Indonesian Journal of Geology, Vol. 8 No. 4 December 2013: 191 - 203

Characteristics and Origin of Sedimentary-Related Manganese Layers in Timor Island, Indonesia

Karakteristik dan Asal-mula Lapisan Mangan yang berkaitan dengan Sedimen di Pulau Timor, Indonesia

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Manuscript is accepted: December 03, 2013, revised: November 28, 2013, approved: December 09, 2013

Abstract

Sedimentary-related manganese layers have been discovered in South Central Timor Regency, Timor Island, Indonesia, which is tectonically active and being uplifted due to north-trending tectonic collision between Timor Island arc and Australian continental crust. The manganese layers of 2 to 10 cm-wide interbed with deep sea sedimentary rocks including reddish - reddish brown claystone, radiolarian chert, slate, marl as well as white and pinkish calcilutite of Nakfunu Formations. Stratigraphically, the rock formations are underlain by Bobonaro Formation. Two types of manganese ores found comprise manganese layers and manganese nodule. The manganese layers strongly deformed, lenticular, and segmented, are composed of manganite [MnO(OH)], groutite [MnO(OH)], pyrolusite (MnO_2), lithioporite (Al,Li) $MnO_2(OH)_2$, and hollandite [Ba $(Mn^{4+}, Mn^{2+})_8O_{16}$] associated with gangue minerals including calcite, quartz, limonite [FeO(OH)], hematite (Fe_2O_3), and barite ($BaSO_4$). Whilst the nodule type is only composed of manganite and less limonite. Geochemically, the manganese layers have grade of 63 - 72 wt.% MnO, whereas the nodule one has grade of 63 - 69 wt.% MnO. Generally, iron in Mn ore is very low ranging from 0.2 to 1.54 wt.% Fe_2O_3, averaged 0.76 wt.%. Hence, Fe/Mn ratio which is very low (0.003 - 0.069), typically indicates a sedimentary origin, which is also supported by petrologic and petrographic data showing layering structure of manganite and lithioporite crystal/grain. Trace element geochemistry indicates that manganese ore was precipitated in a reduction condition. Rare earth element (REE) analysis of manganese ore shows an enrichment of cerium (Ce) suggesting that the ore is basically originated in a marine environment. The manganese nodule is interpreted to be formed by chemical concretion process of unsoluble metals (*i.e.* mangan, iron) in seawater (hydrogenous) and precipitated on deep sea bottom. On the other hand, the manganese layer is a detrital diagenetic deposit formed by Mn remobilization in seawater column, precipitated and sedimented on the deep sea bottom. Manganese layers have probably been influenced by 'hydrothermal process' of mud-volcano activities, proven by the presence of quartz and barite veinlets cutting the Mn layers, manganite recrystallization to be pyrolusite along veinlets cutting manganite and lithioporite layers, and the presence of pyrite and sulphur associated with Mn layers. Field data also exhibit that the significant manganese layers are mostly found around mud volcanoes. The closely spatial and genetic relationships between manganese layers and mud-volcanoes might also be an important guide for the exploration of Mn deposit in the region.

Keywords: manganese nodule, manganese layer, Bobonaro, Timor Island, Indonesia

Abstrak

Lapisan mangan yang berkaitan dengan batuan sedimen telah ditemukan di selatan Kabupaten Timor Tengah, Pulau Timor, Indonesia. Pulau ini secara tektonis aktif dan sedang terangkat akibat tumbukan tektonik yang mengarah ke utara antara busur Pulau Timor dan kerak Benua Australia. Lapisan mangan ini yang lebarnya berkisar antara 2 - 10 cm berselingan dengan batuan sedimen laut yang berupa batulempung kemerahan - coklat kemerahan, rijang radiolaria, batu sabak, napal, dan kalsilutit putih dan merah muda Formasi Nakfunu. Secara stratigrafis, formasi batuan ini menindih Formasi Bobonaro. Dua tipe bijih mangan yang ditemukan, terdiri atas tipe lapisan dan tipe bintal. Mangan tipe lapisan yang tercenangga kuat, melensa, dan tersegmentasi, tersusun atas manganit [MnO(OH)], groutit [MnO(OH)], pirolusit (MnO_2), litioporit (Al,Li) $MnO_2(OH)_2$, dan holandit [Ba (Mn^{4+}, Mn^{2+})8O16] yang berasosiasi dengan mineral merduk termasuk kalsit ($CaCO_3$), kuarsa (SiO_2), limonit [FeO(OH)], hematit (Fe_2O_3), dan barit (BaSO4). Sementara itu, mangan tipe bintal hanya terdiri atas manganit [MnO(OH)] dan sedikit limonit [FeO(OH)]. Secara geokimia, mangan tipe lapisan mengandung 63 -72 wt.% MnO yang relatif lebih tinggi atau sama dengan mangan bintal yang memiliki kadar MnO 63 - 69 wt.%. Pada umumnya, besi pada bijih mangan sangat rendah yang berkisar antara 0,2 -1,54 wt.% Fe_2O_3 dengan rata-rata 0,76 wt.%. Karena itu, rasio Fe/Mn sangat rendah, yaitu 0,003 - 0,069, yang secara khas mengindikasikan asal-sedimen. Karakter ini didukung oleh data petrologi dan petrografi yang memperlihatkan struktur berlapis manganit dan kristal/butiran litioporit. Geokimia unsur jejak mengindikasikan bahwa bijih mangan diendapkan pada kondisi yang tereduksi. Analisis unsur tanah jarang (REE) terhadap bijih mangan memperlihatkan pengayaan cerium (Ce) yang mengesankan bahwa bijih tersebut pada dasarnya berasal dari lingkungan laut. Bintal mangan diduga terbentuk oleh proses konkresi kimia logam tak larut di dalam air laut, yaitu mangan dan besi, dan diendapkan pada dasar laut dalam. Lapisan mangan merupakan deposit asal rombakan yang terbentuk oleh remobilisasi Mn pada kolom air laut, diendapkan dan tersedimentasikan pada dasar laut dalam. Lapisan mangan mungkin telah dipengaruhi oleh proses hidrotermal kegiatan poton. Hal ini dibuktikan oleh keberadaan urat kecil kuarsa dan barit yang memotong lapisan Mn, rekristalisasi manganit menjadi pirolusit sepanjang urat kecil yang memotong lapisan manganit dan litioporit, dan keberadaan pirit dan sulfur yang berasosiasi dengan lapisan mangan. Data lapangan juga memperlihatkan bahwa lapisan mangan terutama ditemukan di sekitar poton. Hubungan spatial dan genetik yang dekat antara lapisan mangan dan poton juga bisa sebagai petunjuk penting bagi eksplorasi deposit mangan di daerah tersebut.

Kata kunci: *bintal mangan, lapisan mangan, Bobonaro, Pulau Timor, Indonesia*

Introduction

Manganese layers have been widely discovered in Timor Island, Indonesia. Manganese nodule and boulders are also found. The manganese ores are associated with Nakfunu Formations. Stratigraphically, the rock formations are underlain by Bobonaro Formation. The researched area is situated in PT. SoE Makmur Resources (PT. SMR) tenement area, Supul Subregency, Timor Tengah Selatan Regency, East Nusa Tenggara Province (Figure 1). The origin of manganese ores in Timor Island is still debatable. This paper, therefore, is dealing with geological setting as well as mineralogical and geochemical characteristics of both manganese nodule and layer types. This may help for a better understanding the origin of the manganese ores in the studied area.

