# REVIEW OF COASTAL CHARACTERISTICS OF IRON SAND DEPOSITS IN CILACAP CENTRAL JAVA

By:

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## ABSTRACT

*Mineable iron sand deposits in Cilacap – southern coastal area of Central Java have certain coastal characteristics that need to be studied in order to understand its depositional environment. With the knowledge of such environment, it can be applied to look for other places prospective of iron sand deposits that have the same characteristics especially recently when Cilacap's deposits were almost depleted.*

*Coastal characteristics of iron sand deposit in Cilacap is shown by successive sandy beach ridges separated by marshy valleys typical of prograded coasts and by dunes of sand elongated parallel to the shore line with elevation varies from 0 m to 15 m above sea level. The iron sand deposit was derived from denudation of andesite and "Old Andesite Formation" enriched in magnetite and ilmenite minerals in the steep elevated and deeply weathered rock hinterlands of Cilacap. High sediment loads of Serayu Basin in the hinterland (3,500-4,500 ton/km2/year; Citarum River basin only 800-1,200 ton/km2/year) was causing extensive deposition of iron sand in the coastal zone.*

Key words: coast, characteristic, iron sand, Cilacap

## SARI

*Endapan pasir besi yang dapat ditambang di Cilacap – pesisir selatan Jawa Tengah memiliki karakteristik pantai tertentu yang perlu dikaji agar dapat dipahami lingkungan pengendapannya. Dengan pengetahuan tentang lingkungan pengendapan tersebut, dapat diterapkan untuk mencari daerah-daerah lain prospek endapan pasir besi yang memiliki karakteristik yang sama terutama pada akhir-akhir ini ketika endapan Cilacap akan habis.*

*Karakteristik pantai endapan pasir besi di Cilacap dicirikan oleh urutan pematang pantai berpasir yang dipisahkan oleh lembah-lembah berawa khas pantai maju dan oleh gumuk-gumuk pasir memanjang sejajar dengan garis pantai dengan ketinggian bervariasi dari 0 m hingga 15 m dari muka laut. Endapan pasir besi di daerah ini berasal dari proses denudasi andesit dan "Formasi Andesit Tua" yang kaya akan mineral magnetit dan ilmenit pada pedalaman Cilacap dengan kondisi elevasi curam dan batuan sangat terlapukkan. Muatan sedimen yang tinggi dari Cekungan Serayu di pedalaman tersebut (3.500-4.500 ton/km2/tahun; cekungan Sungai Citarum hanya 800-1.200 ton/km2/tahun) menyebabkan pengendapan yang sangat luas pasir besi di wilayah pantai.*

Kata kunci: pantai, karakteristik, pasir besi, Cilacap

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## INTRODUCTION

Iron sand deposits in Cilacap - southern coast of Central Java (Figure 1) had been exploited for along time. Nowadays these deposits were almost depleted, explorers are trying to find other places to replace the exhausted deposits in this area. Eventhough the deposits were almost all exploited but the characteristics of its deposits is interested to be studied since understanding of deposition of such mineral will be useful to find other prospective deposits of iron sand. Iron sand in Cilacap was deposited in coastal area; thus discussion on coastal characteristic of the deposit will bring us to understand better the process of its accumulation.

The south coast of Java is dominated by wave action from the Indian Ocean, and receives a relatively gentle southwesterly swell of distant origin and stronger locally generated south-easterly waves that move shore sediments and deflect river outlets westwards, especially in the dry season (www.unu.edu). It is dominated by steep and cliffed sectors and long, sandy beaches rather than protruding deltas such as occurred on the north coast of Java. On the south coast, there is very little information on the extent of shoreline changes in historical times. Changes on this rocky and sandy coast will have been relatively slow eventhough powerful wave action from the Indian Ocean strikes the coast. The geomorphological contrast between the irregular deltaic coast of northern Java and the smooth outlines of depositional sectors on the south Java coast is largely due to contrasts in wave-energy regimes and sea-floor topography. The sediment loads of rivers flowing northwards and southwards from the mountainous watershed are similar, but the finer silt and clay, deposited to form deltas in the low-energy environments of the north coast, are dispersed by high-wave energy on the south coast. The coarser sand fraction seen in beach ridges associated with the north coast deltas is thus concentrated in more substantial beach and dune formations on the south coast. The contrast is emphasized by the shallowness of coastal waters off the north coast, which reduces wave energy, as opposed to the more steeply shelving sea floor off the south coast, which allows larger waves to move into the shoreline. Nevertheless, silt and clay carried in floodwaters settles in the small valleys between successively built beach-ridge systems along the southern coast, and in such embayments as Segara Anakan. (www.unu.edu).

## REGIONAL AND LOCAL GEOLOGY

Regional geology of Cilacap regency is composed of volcanics and sedimentary formations (Figure 2). Alluvium mostly spread at western and southern of this regency (Djuri, 1975; Asikin et al, 1992 and Simanjuntak et al, 1992 in Herman, 2005). Mainland of Cilacap Regency (apart from Nusakambangan Island) is formed by Formations of Rambatan, Halang, Kumbang and Tapak; which mostly covered up by alluvium with the coastal deposits spread at southern coast of Cilacap City until Bengawan River in the east.

The Middle Miocene Rambatan Formation is made up of turbidites consisted of calcareous sandstone with intercalations of marlstone, claystone and breccia. Halang Formation is consisted of sandstone, claystone, marlstone and tuff with intercalations of breccia; which uncomformibly underlayed by Kumbang Formation of Early Pliocene composed of volcanic breccia intercalated with lava, sandstone and conglomerate intercalated with marlstone. On the other hand, Tapak Formation is a sedimentary rock unit deposited in shallow seas, consisted of sandstone contained mollusc shells with intercalations of marlstone and breccia; of Pliocene age layed unconformibly above Halang Formation.

