Nickel in Buli Coastal Area, East Halmahera

Nikel di Pantai Buli, Halmahera Timur

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ABSTRACT: Fragments of ultramafic, metamorphic, basalt and serpentine compose coastal sediments. These fragments derived from outcrops in hinterland as well as the coast. Existence of greywacke sandstone through microscopic observation in coastal sediments indicate deep sea derivation. Marine sediments also show almost the same composition with coastal sediments.

Rock fragment abundances of ultramafic (10-47%), serpentine (12-24%) and metamorphic (3-12%) in stream and coastal sediments which have direct relation with the presence of nickel metal in the research area were resulted from petrographic analyses. While mineralographic analyses of heavy mineral concentrate from wooden pan show the existence of ferro nickel (Fe-Ni) and nickeline (Ni-As) in coastal and stream sediments.

XRF analyses show nickel contents in seabed sediments 0.0140 to 0.793 %, chromite 0.0179 to 0.1128% and iron 1.2 to 6.85%. Coastal water nickel distribution is controlled by local trapped waves in Buli Bay that excite by equatorial Pacific Ocean waves propagate westward. Nickel occurrences in marine sediments would be an interesting further research.

Keywords: nickel, Buli coastal area, East Halmahera

ABSTRAK: *Fragmen-fragmen ultramafik, metamorfik, basalt dan serpentin menyusun sedimen pantai. Fragmen-fragmen ini berasal dari singkapan baik di darat maupun di pantai. Dijumpainya fragmen batupasir grewake yang teramati melalui mikroskop dalam sedimen pantai mengindikasikan asal laut dalam. Sedimen dasar laut menunjukkan kecenderungan komposisi yang hampir sama dengan sedimen pantai.*

Kelimpahan fragmen batuan ultramafik (10-47%), serpentin (12-24%) dan metamofik (3-12%) dalam sedimen sungai dan pantai yang memiliki hubungan langsung dengan keberadaan logam nikel di daerah penelitian dihasilkan dari analisis petrografi. Sedangkan analisis mineralografi pada konsentrat mineral berat hasil dulang mendapatkan fero nikel (Fe-Ni) dan nikelin (Ni-As) dalam sedimen pantai dan sungai.

Analisis XRF mendapatkan nikel dalam sedimen dasar laut dengan kandungan 0,0140 hingga 0,793%, kromit 0,0179 hingga 0,1128% dan besi 1,2 hingga 6,85%. Sebaran nikel di perairan pantai dikontrol oleh gelombang lokal yang ditimbulkan oleh gelombang Samudera Pasifik ekuator yang bergerak ke barat. Keterdapatan nikel dalam sedimen dasar laut dapat menjadi riset yang menarik di masa datang.

***Kata kunci** : nikel, pantai Buli, Halmahera Timur.*

INTRODUCTION

Nickel deposits are generally found in sulfide (Lesher and Keays, 2002) or laterite (Schellmann, 1983) but it also can occur as placer deposits (Nickel, 1959; Rodgers and Hey, 1980; Varnavas and Papatheodorou, 1987; Voutsinou and Varnavas, 1987 and Varnavas, 1990). Possibly due to its heavy mineral character (specific density/gravity 8.9) and its association with iron in nature (http://www.galleries.com/Iron), most of the native nickel-iron has been found in alluvial gravel deposits; such as occurred at Awarua Bay, New Zealand (Happy *et al.*, 1970; Railton and Watters, 1990).

The processes leading to the formation of beach placer deposits generally begin inland and terminate at the coast. It includes source rocks weathering, eroding and transporting by rivers to the coast in a variety of coastal environments (Hou *et al.*, 2017). The coastal sediments are reworked by wave, tides, longshore currents and wind actions for sorting mineral grains based on differences in their size and density resulting in sediments rich in heavy minerals. Very fine sized of nickel ore minerals smaller than 10 micron (<10 μm) on a coastal cliff due to erosion and abrasion will be carried out into the coast and the sea and are deposited as placer sediments (Solihin *et al.*, 2014).

Nickel (Ni) belongs to transition metals group; chemical properties similar to Fe and Co; present in Fe-Mg silicate minerals through octahedral substitution with Fe2 + (Siderophile). Ni (Co, Cr) is an extremely compatible element; concentrated in olivine while Cr in spinel & Clinopyroxene. The high content of Ni elements characterizes sourced from the mantle / earth mantle (primary magma): Ni> 400-500 ppm Cr> 1000 ppm SiO2 <50% (Ridley, 1999).

Nickel is a chalcophile element. Chalcophile elements are elements with a low affinity for oxygen and which preferentially bond with sulfur to form sulfides. Their name derives not from sulfur, but from copper. The term chalcophile derived from the Greek for copper-loving that was originally introduced by Goldschmidt (1923). Ultramafic or mafic rock which has a sulfide phase in the magma may form nickel sulfides (Lesher and Keays, 2002). The best nickel deposits are formed in komatiite lavas (Lesher and Keays, 2002) while komatiite is a type of ultramafic mantle-derived volcanic rock (Le Bas, 2000).

Lateritic nickel ores formed by intensive tropical weathering of olivine-rich ultramafic rocks such as dunite, peridotite, komatiite and serpentinite (Faust and Fahey,1962). Serpentinite contains approximately 0.3 % nickel which in the course of laterization strongly enriched this initial nickel content (Schellmann (1983). Lateritic nickel ore can be distinguished into limonite type and silicate type (Schellmann, 1983); where limonite type laterites (or oxide type) are highly enriched in iron due to very strong leaching of magnesium and silica. Goethite mineral largely occurs in this type and 1-2% nickel incorporated in this mineral. Due to erosion sometime limonite zone disappears.

Silicate type (or saprolite type) nickel ore formed under the limonite zone, and it contains 1.5-2.5% nickel incorporated with dominantly Mg-depleted serpentine. Minor quantities of green garnierite mineral occur in pockets and fissures of serpentinite rock but with high nickel contents (20-40%). All the nickel in the silicate zone is leached downwards from the overlying goethite zone. This process is known as absolute nickel concentration (Schellmann, 1983).

Nickel laterite ore deposits are very large tonnage but low-grade and located close to the surface. Twenty million tonnes contain resource of 200,000 tonnes of nickel at 1%. Unfortunately, ore deposits of this type are restricted to the weathering mantle developed above ultramafic rocks (Golightly, 1981). Area of a deposit being worked for the nickel ore is usually only a few hectares.