Regional Geology

Regional geologic description is based on Timor geologic map of the Kupang-Atambua Quadrangles (Rosidi *et al*., 1979). Geology, particularly geological structures of the Timor Island is very complex. This is shown by the presence of various rock types from various ages in the area; they are strongly deformed and mixed rocks (olisostrome/melange) covering nearly 40% of the island.

Some periods of tectonic movement of Timor Island are recognized. Initial period is marked by Late Cretaceous-Eocene tectonic movement of Australian Continent to the north resulted in the collision between 'Paleo Timor' island arc and Indo-Australian oceanic crust (Audley-Charles *et al*., 1975, in Rosidi *et al*., 1979). The collision produced mixed rocks

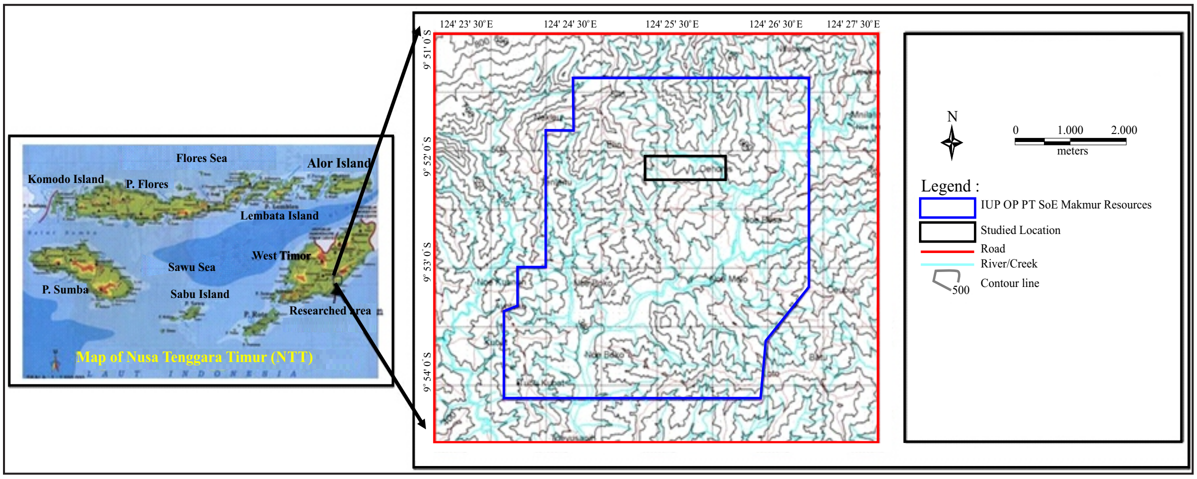


Figure. 1. Locality map of studied area in Supul Village, Kuatnana Subregency, South Central Timor Regency, East Nusa Tenggara Province.

(olisostrome or melange), deposition of Noni, Haulasi, and Ofu rock formations, emplacement of basaltic-ultrabasic rocks, metamorphisme of Maubisse, Ailiu (in East Timor) and the formation of Metan volcanic rocks. Strong folding, thrust fault, and transform fault are predominant structures present in the area.

The next tectonic movement was subduction in Miocene resulted in the collision of northern margin of Australian crust and island arc, which is observed until present/Holocene (Hamilton, 1979). The collision causes pre-Pliostocene rock formations are strongly folded and faulted. The tectonic activity is marked by the occurrences of active earthquakes, mud diapirs/mud volcanos, active faults and reactivated pre-Holocene faults as well as vertical down- and uplifting. Since 35,000 years ago, western part of Timor Island has been uplifted of 0.37 - 0.7 mm/year (Tjia, 1979), whereas central part has been of 3.3 mm/year (Tjokrosapoetro, 1978).

Mud volcano or diapiric mélange in Timor island are mostly related to scaly clay of Bobonaro complex covering about 4000 km^2 of outcrops in Timor island. Mud volcanos in Timor island have surface temperature of 28 - 30º C with geothermal gradient of about 2º C/100 m. This is lower than that of LUSI (4.2º C/100 m) which may be related to volcanic arc (Mazzini *et al*., 2007).

Stratigraphically, Timor island is occupied by three rock units including autochthon, parautochthon, and allochthon (Rosidi *et al*., 1979). Autochthonous and parautochthonous units, from oldest to youngest, consist of Bisane, Aitutu, Wailuli, Nakfunu, Ofu, Noil Toko, and Cablac Formations, Viqueque rock group (Batuputih and Noele formations, conglomerate and gravel, alluvial deposit), whereas allochthonous unit is composed of sedimentary and volcanic rocks consisting of Mutis complex, Maubisse, Noni, Haulasi, and Metan Formations, diorite, Mananas Formation, ultrabasic rock and Bobonaro complex (Rosidi *et al*., 1979).

The studied area is stratigraphically occupied by Jurassic Nakfunu and Late Createaceous-Eocene Ofu Formations unconformably overlain by Bobonaro Complex. Reddish scaly clay of Bobonaro Complex contains Mesozoic-Pliocene foraminifera fossils. Middle Miocene-Pliocene fossils are predominant compared to pre-Miocene fossils (Rosidi *et al*., 1979).

Research methods

Two ‘classic’ research methods including field work and laboratory analysis were applied. Field work covers geologic and manganese ore distribution mapping as well as associated rocks and Mn ores sampling. A total of six limestone samples from various colours (white, cream, and pink) and 17 Mn ore samples were taken for laboratory analyses. Petrographic, ore microscopic, and XRD (X-Ray Diffraction) analyses for mineralogical identification were done at Department of Geological Engineering, Gadjah Mada University. Bulk rock geochemistry for major and trace elements was performed by FUS-ICP (Fusion-Inductively Coupled Plasma) at Actlabs laboratory, Canada. Mineral chemistry for some important Mn-bearing minerals was analyzed by EPMA (Electron Probe Micro Analyser) at RWTH Aachen University, Germany.

Results and Discussion

Geology of Mn Deposit

Stratigraphically, the researched area is occupied by (1) white-pinkish limestone calcilutite intercalated with redish-redish brown claystone, radiolarian chert, slate, marl of Ofu and Nakfunu Formation, (2) Scaly clay containing various xenoliths of Bobonaro Complex, (3) Mud volcano intrusion unit composed of greyish clay containing rare sulfur, and (4) present fluviatil deposit. Geological structures are dominated by compressional regime structures including NE-SW-trending trust fault, dextral strike-slip fault, fold and clay diapirs trucanted Mn-bearing layers (Figure 2 and 3).

In general, on the basis of their form, two types of manganese ores identified in the field are manganese nodule and manganese layer. The manganese nodule has spherical to elliptical form with averaging diameter of millimeter to 6 cm and thickness of about 1 mm to 5 cm. Megascopically, Mn nodule is metallic grey in colour, glossy surface, massive, reddish brown streak and identified as manganite (Figure 4).

