THE MARA ROSA GOLD DISTRICT, CENTRAL BRAZIL

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ABSTRACT In the Mara Rosa District, three different magmatic series have been identified and all of them host gold mineralization. The Mara Rosa Metavolcano-Sedimentary Sequence constitutes a poorly differentiated calc-alkaline magmatic series typical of arc settings. It is arranged into three belts, forming synclinal structures and was affected by high-grade amphibolite facies metamorphism. Early intrusive rocks of the Posse Unit show an alkaline affinity and host the epigenetic Posse Gold Deposit, which is associated with a late hydrothermal event, preferentially where earlier shear zones are present. Early hydrothermal alteration has produced an aluminous, sulphide rich greisen rock, which is barren of gold. Slices of an allochthonous and more magnesian sequence are associated with metachert and graphitic schists that host the syngenetic Au-Ag Zacarias mineralization and extensions. Gold-bearing quartz veins were emplaced before the second main isoclinal folding event. Supergene ore has played an important role in the mining activity of the Mara Rosa Region, since it represents the majority of the ore exploited. It is possible that yet undiscovered deposits lay hidden underneath the extensive lateritic cover.

Keywords: Gold, Volcanic Sequence, Mara Rosa, Brazil

INTRODUCTION

The Mara Rosa Gold District is located in the northern portion of Goiás State within the Tocantins Tectonic Province (Almeida *et al* 1981). This orogenetic province results from the collision between the Amazon and São Francisco Cratons forming the Brasília and Paraguay-Araguaia Mobile Belts (Almeida *et al* 1981). These are separated by the Goiás Massif, that hosts Archean/ Paleoproterozoic granite-greenstone terrains and the Neoproterozoic Goiás Magmatic Arc, defined by Pimentel & Fuck (1992). This Neoproterozoic terrain extends for approximately 300 km into the central portion of the Tocantins Province (Viana *et al*. 1995) and contains the Mara Rosa Gold District.

Regional mapping projects in the Mara Rosa Region (Machado *et al*. 1981, Ribeiro Filho 1981, Arantes *et al*. 1991) have associated the Mara Rosa Metavolcano-Sedimentary Sequence with gold mineralization (Lacerda, 1986) arranged into three belts (eastern, central and western) separated by tonalitic and granodioritic gnaisses (Fig. 1). Recent data on the nature and age of the rocks (Palermo1996 a,b, Viana *et al.* 1995, Junges 1998) have brought new impetus for the regional geological setting of the area and the understanding of gold mineralization. Three different magmatic series have been identified in the area and all of them host gold mineralization (Palermo 1996 a,b). The calc-alkaline series typical of arc settings is the most abundant in the belts and has been interpreted as part of the Neoproterozoic Goiás Magmatic Arc (Viana *et al.* 1995).

The Mara Rosa Region is heavily covered by lateritic regoliths, some 20 to 30-m deep and product of intense tropical weathering, probably since the Tertiary. Laterization is mostly associated with the planation surfaces developed during the Velhas geomorphological cycle of the Lower Pleistocene. In the study area, remnants of these lateritic surfaces form an extensive plateau at the borders of which the Mara Rosa village is located (Fig.1). Elsewhere the landscape is dominated by a more undulating relief, product of the degradation of the lateritic surface under humid tropical conditions. Stone-line horizons, rich in quartz fragments but also containing remnants of lateritic material are commonly found as a product of this degradation. Bedrock exposure in the area is poor, making geological mapping a difficult task and exploration work a challenge.

This paper presents an overview of the Mara Rosa gold-mineralization settings and its insertion into the geological evolution of the area.