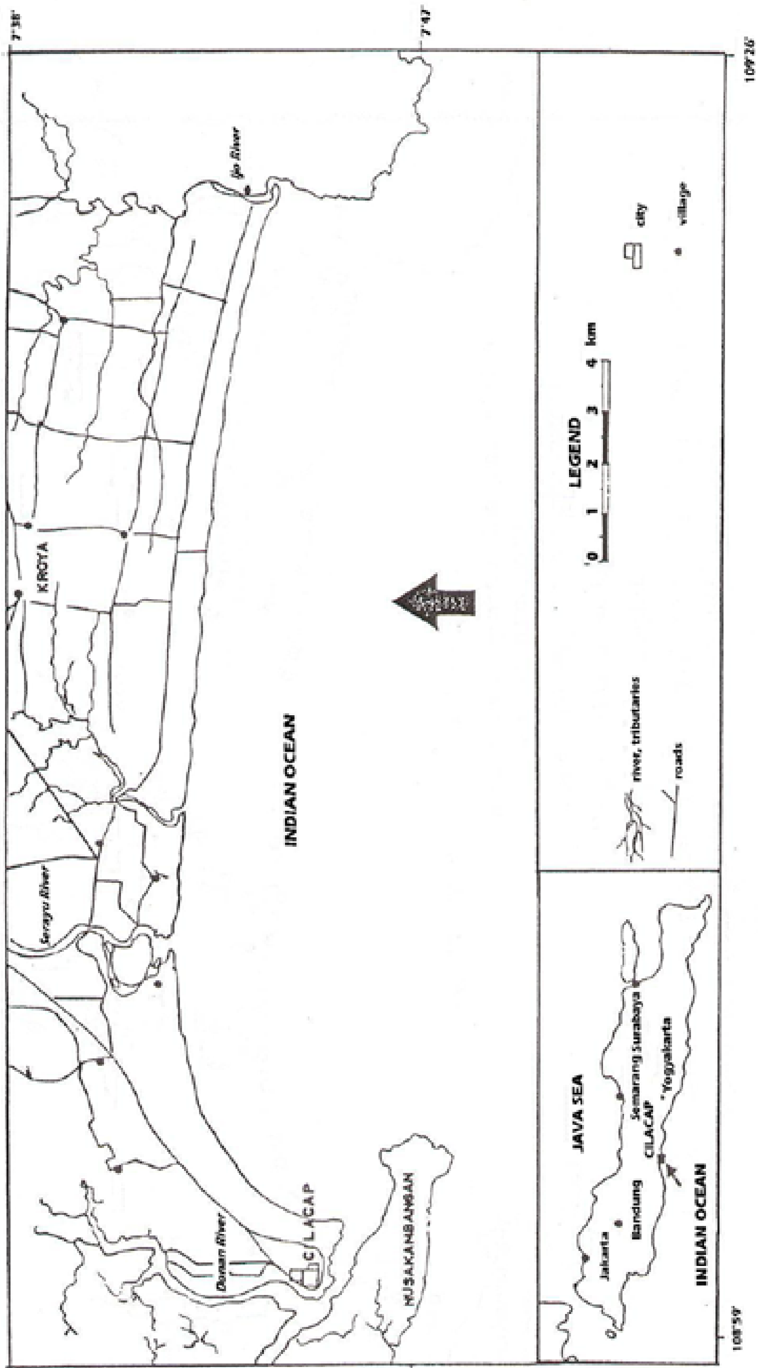


Figure 1. Study area

Halang Formation was intruded by basaltic dykes filling up rock openings parallel with orientation of anticline structures which then sliced by faults of northeast-southwest orientations or almost north-south. The vast distribution of alluvium oriented northwest-southeast is assumed as block piling up of a graben structure resulted from normal faulting.

The consession area of PT Antam Tbk. of Iron Sand Mining unit of Cilacap is stand on basement rock of Tapak Formation partially covered up by alluvium and coastal sediments. Alluvium spread at northern part of the Regency is consisted of clay, silt, gravel and cobble which resulted from denudation of Karang Bolong Mountain and deposited by fluvial system of the area. While the coastal sediments are composed of loose sand which exhibit layering indication where iron sand resources occurred (Herman, 2005). On the other hand, the coastal area of Cilacap was composed of Quarternary deposits of coastal berm, volcanic sediments, old fluviatil, sand berm, Recent coastal sand, Recent fluviatil and estuarine. The pre-Quarternary sediments were spread at mountainous area in eastern and western (Situmorang, 1983).

**Coastal sediment**

Study of coastal sediment deposits of Cilacap had been carried out by many authors. Sarmili et al (1999) noted that along the coastline of Cilacap beach, sand sediment was generally found which also formed, landward, linear shoreline with bars and beaches parallel to the recent coast. Sarmili et al also found out that the distribution of the sand sediment is not only on the beach but also found in some places on the seabed and reaches more than 20 meters in depth.

Sarmili et al had also conducted study on the potentiality of iron sand deposits in the coastal and offshore areas of Cilacap. They found out that in both areas the sediment samples showed magnetite content anomalies either in coastal or offshore but the highest anomaly occurred on coastal samples which reached up to 93.9 percent. The high anomaly was also took place in the west closed to Nusa Kambangan island resulted from westward longshore current which dominant during east monsoon. In offshore areas, high anomaly occurred up to 20 m seadepth.

Situmorang (1983) studied the coastal sediments of Cilacap through observation stations, coastal sampling and shallow borings (Figure 3). He also made some measurements on the slope of Cilacap beaches and found out that to the west, the slopes are steeper than the eastern part of the coast (Figure 4). The steeper coasts in the west are composed of coarser sediments than the gentle slope in the east (Figure 5); the figure demonstrate that the coarser sediments are consisted of medium sands (mean grain size 2.0 – 1.0 phi) while the finer sediments are fine sands (mean < 2.0 phi).

Grain size distribution curves and its accompanying histograms are shown in Figure 5. The figure demonstrates three populations of traction, saltation and suspension. It also represents sand samples from the coast, river, coastal dune and berm.

Coastal sand has different deposition mechanism compared to river sand with mean grain sizes fine to medium sand, sorting moderate to very well sorted, skewness generally negative and where saltation population more dominance while traction and suspension population take place in minor occurrences. On the other hand, river sand has worse sorting and coarser grain size; the distribution curve demonstrates domination of traction population and minor saltation population.

