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Iron-rich formations at the Cerro Manomó region, Southeastern Bolivia: Remnant of a BIF?

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In Southeastern Bolivia, the field relations, geochemical and isotopic data collected in the Manomó area, along with the occurrence of apatite-rich lenses, carbonate blocks and the extensive enrichment in U, Th and REE probably point to a complex history:

1. *An old BIF-like formation with E-W orientation, formed and metamorphosed during Mesoproterozoic times, cuts an older compressive structure at the border of the Amazonic craton;*
2. *Probable intrusion and fenitization by carbonatitic magma in (Early, Late?) Cretaceous times;*
3. *Lateritization processes and formation of a thick duricrust in Tertiary-Quaternary times.*

A more detailed field sampling, as well as additional systematic and extensive geological, mineralogical, petrographic and geochemical studies are required to obtain a more accurate regional picture.

Introduction

Banded iron formations (BIF) are rocks of chemical-sedimentary origin usually deposited during the Precambrian, which consist of pale silica-rich cherty bands alternating with black to dark red iron-rich (hematite or magnetite) bands (Gross, 1980). These contrasting layers are sharply defined, so that the rock has a striped appearance. This dichotomous compositional layering is usually expressed on several scales at any given outcrop, from fine sub-millimetre-scale varve-like laminae to several meters-scale bands. Haematite and magnetite dominate the iron-rich layers, often accompanied by other metal-oxides and -sulphides such as pyrite, chalcopyrite and ilmenite. Varying amounts of carbonate mineral phases, such as calcite and siderite, may or may not be present in both iron-rich and chert-rich layers. Layers of silica may or may not be jasperiferous. Even on a microscopic scale, the transition between iron- and silica-bands is abrupt. Moreover BIF are normally hard rocks, highly resistant to erosion.

Many of the known BIF formed from 3.8 (e.g. Isua, West Greenland) to 1.8 Ga (Klein, 2005). Their overall volume reaches a maximum at about 2.5 Ga (e.g. BIF of Hamersley Basin, Western Australia; Klein, 2005). BIFs are less common after 1.8 Ga, although some are known that are much younger, e.g. Fe and Mn deposits of the Urucum district in W-Brazil and Mutum in SE-Bolivia (1000-600 Ma; Urban et al., 1992; Trompette et al., 1998; Walde and Hagemann, 2007; Kock et al., 2010; cf. Fig. 1).

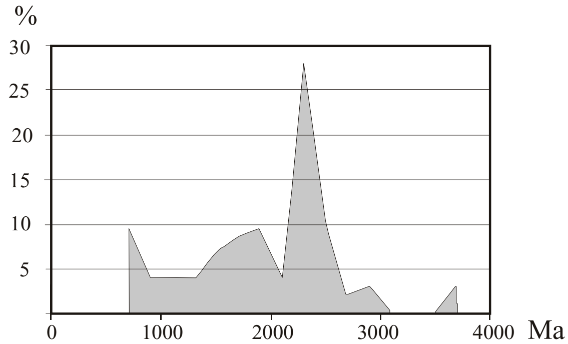

Figure 1. Areal age distribution (%) for world-wide BIF, after Kock et al. (2010) and references therein and Johnson et al. (2008).

Stratabound syngenetic ironstones of the Mesoproterozoic San Ignácio depositional cycle (banded hematite/magnetite rich quartzites and quartz-breccia reefs), in the Southeastern Bolivia, are reported by Litherland et al. (1986).

In the laterized peneplain, NE of San Ignácio town (Fig.2), Southeastern Bolivia, quartz- and hematite-rich bands, up to 100 m thick and with sub-vertical E-W attitude, crop out over a flat plateau due to the development of a iron-rich lateritic duricrust, showing characteristics very similar to the BIF. In particular Cerro Manomó (15°33' South, 60°37' W, s. later), outcropping in an E-W macro-lineament, is also characterized by macro- and microbands of quartz- and hematite-rich types.

On the other hand, ironstone beds with jasper band of Neoproterozoic age occur also in SW Brazil and SE Bolivia (Jacadigo-Boqui Fe-Mn deposits of Graf et al., 1994).

We highlight the characteristics of these rock types with the aim to show the occurrence of BIF-like formation also in this region.

The aim of this article is to study the origin and evolution of a BIF-like formation in the Cerro Manomó region, based mainly on new geochemical and geochronological data.

Geological overview

The SW part of the Amazonian Craton comprises four Proterozoic provinces: Venturi-Tapajós (2.0 - 1.8 Ga), Rio Negro-Juruena (1.78-1.55 Ga), Rondonian-San Ignacio (1.55-1.30 Ga) and Sunsás-Aguapeí (1.25-1.0 Ga) (Cordani and Texeira, 2007; Cordani et al., 2010). In the eastern Bolivian shield, Litherland et al. (1986) proposed the term

