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Indonesian Banded Iron Formation (BIF): A New Controversial Discovery of BIF Deposit Associated with Island Arc System in Tanggamus Area – Lampung, South Sumatra.

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Abstract – The increasing demand on manganese and iron ores in this early third millennium, especially for supplying Chinese steel industry, enhanced the spirit for Fe-Mn exploration in Indonesia. 70% of world iron supply are produced from Banded Iron Formation (BIF) deposits. These BIF deposits are generally associated with sedimentary or meta-sedimentary rocks of rift basin in old craton or shield of Archaean – Precambrian age. The Indonesian Archipelago comprise mainly younger rocks of Mesozoic – Tertiary age and never iron deposit like BIF has been found. Because of that the national steel industry must import from foreign countries, partly from BIF pit like Minas Gerais, Brazil and Hamersley, Australia. However no large iron ore deposits have as yet been identified in Indonesia. The discovery of “BIF-like” outcrops in Tanggamus area of Lampung Province, South Sumatra is presumably a new and controversial geological evidence compared with the famous Archaean BIF’s deposits. It could be as new valuable iron ore resources in Indonesia in the future. This paper present the results of geologic mapping, detail petrology, geochemical mineralogical characterization of rock samples of research area. The aim of this paper is to give a brief description regarding the mode occurrence of the Pre-Tertiary “Banded Iron Formation” (“BIF”) in Indonesia and specially in Lampung, and to carry out a comparative study with famous other BIF deposits in the world. The work was carried out at the request of PT Banjar Makmur Raharta – Lampung.

Sari – Naiknya kebutuhan bijih mangan dan besi pada awal millennium ketiga, terutama untuk mensuplai industri baja Negara Cina, menambah semangat eksplorasi besi dan mangan di Indonesia. 70% pasokan (suplai) besi dunia diproduksi dari endapan formasi besi atau Banded Iron Formation (BIF). Endapan BIF umumnya terdapat pada batuan sediment atau meta-sedimen yang berasosiasi dengan pembentukan cekungan dipedalaman perisai berumur Archaean hingga Pra-Kambrium. Busur kepulauan Indonesia umumnya disusun oleh batuan berumur Mesozoik hingga Tersier dan belum pernah ditemukan endapan BIF. Karena itu industri baja nasional harus mengimport dari Negara yang mempunyai endapan besi BIF seperti Minas Gerais, Brazil dan Hamersley, Australia. Penemuan singkapan yang serupa dengan endapan BIF di Tanggamus, Provinsi Lampung - Sumatra Selatan kemungkinan suatu kontroversi atau anomaly peristiwa geologi bila dibandingkan dengan endapan-endapan BIF berumur Archaean yang terkenal di dunia. Penemuan BIF Tanggamus adalah suatu kesempatan yang sangat baik bagi eksplorasi endapan besi tipe BIF untuk pemenuhan cadangan besi Indonesia dimasa yang akan datang. Publikasi ilmiah ini mengungkapkan hasil analisis pemetaan geologi, studi petrologi, karakterisasi pola geokimia dan mineralografi contoh-contoh batuan dari daerah penelitian. Tujuan publikasi ilmiah ini adalah memberikan penjelasan tentang kehadiran endapan BIF Pra-Tersier di Indonesia, terutama di Lampung. Selain itu dilakukan juga studi banding dengan endapan besi BIF yang terkenal di dunia. Penelitian ini berawal dari ekplorasi bijih mangan di sekitar Tanggamus atas undangan PT Banjar Makmur Raharta – Lampung.

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Introduction

During field work for Mn ore deposit carried out in Tanggamus – Lampung in 2005, some manganese occurrences are identified, but surprisingly, in one group of outcrop in Gunung Kancil hill, nearby Pringsewu city, was found 20-80 cm thick bed of metaquartzite, intercalated with grey-black 5-30 mm layer of iron oxide. The lamination of iron-oxide is like black thin ribbon that can be followed continuously up to 10 m. Meta-sedimentary rock assemblage of Tanggamus of Late Paleozoic crops out over wide area, forming a narrow belt that extends over 50 km along depositional strike that slightly parallel to the main direction of Sumatra Island. The strata of this complex are characterized by a relative homogenous thickness. Protolith of these meta-sedimentary rocks presumably occurred in extensional rift basin. This paper describes the sedimentary attributes of Tanggamus and its iron-manganese mineralization, and discusses the paleogeographic and paleoenvironmental context.

Geology of Banded Iron Formation (BIF)

BIFs are found at the very beginning of the rock record, amongst the oldest rocks on Earth, and known as Proterozoic-style mineralization (Hutchison, 1987). Contrary to earlier belief, there exists a considerable age-spread among Precambrian BIF's (Cloud, 1973; Clout, 2005, Hagemann et al., 2005). 90% of all iron-formation was deposited between 3.8 Ga and 1.6 Ga (Table-1), prior to the Paleoproterozoic-Mesoproterozoic boundary, and mostly associated with very old crustal or shield of passive continental margin (Figure 1 A). All geologists agree that BIFs offer vital insights on the evolution of the early earth (Harnmeijer, 2003).

BIFs are highly controversial chemical precipitates characterized by the presence of alternating layers of iron-rich and amorphous silica-rich layers. This dichotomous compositional layering is usually expressed on several scales at any given outcrop, from fine sub-millimeter-scale varvelike laminae to metre-scale bands. Even on a microscopic scale, the boundary between the ferruginous and siliceous layers is distinctly abrupt (Taylor et al., 2001; Harnmeijer, 2003).

BIF has been classified on the basis of mineralogical composition (James, 1954; James, 1966), proposed tectonic setting (Gross, 1965) and depositional environment (Kimberley, 1978; Simonson, 1985). The large variety of available classification schemes undoubtedly reflects our limited understanding of BIF formation. James' (1954) original facies concept included oxide-, silicate- and carbonate- facies iron formation thought to correspond to different water depths. A fourth so-called sulphide-facies, containing pyrite [FeS₂] and/or pyrrhotite [Fe_{1-x}S], was once regarded as syngenetic in origin (Fripp, 1976) but has subsequently been suggested to be epigenetic (Phillips et al., 1984; Groves et al., 1987) - with a replacement rather than primary sedimentary origin for sulphide mineralization.

Oxide-rich BIF typically consists of alternating bands of hematite [Fe₂³⁺O₃] with or without magnetite [Fe²⁺Fe₂³⁺O₄]. Where the iron oxide is dominantly magnetite, siderite [Fe²⁺CO₃] and iron silicate are usually also present (James, 1966).

Gross (1965) infers a tectonic setting on the basis of BIF size and lithologic associations. Algoma-type iron formations are relatively small, and associated with volcanogenic rocks. Total primary iron content rarely exceeds 1010 tons (James and Trendall 1982). Typical lateral extents are less than 10 km, with thicknesses in the range 10-100 m (Goodwin, 1973; Appel, 1980; Condie, 1981). Favoured depositional environments for this type of BIF include island arc/back arc basins (Veizer, 1983; Clout, 2005) and intracratonic rift zones (Gross, 1983; Clout 2005).

