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COASTAL ACCRETION IN WESTERN INDONESIA

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ABSTRACT

Coastal accretion has been found to be important for Sumatra's East coast and Java's North coast, respectively amounting to 60-500 m/yr and 55 - 214 m/yr near the mouths of large streams. Elsewhere on the same coasts the yearly accretion rates are respectively 15 m and less than 30 m. The annual accretion in the vicinity of Padang (Sumatra's West coast) is less than 10 m. In the Landak region of West Kalimantan a rate of 110 m/yr is known. Data are wanting for other coasts of Indonesia but it seems hardly probable that higher accretion rates are present, except presumably for the Mahakam river, East Kalimantan. Comparing accretion rates on Java's North coast from maps surveyed in the period around 1850 till 1946 (aerial photographs), it was found that aggradation rates most commonly have been accelerating since 1920. This rise is undoubtedly due to an increase in denudation rate through vast deforestations by the growing population and the partial clearance of estates during the Pacific War and the ensuing armed revolution It may also indicate an absolute lowering of sea level and/or tectonic uplift of the land. Positively favourable for coastal growth are the following factors : High denudation rate in the drainage basins through scanty vegetation, high relief, heavy rainfall and the presence of easily erodible rock like marl; tectonic uplift; clastic volcanic activity; rhizophora growth in the coastal swamps; low springtides; quiet and shallow sea. In studying the beach ridges of the Tjiasem Bay area (West Java) it was found that the older generation of beach ridges is invariably of larger size and was formed before the turn of the century, while since then only smaller-sized ridges have been developed. The same relations are also valid for other beach ridge series in Java, i.e. the older ones are larger than the younger ridges. The latter were probably formed because of an important climatic change around 1900 - if the age - data inferred from accretion rates in the Tjiasem Bay area are right - and/or a eustatic lowering of sea level.

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INTRODUCTION

Along many coastal stretches bordering the shallow sea of the Sunda Shelf annual accretion rates are known to be extraordinary. Obdeyn (1941) has accounted the geomorphological development of South Sumatra basing on historical evidence. He has found among others that the Djambi river built out its mouth into the sea as far as 7.5 km between 1821–1922, which amounts to an annual accretion of 75 m. The Kuantan river indicates a yearly growth of 360 m (125 km between ± 1600 – 1940). Van Bemmelen (1941) has shown that the average annual growth of the Semarang coast (Central Java) has amounted to 8 m since 1695. However, in this century the annual accretion rate has increased to 12 m. The Bodri river delta has extended 3300 m between 1913 – 1929, or 200 m yearly. In his monumental work on the geology of Indonesia Van Bemmelen (1949) has summarized accretion data known until that date: Near Landak (W. Kalimantan) the annual growth is 110 m; the Tjimanuk river delta near Indramaju (W. Java) 108 m (according to 't Hoen, 1929). The aggradation along Sumatra's East coast averages 125 m each year; along Java's North coast averages reach the 200 m figure. On the other hand local abrasion along Java's North coast is in the order of 10–20 m/yr.

Verstappen (1953) studied the Djakarta Bay area and has corroborated by Secchi-disc measurements that sedimentation predominantly occurs in the surroundings of river mouths. The maximum coastal extension between 1873 – 1938 reaches 3000 m for the Tjitarum river outlet. Abrasion along the eastern margin of Djakarta Bay engulfed a strip of land 145 m wide during the same period, which amounts to more than 2 m/yr. In 1964 Verstappen published examples of coastal changes in Indonesia, which he has explained as having been influenced by interplay of stream, shore-line, tectonic, and human activities. This author has stressed that coastal growth should be preferably expressed in terms of volume, or at least as areal changes rather than as linear extensions. The last type of measurements is rarely representative, for the bulk of the sediments may be carried by different distributaries during different periods.

Hollerwöger (1964) has again demonstrated that the accretion rates of deltas along Java's North coast are higher than those representing the earlier years of this century. However, the growth rates were shown as linear measures; therefore, the actual increase in annual accretion, though real, is not as high as presented in the paper. The author has ascribed the increase to expanding deforestation and maltreatment of estates during the Pacific war.

