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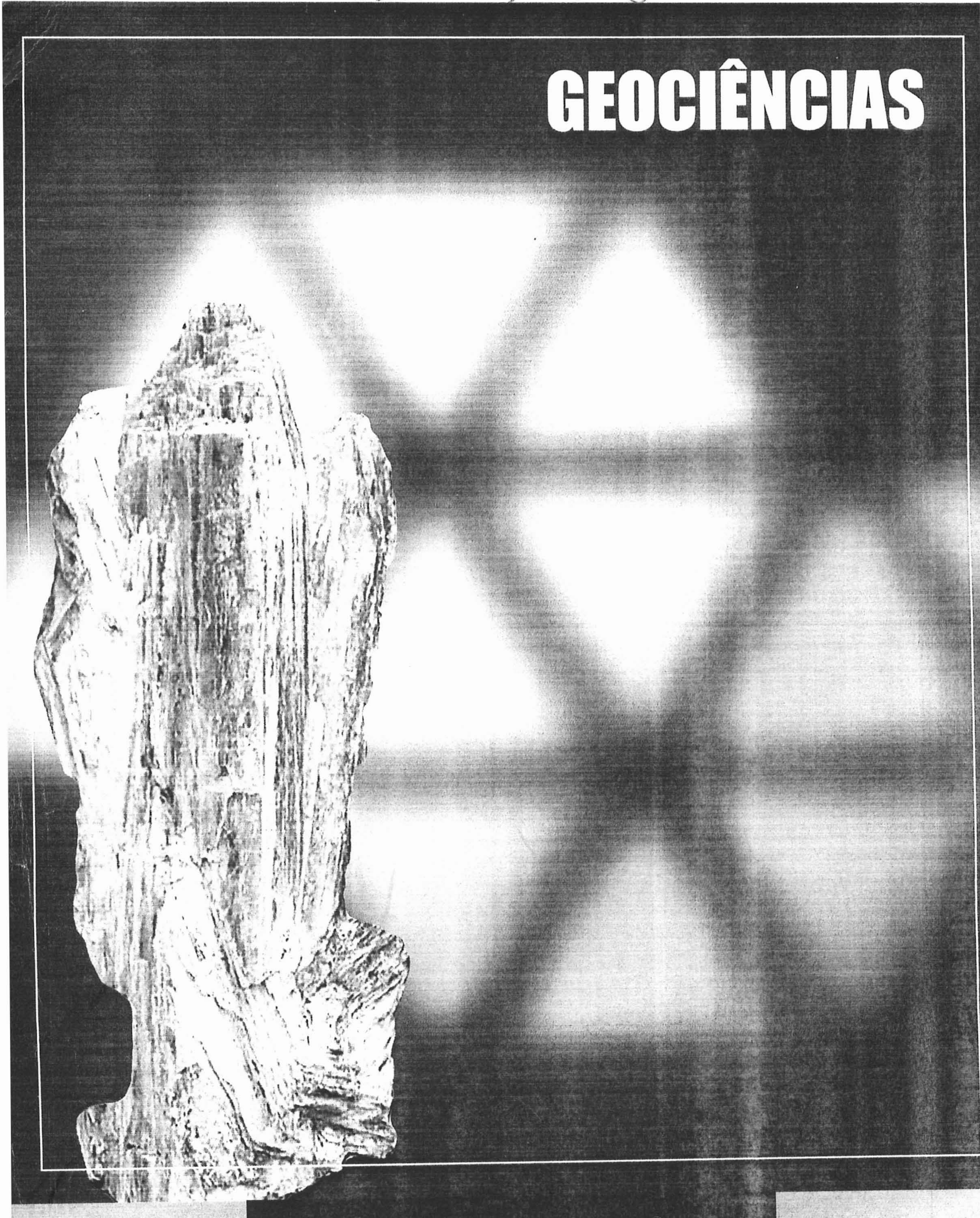
GEOCIÊNCIAS



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GEOLOGY OF THE IPANEMA DISTRICT AND THE SANTA CRUZ LATERITIC NICKEL DEPOSIT, SOUTHEASTERN BRAZIL

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ABSTRACT: The Ipanema Mafic/Ultramafic Complex, Minas Gerais State (Brazil), comprises metamorphosed and deformed bodies of Paleoproterozoic age. The country rocks are orthogneisses, aluminous paragneisses and quartzites that are part of the Archean Juiz de Fora Complex. The bodies typified by the main occurrence of Santa Cruz constitute a differentiated sequence encompassing metadunite, metaperidotites, metapyroxenites, metagabbros and meta-anorthosites. The first two lithotypes are strongly serpentinized, and weathering has resulted in the formation of nickel ore deposits. The weathering profile is constituted of five horizons: altered rock, green saprolite, orange saprolite, silicified red laterite and ferruginous concretions. The maximum nickel content occurs within the green saprolite. The ore is composed mainly of nickeliferous serpentine, smectites, Ni-chlorites and Ni-talc. Measured reserves in Ipanema district have been estimated to be 9.10^6 tonnes grading 1.2% Ni.
Keywords: Mafic-ultramafic complex; lateritic nickel; Araçuaí fold belt; serpentinites.

RESUMO: *N. Angeli; A. Choudhuri; S.M.B. de Oliveira; E.G. de Oliveira – Geologia do distrito de Ipanema e o depósito de níquel laterítico de Santa Cruz, Sudeste do Brasil.* O Complexo Máfico/Ultramáfico de Ipanema, Minas Gerais (Brasil), compreende vários corpos deformados e metamorfizados, de idade Paleoproterozóica, encaixados no Complexo Juiz de Fora. A principal ocorrência, o corpo de Santa Cruz, é constituída por uma seqüência diferenciada composta por metadunito, metaperidotitos, metapiroxenitos, metagabros e metanortositos. As duas primeiras unidades litológicas encontram-se intensamente serpentinizadas e o intemperismo foi responsável pela concentração e formação dos depósitos de níquel. O perfil de alteração é composto por cinco horizontes: rocha alterada, saprolito verde, saprolito alaranjado, laterita vermelha silicificada e concreções ferruginosas. O maior conteúdo em níquel encontra-se no saprolito verde. O minério é composto principalmente por serpentina, esmectita, clorita e talco niquelíferos. A reserva medida no distrito de Ipanema corresponde a cerca de 9 milhões de toneladas de minério com teor médio de 1,2% Ni.
Palavras-chave: Complexo máfico-ultramáfico; níquel laterítico; faixa de dobramentos Araçuaí; serpentinitos.