Manganese layer is the most predominant Mn ore type outcropped in the field. The manganese layers are typically irregular segmented, strongly deformed and occassionally lenses or lenticular, interbededd and/or enveloped by reddish-brown deep sea claystone of Nakfunu formations. Mangenese layers range from 2 cm to 10 cm in width (Figure 5).

Manganese layers are classified into three subtypes. First, it is distributed on surface, weak, brittle, black Mn ore and identified as pyrolusite; Second, it is massive, black to blackish grey, distributed on surface, identified as groutite (Figure 6); and Third, it is commonly distributed in depth, metallic grey, very hard, massive, containing silica (quartz) and calcite, identified as manganite (Figure 7). Lithioporite is sometimes observed in association with manganite, characterized by bluish black colour. Beside those Mn-bearing minerals, hollandite is also identified by EPMA at RWTH Aachen University (in progress; personal communication with Professor F. Michael Meyer).

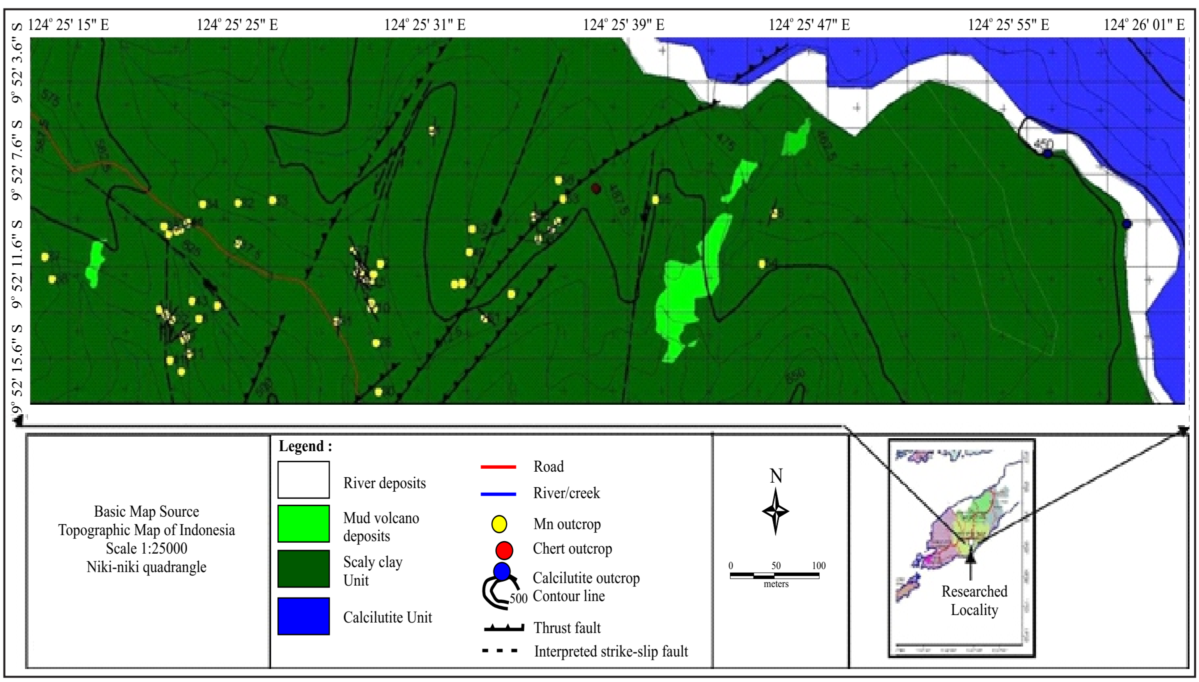


Figure 2: Geological map of the researched area (Ati, 2012).

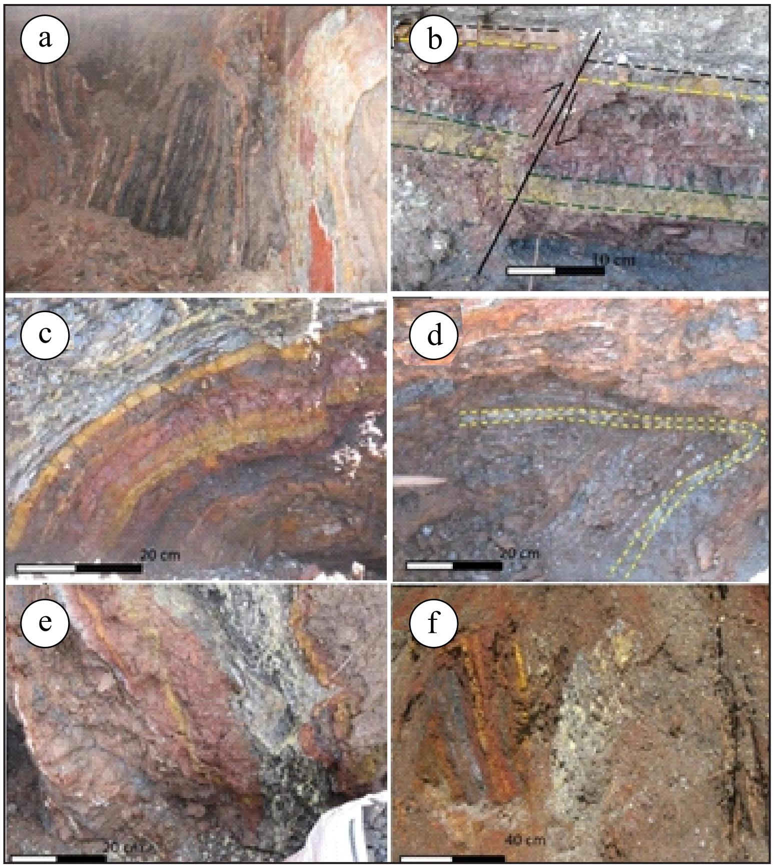


Figure 3. Photograph of (a). Vertical bedding of manganese layers and their interbedded claystone due to thrust fault; (b) Thrust fault, (c) and (d) Minor fold; (e) and (f) Lithological contact of the rock units, the member of Nakfunu Formation.

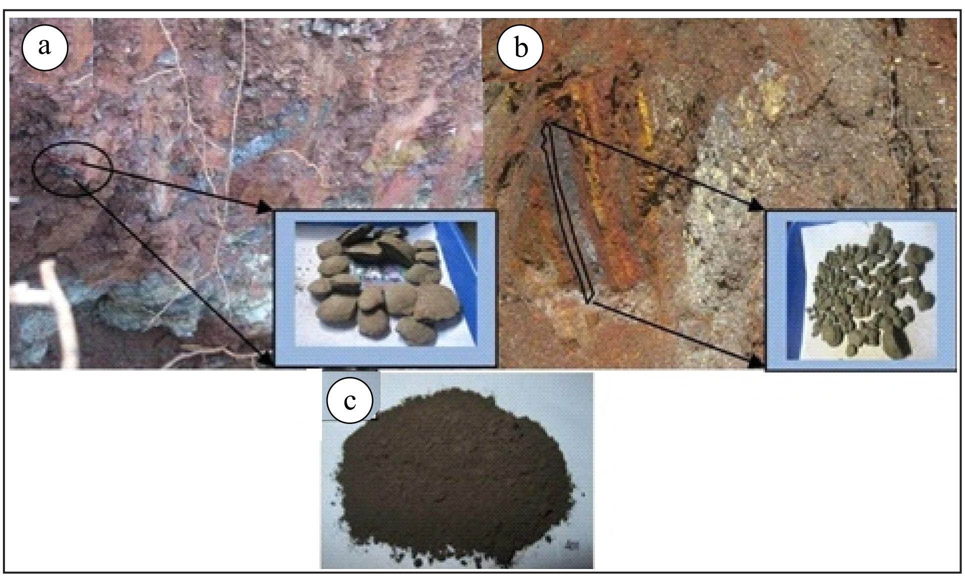


Figure 4. Photograph of (a) and (b) Mn nodule outcrop with ellipse form within reddish brown claystone from Nakfunu Formation, (c) Mn nodulee powder, identified as manganite.

