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Quaternary Geological Phenomena in Labuhan Area, Pandeglang Regency, Banten Province

Fenomena Geologi Kuarter Daerah Labuhan, Kabupaten Pandeglang, Provinsi Banten

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Abstract

Geological features in Labuhan area were studied from the middle of October to the middle of November 2011 covering seventy days. Surface and subsurface data were obtained from interpretation of landsat images and shallow hand-auger boreholes. The geological features are distinctly associated with active tectonics. The stratigraphy clearly indicates at least three phases of tectonic activities since the Late Miocene until Holocene. Tectonics of phase one occurred in the Late Miocene; phase two took place in the period from Pliocene to Late Pleistocene, while tectonics phase three is ongoing in the Holocene. Volcanic activity has intensified since the Early Pleistocene. The landsat images show an irregular outline of the northern coast line. This penomenon is interpreted to be the result of tectonic uplift. On the other hand, the southern coast is linear in plan which is interpreted to correlate with tectonic subsidence. Furthermore, stratigraphic correlation shows that depositional environment changed vertically due to a local subsidence. The northern researched area is occupied by Pleistocene volcanic eruption centres, whilst the younger ones tend to shift southward. This fact tends to indicate that the subduction zone moved southward slowly.

Keywords: Quaternary geological phenomena, tectonics, sea- level, Labuhan

Sari

Studi fenomena geologi Kuarter di daerah Labuhan dilakukan pada pertengahan Oktober - pertengahan November 2011, yaitu selama tujuh puluh hari. Penelitian ini didasarkan pada data geologi permukaan dan bawah permukaan yang diperoleh dari penafsiran citra indraja dan pemboran dangkal dengan menggunakan bor tangan. Fenomena geologinya sangat menarik untuk diteliti karena wilayah ini dipengaruhi oleh aktivitas tektonik. Berdasarkan tataan stratigrafinya selama Miosen Akhir - Holosen terlihat dengan jelas bahwa aktivitas tektonik dapat diidentifikasi menjadi tiga fase. Tektonik fase pertama terjadi pada Miosen Akhir, tektonik fase kedua dimulai dari Pliosen - Plistosen Akhir, dan tektonik fase ketiga pada Holosen. Aktivitas tektonik meningkat secara signifikan sejak Plistosen Awal. Pada citra satelit, konfigurasi pantai di bagian utara jelas memperlihatkan bentuk pantai yang tidak beraturan. Fenomena ini terjadi karena meningkatnya intensitas erosi di daerah ini yang diperkirakan akibat pengaruh proses pengangkatan. Sebaliknya, konfigurasi pantai selatan memperlihatkan bentuk yang lurus dan di sini terjadi proses sedimentasi sebagai indikasi bahwa alas cekungan mengalami penurunan. Selain itu, berdasarkan korelasi tataan stratigrafi terlihat bahwa lingkungan pengendapan berubah secara tegak yang diperkirakan dikontrol oleh tektonik lokal berupa penurunan. Bagian utara daerah penelitian ini ditempati oleh pusat-pusat erupsi gunung api. Kelihatannya gunung api tua berumur Plistosen menempati tempat yang lebih ke arah utara, sementara itu titik erupsi gunung api muda cenderung bergeser ke arah selatan. Fakta ini menunjukkan bahwa barangkali zona subduksi secara perlahan-lahan bergerak ke arah selatan.

Kata kunci: *fenomena geologi Kuarter, tektonik, permukaan laut, Labuhan*

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Introduction

Tectonicaly the studied area is controlled by the Sunda arc system, which is the transition of Sumatra oblique subduction zone**.** Such tectonic condition led to form some interesting geological phenomena to be studied and besides, this area become vulnerable to geological disaster such as earthquake, liquefaction, volcanic eruption, and landslides.

From economic point of view, the development of Sunda Strait Bridge which would be conducted in 2014 and scheduled completely in 2025 will have a major impact on the economic growth in that region.Therefore, the studied area has a potential to grow rapidly, since it is industrial and tourist area. As a consequence, population growth will increase from time to time. Thus, it is necessary to accelerate development progress in the provision of various facilities, such as residences, offices, industries, transportation, and so on.

As we know well, development planning needs to consider the potential of natural resources and its limitation. To anticipate the problems, it needs an understanding of the limitations of capacity and potential of the area. Thus, local government can define concepts and new strategies in a comprehensive sustainable development in order to reduce the impact of the development of the region, in creating livable, safe, and comfortable cities, to have a competitive value for new investments in strategic sectors in the future. But to achieve all of them, there are still many obstacles such as liquefaction and its risks, coastal erosion, and other tectonic effects like subsidence and uplifting, of which its processes are still going on till now.

This study aims to identify the geological phenomena that occur in this region based on surface and subsurface geological information. Based on the data mentioned above, the regional development planning can be done. Thus, the result of development can be avoided from the geological disasters.

Collecting surface geological information was done by interpreting the Landsat ETM +7 RGB 457 images combined with SRTM DEM, while the subsurface geological data collection was conducted by shallow drilling using "hand auger". Drilling was conducted at random, starting from the south to the north in the area of Quaternary sediments. Each drilling was recorded into a log drill (drill section) which has a scale of 1 : 1000. Data include description of rock physical properties (colour, fossil content, organic matter content, clay content, mineral content, grain size, grain shape, structure, density, and other physical properties). Based on its decriptions the sediments were then classified into their sedimentary environment.

Several rock samples were taken for analyzing their absolute age by the carbon dating method (C^{14}). The rock samples contain a lot of organic materials (marsh sediment) which were taken from different stratigraphic positions.

Geographically, the studied area is located at 105° 45'00" - 106° 00 '.00" E and 06° 15'00" - 06° 30'00 S (Figure 1). The area is included in to the geological map of Anyer Sheet, West Java, scale 1 : 100,000 (Santosa, 1991). The northern part of the studied area is included in to Serang Regency, while the southern one into Pandeglang Regency, both in Banten Province.

Geological Setting

Geomorphology

Physiographically this region is part of the western tip of Northern Java Alluvium Plain, Bogor Zone, and the Central Depression/Bandung Zone (Bemmelen, 1949). Furthermore, the morphology of this area can be divided into four units (Figure 2), as follows:

Mountain and Volcanic Cone Unit

This unit occupies the northern part of the studied area characterized by several volcanic cones which have altitude between 600 m and 1040 m above sea level. The highest peak in the studied area is represented by Mount Pulasari (1046 m), Mount Condong (1080 m), Mount Pematangbrangbatu (821 m), Mount Malang (603 m), Mount Sankur (832 m), Mount Sangiangrangrang (616 m), and Mount Parakasak (990 m). The rivers and their channels have a radial pattern, semiparallel, narrow valleys with V-shape, and steep slope. The remnants of the crater or caldera of Mount Pulosari, and Mount Parakasak are still visible to observe.

