Dolomitic Itabirites and Generations of Carbonates in the Cauê Formation, Quadrilátero Ferrífero

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ABSTRACT: Extremely large high-grade iron deposits like Águas Claras, Córrego de Feijão e Mutuca in the Quadrilátero Ferrífero District, Brazil, comprise friable and hard bodies associated with dolomitic itabirites. Dolomitic itabirites are irregularly distributed in the lower proterozoic Cauê Formation, and are understood as a product of the dolomitization and metamorphism of sedimentary banded iron formations. Mineralogic petrographic and microstructural analysis in carbonate and quartz of the dolomitic itabirites from the Aguas Claras Deposit, western Serra do Curral show the existence of four sparitic and micro-sparitic dolomite phases with different compositions and Fe content, that may sequentially replace each other, and two distinct quartz generations. Magnesite may be present too. Dolomitization has produced the protore for friable orebodies and is probably of hydrothermal origin. It seems also to be related with the formation of the hard massive Fe-bodies. Dolomitic itabirite is commonly encountered in the eastern and western domains of the Serra do Curral structure and in the eastern limb of the Moeda Syncline where the metassediments of the Minas Supergroup are in tectonic contact with the underlying schists of the Rio das Velhas Supergroup and with granite gneisses.

1 GEOLOGICAL SETTING – THE QUADRILÁTERO FERRÍFERO

The Quadrilátero Ferrífero is located at the southern border of the São Francisco Craton (Almeida, 1977), a geotectonic unit of Brasiliano age (0.8 – 0.6 Ga). In this area synclines with Paleoproterozoic metasedimentary rocks of the Minas Supergroup present a roughly rectangular arrangement and are separated by antiformal structures dominated by Archean greenstones of the Rio das Velhas Supergroup and domes of Archean and Proterozoic crystalline rocks (Machado et al., 1992; Noce, 1995). The Minas Supergroup comprises, from bottom to top, the Caraça, Itabira, Piracicaba and Sabará Groups (Dorr, 1969). The thickest sequence of iron formations together with enclosing high-grade iron orebodies belong to the Itabira Group, that comprise a sequence of chemical sedimentary rocks deposited in platformal environment with subordinate metapelite units. Carbonate rocks of the upper Itabira Group, which contain algal remnants, have been dated by Babinski et al. (1995) at 2419 +/- 19 Ma (Pb-Pb isochron data). The Sabará Group comprises a 3.0 to 3.5 km-thick sequence of metavolcanoclastic rocks, turbidites and conglomerates separated by an unconformity from the underlying Piracicaba Group.

The regional structure is the result of the superposition of two main deformation events (Chemale Jr. et al., 1994). The first produced the nucleation of regional synclines in the supracrustal sequence, uplifting of the gneissic domes during the Transamazonian Orogenesis (2.1 – 2.0 Ga), and the regional metamorphism. The second was related to a west – verging thrust belt of Brasiliano/ Pan-African age (0.8 – 0.6Ga). The latter event, which was more dramatic in the eastern half of the Quadrilátero Ferrífero, deformed the earlier structures and was responsible for the deformation gradient present in the area. Two main structural domains (Rosière et al., 2001) can be delimited regionally: the Eastern High-Strain Domain includes regional thrust systems and shear zones, whereas the Western Low-Strain Domain displays well preserved megasynclines that are discontinuously cut by discrete shear zones and faults. The iron formation of the Itabira Group delineates the main structures of the entire Quadrilátero Ferrífero as a regional marker, and high-grade iron deposits occur along the limbs of the megasynclines as well as in shear zones in the Eastern High-Strain Domain.

2 ITABIRITES AND HIGH-GRADE ORE TYPES

2.1 Itabirites

The Itabira Group is composed of two formations (Dorr, 1969).

i. The Cauê Formation comprises a thick sequence (ca. 250-300 m) of itabirites intercalated with hematitic phyllites and dolomitic phyllites
ii. The Gandarela Formation, which conformably overlies the Cauê Formation, comprise mainly calcitic and dolomitic marbles with subordinate phyllites.

Itabirites are metamorphic, oxidized and heterogeneously deformed banded iron formations (Dorr, 1969). There are several distinct mineralogical and textural types due to variation in the original composition of the sediments, intensity of deformation, and degree of metamorphism and hydrothermal alteration. Three main compositional types can be distinguished: quartz itabirite, dolomitic itabirite and amphibolitic itabirite. Manganese-rich itabirite and hematite-rich meta-pelitic rocks are also encountered. Quartz itabirite is the most oxidized variety and the more common and wide-spread type as well. It is composed of fine granular quartz alternating with iron oxide bands (hematite/martite with kenomagnetite relics). Dolomitic itabirite is a dolomitized iron formation consisting of red carbonate and black iron oxide bands. Amphibolitic itabirite present several types of amphiboles, depending on the metamorphic grade, together with quartz and eventually dolomite, alternating with iron oxide bands where martite also dominates.

