

The Bélinga Iron Ore Deposit (~2.8 Ga), NE-Gabon: Reactualization and New Interpretations on Crests

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Abstract

The Bélinga iron ore deposit is the biggest iron ore situated in NE-Gabon. Very little is known about that iron ore and available data are sometimes incompatible. We revisited documents that evoke the deposit to reactualize and propose new interpretations. The Bélinga iron ore deposit is composed of thirteen (13) N-S mineralized crests that underwent 3 tectonic events, folding (D₁), fracture (D₂) and folding (D₃). The ore is subdivided into four main categories which are blue and yellow ores, hematitic phyllites and enriched itabirites, with variable amounts of canga. The estimated reserves at Bélinga are ~384 Mt of high grade ore (Fe > 60% and P < 0.09%), and more than 1 Gt by considering an iron ore with Fe > 50% and P < 0.18%.

Keywords: Mesoarchaeon, Bélinga Group, BIFs, iron ore, Gabon

Introduction

Archaean and Paleoproterozoic represent a long period of Precambrian times that recorded the deposition of Iron Formations widespread in most of Archean cratons with maximum abundance around 2.5 Ga (Bontognali *et al.*, 2013; Pecoits *et al.*, 2009; Klein, 2005). Most of iron ores of this period are originated from enormous altered Banded Iron Formations (BIFs) hosted in greenstone belts and constitute the essential resources of iron like those in the Hamersley province in Australia (Dalstra, 2014; Webb *et al.*, 2003), Quadrilátero Ferrífero and Carajás in Brazil (Fabre *et al.*, 2011; Spier *et al.*, 2003), Ashan region in North of China (Wang *et al.*, 2014a), Orissa region in

Eastern India (Roy & Venkatesh, 2009) and Transvaal basin in South Africa (Schweigart, 1965).

NE-Gabon, NW-Congo and S-Cameroon contain greenstone belts hosting BIFs. In Gabon, the greenstone belt hosting BIFs is called Bélinga Group (Combes *et al.*, 1986a). It's suggested that the supergene alteration of these BIFs resulted in the formation of the Bélinga iron ore deposit made of about ten crests in NE-Gabon (Martini & Makanga, 2002; Combes *et al.*, 1986a; Sims, 1973). Parameters like Fe contents and tonnage were estimated (Combes *et al.*, 1986a; Sims, 1973; Plegat, 1955b; Chochine, 1950, 1951, 1952). However, recent documents (e.g. Martini & Makanga, 2002) present some differences when compared to those older (e.g. Combes *et al.*, 1986a), from where the necessity of revisiting the iron ore.

This paper (i) presents old data on the Bélinga iron ore deposit, (ii) examines recent data and (iii) updates, after comparison, data and propose new precisions.

Regional geological setting

The Bélinga iron ore deposit is situated in the Ogooué-Ivindo province, NE-Gabon. The region is a granites-greenstones terrain composed of an ~3.0-2.7 Ga Archaean basement and a ~2.8 Ga greenstone belt called Bélinga Group (Thiéblemont *et al.*, 2009b; Chevallier *et al.*, 2002; Prian *et al.*, 1998; Prian & Johan, 1989) (Fig. 1). The basement includes granites, gneisses and migmatites that underwent principally granulite facies metamorphism. The Bélinga Group consists of meta-ultrabasites, amphibole-pyroxene rocks, amphibolites, amphibole gneisses, metasediments and BIFs essentially metamorphized under amphibolite facies, and locally granulite facies (Thiéblemont *et al.*, 2009b; Chevallier *et al.*, 2002). Quaternary sediments in the border with Congo are noted.

With a N130° of general trend (Chevallier *et al.*, 2002; Stahl & Pohner, 1957), the Bélinga Group is crosscut by two principal fault families, one is N120° and the other is N40° (Combes *et al.*, 1986a). The Nkol shear zone, an important sub-vertical fracture with a right lateral trend and oriented W-E to WNW-ESE (Bassot, 1988), crosscuts the NE-Gabon region in two parts. The Bélinga iron ore deposit is located at ~55 km in North of the Nkol shear zone (Fig. 1).