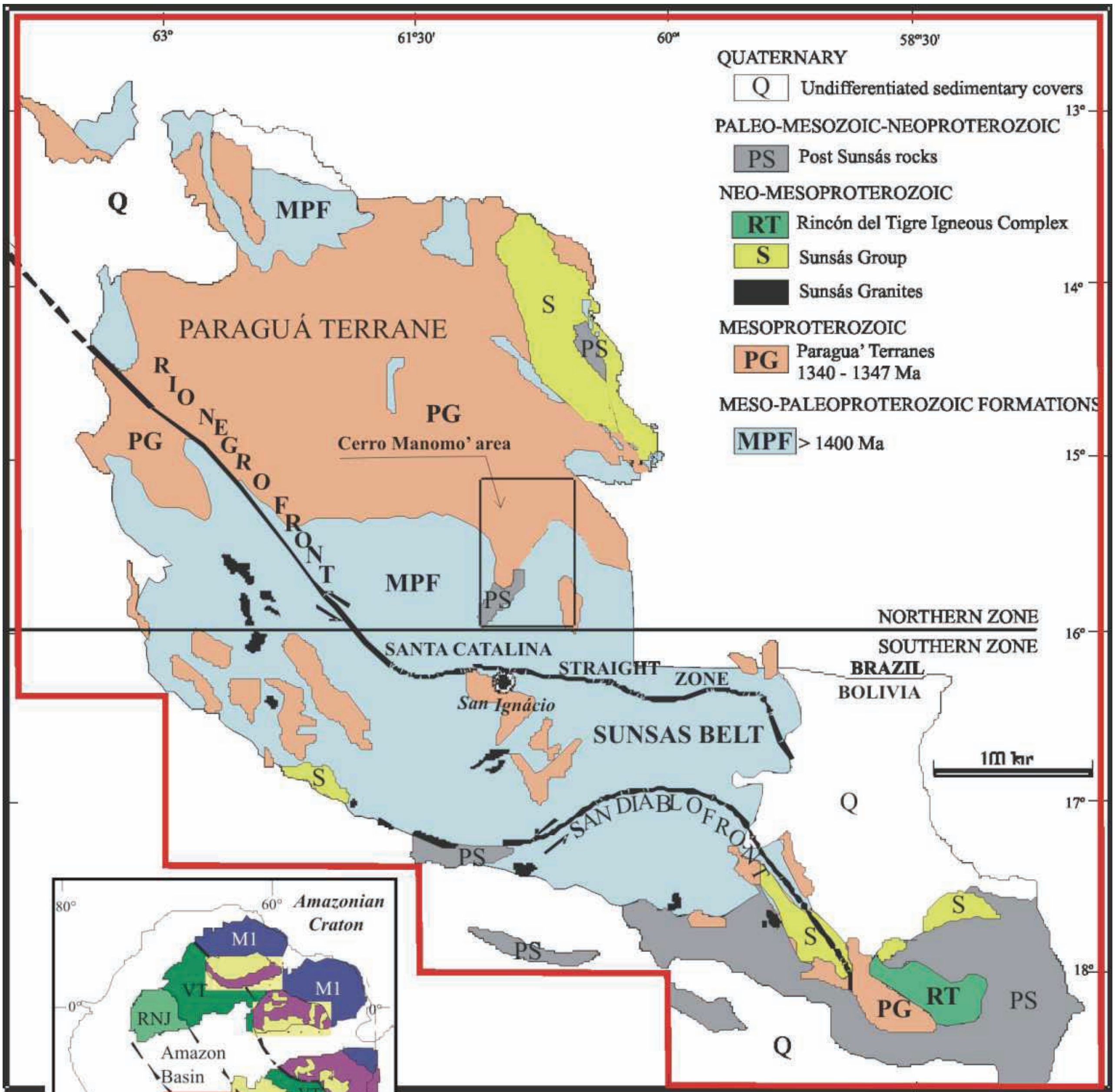

Figure 2 Simplified map of the Southeastern Bolivia (San Ignácio de Velasco area), showing the approximate boundaries of the main tectonic elements and lithologies (after Litherland et al., 1986;, Ruiz, 2005;, Matos et al., 2009;, Bettencourt et al., 2010). Inset: major provinces of the Amazonian Craton (cf. Cordani and Teixeira, 2007): MI, Maroni-Itacaiunas, VT, Ventuari-Tapajós; RNJ, Rio Negro-Juruena; RO, Rondonian-San Ignacio; SS, Sunsás-Aguapeí Province. Location of Figure is shown here (red line).

"Paragua Craton" to characterize a tectonically stable region during the Meso- and Neoproterozoic deformation of the Sunsás and Aguapeí belts. However, in subsequent articles (Tohver et al., 2004; Boger et al., 2005), the Paragua Craton was defined as an allochthonous unit with respect to the southwestern margin of the Amazonia. Boger et al. (2005) advocate that the basement, i.e. Paleoproterozoic units of the Paragua Craton (eastern Bolivia), has no equivalent in Mato Grosso and Rondonia regions.

Based on significant geochronological data, Bettencourt et al. (2010, and therein references) suggested that these rocks could originally be a segment of the Rio Negro–Juruena Province detached in the 1.5-1.4 Ga interval, according to the previous model after Sadowsky and Bettencourt (1996), and amalgamated to the proto-Amazonian Craton at 1.34 -1.32 Ga, during the Rondonian-San Ignacio Orogeny.