Slightly Undulating Hilly Unit

This unit occupies the middle part of the studied area, composed of young volcanic rocks resulted

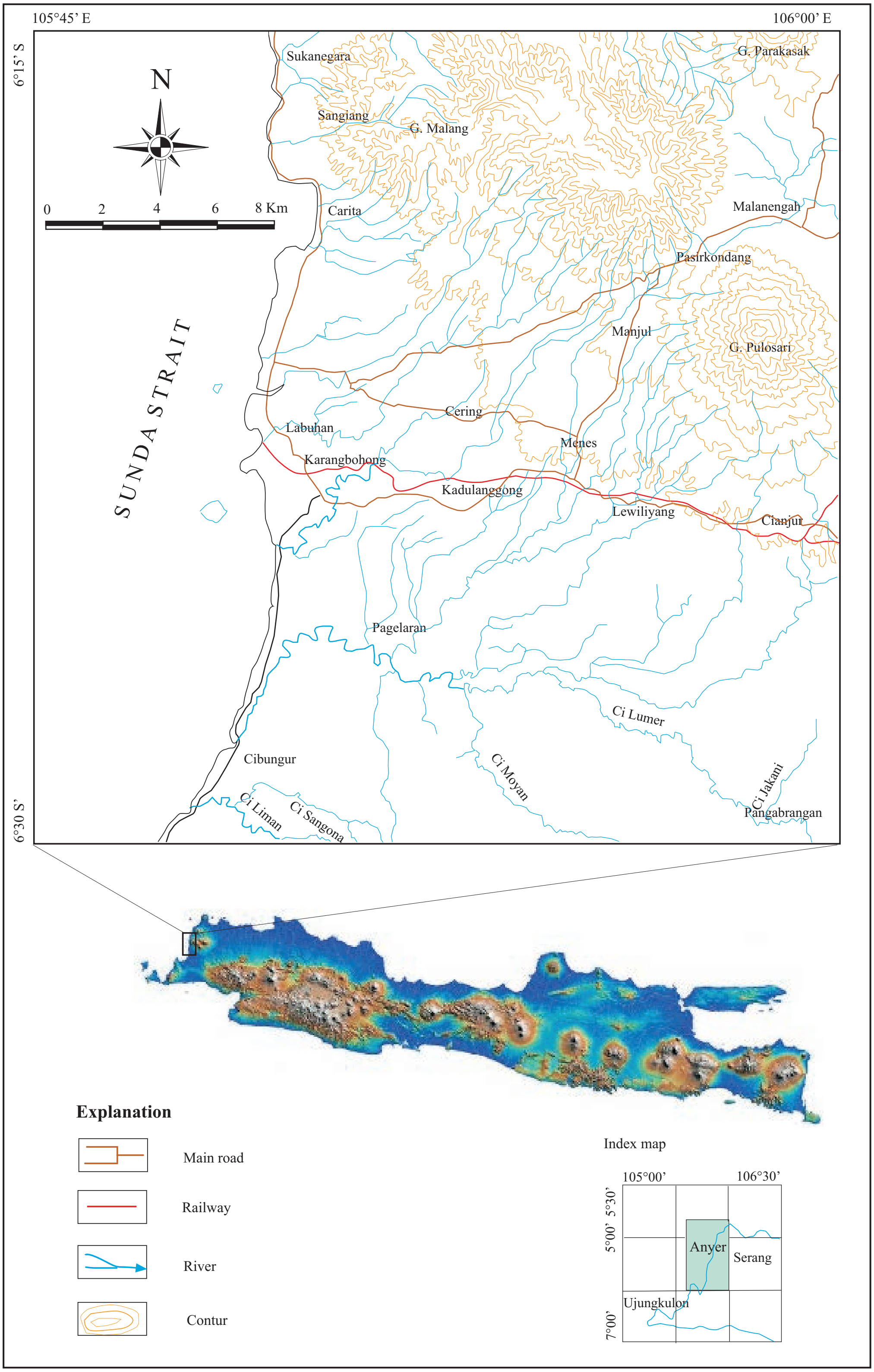

Figure 1. Location map of the study area.

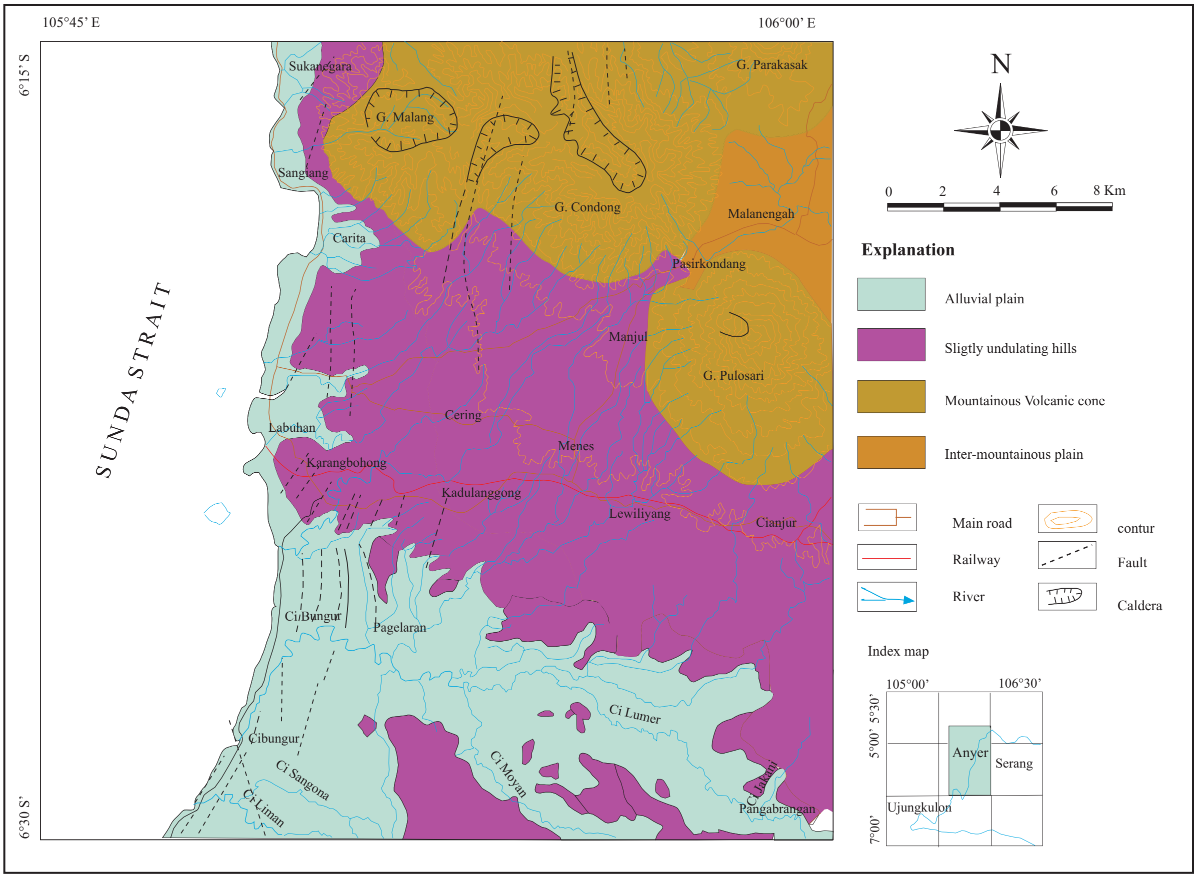

Figure 2. The map showing geomorphological unit of the study area.

from Mount Pulasari (Qhvi) such as volcanic breccia, lava, tuffs, lava flows from the other volcanic eruption of Holocene age. While Upper Banten Tuff (Qtpb) occupies the western part of the studied area. This morphological unit is characterized by series of hills which have elevations between 25 m and 400 m above sea level. The rivers and their channels have a parallel pattern, rather wide valleys with rather steep to almost flat cliffs.

Intermontane Plain Unit

The rocks that make up the intermontane plain unit consist of various types of young volcanic rocks (Qhva, QvBT, Qvk). The Intermontane Plain Unit is situated in the southeast of the studied area which consists of a plain surrounded by Mount Pulasari in the south, Mount Seupan and Mount Leaning in the west, and Mount Parakasak in the north. This intermontane plain unit has elevations between 500 m to 616 m above sea level.

Lowland Unit

Lowland unit is distributed along the west coast and around the downstream of Cilemer (Cibungur) River. Its morphology is formed by a wide plain, and they have elevations between 0 - 25 m above sea level. The main river that flows in this area is Cilemer. The rivers and their cannels have parallel and braided patterns and some of them have a meandering system and periodic to ephimieral characteristics. This morphological unit is made up mainly of alluvium deposits (Qa) which consist of gravel, sand, clay, mud, and pumice granules.