Methodology

This work is based on the synthesis and the interpretation on the one hand of old data before 2000 (Stahl & Pohner, 1957; Anonymous, 1957; Telfair & Hole, 1960; Sims, 1973; Combes *et al.*, 1986a; Combes, 1986c), and on the other hand on the synthesis and the interpretation of data after 2000 (Martini & Makanga, 2002; Thiéblemont *et al.*, 2009a; Thiéblemont,

2009c) especially on cartography, tectonics, petrography and mineralogy, and finally on the geochemistry and tonnage of the Bélinga iron ore deposit.

New precisions are made by crossing old and recent data to highlight differences observed with authors in cartography, tectonics, petrography and mineralogy, geochemistry and tonnage.

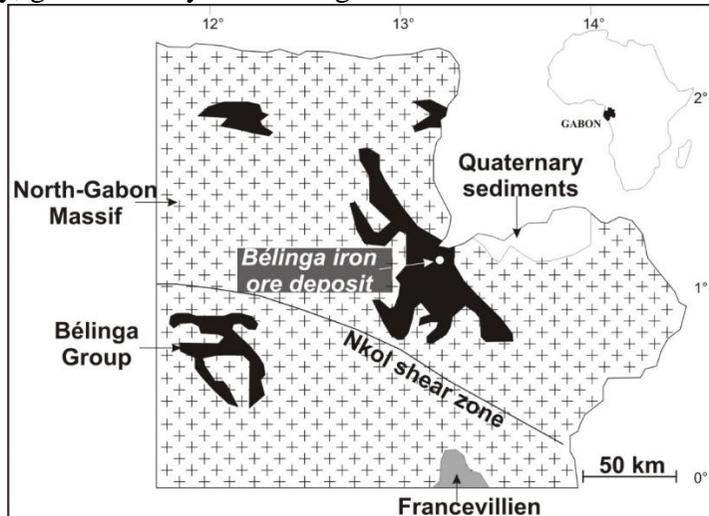


Figure 1: Simplified geological map of NE-Gabon (modified after Chevallier *et al.*, 2002).

Results

Results before 2000

Cartography

The cartography of the Bélinga iron ore deposit improved with years (Fig. 2). Anonymous (1957) adopts a representation of the deposit in which many outcrops of the ore and itabirites are recognized within nine (9) main crests (Fig. 2a). These crests, commonly named with alphabetic letters are North- and South-Babiel, AD, L, the great South crest, AK, AC, AM-AH and Cocotiédié. Sims (1973) mentioned that the deposit is 30 km long and ~8 km large. According to this author, it is made of nine crests which are Momba, Bakouélé, Babiel, Kombi, Okumé, Cocohédié, North-Bakota, South-Bakota and South South-Bakota (Fig. 2b). Combes *et al.* (1986a) propose a cartographic representation with thirteen (13) crests including East- and West-Mvathi, Mombo, Bakouélé, Babiel, Kombo, Okumé, Cocotiédié, North-Bakota, Middle-Bakota, South-Bakota, South South-Bakota and Bamba (Fig. 2c).

Tectonic

Three main chronologically tectonic events D₁, D₂ and D₃ affect the ore (Sims, 1973; Combes *et al.*, 1986a). D₁ event, resulting from metamorphic deformation associated with mineralogical recrystallization, is marked by isoclinal folds responsible of great structures observed at Bélinga.

D₁ folds are subdivided in an area of monoclinial W or E dip folds and an area of tight folds. D₂ event is marked by fractures following two principal directions, N120° and N40°. The N120° faults family has a right lateral trend and the N40° faults family has a vertical trend (Combes *et al.*, 1986a). D₃ event is characterized by decimeter folded structures of kink bands-type, with straight limbs and inclined axial planes affecting only platy ore and would be contemporaneous to the enrichment phase (Combes *et al.*, 1986a; Sims, 1973). In general, itabirites and resulting mineralized rocks are frequently high folded and present dips varying from 5 to 85°, either in E or SE, or in W or NW. On Babel crest for example, the platy ore is W oriented and 55° dip.

Petrography and mineralization

At Bélinga, we have unmineralized and mineralized terrains. Unmineralized terrains are found in surface and in footwall of crests, sometimes as intrusion (Fig. 3). Those terrains include soils, mudrocks, schists, micaschists, amphibolites and metavolcanic rocks (Combes *et al.*, 1986a). At the top and on the slopes of crests, mineralized terrains are canga and scree deposits, and more deeper we have itabirites *s.s* and argillaceous itabirites. The essential of the iron ore is irregularly concentrated between canga (and scree deposits) and itabirites (Fig. 3).

