Relictically preserved saussuritised plagioclase in replacement perthite of Borrachudos Granitoid (vertical dimension ca. 4 mm, photomicrograph, pol. obliq. +).

Fig 10 Fluid inclusions may total as much as 20 Vol.-% of the K-feldspar phases of replacement perthites in the Borrachudos Granitoids. Max. dimensions of the inclusions reach up to 10 μ (photomicrograph, plane pol. light).

Fig. 11 Geology of the <Belmont> Emerald Mine and surroundings (fig. 1, outcroup point 15); Legend:

Precambrian Rocks

1.- thermometamorphic non-deformed Precambrian basalts (post-Minas/Espinhaço to pre-Brasiliano cycle);

Minas Supergroup

2.- itabirites and metacherts (Cauê Fm., Itabira Gr.);

3.- quartzites and quartz-muscovite schists, frequently with kyanite (Moeda Fm., Caraça Gr.);

4.- metapelitic schists with garnet, staurolite and graphitic top-portion (Greenschist Sequence);

Archaean Vulcano-Sedimentary Sequence

5.- metaultramafic amphibolites, at the <Belmont> mine biotitized and disseminated chromitite bearing. Sequence includes additionally metabasic amphibolites, metapelitic and mafic schists and gneisses and very subordinated muscovite quartzite and mu.-qz. schists.

6. Borrachudos granite type rocks (flasergneisses)

7. leucocratic gneisses and migmatites undivided, including Archaean polymetamorphic and Proterozoic rocks. Foliation-trends are indicated by dotted lines.

Fig. 12 B.S.E.- and Element Distribution Immages of Chromite grain. Note Ferrichromite transformation and Ti-enrichment along the border and Zn-content in the unaltered center of the crystal. The diameter of the Chromite grain is about 0.5 mm.

Fig. 13 Thermometamorphic Basalt of Precambrian age. Note lack of deformation and low-grade coronitisation with mainly radially exposed amphibole intergrown with granular clinozoisite-epidote s.s.. (Photomicrograph, vert. dim. ca. 4mm, pol. obliq. +.)

Fig. 14 Thermometamorphic Basalt of Precambrian age. Note lack of deformation and high-grade coronitisation with advanced amphibolitisation of pyroxenes, clinozoisite and garnet formation, and the incipient polygonal recrystallisation of magmatic plagioclases. (Photomicrograph, vert. dim. ca. 4mm, pol. obliq. +.)

Fig. 15 Geologic sketch map of the Sta. Barbara Region. The massive black lines in the Quebra Osso and Nova Lima Groups represent (Archaean) banded iron formations gradational with iron poor metacherts. The São Bento gold deposit is of the banded iron formation hosted Archaean type. The abandoned Quebra Osso gold mine worked in ferruginous, graphitic and pyritic metacherts and quartzphyllonites of most probably Proterozoic, Espinhaço SG. age.

Fig. 16 Massive structured Ultramafics of the Quebra Osso Group showing polyhedral suturing (Fig. 1, outcrop No. 11).

Fig. 17 Hand specimen of massive (peridotitic) Komatiite (Quebra Osso Gr.) with spinifex textured "garland" and younger talc vein (fig. 1, outcrop No. 11).

Fig. 18 Outcrop view of velded coarse ultramafic agglomerate of the Quebra Osso Group (fig. 1, outcrop No. 11).

Fig. 19 Photomicrograph of Quebra Osso Group (micro-)spinifex textured (peridotitic) Komatiite (vert. dim. ca. 4mm, polarisers obliquely crossed).

Fig. 20 "Conglomerate" of the Nova Lima Group (fig. 1, located near outcrop No. 6). Blocks of Fe-poor bifs and metacherts lie in a fine-grained matrix of mafic schists. The phyllitic aspect is due to weathering.

Fig. 21 Gold nugget with about 3mm of major dimension in carbonate vein cutting Quebra Osso Gr. serpentinites.

Fig. 22 Maquiné Gr., Rio das Velhas SG.: Photomicrograph of polished thin section showing pyrite idioblasts with detrital nuclei, surrounded by intermediate zones of diagenetic pyrite replete with tiny silicate mineral inclusions (plane polarised reflected light, vert. dim. ca. 3 mm).

Fig. 23 The quartz-quartzite pebble metaconglomerate of the Moeda Fm. (here coarse facies from the SW termination of the Gandarela Syncline, fig. 1) is detrital pyrite and gold bearing with only subordinated uranium contents.

Fig. 24 Itabirites (Cauê Fm., Minas SG.) are metamorphosed oxide facies banded iron formations here, near the tectonic contact of the Serra do Curral Syncline with the "Basement Complex" (fig. 1, outcrop point 2), intricately folded. Disharmonic, drag-, box- and chevron folds occur, among others.

Fig. 25 Abrupt and discordant passage between low Fe-grade itabirite and almost pure hematite ore in bore core from Conceição Mine (Cauê Fm., Minas SG.), Itabira Iron Ore District (fig. 1, outcrop No. 18).

Fig. 26 Sopa Brumadinho Fm. (Espinhaço SG.) polymictic intraformational conglomerate with abundant itabirite pebbles (black). Note conglomerate pebble below hammer point, indicating reworking of the own conglomerate. Light coloured pebbles are of Espinhaço quartzites.

Fig. 27 Sawed hand specimen of itabirite pebble (upper part) conglomerate with coarse-grained quartzitic matrix (lower part), Sopa Brumadinho Fm., Espinhaço SG., outcrop point 5 (fig. 1). The pebble is of enriched itabirite with replacement structures of light quartz layers through massive hematite (black). Deformation becomes evident in the itabirite pebble and is not accompanied by related metamorphic recrystallisation, i.e. most probably of synsedimentary to syndiagenetic origin.

Fig. 28 Mega-ripple stratification in Galho do Miguel Fm., Espinhaço SG. at outcrop point 3 (fig. 1).

Fig. 29 Geologic sketch map of the Itabira Iron Ore District.

Fig. 30 Geologic sketch map of the Piçarrão Region.

Fig. 31 Boudin structure in high-grade metamorphic hematite ore/itabirite alternating succession from Piçarrão District (fig. 1). Note competent behaviour of pretectonic concordant hematite ore forming central boudins body and incompetent behaviour of enclosing "normal" itabirite.

Fig. 32 Polished iron ore/itabirite hand specimen (approx. natural size; scale bar in mm) from Piçarrão (fig. 1, outcrop point 16) composed of hematite (rich) ore (upper part) and well banded "normal" itabirite (lower portion of sample). Photographed with natural reflected light. Note bright, coarse-grained mosaic textured hematite in rich ore portion (evidenced by polarization of reflected light) and specular hematite in itabirite. Cm-dimensiond, darker (medium-)grey magnetite porphyroblasts occur exclusively in hematite ore layer. One magnetite porphyroblast (center of photograph) includes parts of relictically preserved quartz layer and penetrates with one corner into the "normal" itabirite level.

Fig. 33 Itabirites of the highest regional metamorphic, hydrogranulite facies grade, Piçarrão District (fig. 1, outcrop point 16), loose their typical, well banded structure by magnetite blastesis, progressively, and finally completely. Polished hand specimen slab (approx. natural size; scale bar in mm), photographed in natural reflected light: ores (magnetite, in cm-sized porphyroblasts and hematite, in relictic layers) are bright and repose in dark grey silicate (quartz) matrix.

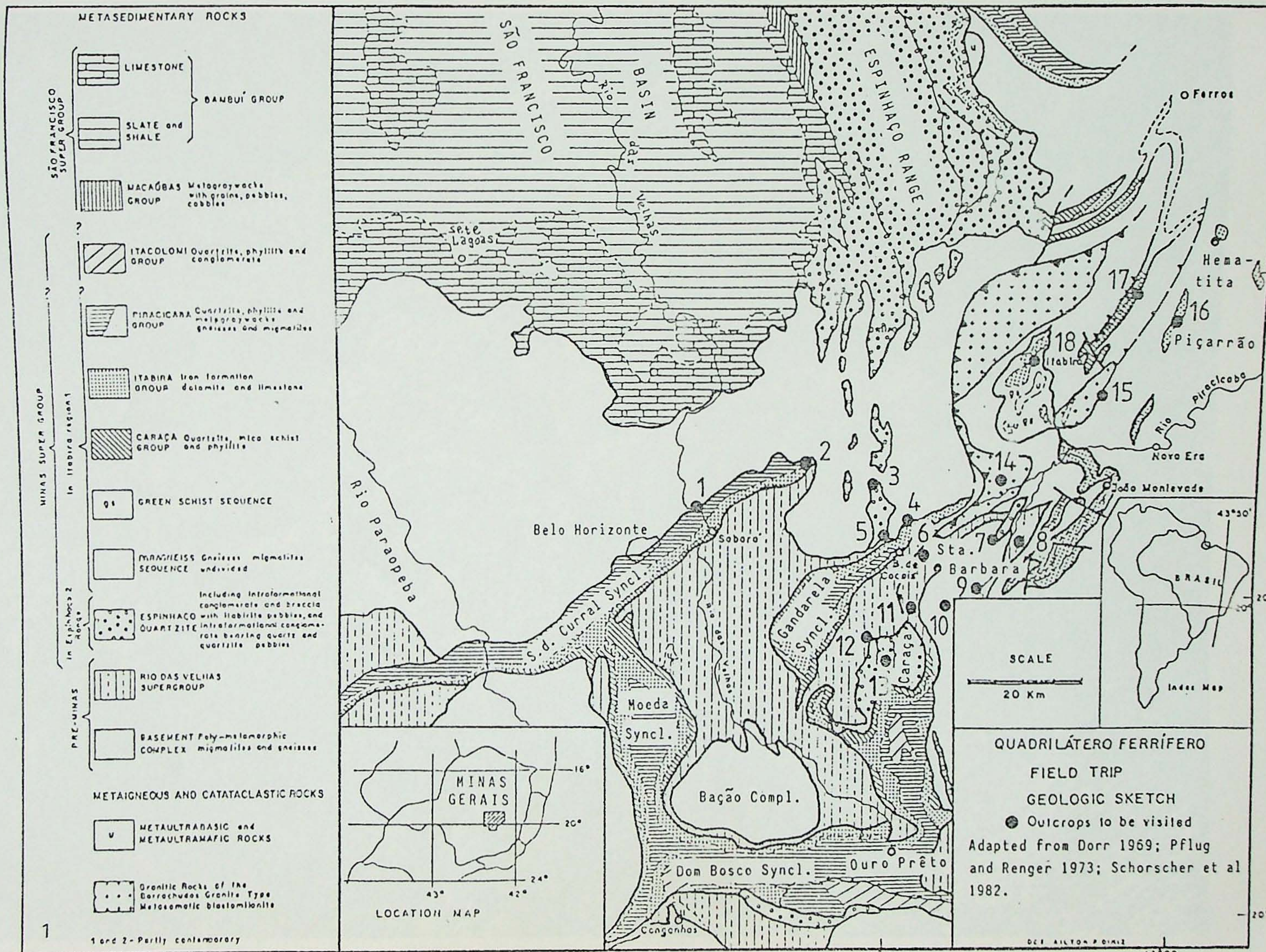
Fig. 34 Marbles from Bambui carbonates, São Francisco SG., in quarry about 35km NNE of Belo Horizonte (fig. 1). Deformation (verticalisation) and greenschist facies thermo-dynamometamorphism are due to the overthrusting of the Espinhaço SG. rocks from the E.

Fig. 35 Geologic sketch map of Cauê Mine.

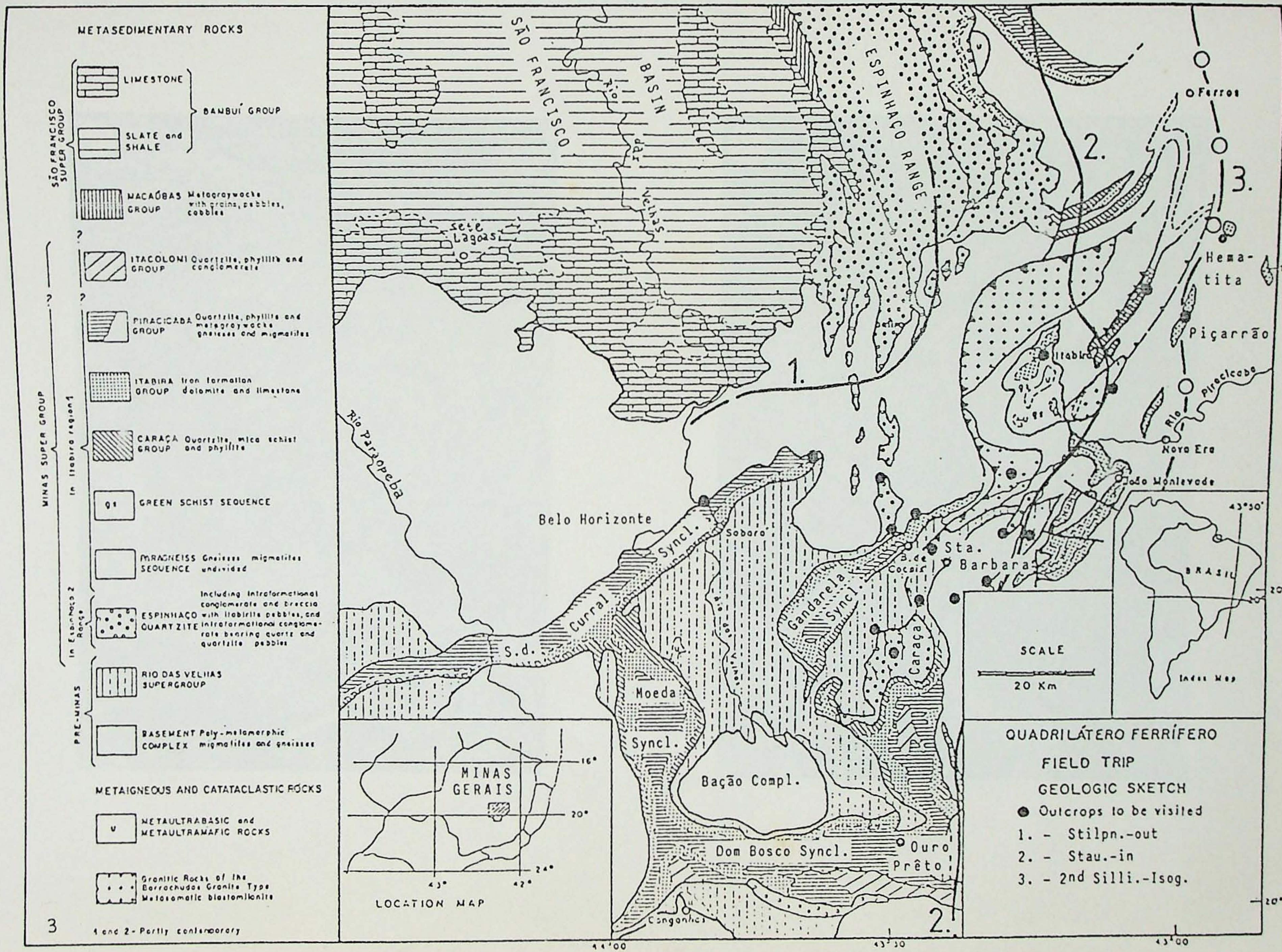
Fig. 36 Vertical (transversal) Cross Section of Cauê Mine.

Fig. 37 Vertical (longitudinal) Cross Section of Cauê Mine.

Fig. 38 Geologic Sketch of Conceição Mine.

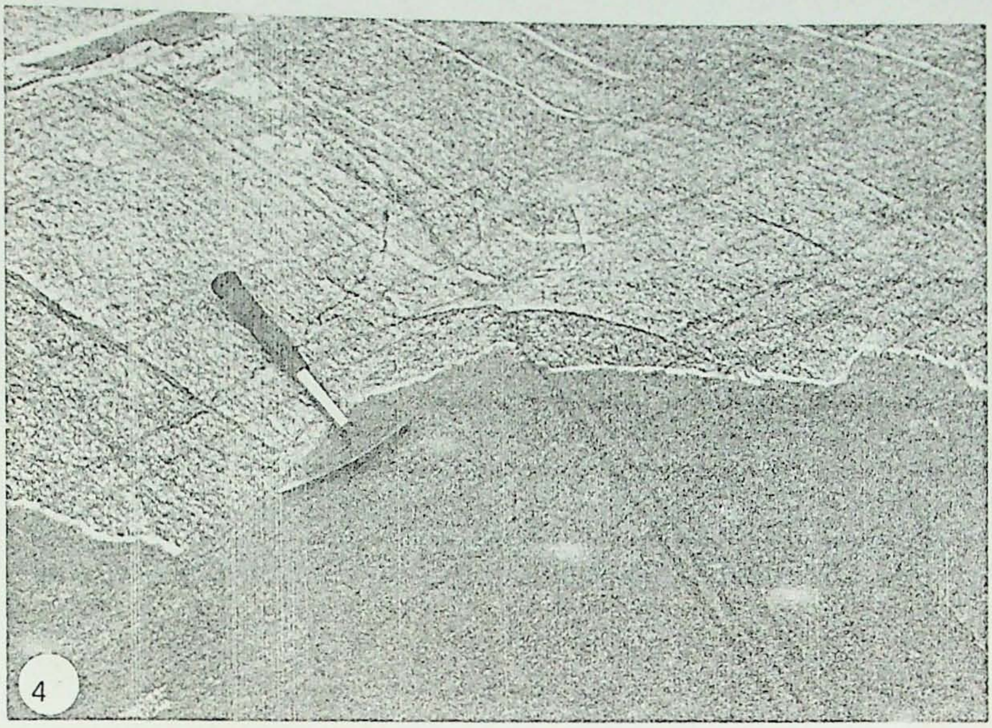

METASEDIMENTARY ROCKS
SÃO FRANCISCO SUPER GROUP
LIMESTONE
SLATE and SHALE
BAMBUÍ GROUP
MACAÚBAS GROUP Metagraywacke with grains, pebbles, cobbles
MINAS SUPER GROUP
ITACOLOMI GROUP Quartzite, phyllite and conglomerate
PIRACICABA GROUP Quartzite, phyllite and metagraywacke gneisses and migmatites
In Itabira region 1
ITABIRA GROUP Iron formation dolomite and limestone
CARAÇA GROUP Quartzite, mica schist and phyllite
GREEN SCHIST SEQUENCE
MIGMATITES GNEISS SEQUENCE Gneisses migmatites undivided
In Espinhaço Range 2
ESPINHAÇO QUARTZITE Including intraformational conglomerate and breccia with itabirite pebbles, and intraformational conglomerate bearing quartz and quartzite pebbles
PRE-MINAS
RIO DAS VELHAS SUPERGROUP
BASEMENT COMPLEX Poly-metamorphic migmatites and gneisses
METAIGNEOUS AND CATACLASTIC ROCKS
METAULTRABASIC and METAULTRAMAFIC ROCKS
Granitic Rocks of the Borrachudos Granite Type Metasomatic blastomilonite
1 and 2 - Partly contemporary
SÃO FRANCISCO
BASIN
Rio das Velhas
ESPINHAÇO RANGE
Sete Lagoas
Rio Paraopeba
Belo Horizonte
Sabará
S. d. Curral Syncl.
Gandarela Syncl.
Moeda Syncl.
Bação Compl.
Dom Bosco Syncl.
Ouro Prêto
Congonhas
Caraça
B. de Cocais
Sta. Barbara
João Monlevade
Nova Era
Rio Piracicaba
Itabira
Piçarrão
Hematita
O Ferros
LOCATION MAP
MINAS GERAIS
SCALE
20 Km
Index Map
BRASIL
QUADRILÁTERO FERRÍFERO
FIELD TRIP
GEOLOGIC SKETCH
Outcrops to be visited
Adapted from Dorr 1969; Pflug and Renger 1973; Schorscher et al 1982.