Groundwater enriched in CO_2 contacts with saprolite zone dissolving unstable minerals such as serpentine and pyroxene; while olivine containing Mg, Si, Ni will be released and give rise to new minerals in the process of re-deposition. Iron oxide enrichment is resulted from the above process in the saprolite and limonite zones (Hasanudin and Rifai, 1992).

The process of weathering and circulation of ground water especially those that are relatively acidic in ultramafic rocks will cause the decomposition of magnesium, nickel, iron, and silica in the minerals of olivine, pyroxene, and serpentine to form concentrated deposits of heavy mineral-rich residues (Ni, Fe, Cr) (Kanmani and Gandhimathi, 2013).

The research area Buli coastal zone belongs to East Halmahera Regency in North Maluku Province (Figure 1). The capital of this regency lies at Maba, a port on the Buli Bay that has been built integrated with industrial zone. The port is consisted of a jetty solid

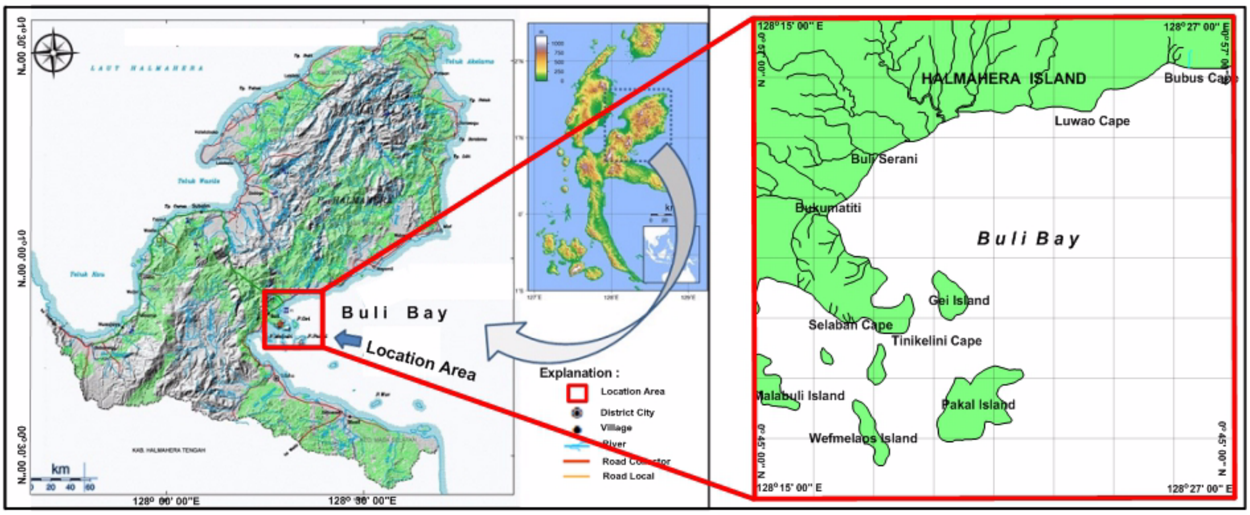

Figure 1. Location of the Buli coastal research area, East Halmahera.

with lengths of wharf 154m, trestle 210m, causeway 242m for the capacity of 35.000 DWT ships (KPPIP, 2016; Baillie and Cook, 2000). Nowadays, the land status of this industrial zone has been acquired by PT Antam Persero. Facilities of industrial zone such as management office and oxygen plant have been built. Ministry of Industry has helped formulate initial Master Plan of 300 Ha land and Detailed Engineering Design (DED) of axis road and environment and Management Office of this Industrial Zone. It integrates Ferronickel industry, stainless steel and its upstream products.

Buli coastal area geographically located between coordinates 00º 45' 38" to 00º 56’ 17” North and 128º 14' 57" to 128º 26' 54” East. This research was carried out along the coast of Buli Serani south to Bubus Cape and from the coast to offshore to a depth of 40 meters and was done in the field through sampling of river, coastal and seabed sediments in order to know the content of the main metal elements of nickel and its association Co, Fe, Mn, and Cr. Inventory of metal minerals in the districts of East Halmahera and Central Halmahera North Maluku Province had been done by Kisman and Ernowo (2007) and Trenggono *et al* (2006).

Geology Regional and Buli Area

The Halmahera island group is located in the northeastern part of the Indonesian archipelago. It lies between latitudes 30N and 30S and between longitudes 250E and 30E (Fig. 1). The island is being 180 km from north to south and 70 km from west to east, and is surrounded by the smaller islands of Morotai, Ternate, Bacan, Obi and Gebe. To the west is the Molluca Sea and to the east is the southern part of the Philippine Sea (Charlton, 1986).

Halmahera Island has a remarkable four-armed morphology, resembling the letter K. This shape is similar to Sulawesi Island to the west, but on a smaller scale; its dimensions are about one third of those of Sulawesi and its surface area is about one tenth. The bays between the arms are Kau Bay in the northeast, Buli Bay in the east and Weda Bay in the south.

One of the characteristic features of the rivers of all sizes of Halmahera is that they are generally deeply incised. They may level out into a flood plain close to the coast but through most of their tracts they have steep-sided V-shaped valleys; in the middle and lower parts of their courses the rivers are sinuous.

The tectonics of Halmahera Island and its surrounding islands are geologically quite unique because the island was formed from the confluence of 3 plates, that is the Australian plate, Eurasian plate, and the Philippine plate that had started since the Cretaceous Period (Hamilton, 1979; Asikin, 2007). The Halmahera region has a double subduction system with volcanoes found in the west and ultramafic in the east. This double subduction system was found in the Molucca Plate (Prasetyo, 1989). Subduction to the northwest of Maluku under the Sangihe Arc is thought to have begun in the early Miocene. Subduction directed eastward from the Maluku sea plate under the Halmahera Arc starts from the Middle Miocene. Double subduction occurred at that time to form a new plate Maluku Sea Plate which is separated from the Philippine Plate. Thus Halmahera, which is located above the sub-plate, is raised from the west by the Maluku Sea Plate and from the northeast direction by the Philippine Sea Plate (Hall and Wilson, 2000).