Stratigraphy

The Geological Map of Anyer Sheet, West Java Scale 1 : 100,000. (Figure 3; Santosa, 1991), shows that the studied area is made up of rocks, that from the oldest to the youngest were as follows:

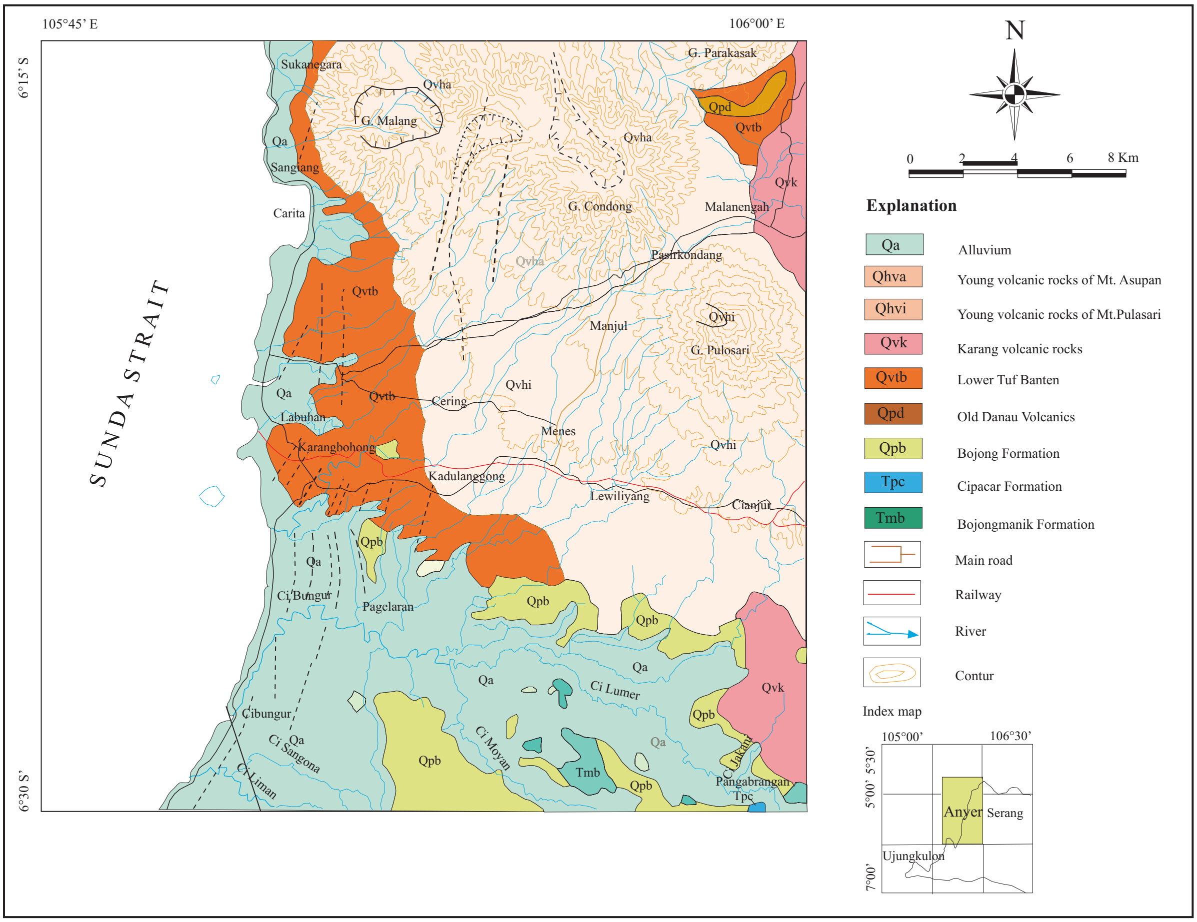

Figure 3. Geological map of Labuhan area, Anyer, Banten Province (Santosa, 1991).

Bojongmanik Formation (Tmb)

This formation is the oldest rock exposed in the studied area. It is composed of intercalation of sandstone and calcareous sandstone with marl, and clay intercalated with lignite and sandy tuff. The formation has a thickness of about 500 m. Depositional environment is suspected to be land to shallow marine. Its foraminifera fossils contained show the age of Late Miocene - Early Pliocene or N16-N19 (Kadar, 1984; *in* Santosa, 1991). This Bojongmanik Formation is then overlain unconformably by alluvium deposits and Bojong Formation (Qpb).

Cipacar Formation (Tpc)

This formation crops out in the southeastern part of the studied area distributed in a very limited area. Generally, it consists of pisolitic pumice tuff, marl, sandstone, and claystone. In general, this unit is well bedded and it has a thickness ranging from 200 - 600 m.

The fossils of *Globigerina bulloides D'ORBIGNY, Pulleniatina obliqueloculata PARKER & JONES, Amphistegina sp., Florilus sp., and Elphidium sp.* show the age of not older than Pliocene. While mollusk fossil of this formation shows Late Pliocene age (Marks, 1956). This unit is unconformably overlain by Bojong Formation and coral limestone.

Bojong Formation (Qpb)

Bojong Formation comprises marl, clay, limestone lenses, sandstone, and tuff. This unit is generally well bedded, having a thickness ranging from 100 - 300 m. This formation contains mollusk fossils showing Pliocene in age. While based on foraminifera fossils, it shows Pleistocene (Rusmana *et al*., 1991). From these data, it is concluded that the formation is of Pleistocene age. This unit is overlain conformably by the Bojongmanik Formation and then overlain unconformably by Quaternary volcanic rocks or alluvium.

Young Volcanic Rocks (Qhv)

The sources of young volcanic rocks in the studied area come from the eruption of Mount Asupan (Qhva), Mount Pulasari (Qhvi), and Mount Tempo (Hpvt). In general, they are composed of volcanic breccias, lavas, tuffs, and lava flows. The young volcanic rocks were deposited on the continental environment of Holocene age, and unconformably overlies the older rock units.

Alluvial and Beach Sediments

Beach and alluvial sediments (Qa) are distributed along the west coast of the studied area, starting from Sukanagara, Carita, Caringin, to Labuhan. The sediments are widespread in the flood plain of major rivers such as Cilemer (Cibungur River), Moyan, and Ciliman Rivers. The lithology consists mainly of gravel, gravelly sand, silt and clay, mud, and gravel pumice beaches locally mixed with pieces of mollusk shells. Gravel pumice has white to gray colour, 5 - 30 cm in size, rounded - subrounded shape with rough surfaces.

Geological Structure

The geological structure in this area is indicated by the presence of lineaments having a north-south direction. Structure identification can well be observed on young volcanic rock of Lower Banten Tuff (Qvbt) consisting of tuff breccia, agglomerate, pumice tuff, lapilli tuffs, and sandy tuff. It seems that the lineaments are continuously up-through into alluvium. It should also be taken into account that the emergence of Tertiary rocks in this area are probably caused by tectonic activities.

Existing Data

To collect surface geologic data, it is necessary to have a high-quality satellite imagery. For that purpose, an image processing was done by a combination of Landsat imagery ETM +7 RGB 457 and DEM - SRTM. The images are expected to provide more detailed information. Such satellite images would provide geological information, such as geological structure, morphogenesis, the configuration of beaches, coastal dikes, the development and evolution of drainage patterns, the growth of young volcanic eruption, and the direction of lahar/lava flow which can destroy the results of development programmes (Figure 4)

Morphology of the studied area based on its origin can be divided into:

- Volcanic Origin
- Marine Origin
- Fluvial Origin
- Fluvio-volcanic Origin

Volcanic origin can be divided into Volcanic cone (V-1), Volcanic foot slope (V-2), Volcanic foot slope strongly denudated (V-3), and Intermontane plain (V-4). Fluvio- volcanic origin is represented by Laharic deposit (VF). Meanwhile, marine origin can be divided into coastal plain (M-1) and beach ridge (M-2). On the other hand, fluvial origin can be divided into oxbow lake, backswamp, palaeo channel, infilled valley bottom, alluvial plain, flood plain, and flood basin.

Moreover, to obtain subsurface geological information/data, shallow drillings were conducted as many as 59 bore holes (Figure 5) with the total depth of 264.19 m and the average depth of 4.47 m. The drilling was carried out in the area occupied by Quaternary sediments, starting from the south to the north. Each point was recorded and plotted into a log drill (drill section) having a scale of 1 : 100.