2

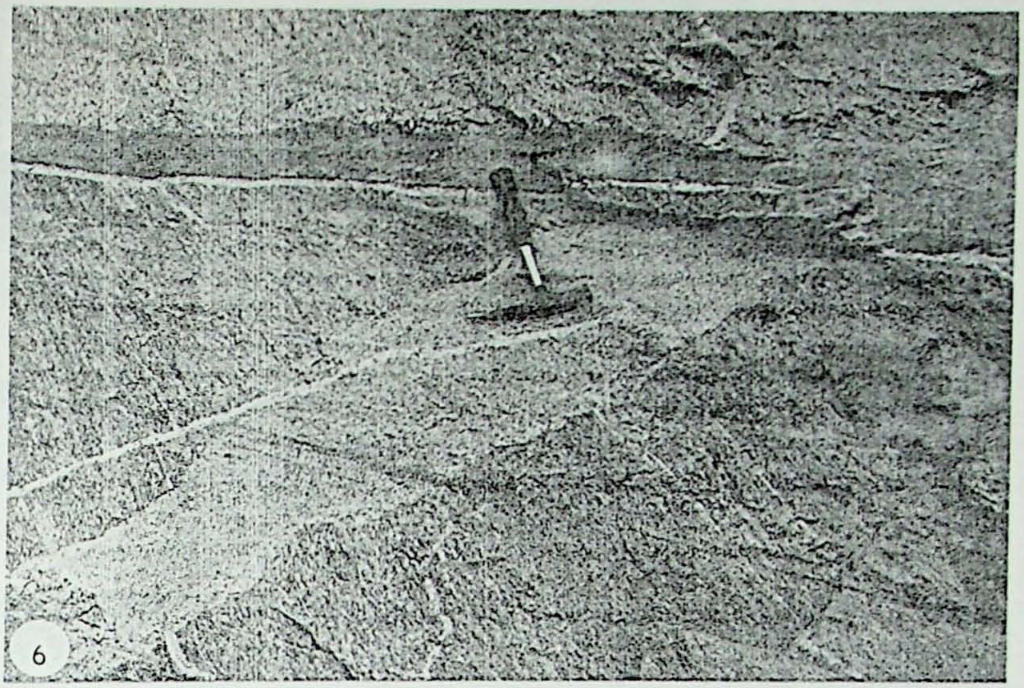


QUADRILÁTERO FERRÍFERO
FIELD TRIP
GEOLOGIC SKETCH
Outcrops to be visited
1. - Stilpn.-out
2. - Stau.-in
3. - 2nd Silli.-Isog.
SCALE
20 Km
METASEDIMENTARY ROCKS
SÃO FRANCISCO SUPER GROUP
LIMESTONE
SLATE and SHALE
BAMBUÍ GROUP
MACAÚBAS GROUP Metagraywacke with grains, pebbles, cobbles
MINAS SUPER GROUP
ITACOLOMI GROUP Quartzite, phyllite and conglomerate
PIRACICABA GROUP Quartzite, phyllite and metagraywacke gneisses and migmatites
ITABIRA GROUP Iron formation dolomite and limestone
CARAÇA GROUP Quartzite, mica schist and phyllite
GREEN SCHIST SEQUENCE
PARAGNEISS SEQUENCE Gneisses migmatites undivided
In Itabira region 1
In Espinhaço 2 Range
ESPINHAÇO QUARTZITE Including intraformational conglomerate and breccia with itabirite pebbles, and intraformational conglomerate bearing quartz and quartzite pebbles
PRE-MINAS
RIO DAS VELHAS SUPERGROUP
BASEMENT COMPLEX Poly-metamorphic migmatites and gneisses
METAIGNEOUS AND CATACLASTIC ROCKS
METAULTRABASIC and METAULTRAMAFIC ROCKS
Granitic Rocks of the Borrachudos Granite Type Metasomatic blastomilonite
1 and 2 - Partly contemporary
SÃO FRANCISCO
BASIN
Rio das Velhas
ESPINHAÇO RANGE
Sete Lagoas
Belo Horizonte
Rio Paraopeba
Curral Syncl.
S.d.
Sabará
Moeda Syncl.
Bação Compl.
Dom Bosco Syncl.
Ouro Prêto
Congonhas
Gandarela Syncl.
Caraça
B. de Cocais
Sta. Barbara
João Monlevade
Nova Era
Rio Piracicaba
Itabira
Piçarrão
Hematita
Ferros
MINAS GERAIS
LOCATION MAP
BRASIL
Index Map
16°
20°
24°
43°
42°
43°30'
19°30'
20°00'
20°30'
44°00
43°30
43°00
1.
2.
3.

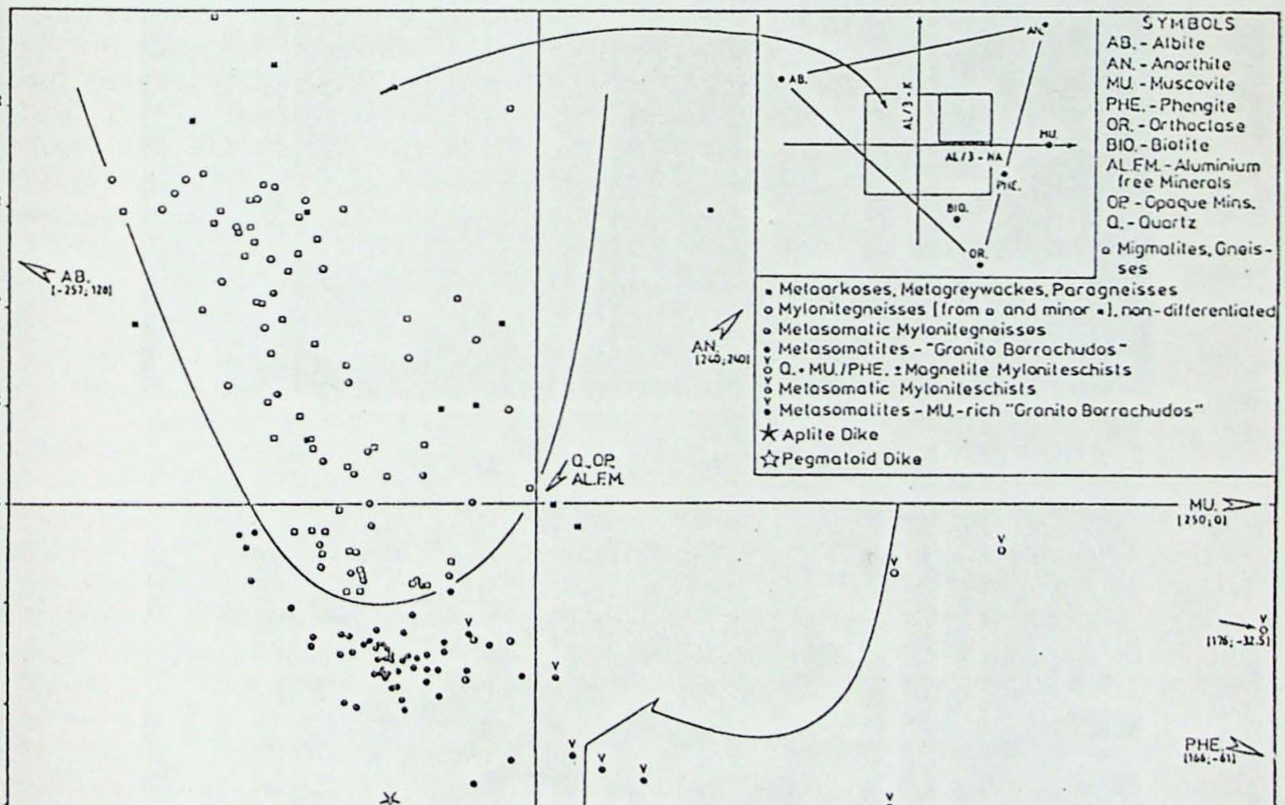
3


4

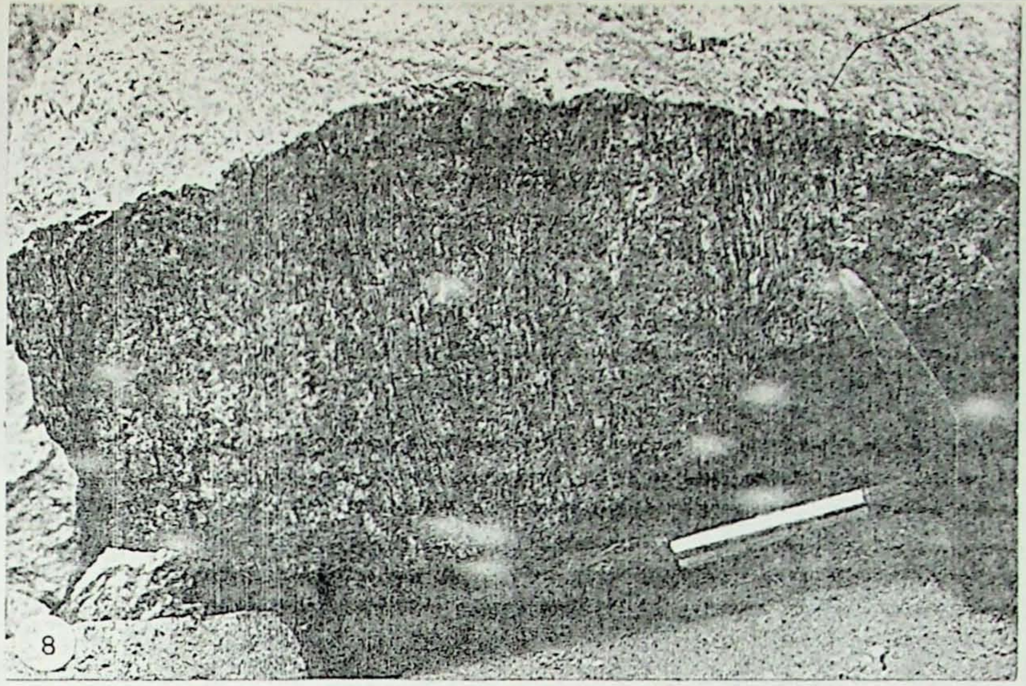

5



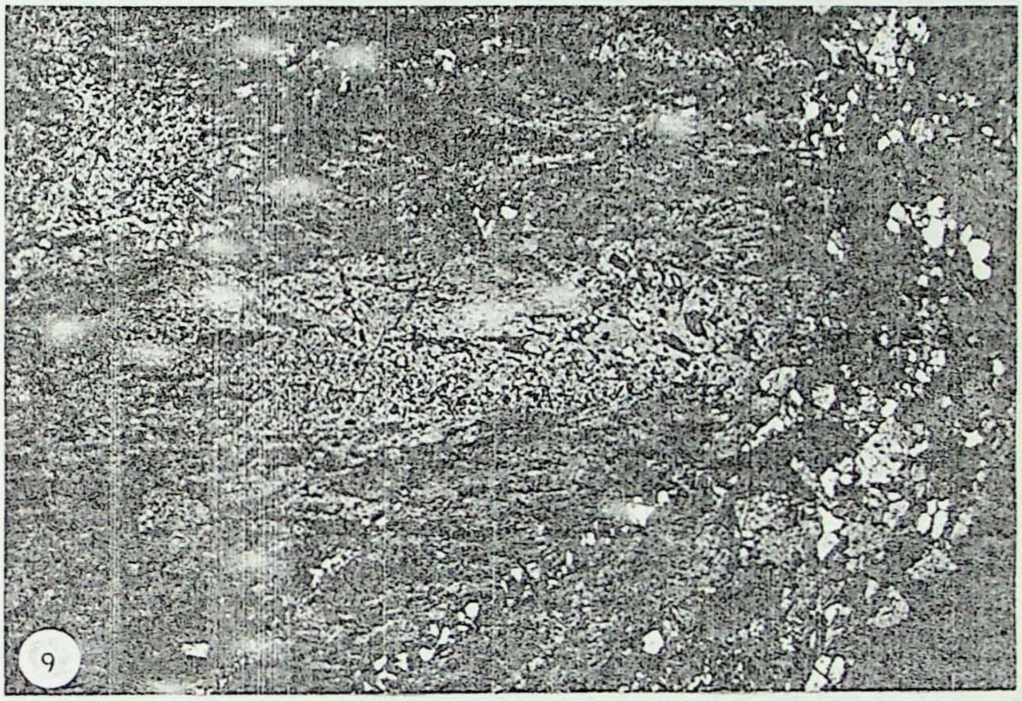
6


SYMBOLS
AB. - Albite
AN. - Anorthite
MU. - Muscovite
PHE. - Phengite
OR. - Orthoclase
BIO. - Biotite
AL.F.M. - Aluminium free Minerals
OP. - Opaque Mins.
Q. - Quartz
Migmatites, Gneisses
Metaarkoses, Metagreywackes, Paragneisses
Mylonitegneisses (from and minor), non-differentiated
Metasomatic Mylonitegneisses
Metasomatites - "Granito Borrachudos"
Q. + MU./PHE. ± Magnetite Myloniteschists
Metasomatic Myloniteschists
Metasomatites - MU.-rich "Granito Borrachudos"
Aplite Dike
Pegmatoid Dike
AB. [-257; 128]
AN. [240; 240]
Q., OP., AL.F.M.
MU. [250; 0]
[176; -32.5]
PHE. [166; -61]
BIO. [74; -149]
OR. [120; -240]
AL/3-K
AL/3-NA
-80
-60
-40
-20
0
20
40
60
80
100
120