INTRODUCTION

Tropical regions of high annual rainfall are characterized by their deep weathering profiles. As a consequence, fresh rock rarely outcrops, making bedrock mapping a difficult task for geologists. Improved remote sensing techniques have, however, helped to alleviate problems related to mapping and mineral exploration in such regions (*e.g.*, Crosta, 1990). On the other hand, the advantage of lateritic weathering is the dissolution of certain elements and the preferential concentration of others, leading to form economic ore deposits of Ni, Co, Al, Mn etc. (Esson, 1983; Schellmann, 1983; Bernardelli et al., 1983, Colin et al., 1990; Costa, 1997).

In the Southeast Brazil, several ultramafic bodies exposed to weathering have given rise to nickeliferous lateritic deposits similar to those that have been exploited in New Caledonia (Trescases, 1975; Besset, 1980). In the Ipanema district, seven ultramafic bodies hosted by gneisses have been evaluated. The gneisses were affected by events of metamorphism and deformation (Angeli et al., 1992, 1993), causing partial or total serpentinization of the ultramafic rocks. Subsequently, weathering has concentrated Ni from the nickel-rich silicates, olivine and orthopyroxene (mainly bronzite). Here, one such example will be focused on by studying the mineralogical and geochemical evolution of a weathering profile located at Santa Cruz Massif in this district.

The Ipanema District, straddles in Mantiqueira Structural Province and is located in eastern portion of Minas Gerais state. The geological results to be presented are part of systematic exploration program carried on 1980's, encompassing, geological mapping, sampling, soil and stream sediment geochemistry. As a result several geochemical anomalies were detected and a direct exploration program through auger drilling, trenches and underground development and shafts, were performed. Drilling and trenching indicated for the Santa Cruz deposit reserves of 4.10^6 tonnes grading 1.24% Ni.

METHODOLOGY

The mineralogical evolution of the altered profile was depicted based on petrography of thin and polished sections, and X-ray diffraction. For the X-ray diffraction was utilized the Rigaku Denki diffratometer with cobalt tube and 3° to 60° of scanning angle. The samples which presented peak of 14 A was submitted to heating (550°C) and after this was treated by ethilene-glycol. Thus it was possible to separate smectite and chlorite. The mineralogy was determined by X-ray diffraction, and the textural relationships between primary and secondary phases were established in thin section studies. The mineralogy and structures of serpentinites was based in Wicks & O'Hanley (1988) and Tardy (1993). Afterwards the analyzed samples were submitted to mass balance for the establishment of nickel-rich mineral phases.

The humidity was determined by the relation of the weighting of natural and dried samples (100 to 110°C). The density was calculated by paraffin impermeabilization of the samples and subsequent weighty on air and in the water.

The chemical evolution was determined by interpretation of the chemical analyses of SiO_2, Al_2O_3, Total Fe, TiO_2, CaO, MgO, MnO and Cr_2O_3 by spectrophotometry, Na_2O and K_2O by flame-photometry, and Ni and Co by atomic absortion. The geochemical balance was obtained by the isovolumetric procedure (Millot & Bonifas, 1955) for the transition fresh rock-green saprolite and isoiron for the fresh rock-orange saprolite.

GEOLOGY

The Precambrian fold belts of southeastern Brazil belong to the Mantiqueira Structural Province (Figure 1) (Almeida et al., 1981). This region is further subdivided into northern and southern parts known as the Paraíba do Sul and Ribeira fold belts, respectively. The northern segment, which contains the ultramafic bodies of this study, extends from Rio de Janeiro State, through Espírito Santo and Minas Gerais states to south Bahia State (Angeli & Choudhuri, 1985). In this belt, a regional gravimetric survey, performed by Haralyi & Hasui (1982), indicated reworking of the Archean rocks during the Proterozoic, especially the gneiss terrain along the margin of the São Francisco craton. During this process, these terrains were subjected to large scale migmatization and thrust tectonics.

The mafic/ultramafic complexes of the eastern part of the Minas Gerais State occur near the southern and southeastern border of the São Francisco craton, which acted as a foreland during the Brasiliano (Panafrican) orogeny. Although these complexes may have been tectonically emplaced, their metamorphic grade (mineral paragenesis) corresponds to that of the country rocks (Angeli et al., 1993). At least two metamorphic events appear to have affected these rocks during the Brasiliano orogeny (Late Proterozoic).

The ultramafic rocks under study occur near Ipanema city within the Atlantic Belt, which has been mapped and studied by Angeli (1988). These rocks form lenticular bodies concordant with the foliation of the surrounding lithologies, and Angeli et al. (2001b) have determined an age of their formation around 1,09 ±70 Ma (Sm-Nd age for whole rock) and 630±3 Ma (U-Pb zircon age in meta-anorthosite) for the regional high grade metamorphism (Neoproterozoic tectono-thermal overprint).

The ultramafic bodies are located in a region having a variety of gneissic rocks, and follow the N-S to N30E regional trend of the surrounding gneisses. Some of these rocks possibly belong to an older basement, whereas others are supracrustal or intrusive unities. Grey tonalitic gneisses presumably belong to the basement or infracrustals above which there are paragneiss sequences consisting of biotite gneisses, garnet-biotite gneisses, sillimanite-garnet quartzites, and subordinate calc-silicate and amphibolitic rocks (Juiz de Fora Complex). Granitic and granodioritic intrusive bodies, of Early Proterozoic age and grouped by Angeli (1988) and Angeli et al. (1999) into the Santa Rita do Mutum Intrusive Suite (Figure 2), are also present.