The ore is essentially composed of platy hematite with variable amounts of magnetite and goethite. Terminology used to classify iron ore is based upon color, hardness and structure (Tab. 1).

Scree deposits consist of decimeter components and stability is assured by an argillaceous limonitic cement.

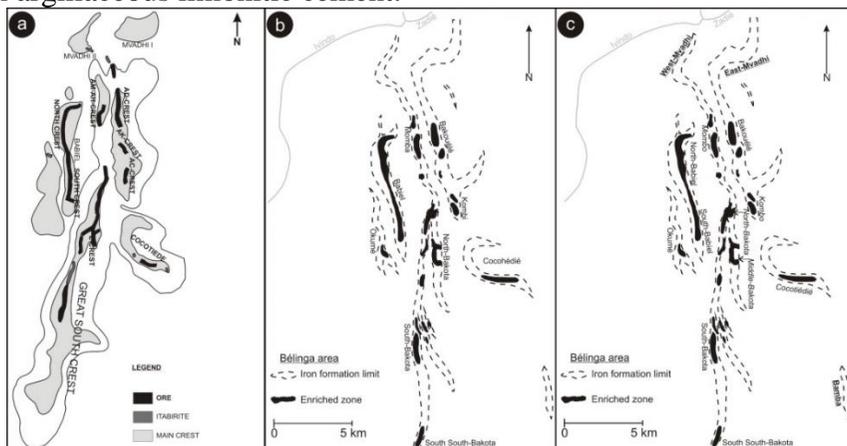


Figure 2: Evolution in the cartography of the Bélinga area with prospected crests. (a), (b) and (c) are modified maps respectively after Anonymous (1957), Sims (1973) and Combes *et al.* (1986a). For (c), names in bold type and underlined are crests prospected after 1980; names in italic show crests presenting differences between Sims (1973) and Combes *et al.* (1986a).

Canga is more abundant than scree deposits. It's enriched in iron (Fe > 55%) and presents components varying from centimeter (pisolitic canga) to meter, with a matrix essentially composed of iron hydroxides (Anonymous, 1957; Combes *et al.*, 1986a).

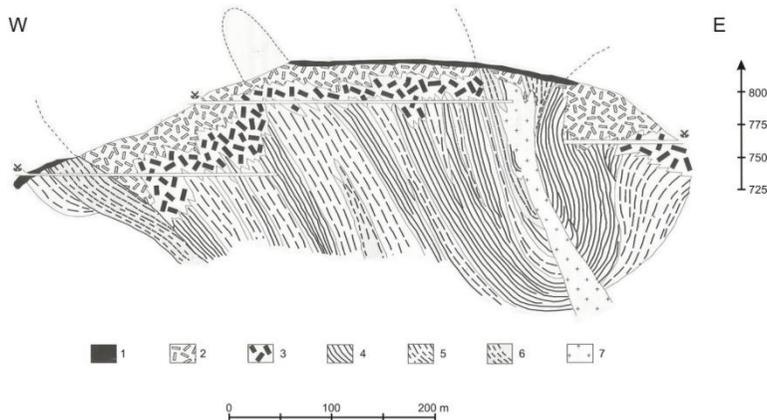


Figure 3: Interpretative cross section of South-Bakota crest (Sims, 1973). 1-Canga and soils; 2-Hydrated and indurated platy ore; 3-Soft platy hematitic ore; 4-Siliceous/argillaceous itabirites; 5-Hematitic phyllites; 6-Clays; 7-Intrusion.

Table 1: Criteria used to classify iron ore at Bélinga (Socomine, 1977 in Combes *et al.*, 1986a).