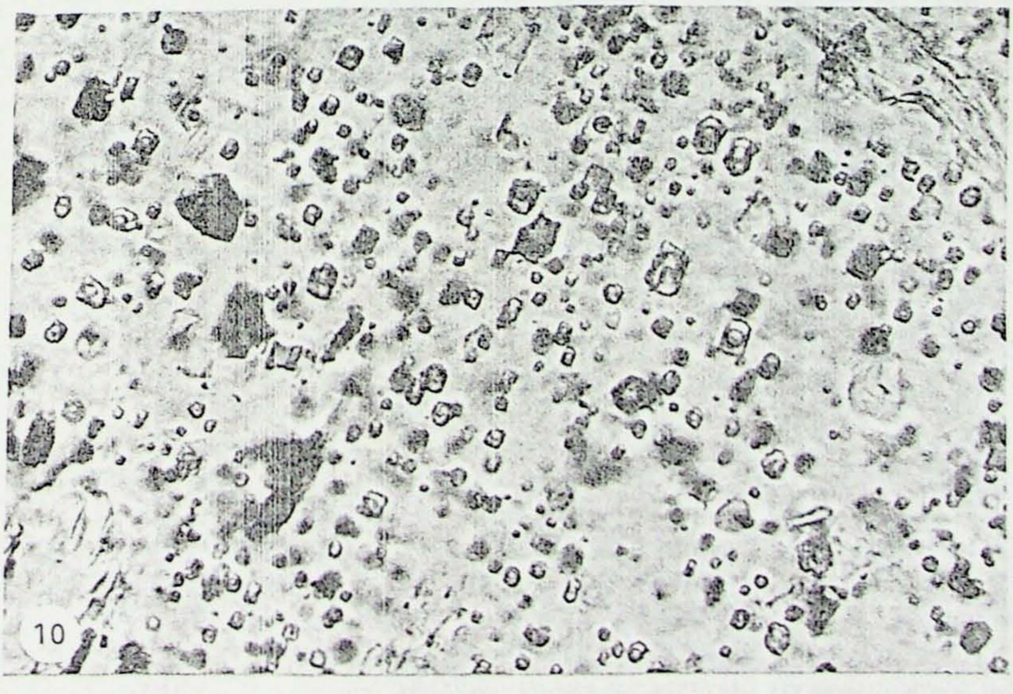
7



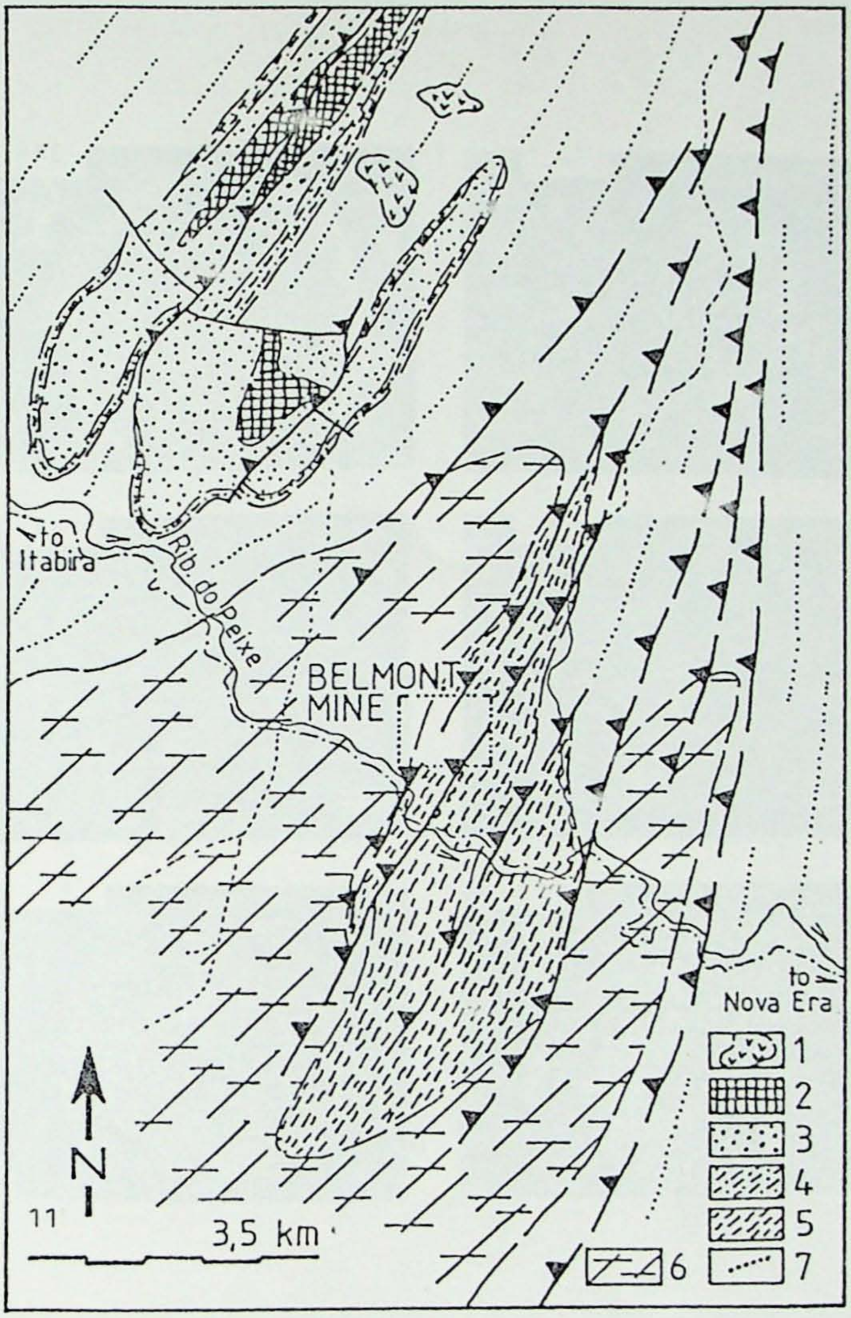
8

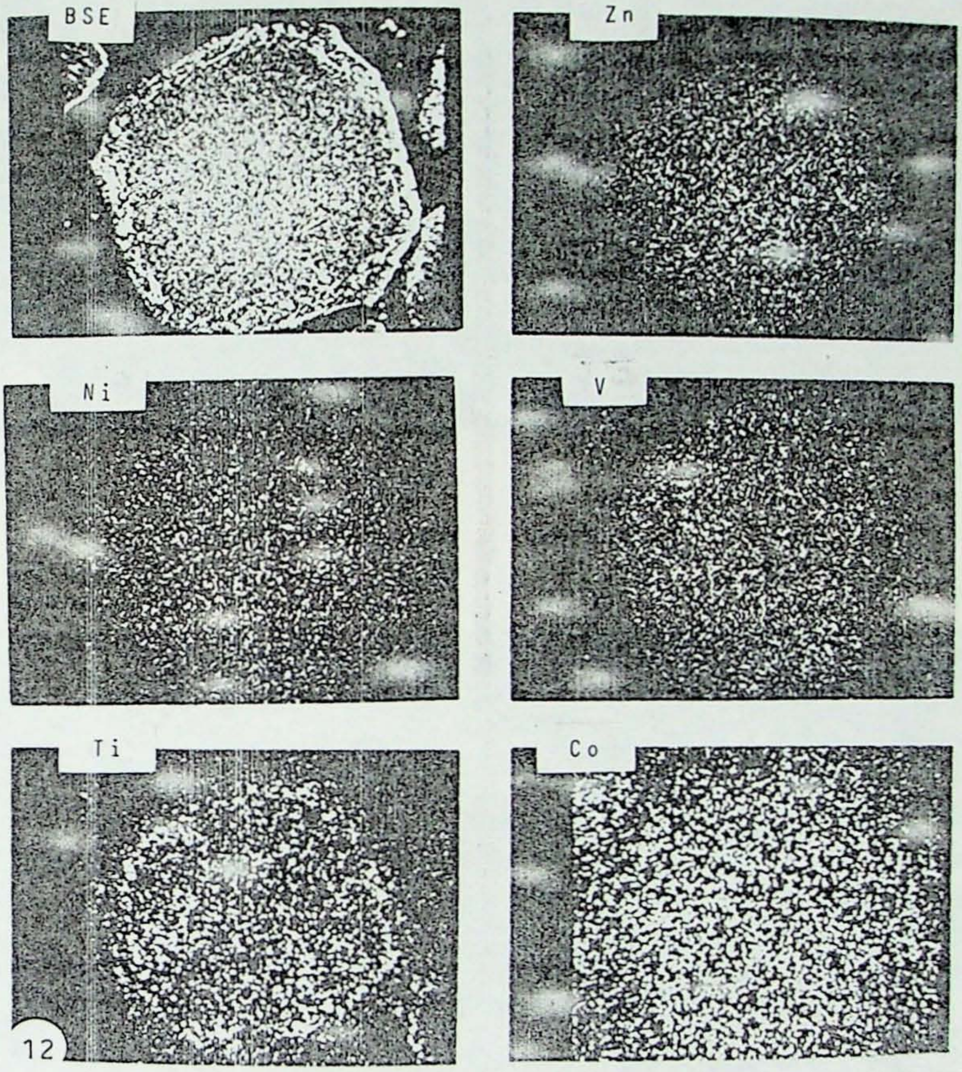


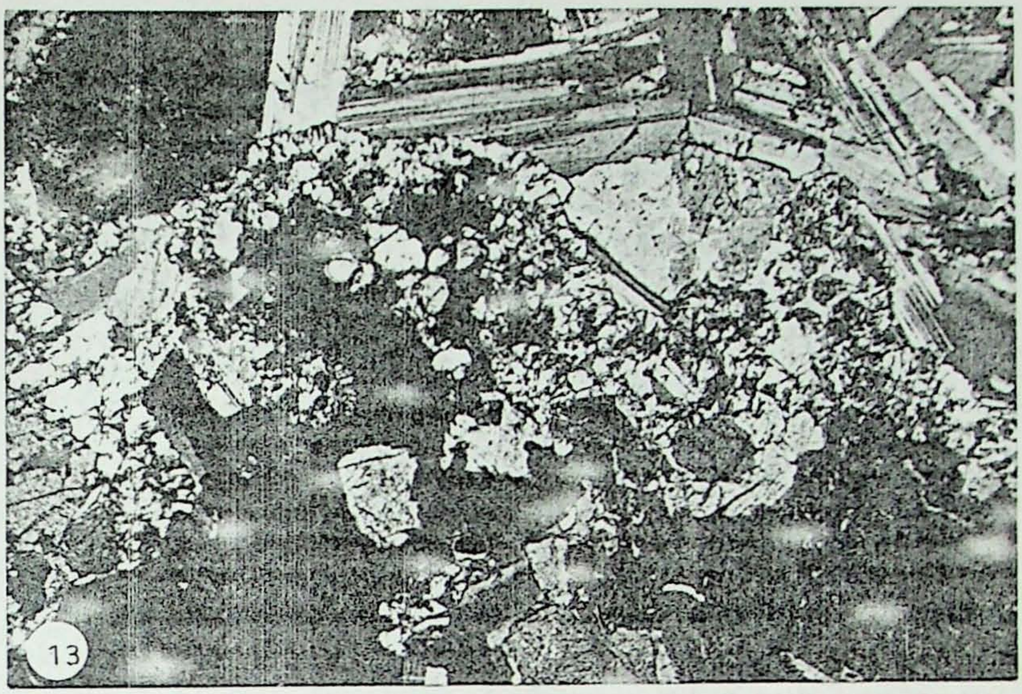
9

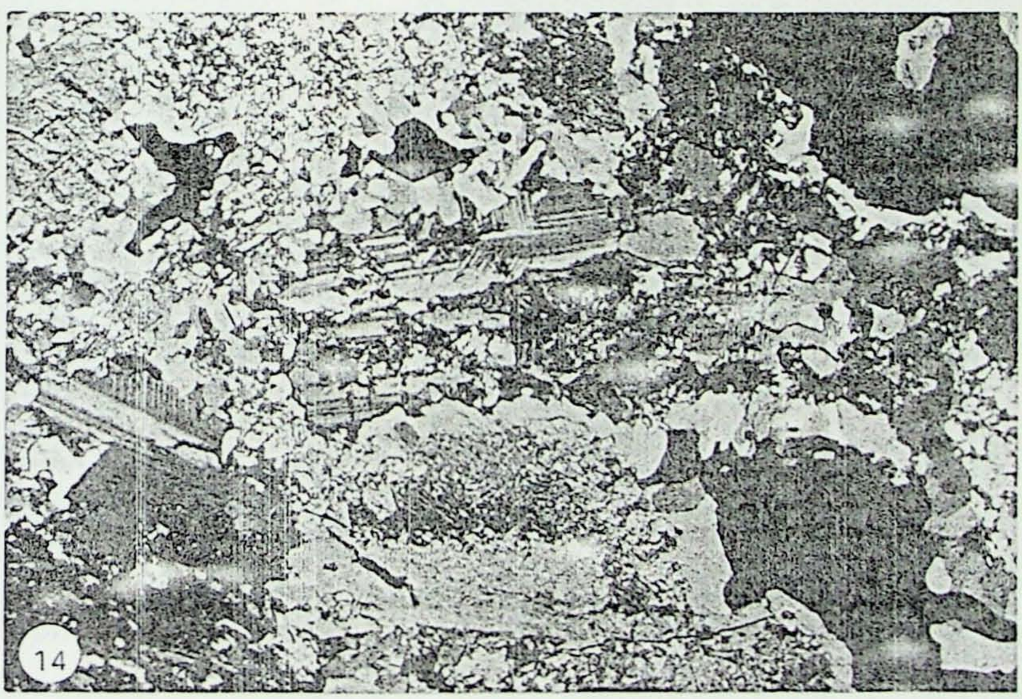


10


to
Itabira
Rib. do Peixe
BELMONT
MINE
to
Nova Era
1
2
3
4
5
6
7
N
11
3,5 km


BSE
Zn
Ni
V
Ti
Co
12


13


14

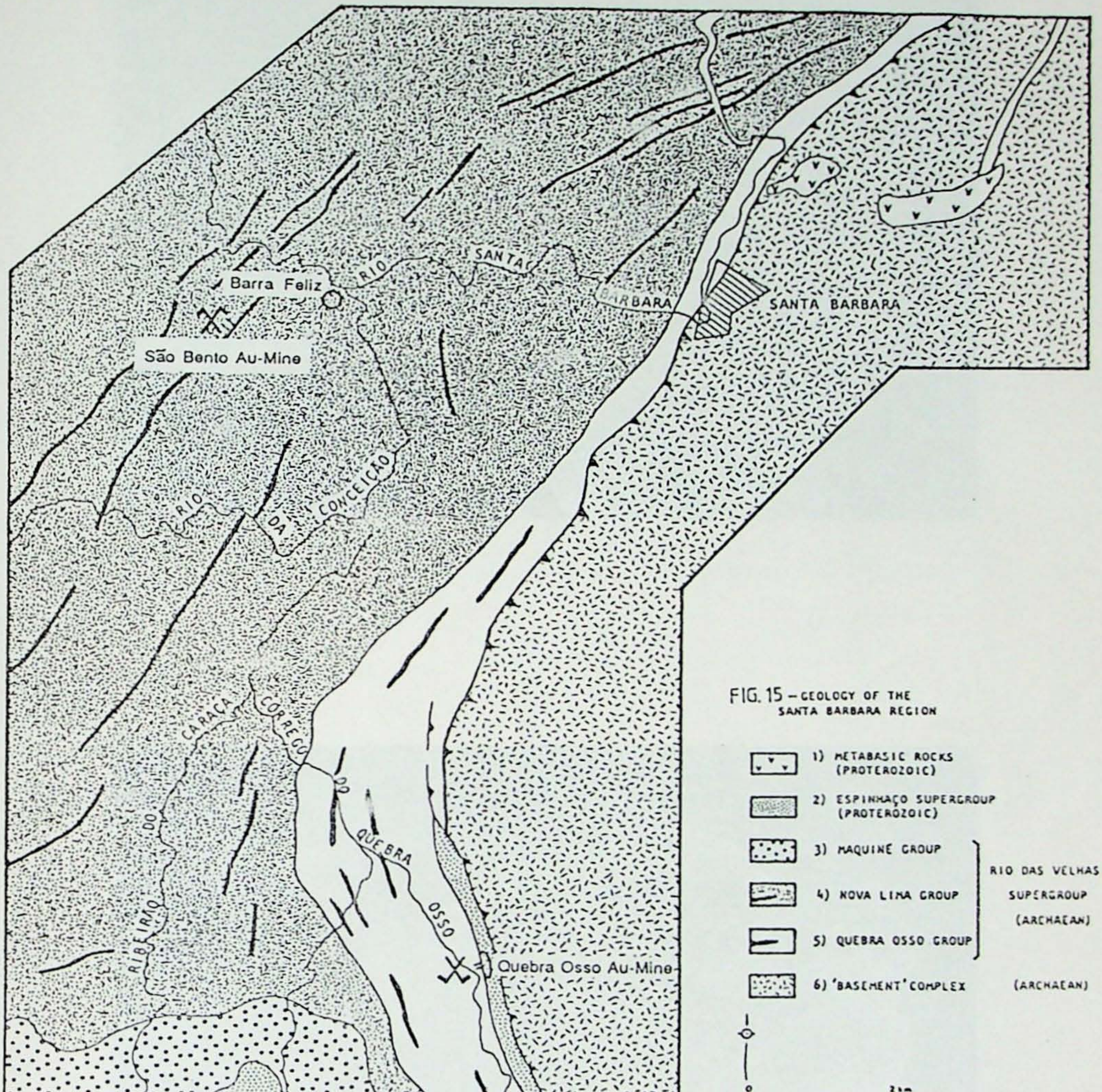
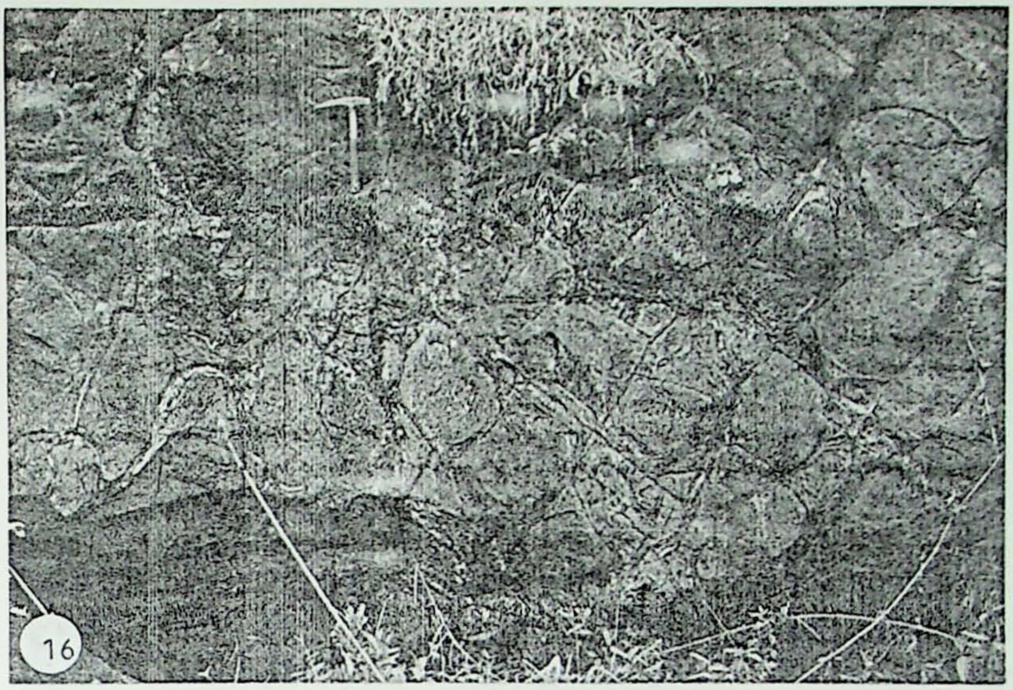
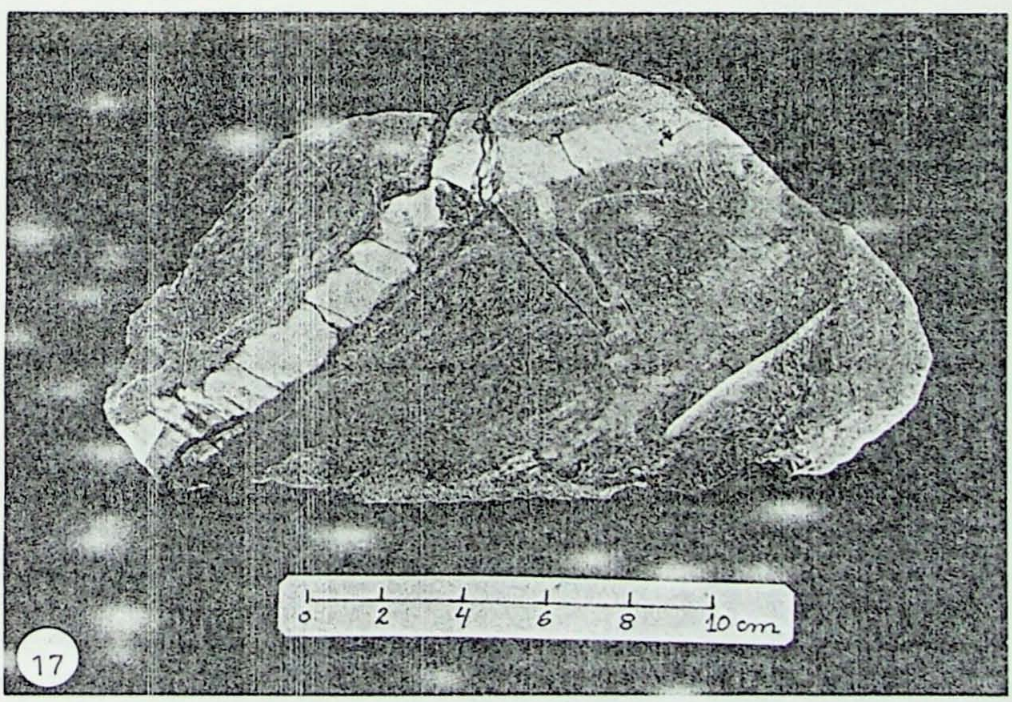
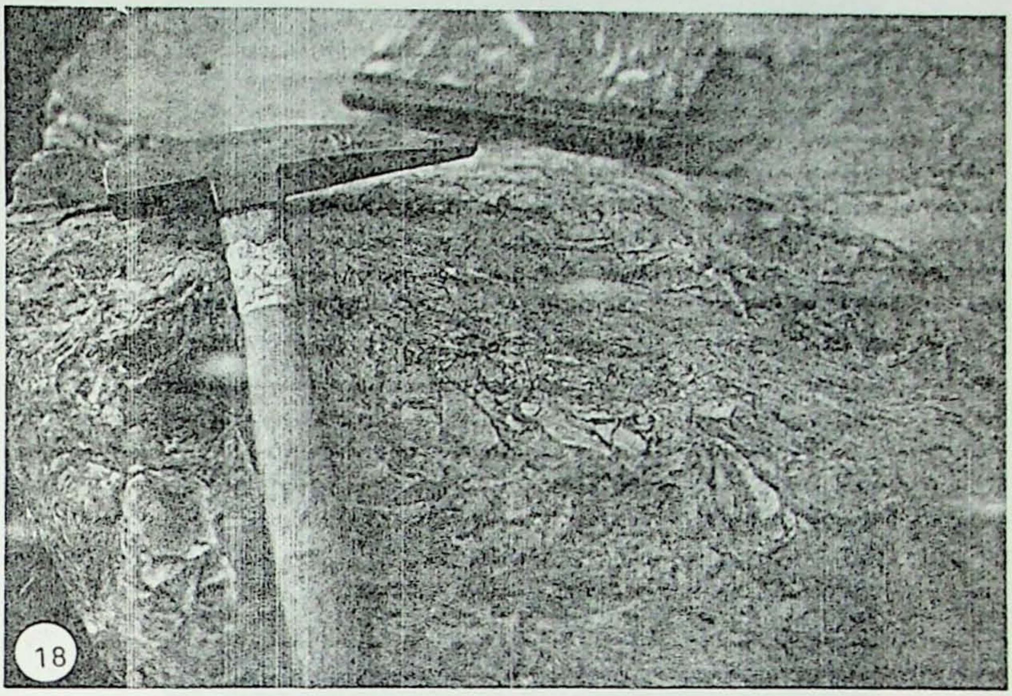
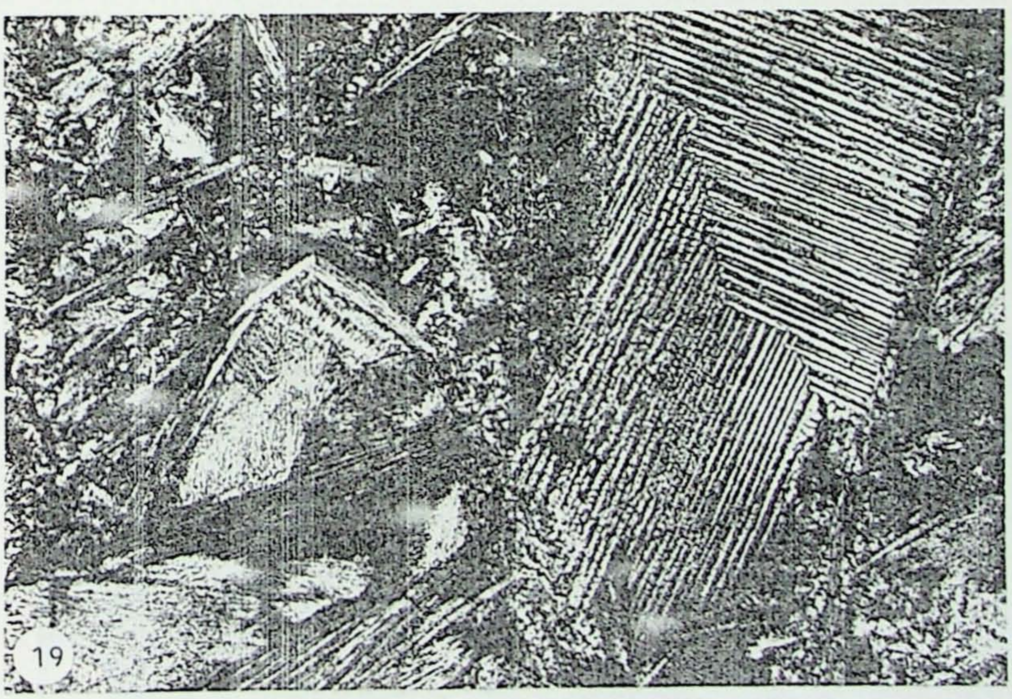