EXPLORATION HISTORY

Gold was first discovered in the area by the Portuguese settlers of the 18th century and was mined from alluvial and colluvial deposits. Since then, rudimentary mining activities exploiting centimetric to metric quartz veins have intermittently taken place, and it is estimated that about 30 to 40 kg of gold have been extracted in the last two decades (Palermo 1984). In 1980, Mineração Colorado (BHP-Utah Mining) started a systematic exploration campaign resulting in the discovery of the Posse Deposit in 1982, as a result of a soil gold panning anomaly. An underground drilling and excavation campaign, comprising some 12.000 m drill-core, a 100 m exploration shaft and 400 m length of galleries, were performed in order to define ore reserves. After a joint venture with WMC, the Posse open-pit reserves, calculated to a depth of 60 m, constitute some 1.7 Mt of ore at a grade of 2.24 g Au/t (Arantes *et al*. 1991). This includes oxide ore reserves of 0.4 Mt at 2.0 g Au/t measured down to 5 m depth (Angeiras *et al*. 1987). Further exploration resulted in the discovery of the Zacarias Deposit, 11 km west of Posse, with reserves of 0.65 Mt at 4.36 g Au/t and 48.06 g Ag/t (Poll 1994). The Posse oxide ore was treated by cyanide heap-leaching process and the primary Posse and Zacarias ores by the carbon in leach process. Following the Zacarias trend are the Cominas, Sorongo and Filó occurrences. These have been worked by small companies and it is estimated that reserves of about 8000 t of ore at 2.8 g Au/t are present at Filó (Osborne 1992). Other deposits discovered in the region include Caranã with 1.13 t Au (Osborne 1992) and extensions of Posse deposit. About 60 km south of Posse Deposit, the Chapada Cu-Au Deposit with 134 Mt at 0.44% Cu and 0.35 g Au/t (Richardson *et al.*1986) was discovered in the early 1970's.

GEOLOGICAL SETTING

The area has been affected by a high-grade regional metamorphism and hydrothermal alteration. Primary rock textures have apparently been completely obliterated. Nonetheless, rock names with a genetic connotation are applied in regional mapping and especially in mine reports, usually lacking an integrated study of lithogeochemistry, petrography and field data. The undertaking of such a study, together with the identification of deformation, metamorphism and alteration events has led to a preliminary synthesis of the geological evolution of the Mara Rosa Region (Palermo 1996a), which is summarized below. Isotope geology revealed the age of some rock units as well as their geotectonic implications (Viana *et al*. 1995, Pimentel *et al.* 1997).

THE MARA ROSA VOLCANO-SEDIMENTARY SEQUENCE

The Mara Rosa Belts are mainly composed by amphibolites and hornblendites, leucocratic microcline gneiss, biotite plagioclase gneiss, kyanite-sillimanite-muscovite schist and/or quartzite, with rare metacherts with graphite layers and talc schists. Lithogeochemical studies based on the relative proportion of less mobile and incompatible elements in amphibolites have identified three groups of rocks representing three different, initial magmatic liquids (Fig.2a,b,c). Each group presents a distinct discriminant geochemical signature during magmatic evolution, as seen by the pattern of major and trace elements (Fig.3), interpreted as the result of three different magmatic series.

The more abundant magmatic series is represented by hornblendites, amphibolites and hornblende-biotite gneiss present in the three belts. They define a calc-alkaline series with minor tholeiitic terms typical of arc settings. Overlying this volcanic unit, is a sedimentary package represented mainly by plagioclase biotite gneiss interpreted as metagreywackes. Minor intercalations of quartzites, calc-silicate rocks and metapelites are also present. The above volcano-sedimentary package constitutes the essence of the Mara Rosa Sequence. The tonalitic gneiss surrounding the Mara Rosa Belts has been dated by Viana *et al* (1995), giving a crystallization age of