The most common country rocks to the mafic-ultramafic massifs are the gray tonalitic gneisses. They are generally coarse to medium grained, leuco- to mesocratic and well foliated. Plagioclases ranging in composition from oligoclase to andesine, and quartz, are the major minerals, often with preserved relict igneous textures, microcline is subordinate and interstitial, and mafic minerals are pale-green hornblende (up to 30%), minor biotite and diopside. Variation in the relative amounts of plagioclase and microcline in this unity led to the formation of minor rock types such as granitic, granodioritic and dioritic gneisses associated with the tonalites. All of these orthogneisses are

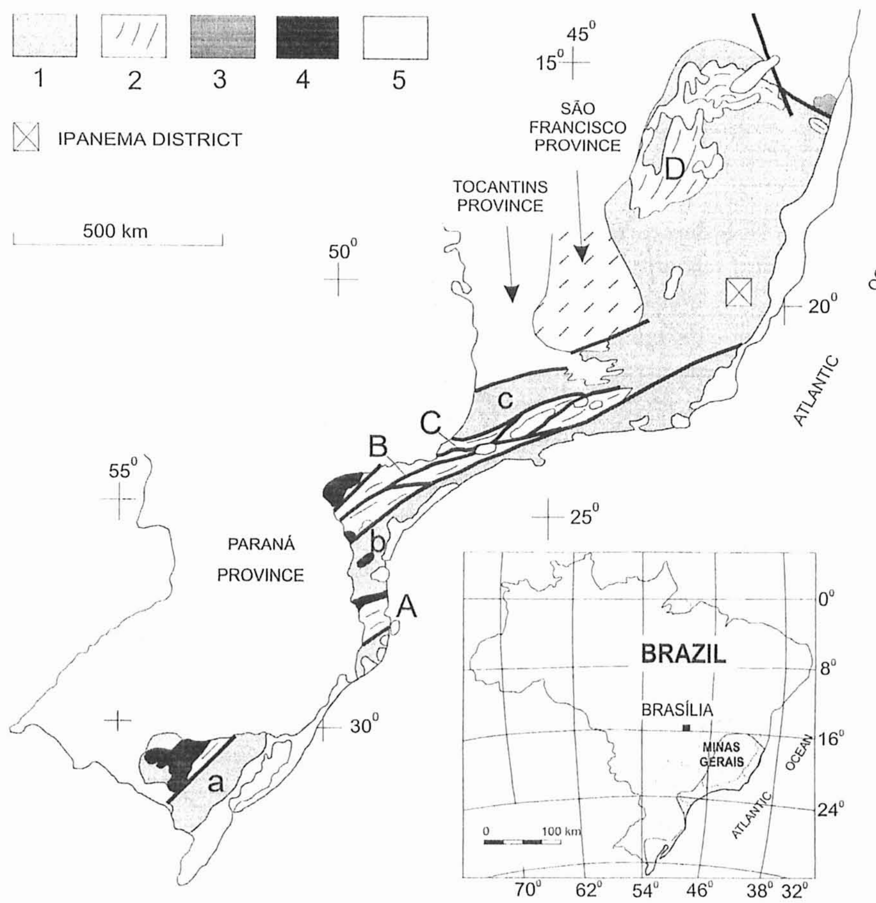

FIGURE 1 – Mantiqueira Structural Province. 1. Older basement reworked during Late Precambrian (a – Pelotas Massif, b – Joinvile Massif, c – Part of the Guaxupé Massif); 2. Brasiliano fold belts (A – Tijucas belt, B – Apiaí belt, C – São Roque belt, D – Araçuaí belt); 3. Metasedimentary area related to the Araçuaí belt (Rio Pardo group); 4. Molasse deposits; 5. Phanerozoic sedimentary covers. Heavy lines represent major faults. After Almeida et al. (1981).

considered to constitute the infra-crustals in the Ipanema district and surrounding regions, whereas some granitic rocks are clearly intrusive and belong to a late intrusive suite.

The most widely distributed units in the region are garnet-biotite gneisses, aluminous gneiss, which consist of quartz + plagioclase + garnet + biotite + microcline + sillimanite ± cordierite; with increasing quartz and decreasing feldspar contents, they grade into quartzites. Generally, the garnet-biotite gneisses have a banded structure, with compositional gradation from one band to the other, which might represent original bedding of the sedimentary protolith. Locally, evidences of incipient anatexis and formation of small amounts of melts made up of quartz and feldspar can also be observed. Within this gneiss unit, calc-silicate and amphibolitic rocks occur as small bodies, lenses or bands.

The polycyclic character of the basement rocks, as evidenced for Transamazonian and Brasiliano orogenies of Paleoproterozoic and Neoproterozoic ages respectively (Trompette, 1994), suggests this to be an Archean-Paleoproterozoic terrain reworked during Neoproterozoic.

Structural contour lines show a non homogeneous pattern, and the foliation drawing alternate folds with non continuous axial traces, defining lenses of less deformed rocks (competent lenses) surrounded by anastomosed more sheared portions. Locally, the orthogneisses exhibit isoclinal folds that indicate intense deformation and conditions of high plasticity. In the paragneisses, muscovite is absent, and titaniferous biotite is found associated with antiperthitic plagioclase. These rocks and their quartzite intercalation contain K-feldspar, sillimanite, garnet (almandine), and small quantities of cordierite, associated with the disappearance of muscovite. These conditions characterize a zone with high temperature and medium pressure of metamorphism (upper amphibolite to granulite facies).