Superior-type iron formations are larger, and associated with other sedimentary units. Total primary iron content exceeds 1013 tons (James and Trendall, 1982). Several BIFs classified as Superior-type have been reported to extend over 105 km² (Trendall and Blockley, 1970; Beukes, 1973). Deposition occurred in relatively shallow marine conditions under transgressing seas (Trendall, 1968; Beukes, 1983; Simonson, 1985; Simonson and Hassler, 1996), perhaps on the continental shelves of passive tectonic margins (Gross, 1965; Clout, 2005).

Iron-bearing units are not restricted exclusively to the Precambrian geologic record. Younger rocks superficially representing BIFs, commonly termed 'ironstones', are distinctly more Al_2O_3 , P_2O_5 and Fe_2O_3 rich and usually

have an oolitic or pisolitic texture (Schopf, 1983). Unequivocal BIFs appear to be absent from the Phanerozoic record. Table 1 (after James, 1966) compares characteristics of ironstones and iron formations.

Table 1. Comparison of typical ironstones with iron formations (James, 1966)

Characteristic	Ironstones	Iron Formations
<i>Age</i>		
Minimum age	Pliocene	Late Precambrian
Major development	Lower Palaeozoic; Jurassic	2.5-3.0 Ga
Maximum age	Palaeo-Proterozoic (~2.0 Ga)	3760 ± 70 Ma
Thickness of major units	1-50 m	50-600 m
Original areal extent, max. dimension	< 150 km	> 100 km
Physical character	massive to poorly banded; silicate and oxide-facies oolitic	thinly bedded; layers of hematite, magnetite, siderite, or silicate alternating with chert; chert ~50%
Mineralogy		
goethite	dominant	none
hematite	fairly common	common
magnetite	relatively rare	common
chamosite	dominant primary silicate	absent
glauconite	minor	absent
siderite	common	common
calcite	common	rare
dolomite	common	fairly common
pelletal collophane	relatively abundant	absent
greenalite	none	dominant primary silicate
quartz (chert)	rare	major constituent
pyrite	common	common
Chemistry	high iron	low Al, Na, K and minor elements; much lower P

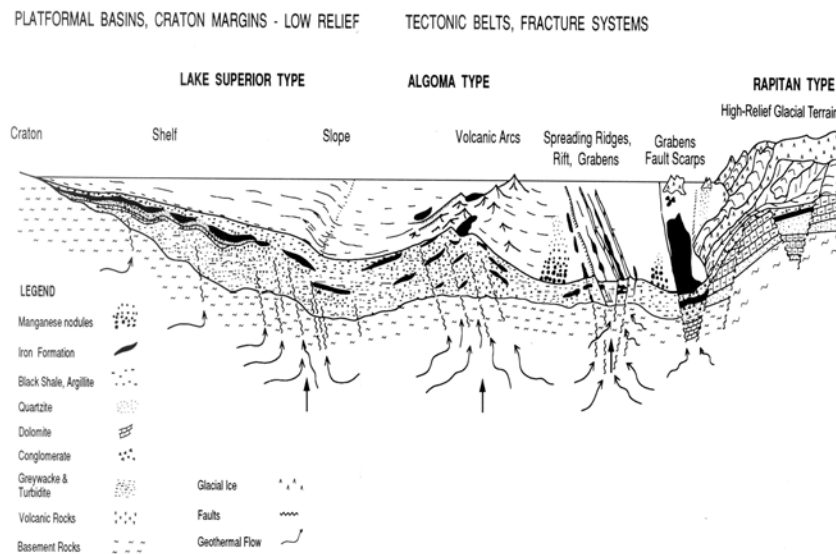


Figure 1. Various type of genesis primary Banded Iron Formation based on tectonic setting and fluid sources (Gross, 1993)

Regional Tectonic of South Sumatra and Lampung

The principal types of basement rocks are generally mica schist, meta-quartzite with scarcely gneissic composition (Pulunggono & Cameron, 1984, Chalik et al., 2004). The basement of the South Sumatra basin is suggested as a paleorift environment (Figure 2) which partly filled by Permian volcanic rocks (Katili, 1980; Pulunggono & Cameron, 1984). The basement of this basin is partly explored for "basement hydrocarbon reservoir" (Chalik et al., 2004). Some side wall cores of Kaliberau basement at a depth interval of 1900-2200 m comprise mica schist, meta-quartzite and marble (Chalik et al., 2004). Absolute age dating by K/Ar method on mica bearing quartz schist of Kaliberau basement samples yielded Cretaceous age (Chalik et al., 2004). This basement rocks partly crop-out intensively in Tanggamus area – in south-western of Lampung Province in association with amphibolites, gneisses containing aluminous minerals.

It was demonstrated that the paleorift basement and rock associations exposed at the surface in the southwestern part of the Lampung block are of Pre-Tertiary age. This paleorift was infilled by Permian volcanic rocks (Katili, 1980) and thick terrigenous clastic sediment which are partly metamorphosed and classified as Mutus Assemblage (Pulungono & Cameron, 1984).

The Pre-Tertiary rocks of South Sumatra basement comprise also Permian volcanic deposits (Katili, 1980) and Pre-Tertiary granitoid plutonic rocks which crop out extensively from the north to the south of Sumatra (Hutchison, 1989; Wikarno et al., 1987). The Fe^{2+} and Fe^{3+} plot for magnetite-ilmenite series classification after Ishihara (1978) and Lehmann (1982) yielded magnetite-series for Sibolga Granite Complex (SGC) of northern Sumatra (Subandrio, 1997). The mineralization of uranium and molybdenum in Sibolga area occurs in a succession of arenite and conglomerates which are clearly associated with granitic basement of SGC (Subandrio 1997). During Permian time the western Sumatra Basin was occupied by an elongated sea basin in which thick sequence of bathyal and neritic sediments were deposited (Figure 1). Pelitic sediments dominated, but at same time

plutonism and volcanism started in this area (Katili, 1980). The magmatic products comprise mainly basic until acid rocks with their tuffs. In some parts of Southern Sumatra the magmatic activity lasted till Cretaceous time. The main phase of folding took place about 120 Ma accompanied by an emplacement of granitic rocks (Katili, 1980.) The basement sedimentation of south-western Sumatra basin was composed generally of quartz abundant arenaceous rocks, which are originated from Paleozoic to Mesozoic granitic terrain (Pulunggono & Cameron, 1980; Amin et al., 1993).

The most intense Pre-Tertiary processes in the South Sumatra basement and its nearest surroundings were intrusion of numerous foliole plutonic bodies, retro-grade metamorphism to medium- low-temperature amphibolites and epidotic amphibolites facies, synmetamorphic magmatization, and emplacement of postkinematic granite dikes. Most Pre-Tertiary processes were determined to have been related to crustal sources (Katili 1980, Pulunggono & Cameron 1984). A western South Sumatra Coastal Basin is also in-filled by Mesozoic-Cenozoic sediments (Pulunggono & Cameron, 1984).