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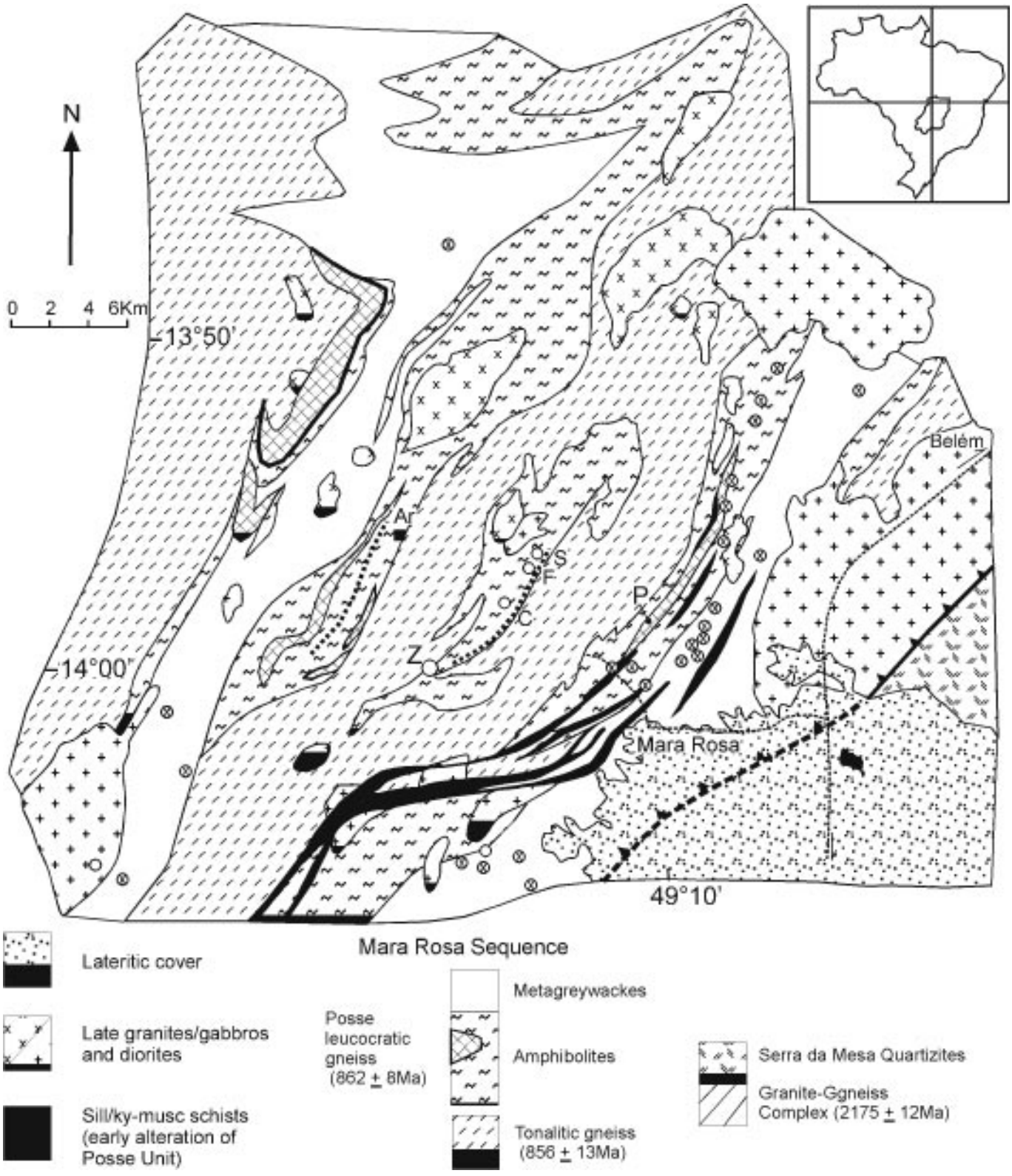

Figure 1-Simplified geological map of the Mara Rosa Region (modified from WMC Mineração Ltda 1991). Z: Zacarias Au-Ag Mine, P: Posse Au Mine, C: Cominas, F: Filó, S: Sorongo, X: gold-bearing quartz veins/alluvium/colluvium.