The eastern part of Halmahera Island forms an arc extending eastward through the islands of Gebe and Gag towards the northern part of Bird’s Head of Irian Jaya. The area is underlain by an ophiolite complex and Mesozoic deep water sediments, imbricated with Paleogene sediments and overlain by Neogene marine clastics and carbonates (Sukamto *et al.*, 1981). Basement rocks of the SE arm of Halmahera consist of a complex of dismembered basic and ultrabasic rocks, with a variable low grade metamorphic overprint, intercalated with Mesozoic and Eocene sediments.

The SE arm has roughly parallel north and south coasts trending WNW-ESE. It has a low central region which rises to the west, north and east giving the SE arm the form of a broad open half-basin, tilted southwards, with its southern part truncated by the coast. The Ophiolitic Basement Complex forms high mountains at the west end of the SE arm (Bemmelen van, 1949).

The geology of Buli East Halmahera (Figure 2) is mostly consisted of Ultrabasic or Ultramafic Rock Complex (Supriatna, 1980; Apandi and Sudana, 1980). This rock is a major resource of Ni as well as accessory metals Cr, Fe, Al, Ti, and Mn. Ultramafic igneous rocks in the research area are rich in olivine, orthopyroxene, clinopyroxene, amphibol, and plagioclase (Baslang R., 1970). The others are sedimentary and volcanic rocks. The andesitic and basaltic volcanic rocks of Bacan Formation of Oligo-Miocene Age which is consisted of breccia and lava are famous for its gemstone. The Ultrabasic Rock Complex is dominated by serpentinite, harzburgite, diabase and a little dunite (Turdjaja *et al.*, 2011). It occupies mountainous areas and its upper parts have become into brownish and reddish laterite. At Buli area, the greenish serpentinite rock contains light green garnierite insertion. Petrographic analyses of ultrabasic rock shows harzburgite. Harzburgite consists of olivine, pyroxene, iron oxide and serpentine (Turdjaja *et al.* 2011).

Geological structures found in the area (Figure 2) are faults, folds and joints. Faults and lineaments are generally directed northwest - southeast with transform fault at Buli Serani area estimated active until now. The fault was allegedly related to the Sorong Fault which

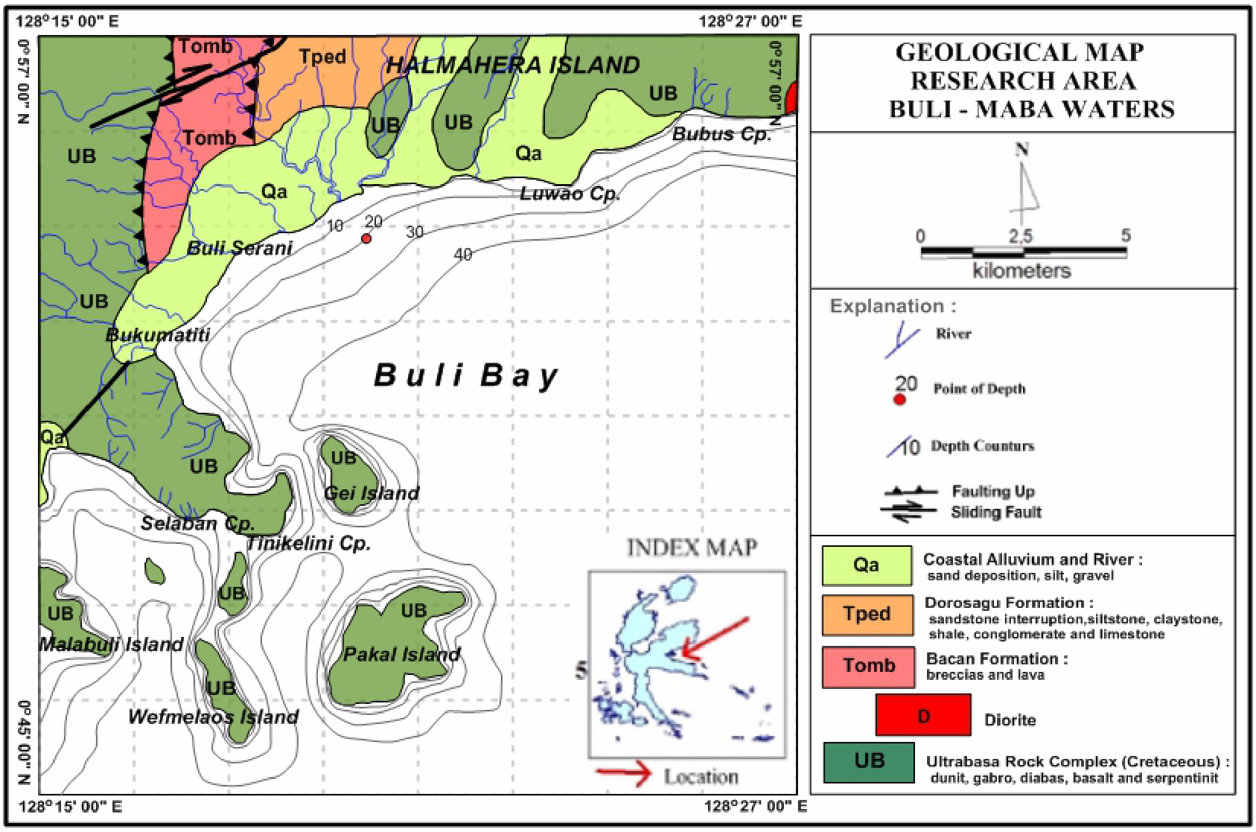

Figure 2. Geological map of Buli East Halmahera (Supriatna, 1980).

was active since Oligocene Period (Simandjuntak and Barber, 1996). Thrust fault was found in the Buli Serani area and the horizontal fault (dextral), has a northwest-southeast direction.

The Oceanography of Halmahera Sea

Halmahera Sea is a regional sea located in the central eastern part of the Australasian Mediterranian Sea (IHO, 1953). It is bordered by the Pacific Ocean to the north, Halmahera to the west, Waigeo and West Papua to the east, and the Seram Sea to the south. It covers about 95,000 km and its topography comprises a number of separate basins and ridges, the chief of which is the Halmahera Basin reaching a depth of 2039 m.

Time series measurements of ocean currents in Halmahera Sea have been conducted for the first time (Li *et al.*, 2020). It shows that significant South Pacific tropical waters join the ITF (Indonesia Through Flow) to enter the Indian Ocean, which must come from upwelling in the South Pacific.