Geology of Tanggamus Area

A predominant rock type in the Tanggamus is foliated crystalline rocks (Amin, 1993) dominated by mica schist and banded meta-quartzite. The meta-quartzite facies mainly occurs in its western part as NW-SE elongated crystal-line bodies of Gunungkasih Complex of Cretaceous age (Figure 3) that crops out around Pringsewu area and represented by the Tangkit Balangbesi massifs (Pzg). In the southwest area, an intensely deformed variation of this unit is represented by crystalline assemblages of Tanjungkemala which consists of foliated fine-to medium-grained quartz schist and meta-chert, partly associated with 5 - 10 cm manganese ore bed. Units of muscovite schist and meta-basalt with associated epidote-chlorite bearing facies are observed as local massifs near Gunungkasih area. These crystalline units are crosscut by Tertiary granitoid intrusions giving delicate hydrothermal mineralization in some places.

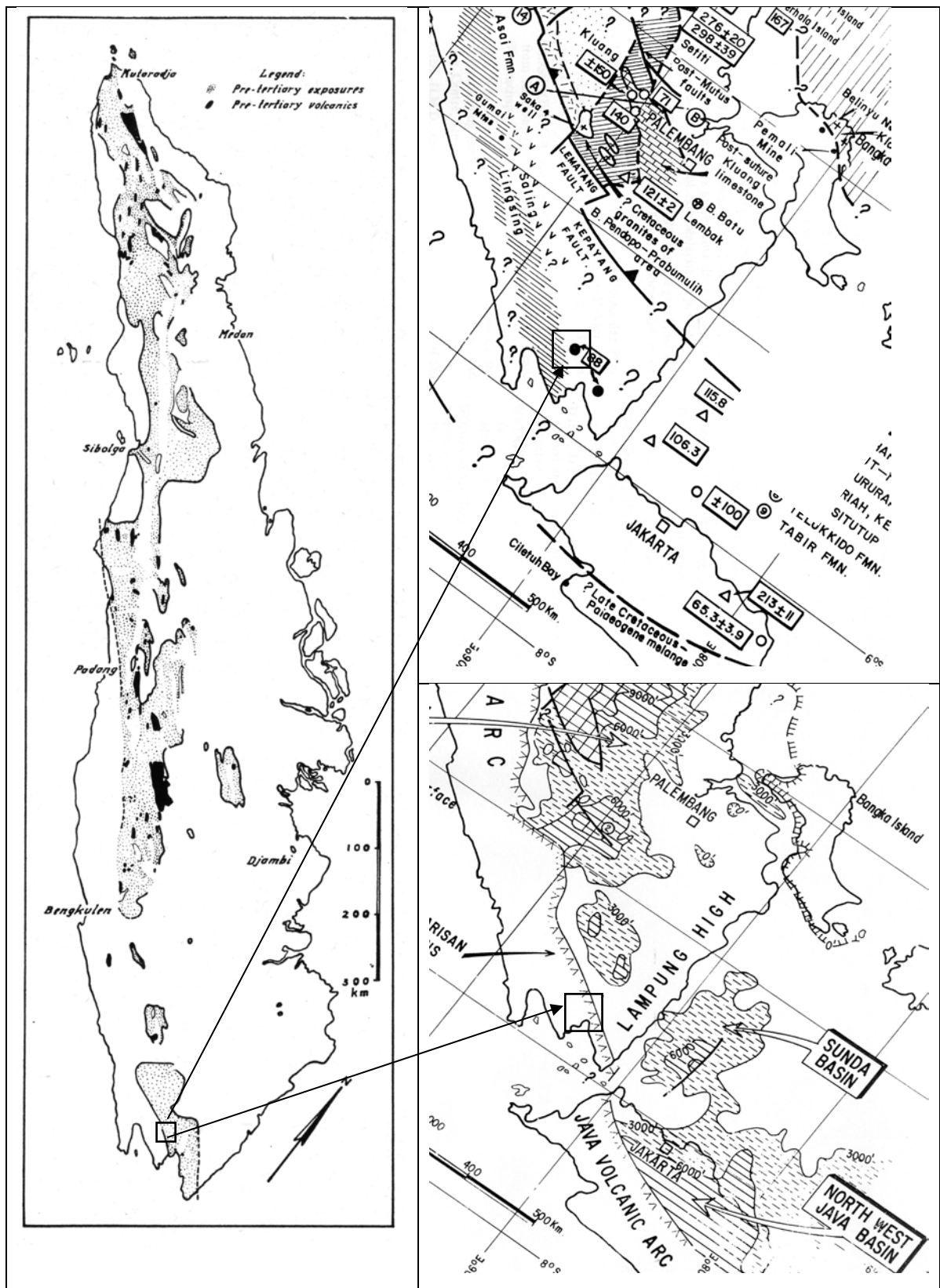


Figure 2. Distribution of Pre-Tertiary (Permian) volcanic rocks of Sumatra (Katili, 1980) and regional geology and basement of South Sumatra basin (Pulunggono and Cameron, 1984). Unfilled square is research area

BIF's occurrences in Tanggamus Area

Regionally, the known Fe-Mn mineralizations in Tanggamus area are recorded in Gunungkasih area, which are associated with schist, quartzite, marble, and migmatite of Paleozoic age. Those rocks are grouped into the Gunungkasih Complex /GKC (Amin et al. 1993). Alternating calcareous shale, claystone and sand-stone with chert intercalation and lime-stone lenses of Cretaceous age of the Menanga Formation has a NW-SE trending thrust fault contact with GKC. The remaining area is occupied by Early Miocene sedimentary rocks of Gading Formation and volcanics of Hulu Simpang Formation (Figure 2). Their contacts with the former two formations are supposed to be unconfomity. A conjugate structure with NW - SE and NE-SW direction is also noted.

The research area lies in the center of the Gunung Tangkit-Balangbesi area, which unfortunately lacks outcrops. There have been only three exposures identified, while the rest are float. The exposures include andesites and tuff in Tanjungkemala and andesites in Tanjungtinggi. It is interpreted that the andesite and tuff are part of Hulu Simpang Formation. While meta-quartzite, meta basalt and hornfels were recognized as float, which are supposed to be part of GKC (Figure 2).

During field work for Mn ore deposit carried out in Tanggamus – Lampung in year 2005, some manganese occurrences are identified, but surprisingly, in one group of outcrop in Gunung Kancil hill, nearby Pringsewu city, was found 20-80 cm thick bed of meta-quartzite intercalated with thin lamination of grey-black of iron oxide (Figure 4). This 50 meter high hill was formerly covered by thick soil and lacked outcrop. However, after excavation work for manganese ore exploration, a huge wall of thrust faulted banded meta-quartzite was exposed. This Gunung Kancil and the other hills in the western and southwestern of Pringsewu have been mapped in detail and studied in relation to the intensive exploration for iron and manganese ore deposit. Integrated analysis from the field, laboratory and literatures are giving surprise that the iron-manganese occurrences in Tanggamus area are presumably associated with Banded Iron Formation. This Tanggamus iron-oxide bed comprises mainly lamination, 20-50mm thick of very-fine to medium-grained hematite and magnetite, intercalated with

foliated quartz layer (Figure 4). The iron-oxide assemblage consist gene-rally of hematite and magnetite, with scarcely goethite veins and limonitic coating on the surface of the rocks (Table 2).