Coastal dune sands show statistic parameters and distribution curves identic with coastal sand but with better sorting and finer grain sizes. These possibly due to different transportation agents where aeolian (wind)

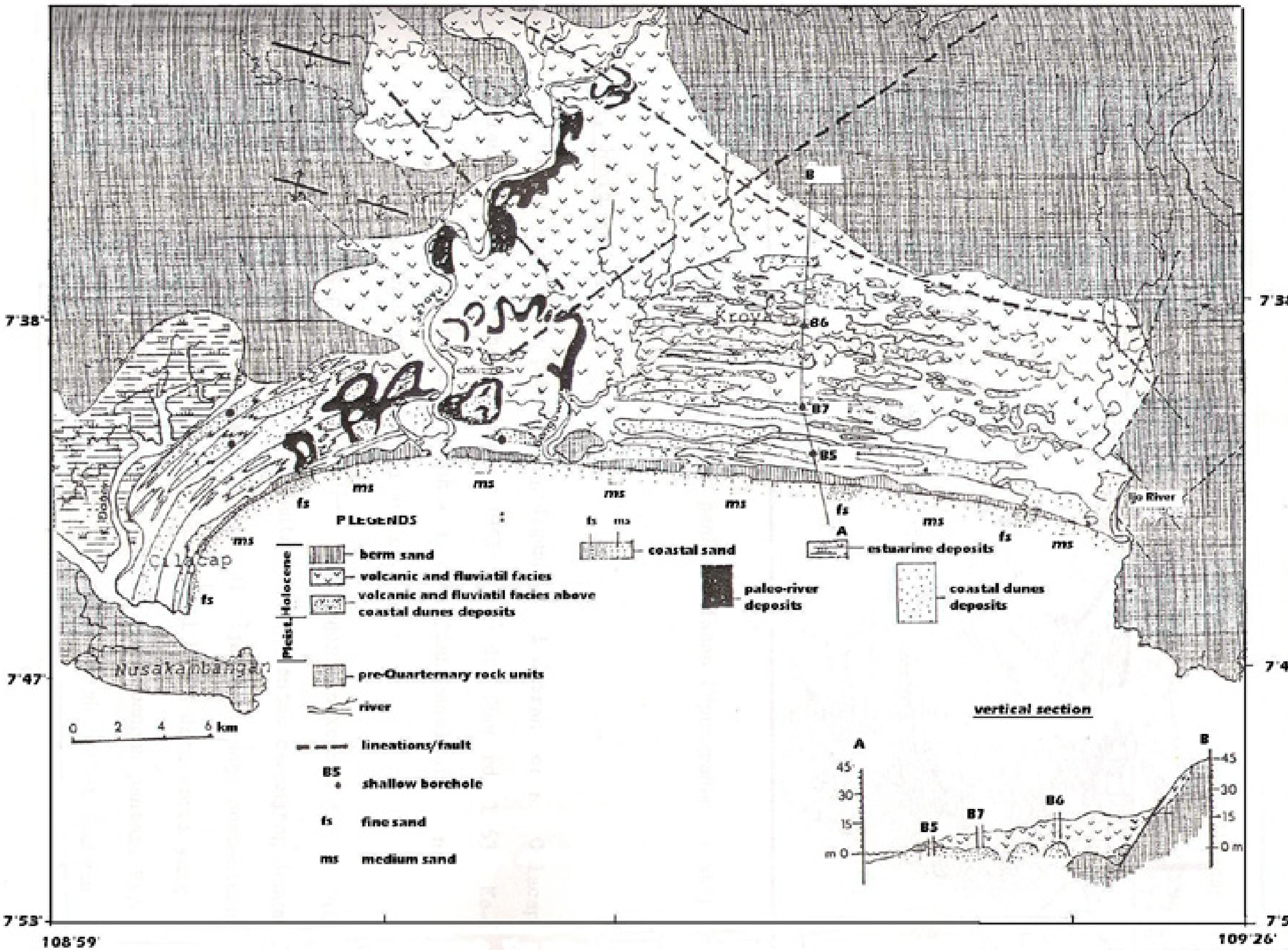


Figure 2. Quarternaly geology map of Cilacap area – Southern Serayu Mountain and sand deposits distribution along Cilacap coastal zone (Source: Situmorang, 1983).

