Similarities between the Banded Iron Formations of West-Africa and South-America — an Aspect of Continental Drift

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Summary

Based on various facts it becomes evident that not only the coastal contours fit to form a single shield but also the local tectonics and the sedimentary environment of the numerous iron ore deposits correlate to an extraordinary degree. In view of this it can be postulated that both the shields with their iron ore deposits belonged to a single Precambrian unit. This unit contained a sedimentation basin which developed into a geosyncline with subsequent folding and the morphologic development of mountain chain. This then later formed the dividing line when the Gondwana Continent disintegrated during the lower Cretaceous period.

Major parts of this discussion are excerpts and data, taken from the archives of Exploration und Bergbau GmbH in Düsseldorf, where the results and papers on investigations performed by its staff, and on its behalf, are documented.

I. Introduction

Excluding a few exceptions, it is now generally accepted that the "Banded Iron Formations" of the Precambrian are of sedimentary origin. Conditions that were favourable for the genesis of these unique and economically extremely interesting iron ore formations predominated only during the Precambrian. Iron formations have been given many local names, such as jaspilite, taconite, ironstone, itabirite, banded hematite jasper, banded hematite quartzites etc. In a report of the United Nations of a survey of the iron ore resources of the world, an international committee UNITED NATIONS (1970) suggested that the Precambrian iron formations and ores derived from them be called "Lake Superior Type".

Despite a common mode of origin and a similar geological environment, local differences are prevalent as a result of differing relative ages, degrees of metamorphism, orogenic modifications and weathering conditions leading to the formation of high grade ores, beneficiation type ores or non-economical iron bearing formations at various locations.

Based on his "chelogenic" concept SUTTON, J. (1963) concludes that through geological time the continents have priodically fragmented and dispersed, possibly from two clusters, one in each hemisphere, and then, reassembled once more in two groups. Each such cycle commenced with the appearance of sedimentary troughs within a basement of rocks, formed during preceding cycles. HURLEY, P. M. (1972) states that continental breakup similar to that of the Mesozoic-Cenozoic occurred periodically throughout the Precambrian. We can thus assume that the above mentioned sedimentary troughs of Precambrian "chelogenic" cycles were the locations for the laying down of the "Banded Iron" and other related rock formations. Using the pre-drift reconstructions of BULLARD, E., J. E. EVERETT and

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G. A. Smith (1965) for the continental land masses around the Atlantic Ocean, we find that the cratonic areas of South America and Africa form a closely knit mosaic chopped up by younger and transcurrent active belts. In addition it becomes evident that the two Precambrian shields of Guyana and West Africa constitute a good example, where pre-existing ore provinces could have been separated by continental drift.

The first part of this paper is therefore dedicated to the summing up of the genesis of itabiritec iron ores, and the second part gives a short description of the producing mines on these two shields.

II.

1. Geochronology and stratigraphy of the Precambrian and its itabirites in the Liberia and Guyana shields

Radiometric dating of the gneisses from the ore formations, of both the Liberia and Guyana shields, indicates that the sedimentation of these itabirites took place between 2500 and 3600 million years ago. In Sierra Leone samples from the basement (granitic to granulitic) were dated between 2700 to 3600 million years and the itabirite containing Kasila-schists showed 3200 million years. Similarly in Liberia gneisses from the Bong Range deposits were dated at 2910 to 3280 million years, Mano River at 2660 to 3350 million years and Nimba Range at 2500 million years. Comparing these to age, data from the Guyana shield, the gneisses from the itabiritec Imataca series show age values between 2700 to 2900 million years, all using Rb/Sr values from whole rock analysis.