856+13/-7 Ma (U/Pb in zircon), and has been interpreted by those authors as part of the Mara Rosa Sequence itself.

The allochthonous sequence A distinct geochemical group composed of pyroxene amphibolites, with relatively high Mg, Cr and Ni and low variation of major and trace elements (Fig.3), occurs in close association with talc schists, actinolitites, graphitic levels and metachert in the central and western belts. These lithological assemblages are limited to bands (decametric width, up to 6 km long) parallel to the main foliation, intercalated in the amphibolites of calc-alkaline affinity. They are preliminary considered as an allochthonous series into the Mara Rosa Sequence and may be interpreted as an oceanic fragment or volcanic rocks of komatiitic affinity. Gold mineralization has been identified in the metacherts of the central belt.

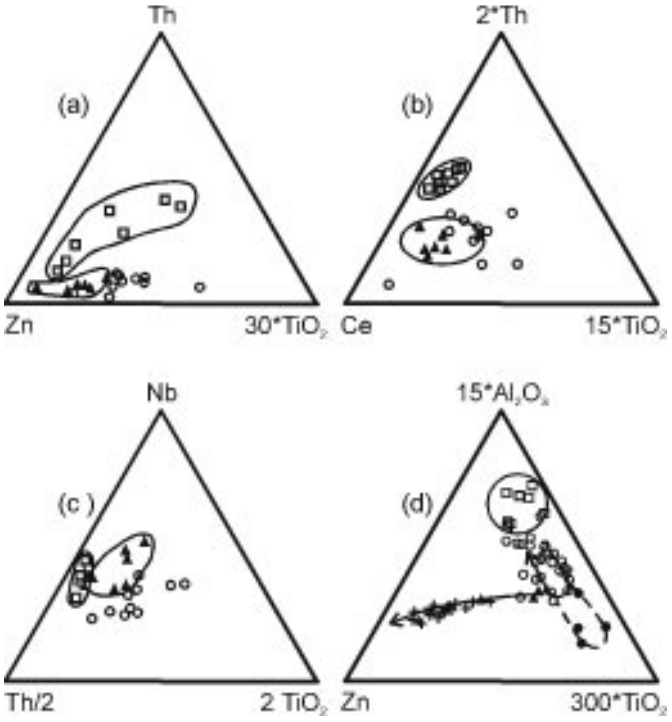

*Figure 2-(a,b,c) Diagrams of incompatible elements for amphibolites (MgO>6); (d) Diagram Al_2O_3*TiO_2*Zr. Distinction of three magmatic series.*

Early intrusive Posse Unit This unit has been identified mainly in the eastern belt where it hosts the Posse Gold Mine. It occurs as kilometric lenses intercalated in the amphibolites of the Mara Rosa calc-alkaline sequence and is represented by leucocratic microcline gneiss, generically named felsite. This gneiss is composed of microcline, plagioclase, quartz and minor biotite, sphene, apatite, zircon, epidote, allanite, garnet, muscovite, magnetite, ilmenite and pyrite. Minor decimetric lenses of amphibolite are found intercalated in the leucocratic gneiss in the Posse Mine. Their geochemical signature is similar to the sub alkaline granite series of Northern Goiás studied by Botelho (1992) (Fig. 2d). They show a characteristic Zr enrichment (up to 500 ppm) with constant alumina content, different from the Mara Rosa calc-alkaline sequence. Petrographic evidences for the intrusive nature of the leucocratic gneiss are the presence of antiperthite and local coarse grained textures. U/Pb zircon dating gives a crystallization age of 862+/-8-Ma (Viana *et al*. 1995), and the model age is 1.0 Ga, which are similar to the *ca*. 856+13/-7 Ma tonalitic gneiss with the same model age. The interpretation of these data remains unresolved.

Late intrusives represented by diorites, gabbros and granites cut the entire rock package.