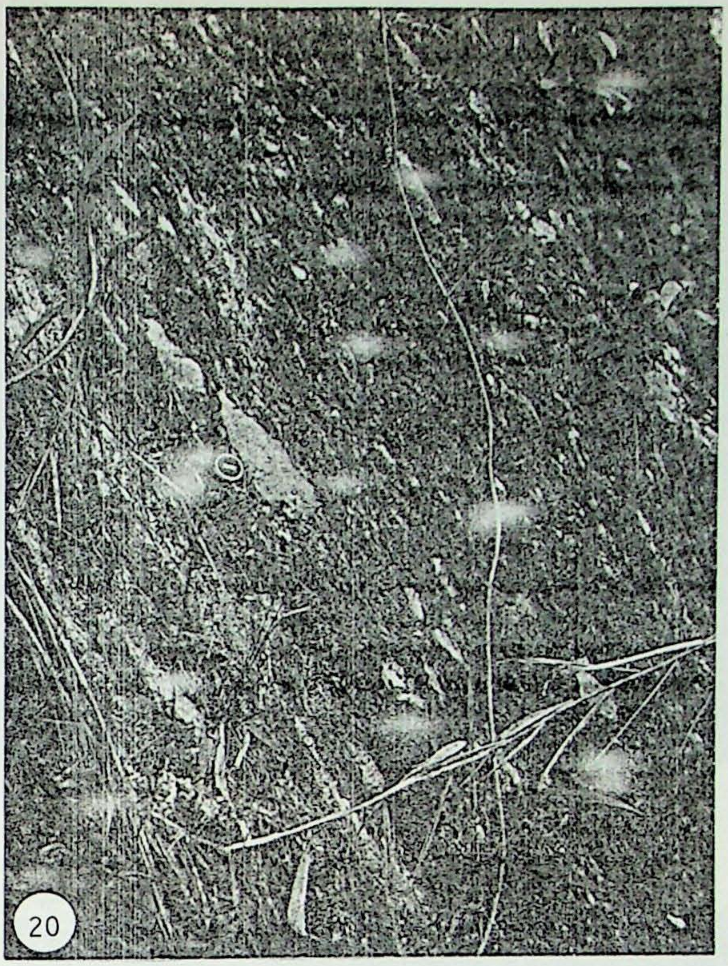
FIG. 15 – GEOLOGY OF THE SANTA BARBARA REGION

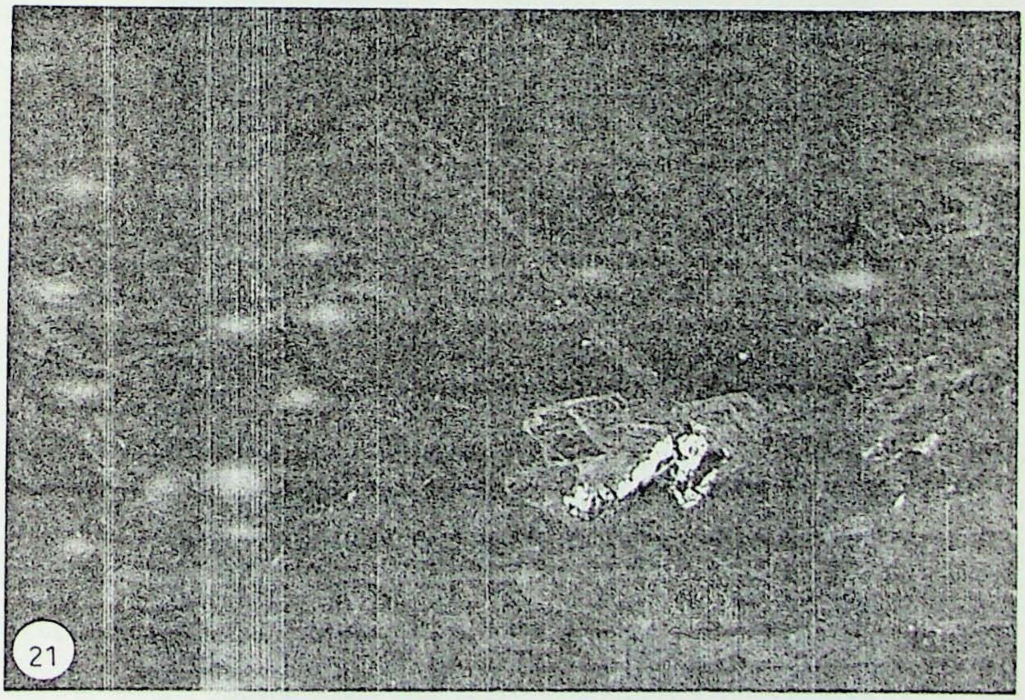

16

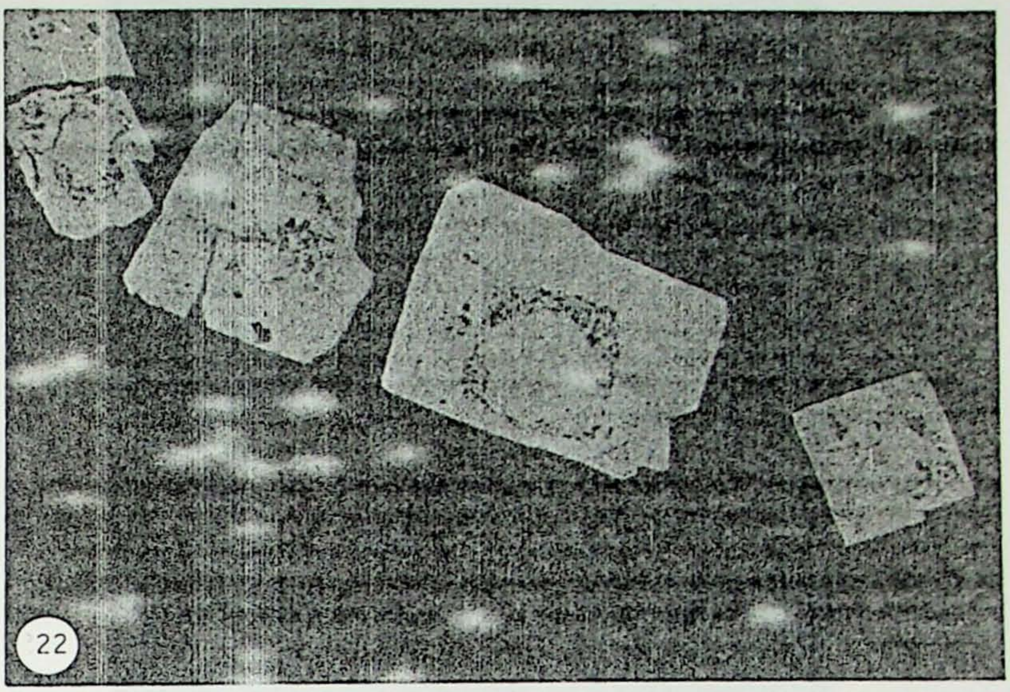

0
2
4
6
8
10 cm
17

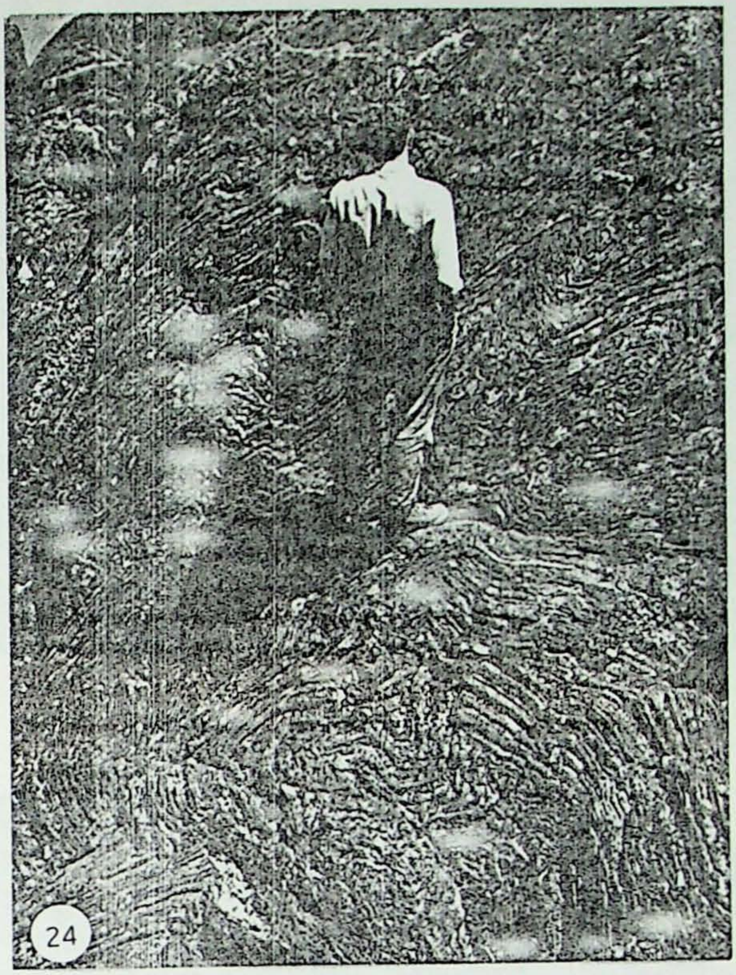

18


19

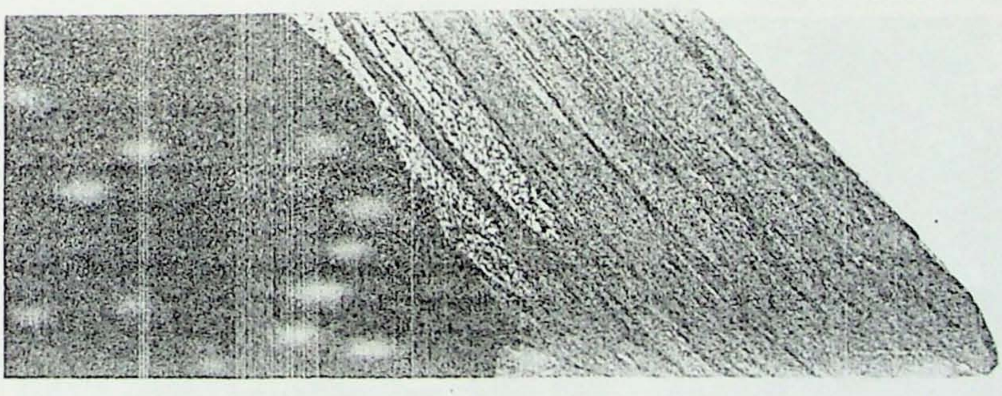




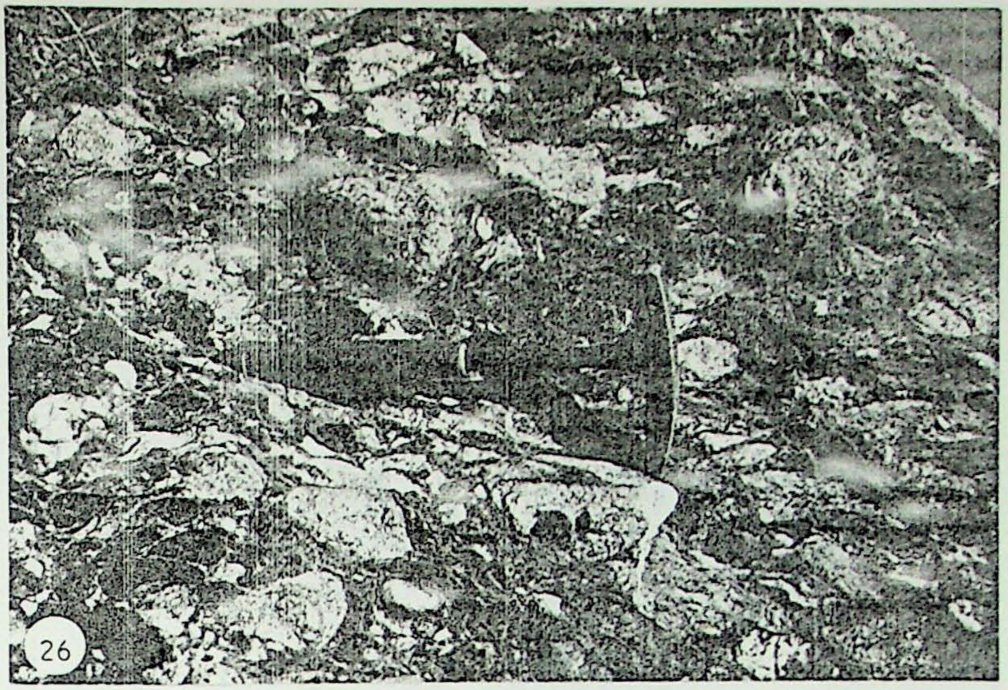


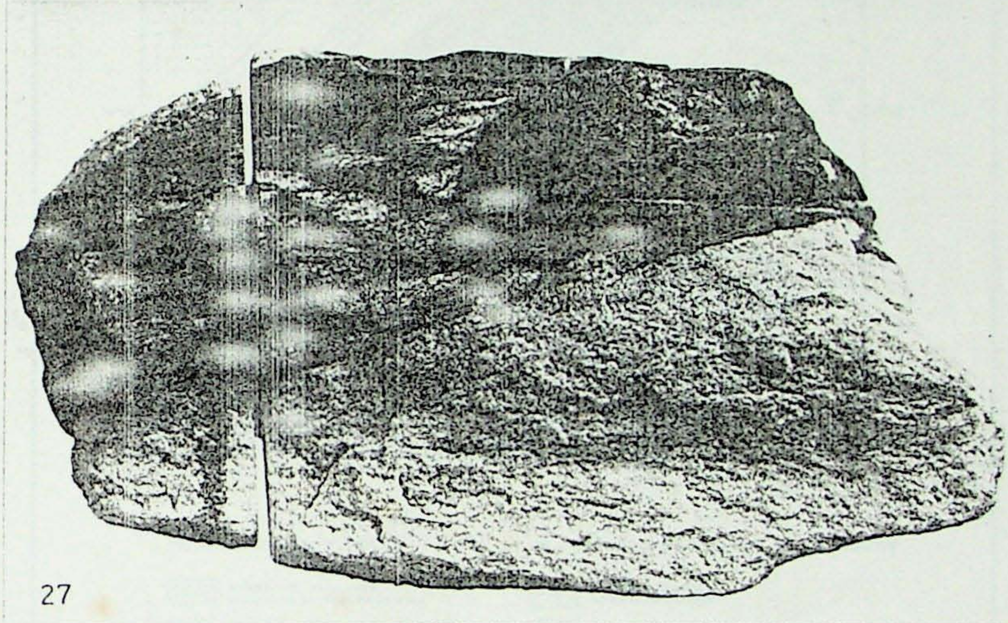


24



25





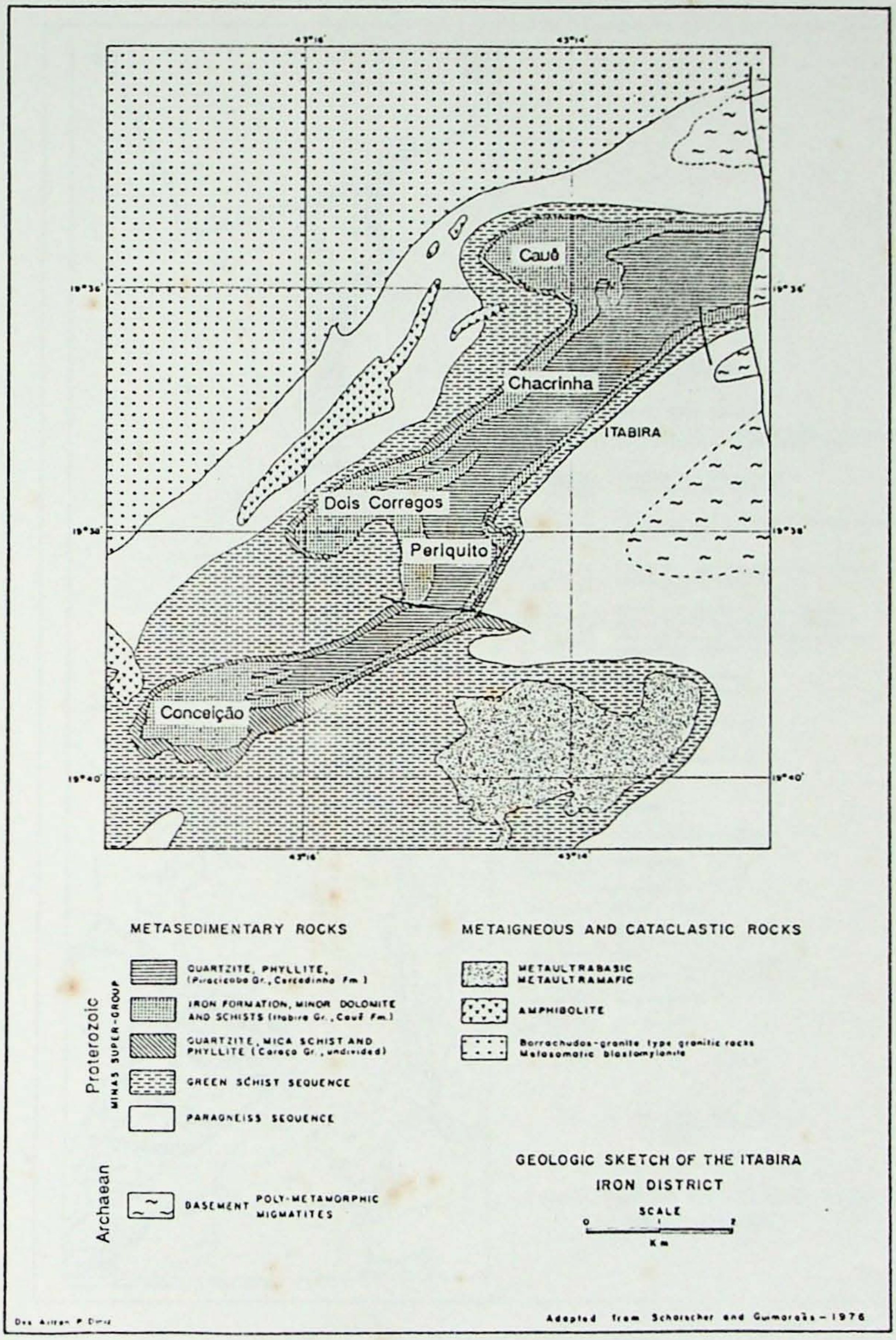


FIG. 29 – Geologic sketch map of the Itabira Iron-Ore District.