2.2 High-grade iron ores

Two distinct types of high-grade iron ore bodies (>65 wt % Fe) occur in the Quadrilátero Ferrífero :

i. Hard ores both as massive and schistose bodies composed of hematite, martite, specularite and iron-deficient magnetite (kenomagnetite). The shape of the massive orebodies is totally or partially controlled by the bedding of the BIF protore, and the granoblastic fabric commonly mimics the itabirite structure. Irregular pockets of high-grade iron ore with a brecciated fabric may also occur but are not as common. Schistose orebodies composed mainly of oriented specularite plates occupy shear zones that crosscut the BIF.
ii. Soft, friable ores, distributed as “alteration halos” around the hard orebodies. Soft high-grade orebodies may be powdery, structureless, or else present a brecciated structure or relics of the original banding. Huge cavities of several meters diameter may also be present. Soft high-grade ores do not considerably differ in mineral composition from the hard ores except in the case of some discontinuous pockets of powdery *blue dust* composed of random textured platy hematite that occur in the middle of granoblastic ores. Goethite occurs only in the surface, with its concentration decreasing quickly with depth. Relics of gangue minerals such as quartz or dolomite, quartz, chlorite, talc and apatite may be detected

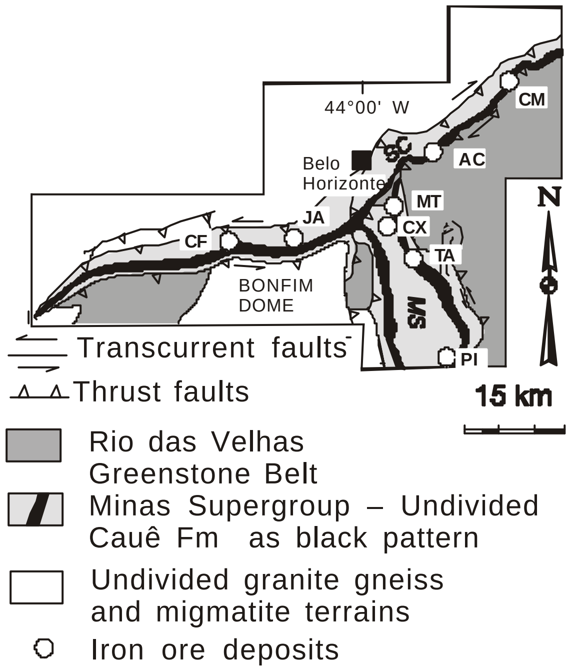

Fig.1 – Geologic location map of the confluence between the Serra do Curral (SC) and Moeda Syncline (MS) with distribution area of dolomitic itabirite (Cauê Formation). Iron deposits: PI – Pico; TA – Tamanduá, MT – Mutuca; CX – Capão Xavier, AC – Águas Claras; JÁ – Jangada, CF – Córrego do Feijão, CM – Córrego do Meio.

3 DOLOMITIC ITABIRITES AND DOLOMITE GENERATIONS

Dolomitic itabirite occur mainly in the western Low-Strain Domain along the central part and western branch of the Serra do Curral Ridge and in the northern half of the western Limb of the Moeda syncline both as outcrops and diamond drill cores around mines such as Fazendão, Jangada, Aguas Claras, Mutuca and Capão Xavier (Figure 1). Contact between dolomitic rocks and normal, quartz itabirite is gradational both laterally and vertically.

This variety of itabirite present both meso- and micro- banding with alternating carbonate/quartz (reddish-white) and iron oxides (dark gray-black) bands (see Spier et al. 2003 for a detailed description). Several dolomite and quartz veins cut across the banding (Figure 2). This structure may be entirely transposed and obliterated in shear zones with the development of a schistosity and a secondary (tectonic) banding that may easily confused with the primary (sedimentary/diagenetic) structure.

Dolomitic itabirite can be hematite-rich (up to 42.5% Fe – Spier et al. 2003) and may locally develop into hard massive ore. It also gradates to the top of the sequence (Gandarela Formation) into iron-poorer banded or massive gray to pink dolomites although the contact between the lithologies are commonly sharp. Dolomitic phyllite may also occur interlayered and with gradational contact.

For the present studies, samples were selected of dolomitic itabirite from the open pit and the diamond drill hole PZ5501 from the Aguas Claras Deposit (Figure 2). This deposit is the most important occurence of dolomitic itabirite and, at the same time, the largest single high-grade orebody of the Quadrilátero Ferrífero (now exhausted). It is located in the eastern branch of the Serra do Curral Range (Chemale Jr et al. 1994) near the confluence with the Moeda Syncline (see Spier et al., 2003 and references therein, for further details). The orebody is composed mainly of soft, friable ore, presenting a banded structure defined by alternating porous and compact mm to cm-thick layers.