STRUCTURAL, METAMORPHISM AND HYDROTHERMAL EVENTS Structural field observations together with interpretation of existing geological maps have allowed an interpretation on the relative chronology of deformation. Major tectonic events are responsible for regional foliation (NE-subvertical NW-striking) and structural framework of the area into three synclines represented by the three Mara Rosa Belts (Fig.4). Thrust faults have laminated the overturned flanks of the large synclinal structures. The biotitization of amphibolites in the Posse and Zacarias Mines represents shear zones related to this event. Late deformations are represented by open folds and strike-slip faults with sinistral movement. Two peaks of metamorphism, both of the amphibolite facies, are identified, the earlier one giving rise to sillimanite-muscovite and hornblende-biotite assemblages and the later developing kyanite after sillimanite. Mineral isochrons indicate ages of *ca*. 750 Ma and 610 Ma for these metamorphic events (Junges 1998 and Morais *et al*. 1997).

At least two hydrothermal events have affected the Mara Rosa

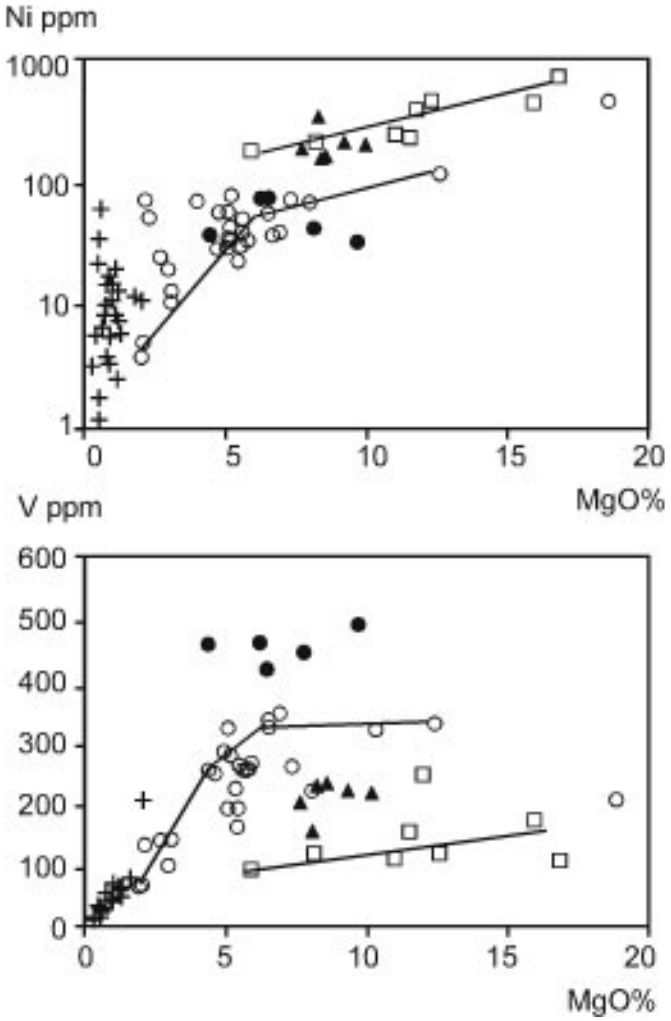

Figure 3-Diagrams MgO versus compatible elements for amphibolites, magmatic trend. Symbols as in Fig. 2.

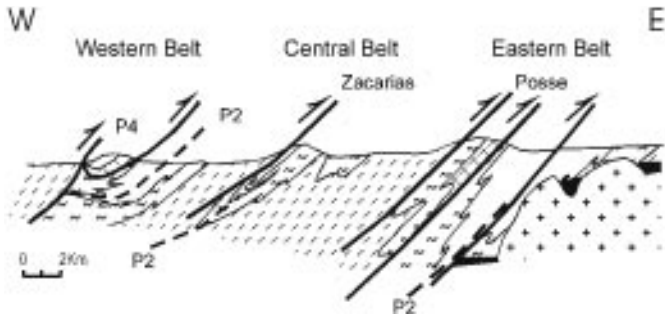

Figure 4-Profile through the Mara Rosa Belts, interpreted as synclinal structures of phase 2. Symbols as in Fig. 1.