Bettencourt et. al (2010) adopt the term "Paraguá terrane" to characterize these composite terranes comprising the Paleoproterozoic basement rocks (Chiquitania Gneissic Complex, San Ignacio Schist Group, Lomas Maneches Granulitic Complex) and the Meso-proterozoic granites.

The Chiquitania Gneiss Complex is mainly composed of migmatitic gneiss associated to schist belts, and the Lomas Maneches

Complex comprises charnockites, granulites, granitoids and calc-silicate rocks (Bettencourt et al., 2010).

The Banded Iron Formation analyzed in the present article is located in the Cerro Manomó region (Fig 2, s. later) and belongs to the San Ignacio Schist Group (according to Bettencourt et al., 2010), which is also made up mainly of pelitic schists with psammitic layers, metavolcanic metarhyolites, metabasalts and cherts. The first articles on these rocks (Litherland and Bronfiled, 1981; Jones, 1985; Litherland et al., 1986, 1989) discuss the relationship between these metavolcanic-sedimentary rocks and the surrounding basement gneisses, in order to compare the belt with the classic Archean greenstone belts. Jones (1985) speculated about the possible Archean age of the San Ignacio Schist Group and associated gneisses. Geochronological data indicate that the sedimentary deposition of the San Ignacio Schist Group occurred after 1690 Ma (Boger at al., 2005; Bettencourt et al., 2010; Matos, 2010), thus determining the maximum age for the deposition of the BIF-like formation. During the orogenic phase, these rocks underwent three WNW phases of deformation (Litherland et al., 1986). Remelting of the crust, low- to medium-grade metamorphism of the volcano-sedimentary sequence took place during the 1.32- 1.34 Ga interval (Bettencourt et al., 2010 and references therein). The syn - to late - and late - to post-tectonic granites of the San Ignacio orogen range from 1.37 to 1.32 Ga (Matos et al., 2010).

The basement rocks of the San Ignacio Schist Group lie within the bounds of the Sunsás collisional belt (Fig. 2). The Sunsás belt is part of the Sunsás-Aguapeí province (1.00-1.25 Ga, Cordani and Teixeira, 2007) and represents the youngest geotectonic event of the SW Amazonian craton in Bolivia. It is coeval with the evolution of the Nova Brasilândia Sequence in Brazil. In spite of the existence of some areas with weak metamorphic overprint and preserved non-penetrative deformations (Litherland et al., 1986; Sadowsky and Bettencourt, 1996; Borger et al., 2005), the Sunsás belt is structurally characterized by extensive shear zones and syn- to late- and post-tectonic to anorogenic granite intrusions (1000 to 1105 Ma, Texeira et al., 2010, and references therein). Estimates of the age of deformation and metamorphism of the supracrustal rocks range from 1.10 (Girardi et al., 2008, Table 1) to 1.11 to 1.18 Ga (Santos et al., 2008). Geochronological data from the banded iron formation indicate the influence of Sunsás-Aguapeí metamorphic event and will be discussed later on.

Cerro Manomó Area

The samples were collected at and around Cerro Manomó, a hill located 22 km northeast of the northeastern outcrop of the Early Cretaceous Velasco alkaline complexes (cf. Comin-Chiaramonti et al., 2005). Although all rock types from Cerro Manomó were strongly altered, Burton (1982, in Litherland et al., 1986) was able to postulate, based on the outcrop forms, macro- and micro-textures and alteration products, that the complex consists of a central core of intensely brecciated and silicified gneisses surrounded by fenitized gneisses and cut by a network of steeply dipping dykes and final stage agglomerates. In particular, some reef-like outcrops are composed by goethite-quartz-barite-bastnaesite assemblages, and were interpreted as altered ferrocarbonatites by Burton (1982). A lens of apatitite-rich rock (Fletcher et al., 1981) can be seen in the northeastern part of the complex associated with rare carbonate blocks. According to Comin-Chiaramonti et al. (2005), the latter rock types are ferrocarbonatites, made up of altered sideritic-ankeritic carbonate with subordinate calcite, goethite-limonite, quartz, apatitite and REE-fluorcarbonates (mainly bastnaesite and synchysite).

According to Litherland et al. (1986), the stratigraphic relationships and the tectonic events suggest that Early Cretaceous faulting and intrusions in the area of the Velasco complexes predate the uplift, faulting and emplacement of the Cerro Manomó complex (Early Cretaceous?, cf. Fletcher et al., 1981).

The Mesozoic tectonic history is though be related to the rifting and to the intrusions of the Velasco (and possibly Manomó) alkaline and alkaline-carbonatitic complexes at 140 Ma (Litherland et al., 1986; Comin-Chiaramonti and Gomes, 2005).

The Cenozoic times are characterized by erosional cycles, and by the formation of a Fe-lateritic duricrust as the main weathering product of the bed rocks (San Ignacio lateritic surface, according to Boulange and Litherland, 1978).

However, the Manomó hill is peculiar for its banding of Fe-rich and Si-rich layers: this banding can be observed on a wide range of scales, i.e. from coarse macrobands (up to several tens of centimeters in thickness) to millimetric and sub-millimetric layers (microbands; Fig. 3). The macrobands correspond to the petrographic description of Fletcher et al. (1981) and are characterized by an association of hematite, goethite, limonite and barite. The microbands show fine-scale banding of chert occasionally associated with some coarse-grained quartz, and hematite-goethite-limonite-rich levels.