Petrology and Geochemistry BIF's ores of Tanggamus Area

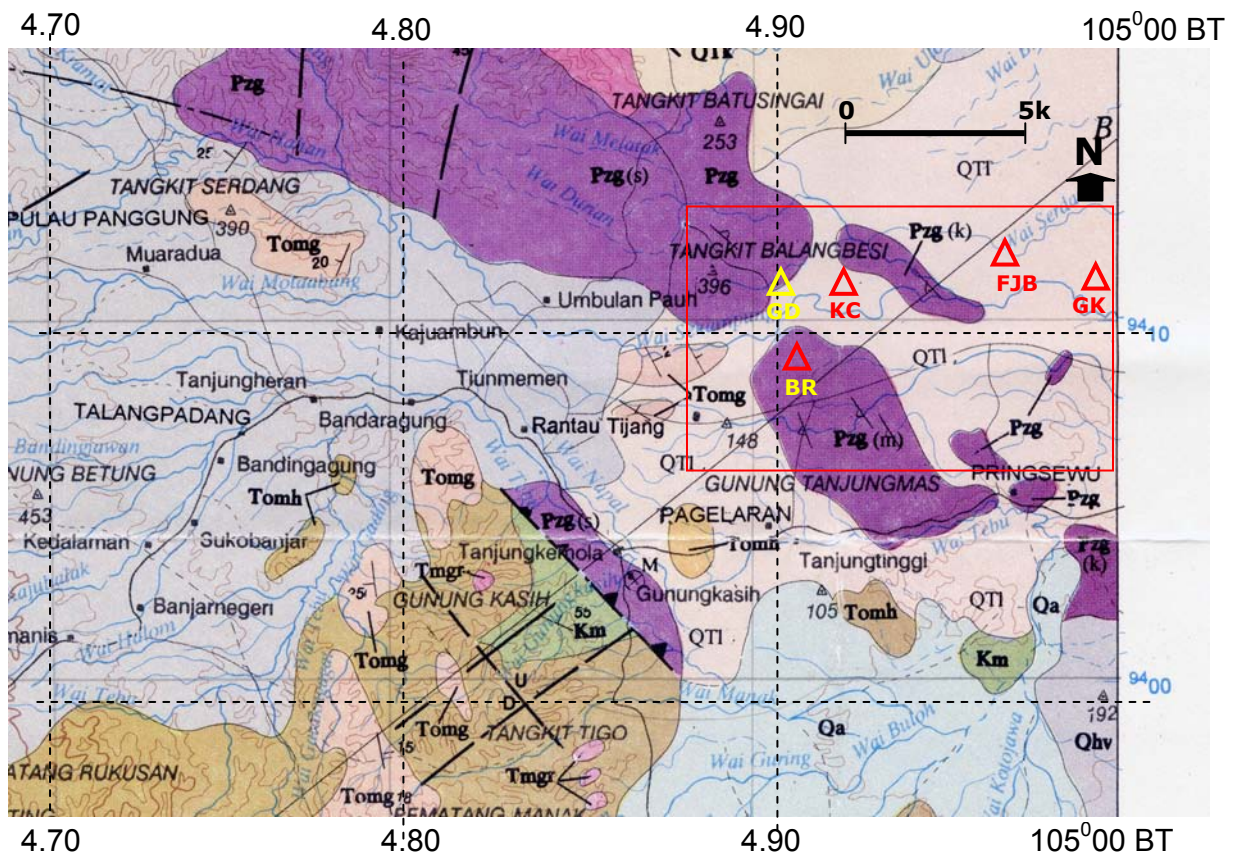
Methods

Polished slabs, polished section, and thin sections were prepared from the rock chips. The polished slab and polished section preparation technique involved saw cutting, continued by polishing of flat side. For polished section, the samples are cut in small chip with diameter up to 3 cm, continued by mounting in epoxy hard. The flat surfaces were then polished by various grade of grinding materials until the finest 200 mesh. A qualitative petrographic description was made of each polished slab, thin section and polished section, and each is illustrated with some slab close up photo and photo-micrographs. All preparations, rock slab, microphotography, and petrology analyses were done in laboratory of economic geology of Geological Department of Institut Teknologi Bandung. Major elements were examined by complete compositional analysis by X-ray fluorescence in geochemical laboratory of Directorate Mineral Inventory in Bandung.

Results

Based on textural and mineralogical characteristics, the samples can be grouped into meta-quartzite and chert. The meta-quartzite rocks of Tanggamus mainly show relict eyes (GK-10), which are clear signs of internal strain: undulatory extinction of quartz, banding of the crystalline structure expressed by curved and folded iron-oxide assemblages (GK-9) and almost universal marginal granulation. Brief petrology analyses of some BIF's samples can be seen in Table 2.

Quartz grains, in particular, developed undulatory extinction bands. Curvature and folding of iron-oxides testify relatively strong internal deformation (Figure 4 and 5). Due to dominant foliated fine to medium grained granobalstic and lack of micaceous mineral, this meta-quartzite can be classified as gneissic rocks.



QTi=Lampung Formation: <i>Pumiceous tuff, tuffaceous sandstone, locally with tuffite intercalation</i>	Tomh=Hulu Simpang Formation: <i>Early Miocene; Volcanic breccias, andesitic to basaltic lavas and tuffs, hydrothermally altered with sulphide mineral bearing quartz veins.</i>	Tomg=Gading Formation: <i>Early Miocene; Sandstone, siltstone and claystone with intercalation of limestone and lignite</i>
Qa=Quaternary alluvium; <i>Alluvium boulder, couple, pebble, sands, silt, clay, and mud</i>	Km=Menanga Formation: <i>Early Cretaceous of alternating calcareous shale, intercalation of tuffite and locally welded tuff.</i>	Pzg (k)=Late Paleozoic of crystalline rocks of Gunungkasih Complex; <i>Schist, quartzite, marble and migmatite</i>
Qhvr=Young Quaternary volcanics <i>Andesitic to basaltic breccias, lavas and tuff.</i>	Tmgr=Late Miocene; <i>Granitic intrusion</i>	Pzg (s)= Late Paleozoic of crystalline rocks of Gunungkasih Complex; <i>Schist, quartzite, marble and migmatite</i>

Figure 3. Geological map of Tanggamus. This figure is a part of regional map of Kotaagung (Amin et al. 1993). Square with red line is area of intensive BIF study. Red and yellow triangles are the groups of BIF sample locations GD=Gunung Gadung, GK=Gunung Kancil, BR=Bumi Ratu, FJB=Fajar Baru, KC=Kali Cawang