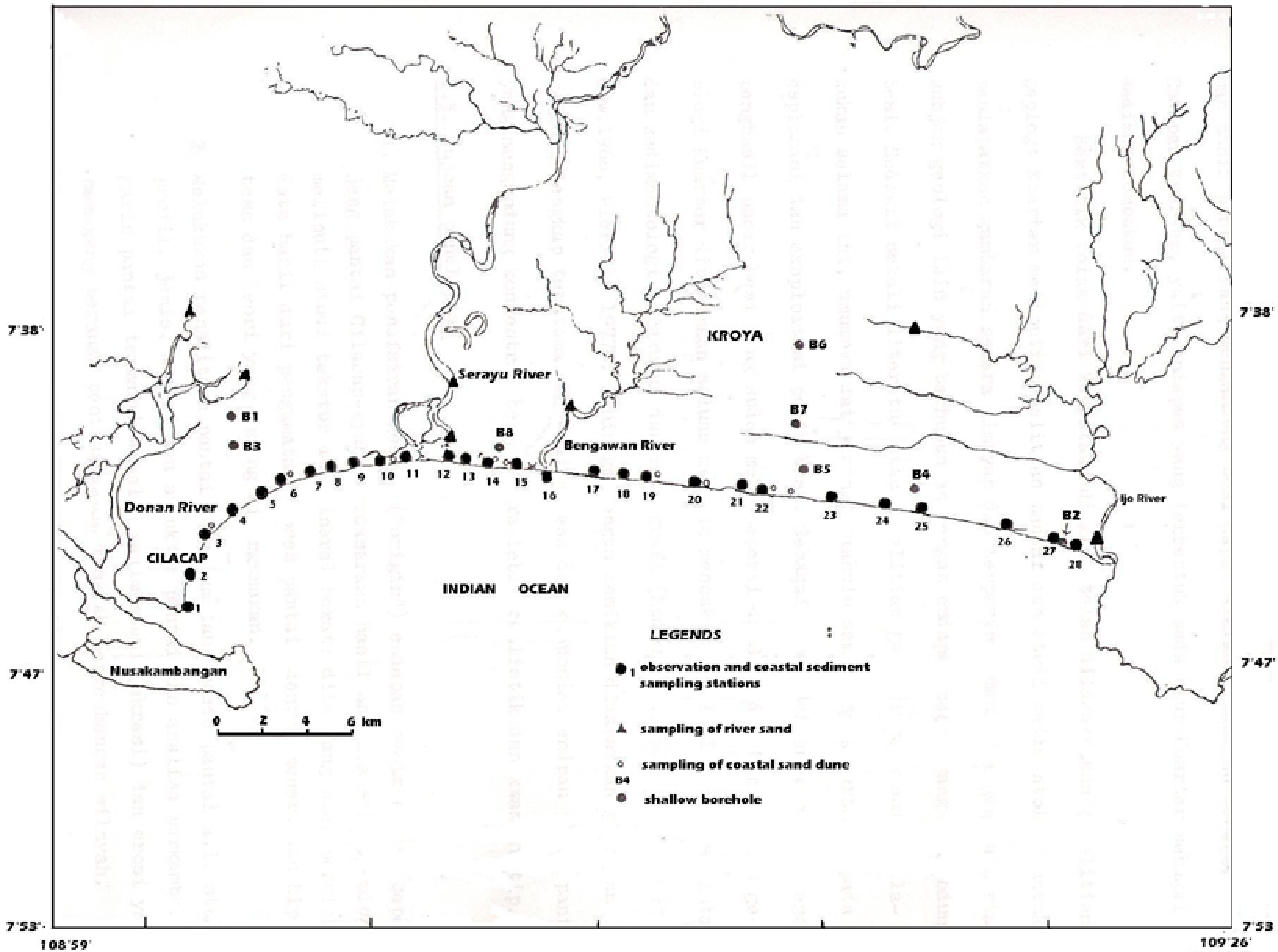


Figure 3. Observation and sampling stations along the coastal area (Source: Situmorang, 1983).

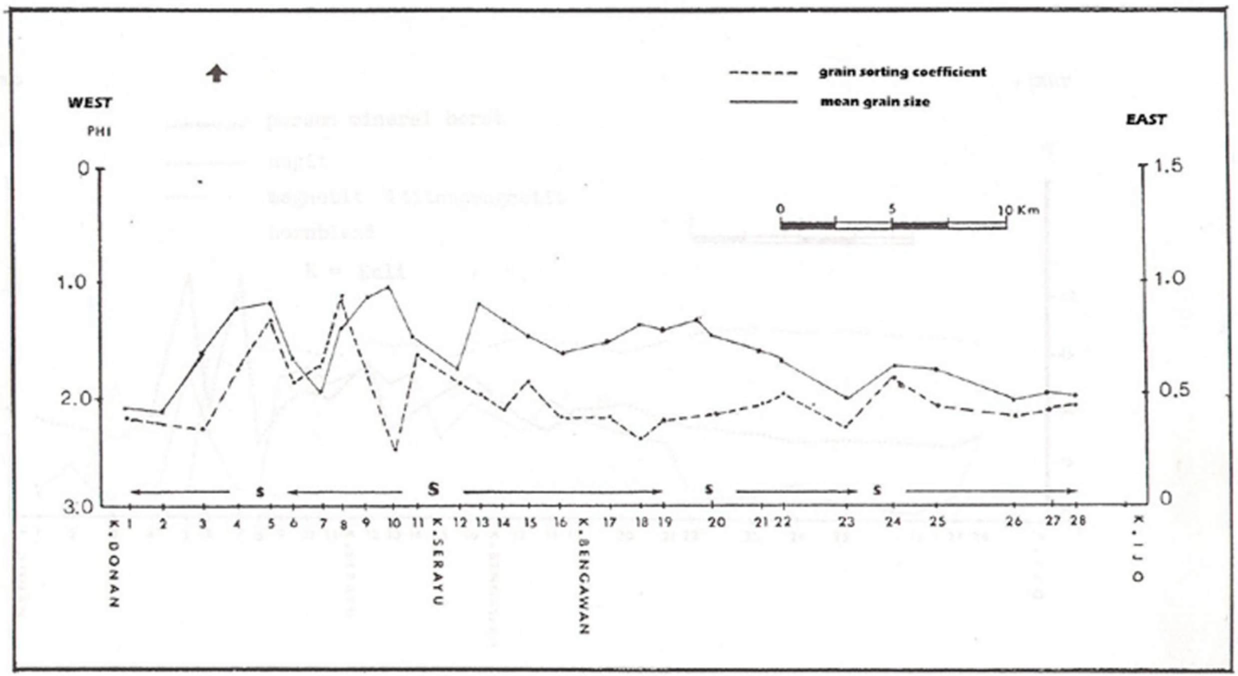


Figure 4. Coastal slopes more gentle eastward and steep westward (Source: Situmorang, 1983).