On the whole, macro- and microbands show marked similarity with those of worldwide banded iron formations.

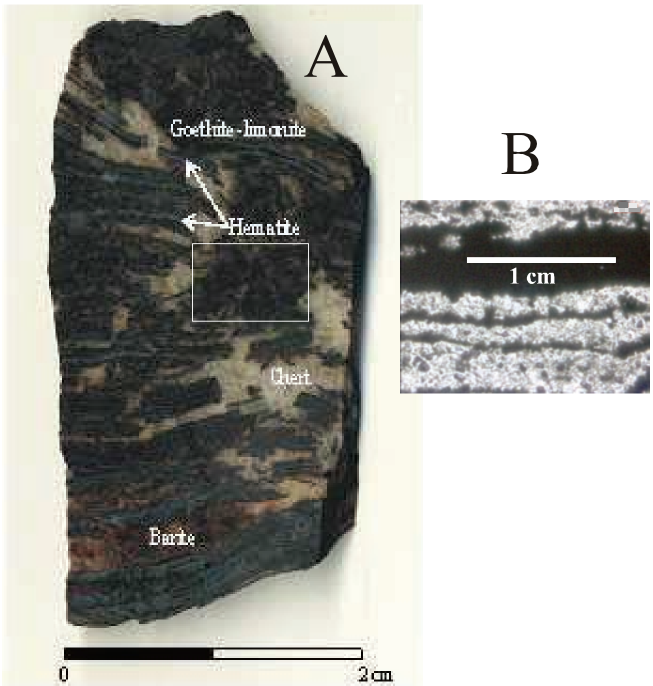

Figure 3. (A) Alternate succession of silica (chert) and iron-rich (femicrite) microbands in a sample from the Cerro Manomó. (B) Detail of A, under microscope (crossed nicols) with a view of microbanding of chert and hematite.

Sampling and analytical methods

Sampling of the rocks from Manomó area was restricted by availability of relatively fresh outcrops. Lithotypes are massive chert-rich and femicrite mesobands, according to the nomenclature of Beukes (1980). Some microbands were also sampled (cf. Fig. 3). Hematite is the dominant oxide, where goethite and limonite often replace hematite. Sample preparation and geochemical analyses were carried out at the Laboratories of the Earth Science Department of the Trieste University.

Major and trace elements (Cr, Ni, Ba, Rb, Sr, Zr, Y) for whole rocks were analyzed by XRF fluorescence techniques using a PW1400 automatic spectrometer and pressed-powder pellets. FeO was determined by volumetric titration, using the ammonium metavanadate.

Trace elements (Rb, Sr, Pb, Nb, Ta, Hf, U, Th, REE) were also determined in selected samples by ICP-MS procedures (cf. Alaimo and Censi, 1992).

The radiogenic isotopes were performed at the Department of Mineralogy and Geotectonic, São Paulo University, USP. Details of the analytical procedures are given in Comin-Chiaramonti and Gomes (2005) and in Comin-Chiaramonti et al. (2005. The standards used for Sr and Nd isotope analyses were NBS 987 and La Jolla, respectively [NBS987: $^{87}Sr/^{86}Sr$=0.710231 (2σ:0.000008) n=20; LaJolla: $^{143}Nd/^{144}Nd$=0.511971 (2σ: 0.000015), n=21].

Oxygen was extracted from the chert and hematite by conventional fluorination methods (Clayton and Mayeda, 1963) and converted to carbon dioxide: isotopic measurements were carried out on a VG 903 mass spectrometer (δ^{18}O‰ notation). During the course of the analyses NBS28 gave $\delta^{18}O = 9.7 \pm 0.2$‰, relative to SMOW.

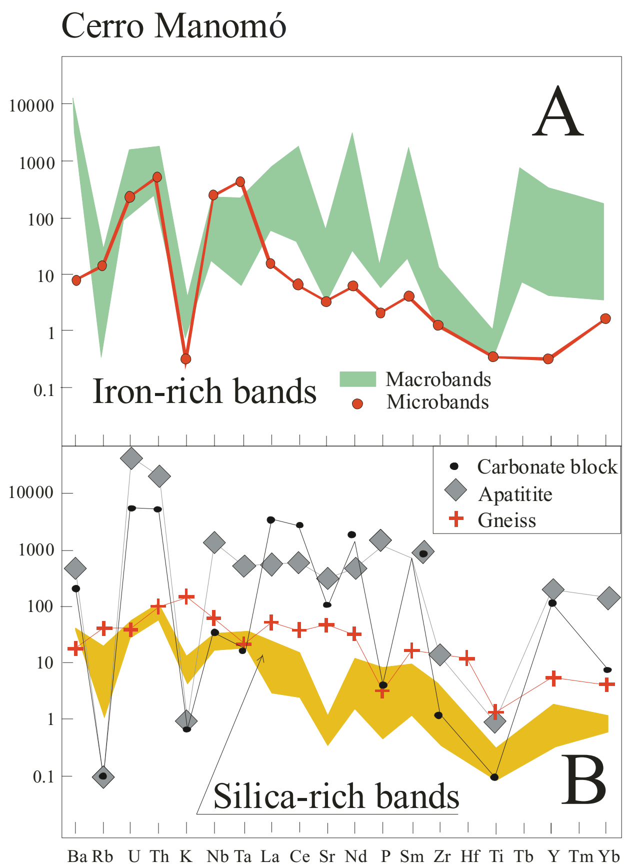

Figure 4. A: Primitive mantle-normalized incompatible elements (Sun and McDonough 1989) of rock-types from the Cerro Manomó complex representing iron-rich macro- and microbands. B: Field representing the silica-rich bands. For comparison are shown the carbonate block and apatitite, along with a representative gneiss from basement (cf. Table 1).