Color	Y= yellow B= blue
Hardness	S= soft M= medium-hard D= hard
Structure	G= granular P= platy M= massive O= ore

Deeper in the ore (> 5m), Fe content is generally higher than 50%. The ore is subdivided into four (4) main categories: hematitic phyllites, yellow ore, blue ore and enriched itabirite (Martini & Makanga, 2002; Combes *et al.*, 1986a). Hematitic phyllites are brown to dark colored, or even reddish depending on hematite enrichment. They are composed of disseminated quartz grains with thin layers of mud and hematite. Fe contents can reach up to 60%. They are directly originated from argillaceous itabirites by weathering, followed by Fe-enrichment. Yellow ore mainly consists of indurated platy hematite in which it is not rare to observe vacuoles and argillaceous levels filled of iron hydroxides. The ore has Fe contents > 60% and is mainly subdivided into soft, medium-hard and hard platy ore (Tab. 2). The blue ore owes its name due to metallic light blue to dark blue colors of the hematite

which is its principal mineral. It has Fe contents > 60% and is also subdivided into soft, medium-hard and hard platy ore. Blue and yellow ores present a granular ore type called " jacuntinga " (Tab. 2) with Fe contents around 60%. Enriched itabirites represent a transitional term between the iron ore (Fe ≥ 55%) and itabirites (Fe < 40%) (Combes *et al.*, 1986a). Its average content of iron is ~50%, but it can reach 60%. Generally, medium-hard and hard platy hematite ore types are most represented, the last making 79.5% of the total volume of the ore (Sims, 1973).

Ferriferous rocks are composed of itabirites *s.s* and argillaceous itabirites.

Table 2: Principal petrographic types (mineralized rock) found in the area of the Bélinga iron ore deposit (Socomine, 1977 and Sims 1978 *in* Combes *et al.*, 1986a). Abbreviation used for the ore and primary ferruginous rocks are based on criteria in Table 2. Scree deposits, clay, schist, micaschist, amphibolite, métavolcanics and others magmatic rocks are not included in this classification.

Ore	YSGP or BSGO	Jacuntinga
	YSPO or BSPO	Soft platy ore
	YMPO or BMPO	Medium-hard platy ore
	YDPO or BDPO	Hard massive ore
	HP	Hematitic phyllite
	ITE	Enriched itabirite
	CG	Canga
Primary ferruginous rocks	IT	Itabirite
	ITA	Argillaceous itabirite

Geochemistry and tonnage

The Bélinga iron ore deposit is the biggest iron deposit in Gabon with more than 600 Mt of high grade ore (Fe > 60%), but only 384 Mt are less phosphorous (Combes *et al.*, 1986a; Telfair & Hole, 1960), the more important reserves being on Babel crest (Tab. 3).

Few chemical elements have been analyzed in relation with the ore. The analyses focus on iron, silica, alumina and phosphor (Tab. 3-4).

Table 3: Contents and tonnage of prospected crests of the Bélinga iron ore deposit. In brackets, numbers 1 and 2 refer to Combes *et al.* (1986a), and Socomine (1983) *in* Combes (1986c) respectively; letters *a* and *b* represent determined and inferred reserves respectively. Mineralized height is ≥ 5 m.

Ore	Crests	Content (%)					Tons (Mt)
		SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	P ₂ O ₅	OI	
Bélinga (Fe>55% and P<0.1%)	Mombo (1,a)	3.66	62.9	3.52	0.055	.41	52.597
	Kombo (1,a)	3.58	62.6	2.72	0.073	.78	23.012
	North-Babel (1,a)	3.28	65.09	1.52	0.071	.71	110.685

South-Babiel (1,a)	3.79	62.85	3.22	0.064	.76	53.769
Okumé (2,b)	2.84	62.77	2.9	0.072	.73	8.4
Cocotiédié						4.7
North-Bakota (1,a)	2.01	65.29	2.61	0.054	.93	14.902
Middle-Bakota (2,a)	1.69	60.98	6.69	0.047	.68	17.4
South-Bokata (1,a)	3.31	64.18	2.9	0.054	.8	90.208
S. South-Bakota (2,a)	2.4	58	5.76	0.082	.64	8.2
Total						383.873
Average	2.951	62.74	3.537	0.064	.27	

Table 4: Average chemical composition and varying thickness of different types of iron ore at Bélinga. Itabirite *s.s* is added to see differences in Fe and Si contents with ores. Values are based on some historical data from South South-Bakota, Middle-Bakota and Okumé crests (Combes *et al.*, 1986b).