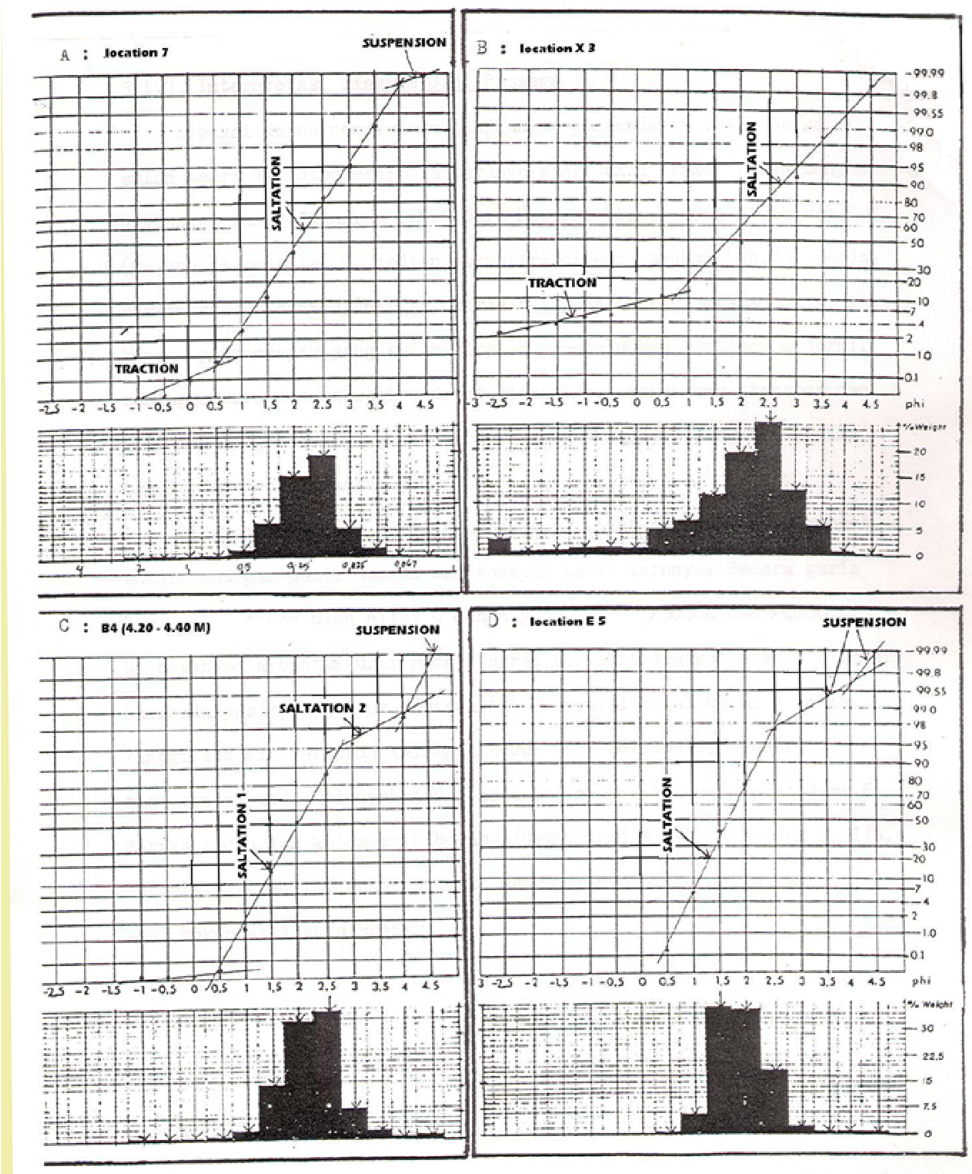


Figure 5. Distribution of mean gain size and sorting coefficient of coastal sand at 28 stations based on Folk (1974) and source (S) interpreted based on Sunamura & Horikawa (1972). (Source: Situmorang, 1983).

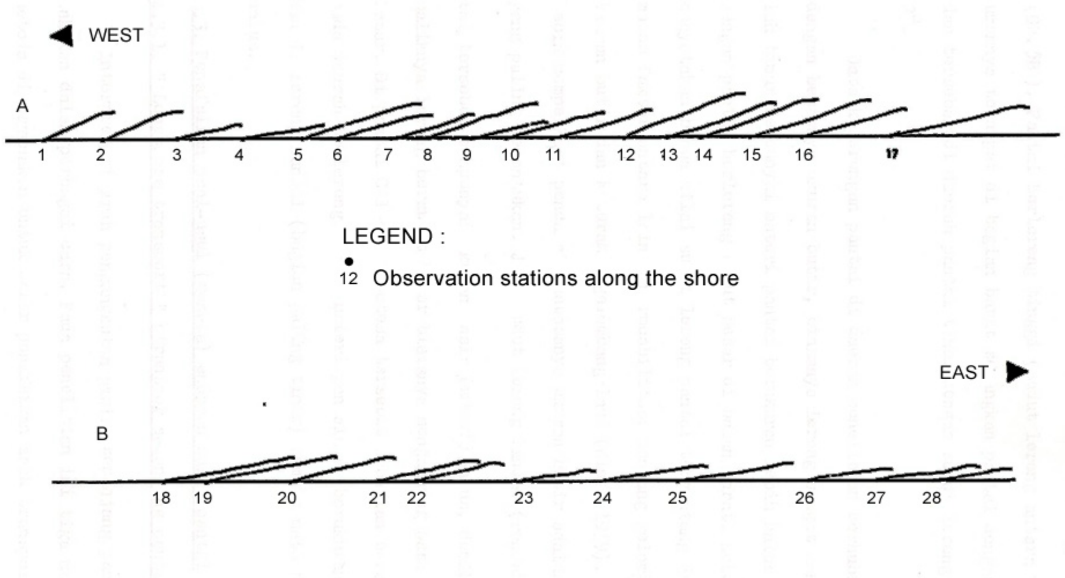


Figure 6. Grain size distribution curves and histograms of : A. coastal sand, B. river sand, C. coastal dune sand, D. berm sand (Source: Situmorang, 1983).

processes are more prominence for the dune and berm sands.

## Coastal morphology of Cilacap

Coastal lowlands contain a variety of landforms which are geologically young due to the rapid post-glacial sea-level rise stabilised only some 6000 years ago (www.fao.org). The formation and properties of today's coastal landforms depend on fluvial processes interact with marine processes. Three factors are important for coastal landform formations (apart from global sea level fluctuations): (1) the *input of fluvial water and sediment* in relation to marine redistribution, (2) the *energy of waves and currents*, and (3) the *amplitude of the tides* (`tidal range'). The combined actions of fluvial and marine processes determine whether or not a depositional body can form at the mouth of a river and what kind of body will form. If the rate of fluvial input of sediment exceeds marine sediment redistribution, the depositional sequence will `prograde' seawards to form a *`delta'*. If marine redistribution can handle the input of fluvial sediments, a depositional body may develop that is not prograding, but only aggrading: a river mouth.

Beaches of sand and gravel are extensive around the coasts of Indonesia, especially near the mouths of rivers delivering this kind of material, adjacent to cliffs of sandstone or conglomerate. Among them, beach sediments of volcanic origin are typically black or grey.

In Cilacap coastal zone, multiple beach ridges occur on sectors that have intermittently prograded. Coastal dunes are developed in this area, where the fluvially nourished beaches take place. The beaches show evidence of a continuing supply of sandy, or gravelly, sediment to maintain or prograde the shoreline.

The sandy and swampy coastal plain extends past the mouth of the Serayu River in the Cilacap coastal zone. In this sector it has been disturbed by the extraction of magnetite and titanium oxide sands; in places, the beach ridges have been changed into irregular drifting dunes, while dredged areas persist as shallow lagoons. On either side of the mouth of the Serayu River the coastal plain has prograded by the addition of successive sandy beach ridges separated by marshy swales. The sediments are of fluvial origin, reworked and emplaced by wave action, and progradation has enclosed a former island as a sandstone hill among the beach ridges. The coastal plain shows a landward slope at a number of places where the streamlets flow land-wards instead of seawards, and this is presumed to be due to very recent differential tectonic movements (Zuidam et al. (1977) in www.unu.edu).