Geochemistry

Major and trace elements

Chemical analyses of selected samples (Table 1) outline the different compositions of alternating ferruginous-siliceous macro- and microbands.

Incompatible elements from the Fe-rich macrobands (values normalized to the primitive mantle; Fig. 4A) are strongly enriched by Ba (up to 10.43 wt%), Th (up to 1739 ppm) and REE (except La, i.e. La 40-469 ppm in comparison to Ce and Yb, up to 3519 and 82 ppm, respectively), and show deep negative anomalies for Rb, K, Sr, P and Zr-Ti. The Th content of the macrobands accounts for the widespread high radioactivity of the area (Fletcher et al., 1981).

The carbonate blocks shows to some extent the same pattern of Fe-rich macrobands, except the high La content (up to 2570 ppm). The apatitite has high U and Th contents (1010 and 1730 ppm, respectively), but a flat Nb-P pattern (approximately 1000 times the primitive mantle; Fig. 4B).

Chondrite normalized REE patterns (Fig. 5) highlight the large variations relative to the iron-rich macrobands and a strong enrichment in particular for LREE and MREE. Nevertheless, the striking similarity between the REE signature of the microbands and the banded iron formations (BIF and JB of Fig. 5) leads us to propose a similar origin for the BIF of the Cerro Manomó complex and neighboring areas (cf. mid-Archean BIF of Kato et al., 1998). Moreover, the positive Eu anomaly in the silica-rich bands (Fig. 5) may imply hydrothermal activity.

In addition to that, the associated crystalline basement has incompatible elements and REE patterns similar to those from the BIF, mostly in the MREE/HREE poor fractionation, as well as HREE flat behavior, probably owing to a REE redistribution during later metamorphic events. The apatitite-rich lens shows a strongly REE enriched pattern (10 times enriched compared to the basement gneiss; cf. Fig. 5) and a poor LREE/HREE fractionation (chondritic La/Yb=3.5), contrasting with the strong REE fractionation of the associated carbonate blocks (chondritic La/Yb=192).

It is important to consider that the region is a jungle-covered highland with lateritic duricrust very thickly developed, and that “minor ferruginous quartzites and meta-ironstones” (Litherland et al.,1989) of the San Ignacio Schist Supergroup in the Cerro Manomó complex and neighbouring areas are very similar to other BIF described by Trendall and Blokey (1970), Trendall (2000) and Klein and Ladeira (2002) as well as by Geraldes et al. (2000) and Leite & Saes (2000) in the states of Rondônia and Mato Grosso (Brazil).

Sr and Nd isotopes

The isotope ratios $^{87}Rb/^{86}Sr$ vs $^{87}Sr/^{86}Sr$ (cf. Table 1) define a regression line corresponding to an age of 1275 ± 20 Ma (Fig. 6A). On the other hand, the isotope ratios $^{147}Sm/^{144}Nd$ vs $^{143}Nd/^{144}Nd$ show an alignment fitting an age of 1174 ± 24 Ma.

Note that the $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ ratios were calculated

Table 1. Chemical analyses and isotopic results for the selected samples from the Cerro Manomó complex(MDL: measure detection limit). Fe and Si, iron- and silica-rich bands, respectively. MR-16**, phosphate-rich rock types (after Litherland et al., 1989; cf. also Comin- Chiaramonti et al., 2005). PV-69C, carbonate block, i.e. carbonatite-like rock; PV-70, basement gneissic rock (after Comin-Chiaramonti et al., 2005). It has to be stressed that apatitite and carbonatite are younger with respect to other rock types. The ($^{87}Sr/^{86}Sr)_0$ and ($^{143}Nd/^{144}Nd)_0$ initial ratios calculated at 1174 Ma, according to Fig. 6B.