Data collected from the fifty-nine drilling holes show that the deposition environment can be divided into six different types, namely:

- Soil
- Fluvial deposit
  - flood plain deposit
  - flood basin deposit
  - palaeo-channel deposit
- Swamp deposit
- Near shore deposit
  - beach sand
  - beach ridge
- Marine deposit
- Pre-Holosen

In the field, it is a little bit dificult to describe the distribution of the beach ridges definitely. This is caused by the region being intensively cultivated

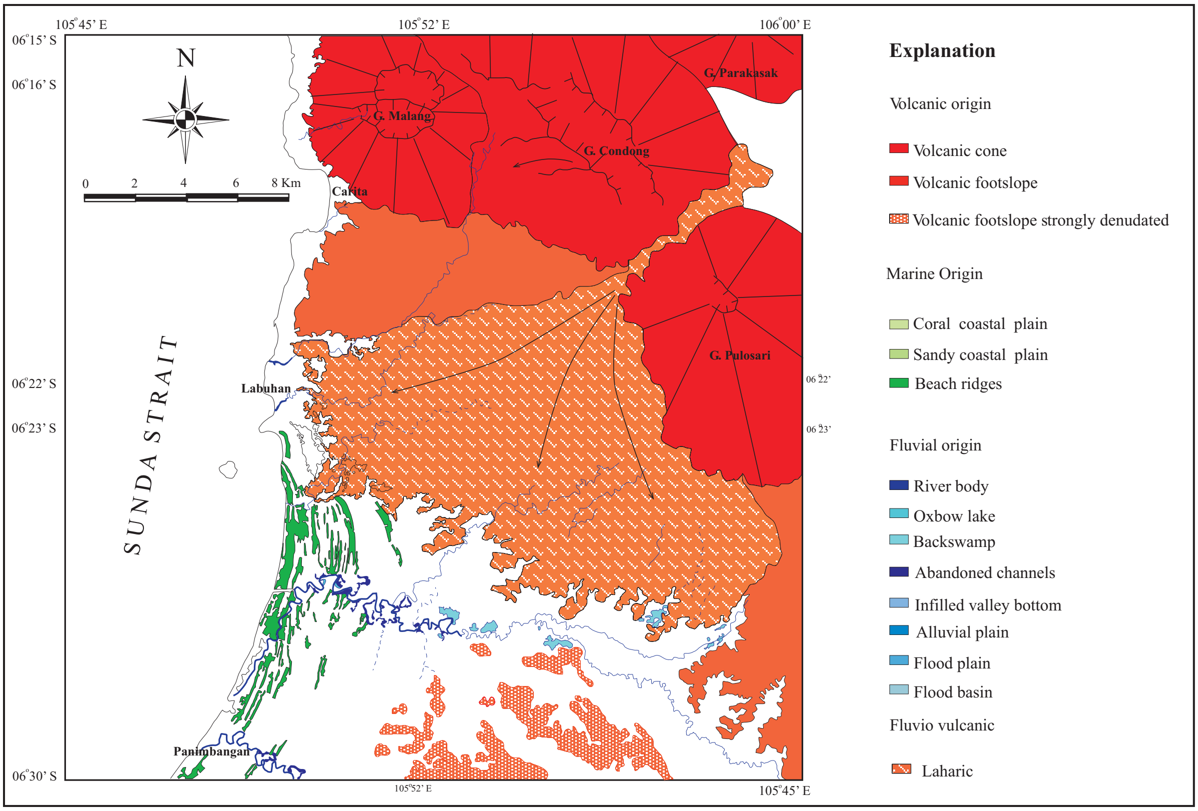

Figure 4. Photogeological map of Labuhan region, Anyer, Banten Province.

as rice fields and used as villages. However, through satellite imagery, the growth and distribution of beach ridges can be described clearly. In order to understand the lithological stratigraphy of the studied area, a section through drilling holes have been corelated. By knowing lithological section both vertically and horizontally, tectonic influences upon deposition environments can be explained.

Geologycal Phenomena

On this part, geological phenomena of Miocene-Pleistocene, as a geological processes in the past and geological phenomena in the Holocene as the geological processes to day will be discussed.

Regional Geological Phenomena (Late Miocene - Pleistocene)

The sedimentation process in the studied area started in Late Miocene (Santosa, 1991) resulted in an intercalation of sandstone, marl, and claystone deposited in a shallow marine to terrestrial environment, known as the Bojongmanik Formation.

The Bojongmanik Formation was then overlain unconformably by the Cipacar Formation which was deposited in a shallow marine-terrestrial environment, and mainly composed of pumice tuffs and tufaceous sandstones. In Early Pleistocene, the Bojong Formation which was deposited in terrestrial to shallow marine environment unconformabbly rest on the Cipacar Formation.

First tectonic phase began in the Miocene-Pliocene indicated by uplifting and folding on the Bojongmanik Formation, accompanied by weak volcanic activity. Then in the Early Pliocene, the area subsided followed by the deposition of Cipacar Formation.

In the Plio-Pleistocene, uplifting and folding took place on the Cipacar Formation (Second tectonic phase). This second tectonic process produced an intensive erosion activity through the Bojongmanik Formation. Furthermore, this area subsided to form a shallow basin filled by the Bojong Forma-

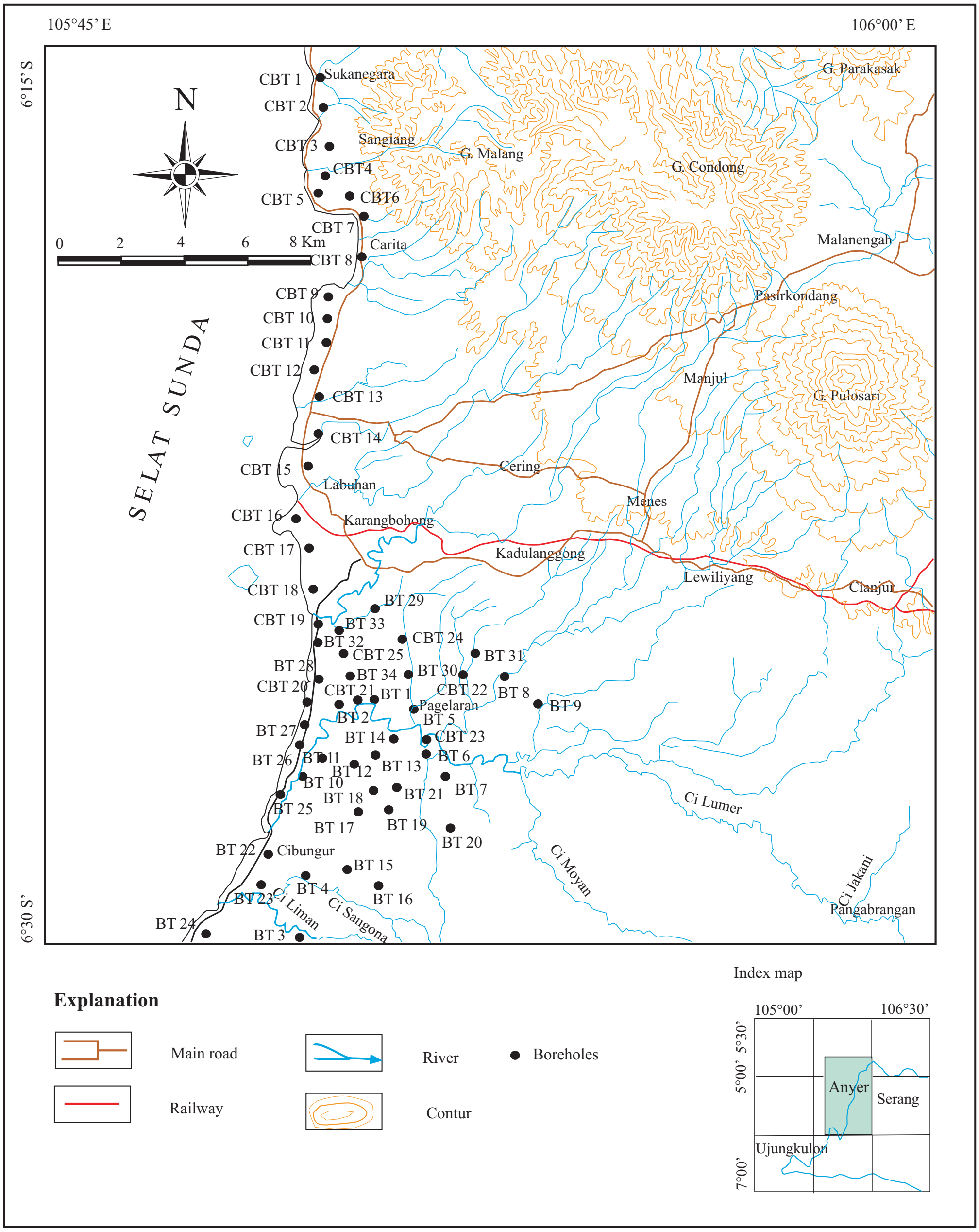

Figure 5. Locality map of boreholes in Labuhan region, Anyer, Banten Province.