The area of Cilacap is a micro-tidal coastal regions (tidal range less than 2 m) and its coastal shelf has a steep gradient; which conclude the type of *wave-dominated* coastal area. In this way, waves attain the energy needed to attack and dissipate freshly deposited fluvial sediments. The main direction of the wind which is perpendicular to the coast, causing fluvial sediments redistributed laterally, in sandy beach ridges parallel to the coast.

Cilacap coast also can be classified as depositional or constructional coastlines, with adequate sediment supply and where accumulation of clastic sediments outweighs erosion by the sea. The clastic material deposited on the coast are provided by nearby rivers (Donan, Serayu, Bengawan and Ijo) and transported by along-shore currents.

West of the Serayu River the sandy shoreline, backed by beach ridges, curves southwards to Cilacap, a high ridge of limestone and conglomerate, with precipitous cliffs along its southern coastline.

According to Situmorang (1983) in Cilacap, there are two types of coastal dunes: pleistocene and Holocene. The Holocene dune was interpreted derived from Serayu and Bengawan River.

Situmorang also measured the beach face slope of Cilacap beaches (Figure 4). The measurements revealed that steep face occurred in western coastal area (range between 9° up to 17°) and moderate to gentle slope took place in eastern area (3° up to 8°). Based on his field observations, Situmorang further concluded that steepness of coastal slope relate to grain size. High slope angle is composed of coarse sand deposits while low angle is made up of fine sand.

Topographically the area of the iron sands deposits in Cilacap is generally flat and composed of dunes of sand, which are elongated parallel, to the shore line, the elevation varies from 0 m to 15 m above sea level. At this moment, the area of the deposit is generally under rice cultivation: further inland agricultural activities are a mixture of rice growing and plantations of various trees for production of fruit and other commodities. The mining operations are commonly restricted to the narrow coastal strip of solely rice producing areas, which are easily rehabilitated and brought back into rice production (www.antam.com).

## Iron sand origin

The magnetite bearing iron sands of the south coast of Java are derived from chemical and physical weathering of the Old Andesite of mid-Tertiary age sub-aerial volcanics, which are composed of andesitic composition but which can range from basalt to rhyolite. Rivers transported to the coast the products of erosion, including magnetite. In the high-energy near-shore marine environment, the heavy minerals, including the magnetite, were concentrated and laid down as beach sand deposits (www.antam.com).

Some previous authors (i.e. Bemmelen (1949) and Kraeff and Gunther (1957) in Situmorang, 1983) stated that iron sand in southern coast of Java are derived from denudation of andesite and "Old Andesite Formation" enriched in magnetite and ilmenite minerals.

In the upstream area of Cilacap, the combination of steep elevated hinterlands of deeply weathered rock and frequent heavy rainfall produces river system that carry substantial quantities of sediment down to the coast. Deposition of this material has built extensive deltas and broad coastal plains on the coastal area of Cilacap Regency (www.unu.edu).

The nature and rate of sediment yield from rivers draining to the south coast of Java vary with the size and steepness of the catchment and with vegetation cover. In the Serayu River basin – upstream of Cilacap coastal zone area, deforestation has accelerated sediment yield and increased the incidence of flooding in recent years. The annual sediment yield from catchments dominated by sedimentary rocks was ten times that of catchments with similar vegetation and land use on volcanic formations, the contrast being reflected in the nature and scale of depositional features developed at the river mouth (Meijerink (1977) in www.unu.edu).

The lithology of outcrops within Serayu catchment (700 km2) upstream strongly influences the composition of sediment loads (3,500 - 4,500 Sediment yield ton/km² /year**)** carried downstream by the Serayu River. Compared with other river such as Citarum River in West Java (catchment area 73,000 km2, sediment yield 800 -1,200 ton/km2/ year); the Serayu River has capability to transport large quantities of sediments to the coastal area. That's why iron sand was extensively deposited in Cilacap coastal zone as the hinterland composed mainly of volcanic of Old Andesite Formation.

Although much of the sediment supplied to the coast under humid tropical conditions has been delivered by rivers, material has also been derived from the erosion of cliffs along the shore, and from the sea floor (www.unu.edu).

Situmorang (1983) proposed that one criteria for sediment transport direction determination is through study of heavy mineral distribution which already known its sources. Figure 7 demonstrates heavy minerals distribution pattern along the coast of Cilacap where the high percentages occurred closed to Serayu River as the main agent of sediment supply to the coast.

**Exploration and Laboratory Methods**

The method of exploration of iron sand deposits were adopted from Antam field operations (www.antam.com). Antam has explored the magnetite bearing iron sands by drilling on an initial grid of 400 m by 20 m and then a closer spacing of 100 m by 20 m. The drill holes, mine workings and topography have been surveyed using standard techniques and equipment. The topographic maps are plotted on a scale of 1 : 5,000; and drilling is plotted on a scale of 1 : 1000.

Exploration samples were collected with an auger of specification 5 cm in diameter and 150 cm in length. The holes are augered vertically to the " bedrock" or the water table.

The samples are logged and bagged up and sent to the Laboratory, if possible closed to the mining area, for analysis.

Holes have been drilled on a grid of 400 by 20 m, which is closed down to a 100 by 20 m grid for Measured Mineral Resource definition. The closer spaced drillhole direction is orientated which perpendicular to the coastline and at right angles to the expected strike direction of the iron sand deposits. The holes are sampled at 1 m intervals.