This crystalline basement in both shields is overlain by sediments and igneous rocks which are locally more or less metamorphosed. These overlying metasediments contain quartzites, quartz mica schists, amphibolites and igneous rocks interlain by itabirites. Depending on the grade of metamorphism the overlying grades into the gneissic underground, showing no marked unconformity as in most other Precambrian shields therefore, allowing the conclusion that both the itabiritic formations are of a similar age. Owing to the geographical and political splitting of the areas these formations bear different names. In Sierra Leone they are called Kambui-series, in Liberia Nimba-series, in Guinea Simandou-series and in Venezuela Imataca-series. Both the gneissic underground and the overlying metasediments are thus contained in Precambrian I. Varying regional metamorphosis in early Precambrian resulted, however, in the development of locally different metamorphic facies. In Liberia the metasediments belong to the green-schist to amphibolite facies, whereas in Sierra Leone and the Guyana shield gneisses and granite intrusions are predominant. According to Gruss, H. (1970) the coastal areas of both the shields are higher metamorph and the metamorphic intensity seems to diminish toward the interior. These orogenic events of Precambrian I did not, however, cause a consolidation of the two shields, because in later Precambrian thick series of igneous rocks and sediments were deposited on them (Precambrium II). In Venezuela the Precambrian II contains the Pastora-series dated between 1600 to 1800 million years, whereas the Birrimien of West-Africa, also Precambrian II, shows an age of 1800 to 2000 million years according to Machens, E. (1966). Both the Precambrian I and II were effected by a later second metamorphism which resulted in gneisses and granitic intrusions. The younger granites of Guyana belong to this metamorphic cycle and date between 1800 to 2000 million years. Corresponding values are shown by gneisses from the Ivory Coast (1800 to 2000 million years) and Bong Range in Liberia (1600 million years). After both these orogenic and metamorphic cycles the shield areas became stable, as the younger unconformably overlying Precambrian-series are practically devoid of metamorphism and belong to the molasse facies. In the Liberia shield these series are denoted as Tarkwaien, whereas the Roraima formation dating 1675 million years, corresponds to these, in the Guyana shield. The following Fig. 1 shows the above discussed relationships after GRUSS, H. (1970).

	LIBERIA SHIELD		GUYANA SHIELD	
orogenesis	folding and metamorphism 700—800 m. y. (gneisses, NW—SE striking) Liberia, Sierra Leone			
sedimentation	Tarkwaien (Ghana) (Molasse-facies)		Roraimaformation 1675 m. y. (Molasse-facies)	
orogenesis	metatexis — anatexis 1800—2000 m. y. granites and gneisses		metatexis — anatexis 1800—2000 m. y. "younger granites"	
orogenesis	folding and regional metamorphism 2500—3000 m. y.		folding and regional metamorphism 2700—2900 m. y. "older granites"	
sedimentation	itabirites metasediments	Kambui-series Simandou-series Nimba-series Dahomeyen	itabirites metasediments	Imataca-series Barama-Mazaruni-system
unconformity ? basement ?	granites granulites	Kasila-schists (3200 m. y.) "basement" 2700—3600 m. y.)		

Fig. 1 Precambrian of the Liberia and Guyana shields.

2. Sedimentary environment and facies of the iron formation

Based on detailed mapping of the producing mines in the Liberia shield, the sedimentary facies begins with quartzites, having a thickness of several hundred metres. This is overlain by a quartz-muscovite series, with sporadic intercalations of amphibolites. In the Guyana shield where the Imataca-series constitute the footwall of the itabirites, a similar sequence is present, consisting of quartzites, ferrogenous quartzites, hematitic gneisses, feldspathic and hornblende gneisses, amphibolitic schists, amphibolites and phyllites. Owing to the higher metamorphic intensity in the Guyana shield, locally large areas of migmatite are developed, as well as granites and more basic intrusions, after STAM, J. C. (1963). Following the laying down of these quartzitic formations, a sporadic deposition of itabirites took place. Generally the thickness of the itabirites reaches a few metres, but only in areas of continuous subsidence did the thickness increase to a few tens or hundreds of metres. In certain areas folding and repitition of the itabirites also contributed to increased thickness. Measured thickness for Cerro Bolivar approx. 200 m, Bong Range 20 to 80 m and Nimba 250 to 400 m. In both the shield areas the itabirites are of the oxide facies of James, H. L. (1954), other facies such as carbonate or sulphide are not known to occur. The iron oxides are mostly hematite and magnetite with minor amounts of goethite. The quartz is completely recrystallized and the accessory minerals include pyroxene, apatite, zircon, garnet etc. The degree of oxidation gradually increases from the base to the hanging wall. In exposed positions the hanging wall schists have been almost completely eroded, the magnetite nearly totally oxidized to hematite, and the quartz partially or entirely leached, resulting in the formation of weathered or supergene high grade ore deposits, like Nimba in West-Africa and San Isidro or Cerro Bolivar in Venezuela. Fig. 2 shows a typical profil of such deposits. Principally