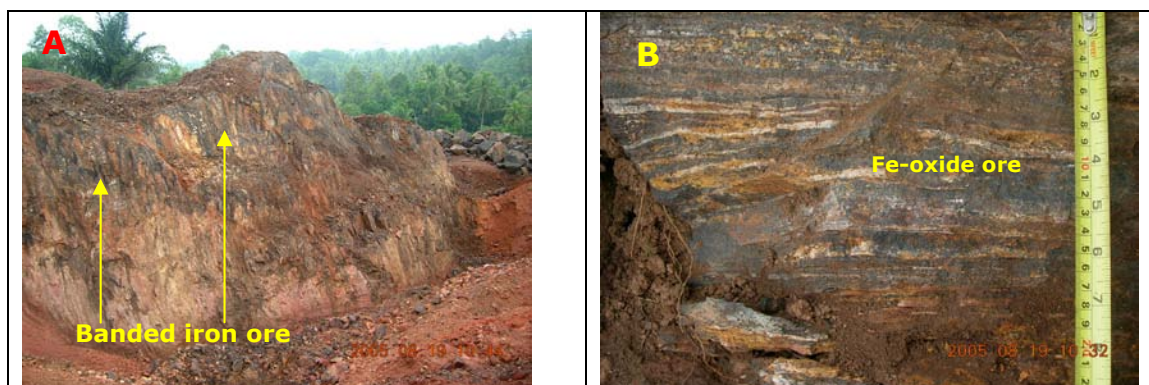


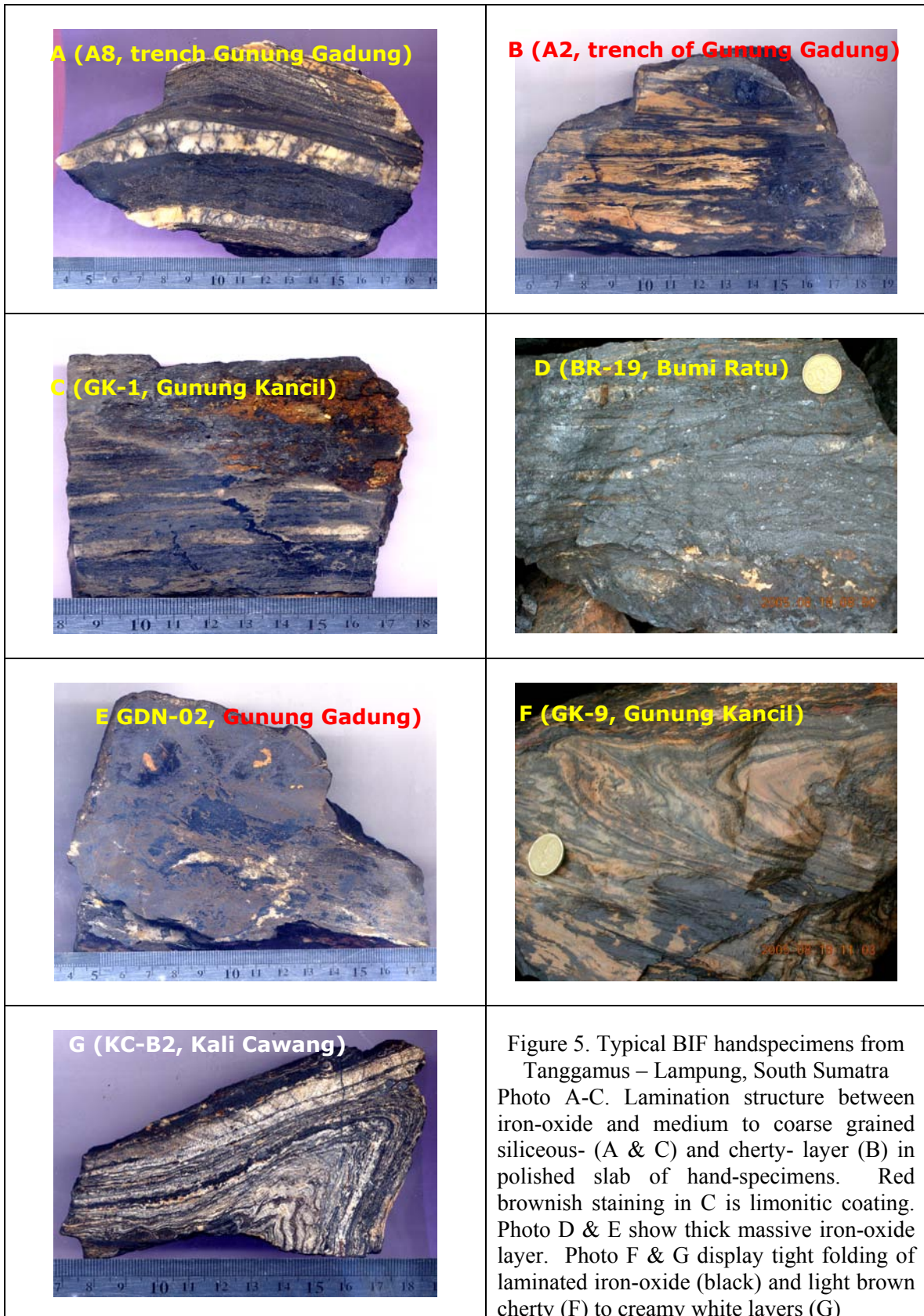
Figure 4. A. Thrust faulted thick banded meta-quartzite of Gunung-Kancil (GK) and B. The outcrop close up showing intercalation of iron-oxide (black) and siliceous layer.

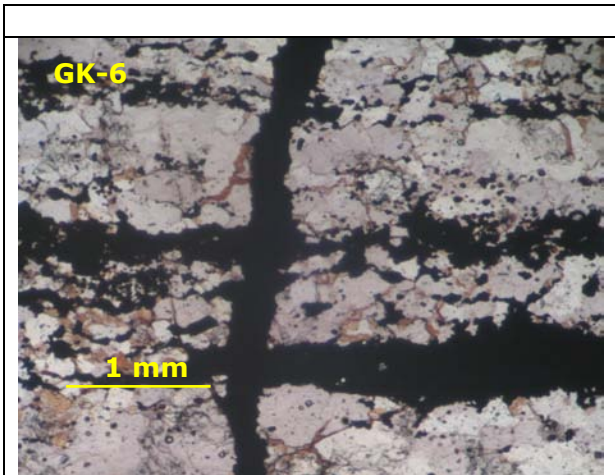
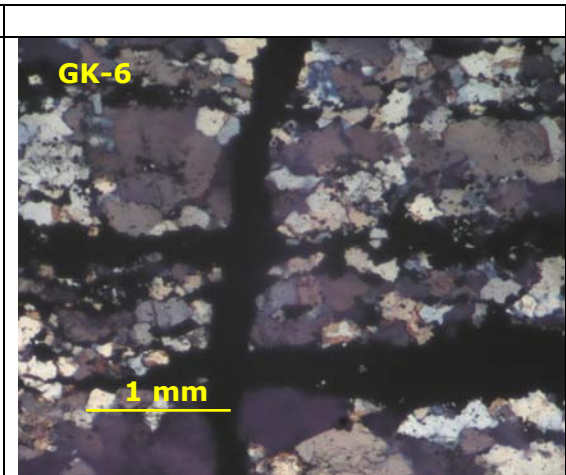
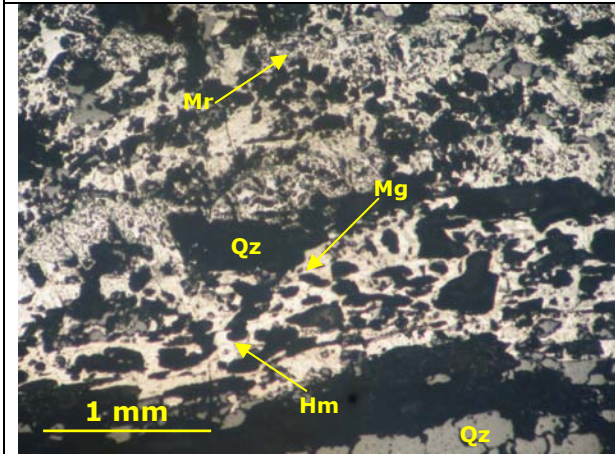
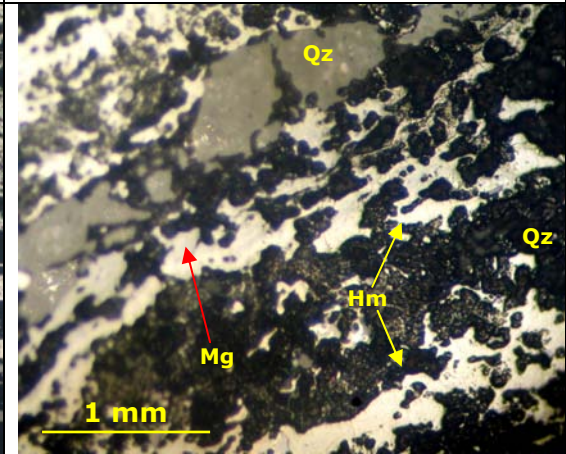
Table 2. Various BIF's samples of Tanggamus area – Lampung, South Sumatra. Iron grade can be seen also in Table-2