The mafic-ultramafic intrusions were submitted to same conditions and in places there are isoclinal folds in the metaperidotites. Anthophyllite is a common amphibole in these rocks, green spinel (hercynite) is found frequently in metapyroxenites, and titaniferous magnetite is associated to hematite exsolutions in metagabbros and meta-anorthosites. Similar features

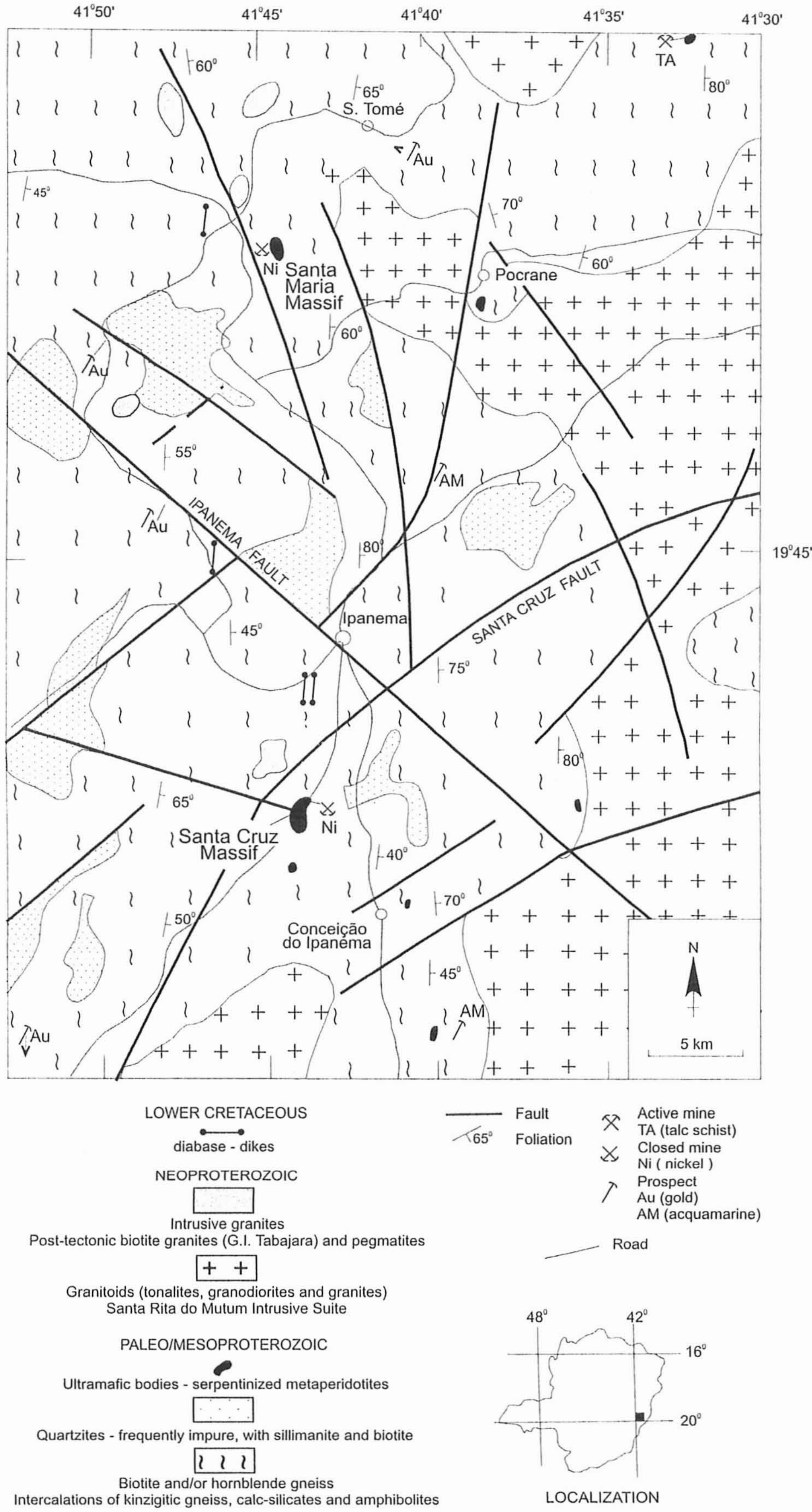

FIGURE 2 – Geological map of Ipanema District, Minas Gerais State. Past/present mining activity: Ni – nickel; TA – talc schist; Au – gold; AM – aquamarine. After Angeli (1988).

are present in other ultramafic bodies to the north and south of the Ipanema district (Angeli et al., 1993).

Subsequently, retrograde greenschist facies metamorphism affected the region. As a result the gneisses contain sillimanite changing to sericite, as well as biotite altering to sericite and to chlorite, and plagioclase transforming to epidote. Regionally, the alteration of plagioclase and biotite to muscovite is common. Retrograde metamorphism has resulted in ultramafic rocks serpentinization, which is represented mainly by olivine alteration to serpentine.

The eastern portion of the study area is underlain by the Santa Rita do Mutum Intrusive Suite, which is associated into a low-grade metamorphic event. The contact with gneisses is commonly marked by prominent faults. This suite is composed mainly of granites, granodiorites and tonalites, and corresponds to syn- to late-tectonic magmatism. These granitoids represent an expanded series with calc-alkaline composition. Angeli (1988) found an age of 547±69 Ma (IR=0.713) for this unit (Rb-Sr method). Conversely, the Tabajara Intrusive Granite consists of post-tectonic biotite granites and pegmatites occur associated to this unit.

Finally, in the Ipanema district small diabase dykes 124±4 Ma (K-Ar method) old are present, related to reactivation of the South American Platform.

MAFIC–ULTRAMAFIC BODIES

The main occurrences of mafic-ultramafic rocks within the Ipanema district are the Santa Cruz and Santa Maria massifs, which are 1 to 1.5 km long and about 0.5 to 0.6 km wide. There are also scattered, smaller occurrences, which may have been a part of the main body prior to regional deformation. The Santa Cruz massif consists of metadunites, metaharzburgites, metapyroxenites, metagabbros and meta-anorthosites, which suggests magmatic differentiation before the rocks were subjected to metamorphism and deformation (Figure 3).