Sample	PV-67 Fe-Macro band	PV-68 Si-Macro band	PV-69A Fe-Macro band	PV-69B Fe- Macro band	PV-67A Fe- Micro band	PV-67B Si-Micro band	PV-69C Carbonate block	MR-16** Phosphate Rock (Apatitite)	PV-70 Basement gneiss	MDL
wt%										
SiO_2	40.55	87.66	38.55		22.02	92.88	3.02	5.67	74.18	0.01
TiO_2	0.07	0.07	0.17	0.10	0.08	0.02	0.02	0.20	0.29	0.01
Al_2O_3	0.27	3.90	0.12		0.88	0.60	0.11	1.20	13.11	0.01
Fe_2O_3	53.16	5.64	50.07		74.13	0.86		23.27	1.20	0.01
FeO							40.49			0.01
MnO	0.36	0.06	0.42		0.20	0.06	7.13	0.45	0.01	0.01
MgO	0.09	0.11	0.25		0.08	0.01	0.34	0.40	0.02	0.01
CaO	0.16	0.15	0.50		0.11	0.07	7.68	37.51	0.12	0.01
BaO	2.58		6.23	8.52				0.40		0.01
Na_2O	0.09	0.01	0.29		0.09	0.01	0.08	0.57	2.89	0.01
K_2O	0.02	0.40	0.07	0.08	0.01	0.12	0.02	0.03	4.40	0.01
P_2O_5	0.12	0.18	0.32	0.29	0.05	0.01	0.10	25.19	0.07	0.01
LOI	1.41	1.68	2.11		1.83	4.65	35.28	3.77	3.38	0.02
F							0.31	1.69		0.01
Sum	**98.88**	**99.86**	**99.10**		**99.48**	**99.28**	**94.58**	**99.66**	**99.67**	
ppm										
Cr	46		9	12	74			162	10	8
Ni	26		113	8	42					0.1
Ba	25783	315	56728	76293	57	278	1560	3600	137	1
Rb	19.2	13.5	10.3	0.2	10.0	0.72			26.0	0.1
Sr	54.6	954	333.8	928.2	78	28	2342	7103	1058	1
Pb	57.3	29.8	64.4	58.8	82	7.3		110	16.6	0.1
Nb	159	26.4	12.1	52.4	202	13.1	25	1025	43.4	0.1
Ta	9.5	1.6	0.3	0.6	20.0				0.9	0.1
Hf	0.9	0.3	0.4	0.2					3.9	0.1
U	2.5	1.3	22.3	34.0	5.3	0.6	121	1010	0.9	0.1
Th	22.1	11.3	763.3	1739	46.9	5.2	481	1730	8.4	0.2
Zr	33.2	47.7	11.6	33.8	14.8	4.4	15.0	159	157	0.1
Y	18.0	9.0	714.9	965	38.00	1.5	49	755	18	0.1
La	40.3	18.1	342	469	11.3	2.1	2570	396	37.5	0.1
Ce	63.6	28.6	892	3519	12.8	4.4	5238	1150	70.3	0.1
Pr	4.1	4.1	220	770	2.1	0.6	787		11.3	0.1
Nd	35.1	17.0	1238	3441	9.2	2.32	2142	655	44.2	0.3
Sm	8.5	4.7	273	533	2.0	0.6	369	330	7.66	0.05
Eu	2.10	1.37	76.3	128.4	0.47	0.32	79	95	1.60	0.02
Gd	6.0	3.4	233	513	1.5	0.5	221		4.55	0.05
Tb	0.82	0.41	52.5	73.0			13	23	0.60	0.01
Dy	3.7	2.0	290	357	1.4	0.5	60	137	3.10	0.05
Ho	0.60	0.31	51.0	61.8			10.0		0.58	0.02
Er	1.65	0.74	105.6	158.0	0.81	0.29	24.0		1.72	0.03
Tm	0.24	0.10	11.4	17.8			3.00		0.27	0.01
Yb	1.55	0.65	51.0	82.5	0.90	0.30	9.0	75	1.99	0.05
Lu	0.15	0.10	5.80	8.80			1.00	12.0	0.32	0.01
Eu/Eu*	0.85	1.00	0.90	0.78	0.79	1.79	0.78	1.00	0.77	
Measured										
$^{87}Sr/^{86}Sr$ (2σ)	0.72715 (2)	0.70925 (7)	0.71013 (6)	0.70861 (9)					0.711081 (8)	
$^{143}Nd/^{144}Nd$ (2σ)	0.512495 (2)	0.512657 (2)	0.512385 (2)	0.512083 (3)					0.511798 (7)	
Initial (1174 Ma)										
$(^{87}Sr/^{86}Sr)_0$	0.70987	0.70856	0.70862	0.70860						
$(^{143}Nd/^{144}Nd)_0$	0.51135	0.51136	0.51135	0.51136						
$\delta^{18}O‰_{Quartz}$		16.2	17.3		15.6	13.5				
$\delta^{18}O‰_{Hematite}$		2.1	3.4		1.3	-0.9				