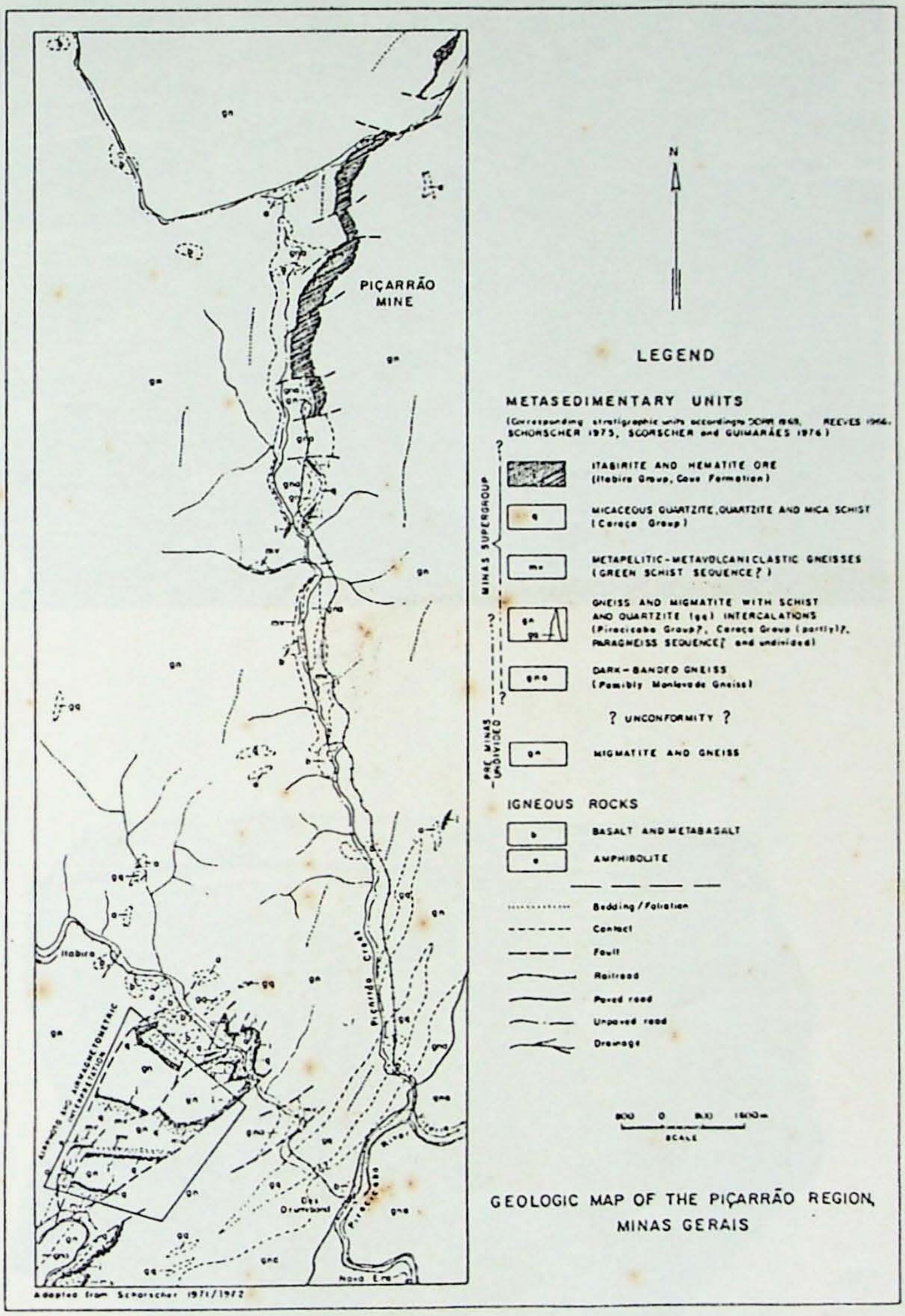
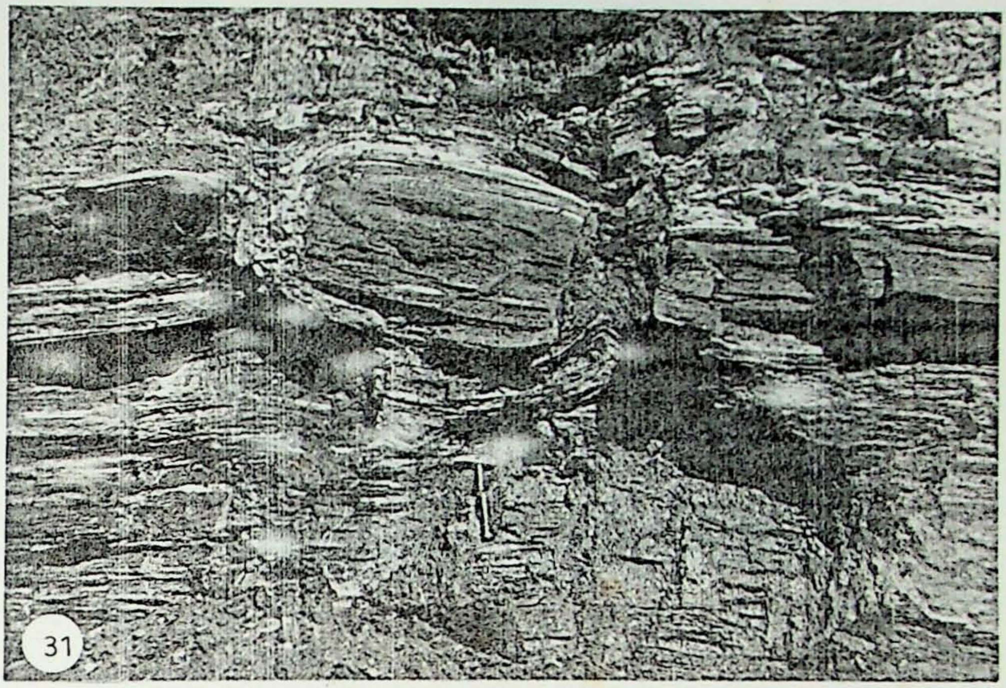
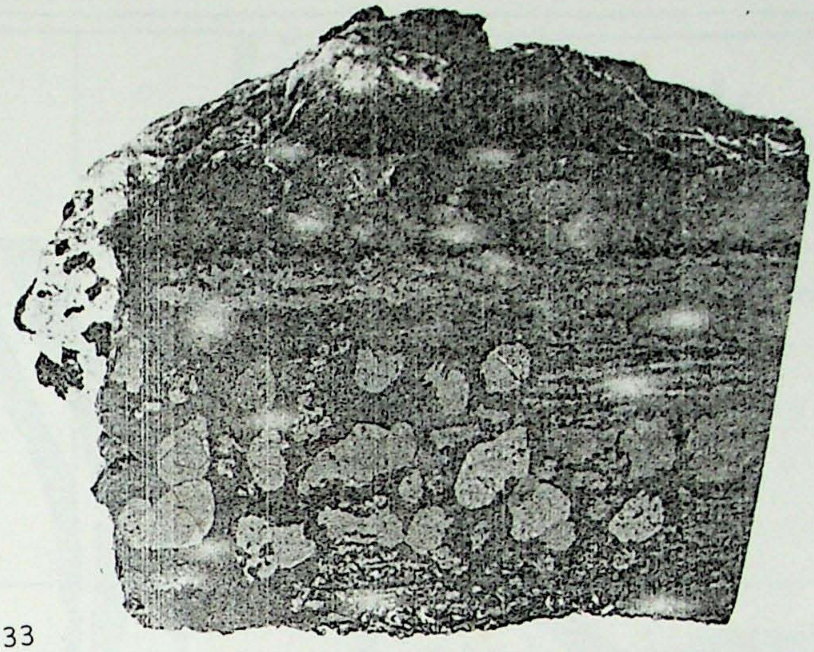


FIG. 30 – Geologic map of the Piçarrão Region.


31


32



33

34

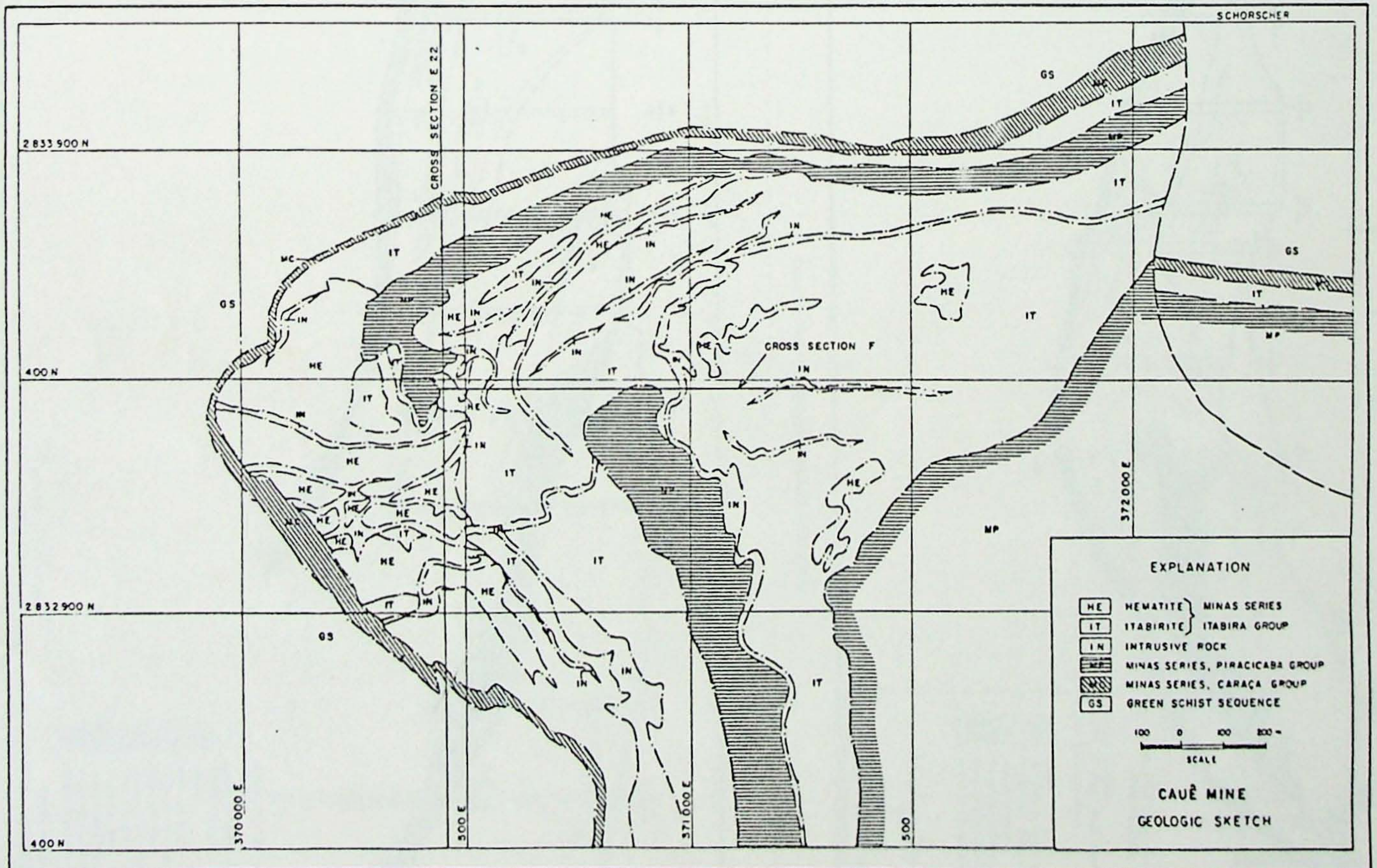


FIG. 35 – Geologic sketch of Cauê Mine.

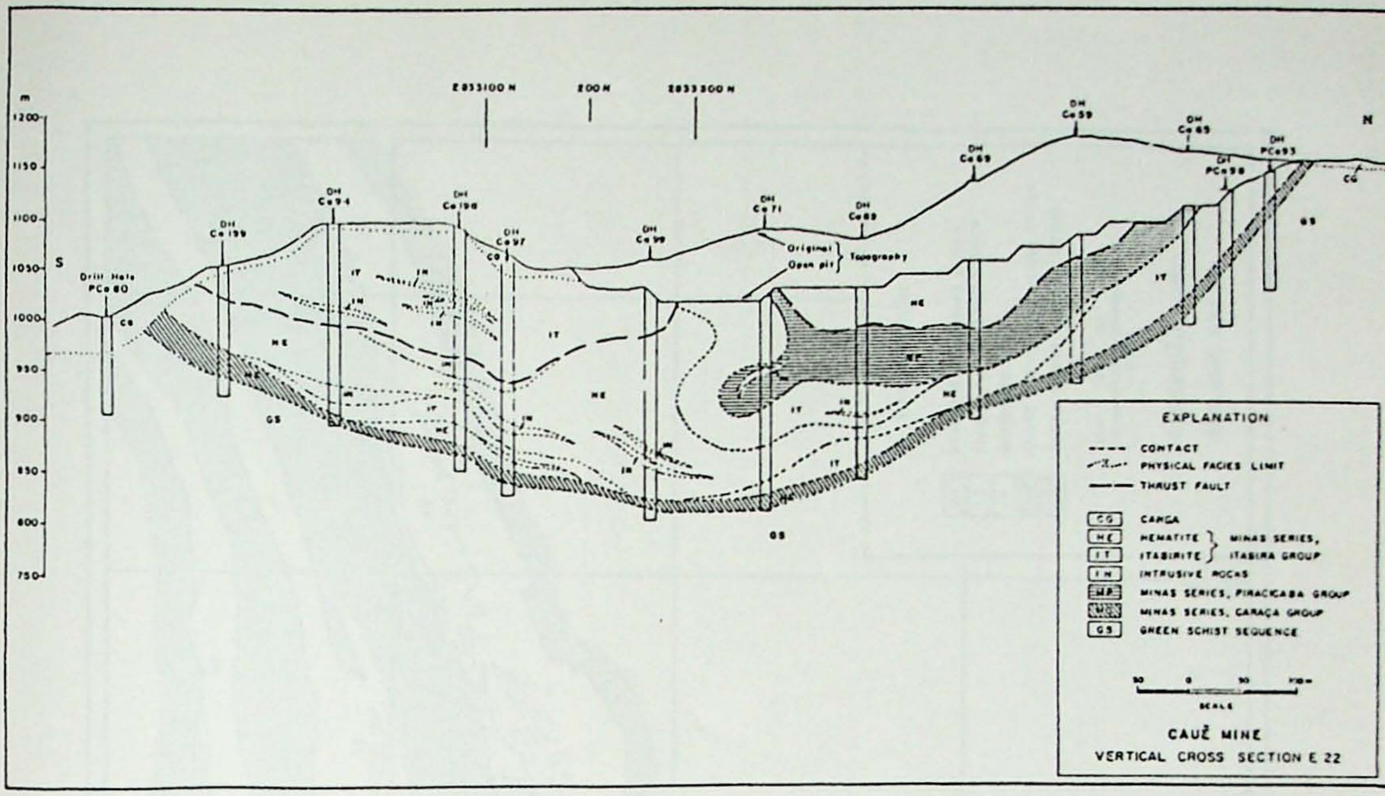


FIG. 36 – Vertical (transversal) Cross Section of Cauê Mine.

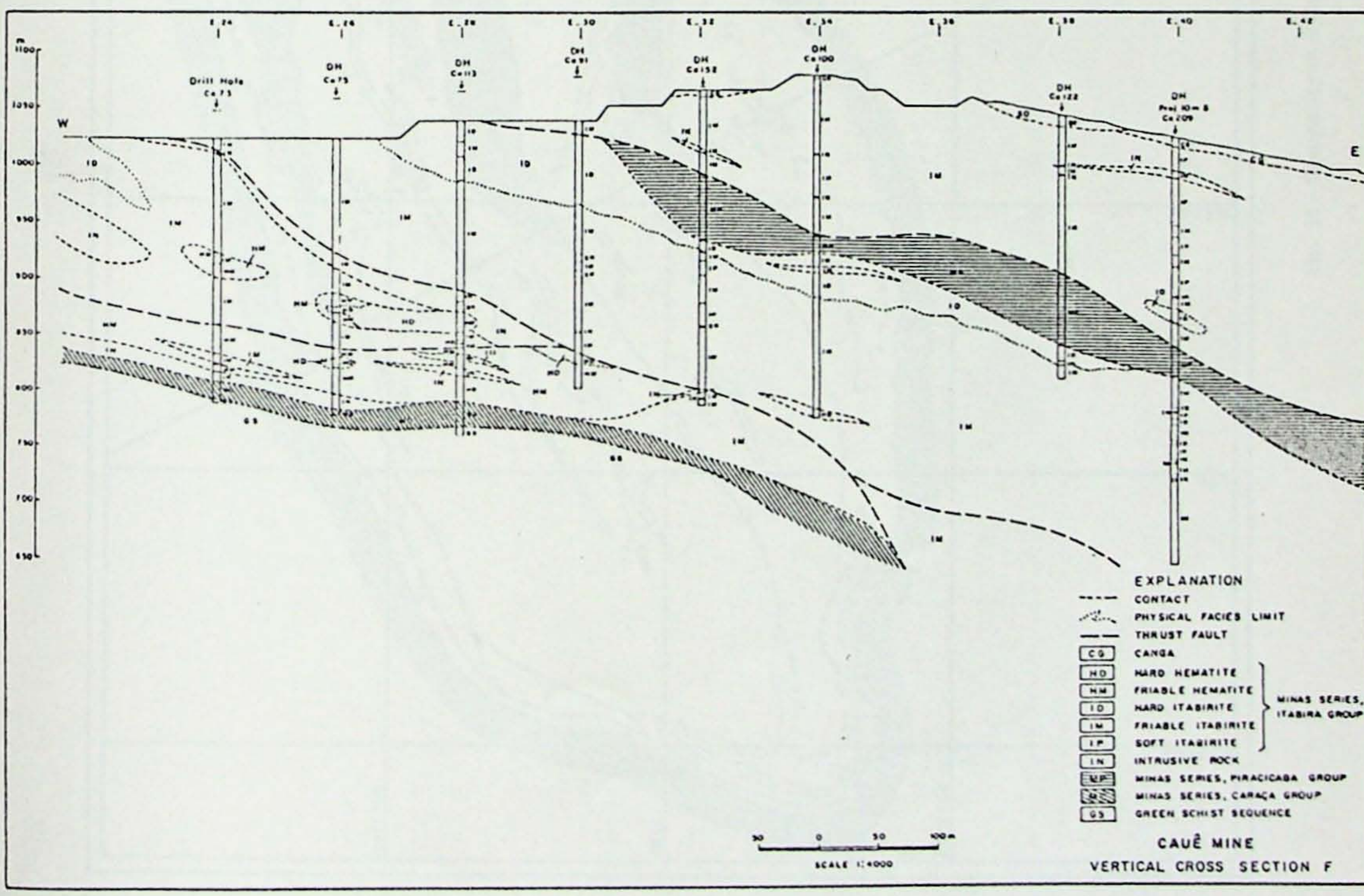


FIG. 37 – Vertical (longitudinal) Cross Section of Cauê Mine.

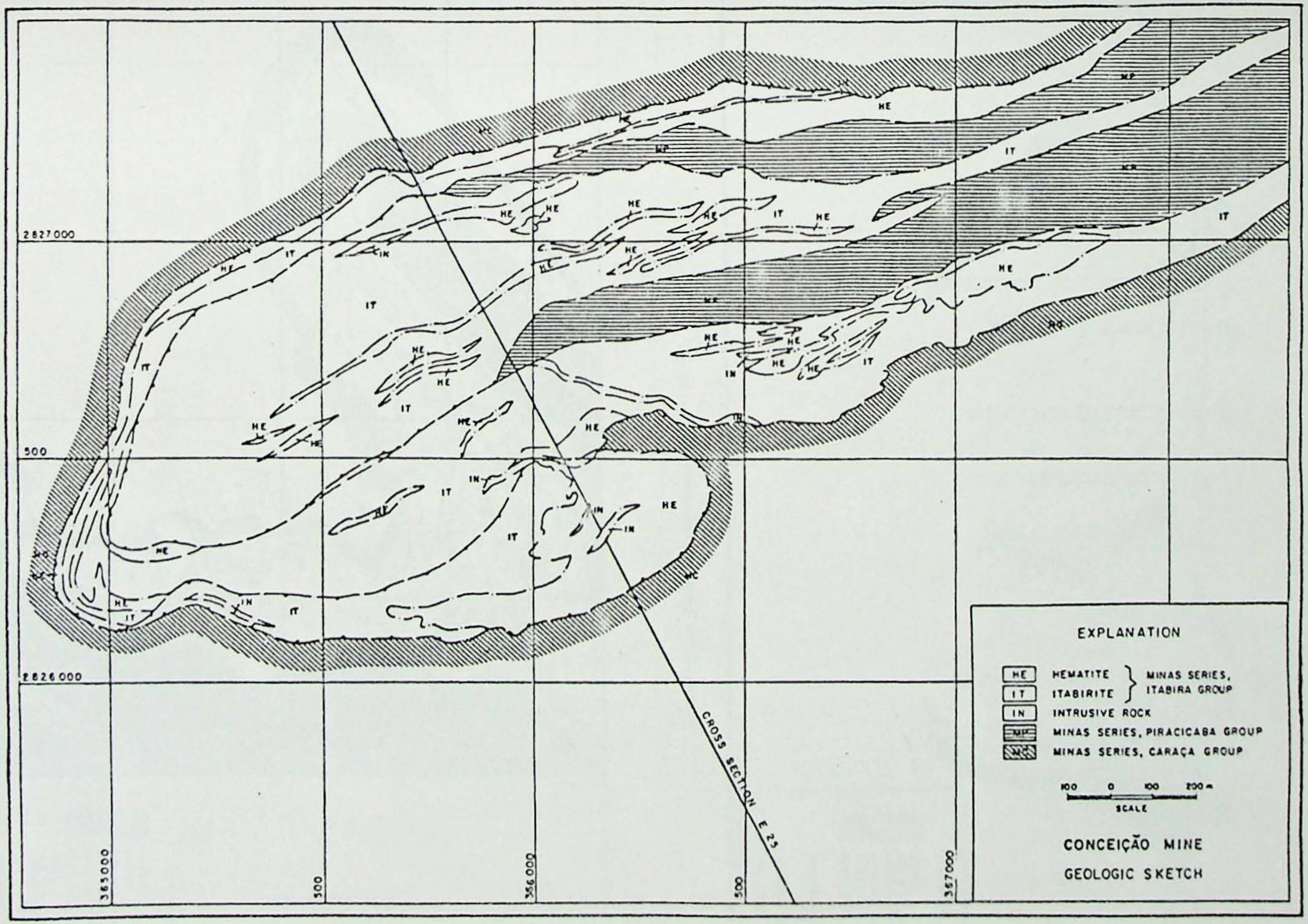


FIG. 38 – Geologic Sketch of Conceição Mine.