tion. In that case, the Bojong Formation overlies both older formations (Bojongmanik and Cipacar Formations). The sedimentation process of Bojong Formation was characterized by a significant volcanic activity. The formation is generally composed of sandy marl, sandy clays, and tuffs deposited in a terrestrial to shallow marine environment. It seems that the regional tectonic activity ended after the deposition of Bojong Formation then continued by the increase of volcanic activity as represented by the presence of volcanic products of Mount Gede (Qpg), Old Danau Volcanic Rocks (Qpd), Lower Banten Tuff (Qptb), Young Volcanic Rocks (Qvd), Upper Banten Tuff (Qvtb), Volcanic Rock of Mount Karang (Qvk), and Young Volcanic Rocks (Qhv). This fact explains that geological processes during the Pleistocene - Holocene were strongly affected by volcanic activity.

The youngest rocks in the area are composed of reef limestone (Ql), Fluvial and Coastal Sediments (Qa), Swamp Lake Sediments (Qr), and Colluvium (Qk) of Holocene in age. The presence of coral limestone (Late Pleistocene) is very important because it can be used as an indication of inundation, especially if the coral limestone contains fossil *Acropora palmata*. Subsidence of the basement is estimated to have occurred during tectonics phase three.

Based on the above explanation, it is known that uplifting and subsidence from the Late Miocene to Holocene occurred as many as three phases which were characterized by unconformable phenomena and recurring terrestrial depositional environment to a shallow marine. Intensive volcanic activities were initiated during and after the Bojong Formation sedimentation up to Holocene.

Holocene Geological Phenomena (local)

In order to understand Holocene geological phenomena, the surface geological and subsurface geological data have been collected. Surface geological information was obtained from the interpretation of satellite imageries and field observation. Meanwhile, for collecting subsurface geological data, shallow drillings have been done by hand auger (hand drill).

Figure 6 shows that in the northern part of the studied area, old volcanoes (Pleistocene) are dominantly distributed, namely Mount Gede (774 m), Mount Tumpang (316 m), Mount Puyung (334 m), and Mount Salak (668 m). While young volcanoes (Holocene) represented by Mount Parakasak (990 m), Mount Condong (1081 m), Mount Pulasari (1046 m), Mount Malang 603 m), and Mount Karang (1778 m) are distributed in the southern part. This condition gives the sense that during Pleistocene - Holocene, the centre of volcanism was shifting from north to south. The fact can be used as preliminary data to indicate a shift of the Java subduction zone to the south. It can also be caused by other factors such as the geological structure. It is believed that in late Pleistocene, some normal faults or blocks occurred having east-west , northwest-southeast, and northeast-southeast directions (Santosa, 1991).

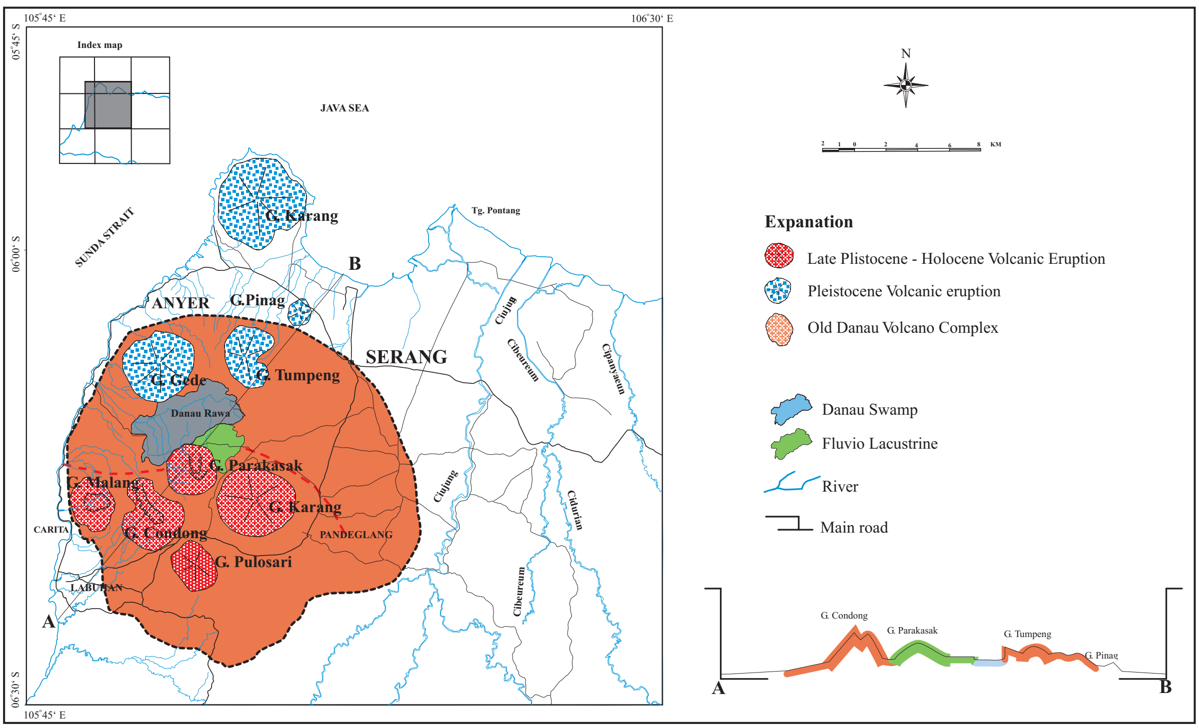

Figure 6. Showing the growth of young volcanic center (Pleistocene - Holocene) are shifted to the south.

To prove the influence of subduction system, it is necessary to study the dynamics of the subduction system itself. Retrograde of the mountains is an indication of the dynamics of subduction movement itself. Olbertz *et al*., (1997) suggest that the geometry of the subduction zone is very sensitive to retrograde even just 1 cm/year. As an impact, the average trough migration increased, and reduced the angle of subduction and the ability to penetrate.

Recently, studies of the structure of subduction zones by seismic tomography models in the Western Pacific Subduction Zone and Subduction Indian Ocean indicate that both regions simultaneously showed that the depth zone of 660 km (seismic discontinuity) has a function as a barrier against penetration of subduction zone (Van der Hilst *et al*., 1991; Fukao *et al*., 1992 in Guillou-Frottier *et al*., 1995). For instance, in the northwest Pacific Arc, penetration and deflection of subduction zone coincided with discontinuity 660 km in depth. In the Java Arc, the subduction passs through discontinuity 660 km with a sharp angle and then curved with a sloping and spread horizontally. This fact shows that a series of mountains on the island of Java has not changed. Perhaps, the scale retreat of the subduction zone is still so small, thus by the tomographic method it still can not be detected yet. While at the field, it was clearly shown that the centre of volcanic eruptions were shifted. Research and dynamic system modeling of subduction-related shift in the trough (trench migration) and slab geometry have been conducted (Billen, 2008; Beccer and Faccenna, 2009).