In Halmahera Sea, surface currents are variable with the seasonal monsoon winds. The deep water is renewed by water from the Pacific which passes from north to south over parts 700 and 940 m deep. The surface waters are a mixture of oxygen rich Pacific water and oxygen poor water from the Seram Sea. On the other hand, surface salinities range from 34 (March-May) to 34.6 (September-November) while temperatures 25.7 C in August to 28.6 C in May.

The subtidal ocean currents in Halmahera Sea are characterized by a two-layer system where current variability below approximately 200 m in opposite phases to that in the upper layer (Li *et al.*, 2020). The variability of currents are suggested to be driven by the pressure difference between the Pacific Ocean and the Indonesian seas. Interannual variability of current is much smaller than the seasonal cycle. In the upper 200 m, the currents are northward to the Pacific Ocean during December through April, but stronger and southward for the rest of the year with maximum velocity larger than 0.5 m/second. Below 200 m, the currents are also dominated by an annual cycle with amplitudes 0.5 and 0.1 m/second.

Water transport through Maluku Sea and Halmahera Sea is the eastern route and contribute to ITF. Based on sporadic observation Li *et al.* suggested that salty lower-thermocline waters from the South Pacific Ocean enter the Halmahera Sea and meet the western route ITF in the Banda Sea.

The Halmahera Sea has been suggested to be the primary channel of the interbasin wave propagation between the Pacific and the Indian Oceans based on tide gauge sea level data (Clarke and Liu, 1994). Westward-propagating Rossby waves from the equatorial Pacific

Ocean excite coastally trapped waves in the Indonesian seas. It propagates toward the Indian Ocean along the west coast of the New Guinea Island and the Australian continent. Oceanic Rossby waves are large-scale waves have a low amplitude from centimeters at the surface to metres at depth. They take months to cross an ocean basin and get its momentum from wind stress at the ocean surface layer. Satellite observations have confirmed the existence of oceanic Rossby waves (Chelton and Schlax, 1996).

METHODS

For this study, several type of sediments and rocks have been collected. Fifty seabed sediments were collected from water depth between 5 - 40 meters by using grab sampler equipment (Figure 3). Sediment samples were also collected from stream sediment (notified as SS which are consisted of 4 samples) and 13 samples from coastal sediment (PMB). Furthermore, fresh rock from outcrops along the coast of Buli waters were also collected (OC) using hammer.

Both sediments and rocks then analysed for petrography and ore mineral analysis under polarizing microscope available at Marine Geological Institute. Furthermore, XRF (X-Ray Fluorescence) analysis was carried out for metal elements composition of the sediments by using XRF portable Delta Professional from Olympus, also available at laboratory of Marine Geological Institute. SEM-EDX micrograph was conducted at laboratory of Centre of Geological Survey, Geological Agency.

RESULTS

Megascopic descriptions of coastal sand deposits are generally brownish-blackish-gray, clastic texture, medium sorting, angular-rounded, fine-grained sand size consisting of ultramafic rock fragments, metamorphic, sediment, basalt, serpentine. Its distribution in the coast of the research area can be found at Wefmelaos Island, Pakal Island, Mabuli Island, around Cape Tinikelini, Gei Island and Busbus Cape at the eastern end; occupying the morphology of the slope above 10 . In the coast mostly the rock outcrops are serpentine rocks at the bottom and laterite soils above.

The results of petrographic analysis of coastal and river sediments (Figure 4) : the first is interpreted derived from greywacke sandstones from deep sea, diagenetically cemented between fragments and matrices which showing depositional textures; the second is from river sediments (fluvial) with physical characteristics rather compact, loose, gravel, good sorting, and clastic. Stream and coastal sediments also