	Fe ₂ O ₃ t (%)	SiO ₂ (%)	Al ₂ O ₃ (%)	P (%)	LOI (%)	Thickness (m)
Canga	56.73	2.36	7.206	0.169	7.68	1-10
Hematitic phyllites	54.63	6.61	6.63	0.116	7.54	3-32.5
Yellow ore	61.27	1.77	4.63	0.118	4.97	3-47.5
Blue ore	64.50	1.63	2.40	0.097	2.82	1-32
Enriched itabirite	51.69	17.36	3.21	0.133	4.48	7-46
Itabirite <i>s.s</i>	34.26	47	0.98	0.076	2.46	6-20

Results after 2000

Cartography

Martini & Makanga (2002) propose a map gathering the cartographic data of Sims (1973) and Combes *et al.* (1986a). Thiéblemont (2009c) locates the Bélinga iron ore deposit from a Gabonese geological map. These cartographic representations of the iron deposit are more or less identical to the old representations. The new synthesis and the interpretation based on the reactualized geological map of Gabon and old data enable us to propose a map with thirteen crests on a geological bottom made of itabirites, greenstones and basement (Fig. 4).

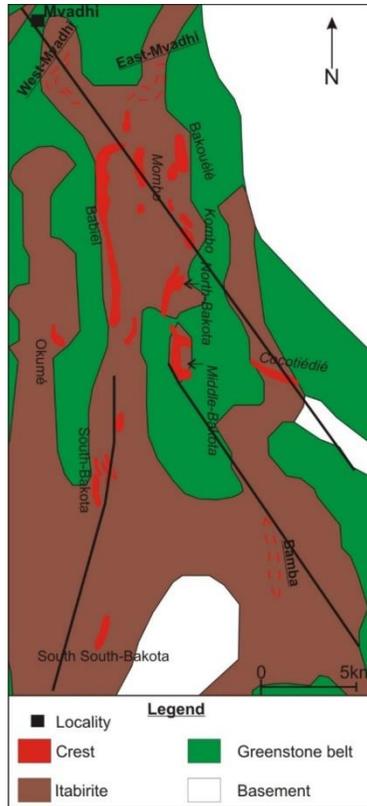


Figure 4: Reactualized map of the Bélinga iron ore deposit. The geological background map is from Thiéblemont (2009c).

Tectonic, petrography, mineralogy, geochemistry and tonnage

Recent results on petrographic interpretations, mineralization, geochemistry and tonnage remain identical to old data.

About tectonics, figures 5 and 6 respectively show cross sections realized on Okumé and Middle-Bakota crests. From top to bottom we have canga and/or scree deposits, a mixing of yellow/blue ores and finally enriches itabirites, in which it’s not rare to find argillaceous intercalations. These cross sections show the role played by tectonics via local to regional reverse faults and the multiple associated deformations. On the Okumé cross section (Fig. 5), the ore (yellow and blue) is close to the surface and quickly reached because the canga is not very thick. From side to side of the reverse faults, the ore is frequently thicker and deeper in the lowered compartments in contrary to the raised compartments (pit 6-15w, 6-05w, 6-17). On Middle-Bakota, as well as on Okumé crest, we also notice that the ore thickens when we move away from the top of the crest towards its sides (Fig. 5-6). The different levels of the ore are strongly inclined. The weathering level is irregular and affected by micro-folds.

Discussion

Anonymous (1957) proposes a cartographic representation of the Bélinga iron ore deposit based on the sections traversed by the geologists Park, Hole, Michel in 1956 who mentioned the zones where the ore and itabirites (BIFs) were recognized. Nine (9) mineralized crests of several hundreds of square meters were named (Fig. 2a). Sims (1973) proposes a map of the deposit with 9 mineralized crests with some differences with the old map (Fig. 2b) and Combes *et al.* (1986a) propose a new cartographic representation with 13 crests (Fig. 2c). The comparison of these cartographic data emphasizes differences on the number and the name of crests of the iron ore deposit. The current synthesis and the interpretations carried out during this work show 13 crests and agree to the results of Combes *et al.* (1986a).