The other geological phenomena which demonstrate that the northern part of the studied area had been uplifted, was reflected by the presence of volcanic eruption which was concentrated in the northern part of the studied area. The area is assumed to have been uplifted, while the southern part is a subsided area and it formed a shallow basin. The basin is filled up by sediments of corals (Ql), Fluvial and Coastal Sediments (Qa), Swamp Lake Sediments (Qr), and Colluvium (Qk) of Holocene age underlain by shallow marine sediments. Moreover, the fact is also supported by the configuration of the coast and characteristic of the coast shape. The beach formed on the north coast is irregular while in the southern part is straight (Figure 7). The irregular form of the beach is caused by the abrasion process (Figure 8) interpreted to be controlled by currents and waves as well as by the upflifting process of this area.

In general, an irregular beach is filled up by sediments of coral debris, sand to gravel in size, and volcanic materials. Meanwhile, a straight coast developing in areas of subsidence is filled up by fine - coarse sand, well sorted.

In Figure 7, there are seventy-nine lineaments to be classified in studied area (Table 1) based on its azimuth (Table 2). Based on the analysis of lineament patterns, it seems that the main force working in this area has a trend of N 340^o E or N 160^o E. This force can form groups of horizontal and normal faults (Figure 9). The emergence of a volcanic complex in the northern part of the area is predicted through the normal faults that were generated by the tensional force of the southwest - northeast direction.

In order to understand well the stratigraphical succession in this area, correlation of drilling points is needed such as stratigraphical correlation section AB (BT 32, BT 34, BT 30, BT 3), Section CD (CBT 20, BT 02, CBT 21, BT 01, BT 05, and BT 08,) Section EF (BT 26, BT 13, BT 07), and Section GH (BT 23, BT 04, BT 15, and BT 16) (Figure 10). The correlation of those cross-sections is presented in Figure 11. In Figure 11, at the CD section on the drill point BT 02 (S 06º 25'48 .3 "; E 105º 49'43 .1") it can be seen that the pre-Holocene sediments as the base are covered by marsh sediments. It has an age of 9423 ± 513 y. BC (calendric age calibration), with the number of Geolab Identification 14C - 625. The marsh sediment consists of clay deposits, dark gray-black in colour, containing many plant remains in the form of roots, leaves, branches of plants, and often emits foul odour. The sediments have a thickness of 1.20 m and a depth ranging from 6.00 m to 7.20 m below the surface. Marsh sediments then are covered by near shore marine sediments that are dominated by dark gray to a bluish clay containing numerous shells of mollusk, while the pre-Holocene sediments consist of weathered volcanic materials. Such stratigraphic settings indicate a sea-level rise. The end of rising sea levels is characterized by the formation of sand beach ridges consisting of fine -coarse sand, reddish yellow in colour, and gradually grayish downward. In the drill point BT 08 (S 06º

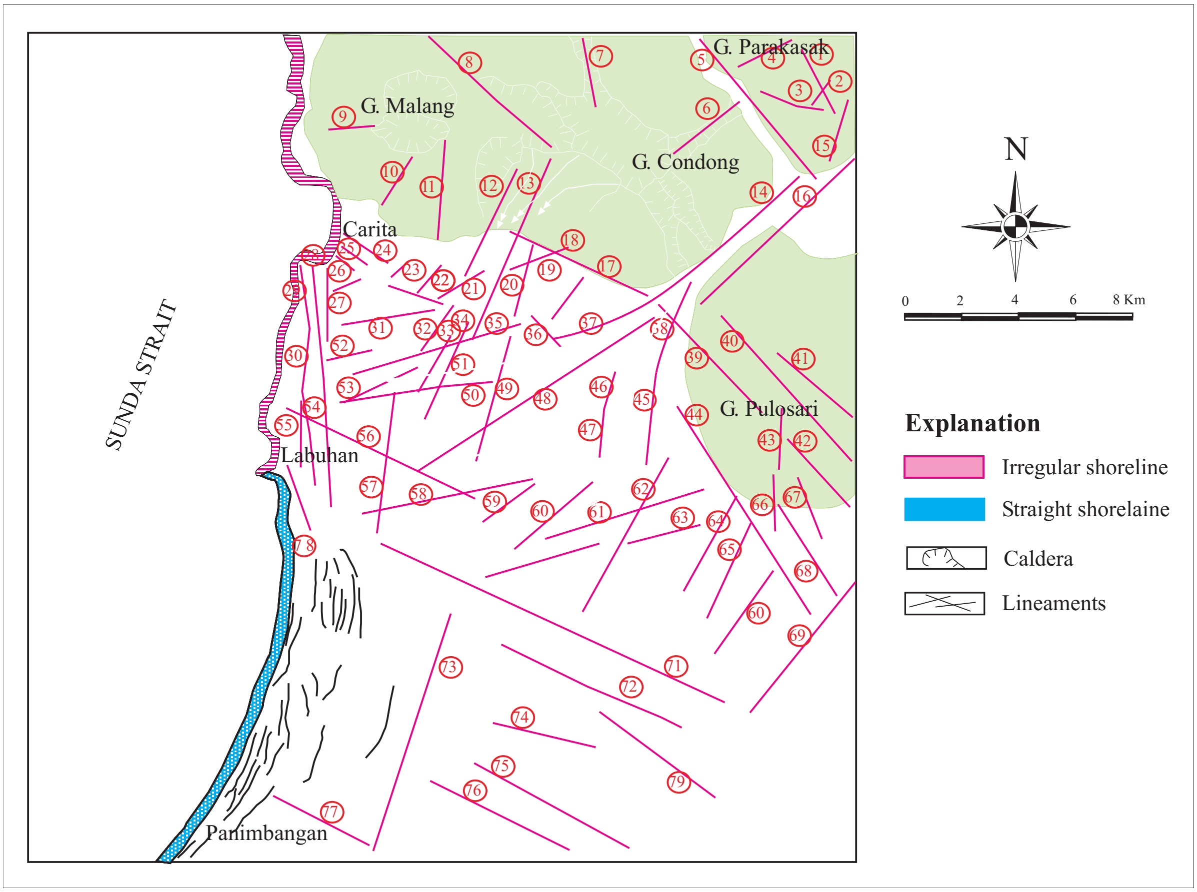

Figure 7. Satelite image interpretation showing beach configuration, and lineaments pattern.

Figure 8. The appearance of abrasion intensity shown by the erosion of the coconut trees that grow on the beach.

25'55 .7 "and E 105º 52'19 .2") of the same section (CD), it can be recognized that the formation of sand beach ridges as well as the marsh sediments have an age of 4571 ± 137 y. BC. (calendric age calibration) with laboratory identification number of Geolab - 14C - 626. The sediments are found at depths between 1.80 - 3.10 m below the surface. While at BT 01 (S 06º 25'46 .9 "and E 105º 50 '25.8") swamp

Table 1. Azimuth of Morphological Lineament in the Studied Area

No	Azimuth (N°E)	No	Azimuth (N°E)	No	Azimuth (N°E)
1	153 - 333	21	42 - 222	61	73 - 253
2	37 - 217	22	49 - 229	62	30 - 210
3	113 - 293	23	125 - 305	63	76 - 256
4	63 - 243	24	124 - 304	64	28 - 208
5	140 - 320	25	126 - 306	65	24 - 204
6	52 - 172	26	130 - 310	66	79 - 359
7	170 - 350	27	0 - 180	67	160 - 340
8	133 - 313	28	175 - 345	68	148 - 328
9	87 - 267	29	171 - 351	69	39 - 219
10	32 - 212	30	6 - 186	70	36 - 216
11	4 - 184	31	81 - 261	71	114 - 294
12	21 - 201	32	35 - 251	72	115 - 295
13	24 - 204	33	30 - 210	73	18 - 198
14	50 - 230	34	24 - 204	74	104 - 284
15	16 - 196	35	73 - 253	75	119 - 299
16	46 - 226	36	137 - 317	76	116 - 286
17	115 - 180	37	70 - 250	77	118 - 298
18	69 - 249	38	23 - 203	78	160 - 340
19	13 - 213	39	136 - 316	79	127 - 307
20	60 - 240	40	138 - 318		