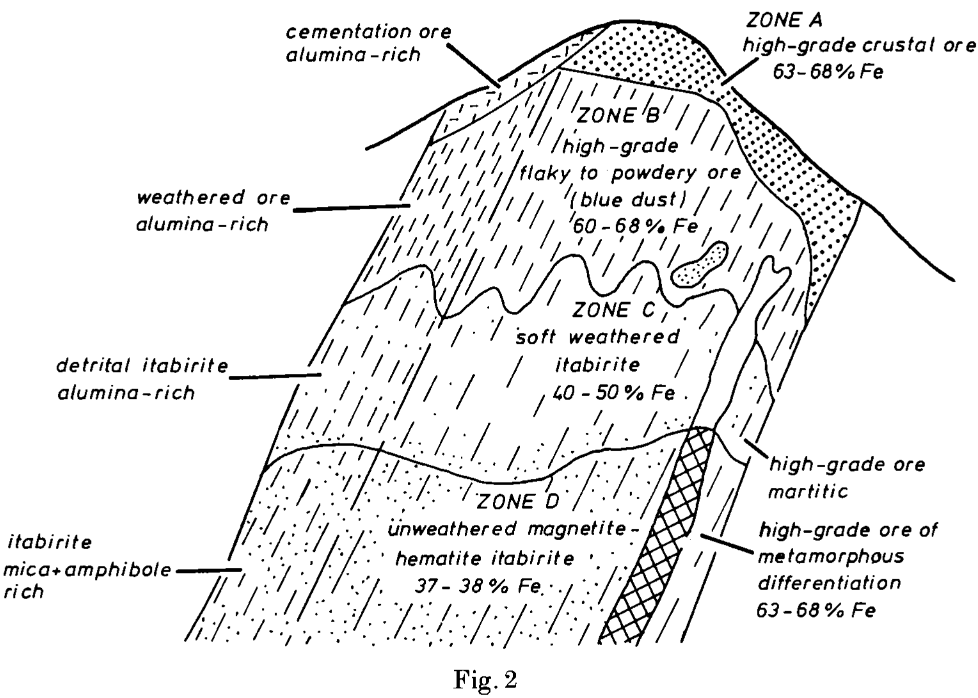

Fig. 2

a second type of high grade deposit can also be distinguished in the itabirites of these shield areas. Locally the sedimentary itabirites came into direct contact with the rising gneissic fronts and deep seated intrusions of basic plutons in the central part of the orogene. In such cases according to Gruss, H. (1970) a metamorphic conversion of the itabirites took place — as a result of increased pressure and temperature conditions — resulting in the mobilization and removal of silica, whilst the magnetite-hematite content was residually enriched. Typical examples of such deposits are Bomi Hill in Liberia and El Pao in Venezuela.

Investigations on the supergene ores of both shield areas show that the period of enrichment at Cerro Bolivar began about 24 million years ago as recognized by RUCKMICK, J. C. (1963). Similar conditions can be expected in the Liberia shield where the supergene ores are also bound to the relicts of the Gondwana Peneplain in Nimba. The presence of a definite subtype called "Blue Dust", however, complicates this approach to a certain degree, and according to GAERTNER, H. R. v. (1961) can be related to a Precretaceous Cycle of weathering. Such a subtype exists in both shield areas.

III. As the economic significance of the itabirites in both shields lies in the occurance of large deposits of partially enriched or high grade ore, a short description of the producing mines is given below

1. GUYANA-SHIELD AREA

1.1. El Pao — Venezuela

This deposit has been known since 1926 and the Iron Mines Company of Venezuela started full mining operations in 1950.