Laboratory standard used is depended on standard utilized in the export destination country. Antam's laboratory follows Japan Industrial Standard (JIS M.8212) for

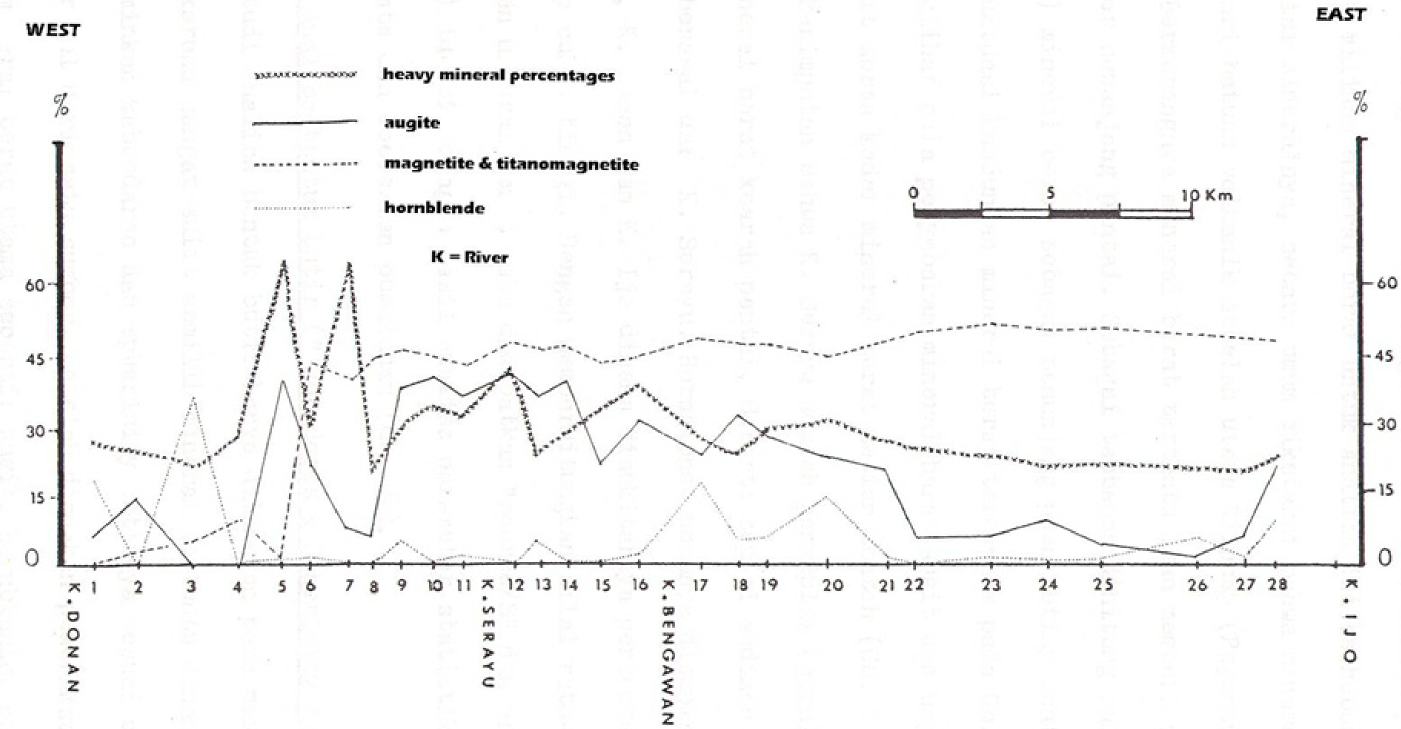


Figure 7. Heavy minerals distribution pattern along the coast of Cilacap (Source:Situmorang, 1983)

preparation and analysis for the total magnetic percentage (MD), Fe total of magnetic concentrate and tonnage factors.

Samples are dried and then reduced by coning and quartering and riffling to 100 g, from which the magnetic fraction is separated manually with a 500 gauss strength magnet. The non-magnetic fraction is discarded and the process of magnetic separation is repeated with the magnetic fraction a total of seven times. The final magnetic fraction is then weighed. This process simulates the magnetic separation at the operation and it produces a measure of total percentage magnetic fraction (MD %). The magnetic fraction is then ground down to minus 150 mesh, after mixing and quartering, and split for wet chemical analysis.

The laboratory should follow a precise procedure to chemically analyze the total Fe content. The laboratory has to prepares its own standard from pure iron, as no suitable standard is commercially available.

The main check on the results of the laboratory is by comparison with shipment analyses performed by the customers, for which there is close correlation.

The dry bulk densities are measured both for raw sand and concentrate. A 100 g split is weighed out and its volume measured in a measuring cylinder after light compaction. For each mining area, a separate bulk density is applied to estimate in-situ tonnages. Results of density measurements by Antam produced bulk densities for Cilacap iron sand range from 1.61 to 2.00.

The sampling method and sampling density mentioned are appropriate and adequate for the definition of Mineral Resources; while the preparation and analysis of samples are appropriate for use in the estimation of Mineral Resources.

Database integrity should be checked. Inputs of exploration data to the computer system (Antam used spreadsheet softwares such as Microsoft excel for this purpose) with the transcription of drillholes and assay results of data must be in conformity.

Review of economic reliability should include Cut-off Grades and Metallurgical Factors. At Cilacap Antam applied an economic cut-off of 10 % MD (total percentage of magnetic fraction) but the iron content is high enough not to require a Fe % cut-off.

Classification of Mineral Resources based on the density of auger drilling. Measured Mineral Resources require auger drilling on a 100 m by 20 m grid and Indicated Mineral Resources on a 400 m by 20 m grid.

In order to convert the magnetite concentrate of iron sands Mineral Resources to Ore Reserves, the following factors are applied: a combined mining recovery and dilution factor and an operational magnetic separation recovery factor. At Cilacap, Antam applied a combined mining recovery and dilution factor of effectively 85 % and an operational magnetic separation recovery of 90 %. Magnetic fraction (% MD) and % Fe grade of magnetic concentrate remain unchanged in converting Mineral Resources to Ore Reserves.

Proved Ore Reserves and Probable Ore Reserves are defined as those Measured Mineral Resources and Indicated Mineral Resources which have mine plan and meet the required specifications, allowing mining recovery, dilution and magnetic separation recovery, and for which the economics of mining have been demonstrated as positive.

## Iron Sand Extractions

Exploration activities for iron sand deposits had been done by PT Antam at southern coast of Cilacap Regency (1960 – 1972); at areas 2,004 hectares which include KP (Kuasa Pertambangan or concession permit) numbers Du 109, 110, 207, 208, 209 and 291 (Figure 8). The iron sand deposits are formed by particles of magnetite, hematite and ilmenite with associated elements S, P, Mg, Zn and Al2O3. The deposits are formed 500 meters width from coastline landward with thickness 3 to 4 meters generally below sandy soils. Identified iron sand deposits based on information of Indonesian Exploration and Mining (Directory 1999/2000) and Potency and Figures of Mineral Resources/Reserves of Cilacap Regency Central Java Map (2003) are consisted of indicated 724,511 tons and measured 1,930,725 tons with mean grade 51.7% Fe (Herman, 2005).