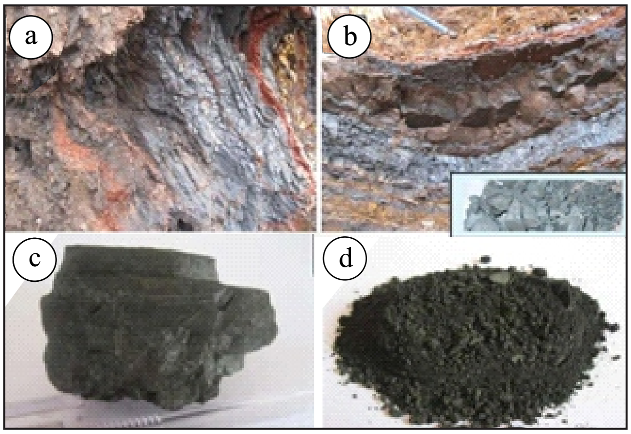


Figure 5. Photograph of (a) and (b). Manganese layer outcrops, (c). Manganese layer handspecimen, and (d) Crushed Mn ore identified as pyrolusite.

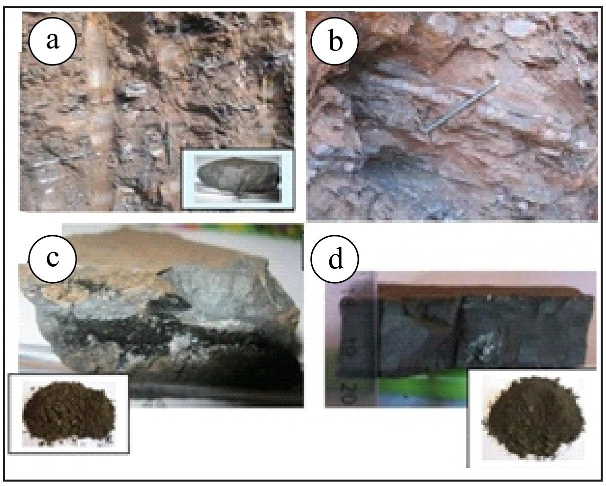


Figure 6. Photograph of (a) and (b). Outcrops of interbedded manganese layers and claystone/siltstone. (c) and (d). Hand-specimen of manganese layers identified as pyrolusite.

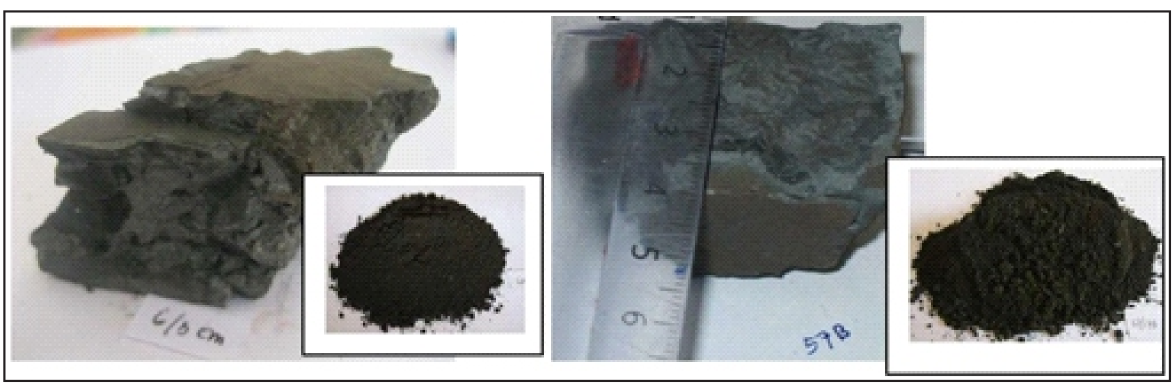


Figure 7. Photograph of Manganese layer handspecimen with physical properties: blackish grey, weak, less massive, lighter than Mn ore in Figure 6d (pyrolusite), brownish black-pale reddish brown powder colour. Based on those characteristics, it may meet with the characteristics of groutite.

Mineralogy of Limestone and Manganese Ore

Petrographic analysis shows that limestone contains fossil, opaque, micrite, sparite, glauconite, iron oxides, and silica. Changing in colour from white to pink of limestone corresponds to an increase of iron oxide and Mn contents. XRD data indicate the presence of calcite and quartz.

Ore microscopic analysis shows manganese nodule is typified by manganite only (Figure 8) and manganese layers are composed of manganite as a main Mn-bearing mineral (Figure 9), and other Mn minerals such as lithioporite, hollandite, groutite, and pyrolusite (Figure 10 - 12).

Manganite and lithioporite are predominant minerals occurred in Mn layer (Figure 13) and degradation of crystal grains (from fine-grained to moderate-grained crystals). Recrystallization of manganite along veinlets crosscutting manganite and lithioporite layers is observed (Figure 14). This ore type is also associated with gangue minerals including calcite, limonite, hematite as well as quartz and barite veinlets (Figure 15).

Geochemistry of Limestone and Manganese Ores

Bulk geochemical analysis of limestone shows that in general MnO and Fe_2O_3 content vary from 0.17 - 0.25 wt.%, and 0.46 - 1.32 wt.%, respectively. The changing of limestone colour from white to pink expresses the increase of Mn and Fe contents in the rock. REE geochemistry indicates a negative Ce anomaly and Sr/Ba ratio > 1 suggesting a marine depositional environment.

Manganese layer geochemistry shows MnO content ranging from 63 to 72 wt.% MnO, relatively higher or similar compared to those of manganese nodule varying between 63 and 69 wt.% MnO. Fe_2O_3 (tot) in both manganese ore types is very low indicated by 0.2 - 1.5 wt.% Fe_2O_3 in manganese layers, which are relatively lower than those in manganese nodule (1.3 - 4.8 wt.% Fe_2O_3). Fe/Mn ratio of Mn layers is very low ranging between 0.003 and 0.069 implying a sedimentary origin (Evans, 1993).

Other important major elements including Al and Si shows significant grade in Mn layer. Al_2O_3 content ranges from 0.5 to 4.3 wt.% (average 1.8 wt.%), and SiO_2 content varies from 0.6 to 3.8 wt.% (average 1.6 wt.%). High content of Al and Si may represent clay associated with the Mn layer. Additionally, it may also suggest the hydrothermal fluid modification sourced from mud volcanos.