The average chemical analysis of the ore reserves is almost identical with the shipped product: 62.5 p. c. Fe; 1 to 2.5 p. c. SiO_2; 3.5 to 4 p. c. Al_2O_3; 0.06 p. c. P and 3.66 p. c. L. O. I. The El Pao deposit contains high grade ores as a result of metamorphic differentiation and removal of silica. The high grade mineralization is always bound to the contacts of itabirite with the intrusive gabbro. The gabbro fills the troughlike body of the hard ore type and constitutes the hanging wall of the deposit. The high grade ores consist of hematite and magnetite in variying proportions, with grain sizes up to 10 mm, and analizes 67.5 to 71.0 p. c. Fe; 0.1 to 0.7 p. c. SiO_2; 0.1 to 4.0 p. c. Al_2O_3; 0.01 to 0.03 p. c. P. The enriched weathered itabirites are no genuine supergene high grade ores, but results of metamorphosis and weathering enrichment, leading to concentrations of 56 to 62 p. c. Fe; 6 to 10 p. c. SiO_2; 2 to 4 p. c. Al_2O_3 and 2 to 5 p. c. L. O. I. Average overburden to be moved per ton of product is approx. 1.6 tons. Both ore types are simultaneously mined, crushed and screened. Screen analyses of the product reads 20.3 p. c. + 51 mm; 26.3 p. c. between 13—51 mm and 53.4 p. c.—13 mm. The mineable reserves of the deposit at the beginning of the operation were: 85 to 90 m.tons of measured high grade ores and approx. 20 to 30 m.tons of low grade itabirites, as inferred reserves.

1.2. Cerro Bolivar — Venezuela

After its discovery in the early forties the deposit has been worked by the Orinoco Mining Company since 1954. Using a cut-off grade of 55 p. c. Fe, the reserves average 63.84 p. c. Fe; 1.86 p. c. SiO_2; 1.44 p. c. Al_2O_3; 0.10 p. c. P and 5.11 p. c. L. O. I.

The supergene high grade ores of Cerro Bolivar are bound to the old Gondwana Peneplain with the itabirite outcrops at approx. 700 metres above sea level, with strike lengths of 20 km and widths up to 750 metres. The thickness of the itabirite formation in this area can be up to 200 metres and is isoclinally folded.

The unweathered itabirites average 39 p. c. Fe and 42 p. c. SiO_2 with grain sizes ranging between 0.05 to 0.15 mm. The main oxide is oxidized magnetite accompanied by varying amounts of specularite. Supergene enrichment has led to the formation of approx. 10 metres of soft partially enriched itabirites directly above the unweathered formation. This zone contains the two technical siliceous ore types: a) siliceous fine ores, averaging 50 to 62 p. c. Fe; 6 to 10 p. c. SiO_2; 1 p. c. Al_2O_3 and 3 p. c. L. O. I. b) soft itabirite, containing 45 to 55 p. c. Fe; approx. 30 p. c. SiO_2; 0.5p. c Al_2O_3 and 1.5 p. c. L. O. I.

The supergene high grade ores lies above the zone of partial enrichment, and thicknesses of 100 m and more are quite common. Two types of supergene high grade ores comprise this zone: a) black ores with 66 to 68 p. c. Fe; 0 to 6 p. c. SiO_2; 1 p. c. Al_2O_3 and 0.3 p.c. L. O. I. b) brown ores contain 62 to 64 p. c. Fe; 0 to 6 p. c. SiO_2; 1 p. c. Al_2O_3 and 3 p. c. L. O. I.

Above the supergene high grade ores there is a covering by surficial crustal ores, with a thickness between 10 to 30 metres, depending on the morphology of the underground and weathering intensity. The average chemical composition of the crustal ores lies at 62 to 69 p. c. Fe; 0.1 to 6.0 p. c. SiO_2; 0.1 to 1.5 p. c. Al_2O_3 and 0 to 5 p. c. L. O. I.