Table 2. Lineament Classification Based on Azimuth Alignment

Azimuth Group		Frequency	Length (km)	Length (%)
0º - 10º	181º - 190º	9	20.6	7.24
11º - 20º	191º - 200º	5	17.3	6.08
21º - 30º	201º - 210º	9	34.9	12.28
31º - 40º	211º - 220º	6	16.3	5.73
41º - 50º	221º - 230º	5	14.5	5.10
51º - 60º	231º - 240º	3	15.9	5.59
61º - 70º	241º - 250º	5	15.7	5.52
71º - 80º	251º - 260º	6	22.3	7.84
81º - 90º	261º - 270º	2	4.5	1.58
91º - 100º	271º - 280º	-	-	-
101º - 110º	281º - 290º	1	3.5	1.23
111º - 120º	291º - 300º	8	47.6	16.75
121º - 130º	301º - 310º	5	8.9	3.13
131º - 140º	311º - 320º	7	28.5	10.02
141º - 150º	321º - 330º	2	11.5	4.04
151º - 160º	331º - 340º	3	6.9	2.42
161º - 170º	341º - 350º	1	2.3	0.008
171º - 180º	351º - 360º	3	13.15	4.62
Total length			284.15	100
Total frequence		79	-	-

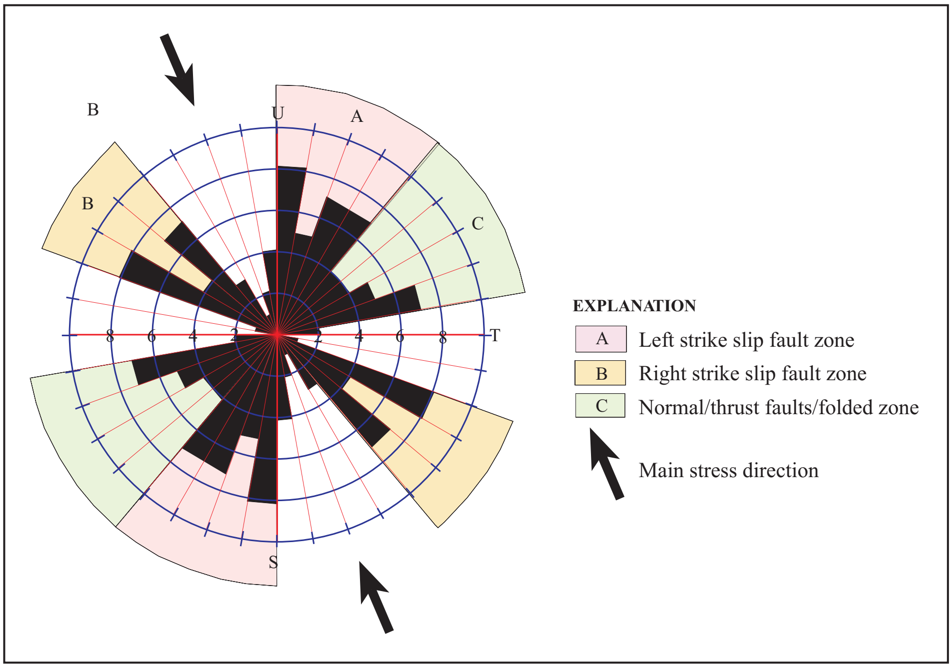

Figure 9. Rose diagram of lineaments in the studied area.

sediments are younger (2546 ± 237 y. BC.) (calendric age calibration) with laboratory identification number of Geolab - 14C - 627.

The sediments are found at depths of 1.20 - 1.60 m below the surface. Based on these data, it can be stated that the Holocene sediments had gradually been covered by marine sediments since 9423 ± 513 y. BC up to the age of 2546 ± 237 y. BC. This indication suggests that the sea level is likely to increase till present.

Other data that can be used as a basis to strengthen the argument is paleo channel sediments which were distributed in a very restricted area. In the subsided region, the river sediments tend to be stagnant, while in horizontally tectonic area then usually the river sediments were shifting. Evolution of the river systems is shown by the formation of several environments such as oxbow lake, backswamp, palaeo-channel, infilled valley bottom, alluvial plains, and flood basin.

Study and discussion about the phenomena of sea-level rise (eustatic) in recent years has been widely applied. Douglas (1995) conducted a comprehensive study concerning determination of global sea-level-change, the impact, and climate change related to climate. He designed the concept and models of studying sea level change in the future. Barnett (1990) discussed the changes in sea level at the present time, meanwhile Fairbridge and Krebsjr., (1962) tried to make an estimate of relative sea-level changes globally since the year 1860 to 1960. They found a rise in sea level was about 1.2 mm/year. Meanwhile Etkin and Epstein (1982) found the rate of sea level change was 3 mm/year, the same as Emery (1980). These differences can be understood, because changes in sea level can also be influenced by tectonics, climate, tides (tidal), and the temperature of the sea water (oceanic fluctuation) (Schofield; 1962, Morner, 1971; Kidson, 2003;). Therefore, the study of sea-level change is related to multidiscipline science, such as oceanography, geophysics, meteorology, geology, geodesy, geomorphology, and others.

One of the causes of sea level rise is the effect of global warming. Global warming is the increase of the average temperature of the atmosphere, ocean, and land. One of the main causes is a human activity burning fossil fuels such as coal, petroleum, and natural gas (antrophogenic).

When the earth surface temperature rises due to the greenhouse gas effect, the surface layer of the oceans is also warmed up, so its volume will be larger