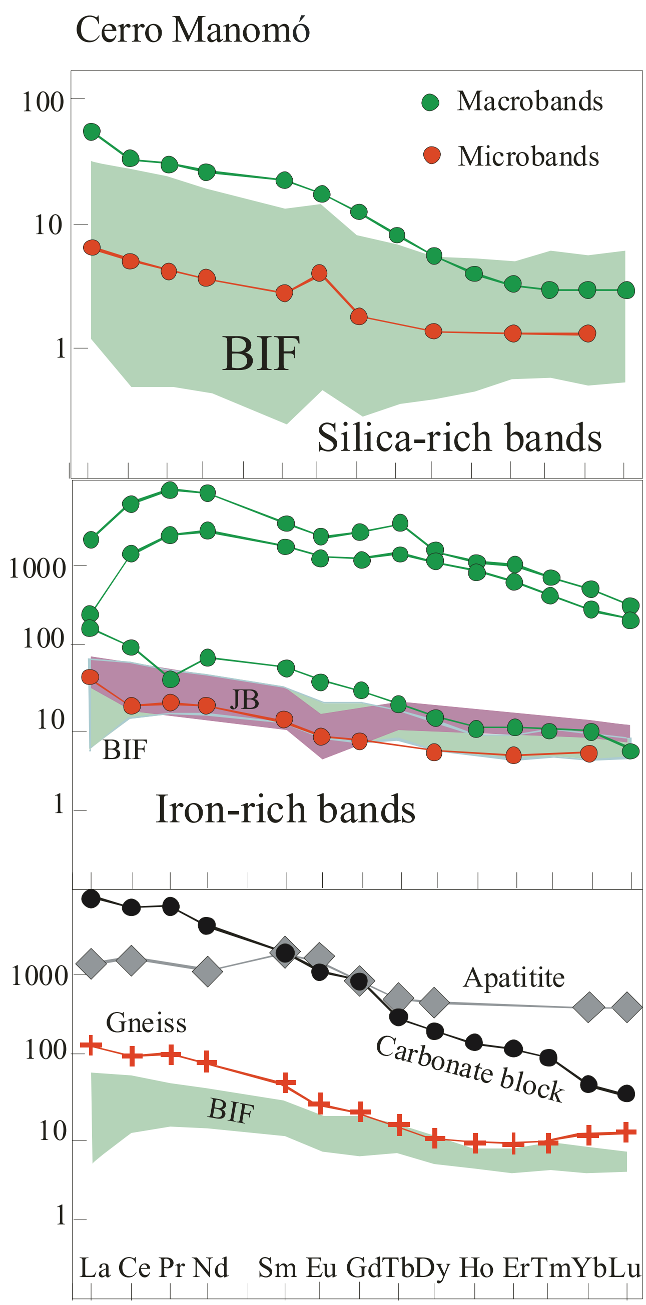

Figure 5. Chondrite-normalized REE (Boynton, 1984) patterns of rock-types from the Cerro Manomó complex. The light brown fields represent mid-Archean Banded Iron Formations (BIF), after Kato et al. (1998), the violet fied (JB) represents the Neoproterozoic Jocadigo-Boqui deposits of Graf et al. (1994). Note the strong Eu/Eu anomaly in Si-microband.*

starting by Rb, Sr, Sm and Nd concentrations (detection limits in Table 1 as MDL) in the whole-rocks from the ICP-MS data (cf. Faure, 1986).

Although the apparent disagreement between the two isotopic systems, probably due to the different mobilities of the elements during geodynamic events, a Mesoproterozoic age may be assumed for the BIF of Cerro Manomó, and the Sm-Nd age must be preferred for the very low MSWD, i.e. 0.54, and for the x-y distribution (Fig.6B).

In order to interpret this age, we must consider the stratigraphy and the available geochronological data of the San Ignacio Schist

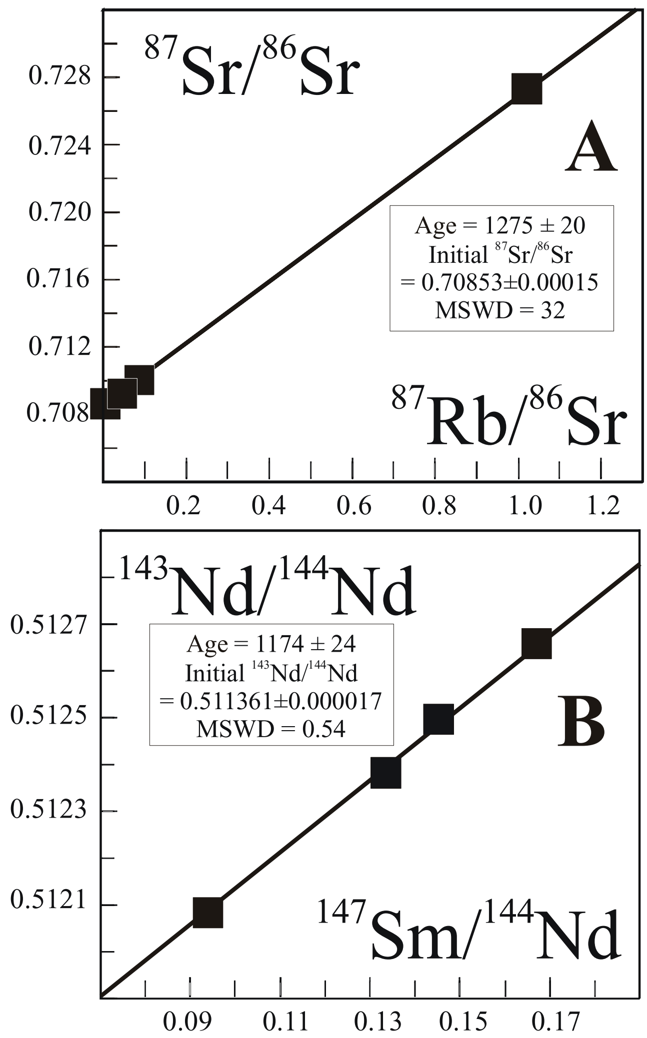

Figure 6. (A)** $^{87}Rb/^{86}Sr$ **vs** $^{87}Sr/^{86}Sr$ **regression line, corresponding to an age of 1.29 Ga and to an initial** $^{87}Sr/^{86}Sr$ **(**R_0**) = 0.70853. (B)** $^{147}Sm/^{144}Nd$ **vs** $^{143}Nd/^{144}Nd$ **isochrone, corresponding to an age of 1.19 Ga and an initial** $^{143}Nd/^{144}Nd$ **(**Nd_0**) = 0.511361.