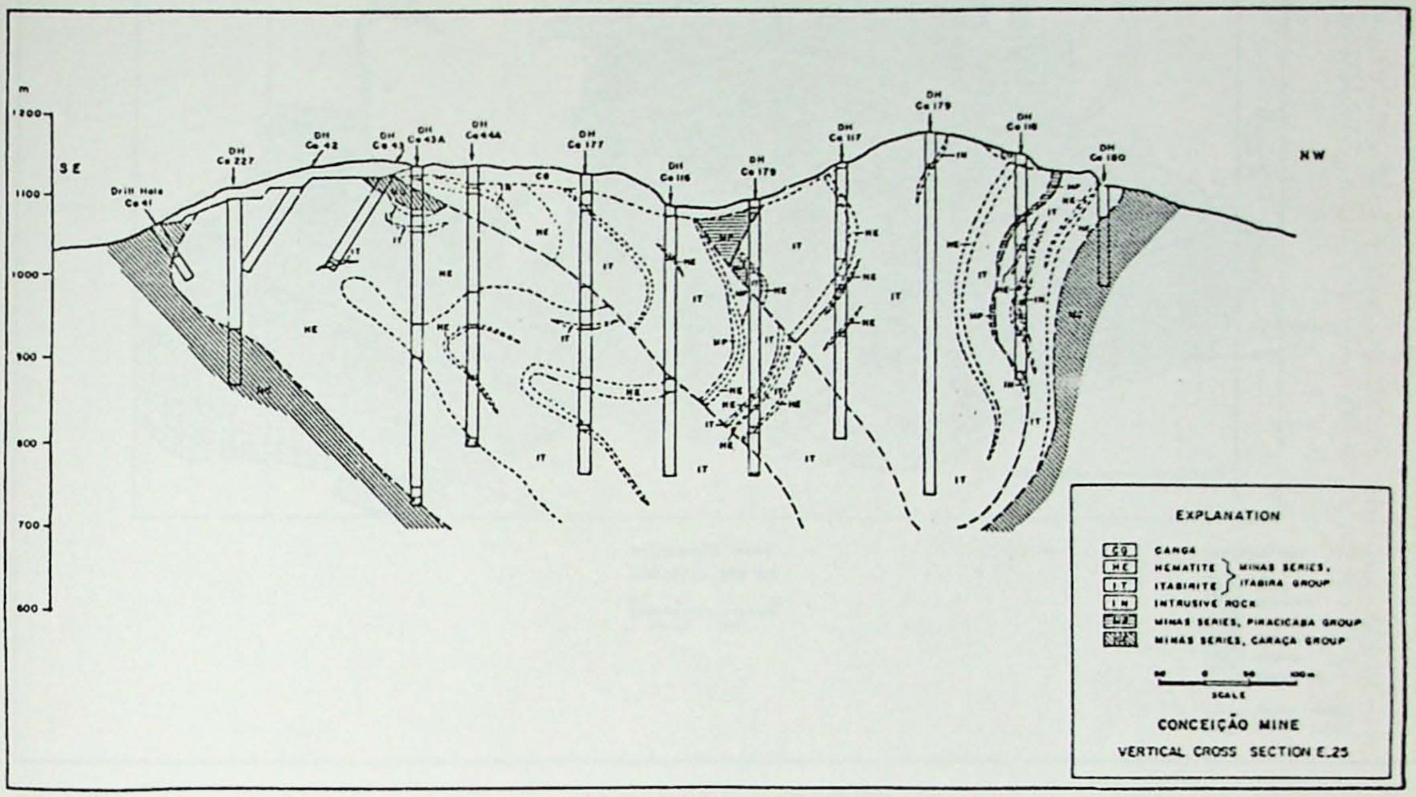


FIG. 39 – Vertical (transversal) Cross Section of Conceição Mine.

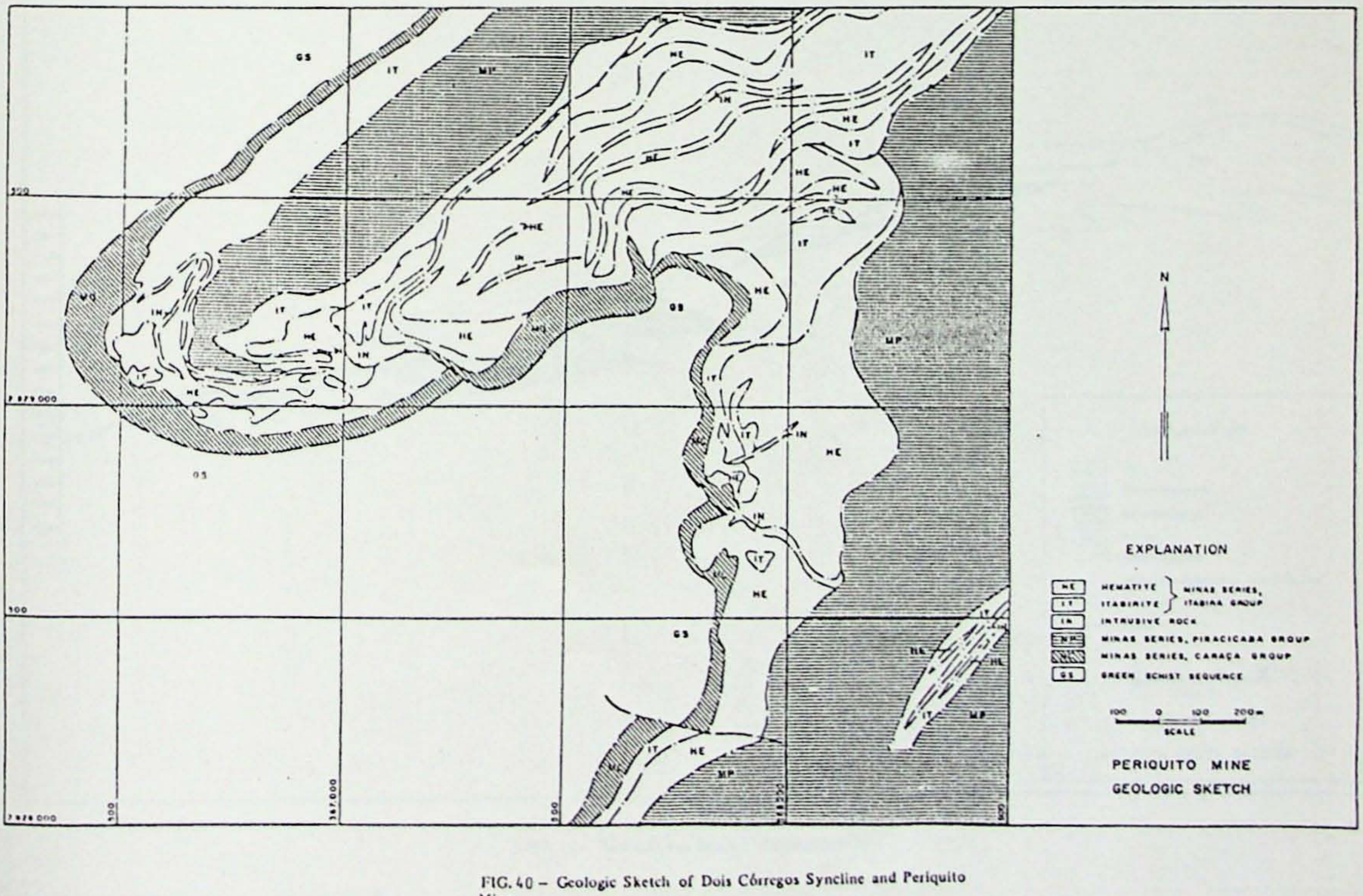


FIG. 40 – Geologic Sketch of Dois Córregos Syncline and Periquito Mine.

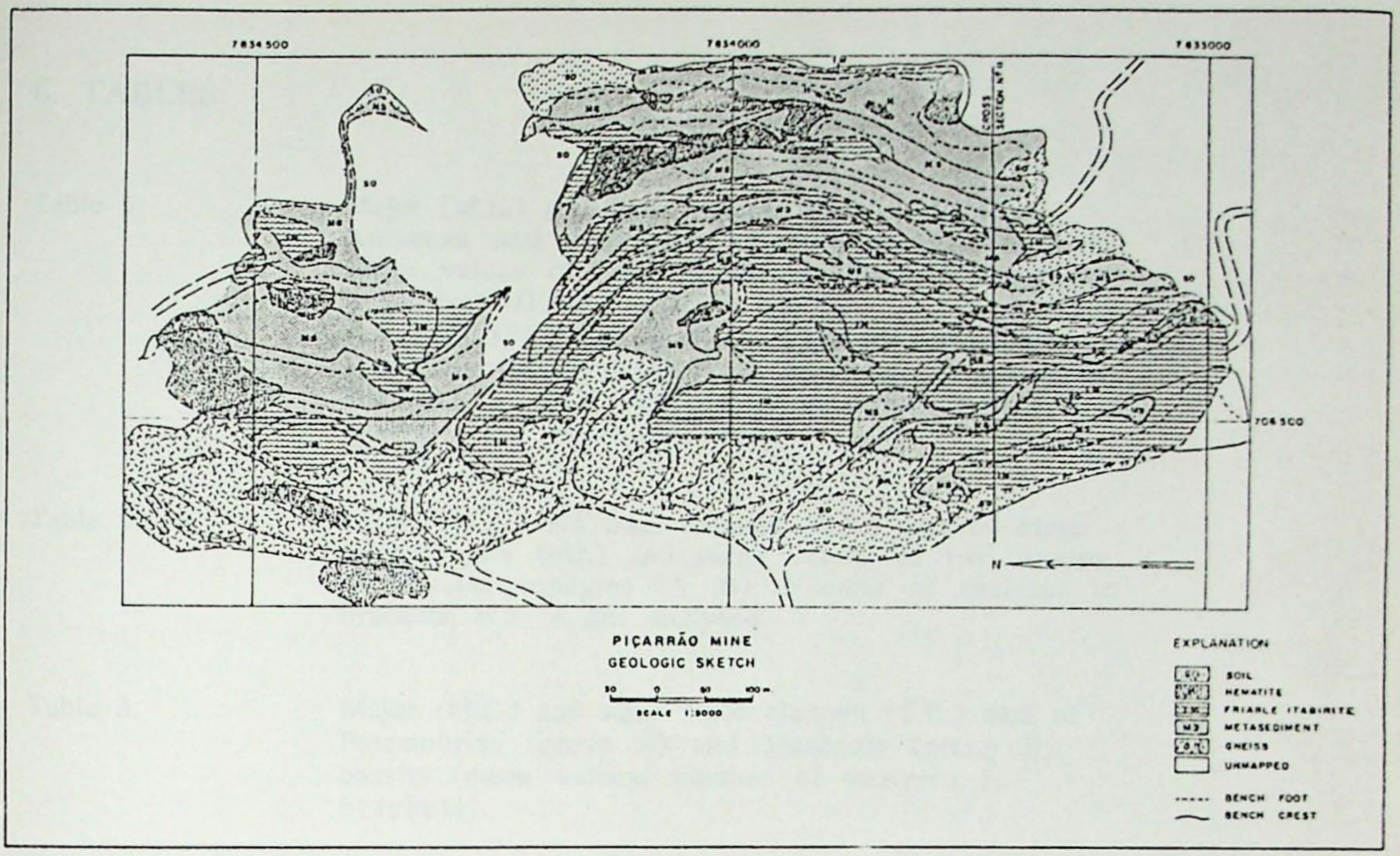


FIG. 41 – Geologic Sketch of Piçarrão Mine.

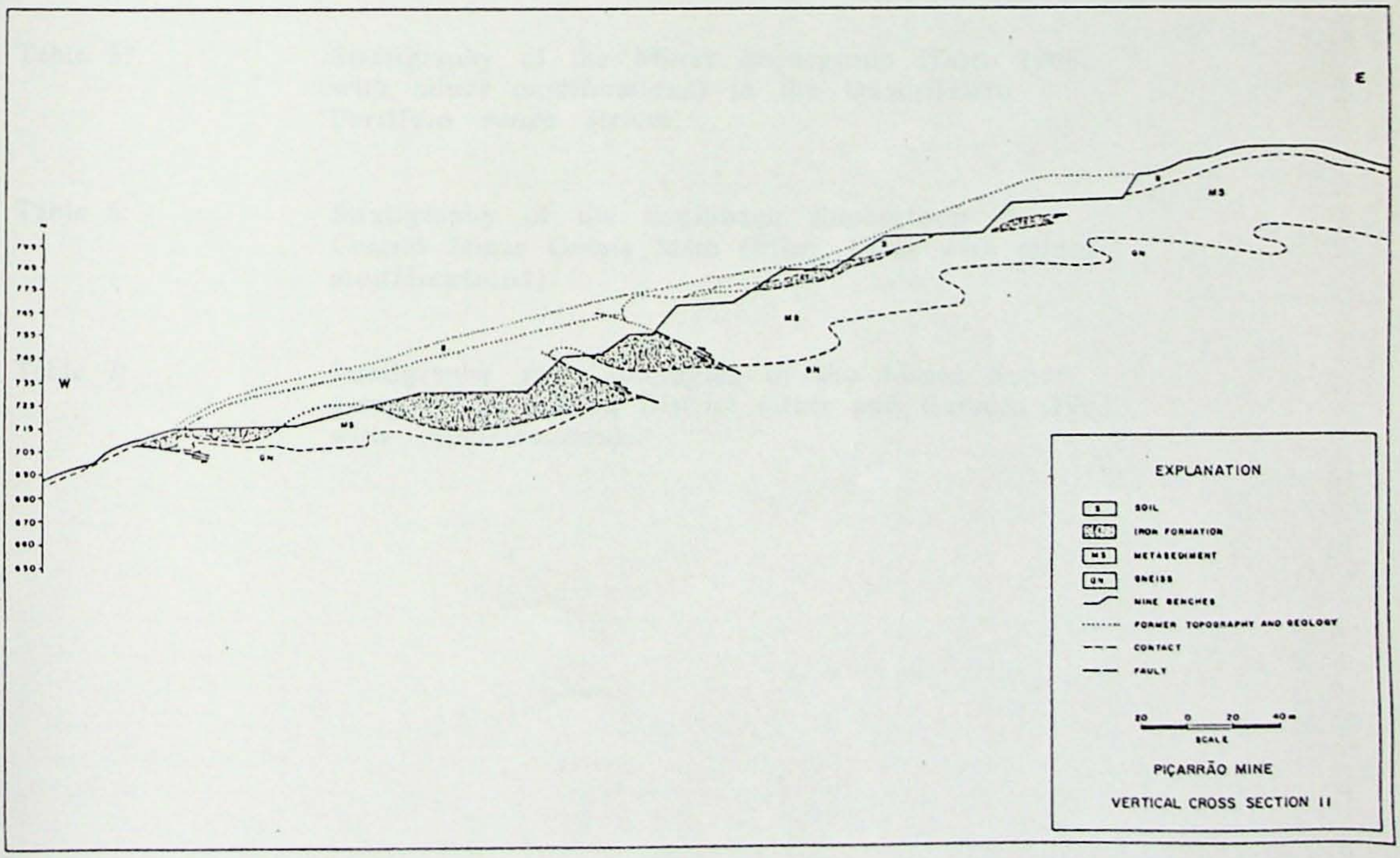


FIG. 42 – Vertical Cross Section of Piçarrão Mine.

6. TABLES

Table 1:	Major (M.E.) and trace element (T.E.) data of Archaean and Proterozoic granitic rocks s.l.. Mean values of rock groups, established according to the Na_2O/K_2O ratios (in wt.-%): A > 1,50; 0,75 <B <1,50; C <0,75 and for Borrachudos granitoids (B.G.). Number of analyses per group in brackets; * - for Li and Cs are mean values of 8 analyses; n.a. = not analysed.
Table 2:	Major (M.E.) and trace element (T.E.) data of Metajacupirangite (MJ.) and mean values of two groups of Metalamprophyres (A, B). Number of analyses in brackets; n.a. = not analysed.
Table 3:	Major (M.E.) and some trace element (T.E.) data of Precambrian (group A) and Mesozoic (group B) basalts (mean values, number of analyses in brackets).
Table 4:	Stratigraphy and depositional environments of the Rio das Velhas Supergroup (Dorr 1969, with modifications).
Table 5:	Stratigraphy of the Minas Supergroup (Dorr 1969, with minor modifications) in the Quadrilátero Ferrífero sensu strictu.
Table 6:	Stratigraphy of the Espinhaço Supergroup in Central Minas Gerais State (Pflug 1968, with minor modifications).
Table 7:	Stratigraphy and Lithologies of the Minas Supergroup in the Itabira District (Dorr and Barbosa 1963, with modifications).

Table 1: Major (M.E.) and trace element (T.E.) data of Archaean and Proterozoic granitic rocks s.l.. Mean values of rock groups, established according to the Na_2O/K_2O ratios (in wt.%): A >1,50; 0,75 < B < 1,50; C < 0,75 and for Borrachudos granitoids (B.G.). Number of analyses per group in brackets(..); * = for Li and Cs are mean values of 8 analyses; n.a. = not analysed.

M.E. (wt.-%)	A (39) Na_2O/K_2O > 1,50	B (43) Na_2O/K_2O 1,50-0,75	C (15) Na_2O/K_2O ≤ 0,75	BG (46)
SiO_2	72,08	71,99	71,71	75,04
TiO_2	0,34	0,28	0,32	0,18
Al_2O_3	15,67	14,20	13,86	12,30
Fe_2O_3 Tot.	2,52	1,48	2,61	2,27
MnO	0,04	0,03	0,04	0,03
MgO	0,87	0,68	0,74	0,12
CaO	2,35	1,34	0,92	0,31
Na_2O	4,88	3,89	3,00	3,27
K_2O	2,13	3,92	5,22	5,23
F	0,09	0,05	0,09	0,16

T.E.(ppm)	A (39)	B (43)	C (15)	BG (46)
Ba	499	827	790	346
Rb	96	161	241	297
Sr	394	256	155	42,6
Pb	24,3	36,2	38	48,3
Th	9,1	23,5	33,1	44,1
U	2,7	7,6	8,3	5,0
Nb	13,9	16,3	18,7	66,4
La	34,3	46,6	49,5	214
Ce	68,3	64,2	97	278
Y	23,7	35	31	156
Zr	154,4	160,5	183	424
V	43,5	30,5	28,7	8,1
Cr	10,6	10,3	13,3	<5
Ni	22,3	15,5	9,9	5,4
Co	60,5	62	48	66,3
Cu	11,3	9,9	7,2	9,2
Li	37 *	41,4 *	25 *	13,7 *
Cs	n.a.	n.a.	n.a.	2,0 *

Ratios				
Na_2O/K_2O	2,29	0,99	0,57	0,62
K/Rb	184	202	180	146
K/Ba	35	39	55	125
K/Sr	45	127	280	1019
Rb/Sr	0,24	0,63	1,55	6,97

Table 2: Major (M.E.) and trace element (T.E.) data of Metajacupirangite (MJ.) and mean values of two groups of Metalamprophyres (A, B). Number of analyses in brackets; n.a. = not analysed.