Sequence including the Posse intrusive. The earlier one has produced quartz-muscovite-(kyanite)-sillimanite rocks derived from the intense and pre-metamorphic leaching of the Posse intrusive. The second event is post peak metamorphism and is characterized by the development of a mineral assemblage typical of greenschist facies conditions (epidote, actinolite, muscovite, quartz, albite and calcite), which are intense and diverse at Posse Mine.

GOLD MINERALIZATION Posse Gold Mine The mineralized zone extends for almost 1 km in a NNE direction with a thickness of up to 70 m. It is hosted by the leucocratic Posse orthogneiss (Early Posse intrusive) near the contact with the Mara Rosa amphibolites, where the late hydrothermal event produced an

intense alteration with the development of muscovite, epidote, quartz, albite, sericite and carbonate. Amphibolite and biotite sheared rocks from the Posse Unit are barren. Detailed analysis of primary gold under the SEM (Porto & Hale 1996 and Palermo 1996) has revealed that about 90% of the gold occurs intimately intergrown with Fe(Au, Ag, Pb) tellurides as fine, disseminated grains up to 100 mm and the remainder as free isolated grains less than 10mm. This explains the relatively refractory nature of the ore to cyanide leaching (recoveries up to 65%). In general, these mineralogical gold assemblages are also associated with Fe sulphides (pyrite, pyrrhotite, chalcopyrite). Gold fineness ranges from 938 to 1000, with Cu (<0.58%) and As (<0.14%) as trace elements.

Zacarias Au-Ag Mine It is situated about 15 km west of the Posse Mine. The mineralization is hosted by a barite quartzite, rich in a Cr-Ba mica (oelacherite), intercalated in the amphibolites and ultramafics of the central belt. These are intensively altered to aluminous schists composed of a complex paragenesis made of biotite, phlogopite, sillimanite, kyanite, staurolite, cummingtonite, anthophyllite and talc. The orebodies are concordant with their hosting strata and form two major lenses, extending for about 700 m along strike (Poll 1994). Small-scale folds and boudins are observed throughout the orebodies, amphibolites and aluminous schists. Ore mineralogy studies by Marchetto (1990) and Page (1990) showed that gold grains are up to 40 μm in diameter and of a high silver content. It occurs associated with galena, sphalerite, tetrahedrite, pyrite and minor chalcopyrite. It has also been observed as free grain close to quartz and barite. Gold recovery rates by carbon in pulp leaching are above 90% (Poll 1994).

Other central belt occurrences The Zacarias ore horizon extends north for a few hundred meters along strike changing its composition to a sulphide-rich metachert with graphitic shale and manganiferous iron formation. These host Filó, Sorongo and Cominas orebodies, which occur in metachert lenses with minor intercalation of graphite bands, approximately one-meter thick with some galena and pyrite. Talc schist lenses and actinolitites probably belonging to the allochthonous series, are present in the footwall. Late, open folds are well observed in the pit. Filó and Sorongo were mined by rudimentary methods, resulting in extremely poor recovery rates (< 50%).

Gold bearing quartz veins in the eastern belt These constitute several small occurrences mostly hosted in the metagraywackes and amphibolites of the Mara Rosa volcano-sedimentary sequence. Quartz veins vary from a few centimeters to a meter thick, and show massive to granular textures, sericite rich and foliated in places. They are concordant to subconcordant with regional foliation. Late isoclinal folds have affected the veins. Petrographic work shows quartz with deformation textures. Gold occurs as disseminated free grains or filling microfissures. Gold fineness ranges from 853 to 894. Pyrite and galena are present (Palermo 1983, 1984, Porto 1984) .