REE geochemistry shows a positive Ce (cerium) anomaly (addition) and REE-NASC (North American Shale Composite) normalized diagram pattern (Figure 16) is consistent with those of Timor Mn nodule and Pacific hydrogenous Mn suggesting deep sea depositional environment and nonhydrothermal origin. Trace element plotting between (Co+Ni) and (As+Cu+Mo+Pb+V+Zn) (Figure 17) indicates that Mn nodule is plotted as hydrogenous detrital and Mn layer is obviously included in detrital diagenic field (Figure 18). Comprehensive geochemical data of manganese ores are tabulated in Table 1 and Table 2.

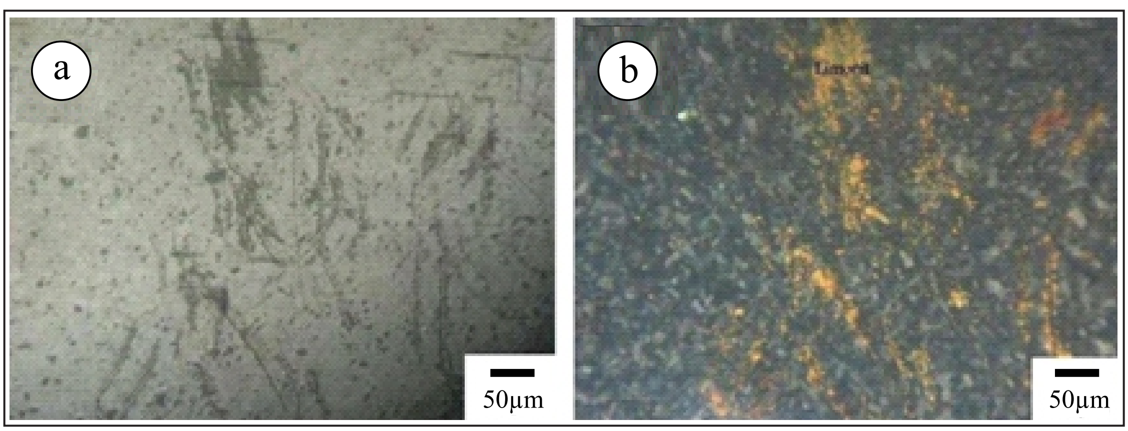


Figure 8. Microphotographs of manganese nodule characterized by manganite and less limonite: (a) parallel nicols and (b) cross nicols.

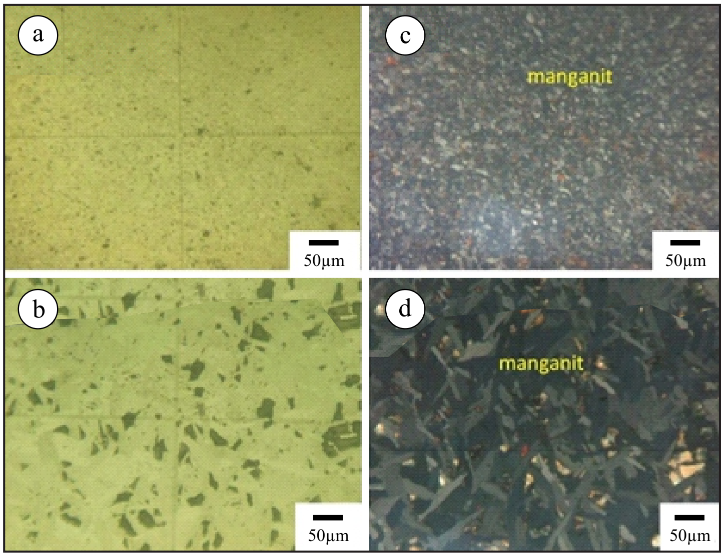


Figure 9. Microphotographs of manganese layer containing manganite: (a) and (b) parallel nicols and (c) and (d) cross nicols.

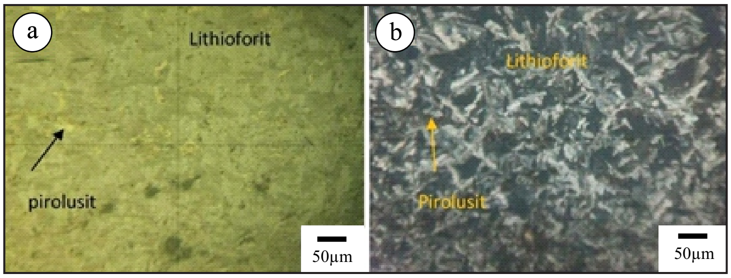


Figure 10. Microphotographs of manganese layer composed of lithioporite and pyrolusite: (a) parallel nicol and (b) cross nicols.

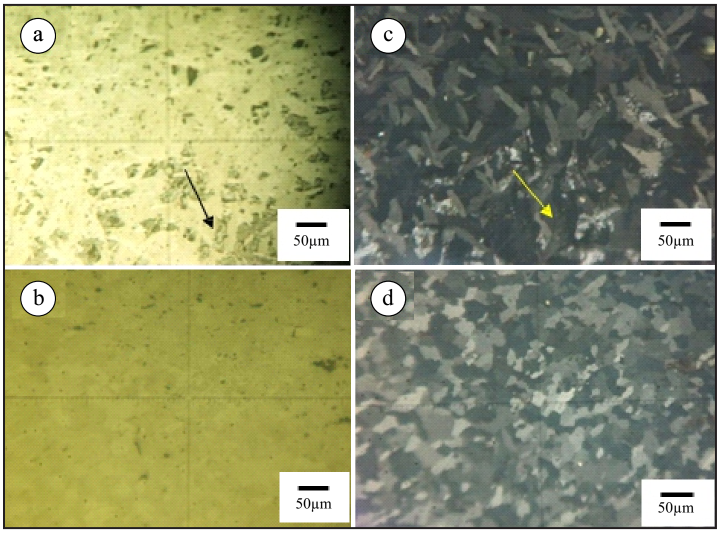


Figure 11. Microphotograph of manganese layer containing groutite and lithioporite: (a) and (c) parallel nicol, and (b) and (d) cross nicol.

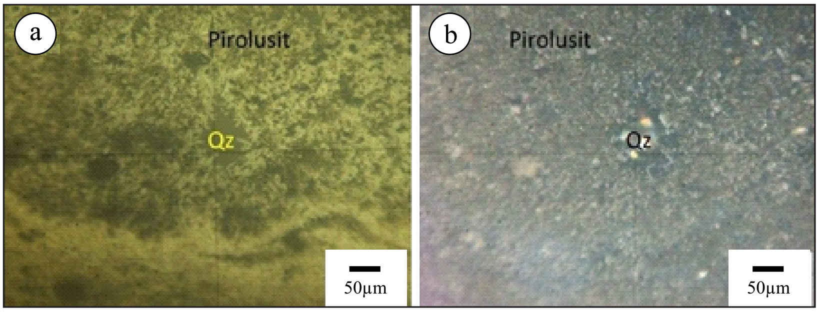


Figure 12. Microphotographs of manganese layer marked by pyrolusite and quartz (Qz): (a) parallel nicol and (b) cross nicol.