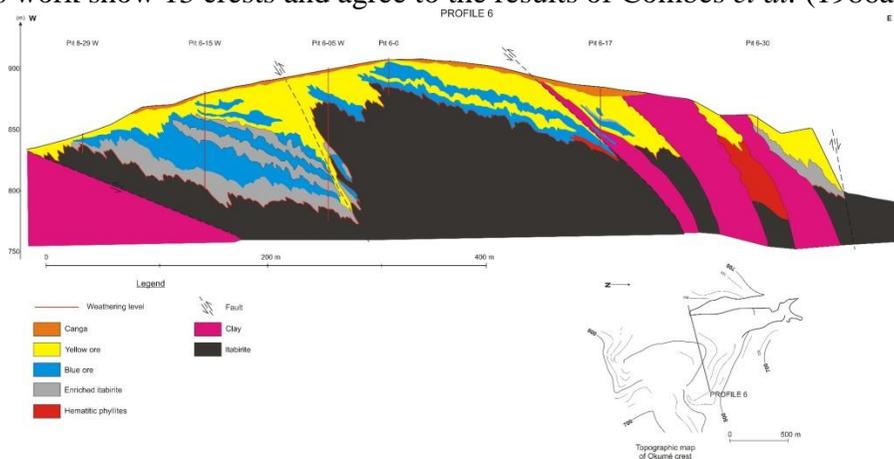


Figure 5: Cross section of profile 6 from Okumé crest (modified after Combes *et al.*, 1986b). Blue and yellow ores are globally taken without considering hardness and structure. Itabirite refers to itabirite s.s and argillaceous itabirite. Vertical red lines represent realized pits.

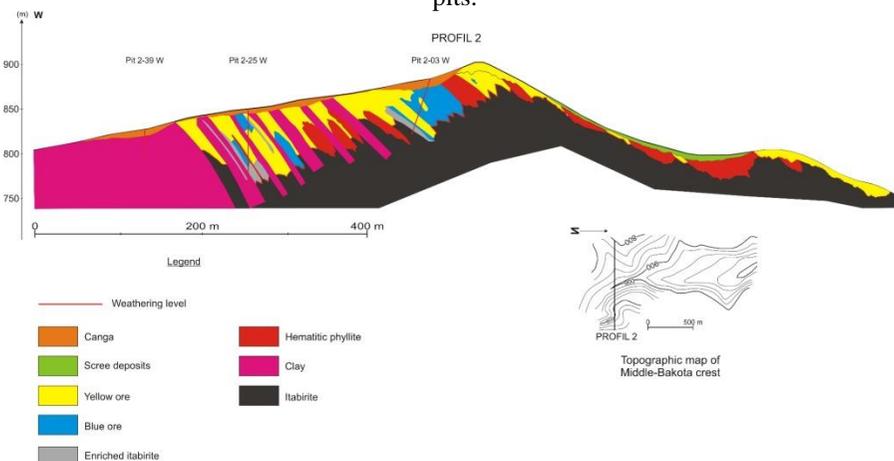


Figure 6: Cross section of profile 2 from Middle-Bakota crest (modified after Combes *et al.*, 1986b).

About the names of crests, Anonymous (1957) and Sims (1973) mention 9 mineralized crests whereas Combes *et al.* (1986a) find 13. The current synthesis confirms the results of Combes *et al.* (1986a) by harmonizing names. On Bakota crests, the old maps (Anonymous, 1957) taken again by Combes *et al.* (1986a) indicate Middle-Bakota and North-Bakota contrary to Sims (1973) who indicates only North-Bakota (Fig. 2). For Cocotiédié, Kombo and Mombo, we regard them as true names (Combes *et al.*, 1986a), in opposition to misspellings on the names suggested by Sims (1973). Martini & Makanga (2002) and Thiéblemont *et al.* (2009a) did not take into account all the data of Combes *et al.* (1986a) when writing recent documents.

A summary table (Tab. 5) specifies the harmonization of all these data. A new map of the deposit based on the known positions of crests coupled to a recent geological map is also proposed (Fig. 4).

Table 5: Summary of proposed names (Anonymous, 1957; Sims, 1973; Combes *et al.*, 1986a) and new proposed names of mineralized prospected crests from the Bélinga iron ore deposit.