Fig. 3 shows the granulometric distribution in the various ore types. At the beginning of mining operations approx. 781 m.tons of measured and indicated ore reserves, with an ore: waste ratio of approx. 6 : 1, formed the basis of the Cerro Bolivar Project.

1.3. San Isidro — Venezuela

The San Isidro iron ore deposits were discovered in 1948 and lie approx. 15 km south of Cerro Bolivar at an altitude of 700 m, and belong to the supergene high grade type of ores. The individual ore deposits cover approx. 50 km^2 of area and are also related to the old Gondwana Peneplain.

Analogous to the Cerro Bolivar deposits, the unweathered itabirites at San Isidro are fine banded and contain approx. 42 p. c. Fe and 35 p. c. SiO_2, with grain sizes between 0.03 to 0.2 mm. The major oxides are again oxidized magnetite and hematite with minor amounts of iron silicates.

The zone of partial enrichment overlying the unweathered zone, is very thin in contrast to Cerro Bolivar, showing average thicknesses between 10 to 20 mm, and the fine ores of this zone can again be separated into two types: a) siliceous fine ores containing 58 p. c. Fe, 4 p. c. SiO_2, 0.5 p. c. $Al_2O_3$and 5.0 p. c. L. O. I. b) soft itabirites with 50 p. c. Fe, 30 p. c. SiO_2; 0.3 p. c. Al_2O_3 and 2.8 p. c. L. O. I.

Again a zone of supergene high grade ores covers the zone of partial enrichment with a thickness of approx. 240 metres. Similar to Cerro Bolivar the supergene high grade ores of San Isidro can be divided into two types: a) black ores and b) brown ores. Using a cut-off grade of 58 p. c. Fe the black ores contain 67 p. c. Fe, 0.8 p. c. SiO_2, 0.5 p. c. Al_2O_3 and 2.8 p. c. L. O. I., whereas the brown ores show 62 p. c. Fe, 2.8 p. c. SiO_2, 0.5 p. c. Al_2O_3 and 4.0 p. c. L. O. I. as their average chemical composition. Lying above the supergene high grade ores we find approx. 10 metres of surficial crustal ores. These have an average composition of 62 to 67 p. c. Fe, 0.6 to 1.3 p. c. SiO_2, 0.5 to 1.3 p. c. Al_2O_3 and 2.5 to 4.3 p. c. L. O. I. if a cut-off grade of 58 p. c. is used.

Although discovered in 1954 the San Isidro deposits have not been worked on a large scale. Based on initial investigations the total complex contains approx. 1.260 m.tons of measured and indicated reserves, which average between 62.8 to 63.5 p. c. Fe, 1.8 to 7.3 p. c. SiO_2, 0.5 to 1.2 p. c. Al_2O_3 < 0.03 p. c. P, < 0.01 p. c.S and

Inch/mesh	mm	Crustal ore crushed —100 mm	Fine ore brown	Fine ore black
1.050	26.6	6.72	30.43	3.43
0.742	18.85	12.53	—	6.96
0.525	13.33	23.59	43.47	14.92
0.371	9.42	36.05	—	26.97
3	6.68	44.47	48.80	33.01
6	3.23	54.39	64.58	46.16
10	1.65	63.31	80.93	57.34
20	0.83	71.25	89.33	66.15
35	0.42	79.99	91.57	73.25
65	0.21	89.70	93.10	79.16
100	0.147	92.94	93.90	81.93
200	0.074	100.00	100.00	100.00

Fig. 3 (Bolivar ore)

Inch/mesh	mm	Total percentage
1.050	26.6	8.2
0.742	18.85	—
0.525	13.33	20.5
0.371	9.42	—
3	6.68	37.1
6	3.23	50.2
10	1.65	60.8
20	0.83	70.7
35	0.42	77.1
65	0.21	82.2
100	0.147	85.3
200	0.074	100.0

Fig. 4 (San Isidro ore)