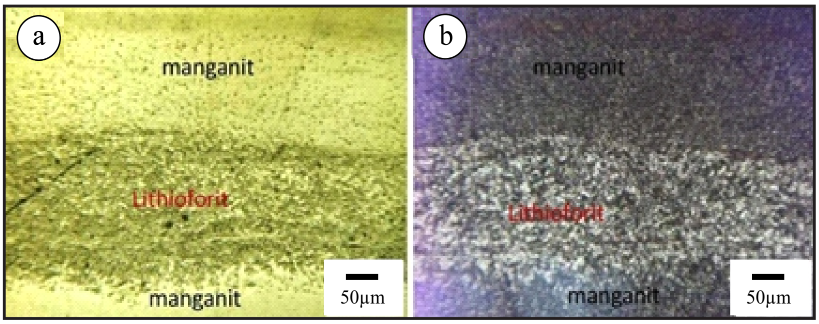


Figure 13. Photograph of bedding-like structure of manganite and lithioporite within the manganese layer: (a) parallel nicols and (b) cross nicols.

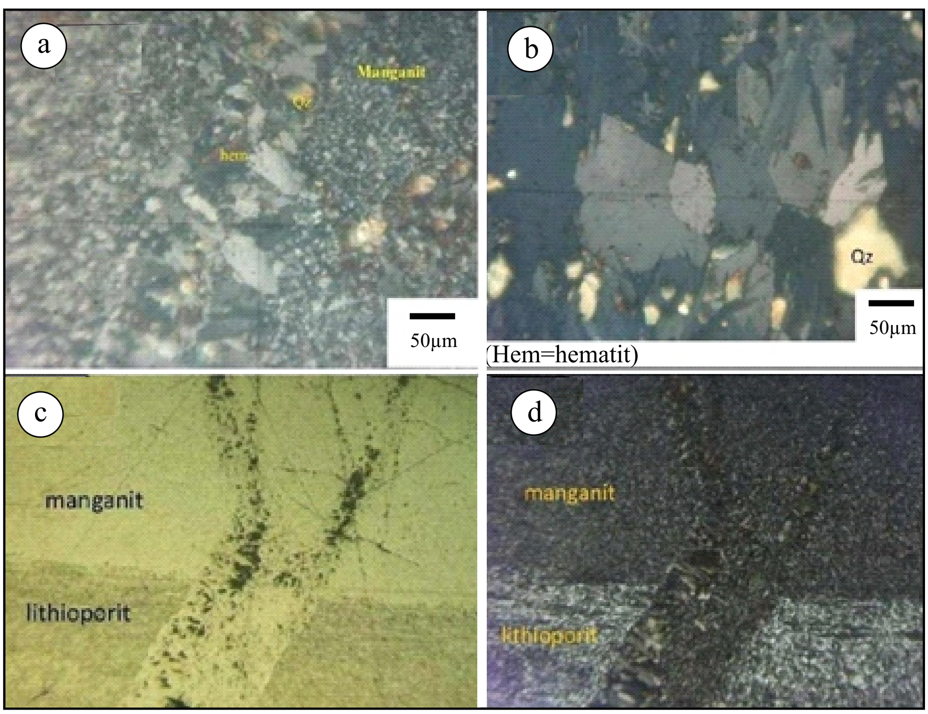


Figure 14. Microphotograph of manganese layer: (a) and (b) Coarse-grained manganite crystal in vein, and (c) and (d) manganite vein cross-cutting manganite and lithioporite bedding-like.

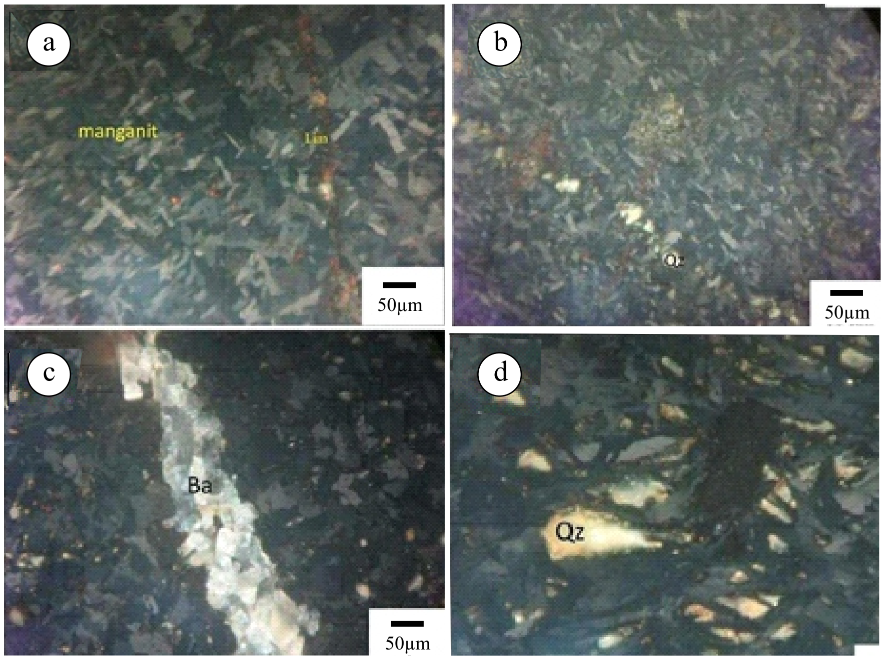


Figure 15. Microphotograph of limonite (Lim), barite (Ba) and quartz (Qz) veinlets crosscutting manganite crystals of manganese layers. This may suggest that sedimentary-related manganese layers have been modified by ‘hydrothermal fluid’ produced by mud volcanos.