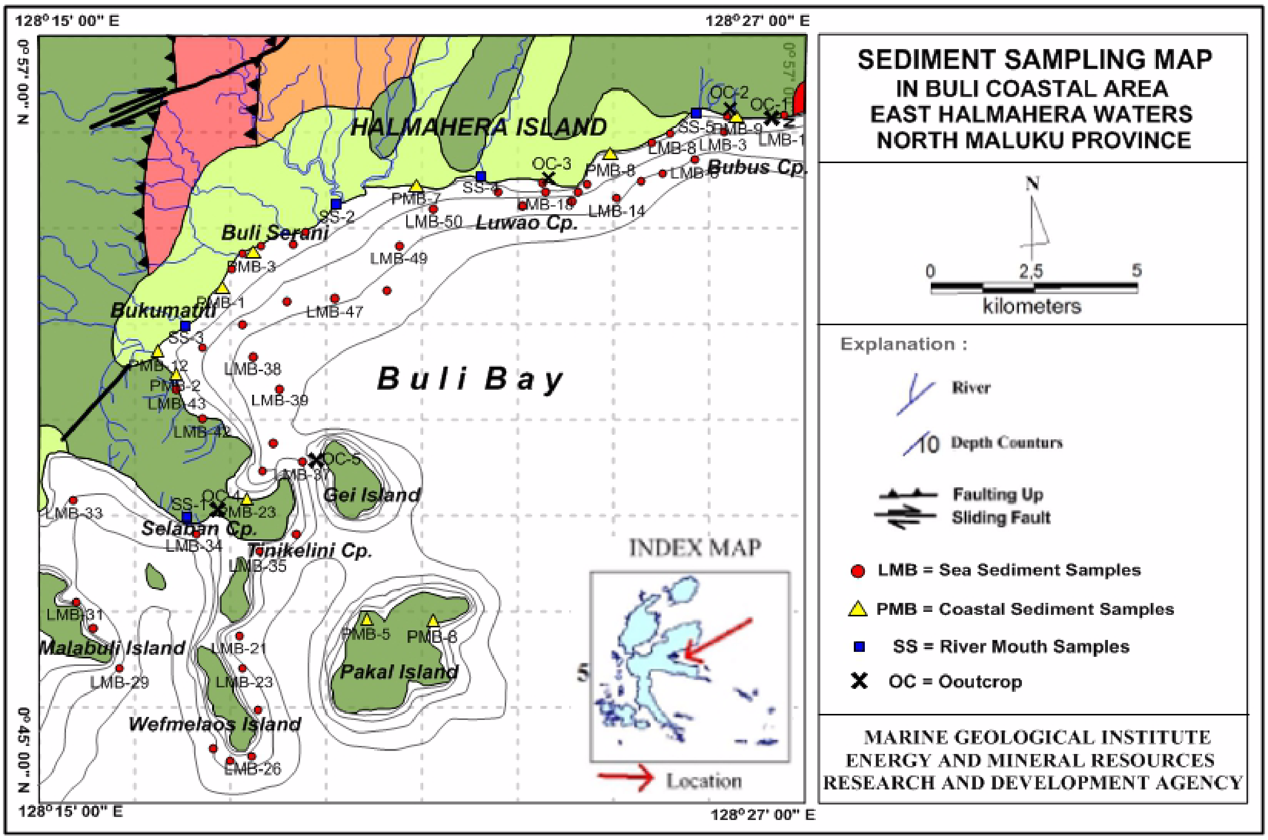

Figure 3. Location map of samples for analysis : river (SS), seafloor (LMB) and coastal sediments (PMB). (Widiatmoko and Nurdin, 2009).

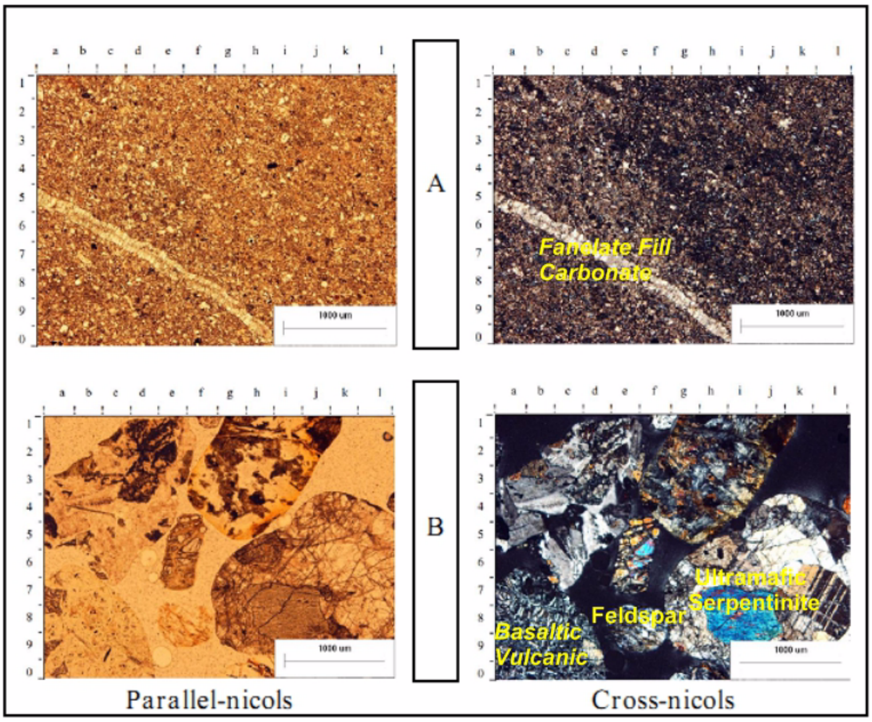

Figure 4. Petrography of coastal and river Sediments :

A. The sand unit is interpreted as a greywacke feldspathic sandstone derived from deep sea (PMB-9). It shows fragmentation followed by fine vein cementing of calcite (ah 5-9).

B. Stream sediment (SS-3) is consisted of fragments from basaltic volcanic rock (ad, 8-9), olivine (jl 4-9), serpentinite rock (gk 1-5).

show fresh olivine and pyroxene granules, relatively fresh feldspar, and very rare ore minerals (Table 1).

On the other hand, marine sediments are almost composed of fragments in balanced compositions : ranging from serpentine rocks of coarse textured, basaltic volcanics, gabro rocks and ultramafic rock, advanced argillic sedimentary rock, limestone, and fossils.

Table 1. Petrography results of stream (SS) and coastal sediments (PMB)

Sample No.	1	2	3	4	5	6
Location	SS-1	SS-2	SS-3	SS-5	PMB-1	PMB-9
Mineral Name	% Composition					
Ultramafic Rock Frag.	47	25	10	12	42	26
Gabro Rock Frag.	2	18	20	16	8	20
Volcanic Rock Frag.	1	12	30	20	5	2
Serpentin Rock Frag.	24	18	12	12	15	19
Ultrabasic Rock Frag.	6	5	4	6	4	7
Metamorphic Rock Frag.	10	9	8	12	3	5
pyroxene granules	8	2	4	2	8	6
Olivin granules	1	2	5	9	12	2
Ore min granules	2	3	3	1	3	4
Felsdpar granules	1	2	4	6	-	10
Sediment name	Sandy Gravels	Sandy Gravels	Sandy Gravels	Sandy Gravels	Greywacke Coarse sand	Greywacke fine sand

Ore mineralographic analysis was carried out to determine the mineral content in concentrates and other granules. Peridotite rock fragments of sample PMB-1 indicate the appearance of rocks, yellowish gray color, aggregates with a smooth texture, colloform-very fine, containing ore minerals, local pyrite, goethite, hematite spread evenly, fine pyrite crystal spots, bright gray, anhedral as fine aggregates that fill the cavity. The pyrite mineralization process is followed by hematite and goethite. Serpentinite rock fragments of PMB-04 exhibit yellowish-dark gray color which is supported mainly by mineral serpentine, olivine and pyroxene. Appearance of granular pyrite spots, mixed with dominant non-metallic mineral hematite and talc appear to be highly crystallized which fills the cavity with anhedral crystalline forms. Some hematite has turned into goethite (Figure 5).