Sample No.	Petrology Rock Name	Remarks
A1 – A8	Banded meta-quartzite	The samples have been taken from the base and wall of trench in the complex of Gunung Gadung. The rocks are mostly creamy white in color, hard, consist mostly of banded meta-quartzite. Scarcely grey-black of iron-oxide lying between the meta-quartzite layers. The iron-oxide minerals are partly magnetite, attracted to small hand magnet. Fe-Total content between 2.96 – 29.39 %.
KC A-1 & KC A-2	Banded meta-quartzite	This group of samples from Kali Cawang comprises intercalation of 2-20 mm hematite-magnetite and 20 - 30 mm meta-quartzite layers. Bedding plane is N 300 E/55-60 ⁰ . Fe-total content between 16.97 – 18.71 %.
GDN-02	Banded meta-quartzite	The sample was taken from trench in the slope of Gunung Gadung. The trench outcrop shows very good banded structure consisting of 5-20 mm black hematite-magnetite intercalated with 20-30 mm creamy white meta-quartzite. Bedding plane dipping N 310 E/65 ⁰ . Fe-total content 44.69%
FJB	Banded meta-quartzite	The sample was taken from Fajar Baru hill. The out crop on steep wall after bulldozer excavation for manganese ore. The rocks comprise mainly massive or thick meta-quartzite (30 - 50 cm thick) layer. The iron oxides mostly occur as thin layer or as hematite-manganese coating on the rock surfaces. Fe total content 24.59%
BR-19	Banded meta-quartzite	The sample was taken from trench in the slope of Gunung Bumi Ratu. The trench outcrop shows very good banded structure consisting of massive thick layer of 30 - 50 mm black hematite-magnetite intercalated with 20 - 30 mm creamy white meta-quartzite. Bedding plane dipping N 300 E/70 ⁰ . Fe-oxide content 62.60%
GK-1, GK-4, GK-7, GK-9 & GK-10	Banded meta-quartzite & Banded cherty silica	The sample location is a small hill of Gunung Kancil in the northwest of Pringsewu city. Very good outcrop of Banded Iron Formation present in this hill. The outcrop show thrust faulted thick (mainly 50 – 100 cm partly to 200 cm thick) banded meta-quartzite intercalated with 20-30 mm, partly 30-50 mm iron-oxide layers. These banded rocks are partly highly deformed and form foliation (GK-1and GK-7) and tight folding (GK-9). Scarcely the siliceous layers are very fine grain and showing amorph which can be classified as cherty silica layer (GK-10). The exact iron content is represented only by sample of siliceous dominated rock of GK-1 where Fe-total =20.79%. Visual estimation of Fe-oxide content of GK-4 which is characterized by thick (up to 80 mm) massive hematite-magnetite ore, ranges, between 60-70%.

The iron-oxide bearing gneissic rocks typically show prominent schistosity or foliation (GK-6, BR-19, GD-2), lineations, and segregation

lamination (GK-6) mar-ked by alternation of thin lamination of distinct mineral composition, mainly iron-oxides and quartz (Figure 5 and 6).



	
<p>Figure 6a. Photomicrograph of sample GK-6 in parallel polar shows thin laminae of iron-oxide (black) and meta-quartzite (white/ colorless)</p>	<p>Figure 6b. The same view of sample GK-6 as 6a in cross polar shows intercalation between elongated granoblastic (segregation banding) and banded of iron-oxide (black). Most the quartz crystals have undulatory extinction</p>
	
<p>Figure 6c. Polished section of sample GK-1 under plane reflected light showing continued platy hematite-magnetite and scarcely martite as small part of wavy lamination. Qz=Quartz, Mg=Magnetite, Hm=Hematite, Mr=Martite</p>	<p>Figure 6d. Polished section of sample GK-6 under plane reflected light showing very thin curved hematite-magnetite ribbons enclosed by quartz groundmass</p>

This gneissic rocks show generally relative simple imprint texture that suggest repeated episodes of deformation accompanied and finally outlasted by recrystallization (Figure 6). The later affected the mineralogy alteration and grain or crystal habit of iron-oxide assemblages in some sample significantly. For example, some rocks comprising iron-oxide assemblages with coarser grain size and cubic euhedral (GK-1 and KC-A1), can be estimated as rocks containing of more magnetite than hematite. Fine grained gneissic rocks which comprise platy iron-oxide and quartz assemblages have possibility of hematite dominated ore (GD-2,

BR-19). Platy hematite or micaceous hematite in the metamorphic rocks is associated generally with relatively high pressure or shear stress of strain slip deformation.

The effects of shear stress are more noticeable and more extensive in some samples. In general the most visible effect is tight foliation which produces firmly platy or micaceous hematite (Figure 6) and highly sutured quartz of interlocked groundmass (GK-6, GK-7)

Some coarser iron-oxide assemblages have been converted, by a process combining grain

deformation and partial oxidation and weathering (GK-4, GK-8) into goethite and limonite (Figure 5).

Geochemistry

Complete analyses of some BIF ores of research area are given in Tables 2 and 3. Comparison of geochemical data from some locations shows big variation in SiO₂ and Fe₂O₃ contents. However, these high variations in silica and iron-oxide contents are correlated with their ore texture. When iron-oxide is more frequent than

siliceous layers, the iron content is higher than silica significantly. The highest grade of iron belongs to sample from Bumiratu hill BR-19 (Fe-oxide total =62.60%, SiO₂=13.36%) in which, visually, the lamination of iron-oxide is more dominant than silica (Figure 5D). Chemical properties of sample GK-1 that contain ferrous oxide of 35.71% show more unit of siliceous than iron oxide layers (Figure 5C). The relationship between total iron and iron-oxide as well as between iron and siliceous is given in graphics of Figure 7 and 8.