100 per cent crude ore		37 per cent washed lump		43 per cent fine ore		20 per cent slimes
—85 mm		+ 5 mm		0.25—5 mm		—0.25 mm
63.0	per cent Fe	64.5	per cent Fe	66.9	per cent Fe	
6.17	per cent SiO_2	4.0	per cent SiO_2	3.1	per cent SiO_2	
1.03	per cent Al_2O_3	0.92	per cent Al_2O_3	0.73	per cent Al_2O_3	
0.057	per cent P	0.07	per cent P	0.048	per cent p	
		2.1	per cent ignition loss	1.6	per cent P	

Fig. 5 (Nimba ore)

3.2 to 5.1 p. c. L. O. I. using different cut-off grades ranging between 55 p. c. Fe and 58 p. c. Fe. The ore : waste ratio can be expected to be approx. 20 : 1. Fig. 4 shows the granulometric composition. Further occurrences of iron bearing formation are known on the Guyana shield (e. g. Piacoa etc.), but have not been investigated to a degree that would merit discussing them in detail.

2. Liberia-Shield Area

2.1. Bomi Hill — Liberia

This deposit was first investigated in the early thirties, and mining began after the second World War in 1951. Although geologically a syncline, the ore body is morphologically a hill, and lies near the coast to the east-north-east of Monrovia in Liberia.

In addition to large reserves of fine grained low grade itabirites, the area contains a large ore body of coarse grained magnetitic high grade ore, formed by metamorphic differentiation analogous to El Pao in Venezuela. The magnetitic high grade ore body averages a thickness of approx. 40 metres, overlain from top to bottom by 40 metres of schist, 60 metres of low grade itabirites and followed again by 60 metres of schists. Below this series lies the high grade ore body with an average composition of 64.5 p. c. Fe, 4.5 p. c. SiO_2, 1.5 p. c. Al_2O_3, 0.13 p. c. P and 0.12 p. c. S. The product from this ore body is approx. 53 p. c. lumpore between 11 to 37 mm and 47 p. c. fine ore minus 11 mm.

Through weathering the itabirite of the hangingwall series has partially become amenable to beneficiation, delivering a product containing 64.0 p. c. Fe, 6.0 p. c. SiO_2, 1.0 p. c. Al_2O_3, 0.04 to 0.05 p. c. P and 0.08 to 0.12 p. c. S. Together with the fine ores from the high grade ore body, these products constitute the sinterfeed produced at Bomi Hill. The average ore to overburden ratio is 1 : 3.6.

At the beginning of mining operations in 1951 the deposit contained approx. 50 to 60 m.tons of high grade ore, and another 50 m.tons of weathered low grade itabirite amenable to concentration.

2.2. Bong Range —Liberia

The Bong Range area deposits can be considered to belong to the partially enriched itabirite type of ore bodies. Through supergene influences the itabirites were weathered and partially enriched. No ores of the supergene high grade ore type could either develop, or these high grade ores if present, fell a prey to erosion. Bong Range consists of four individual ore-bodies forming a single steeply folded itabirite syncline, of over 13 km length, with an outcrop width up to 300 metres. The itabirite body proper is not thicker than 80 metres, the apparently larger outcrop width is due to folding and repitition. Both the footwall and hangingwall is comprised of schists, reaching the mesozonal metamorphic facies in the footwall. The main oxides are magnetite, hematite and quartz with varying proportions of biotite, cummingtonite and grunerite, in the unweathered portions and martite, hematite as well as some goethite in the weathered parts of the deposits. Oxide bands are between 1 to 10 mm in width with average grain size of 0.1 mm. As a result of modification through weathering three technical ore types can be recognised in the deposits: a) soft itabirite (heavily weathered) containing 42.6 p. c. Fe, 7.1 p. c. magnetite, 37.1 p. c. SiO_2, 0.5 p. c. Al_2O_3, 0.05 p. c. P, an 0.008 p. c. S. Grain size distribution of this type 80 p. c. minus 0.25 mm. Approximately 11.5 p. c. of the measured reserve are represented by this ore type; b) transitional ores with 40.6 p. c. Fe, 12.0 p. c. magnetite, 40.0 p. c. SiO_2, 0.5 p. c. Al_2O_3, 0.03 p. c. P and 0.01 p. c. S. These ores are medium hard, slightly weathered and represent approx. 13.5 p. c. of the measured reserves. Grain size is 90 p. c. minus 0.1 mm; c) magnetic ores have an average chemical analysis of 37.4 p. c. Fe, 35.2 p. c. magnetite, 42.0 p. c. SiO_2, 0.4 p. c. Al_2O_3, 0.04 p. c. P and 0.03 p. c. S. Approximately 75 p. c. of the measured reserves are represented by this ore type with a grain size of 90 p. c. minus 0.1 mm. Through beneficiation and pelletizing, the products from the Bong Mine are, concentrates, with an analysis of 65.15 p. c. Fe, 9.64 p. c. FeO, 7.00 p. c. SiO_2, 0.28 p. c. Al_2O_3, 0.034 p. c. P, 0.022 p. c. S, 0.05 p. c. Mn, 0.05 p. c. CaO, 0.06 p. c. MgO, nil Cu and 0.60 p. c. L. O. I., as well as pellets averaging 64 to 65 p. c. Fe, 0.4 p. c. FeO, 7 to 8.5 p. c. SiO_2, 0.3 to 0.4 p. c. Al_2O_3, 0.25 p. c. Ca, 0.02 to 0.04 p. c. P and 0.02 to 0.04 p. c. S.