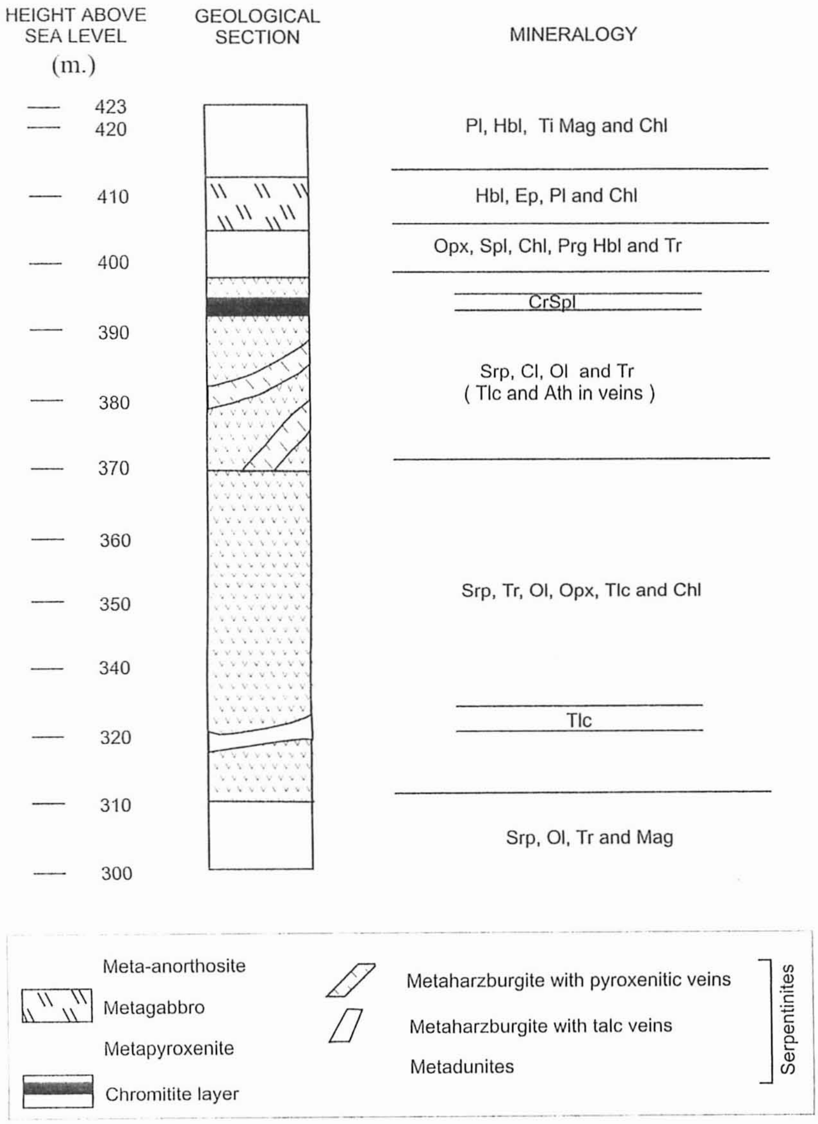

FIGURE 3 – Profile and mineralogy of southeast portion of the main body of Santa Cruz Massif, Ipanema Mafic/Ultramafic Complex. After Angeli (1988). Mineral abbreviations after Kretz (1983).

The metadunites and metaharzburgites make up about 75% of the massif. These rocks are olivine-rich (5 to 40%), with lesser amounts of orthopyroxene (around 5 %) and opaques (5%), but presents serpentine, tremolite-actinolite and chlorite in high quantities (more than 50%). Variable amounts of these minerals impart a banded appearance in outcrop scale, the banding being overprinted by a later oblique metamorphic foliation marked by long and prismatic tremolite-actinolite and trails of granular magnetite. Post-metamorphic serpentinization has resulted in an overall mesh texture where olivine predominates, whereas talc and chlorite replacement is more common in the orthopyroxene-rich portions. Despite serpentinization, occasionally relicts of cumulus texture encompassing olivine, orthopyroxene or serpentine (parental olivine) and chromium spinel can still be observed. Most of the olivine is therefore probably primary. Only in those parts of the body where the effects of metamorphism and accompanying deformation were more intense, olivine is clearly of metamorphic origin, as well as tremolite and rare orthoamphibole, whereas traces of relict, possibly pargasitic hornblende in portions with cumulus texture may also be of primary origin.

Three thin layers of chromitite overlie the meta-peridotites, and the largest one is 1.50 m thick exhibiting high concentration of Ru (17 to 242 ppb) and Au (1.9 to 180 ppb) in whole rock (Angeli, 1996). This layer constitutes the main chromitite level, which contains 60-65% of chromite dispersed in a serpentine and chlorite matrix. The chromite crystals were affected by metamorphism, which is represented by an impressive zoning represented by a chromite core and an Al-chromite/ferritchromite rim. REE distribution in this layer is similar to that of the Merensky Reef in Bushveld Complex, South Africa (Angeli et al., 2001a).

At the northeastern and eastern part of the main body metapyroxenite veins crosscut the dunite and peridotite. Their original mineralogy can still be locally observed, despite intense shearing and serpentinization, and mainly comprises subhedral crystals of orthopyroxene and clinopyroxene with minor amounts of olivine and pargasite. In addition, green aluminous spinel occurs associated with pargasitic hornblende, whereas tremolite is a later amphibole. Orthopyroxene and tremolite are pseudomorphically substituted by talc and chlorite, indicating that these minerals belong to a still later metamorphic episode. The mineralogical composition indicates that these rocks are metamorphic equivalents of websterite and olivine websterite. Some of them are strongly sheared near fault zones, being totally transformed into tremolite-actinolite schist and amphibolites. The main minerals of the metagabbros are hornblende and plagioclase, which in places preserve their original granular texture; epidote and chlorite are secondary minerals in these rocks. With increasing plagioclase content, the metagabbros grades into meta-anorthosites, with >90% plagioclase and up to 10% hornblende. Although most of these rocks have granoblastic textures, locally granular hypidiomorphic textures are still preserved.

The Santa Maria mafic-ultramafic body is very similar to Santa Cruz and consists of metadunite, metaharzburgite and metapyroxenites. The other differentiated members appear to be missing, and possibly due to tectonic disruption of this body (Angeli et al., 1992).

Both bodies seem to be metamorphosed at granulite facies, as indicated by the paragenesis of the ultramafic rocks: olivine + orthopyroxene + pargasitic hornblende + aluminous spinel. Further retrograde metamorphism caused the replacement of these minerals by talc and chlorite with subsequent pervasive serpentinization. The metamorphic effects and the paragenesis in different rocks are summarized in Table 1.