Table 2. Geochemical composition of representative BIF's samples of Tanggamus – Lampung, South Sumatra

Wt.%	Trench samples of Gunung Gadung								Kali Cawang		
	A1	A2	A3	A4	A5	A6	A7	A8	KC-A1	KC-A2	KC-B2
Fe Total	5.4	19.94	26.4	2.96	18.91	29.39	17.59	35.8	18.71	16.97	21.13
Fe-oxide Total	7.72	28.5	36.36	4.23	27.04	42.02	26.07	51.3	26.75	24.26	30.21
CaO	1.2	0.33	0.89	0	0	0.32	0	0.05	5.57	0.2	0
MgO	0.15	0	0.67	0	0	0	0	0	2.03	0	0
Na₂O	0.04	0	0	0	0	0.05	0	0	4.25	0	0
K₂O	0.1	0.19	0.29	0.04	0.23	0.44	0.18	0.32	3.07	0.16	0.28
TiO₂	0.25	0.25	0.31	0.04	0.06	0.5	0.21	0.4	0.06	0.09	0.06
MnO	0.25	0.25	0.31	0.04	0.06	0.5	0.21	0.4	5.24	0.22	4.66
MnO₂	4.09	17.77	24.4	0.77	17.77	26.39	17.66	13.69	29.37	23.52	8.39
Mn-Total	4.54	12.05	17.25	1.65	12.22	18.9	12.3	10.65	22.62	15.03	8.91
P-Total	0.07	0.04	0.25	0.03	0.04	0.06	0.05	0.14	0.05	0.07	0.27
S-Total	0	13.76	0.03	0	0.01	9.16	0.02	0.05	0	0.03	0.03
H₂O	0.51	1.32	1.85	0.11	0.81	1.26	1.01	1.06	1.05	1.41	0.58
HD	3.21	7.23	8.54	1.51	6.28	7.07	7.27	8.51	10.56	8.27	2.63
	Peak of Gunung Gadung			Gunung Kancil	Fajar Baru	Bumi Ratu					
Wt.%	GDN-01	GDN-02	GDN-03A	GK-1	FJB	BR-19	BR-3C				
Fe Total	1.73	44.69	8.31	20.79	24.59	44.00					
Fe-oxide Total	2.47	63.89	11.8	29.72	35.17	62.60	18.78				
CaO	0.01	5	0.27	0	38.83	0.19	0.14				
MgO	0.01	1.62	0.16	0	0.37	0.09	0.10				
Na₂O	0.31	0.23	1	0.01	0	0.02	0.01				
K₂O	0.53	0.3	0.14	0.24	0.55	0.18	0.22				
TiO₂	0	0.31	0.19	0.25	0.16	0.72	0.00				
MnO	0.23	1.86	0.05	2.31	5.62	0.00	1.25				
MnO₂	0	6.62	0	4.86	11.81	14.25	12.24				
Mn-Total	0.18	5.62	0.04	8.09	8.83	8.94	8.70				
P-Total	0.03	1.7	0.05	0.36	0.12	0.05	0.05				
S-Total	0	0	0.02	0	0.07	0.14	0.17				
H₂O	0.12	1.26	0.24	0.5	1.08	0.37	0.16				
HD	3.56	12.23	3.46	1.33	4.63	4.67	3.49				

Table 3. Geochemical Composition of southwestern slope of Gunung Gadung and Bumiratu

Wt.%	GD-1	GD-8	BR-1	BR-3B	BR-3D	BR-20
SiO ₂	72.49	80.19	74.74	72.12	80.04	77.33
Al ₂ O ₃	3.92	1.68	2.14	2.68	1.37	2.16
Fe ₂ O ₃	8.92	4.96	6.98	15.84	5.18	6.29
CaO	0.75	0.17	0.12	0.13	0.71	0.08
MgO	0.18	0.16	0.12	0.06	0.40	0.13
Na ₂ O	0.05	0.06	0.06	0.01	0.25	0.03
K ₂ O	0.13	0.17	0.21	0.04	0.05	0.44
TiO ₂	0.13	0.00	0.00	0.11	0.00	0.00
MnO	0.98	0.98	0.00	0.22	3.80	0.06
MnO ₂	8.68	8.68	11.35	5.34	4.90	8.90
Mn Total	6.24	6.24	7.18	3.54	6.04	5.66
P Total	0.02	0.02	0.01	0.05	0.03	0.04
S Total	0.31	0.15	0.03	0.08	0.03	0.03
H ₂ O	0.28	0.24	0.22	0.16	0.17	0.15
HD (LOI)	3.31	2.42	3.48	2.92	1.32	2.98

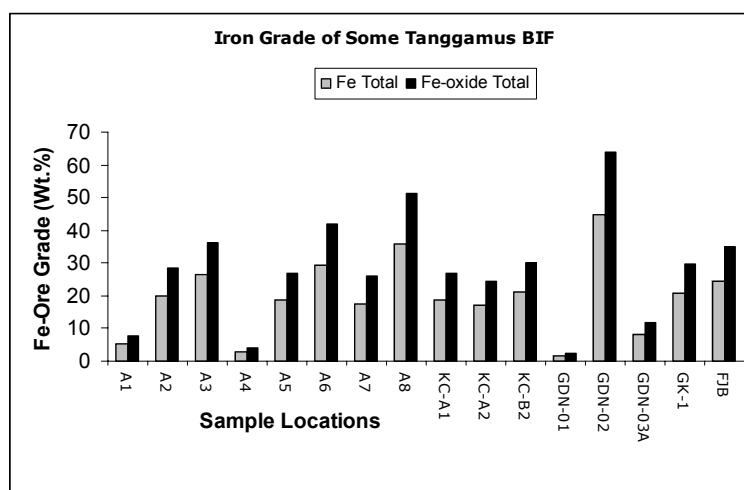


Figure 6. Chart showing iron grade of Tanggamus BIF. A8 represents a group of samples from trench in SW whereas GDN-02 taken from NW slope of Gunung Gadung. Both samples comprise relative abundant thick (20 - 40mm) iron oxide layer intercalated with thin (10 mm) siliceous lamination (see group of photo in Figure 5). The numerical data of this chart is apart of Table-2

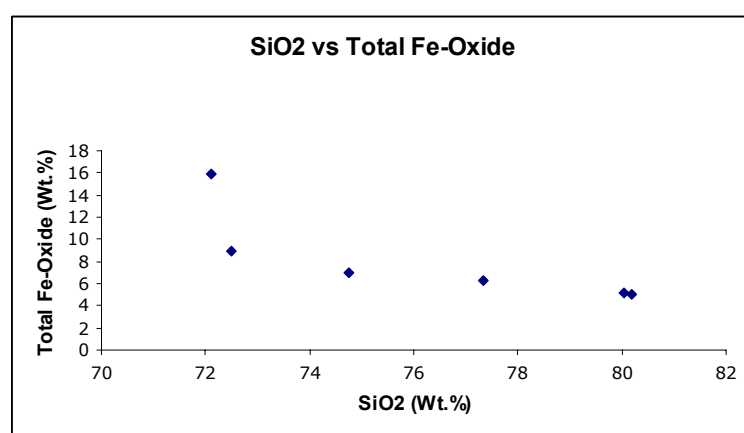


Figure 7. Scatter diagram of SiO₂ vs. Total Fe-Oxide of sample groups A and GDN from SW and NE slope of Gunung Gadung. The sample with silica exceeds 80% and low iron represent a sample with very thin iron-oxide layer intercalated with thick bed of meta-quartzite. The numerical data of this chart is a part of Table-3