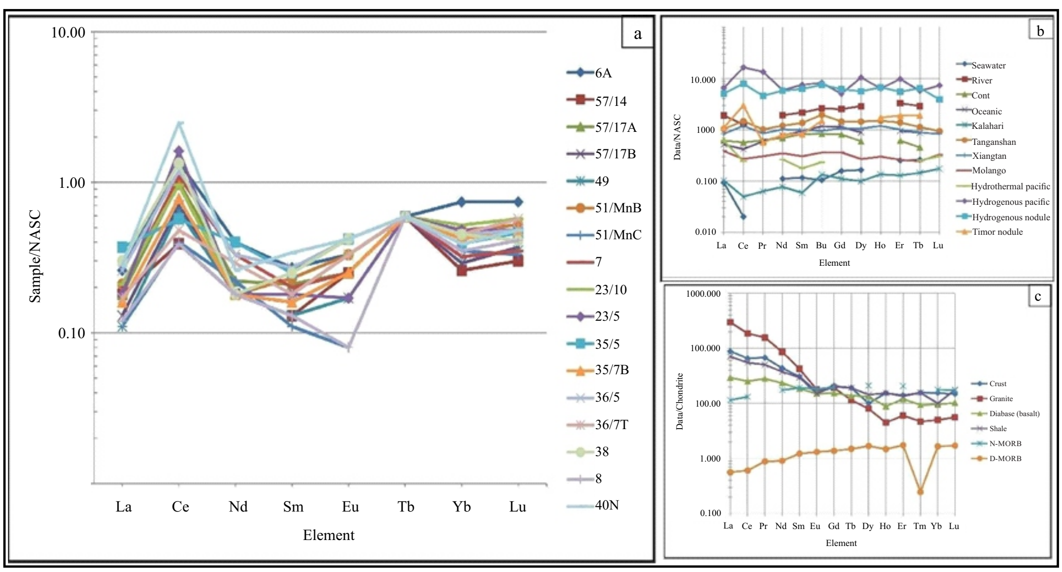
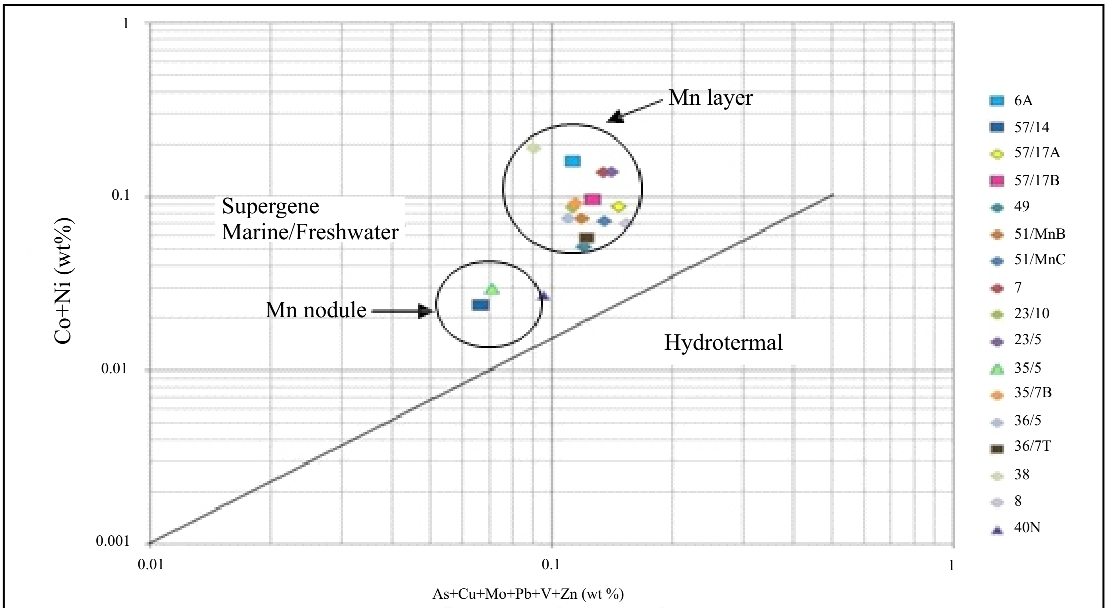
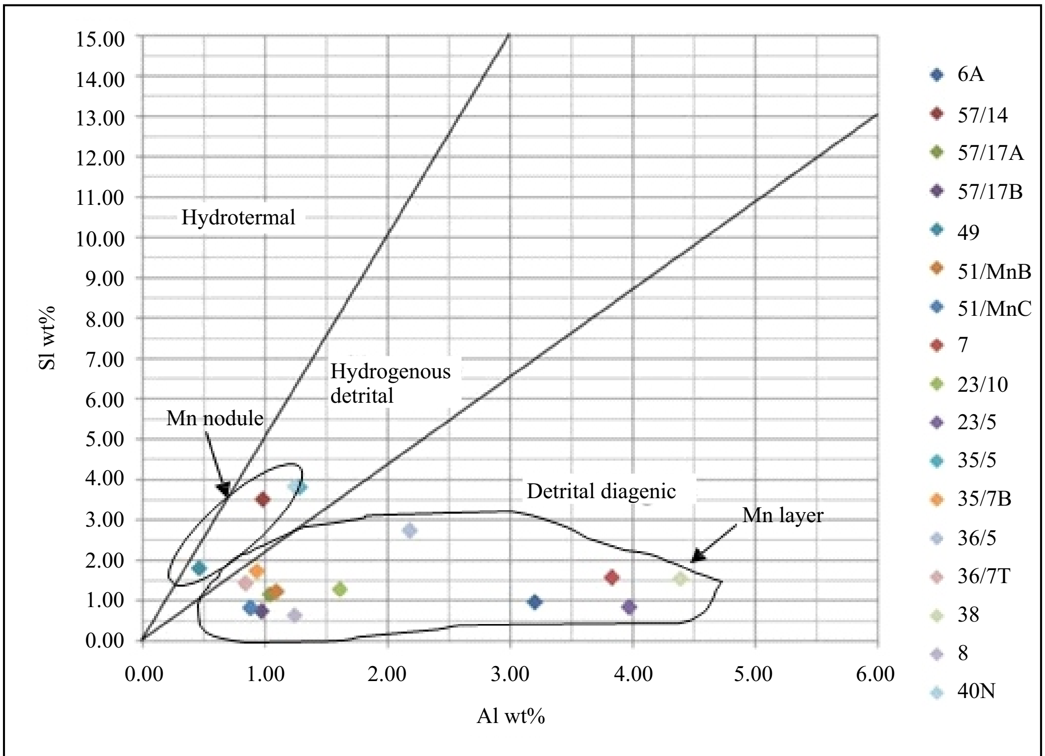


Figure 16. REE-NASC normalized diagram: (a) REE of analysed samples normalized by NASC data (Note: Tb is below detection limit), (b) REE-NASC normalized diagram of sea water and river (Rollinson, 1995), continental and oceanic (Jiancheng *et al*., 2006); Timor nodule (Glasby *et al*., 1978); Other data (Maynard, 2005). Note: Manganese ore of Tanganshan and Xiangtan in China is a Neoproterozoic Mn deposit with REE distribution and positive Ce anomaly implying a mixing of hydrothermal fluid and hydrogenous; ancient manganese deposits of Molango (Jurrasic) and Kalahari (Paleo-proterozoic) shows a similar REE distribution pattern with hydrothermal Pacific Mn which has a negative Ce anomaly due to hydrothermal fluid mixing with seawater; Hydrogenous Mn ore contains a highest REE and positive Ce anomaly; Timor Mn nodule shows a REE distribution pattern and positive Ce anomaly, which correspond to Pacific Mn nodule; (c) Various rock REE composition normalized by chondrite (Krauskopf and Bird, 1995).



Legend: △ (mangan nodule), □ and ◇ (mangan layer)

Figure 17. Diagnostic chemical diagram to distinguish the hydrothermal and supergene marine/fresh Mn ores (Nicholson, 1992); Total data=17.



Explanation : Sample 40N and 35/5 occur as mangan nodules, whereas other samples are as mangan layer.

Figure 18. Plotting Si *vs*. Al classifying the Mn nodulee into hydrogenous detrital (chemical concretion process), and Mn layers into detrital diagenetics (sedimentary process) (cf. Crerar *et al*., 1982 *in* Nicholson, 1992).