Group, which contains the studied BIF. The sedimentary deposition of the Group occurred after 1690 Ma (Boger at al., 2005; Bettencourt et al., 2010; Matos, 2010). Geochronological data indicate that the region underwent two regional metamorphic events, the first occurred at ca. 1.37-1.32 Ga and was related to the San Ignacio orogeny (Bettencourt et al., 2010), and second occurred at ca. 1.1 -1.2 Ga and was related to the Sunsás orogeny (Matos et al., 2008; Girardi et al., 2008; Teixeira et al., 2010).

The geochronological results presented here, in particular the Sm-Nd data which yielded an age of ca. 1.2 Ga, are within the age interval attributed to the last metamorphism that affected the SW Amazonian Craton related to the Sunsás orogeny.

O isotopes

The oxygen isotopic compositions ($\delta^{18}O$‰ notation; cf. Faure, 1986) for the pure-end members SiO_2 and hematite fractions vary from 13.5 to 17.3 and from -0.9 to 3.4, respectively (cf. Table 1). If mineral pairs, representing different samples, are equilibrated at constant temperature, then they should fall along a straight line on a

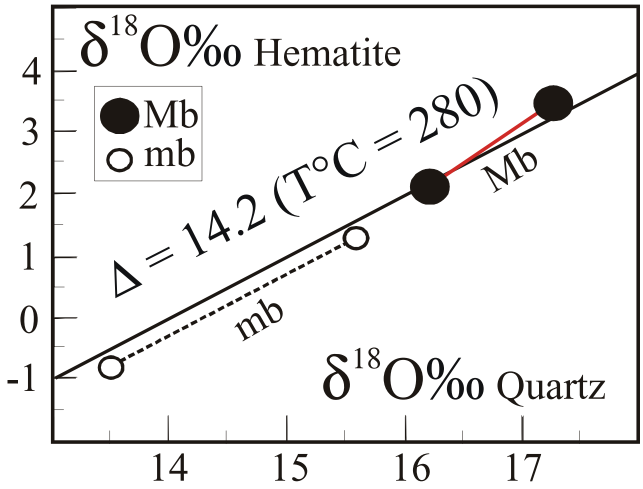

Figure 7. Temperature (D = 14) regression line corresponding to 280 ± 4 °C (Yapp, 1990). Mb, macrobands; mb, microbands.

d-d plot. Figure 7 shows d-d plot for four mineral pairs (D = 14.2 ± 0.2). Assuming that each pair of silica and hematite represents an equilibrium assemblage, their values can be used to calculate the corresponding temperature (Yapp, 1990). The estimated temperatures are 280° ± 4°C, indicating a hydrothermal exhalative source for FeO and SiO_2 (Khan and Naqvi, 1996).

Concluding remarks

In Southeastern Bolivia, remnants of a Fe-rich formation occur in the Cerro Manomó region, a laterized area containing also apatitite-rich lenses and carbonate blocks, possibly due to the intrusion and fenitization by carbonatitic magma in Early or Late Cretaceous times, and are probably genetically related to Velasco alkaline complexes (Comin-Chiaramonti et al., 2005), which are located approximately 22 km away from Cerro Manomó,. The Fe-rich formation belongs to the San Ignacio Schist Group. The petrographic, mineralogical and geochemical features of the studied ferruginous-siliceous banded samples are very similar to those described for the typical BIFs, which indicates that our samples probably belong to a Banded Iron Formation.

Available stratigraphic and geochronological data from the literature show that the deposition of the sedimentary rocks of the San Ignacio Schist Group took place after 1690 Ma, which consequently would be the maximum age of the ferruginous-siliceous sedimentary sequence. These data also indicate that the first regional metamorphic event occurred at 1.32 -1.37 Ga., which would be the minimum age of the BIF formation. Based on this time interval, it is possible to classify this BIF as belonging to a small, young group (see Fig 1), when compared with the most common Banded Iron Formations in the world, which range from approximately 2.1 to 2.7 Ga (peak at 2.5 Ga).

Rb-Sr and Sm-Nd isotope systematics indicate Mesoproterozoic ages of ca 1.2 Ga, which, taking into account the geochronological data from the literature, correspond to the last metamorphism of the SW Amazonian Craton, attributed to the Sunsás orogeny. The temperature of 280 ± 4° C derived from the oxygen isotopic composition of SiO_2 and hematite components could correspond to hydrothermal effects at the end of the metamorphism.

In the Mesozoic times, probably the area was affected by intrusion and fenitization through a carbonatitic magma (Early Cretaceous times?), and during Cenozoic laterization processes were dominant in the bedrock.

More detailed field sampling and extensive geological, mineralogical, petrographical and geochemical studies are necessary for a more convincing regional picture.

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