Names of crests of the Bélinga iron ore deposit			
Anonymous (1957)	Sims (1973)	Combes <i>et al.</i> (1986a)	Present paper
Babiel Nord	Babiel	Babiel	Babiel
Babiel Sud			
AD	Bakouélé	Bakouélé	Bakouélé
		Bamba	Bamba
L	North-Bakota	North-Bakota	North-Bakota
		Middle-Bakota	Middle-Bakota
Great South crest	South-Bakota	South-Bakota	South-Bakota
	South South-Bakota	South South-Bakota	South South-Bakota
Cocotiédié	Cocohédié	Cocotiédié	Cocotiédié
AK	Kombi	Kombo	Kombo
AC			
AM-AH	Momba	Mombo	Mombo
		East-Mvadi	East-Mvadi
		West-Mvadi	West-Mvadi
	Okumé	Okumé	Okumé

Petrographic interpretations, mineralization, geochemistry and tonnage remain identical to the old data. The Bélinga iron ore deposit is composed of yellow and blue ores, accompanied by variable quantities of hematitic phyllites and enriched itabirites, of which the thicknesses are very variable (Thiéblemont *et al.*, 2009a; Martini & Makanga, 2002; Combes *et al.*, 1986a; Combes, 1986c; Sims, 1973; Anonymous, 1957).

On a tectonic point of view, new interpretations highlight the various deformation phases D₁, D₂ and D₃, recognized by Sims (1973) and Combes

et al. (1986a) which affected the deposit. The repetition and the strong dips of the mineralized zones (Fig. 3, 5-6) towards E or W on the one hand, and on the other hand as isoclinal folds characterize the D₁ deformation phase. Local to regional reverse accidents characterize the D₂ event, marked by fracturing according to the main directions N40° and N120°. The weathering level, affected by decimeter micro-folds of kink bands-type characterize D₃ event. The precise ages of these tectono-metamorphic events are not clearly known, but Thiéblemont *et al.* (2009a) suggest that they would be related to Neoproterozoic orogen.

New interpretations show the role played by reserve faults within ore. On the realized cross section in figure 5, the thickness variation of iron-bearing zone on both sides of the accidents suggests a creation of differential space consecutive to the faults and that the later should be contemporaneous to the supergene enrichment processes. They thus could not simply be limited to D₂ event, but should have also played during D₃ event. It's the first time that the interactions between tectonics and the iron-bearing zones on a short wavelength scale are proposed at Bélinga, particularly on Okumé crest.

The Bélinga iron ore deposit remains unexploited and the reserves are estimated at ~384 Mt of high grade ore (Fe > 55% and P ≤ 0.1%). If we consider an ore with Fe > 50% and P ≤ 0.15%, the reserves exceed 1 Gt (Martini & Makanga, 2002). It's therefore an importance deposit, in comparison with other iron deposits (Tab. 6).

Table 6: Summary of some known iron ore deposits around the world in comparison to Bélinga. We expressly represent Bélinga with Fe > 50% and not with Fe > 60% to show Fe-potentiality in Gabon.

Iron ore	Country/Region	Fe content (%)	P content (%)	Tons (Mt)	Authors
Xi'Anshan	China	34.22		172.861	Han <i>et al.</i> (2014)
Bélinga	Gabon	>50	0.05-0.18	>1.000	Martini and Makanga (2002); Sims (1973)
Nkout	Cameroon	>50		72.5	Anderson <i>et al.</i> (2014)
Gongchanling	China	>50	<0.1	150	Wang <i>et al.</i> (2014b) ; Li <i>et al.</i> (2014)
Madoonga	Western Australia	57.7		68	Duiring et Hagemann (2013)
Koolyanobbing	Western Australia	>58	<0.1	>100	Angerer et Hagemann (2010)
Pico	Brazil	67	0.05	313	Spier <i>et al.</i> (2003)
Águas Claras	Brazil	68.23	0.17	376	Spier <i>et al.</i> (2003)

Conclusion

The comparison of old data and recent investigations on the Bélinga iron ore deposit, in relation to the cartography, tectonics, petrography, mineralization, tonnage and geochemistry made on it allow us to propose new tectono-sedimentary precisions. The reactualized interpretation of the cartography highlights thirteen mineralized crests. The mineralization essentially consists of yellow and blue ores in platy hematite form, with hematitic phyllites and enriched itabirites. Tectonics confirms several episodes of deformation characterized by isoclinal folds, fracturing and micro-folds of the weathering level. The thickness variations of the iron-bearing zone from side to side of tectonic accidents limiting kilometric blocks suggest the interactions between tectonics and the iron-bearing zones.

The Bélinga iron ore deposit is little known by public and scientific communities because of the insignificant number of scientific publications, of which last dates of about forty years. It still remains unexploited to date and the reserves of ~384 Mt of high grade ore makes this deposit one of the largest in Central Africa.

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