Lithological unit	Primary paragenesis	Metamorphic paragenesis		
		Metamorphism 1	Metamorphism 2	
			Association A	Association B
Serpentinized metadunites and metaperidotites	Ol Opx Opx Cr-Spl	recr. Ol recr. Opx recr. Cpx Prg Hbl and/or Prg Cr-Spl Al-Spl Ti-Mag	Srp I Chl I Bastite Tr-Act Mag	Srp II Chl II Tlc Mgs recr. Tr-Act Mag
Serpentinized metapyroxenites	Opx Cpx Ol	recr. Opx recr. Cpx Hbl and/or Prg Al-Spl	Chl I Srp I Tr-Act Mag	Chl II Tlc Srp II recr. Tr-Act Mag
Metagabbros and meta-anorthosites	Pl Opx Cpx Ilm	recr. Opx recr. Cpx recr. Pl Hbl Ti-Mag and Ilm	Ep Chl I recr. Hbl Mag Tr-Act	Chl II Tlc Mag

Note: Mineral abbreviations after Kretz (1983). The symbols for rock-forming minerals followed by recr. indicate that are recrystallized.

TABLE 1 – Metamorphic stages and paragenesis found in Santa Cruz and Santa Maria Mafic/Ultramafic bodies (Ipanema Layered Complex). After Angeli (1988).

THE LATERITIC NICKEL DEPOSIT

Two kinds of ore can be distinguished in the lateritic nickel deposit: oxide and silicate. The first is rich in Fe and the latter in SiO_2 and MgO. Silicate ores are common over several bodies in the eastern part of Minas Gerais State. At Ipanema district, there are several small deposits containing a total of 9.10^6 tons of ore at 1.2% Ni (Angeli, 1988). The most important of them, the Santa Cruz massif, is a small hill (0.55 km^2) formed mainly by metaperidotites. On its top an undisturbed weathering profile was selected for detailed study (Figure 4, Table 2). It comprises five layers from bottom to top (Figure 5):

- Altered rock (8 m thick) – slightly weathered ultramafic rock of gray colour, cut by garnieritic veins;
- Green saprolite (12 m thick) – greenish yellow material, which preserves the structure of the parental rock and consists of an argillaceous matrix containing weathered rock cores, less abundant upwards;
- Orange saprolite (4 m thick) – brownish yellow loose material of silty-clayey granulometry in which the structure of the parent rock is no longer visible;
- Red laterite (2 m thick) – brown to purple ferralitic soil of sandy-clayey granulometry, with ferruginous concretions and abundant quartz;
- Ferruginous concretions (centimeters thick) – fragments on top;
- Unweathered bedrock, mainly metadunite and metaharzburgites were collected from drill cores (Figure 4).

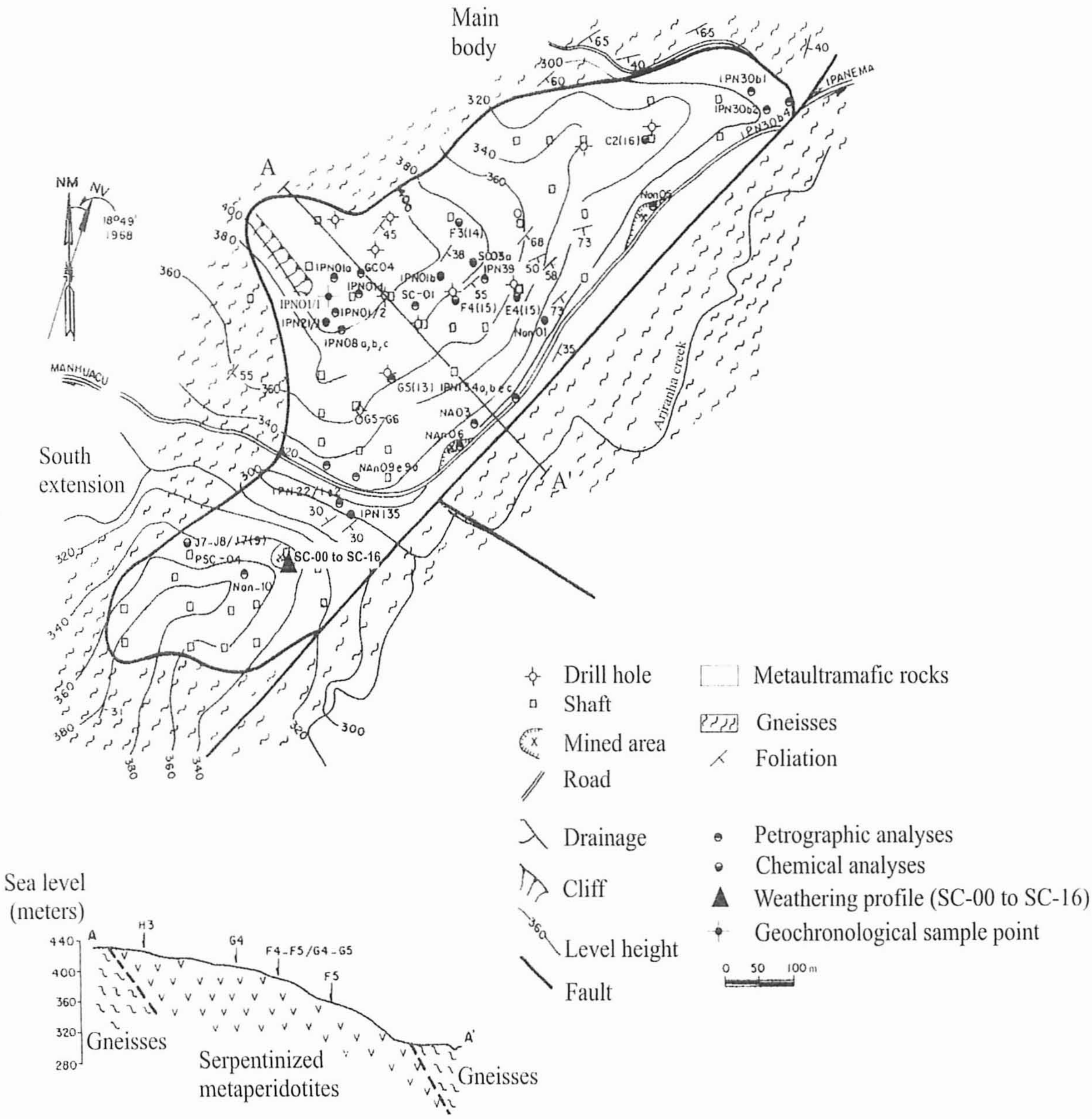

FIGURE 4 - Geological map of Santa Cruz Massif with location of the studied samples. After Angeli (1988).