Morro do Caranã The Morro do Caranã occurrence is located 27 km northeast of the Posse Mine. It is composed by kyanite and pyrite rich micaschists enclosed by amphibolites and felsic rocks. Gold soil anomalies are associated with Cu, Te, Se and Ba. The geological and geochemical characteristics suggest some similarity with the Posse environment, although Osborne (1992) has proposed a resemblance with the Zacarias geological setting.

Supergene gold Deep weathering and lateritization has produced gold concentrations in the regolith which constitute the bulk of the mineable ore in the area since colonial times. This ore has been mined as profitable small operations due to the soft nature of the host rocks and to the predominance of free gold. Deposits of this type includes alluvium/paleoalluvium, colluvium, including stone-line horizons, and residual, ferruginous, clay-rich materials such as latossoils, saprolites and mottled zones. Detailed studies at Posse (Porto 1991) show that the regolith is dominated by a 20-m thick saprolite zone where gold is mostly residually concentrated and constitutes most of the oxide ore. Morphological analysis of the gold grains under SEM shows that the close association of Au with tellurides in the primary ore is substituted in the regolith by an association of Au with limonite which is the result of the oxidation of the tellurides. This has produced an ore where Au is amenable to extraction by cyanide heap leaching with a recovery rate of 95%. Gold enrichment by absolute accumulation occurs only within 1 to 2 m below the surface where a stone line horizon is present. Mass-balance calculations suggest that this enrichment may reach over 200%. It results from chemical and mechanical processes, where gold is probably mobilized by organic compounds and migrates downwards by pedoturbation, related to the degradation of the lateritic surface. Gold is also laterally dispersed into the stone line and so are lateritic pisoliths highly enriched in Te (>50

Table 1: Geological evolution of the Mara Rosa gold district

Deformation	Magmatism/ Sedimentation	Metamorphism	Hydrothermal alteration	**Mineralization**
				Supergene gold
Late Deformations (open folds, strike slips aults)	Late granites, gabbros, diabase		Late hydrothermal event (musc+alb+carb+act+ epid.)	**Au Posse Deposit (tellurures, sulphide)**
Main Deformations (foliation, regional synclinals, shear)		Amphibolite facies Metamorphism (sillimanite/kyanite) (730 Ma/630 Ma)		**Au-bearing quartz veins**
	Early Posse Intrusive Unit (U/Pb 862 Ma)		Early hydrotermal event (greisen type)	**Au-barren sulphide**
Early Tectonic Event (without evidences)	Allochthonous Sequence emplacement ??			**Au-Ag Zacarias Mine**
	Mara Rosa Sequence (volcanic-sed. sequenc of arc setting)			

ppm).

CONCLUSIONS According to the geological setting established for the area, an evolutionary geological framework for gold mineralization is proposed. This is schematically displayed in table 1, which uses the regional deformation events as a relative chronological scale.

There are at least four episodes of ore generation in the study area. The oldest one is represented by the Zacarias Au-Ag Mine and its extensions. These are hosted by chemical sediments (barite quartzite and graphite rich metachert) associated to the allochthonous sequence and are probably of a syngenetic origin (Poll 1994). The second episode of gold mineralization is associated with quartz veins in weathered metagreywackes and amphibolites of the Mara Rosa Sequence. These veins were emplaced at least prior to the second isoclinal deformational phase. The Posse Gold Mine represents the third event of mineralization. It is related to late hydrothermal mineral assemblages formed in previously sheared rocks of the Posse Intrusive Unit and is considered to be of a epigenetic origin. Gold here is of a high fineness, which contrasts to the syngenetic Ag rich ore at Zacarias. Supergene ore represents the last event and has played an important role at the mining activity of the Mara Rosa Region since it represents the majority of the ore exploited. It is possible that undiscovered deposits lay hidden underneath the extensive lateritic cover.

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