Fig 2. Quartz dolomite itabirite. C1B Fe-dolomite (dark-grey) substitutes quartz (white) in fold hinges

3.1 *Dolomite Generations*

Detailed petrographic and mineralogical analysis of the carbonates from itabirite show distinct generations of dolomites: dolomite C1 is microsparitic with average grain size of 15mm and occurs in the mesobands of the itabirite. Dolomite C1A is colorless but C1B is red to pink due to its higher Fe and Mn content. C1B may substitute fine-grained quartz, especially in the fold hinges (Figure 2). Generations C2 and C3 occur in veins as corser sparry dolomite. C2 carbonates are Fe-rich and occur in stretched veins with *boudin* structure. C3 carbonates are colorless, Fe-poor, precipitated in veins and strain shadows from C2 *boudins*. Late calcite and quartz veins cross-cut the fabric.

4 GENETIC CONSEQUENCES AND DISCUSSION

A hypogene hydrothermal model (Oliver & Dickens, (1999) Barley et al., (1999), Hagemann et al., (1999), Taylor et al., (2001) and Rosière & Rios, (in press) is now widely accepted to explain the origin of hard high-grade iron orebodies, probably envolving both meteoric and deep-seated fluids. Rosière & Rios (in press) suggest that meteoric fluids moved downwards from the surface along normal faults and fractures during progressive uplift and extension of the crust during the collapse stage of the Transamazonian event (Alkmim & Marshak, 1998). These fluids pervasively oxidized the original BIF in the entire QF, producing high-grade bodies in sites of more intensive water percolation such as along major faults and second-order folds, due to its higher permeability.

Soft high-grade ore seem to have undergone related but distinct processes with superposed supergene and hypogene mineralization events. The intimate association between large soft high-grade ore and dolomitic itabirite and the presence of large caves occasionally encountered during the mine operations presenting typical collapse structures speak for the importance of supergene processes as already pointed out by Viel et al (1999) and Spier et al. (2003).

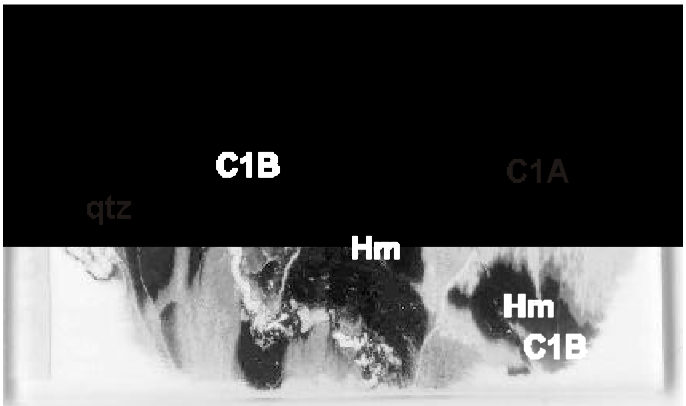

Fig 3. Thin section of partially oxidized dolomitic itabirite. C1A Microsparitic light-colored dolomite, C1B – Microsparitic Fe-dolomite. Hm – Hematite. Qtz – Quartz vein

Dolomitic itabirite probably forms from folding-related substitution of quartz to ferroan dolomite (C1B dolomites). An intense magnesium remobilization is also attested by the presence of large magnesite body partially controlled by the hinge zone of a regional fold in the Acaba-Mundo Quarry, just a couple of kilometers distant from the

Aguas Claras Mine. Further remobilization of carbonates producing coarse sparry Fe-rich dolomites (C2 dolomites) and minor calcite veins completed the process. Fe-dolomite was oxidized by hydrothermal fluids in order to form hematite (as it is possible to observe in Figure 3) in a much more efficient way than would be expected for a presumed metassomatic substitution of quartz. High-grade orebodies developed by complete substitution of dolomite, enveloped by an Fe-rich dolomitic protore. Soft ore is therefore, the weathering product of an incomplete mineralized dolomitic itabirite. Remaining carbonates and minor quartz from the hypogene phase were leached resulting in gigantic deposits like Aguas Claras by residual enrichment. Soft high-grade bodies may also occur related to quartz-itabirite such as in the Cauê Deposit, but they are smaller, extend to much shallower levels, and are considerably different, presenting relics of interstitial quartz and gradational transition to the protore, especially close to the land surface, forming high-grade soft, friable, quartz-itabirites.

5 ACKNOWLEDGEMENTS

The authors thank the MBR in the name of O. Tessari and particularly C.A. Spier for making available the samples and for the fruitful discussions, sharing valuable information. N.B-F-S thanks the FAPEMIG and UFMG for the BIC-scholarship (PROBIC-Program) and C.A.R thanks the CNPq for the all-round financial support.

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