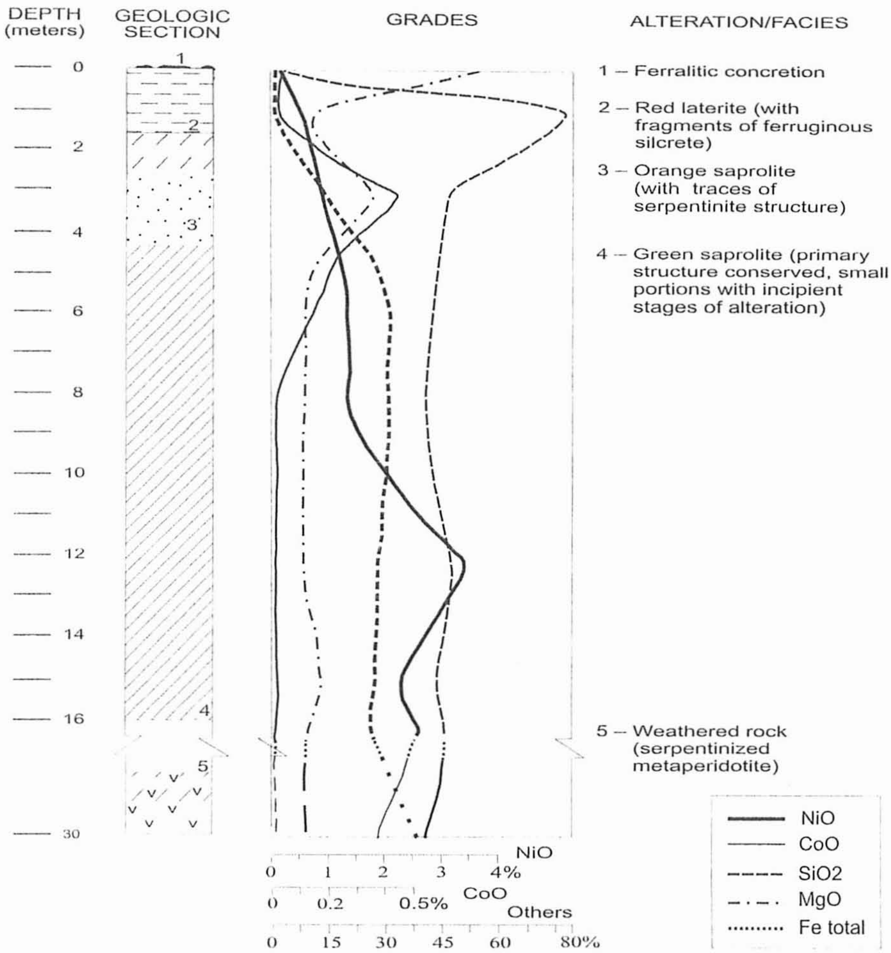

FIGURE 5 – Weathering profile of south extension of Santa Cruz Massif with geochemical distribution of elements (location of profile shown in Figure 4). After Angeli (1988).

TABLE 2 – Mineralogical composition of: (2) green saprolite, (3) orange saprolite, (4) silicified red laterite (+++ dominant, ++ present, + trace), determined by X-ray diffraction.

MINERALS	2	3	4
olivine+serpentine	+++	+	
talc + chlorite	+	+	+
amphiboles	+	+	+
magnetite	++	+	
chromite	++		
magnesite	+		
smectites	++		
goethite		+++	+++
hematite			+
quartz	+	++	+++

The fresh rock consists of a network of mesh serpentine (serpentine I) filled up by relicts of olivine or by a second generation of a poorly crystallized serpentine (serpentine II). Tremolite, actinolite, anthophyllite, talc and chlorite are present in lesser amounts, and chromite and magnetite are the opaque accessory minerals.

Weathering was initiated by gradual dissolution of olivines, which is replaced by smectites. Serpentine I remains unaltered, but serpentine II becomes yellowish due to the absorption of iron and nickel compounds derived from the dissolution of olivine. In the cracks of the weathered rock, supergene garnierites (serpentine, talc and chlorite-rich varieties) and quartz crystallize.

As the weathering proceeds within the green saprolite, olivine is totally altered, smectitization is intense and serpentine I becomes also yellowish and richer in nickel (established by mass balance procedure). This layer, together with the weathered rock, constitutes the silicate nickel ore.

The further step is the weathering of serpentine I. It slowly breaks down, leaving behind a Ni-goethitic residue (orange saprolite). The garnierites become unstable, provoking a new distribution of Ni, leaving in their place a mixture of Mn, Co and Ni oxides and hydroxides (asbolanes). The accumulation of quartz derived from the crystallization of silica released from the hydrolysis of the silicates increases. The incongruent dissolution of olivine leads to the formation of amorphous silica, ferric hydroxides and goethite. The resulting ferruginous material is the oxidized ore. Finally, there is an incipient transformation of goethite into hematite with loss of nickel (silicified red laterite). The mineral resistant phases concentrate on top of the profile.

CHEMISTRY OF THE LATERITIC PROFILE

The chemical composition of each horizon of the laterite profile is shown in Table 3 (representative samples). SiO_2, the main constituent, concentrates at the bottom of the profile, where it forms a boxwork structure and MgO concentrates as magnesite. Both components are present in the lower portion of the green saprolite layer. Fe, Ti and Cr are less mobile and the first one forms a ferruginous horizon on top of the lateritic profile. Co, Mn and Ni present a relative mobility which results in their concentration in the orange saprolite (Co, Mn) and green saprolite (Ni).