Discussion and Interpretation

Some reactions occur after magnetite rich quartz arenite or quartz sandstone has been buried at great depth below the surface that are followed by low to high grade regional metamorphism which generally display schistosity or foliation, banding and scarcely folding (Taylor et al., 2001; Harnmeijer, 2003; Hagemann et al., 2005). Heat and pressure increases due to regional metamorphism can alter the texture and mineralogy of rocks. Granular cubic magnetites are altered to micaceous hematite associated mainly with fine-grained, fine lamination of elongated quartz groundmass. These texture and dominated platy hematite assemblages suggested higher grade of gneissic rocks.

Variation in proportion between hematite and magnetite observed in Tanggamus area are presumably controlled by texture, especially by "grainsize decrease" of gneissic rocks.

The coarse grained gneissic rock of sample (BR-19) typically has relatively higher magnetite portion (visual estimate of magnetite » 70% volume).

Higher grade gneissic rocks of fine-grained assemblages have resulted significant of increasing hematite portion. Local stress and also heat increase, probably associated with strike slip or thrust fault zone after regional metamorphism, appears to generally altered magnetite to hematite.

The gneissic rocks contain mostly quartz and black layer, partly lamination of iron-oxide and locally iron-hydroxide. The iron-oxide layers are usually aligned parallel to the schistosity or foliation. Some samples have been folded (KC-B2, GK-9), sheared, scarcely fractured and then veined by silica and iron-oxide. This is shown significantly by folding, wavy lamination and fracturing of the schistosity in the polished slab and under petrography microscope.

The iron-oxide composition in the rock samples (by visual estimation) of Gunung Gadding and Bumi Ratu (BR-19) are is relatively higher than Gunung Kancil. Iron-oxides, which are present abundantly in the samples from both areas, are only hematite and magnetite. Martite occurs usually as alteration product of magnetite, whereas goethite is scarce. Hematite ores are probably from alteration of magnetite due to

heat increase during regional metamorphism and presumably hydro-thermal influences, which change the magnetite rich quartz sandstone to hematite-magnetite bearing quartz gneiss (Taylor et al. 2001; Hagemann, 2005; Clout, 2005). Another potential factor according to alteration from magnetite to hematite is local heat increase due to compression in fault zone or associated with cataclastic metamorphism (Klein & Hurlbut 1977; Winkler, 1979 and Taylor et al. 2001).

The geological and tectonic environment of Permian to Pre-Tertiary of Tanggamus can be suggested as the precursor of stratiform iron-oxide mineralization which can be compared with the world famous BIF deposits. Some unique analogies are shown in Table 4.

Conclusions

From the foregoing discussions the following conclusions can be drawn:

1. The discovery of Tanggamus BIF's like outcrops suggest that active and young island arc system like Sumatra could be prospect for banded iron deposits.
2. The iron deposit of Tanggamus presumably associated with Permian magmatism and volcanism of western Sumatra and sedimentation in South Sumatra rift basin. Based on relationship between tectonic setting and size of the basin, the Tanggamus BIF's can be classified on Algoma type iron formation which are characterized by relative small, and associated with volcanogenic rocks.
3. The sources of magnetite are presumably from magnetite rich granitic terrain (magnetite series) of Paleozoic-Mesozoic age which deposited in intermountain or rift basin. Some reactions occur after magnetite rich arenite have been buried at great depth and followed by regional metamorphism. This metamorphism yielded meta-quartzite to gneiss and is suggested as the main precursor for alteration or metasomatism of magnetite to hematite.
4. Based on mineralogy, texture and geochemistry as well as stratiform ore body, iron-bearing units of Tanggamus close to BIF of Archean –Proterozoic styles. No oolitic or pisolitic ironstone has been found, of which representing superficially iron mineralization in younger rocks.

Table 4. Analogy of geological characteristic between Tanggamus and world famous BIF's deposits

Geological Characteristic	Australia, South & West Africa, Canada, Brazil	Tanggamus – Lampung of South Sumatra – Indonesia
Geotectonic & physiography	Mostly associated with stable continent or of craton affiliation	Associated with subduction zone of active continental margin
Age of deposition/mineralization	Generally occur in Archean, Proterozoic until Precambrian	Presumably associated with Permian volcanism or infilling of South Sumatra rift basin by Cretaceous – Late Pre-Tertiary sedimentary rocks.
Deposition environment	Deep magmatic hydrothermal or rift basin development associated with craton or shield of stable continent	Probably associated with intra-mountain rift basin development that continued soon by magmatism and sedimentation in SE Asian Mergui microplates which in Sumatra known as Mutus Assemblages of Mesozoic age.
Original area extent, max. dimension	The ore bodies extend over 10 ³ km ² and the outcrop is mostly found in arid-semiarid or desert climate, and can be followed more than > 100 km away.	Small ore bodies, presumably less than 100 km ² associated with narrow rift basin of island arc system (fore arc?). Lack of outcrop due to thick soil covering and vegetation.
Thickness of major units	50-600 m. Most the BIF's areas have been mined and intensively drilled. Thickness can be measured correctly.	Estimated from topography and structural data the thickness is between 25-50 m. No drill hole data are available and lack of outcrop.
Physical character	thinly bedded; layers of hematite, magnetite, siderite, or silicate alternating with chert; average chert portion ~50%	Thinly bedded; layers of hematite & magnetite intercalated with mm – cm lamination partly foliated “ meta-quartzite ” or quartz gneissic layer. Generally with manganese oxide, no siderite and lack of chert.
Micro texture	Generally hematite-magnetite intercalated with cherty lamina- nation. Magnetite is often altered to hematite and porous martite. Micaceous or platy hematite is the main ore in Australia and Brazil that indicates deep burial metamorphism.	Ore minerals are mainly hematite and magnetite with ± Mn-oxide, granoblastic, partly a group of mm thick micaceous or platy hematite. Porous martite present often as alteration product of magnetite and hematite. Siliceous layer consisting of fine-medium grained, granoblastic, sutured, partly ellipsoid quartz minerals. Lack of cherty layer. Scarcely very fine-grained garnets are present.
Genesis	Chemical deposition is associated with cherty limestone deep marine sedimentation. Fe-oxide intercalated with cherty layer	Presumably began with classic of magnetite and quartz deposition associated with arenite and continued by diagenesis, metamorphism and hydrothermal alteration
Geochemical	Fe-Total average 40-70 Wt.%	Fe-Total average 15-45 Wt.%

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