Previously, a screening process was carried out first, then a microscopic description was performed to find out information about the type of mineral, grain size, the relationship between minerals, mineral distribution, degree of release, mineral composition and photomicrographic results. Results of heavy mineral concentrates of samples SS-01, SS-02, SS-03, PMB-04 and LMB-06 are shown in Table 2. These samples of fine and coarse sand were meant to obtain heavy minerals fragments and matrix of sizes (200-400 μm) and (5-100 μm). Megascopic descriptions, they show angular to rounded shapes, poor sorting, green color olivine, black pyroxene. plagioclase milky white gray, light brown serpentine. In general, the concentration of heavy mineral concentrations observed were olivine 2.16%-34.5%, piroxene

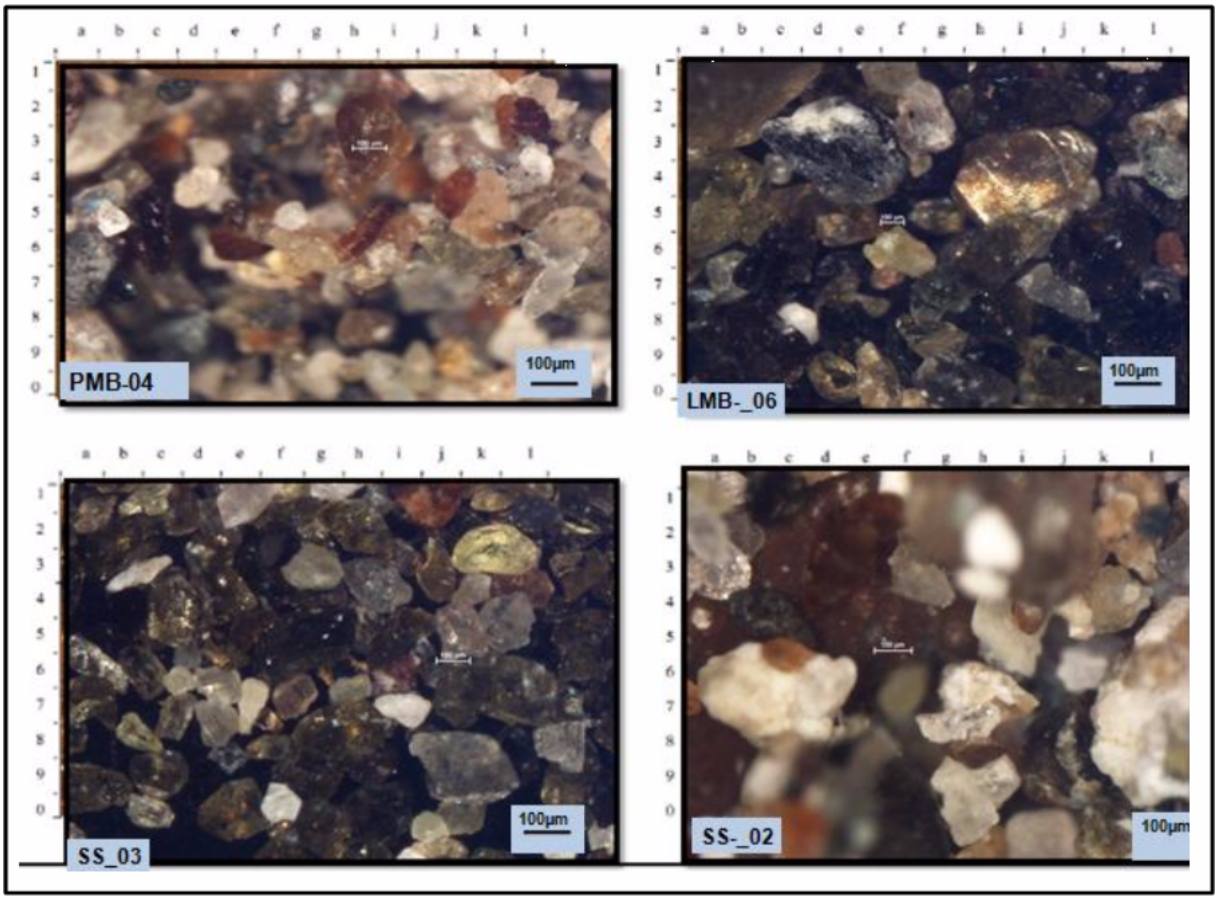

Figure 5. Mineralographic analysis:
Sample PMB-04 shows coarse sand sediment. diagenetic features of fragmentation, followed by ferro nickel (kj 3-4), magnetic (bc 4-6), and plagioclase (jk,4-5). Sample LMB-06 demonstrates coarse sand unit with fragments of covelite (gj, 3-5), nickel-iron (hj 1-2), serpentinic rock (ac6-9) and feldspar (fg2-3). Sample SS-03 shows coarse sand. Sample SS-02 exhibits coarse sand with ferro nickel (be,1-5), magnesit (ac,6-8), and magnetic (ik,8-9).

2.26%-12.62%, magnetite 10%-19%, and nickeline (NiAs) 1-3.36%. Gangue minerals were quartz 15%-25% and plagioclase 2.25%-14%.

SEM-EDX micrograph analysis shows indications of boron, natrium, magnesium, aluminium, silika, sulfur, chlor, calsium, titanium and iron in seabed sediment (LMB-03) in the form of loose sand aggregates. This analysis is very helpful to find out the elemental composition of very fine grain sediments. From XRF analysis of offshore (LMB) and stream sediments (SS); secondary nickel (Ni), chromite (Cr), strontium (Sr), zinc (Zn), titanium (Ti), zircon (Zr), copper (Cu) and iron (Fe) deposits have been found. Table 4 and 5 show all the metal mentioned. The results of the analysis of river sediments (SS) containing Ni metal 0.0398 to 0.535 %. Whereas seabed sediments Ni metal mineral content 0.0140 to 0.793 %.

DISCUSSION

Placer nickel either in seabed or coastal sediments are possibly derived from serpentinite, dunite and peridotite rocks rich in olivine and pyroxene and from lateritic soils which are all exposed in coastal area of Buli, Bubus Cape and Gei Island (Figure 6). The placer is spread through river media and by coastal erosion. Association of nickel placer with gravel size sediment was observed in the river mouth (Figure 7). It is an evidence of high energy environment to deposit heavy mineral nickel placer.

Field observations on the beaches and the cliffs have found outcrops of laterite soils (Figure 8). These laterite soils are derived from weathering of source rocks. These laterite soils are exposed on the coastal cliffs of the Buli Serani Islands, Selaban, Mabuli Island, Tinikelini, Pangkal and Gei. Petrographic and mineralographic analyses did not show nickel in seabed sediments but XRF analyses revealed other results. It contains Ni metal minerals 0.0140 to 0.793% (Figure 9). The presence of nickel in submarine sediments can be an interesting further research in the future.

Table 2. The yield of heavy mineral fragment and granules concentrate using "pendulang kayu" (wooden panning).