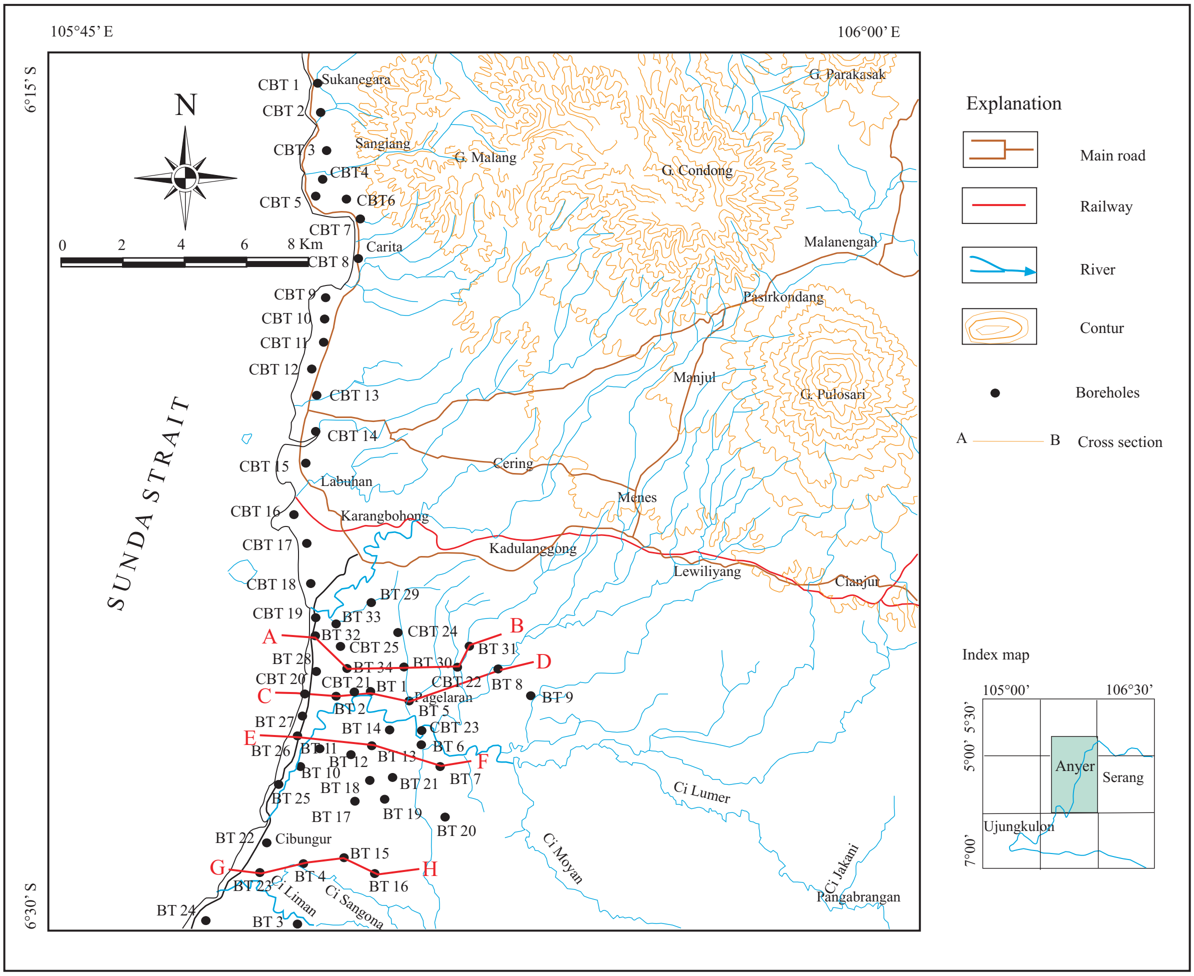

Figure 10. Showing a cross section of A-B, C-D, E-F, and G-H of Labuhan, Banten area.

and consequently the sea level rises. Global warming will also cause a lot of ice sheet at the poles, to melt especially around Greenland affecting the change of volume of the sea. Sea levels worldwide rose about 10 - 25 cm (4 -10 inches) high during the 20th century and Intergovermental Panel on Climate Change (IPCC) scientists predict a further rise of about 9 - 88 cm (4 - 35 inches) in the 21 century (Hegerl, 2007).

Sea level rise is particularly sensitive to coastal areas. This is caused by the topography/elevation of coastal plain being generally very low. The rise of sea level will certainly lead to changes in the coastal plain (coastal changes). Sea-level rise may result in inundation plains (low-lying areas), erosion of the shore (shore-line) swamps (wetlands) become stagnant water (open water), an increase in salt level to an estuary and aquifer. This condition will damage the environment and species (Nicholls and Leatherman, 1994). On the coastal plain of such environment, swamp mangroves and beach sand will be formed.

Another impact caused by sea level rise is very broad (Bird, 1993; Warrick *et al*., 1993), relating to changes in land use along the coast. It should be necessary to relocate infrastructure (roads, railways), public infrastructure such as schools, hospitals, settlements, rice fields, fish farms, salt hotel, and other industrial centre. To reduce losses caused by sea level rise, it is recommended to create regional distribution maps showing inundation of sea water to anticipate the threat of disasters. In the California coastal plain of United States (Heberger *et al*., 2009), integrated studies involving hazards due to rising sea level have been done, and are expected to be implemented in Indonesia.

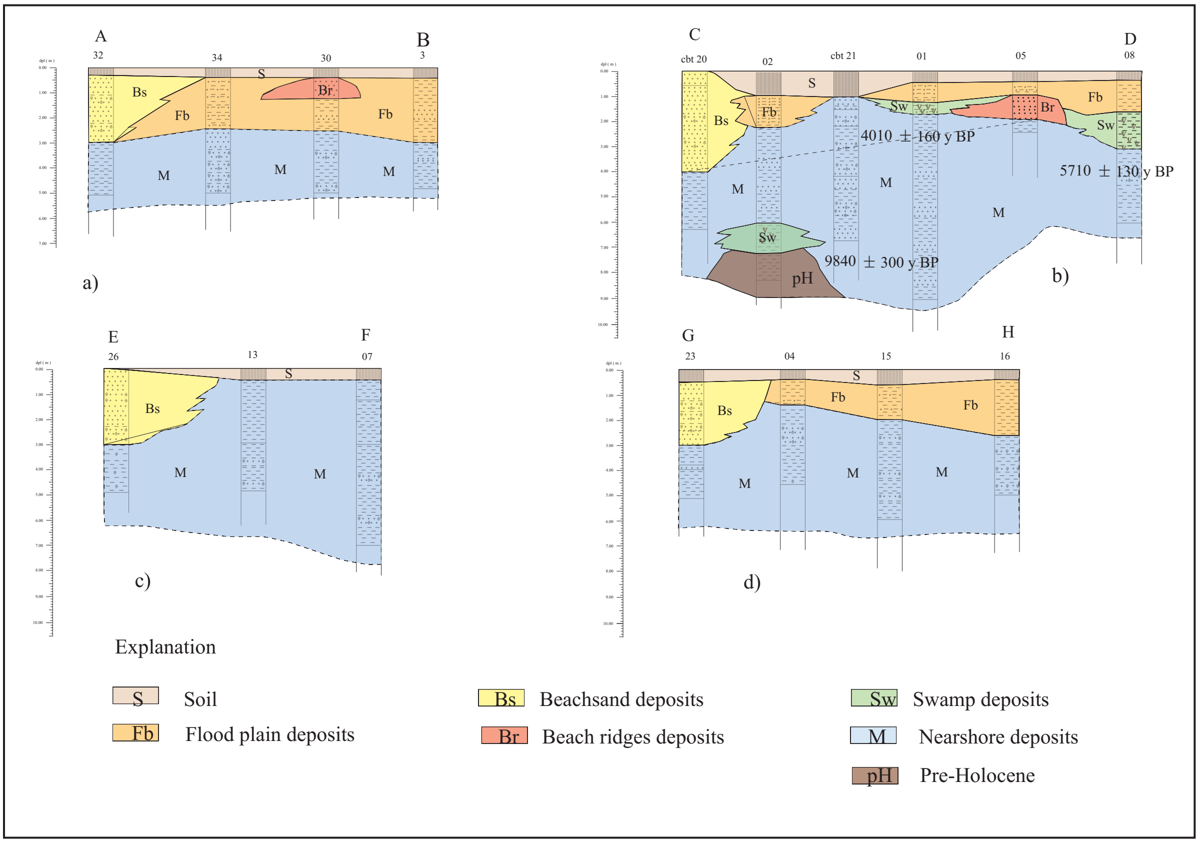

Figure 11. Correlation of borehole section A-B, C-D, E-F, and G-H.

Conclusions

Geological phenomena recorded since the Late Miocene to Holocene in the studied area indicate that there is an influence of tectonic activity reflected on stratigraphic and structural settings. It is known, at least there have been three phases of tectonic upflifting and subduction since the Late Miocene to the Holocene. The first phase began in the Miocene-Pliocene where upfliting and folding on the Bojongmanik Formation occurred. Then in the Plio-Pleistocene, the upfliting and folding processes on the Cipacar Formation (second phase) were accompanied by volcanic activities.

In the Early Pleistocene, this area subsided to form a shallow basin filled with the Bojong Formation. Meanwhile, volcanic activity increased which was focused on Mount Gede and Old Mount Danau. Volcanic activity occurred in the Middle Pleistocene resulted in Lower Banten Tuff, and generated Old Caldera Lake covering an area of 200 km^2. Old Mount Danau eruption (Middle - Late Pleistocene) producing Upper Banten Tuff and young volcanic rocks formed a new caldera adjacent to the northwest of the old caldera with an area of approximately 90 km^2. Furthermore, it is predicted several faults and fault blocks occurred in the east-west, northwest-southeast, and northeast-southwest directions.

Tectonic third phase occurred at the end of the Pleistocene, characterized by the presence of coral limestone overlying younger volcanic rocks.

The sea level rise phenomena in the Holocene is predicted to be caused by the influence of isostatic movement on the basin floor which was caused by upfliting in the north, as a consequence of the south basin floor subsidence. As the result, the configuration on the north coast is irregular due to the increased intensity of erosion processes, while the southern coastal plains are straight and sedimentation proceses are still going on.

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