At the start of the mining operation in 1965 the measured, indicated and inferred reserves were 533 m.tons distributed in four ore bodies a) Zaweah I with 232 m.tons of measured reserves, b) Zaweah II with 60 m.tons as indicated reserves, c) Bong Peak with 128 m.tons as indicated reserves, d) Gomma contained 15 m.tons as inferred reserves and e) Northern deposit with 38 m.tons of measured reserves. The total measured and mineable reserves were, however, contained only in the ore bodies Zaweah I and Northern deposit totalling 275 m.tons. Both these ore bodies contain the above described technical ore types, which are situated from base to top in the following manner; lower-most magnetic ore, transition ore followed by weathered soft itabirite ore. Ore: waste ratio of the mineable ores varies from 1 : 0.5—1 : 1.0.

2.3. Nimba —Liberia

One of the largest iron ore mines in Africa is the Nimba ore deposit. The ores mined at Nimba belong to the supergene high grade ore variety. The primary itabirites are fine banded with band widths of 0.5 to 5.0 mm, fine grained (0.03 to 0.1 mm) and belong to the oxide facies. The sedimentary thickness of the itabirites varies between 250 to 400 metres with larger outcrop widths, through folding and repition. Major ore minerals are magnetite oxidized to martite and hematite. Iron silicates if present have been leached and converted into goethite or hematite. According to GAERTNER, H. R. v. (1961) the supergene high grade ores consist of two main types a) blue high grade ores and b) brown high grade ores, and belong to two weathering cycles. The brown ores are bound to the cretaceous Gondwana Peneplain and the blue ores originate from an older, higher situated, weathering cycle.

The basal primary hard itabirites, apparently unweathered, show the following analysis: 38 p. c. Fe, 42.0 p. c. SiO_2, 0.5 p. c. Al_2O_3 and 1.5 p. c. L. O. I. At the footwall of the brown ores and hanging wall of the hard itabirite, there is a thin zone of soft itabirites. A chemical analysis of these siliceous fine ores shows them to contain 50 to 60 p. c. Fe, 10 to 20 p. c. SiO_2 and 1 p. c. AO_2O_3. Directly following the soft itabirites is the zone of high grade ores. Brown ores contain 65.5 p. c. Fe, 1.5 p c. SiO_2, 0.8 p. c. Al_2O_3 and 4.0 p. c. L. O. I. Thickness of the brown ores can be up to 100 metres. Whereas the older supergene high grade blue ores have a chemical composition of

67.8 p. c. Fe, 1.5 p. c. SiO_2, 0.5 p. c. Al_2O_3 and 1.5 p. c. L. O. I., and can go as far deep as 600 metres below the surface. These can be considered to be the roots of much older ore bodies resulting from an older weathering cycle. Fig. 5 shows the granulometric composition of the mined ore. The total mineable reserves in 1972 were 170 m.tons measured, plus 33 m.tons indicated, of these 105.4 m.tons are blue ore and 64.6 m.tons of the brown variety. These figures are valid only for the portion of the Nimba deposit in Liberia called Nimba-south.