M.E. (wt.-%)	MJ.	Metalamprophyres A (3)	Metalamprophyres B (5)
SiO_2	46,97	48,07	51,39
TiO_2	3,74	3,22	2,19
Al_2O_3	4,70	12,89	12,61
Fe_2O_3 tot.	16,52	14,83	12,41
MnO	1,32	0,21	0,20
MgO	0,82	4,41	5,00
CaO	21,17	9,31	7,15
Na_2O	0,49	0,10	0,92
K_2O	1,46	3,64	4,79
P_2O_5	1,95	0,43	0,24
CO_2	0,79	n.a.	n.a.
SO_3	n.a.	0,10	0,00
L.o.i.	1,85	2,60	2,75

T.E. (ppm)	MJ.	A (3)	B (5)
Ba	1.538	555	202
Rb	38	183	417
Sr	2.500	417	157
Pb	88	26	20
Th	2.100	n.a.	n.a.
Nb	68	n.a.	n.a.
La	917	n.a.	n.a.
Ce	1.960	n.a.	n.a.
Y	1.300	n.a.	n.a.
Zr	127	n.a.	n.a.
V	n.a.	449	368
Cr	30	82	141
Ni	15	n.a.	n.a.
Co	n.a.	101	106
Cu	3	101	20
Zn	255	146	186
Ag	8	n.a.	n.a.

Table 3: Major (M.E.) and some trace element (T.E.) data of Precambrian (Group A) and Mesozoic (Group B) basalts (mean values - number of analyses in brackets).

M.E. (wt.-%)	A (7)	B (11)
SiO_2	48,57	49,11
TiO_2	1,89	3,49
Al_2O_3	11,69	13,65
Fe_2O_3 tot.	15,04	15,16
MnO	0,22	0,20
CaO	10,21	8,21
MgO	9,20	4,56
Na_2O	1,94	2,39
K_2O	0,47	1,81
P_2O_5	0,36	0,56
SO_3	0,00	0,02

T.E. (ppm)	A (7)	B (11)
Ba	230	748
Sr	376	579
Rb	17	56
Pb	6	14
Zn	107	152
Cu	133	260
Co	114	101
Cr	268	108
V	380	488

Table 4: Stratigraphy and Depositional Environments of the Rio das Velhas Supergroup (Dorr 1969, with modifications).

S.Gr.	Gr.	Fm.	Lithology	Thickness (in m)	Depositional Environemnt
RIO DAS VELHAS GREENSTONE BELT	MAQUINÉ	Casa Forte	Quartzites (mica-poor, coarse-grained, detrital pyrite, dm-scaled cross-bedding); Conglomerates (oligo- and polymictic, intraformational in basal part of Fm., quartzitic and phyllitic matrix, detrital sulfides); Phyllites (quartz-chlorite-chloritoid-sericite phyllites, subordinated constituent in basis near part of Fm).	>400	upper epiclastic quartzitic unit of greenstone belt (Similarities with Molasse sequences) shallow water, high energy environment
		Palmital	Phyllites, Protoquartzite, Graywacke, Subgraywacke, minor Basal Conglomerate (Fm. is absent in the Eastern Q.F.)	varying: from absent to >1000	transitional from volcano-sedimentary to epiclastic (towards top)
			Erosional, locally angular Unconformity		
	NOVA LIMA	undivided	Mafic, largely chloritic schists and Graywacke; pelitic schists; tilloid Conglomerate; minor Quartzite; Carbonate-, sulfide-, silicate- and oxide (magnetite-)facies Bif's; Dolomite; Metavolcanics, predominantly mafic to intermediate, lesser felsic and ultramafic; important Au-Deposits.	>4.000	middle, mainly mafic volcanosedimentary unit of greenstone belt (Similarities with Flysch sequences)
			Normal Gradational Contact		
	QUEBRA OSSO	undivided	Ultramafic Volcanics and Volcaniclastics (massive, spinifex, pillow and brecciated lavas, ultramafic tuffs, tuffites and agglomerates) with Secondary Alterations (serpentinisation, chloritisation, tourmalinisation, magnetitisation, carbonatisation, talcification), and intercalated Metasediments (metacherts grading into Fe-poor bif's).	varying from absent to >650	lower, ultramafic volcanic unit of greenstone belt environment of subaquatic magmatism with minor chemical sedimentation without terrigenous influences
Basal Contacts and Basement unknown. Contacts with surrounding Gneisses, Migmatites and Granitoids are Tectonic.					

TABLE 5
STRATIGRAPHY OF THE MINAS SUPERGROUP (DORR 1969, WITH MINOR MODIFICATIONS) IN THE QUADRILÁTERO FERRÍFERO SENSU STRICTU

SUPERGROUP	GROUP	FORMATION	LITHOLOGY	SEDIMENTARY ENVIRONMENT	APROX. MAX. THICKNESS (m)
MINAS	ITACOLOMI	UNDIVIDED	Type Area: Orthoquartzite, Protoquártzite, Conglomerate, Grit.	Paralic	2,000 ?
			Santo Antônio Facies: Protoquartzite, Phyllite, Phyllitic Quartzite, Conglomerate	Molasse ?	1,000 ?
			ANGULAR (?) AND EROSIONAL UNCONFORMITY		
	PIRACICABA	SABARÁ	Chlorite Schist and Phyllite, Metatuff Graywacke, tilloid conglomerate, Quartzite, Minor Iron-Formation	Eugeosynclinal Flysch	> 3,000
			LOCALLY PROFOUND EROSIONAL AND MINOR ANGULAR UNCONFORMITY		
		BARREIRO	Phyllite and Graphitic Phyllite	Stable Shelf (Blanket)	150
		TABÕES	Orthoquartzite	Stable Shelf (Blanket)	125
		FECHO DO FUNIL	Quartzitic Phyllite Dolomitic Phyllite Siliceous Dolomite	Stable Shelf (Blanket)	410
		CERCADINHO	Ferruginous Quartzite, Quartzite, Grit Phyllite, Ferruginous Phyllite, Minor Conglomerate and Dolomite	Stable Shelf (Blanket)	600
			LOCAL EROSIONAL UNCONFORMITY		
	ITABIRA	GANDARELA	Dolomite and Minor Limestone, Dolomitic Itabirite, Itabirite, Dolomitic Phyllite, Tuffogenous Greenschist	Stable Shelf (Blanket)	600
		CAUÊ	Itabirite (Oxide-facies Iron-Formation), Dolomitic Itabirite, Minor Phyllite, Dolomite Tuffogenous Greenschist and Metachert	Stable Shelf (Blanket)	> 350
	CARAÇA	BATATAL	Phyllite, Graphitic Phyllite, Minor Metachert and Oxide-Facies Iron-Formation	Stable Shelf (Blanket)	250
		MOEDA	Paralic Facies: Orthoquartzite, Conglomerate, Grit, Phyllite Blanket Facies: Sericitic Quartzite, Quartzose Phyllite, Protoquartzite	Stable Shelf	1,000 Respect. 150

TABLE 6
STRATIGRAPHY OF THE ESPINHAÇO
SUPERGROUP IN CENTRAL MINAS GERAIS STATE

SUPER GROUP	FORMATION	LITHOLOGY	APROX. THICKNESS (m)	ENVIRONMENT	
SÃO FRANCISCO	RIO PARDO GRANDE	Phyllites, in portions rich in Fe and Mn, Quartzite and Dolomite in individual Layers	> 900	MOLASSE ?	
ESPINHAÇO	CÓRREGO PEREIRA	Orthoquartzite Minor Micaquartzite	750		MIOGEOSYNCLINAL SEDIMENTS
	CÓRREGO DA BANDEIRA	Phyllite, Siltite, Minor Quartzite Layers (Lithologic interpretation Mostly Based on Air-Photographs)	170		
	CÓRREGO DOS BORGES	Orthoquartzite, Minor Micaquartzite, Local Intraformational Breccias	250		
	SANTA RITA	Phyllite, Siltite	250		
	GALHO DO MIGUEL	Orthoquartzite, in Minor Portions Conglomeratic, Characteristic Megaripple - Stratification, Rare Phyllite	2,400		
	SOPA BRUMADINHO	Quartzite, Micaquartzite, Phyllite Extensive Lenses of Diamond-Bearing Intraformational Conglomerates, Breccia. Characteristics Itabirite Pebbles Hematite – Phyllite	200	COASTAL DEPOSITS	
	SÃO JOÃO DA CHAPADA	Orthoquartzite, in Minor Portions Conglomeratic Rare Phyllite	200		
	GREENSCHIST SEQUENCE	Greenschists from Basic to Intermediate Volcanics and Volcaniclastics, Minor Acid Metavolcanics and Quartz – Sericite Schist and Phyllite	180 to Absent	RIFT DEPOSITS	

Table 7: Stratigraphy and Lithologies of the Minas Supergroup in the Itabira District (Dorr and Barbosa 1963, with modifications).

S Gr.	G r.	F m.	Lithology	Thickness (in m)
MINAS SUPERGROUP	PIRACICABA	Cercadinho	Quartzite, Phyllite, minor Conglomerate, ferruginous Metachert, minor Itabirite	variable due to tectonics and erosion from <10 to >150
	ITABIRA	Cauê	Itabirite, Hematite, minor Dolomite and Phyllite, Metachert. Intraformational reworking and tectonically intercalated metaultramafics ("intrusives").	variable due to tectonics from <20 to >600
	CARRAÇA	undiv.	Quartzite, Phyllite, muscovite-quartz Schists	variable, from <10 to >100
	GREENSCHIST SEQUENCE	undivided	Graphitic Schists and Phyllites, carbonatic Greenschists, mafic Metatuff and Metatuffite, micaceous Metarenites	uncertain, estimated >500
	PARAGNEISS SEQUENCE	undivided	Metarkose, Metagraywacke, minor intercalations of Mica-quartzite, quartz-mica-Schists, Metapelites and Calc-silicate rocks	uncertain, estimated >800
MAJOR UNCONFORMITY				
Archaean polymetamorphic Gneisses, Migmatites and Granitoids				

7. REFERENCES

ALMEIDA, F.F.M. (1977): O Craton de São Francisco. - Revista Bras. Geoci., 7, 349-363.

ALMEIDA, F.F.M., HASUI, Y. and BRITO NEVES, B.B. de (1976): The Upper Precambrian of South America. - Bol. Inst. Geoci., 16(7), 45-80, São Paulo.

ANDRADE, RAMOS, J.R. and FRAENKEL, M.O. (1974): Uranium occurrences in Brazil (IAEA-SM-183/24).-637-657, in: "Formation o Uranium Ore Deposits", Proc. Symp. Athens 1974, IAEA, Vienna.

BARBOSA, O. (1949): Contribuição à geologia do centro de Minas Gerais. - Mineração e Metalurgia, 14(79), 3-19.

BARBOSA, O. (1954): Evolution du Géosynclinal Espinhaço. - 19th Inter. Geol. Cong., Sec. XIII, part 2, fasc. XIV, 117-36, Alger.

BELEZKIJ, V. and GUIMARÃES, D. (1959): Sobre uma ocorrência singular de platina, e geologia da parte central da Serra do Cipó. Notas à margem de "O paládio e a platina no Brasil", de E. Hussak. - D.N.P.M. Div. Fom. Prod. Miner., Bol. 106, 102 p.

BIONDI, J.C. (1979): Correção quantitativa dos efeitos de metassomatismo em rochas vulcanicas básicas. Exemplo dos metabasitos do Espinhaço meridional (MG.-Brasil). - Rev. Bras. Geoc. 9, 89-115.

BRAUN, E. and SCHORSCHER, H.D. (1977): Bildung und Kristallisation regionalmetamorpher Partialschmelzen in präkambrischen pelitischen Gneisen aus Minas Gerais/Brasilien. - Fortschr. Miner. 55, Beiheft 1, (I-II), 18-19.

BRITO NEVES, B.B. de, KAWASHITA, K. and DELHAL, J. (1979): A evolução geochronológica da cordilheira do Espinhaço: dados novos e integração. - Rev. Bras. Geoc. 9(1), 71-85.

CORDANI, U.G., KAWASHITA, K., MÜLLER, G., QUADE, H., REIMER, V. and ROESER, H. (1980): Interpretação tectônica e petrológica de dados geocronológocos do embasamento no bordo sudeste do Quadrilátero Ferrífero, MG.. - Anais Acad. Bras. Ciênc. 52(4), 785-799.

DAVINO, A. (1974): Estudos sobre a prospecção magnetométrica das ocorrências de ferro da faixa Nova Era - Itamarandiba, Minas Gerais. - Bol. Inst. Geoci. 5, 1-16, São Paulo.

DELHAL, J. and DEMAIFFE, D. (1985): U-Pb Archaean geochronology of the São Francisco Craton (Eastern Brazil). - Rev. Bras. Geoc. 15(1), 55-60.

DERBY, O.A. (1881a): Contribuição para o estudo da geologia do vale do Rio São Francisco. - Arch. Mus. Nac. Rio de Janeiro 4, 87-119.

DERBY, O.A. (1881b): Observações sobre algumas rochas diamantíferas da província de Minas Gerais. - Arch. Mus. Nac. Rio de Janeiro 4, 121-132.

DERBY, O.A. (1884): Physical Geography and Geology of Brazil. - The Rio New, 5th., 15th., and 24th. December 1884, translated from: "Brasil Geographico e Historico", Vol. 1, Abreu e Cabral, Rio de Janeiro.

DERBY, O.A. (1906): The Serra do Espinhaço. - J. Geol. 14, 374-401.

DNPM/PROSPEC/CPRM (1975): Unpublished joint document, cited in: Inda, H.A.V. and Barbosa, J.F.: Texto Explicativo para o Mapa Geológico do Estado da Bahia, Escala 1:1.000.000. - 122 p., SME/CPM, Salvador, 1978.

DORR, J.V.N. 2d. (1969): Physiographic, Stratigraphic and Structural Development of the Quadrilátero Ferrífero, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 641-A, 110 p.

DORR, J.V.N. 2d. (1973): Iron-Formation in South America. - Econ. Geol. 68, 1005-1022.
DORR, J.V.N. 2d., GAIR, J.E., POMERENE, J.B. and RYNEARSON, G.A. (1957): Revisão da estratigrafia pré-canbriana do Quadrilátero Ferrífero. - D.N.P.M., Div. Fom. Prod. Min., Av. 81, 31 p.
DORR, J.V.N. 2d. and BARBOSA, A.L.M. de (1963): Geology and ore deposits of the Itabira district, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 341-C, 110 p.
DRAKE, A.A. Jr. and MORGAN, B.A. (1980): Tectonic studies in the Brazilian Shield. - U.S.G.S. Prof. Pap. 1119-B, 1-19.
DRAPER, D. (1920): The high-level diamond bearing deposits of Brazil. - R. Sci. 4(1), 6-11; 4(2), 39-54, Rio de Janeiro.
ESCHWEGE, W.L. v. (1817): Idées générales sur la constitution géologique du Brésil. - Ann. Mines II, 238-240.
ESCHWEGE, W.L. v. (1822): Geognostisches Gemälde von Brasilien und wahrscheinliches Muttergestein der Diamanten. - 44 S., Landes - Industries - Comptoirs, Weimar.
ESCHWEGE, W.L. v. (1832): Beiträge zur Gebirgskunde Brasiliens. - 488 S., Reimer, Berlin.
FREYBERG, B. v. (1932): Ergebnisse geologischer Forschungen in Minas Geraes (Brasilien). - N. Jb. Min. etc., Sonderband 2, 403 p.
FREYBERG, B. v. (1934): Die Bodenschätze des Staates Minas Geraes. - 453 p., Schweizerbart, Stuttgart.
GAIR, J.E. (1958): The Sabará Formation. - Soc. Bras. Geol. Bol. 7(2), 68-69.
GAIR, J.E. (1962): Geology and ore deposits of the Nova Lima and Rio Acima quadrangles, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 341-A, 67 p.
GORLT, G. (1972): Fazieswechsel und Metamorphose in der westlichen Serra Negra (Espinhaço-Zone, Minas Gerais, Brasilien). - Geol. Rdsch. 61, 166-201.
GUERRA, W.J. (1979): Stratigraphie und Sedimentologie des proterozoischen Moeda-Quarzits der Minas-Serie des Eisernen Vierecks, Minas Gerais/Brasilien. - Clausthaler Geowiss. Diss. H.1, 271 S., T.U. Clausthal.
GUILD, P.W. (1957): Geology and mineral resources of the Congonhas district, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 290, 90 p.

GUIMARÃES, D. (1931): Contribuição à geologia do Estado de Minas Geraes. - DNPM. Serv. Geol. Min. Bol. 55, 36 p.
GUIMARÃES, D. (1933): Os amphibolitos da região diamantífera do norte de Minas Geraes. - Acad. Bras. Sci., Ann. 5(4), 237-258.
HARDER, E.C. and CHAMBERLIN, R.T. (1915): The Geology of central Minas Geraes, Brazil. - J. Geol. 23, 341-378 and 385-424.
HARGRAVES, R.B. (1976): Precambrian Geologic History. - Science 193, No. 4251, 363-371.
HÄNNI, A.H. , SCHWARZ, D. and FISCHER, M. (1987): The Emeralds of the Belmont Mine, Minas Gerais, Brazil. - J. Gemm. 20, 7/8, 446-456.

HERZ, N. (1970): Gneissic and igneous rocks of the Quadrilátero Ferrífero, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 641-B, 58 p.
HERZ, N. (1978): Metamorphic rocks of the Quadrilátero Ferrífero, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 641-C, 81 p.
HOEFS, J., MÜLLER, G. and SCHUSTER, A. (1980): Sauerstoff-Isotopen-Thermometrie zur Genese präkambrischer Eisenreicherze des Eisernen Vierecks in Minas Gerais, Brasilien. - Fortschr. Miner. 58, Bh. 1, 55-56.

HOPPE, A. (1978): Beiträge zur Geologie und Paläogeographie der südlichen Serra do Espinhaço (Minas Gerais, Brasilien). - Doctorate thesis, 102 p., unpub., Universität Freiburg i. Br.
HOPPE, A. (1980): Lokale Becken- und Schwellenbildung im Minas-Schelf (Mittleres Präkambrium, Minas Gerais, Brasilien). - Münstersche Forsch. Geol. Paläont., publ. by Geowiss. Lateinamerika Kolloq., Münster.
HOPPE, A. (1980a): Geology and Petrography of the middle Precambrian in the Southern Serra do Espinhaço, Minas Gerais, Brazil. - Precambrian Research 13(2/3), 275-296.
HUSSAK, E. (1906): Ueber das Vorkommen von Palladium und Platin in Brasilien. - Zeitschr. prakt. Geol. 14, 284-293.
INDA, H.A.V., SCHORSCHER, H.D., DARDENNE, M.A., SCHOBBENHAUS, C., HARALY, N.L.E., BRANCO, P.C. de A. and RAMALHO, R. (1984): O Craton do São Francisco e a Faixa de Dobramentos Araçuaí. - Chap. 5 (p. 193-248) in: Geologia do Brasil, coords. Schobbenhaus, C:, Campos, D. de A., Derze, G.R., Asmus, H.E.A.. A Publication of M.M.E. (Ministry of Mining and Energy) D.N.P.M. (Nat. Dept. of Mineral Prod.), Brasilia DF.
KEHRER, P. (1972): Zur Geologie der Itabirite in der südlichen Serra do Espinhaço (Minas Gerais, Brasilien). - Geol. Rdsch. 61, 216-249.
KNEIDL, V. and SCHORSCHER, H.D. (1972): Faziesübergänge der Minas-Serie im Raum zwischen Itabira und Altamira (Minas Gerais, Brasilien). - N. Jb. Geol. Paläont. Mh., Jg. 1972, 224-235.
LADEIRA, E.A. (1980): Metallogenesis of Gold at the Morro Velho Mine and in the Nova Lima district, Quadrilátero Ferrífero, Minas Gerais, Brazil. - 272 p., doctorate thesis unpubl., University of Western Ontario.
LA ROCHE, H. de (1968): Comportement géochimique differentiel de Na, K et Al dans les formations volcaniques et sedimentaires: un guide pour l'étude des formations metamorphiques et plutoniques. - C.R. Acad. Sci. Fr. 267, Série D, 39-42.
LA ROCHE, H. de (1972): Revue sommaire de quelques diagrammes chimico-minéralogiques pour l'étude des associations ignées ou sédimentaires et de leurs dérivés metamorphiques. - Sci. Terre 17/1-2, 31-46, Nancy.
LA ROCHE, H. de and OHNENSTETTER, D. (1980): Exploitation globale des analyses de roches. Implications pétrogénetiques et metallogéniques. - Chap. 2 (port. III), p. 96-128, in: M. Besson (coord.), "Facteurs contrôlant les minéralisations sulfurées de nickel". - Mém. du BRGM, No. 97, 281 p. (publication du 26e CGI.-D2), ed. BRGM, Paris.
MARANHÃO, C.M.L. (1979): Sobre a ocorrência de pirita detrítica nos metaconglomerados uraníferos da Formação Moeda - Quadrilátero Ferrífero, Minas Gerais. - 9°. Simp. Geol. Nordeste, Bol. Esp., Resumos das Comunicações, p. 75, Soc. Bras. Geol., Núcleo Nordeste, Natal.
MAXWELL, C.H. (1972): Geology and ore deposits of the Alegria district, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 341-J, 72 p.
MOORE, S.L. (1969): Geology and ore deposits of the Antônio dos Santos, Gongo Soco, and Conceição do Rio Acima quadrangles, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 341-I, 50 p.
MORAES REGO, L.F. (1931): As Estruturas antigas do Brasil. - Esc. de Minas, An. 22, 27-85, Ouro Preto.
MÜLLER, G., SCHUSTER, A. and HOEFS, J. (1982): Oxygen isotope variations in polymetamorphic iron ores from the Quadrilátero Ferrífero, Brazil. - Rev. Bras. Geociências 12(1-3), 348-355.