Identified Fragment or Granules Mineral	Mineral Chemical Compound	Location % Composition SS-1	SS-2	SS-3	PMB-4	LMB-6
Quartz	$Si O_2$	20,65	22.05	15,86	17,49	25.97
Nikel- Iron	(Ni,Fe)	34,50	15,6	10,20	14,61	-
Plagioklas	$((Ca,Na)(Al,Si)AlSi_{2O8)}$	7.88,	11.97	2,25	-	4.96
Magnetik	$Fe_3 O_4$	10.49,	11,68	11,51	11,49	19,36
Piroksen		1,00	-	1,21	-	-
Olivin	$((Mg,Fe)_2SiO_4)$,	2,45	3,10	9,80	2,26	12,62
Serpentin	$(Mg_3Si_2O_5(OH)_4)$,	2,00	-	-	-	2,23
Zirkon	$(ZrSi0_4)$,	-	0,70	1,10	0,80	-
Apatit	$(Ca_5(PO4)_3(F,Cl,OH))$	-	3,00	3,00	2,00	-
Nickeline	(NiAs)	-	3.36	2,16	-	-
Pendlantite	$(Fe,Ni)9S_8$	-	-	-	-	4.77
Sediment name		Coarse sand	Coarse sand	Coarse sand	Coarse sand	Fine sand

Table 3.The result XRD analysis of seabed sediment at LMB location (Figure5)

Brief description Samples are in the form of general brown, dark gray, loose, soft, soil material, clay grain size to fine sand, good sorting		Location				
Identified mineral	Mineral chemical compound	% composition				
LMB-12		LMB-12	LMB-16	LMB-30	LMB-45	LMB-60
Quartz	SiO_2	22	17		36	42
Albite, calcian, ordered	$(Na, Ca) Al (Si, Al)_3 O_8$	6	44			3
Stilbite-Ca	$Ca_{2.62} Al_{2.8} Si_{28.2} O_{72\ H4.56}$	5				
Metaheulandite	$Ca(Al_2 Si_7O_{18})1\ !_7 H_2O$					
Silhydrit	Si_3O_6 ! H_2O			17		
Lizardite-1	$(Mg, Al)_3 [(Si, Fe)_2O_5] (OH)_4$	10	32			
Montmorillonite	$(Na, Ca)_{0.3} (Al, Mg)_2 Si_2 O_{10} (OH)_2$!n H_2O					
Labradorite	$(Na_{0.4}Ca_{0.6}) Al_{1.6} Si_{2.4} O_8$	17			12	
Calcite	$CaCO_3$	20		56	15	18
Chrysotile	$Mg_3[Si_{2-x} O_5] (OH)_{4-4x}$.	18				
Aragonite	$Ca(CO_3)$		5	17		
Clinochrysotile	$Mg_3 Si_2 O_5 (OH)_4$				22	20
Garnierit	$(NiMg)_2(OH)_3(Si_4O_{10})$		2			
Clinopiroxen	-				7	
Covellite	CuS			10		
Augite	$(Ca_{.818} Mg_{.722} Fe_{.183} Fe_{.086} Al_{.151} Al_{.289} Si_{1.751})O_6$	6				
Sediment/Soil name		clay	clay	clay	clay	Sandy clay

Table 4.Results of Metal Mineral XRF Analysis of stream sediments (SS)

No.	Sample Location Code	METAL ELEMENTS								
		Ni (%)	Cr (%)	Sr (%)	Zr (%)	Cu (%)	Zn (%)	Fe (%)	Mn (%)	Ti (%)
1	SS-1	0.535	0.299	0.0160	0.0013	0.0044	0.0082	9.82	0.357	0.114
2	SS-2	0.0780	0.111	0.0178	0.0053	0.0037	0.0058	5.62	0.102	0.232
3	SS-3	0.0633	0.0911	0.0281	0.0061	0.0047	0.0064	5.17	0.0926	0.243
4	SS-4	0.0398	0.0862	0.0237	0.0065	0.0045	0.0051	4.97	0.100	0.309
METHOD		XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF

Table 5.Results of metal mineral XRF Analysis of Seabed sediments (LMB)

No	Sample Location Code	METAL ELEMENTS								
		Ni (%)	Cr (%)	Sr (%)	Zr (%)	Cu (%)	Zn (%)	Fe (%)	Mn (%)	Ti (%)
1	LMB-1	0.533	0.128	0.0520	0.0044	0.0026	0.0055	4.81	0.0746	0.287
2	LMB-4	0.0606	0.111	0.0476	0.0049	0.0030	0.0071	5.85	0.0739	0.297
3	LMB-8	0.0591	0.105	0.0501	0.0047	0.0029	0.0064	4.99	0.0926	0.276
4	LMB-12	0.0551	0.113	0.106	0.0052	0.0032	0.0062	4.84	0.100	0.279
5	LMB-16	0.793	0.0810	0.205	0.0047	0.0044	0.0075	5.77	0.0675	0.253
6	LMB-23	0.0366	0.184	0.0260	0.0033	0.0020	0.0045	3.85	0.0654	0.259
7	LMB-26	0.0140	0.0179	0. 364	0.0061	0.0047	0.0064	1.21	0.0926	0.0544
8	LMB-30	0.0651	0.0567	0.172	0.0041	0.0035	0.0066	4.83	0.100	0.197
9	LMB-31	0.0637	0.0579	0.172	0.0038	0.0030	0.0054	4.83	0.0472	0.199
10	LMB-35	0.0155	0.0118	0.529	0.0038	0.010	-	0.914	0.0142	0.023
11	LMB-38	0.0613	0.0496	0.0648	0.0060	0.0048	0.0083	5.80	0.0696	0.319
12	LMB-40	0.197	0.0974	0.100	0.0048	0.0032	0.0086	6.85	0.0819	0.229
13	LMB-46	0.0464	0.0454	0. 0455	0.0073	0.0052	0.0085	5.77	0.0702	0.349
14	LMB-48	0.0540	0.0876	0.0435	0.0063	0.0028	0.0074	6.20	0.0780	0.296
15	LMB-50	0.0545	0.0734	0.0443	0.0059	0.0048	0.0072	5.63	0.0699	0.315
Total		2.1082	1.2197	1.6123	0.0753	0.0601	0.0956	72.144	1.0976	3.6324
Average		0.140	0.0813	0.107	0.00502	0.0040	0.0580	4.8096	0.0731	0.2421
METHOD		XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF	XRF

Figure 6. Outcrops of ultramafic source rocks serpentinit, dunite and saprolite (left, location PMB-04), laterite soil at coastal cliff of Gei Island (middle) and seabed sediments was being sampled by grab sampler to examine its possibility as nickel placer deposits (right).