From the fresh rock to the orange saprolite, there is a slight relative increase in SiO_2 and a strong increase in Fe_2O_3, MnO and CoO contents. This corresponds to a significant decrease in MgO due to the hydrolysis of the main Mg-silicates, that results in the almost complete leaching of Mg, partial leaching of silica and residual accumulation of the remaining elements as oxides. The higher Al_2O_3, CaO and Cr_2O_3 contents in the orange saprolite reflects the resistance to weathering of chromite, amphiboles and chlorite.

The nickel content is greatest (up to 2.5%) in the green saprolite. It is released from olivine and serpentine as initially retained by the neoformed silicate phases such as garnierites and smectites at the bottom of the weathering profile. As the weathering proceeds these silicates are further altered to oxides in the orange clays, retaining a part of Ni. Some Ni is leached downwards and is incorporated in the incipiently altered serpentine and in the silicate phases. This addition of nickel from the upper levels makes the altered rock and the green saprolite the zones of maximum supergene enrichment. Manganese and cobalt, less soluble than nickel, are concentrated further up in the profile, in the orange saprolite (Figure 5). Figure 6 shows the nickel ore composition at Santa Cruz deposit, where it was used all analyzed samples (34 in total).

Oxides	0	1	2	3	4
SiO_2	36.62	41.18	43.20	46.71	79.88
Al_2O_3	0.93	1.53	0.74	1.85	0.39
Fe_2O_3	8.79	6.32	10.34	26.40	12.94
MgO	39.06	37.75	27.62	14.14	1.28
CaO	1.76	0.12	1.49	1.90	0.06
Na_2O	0.03	0.01	0.02	0.06	0.01
K_2O	0.39	0.04	0.02	0.01	0.01
TiO_2	0.03	0.04	0.02	0.01	0.07
MnO	0.16	0.11	0.15	0.38	0.16
Cr_2O_3	0.24	0.47	0.26	0.79	0.25
NiO	0.24	2.96	2.17	0.87	0.48
CoO	0.010	0.010	0.049	0.445	0.017
LOI	11.72	10.81	13.90	6.40	4.44
Sum	99.98	101.35	99.98	99.97	99.99
n	4	1	5	1	1

TABLE 3 – Chemical composition (weight %) of fresh rock (0), altered rock (1), (2) green saprolite, orange saprolite (3), silicified red laterite (4) (representative samples).

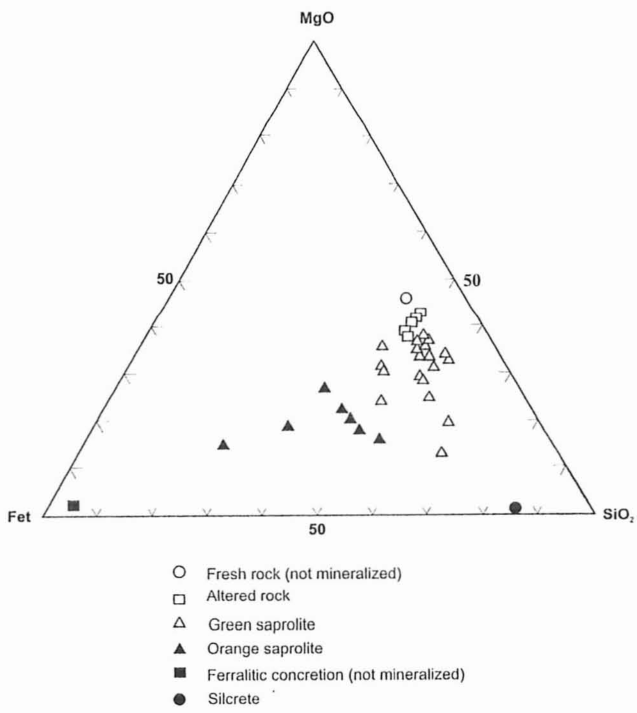

FIGURE 6 – Fe total-MgO-SiO2 diagram showing the nickel ore composition, Santa Cruz Massif (Ipanema Mafic/Ultramafic Complex), Minas Gerais State.

FINAL REMARKS

The metamafic/ultramafic massifs in the Ipanema District occur in high-grade metamorphic terrain and they correspond to alloctonous lower crust block tectonically uplifted. They are emplaced in Archean-Paleoproterozoic country rocks that are composed predominantly by orthogneiss TTG types with narrow and lenticular metassediment intercalations. These metasedimentary rocks are also highly metamorphosed. The mafic-ultramafic bodies seem to be related to a colisional belt accreted to an Archean or Paleoproterozoic continental margin.

At the Ipanema deposits the trends in the chemical evolution of the weathering profile from the fresh rock to the orange saprolite are similar to those described for other lateritic nickel deposits elsewhere in the world (Golightly, 1981). The strongly silicified red laterite, observed on the top of the Santa Cruz massif profile, is a characteristic feature of many Brazilian nickel deposits (Oliveira et al., 1992). With about 80% of quartz (Table 3), this material can not be derived from the evolution of the present day underlying horizons. It probably represents a dismantled silcrete formed in a previous weathering cycle under drier climatic conditions. The SiO_2/Al_2O_3, Fe_2O_3 or Cr_2O_3 ratio, is higher in the silicified laterite than in the parent rock or in the green saprolite, seems to confirm this hypothesis.

For industrial profit, at the Ipanema district, only the silicate ore may be mined. The thin layers of oxidized ore, with less than 1% Ni, are generally not suitable for explotation and concentration. The measured ore reserve of Santa Cruz deposit is 4.10^6 tons (1.24% Ni). Nevertheless all the region may contain a inferred reserve around 12.10^6 tons of ore with 1.25% Ni. Considering their proximity to other small to medium nickel deposits and to the Ipatinga siderurgical pole, roughly 150 km away, these mineral deposits can be considered very interesting from an economic point of view.

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