Table 1. Major Oxides of Manganese Ores from Supul Subregency, Timor Island, Indonesia (Note: analysed by FUS-ICP, in wt.% unit)

Major Oxides	SiO_2	Al_2O_3	Fe_2O_3(T)	MnO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	LoI	Total
40N (nodule)	8.19	2.35	1.34	69.42	0.2	0.1	0.38	0.15	0.05	11.15	93.54
35/5 (nodule)	8.15	2.42	4.8	62.72	0.5	0.09	0.36	0.113	0.36	11.3	91.08
57/14 (nodule)	7.5	1.85	1.54	66.05	0.6	0.09	0.32	0.086	0.14	11.83	90.23
57/17A	2.45	1.96	0.44	67.76	0.4	0.04	0.21	0.033	0.08	13.54	87.21
49	3.85	0.87	0.45	68.39	0.05	0.05	0.11	0.037	0.16	11.25	85.4
51/MnB	2.63	2.05	0.36	67.66	0.04	0.04	0.25	0.026	0.06	13.84	87.73
51/MnC	1.75	1.60	0.3	69.19	0.03	0.03	0.13	0.023	0.09	13.45	86.95
7	3.35	7.23	0.36	63.09	0.11	0.11	0.89	0.028	0.03	13.84	90.26
23/10	2.75	5.05	0.48	69.3	0.05	0.05	0.23	0.036	0.06	13.64	90.12
23/5	1.79	7.5	0.29	64.19	0.07	0.07	0.87	0.019	0.02	14.82	91.2
35/78	3.71	1.76	0.4	69.91	0.03	0.03	0.14	0.035	0.06	13.09	89.49
36/5	5.86	4.11	0.98	68.79	0.08	0.08	0.54	0.083	0.04	13.21	94.43
38	3.29	8.29	0.62	63.33	0.06	0.06	0.53	0.051	0.05	13.97	91.41
8	1.36	2.34	0.2	71.83	0.03	0.03	0.19	0.014	0.09	13.87	90.42
6A	2.06	6.05	0.27	65.6	0.05	0.05	0.51	0.02	0.03	14.26	89.84
57/17B	1.59	1.83	0.29	68.79	0.03	0.03	0.15	0.022	0.09	13.63	86.92
36/7T	3.05	1.58	0.34	71.57	0.03	0.03	0.14	0.029	0.07	13.32	90.43

Table 2. Trace Elements of Manganese Ores from Supul Subregency, Timor Island, Indonesia (in ppm unit with an exception of S in wt.%, analyzed by FUS-ICP)

Elements	As	Ba	Be	Bi	Cd	Co	Cr	Cu	Mo	Ni	Pb	S	Sb	Sc	Sr	Th	U	V	W	Y	Zn	Zr
40N (nodule)	60	1090	3	31	2.6	59	13	408	47	212	94	0.01	5.5	10.4	55	2.5	1.7	76	33	9	269	52
35/5 (nodule)	77	1280	3	30	2.9	93	8	221	60	203	67	0.01	4.5	3.3	92	2.3	1.4	30	65	15	255	29
57/14 (nodule)	55	1150	2	36	1.6	33	5	197	86	205	55	0.01	4.3	2.4	317	1.7	1.6	31	48	6	241	18
57/17A	37	2550	2	40	2.2	138	14	543	123	738	48	0.01	6.8	7.3	505	<0.5	2.3	122	61	8	599	31
49	37	216	3	42	3.1	22	16	523	88	495	48	0.01	5.4	4.1	53	0.5	2	56	54	5	450	26
51/MnB	27	13600	2	35	1.9	124	12	238	146	622	48	0.06	3.1	2.9	712	0.5	2.7	117	60	8	613	20
51/MnC	32	3320	2	36	2.9	78	15	494	149	642	50	0.07	4.1	3.7	203	<0.5	1.9	68	50	4	560	20
7	23	6460	2	27	0.7	283	20	412	142	1090	45	0.08	4.3	6.8	1226	<0.5	0.9	106	43	6	617	23
23/10	32	6630	2	32	1.5	199	17	346	116	666	50	0.09	3.6	4.2	327	0.5	2.1	79	58	8	506	22
23/5	19	5780	1	29	1.5	271	21	398	135	1110	45	0.05	4.5	5.6	876	<0.5	1.6	102	37	8	711	15
35/78	32	14500	2	38	1.9	164	9	324	107	751	61	0.06	4.1	2.4	341	0.7	1.4	65	65	5	560	13
36/5	29	3570	2	30	1.8	201	14	365	93	545	58	0.04	3.6	4.9	428	1.5	1.8	104	53	9	453	31
38	31	17000	1	20	0.5	741	14	107	65	1160	49	0.07	2.4	3.4	930	0.7	<0.5	109	67	7	542	25
8	34	15300	2	32	1.9	104	13	561	186	593	59	0.11	3.8	4.8	421	<0.5	1.5	76	41	5	622	20
6A	21	4760	1	35	1	418	18	211	134	1180	48	0.02	3.7	2.2	769	<0.5	2.9	97	50	9	619	13
57/17B	32	1700	2	41	1.8	130	16	414	128	835	49	0.01	3.4	4	262	0.5	2.1	70	53	7	573	17
36/7T	39	14500	2	34	1.9	88	7	309	116	494	51	0.06	2.3	2.8	340	0.5	2	128	64	10	580	16

Conclusions

Timor Island, Indonesia, has a potential manganese ore. Tectonically, this island is acive uplifted due to north-trending tectonic collision between Timor island arc and Australian continental crust. The manganese ores in Timor Island are recognized into two types: Mn nodule and Mn layer types. Mn layers range from 2 to 10 cm in width and interbedded with deep sea sedimentary rocks including redish-redish brown claystone, radiolarian chert, slate, marl as well as white and pinkish calcilutite of Nakfunu Formations. Stratigraphically, the rock formations are underlain by Bobonaro Formation. Locally manganese layers are commonly interbedded with redish-redish brown claystone. The manganese layers are strongly deformed, lenticular, and segmented.

Mn nodule is characterized by manganite, whereas Mn layers are composed of manganite as a main Mn-bearing mineral, and other Mn minerals such as lithioporite, hollandite, groutite, and pyrolusite.

Major oxide geochemistry shows that MnO content in Mn layer ranges from 63 to 72 wt.% MnO, relatively higher or similar to those of Mn nodule varying between 63 and 69 wt.% MnO. Fe_2O_3 (tot) in both manganese ore types is very low (0.2-4.8wt.%) with Fe/Mn ratio that lies between 0.003 and 0.069. This value implies a sedimentary origin and not a typical hydrothermal process. Trace element geochemistry indicates that Mn nodule is originated from hydrogenous detrital process, whereas Mn layer is formed through a detrital diagenetic process. Manganese layers were likely modified by 'hydrothermal process' from mud volcano activities. This is proven by recrystallization of manganite along veinlets crosscutting manganite and lithioporite layers, and the association of this Mn ore with gangue minerals including calcite, limonite, hematite as well as quartz and barite veinlets.

Acknowledgements–The authors are thankful to Dodi Hendra Wijaya (Director of PT. SoE Makmur Resources), who has permitted the authors to conduct fieldwork and ore samping in the concession area. Fieldwork was sponsored by PT. Kanaan Resources and assisted by Aryana Catur Trapsila and Yacobos Irkadwi Anggoro. Discussion during fieldwork with Noni Banunaek and Muhammad Aziz was very appreciated.

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