Figure 7. Appearance of loose sand pebble and gravel sediment at river mouth of SS-3 Location (Photo of Nurdin, 2009).

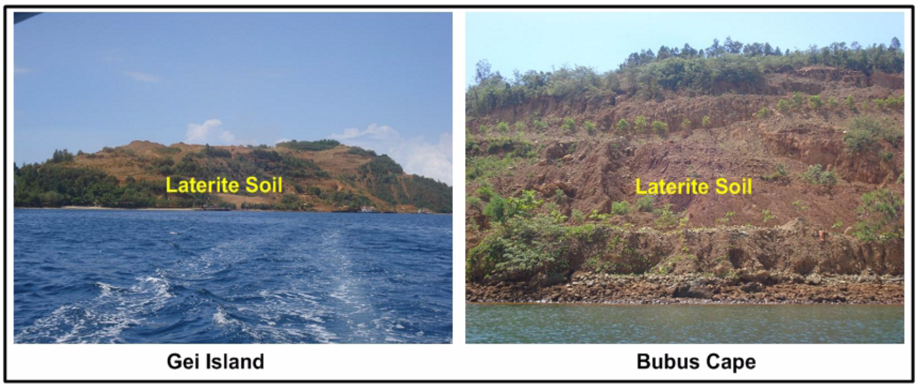

Figure 8. Reddish gray to brown laterite soils in Gei Island and Tanjung Bubus locations. (Photo : Widiatmoko, 2009)

CONCLUSIONS

Coastal sediments reflect its surrounding source rocks which are consisted of fragments of ultramafic, metamorphic, basalt and serpentine; while mostly rock outcrops in the coast are serpentine rocks at the bottom and laterite soils above. Coastal sediments also show indications derived from deep sea with the existence of greywacke sandstone fragments as observed microscopically in petrographic analyses. The tendency of source rock derived from its surrounding environments also occurred at marine sediments; they are basically composed of rock fragments of serpentine, basaltic volcanics, gabro and ultramafic with additions of advanced argillic sedimentary rock, limestone and fossils.

Petrographic analyses found fragment abundances of ultramafic rock (10-47%), serpentin rock (12-24%) and metamorphic rock (3-12%) in stream and coastal sediments. These rocks have direct relation with the presence of nickel metal in the research area. Mineralographic analyses show the existence of ferro nickel (Fe-Ni) and nickeline (Ni-As) in coastal and stream sediments. The analyses were done in heavy mineral concentrates using wooden pan and observed

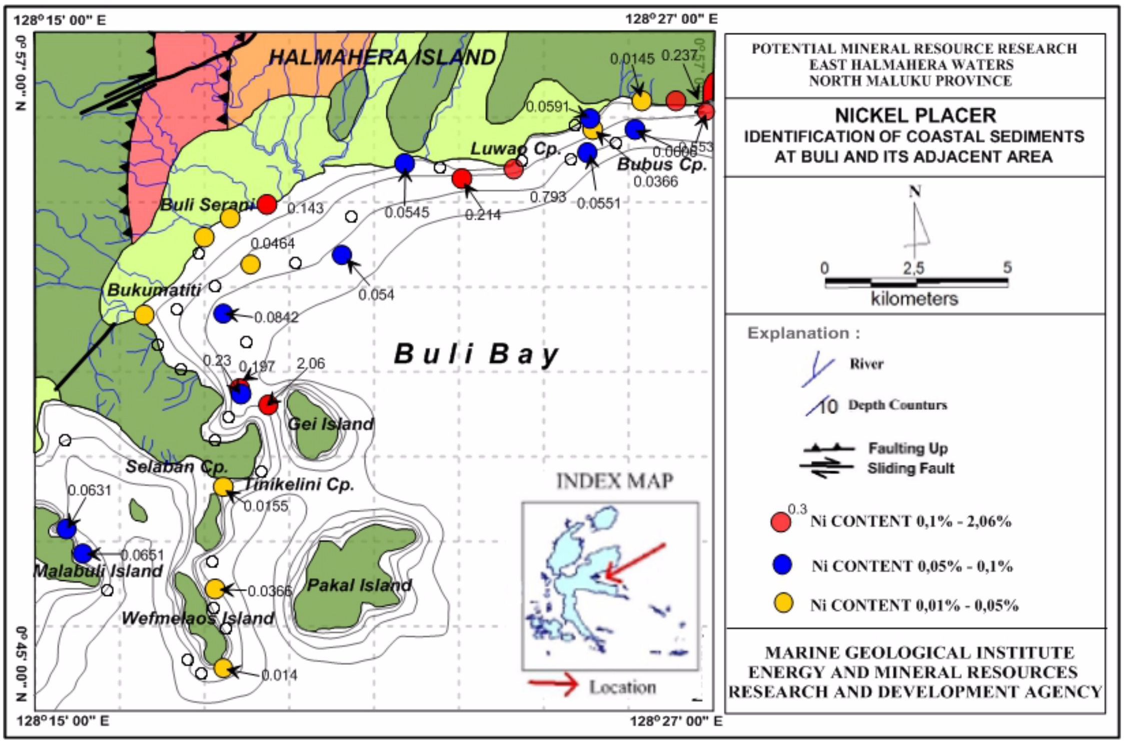

Figure 9. Map of nickel content distribution on the coast and seabed of Buli waters (Widiatmoko and Nurdin, 2009).

through microscope. Peridotite and serpentinite rock fragments were also observed in coastal sediments through these mineralographic analyses.

Nickel in seabed sediments only appears through XRF analyses while petrographic and mineralographic show negative results. XRF analyses show nickel contents of 0.0140 to 0.793 %, chromite 0.0179 to 0.1128% and iron 1.2 to 6.85%. Nickel distribution in coastal water is controlled by equatorial Pacific Ocean waves that propagate westward and excite local trapped waves in Buli Bay. The presence of nickel in submarine sediments can be an interesting further research in the future.

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