2.4. Mano River — Liberia

The discovery and preliminary geological investigations of the Mano River area at the end of the fifties resulted in the start up of mining operations in 1961. The deposits at Mano consist of a series of metamorphic schists, amphibolites and itabirites. These intercalated itabirites are almost always of the silicate facies, and grade both laterally and vertically into the schists over very short distances. Intensive weathering has completely modified the whole series and unweathered itabirite is not be encountered at the base of the deposits anymore. The highly weathered itabirite remanents, can be considered to have been banded magnetite and iron silicate rocks, perhaps amphibolites. Overlying these is a limonitic, clayey rock detritus with an Fe-content of 40 to 50 p. c. Further towards the hanging wall the ore zone is characterized by intensive removal of silica and thus residual enrichment of the Al_2O_3 content. Crustal ores cover the intensively weathered series at the surface. Where the crustal ores resisted erosion, the underlying ore bearing series could be preserved, so that the Mano deposit appears as a series of hills, each hill containing an ore body. Through washing and screening stages the crude ore is converted into the following products: Sinterfeed Mano I with 55 to 58 p. c. Fe, 2.2 to 5.6 p. c. SiO_2, 8.7 to 5.0 p. c. Al_2O_3, 0.065 p. c. P and 0.09 p. c. S as well as Sinterfeed Mano II with an average of 59 p. c. Fe, 4.0 to 4.6 p. c. SiO_2 and 5.5 to 6.4 p. c. L. O. I. Approximately 45 p. c. of the total product is lumpore + 25 mm and originates from the crustal ore cappings. In 1973 the Mano deposits contained 125 m.tons of measured reserves, of these 50 p. c. were crustal ore and 50 p. c. were siliceous plus aluminious fines.

2.5. Marampa —Sierra Leone

The ore deposit of Marampa in Sierra Leone have been worked since 1933. Owing to depletion of reserves and the adverse market conditions in 1975 the operations were finally suspended. The area contains a series of highly metamorphic hematite quartites and hematitic mica schists. These iron bearing series can be considered to be itabirites of both the oxide and silicate facies. The series beginn at the base with mor than 100 metres of lower quartz mica schists followed by approx. 40 metres of the lower hematite schists. Overlying this are approx. 60 metres of the middle quartz mica schists. Above this are approximately 75 metres of the middle hematite schists covered by approximately 40 metres of upper quartz mica schists. Finally the whole series is topped by approximately 150 metres of upper hematite quartzites. These metasediments form a flat sycline underlain by granites and gneisses of the Kasila-series.

The unweathered iron bearing rocks are hard and slaty, containing hematite, quartz and a little biotite. Grain sizes of the iron oxides is approximately 0.5 mm. Upon weathering, soft itabirites are formed with an average Fe-content of 49 p. c.

Owing to local conditions no supergene high grade ores were formed therefore directly on top of the soft itabirites there is a cover of clayey crustal ore with a thickness of 5 to 3 metres. Only the weathered crude ores of the soft variety are mined to produce a concentrate, through benefication, with 64.1 p. c. Fe, 6.37 p. c. SiO_2, 0.84 p. c. Al_2O_3, 0.23 p. c. Mn, 0.008 p. c. P and 0.65 p. c. L. O. I. The granulometric distribution shows 19.5 p. c. in the range 0.32 to 3.1 mm, 20.0 p. c. minus 0.32 mm, 22.5 p. c. minus 0.25 mm, 18.5 p. c. minus 0.18 mm, 14.5 p. c. minus 0.125 mm, 1.5 p. c. minus 0.09 mm and 3.5 p. c. minus 0.075 mm.

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