PATERNOSTER, K. (1979): Faziesverzahnung zwischen diamantführenden Konglomeraten und Bändererzen (BIF) in der südlichen Serra do Espinhaço (Minas Gerais, Brasilien). - 88 p., doctorate thesis, unpub., Universität Freiburg i.Br.
PETITJOHN, F.J. (1975): Sedimentary rocks. - 2d. ed., 718 p., Harper & Bros., N.Y.
PFLUG, R. (1965): Zur Geologie der südlichen Espinhaço-Zone und ihrer präkambrischen Diamantvorkommen, Minas Gerais, Brasilien. - Z. Deutsch. Geol. Ges. 115, 177-215.
PFLUG, R. (1967): Die präkambrische Miogeosynklinale der Espinhaço Kordillere, Minas Gerais, Brasilien. - Geol. Rdsch. 56, 825-844.
PFLUG, R. (1968): Observações sobre a estratigrafia da Série Minas na região de Diamantina, Minas Gerais. - D.N.M.P., Div. Geol. Min., Notas prelim. e Estudos 142, 20 p.
PFLUG, R. and RENGER, F. (1973): A evolução geológica da margem SE do Craton Sanfranciscano. - 27. Cong. Bras. Geol., Anais 2, 5-19.
PIRES, F. (1977): Geologia do Distrito manganesífero de Conselheiro Lafaiete. - Tese de mestrado, Inst. Geociências, U.F.R.J. (M.Sc. thesis, unpubl., Inst. Geoc., Fed. Univ. Rio de Janeiro).
PISSIS, A. (1842): Mémoire sur la position géologique des terrains de la partie australe du Brésil et sur les soulèvements qui, à diverses époques, ont changé le relief de cette contrée. - Mem. Inst. France, Tome X, 353-413.
READ, H.H. (1955): Granite Series in Mobile Belts. - p. 409-430 in: A. Poldervaart (ed.), "Crust of the Earth". - Geol. Soc. Am., Spec. Pap. 62.
REEVES, R.G. (1966): Geology and mineral resources of the Monlevade and Rio Piracicaba quadrangles, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 341-E, 58 p.
RENGER, F. (1970): Fazies und Magmatismus der Minas-Serie in der südlichen Serra do Espinhaço, Minas Gerais, Brasilien. - Geol. Rdsch. 59, 1253-1292.
ROESER, H. (1977): Petrographisch-geochemische Untersuchungen der metamorphen Gesteinsserien im südöstlichen Grenzbereich des Eisernen Vierecks, Minas Gerais, Brasilien. - 341 p., doctorate thesis, unpub., University of Clausthal.
SCHEUCH, R. (1976): Geochemische, biochemische und sediment-petrographische Untersuchungen an Itabiriten und deren faziellen Äquivalenten in der südlichen Espinhaço-Zone (Brasilien). - 63 p., doctorate thesis, unpub., Universität Freiburg i.Br.
SCHNEIDERHÖHN, P. (1935): Brasilianische Gesteine. - N.Jb.Min. etc. 70, Beilage-Band, Abt. A, 152-201.
SCHOBBENHAUS, C. et al. (1978): Carta geológica do Brasil ao Milionésimo. Folha Belo Horizonte. - D.N.P.M., D.G.M., Brasília.
SCHÖLL, W.U. (1973): Sedimentologie der Bambui-Gruppe im SE-Teil des São Francisco Beckens (Minas Gerais, Brasilien). - Münstersche Forsch. Geol. Paläont., H. 31/32, 71-91.
SCHÖLL, W.U. and FOGAÇA, A.C.C. (1979): Estratigrafia da Serra do Espinhaço na região de Diamantina. - 1°. Simp. Geol. Minas Gerais, Soc. Bras. Geol., Núcleo Minas Gerais, 55-73, Belo Horizonte.
SCHORSCHER, H.D. (1973): Zur liegenden Abgrenzung der präkambrischen Minas-Gruppe, am Beispiel des Raumes Itabira, Minas Gerais, Brasilien. - Münster. Forsch. Geol. Paläont. 31/32, 29-53.
SCHORSCHER, H.D. (1975a): Entwicklung des polymetamorphen präkambrischen Raumes Itabira, Minas Gerais, Brasilien. - 304 p., 11 maps, doctorate thesis, unpub., University of Heidelberg (Biblioteca D.N.P.M., D.G.M., Brasília, DF.).

SCHORSCHER, H.D. (1975b): Zur Bildung der metamorphen, itabiritischen Reicherze im Raum Itabira, Minas Gerais, Brasilien. - Fortschr. Min. 53, Beih. 1, p. 73.

SCHORSCHER, H.D. (1976a): Polimetamorfísmo do Pré-Cambriano na Região de Itabira, Minas Gerais, Brasil. - 29°. Cong. Bras. Geol., Resumos dos Trabalhos, 194-195, Belo Horizonte.

SCHORSCHER, H.D. (1976b): Natürliche Beobachtungen zur Stabilität von Chloritoid. - Fortschr. Min. 54, Beih. 1, 84-85.

SCHORSCHER, H.D. (1976c): Alpinotype Deckentektonik im Präkambrium des Eisernen Vierecks, Minas Gerais, Brasilien. - 5°. Geowiss. Lateinamerika-Kolloquium, Tagungsunterl., 33-35, Clausthal-Zellerfeld.

SCHORSCHR, H.D. (1978): Komatiitos na estrutura "Greenstone Belt" Série Rio das Velhas, Quadrilátero Ferrífero, Minas Gerais, Brasil. - 30°. Cong. Bras. Geol., Resumo das Comunicações, 292-293. Recife.

SCHORSCHER, H.D. (1979a): Evolução Geotectônica e Petrogenética do Embasamento Arqueano do Quadrilátero Ferrífero. - Anais Acad. Bras. Ci. 51(4), 767-768.

SCHORSCHER, H.D. (1979b): Evolução Arqueana e Proterozóica do Quadrilátero Ferrífero e de Partes Meridionais da Serra do Espinhaço. - 1°. Simp. sobre a Geologia do Craton do São Francisco e suas Faixas Marginais, Resumos ,Salvador.

SCHORSCHER, H.D. (1980a): Contribuição à Estratigrafia Proterozóica do Quadrilátero Ferrífero. - Anais Acad. Bras. Ci. 52(1), 195.

SCHORSCHER, H.D. (1980b): Zinc - a useful element for the prospection of pre-cambrian chromitites? - 8th. Inter. Geochem. Explor. Symp., Abstracts, p. 47, Hannover.

SCHORSCHER, H.D. (1980c): Geotectonic evolution of the Quadrilátero Ferrífero, Brazil. - 26th. Intern. Geol. Cong., Abstracts 2, p. 613, Paris.

SCHORSCHER, H.D. and GUIMARÃES, P.F. (1976): Estratigrafia e Tectônica do Supergrupo Minas e Geologia do Distrito Ferrífero de Itabira. - 29°. Cong. Bras. Geol., Roteiro das Excursões, 75-86, Belo Horizonte.

SCHORSCHER, H.D. and LETERRIER, J. (1980): Metasomatic formation of granitic rocks: Petrology and Chemistry. - 26th. Inter. Geol. Cong., Abstracts 1, p. 87, Paris.

SCHORSCHER, H.D. and MÜLLER, G. (1977): Granitisation tiefkrustaler Mylonite durch metasomatische Feldspatisierung im Präkambrium E-Brasiliens. - Fortschr. Min. 55, Beih. 1, 123-124.

SCHORSCHER, H.D., SANTANA, F.C., POLONIA, J.C. and MOREIRA, J.M.P. (1982): Quadrilátero Ferrífero - Minas Gerais State: Rio das Velhas greenstone belt and Proterozoic rocks. - Int. Symp. on Archaean and Early Proterozoic Geologic Evolution and Metallogenesis - ISAP, Excursions Annex, 46 p., S.M.E. - BA. (a publication of the State-Secretary of Mines and Energy - S.M.E., Bahia), Salvador.

SIMMONS, G.C. and MAXWELL, C.H. (1961): Grupo Tamanduá da Série Rio das Velhas. - D.N.P.M., Div. Geol. Min. Bol. 211, 30 p.

STUTZER, O. (1913): Ueber ein feldspatreiches, knollenartiges Mineralaggregat der Luanza-Pipe im Kundelungu (Katanga, Belgisch-Kongo). - Z. Dtsch. Geol. Ges. 65 B, Monatsber. 4, 226-228.

TEIXEIRA, W. (1982): Geochronology of the Southern Part of the São Francisco Craton. - Rev. Bras. Geoc. 12(1-3), 268-277.

TOLBERT, G.E. (1964): Geology of the Raposos gold mine, Minas Gerais, Brazil. - Econ. Geol. 59(5), 775-798.

TORQUATO, J.R. and FOGAÇA, Ac.C.C. (1979): Correlação entre o Supergroup Espinhaço no Brasil, o Grupo Chela em Angola e as Formações Nosib e Khoabendus da Namibia. - 1°. Simpósio sobre a Geologia do Craton do São Francisco e suas Faixas Marginais, Resumos, Salvador.

WALLACE, R.M. (1965): Geology and mineral resources of the Pico de Itabirito district, Minas Gerais, Brazil. - U.S.G.S. Prof. Pap. 341-F, 68 p.

WIEDEMANN, C. and SCHORSCHER, H.D. (1978): Zinco nas rochas ultrabásicas e nos cromititos da região de Itabira, Minas Gerais, Brasil. - 30°. Cong. Bras. Geol., Res. das Conumicações, 211-212, Recife.

ANNEX

I. Excursion Area

. Climate:	Normally dry, with daily temperatures around 15-25°C and cooler nights, about 7 to 17°C.
. Clothing:	resistent field clothing (shorts not recommended). A second pair of light fieldboots (basketball type boots) may be useful for change, in case of (probable) wetness, since some outcrops are in and along river courses.
. Inconveniences:	Locally, abundant ticks may occur (in port.: carrapatos) - persons allergic to insect bites should take necessary precautions.

II. Field Trip Program - Schedule

. July 17 (Sunday)

08.00 h	Departure from meeting point (Palace Hotel, Poços de Caldas) by bus. Travel to Belo Horizonte, with lunch stop en route. Shortly after Belo Horizonte, field stops will begin. - Visit to outcrops points 1 - 4;
20.00 h	Arrival at Barão de Cocais (Hotel Caraça, Tel. 031/837.14.32).) and/or Santa Barbara (Hotel Caraiba, Tel. 031/832.14.15).

. July 18 (Monday)

07.00 h	Departure from Hotels Caraça and/or Caraiba. - Visit to outcrop points 5, 10 - 11; Rest for lunch will be in the field.
19.00 h	Return to Hotels.

. July 19 (Tuesday)

07.00 h	Departure from Hotels - Visit to outcrop points 7 - 9. Rest for lunch will be in the field.
19.00 h	Return to Hotels.

. July 20 (Wednesday)

07.00 h	Departure from Hotels - Visit to outcrop points 6, 12, 13. Rest for lunch will be in the field.
19.00 h	Return to Hotels (this will be the last night in Barão de Cocais and/or Sta. Barbara).

. July 21 /Thursday)

07.00 h	Departure from Hotels and leave from Barão de Cocais/Sta. Barbara for Piçarrão and Itabira.

	- Visit to outcrop points 14, 16, 17.
	Rest for lunch will be in the field.
19.00 h	Arrival in Itabira (Hotel Pousada dos Pinheiros, Tel.)
20.30 h	Dinner
. July 22 (Friday)	
07.00 h	Departure from Hotel
	- Visit to outcrop points 15, 18.
	Rest for lunch will be in the field.
19.00 h	Return to Hotel Pousada dos Pinheiros.
20.30 h	Cocktail, Dinner and Closing Party (this will be the last night in Itabira).
. July 23 (Saturday)	
07.00 h	Departure from Hotel
	- Visit to outcrop point 18
11.00 h	Return to Hotel Pousada dos Pinheiros
12.00 h	Lunch at Hotel Pousada dos Pinheiros
14.00 h	Departure from Hotel and leave from Itabira for Belo Horizonte airport.
16.00 h	End of excursion at Belo Horizonte airport. The bus will return to São Paulo and will take about 10 hrs to reach there. For flight connections see below.

!!! IMPORTANT . IMPORTANT . IMPORTANT !!!

. Flight connections from Belo Horizonte to São Paulo and Rio de Janeiro for July 23rd, 1988 (end of excursion) will be communicated at the meeting in Poços de Caldas. Reservations and specific traval arrangements should be confirmed there.

III. <u>Outcrop Points and Profiles, to be visited on field trip (see fig. 1)</u>

Point 1

Tectonic contact between Serra do Curral overturned syncline, Sabará Formation and/or Nova Lima Group with "Basement" Complex.

Stratigraphy and structure of the Minas Supergroup of inverted flank of syncline.

Point 2

Strongly deformed Cauê Itabirites at eastern extremity of Serra do Curral syncline in relictic preserved parts of normal flank of the allochthonous structure, near the tectonic (nappe-)contact with the autochthonous basement. Prospect-point: general view of the Q.F. s.s. morphology and structure.

Point 3

Espinhaço Supergroup stratigraphy of the Serra das Cambotas - Sopa Brumadinho Formation with infraformational itabirite-pebble conglomerates and Galho de Miguel Formation with megaripple stratification.

Point 4
Tectonic contact between Minas Supergroup (Gandarela Syncline) and "Basement Complex". Profile exposing intrusive metabasics in migmatites and gneisses, that show increasing mylonitisation towards the contact with the Minas Supergroup. Profile through Minas SG.

Point 5
Tectonic contact between Minas (Gandarela Syncline), and Espinhaço Supergroups. Profiles through both sequences.

Point 6
Rio das Velhas Supergroup - Nova Lima lithologies with turbidite type metaconglomerate, synsedimentary slumping and sliding structures in bifs. and graphitic schists. Visit to <São Bento> gold mine and benefication plant.

Point 7
Espinhaço SG. lithostratigraphic succession in the Floralia District with quartzites and intraformational itabirite pebble conglomerates of the Sopa Brumadinho Fm.

Point 8
Rio das Velhas greenstone belt: lithostructural and stratigraphic succession in the Florália District. Visit to abandoned <Pari> goldmine.

Point 9
"Basement Complex" migmatites and tonalitic intrusives cut by meta-lamprophyric dikes.

Point 10
"Basement Complex" migmatites cut by various generations of tonalitic and granodioritic intrusives and by younger pegmatite dikes.

Point 11
Rio das Velhas Supergroup - Quebra Osso Group with various types of effusive (peridotitic) komatiites. Profiles through contacts with Granitic Complex mylonitized gneisses and migmatites, Nova Lima Gr. Schists and, supposed Espinhaço SG., mainly quartzitic metasediments. Visit to abandoned <Quebra Osso> goldmine and historical, slave constructed aqueduct to Catas Altas (= "high diggings").

Point 12
Rio das Velhas Supergroup - Profile across Nova Lima and Maquiné Groups. Conglomerates and quartzites with detrital pyrite of Maquiné Group.

Point 13
Espinhaço Supergroup quartzites. Prospect-point: Historical Colégio do Caraça.

Point 14
Granito Borrachudos type granitic rocks.

Point 15

Visit to <Belmont> Emerald Mine. Profile across tectonic contact of Borrachudos granitoids with Archaean volcano-sedimentary sequence.

Point 16

Profile across high grade gneisses and Minas SG. rocks with oxide facies Fe-formation. Visit to CVRD's Piçarrão Mine and <Liberdade> ore body (abandoned open pit).

Point 17

Minas Supergroup east of Itabira. Itabira Group represented by minor iron formation and major metachert. En route to Itabira, paragneisses with quartz-muscovite schist intercalations, amphibolites, Archaean polymetamorphic migmatites and younger basalts.

Point 18

Visit to CVRD's Mines and profiles across Minas SG. in the Itabira District.

IV <u>Historical and background information</u>

The excursion area as the whole Q.F. played an important role in the history of Brazil since the colonial period, and of the Portuguese Empire in the 18th and early 19th centuries, mainly due to the mineral, especially gold production. An old Brazilian proverb that describes the people and resources of the state of Minas Gerais says: "Minas has a heart of gold and a chest of iron", and certainly owes its origins, at least in part, to the mineral deposits of the Q.F. and the people there involved in mining since historical times.

Gold was first discovered in the Sta. Barbara region (before 1704), shortly afterwards, in 1713, at the site of Barão de Cocais and, in 1720 of Itabira , by "bandeirantes" (groups of adventurers from São Paulo , who roamed the interior of Brazil in the search of personel fortune, at the same time definitely establishing the country's continental dimensions). Settlers followed and, for example, impressive aqueducts were constructed by slave work, as will be visited in the upper Quebra Osso valley (fig. 15), to bring water to morphologically higher gold workings, in that case to Catas Altas (="high diggings") over a distance of about 10 kms.

Several hundred tons of gold were produced during colonial times in the Q.F., mainly from rich placer deposits, and financed much of the rapid, worldwide expansion and influence of the Portuguese Empire.
Placer deposits became exhausted early in the 19th century and Au lode mining started with industrial methods and the important participation of European capital. When Au lode mining reached the economic limits (by the middle of the 19th century), a period of general decay followed, and lasted about 100 years, until the modern inset of iron ore mining and metallurgy, by the middle of our century.

Modern developments in the iron ore mining through C.V.R.D., and private, national and international companies created a solid regional industrial infrastructure over the last few decades, reaching almost all the parts of the Q.F. and neighbouring urban centers (fig. 1). This stimulated further developments, expansion and diversification, not only in mineral production, but had major influences on the whole socio-economic life too.

Most of the cities that will be met during the field trip (Cocais, Barão de Cocais, Sta. Barbara, Catas Altas, Florália, Itabira) still possess picturesque historical town relicts, individual buildings and/or churches in the style of "Colonial Baroque" architecture and decoration.

Another historical place that will be visited en route of the field trip is the "Colégio do Caraça", presently a seminary and touristic place maintained by fathers. It was established in 1744 with the construction of a beautiful gothic cathedral and dependencies, at an altitude of 1.280m, in the spectacular setting of an isolated, almost inaccessible part of the Serra do Caraça (fig. 1, point 13). As historically commented, at the place where a Jesuit father was hiding from banning with the aid of populars, during the times of political cassation of Jesuits from colonial Brazil.

The Colégio do Caraça acted as boarding school and counts among its distinguished pupils several heads of the state of Brazil. After a conflagration of the library with hazardous consequences for most of the school's dependencies, scholar activities were interrupted and reconstruction is now underway.

The fathers continue to produce most of their own food, several varieties of (excellent) wine and brandy and encompassed as a new task, in consequence of expanding tourism, the protection of nature, wildlife and environment.

This text was compiled, in some parts with only minor modifications, from Dorr and Barbosa (1963) , Simmons (1968), Dorr (1969), Moore (1969) and Maxwell (1972) and complemented with own comments and observations.