In the mining area owned by PT Antam, iron sand extraction was initiated using methods of open pit mining and back filling. In the period 1971 – 1978, the company produced iron ore concentrates for export to Japan 300,000 ton/year, with grade specification 55% Fe total, 10% TiO2, 6% Al2O3 and 10% MC (Moisture Content). Period of 1979 – 2004 PT Antam Tbk. produced iron ore concentrates to fulfill national cement industries demands, with specification 48% Fe total, 68% Fe2O3 and 10% MC. At october 1$^{st}$ 2003, officially Cilacap iron sand mining was closed. The closing process was still studied by relevant government competent institution Coal and Mineral Technology Research and Development Centre (tekMIRA), Research and Development Agency of Department of Energy and mineral Resources. Field observation at May 2004 (Herman, 2005), the company continued conducting ex mining sites reclamation for reuse by local community as paddy field, plantation and reforestation.

Not all concession area could be mined. Heavily occupied by settlements of area of iron sand deposits such as occurred at most of the mining concession or Kuasa Pertambangan (KP) DU 209 (Figure 8) which located approximately 40 kms east of Cilacap City are causing the area unavailable for mining (www.antam.com).

## CONCLUSIONS

Iron sands in Cilacap coastal zone are derived from denudation of andesite and "Old Andesite Formation" enriched in magnetite and ilmenite minerals. The combination of steep elevated hinterlands – upstream of Cilacap coast of deeply weathered rock and frequent heavy rainfall produces river system that carry substantial quantities of sediment enriched in magnetic minerals down to the coast.

The coastal area of Cilacap was composed of Quarternary deposits of coastal berm, volcanic sediments, old fluviatil, sand berm, Recent coastal sand, Recent fluviatil and estuarine; while the pre-Quarternary sediments were spread at mountainous area in eastern and western.

Coastal characteristics of iron sand deposits in Cilacap are shown by successive sandy beach ridges separated by marshy swales characteristic of prograded coasts and dunes of sand elongated parallel to the shore line with elevation varies from 0 m to 15 m above sea level.

Serayu river delta in Cilacap coastal area is wave-dominated delta due to tidal range less than 2 m and to steep shelf gradient. The incoming wave perpendicular to the main delta axis distribute fluvial sediments in sandy beach ridges parallel to the coast.

The high sediment loads of the Serayu Basin composed mainly of volcanic of Old Andesite Formation (3,500 - 4,500 Sediment yield ton/km$^2$ /year compared to sediment yield 800 -1,200 ton/km2/year of Citarum River) carried downstream causing extensive deposition of iron sand in Cilacap zone.

Beach face slope measurements of Cilacap beaches revealed that steep face (9° up to 17°) occurred in western coastal area related to coarse sand deposits and moderate to gentle slope (3° up to 8°) in eastern area associated to fine sand.

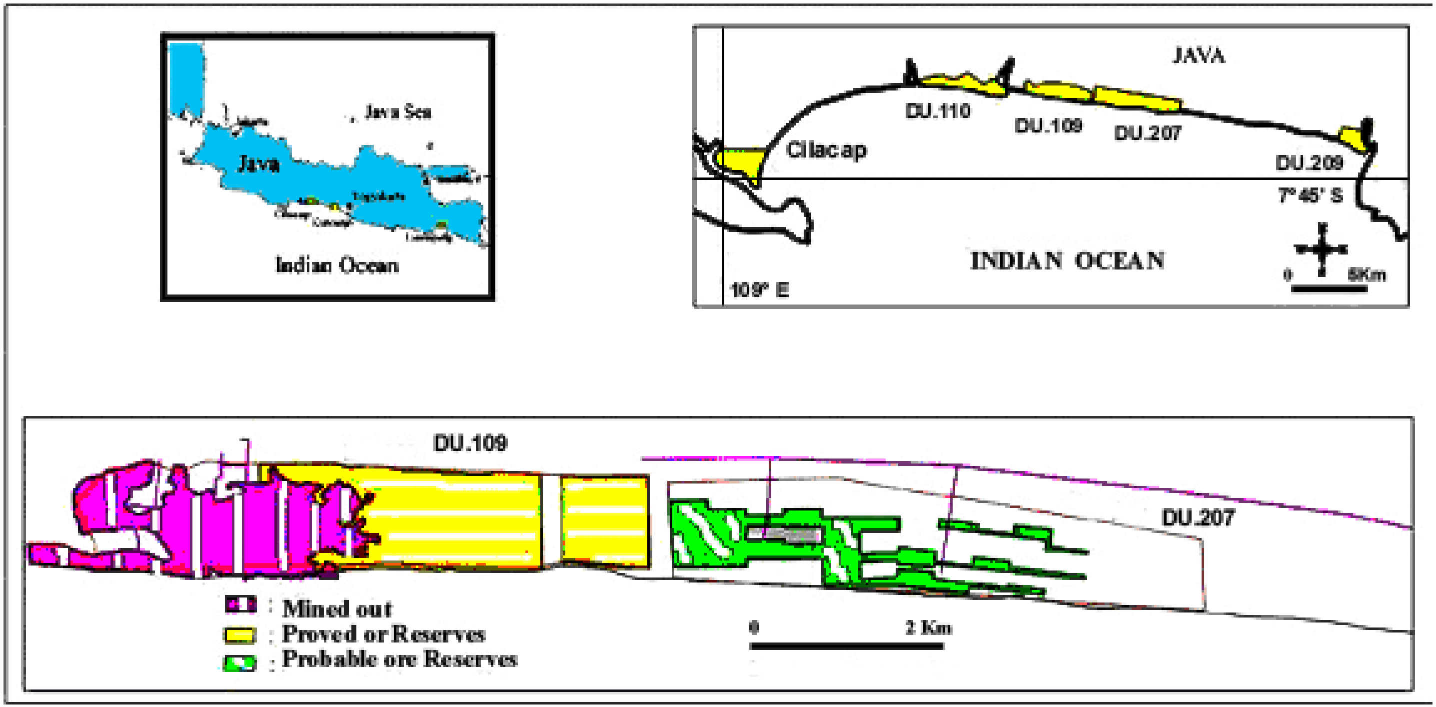


Figure 8 . Area of iron sand concession in Cilacap of PT Antam Tbk (www.antam.com)

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