The present paper focusses on western Indonesia and accumulates the available data and new measurements on coastal accretion. It also describes the factors influencing shore-line changes. This study was made possible by a 1964 research grant from the former Ministry of National Research through the National Institute of Geology and

Mining. The authors gratefully acknowledge the cooperation of Prof. Dr. J. A. Katili, Director of the N. I. G. M., in obtaining the grant. Drs. M. M. Purbo-Hadiwidjojo, Geological Survey, has been invaluable in directing our attention to many publications related to the subject.

FACTORS INFLUENCING COASTAL ACCRETION

A great number of factors bears upon the development of shorelines, like size of stream, size of drainage area, silt-volume transported, longshore currents, tidal range, storms, coastal topography and nearshore bottom configuration, salinity, tectonics, coastal and drainage area vegetation, and others. The important factors will be discussed below.

a. Rate of denudation, tectonics, and volcanic activity.

Rutten (1917, 1925, 1927, 1932, 1938) demonstrated that the rate of denudation is extremely high in Indonesia. On account of the humid tropical climate and the soil consistency, drainage densities are higher than in comparable rocks in other climatic regions. This is borne out by the observations that the smallest streams have already attained an advanced erosional stage and that remnants of erosion surfaces are much narrower than e.g. in Europe. Furthermore, the relief experiences continuous change, of which elevated subrecent coral reefs at heights of several tens of meters bear witness. Uplift adds in increasing the denudation rate, while subsidence acts in the opposite sense.

The Digul river (W. Irian) does not appreciably indicate coastal growth in the period 1903 – 1945, while "Frederik Hendrik" island situated only a score of kilometers farther south of said river, shows a remarkable increase of land area. This growth is not caused by sediments from the Digul river, but is due to warping of the structural Merauke Ridge which bears the island (Verstappen, 1964).

Volcanic activity also increases denudation through the addition of relief and the production of loose pyroclastics, lahar, and ash. The distribution of volcanic material may be extensive; the 1815 Tambora eruption produced approximately 100,000 km^3 pyroclastic material and blanketed its surroundings with a 120 cm thick ash layer, while at Java's eastern tip the ash still attains a thickness of 25 cm (Petroschevsky, 1949).

Comparison of denudation rates of certain areas in Europe, North America, and Indonesia led Rutten (1925) to the general conclusion that orogenetic regions possess denudation rates in the order of 0.06 – 5 mm/yr and epirogenetic areas less than 0.06 mm/yr, but commonly 0.025 mm/yr. A denudation rate of 3 – 5 mm/yr already explains why in Indonesia 2000 – 5000 m high, young Tertiary mountain ranges are level at present. Denudation of the land surface is known to occur after heavy rainfall and almost the entire annual denudation may be accomplished within as little as 10 days during the wet monsoon, like in the watershed of the Djragung river, C. Java (Rutten, 1932, 1938). During floods a 10 kilograms silt content in each cubic meter of water is not uncommon. The Tjitarum, Bengawan Solo, and Seraju rivers together transport more than 100,000 tons of silt during one flood, which is equivalent to 10,000 wagon loads, apart from the bed load material.

b. Rhizophora.

Rhizophora are regarded as favorable to land growth, their roots acting as sediment traps.

c. Eustatism.

Since Daly (1920) observed that the 20 ft terrace (slightly over 6 m) is most extensively distributed and Van Tuyn (1932a) proved the Recent sea level drops for Sumatra, North Java, and West Kalimantan to amount to 5 – 10 m (basing on raised subrecent coral reefs and beach ridges far inland), subsequent investigators have proven Recent eustatic subsidence to exist beyond doubt for many parts of the globe. R. W. Fairbridge (personal communication) accepts three successive eustatic drops of sea level, resulting in terraces at 3 –5, 1 – 2, and 0.5 m heights. Eustatic subsidence directly influences land growth and indirectly rejuvenates the erosion cycle bringing more detritus to the sea. Age data on the first retreat of the sea due to Recent eustatism have not yet been agreed upon. An example is given by Verstappen (1964), who has estimated that the plain of Bireuen (Atjeh, N. Sumatra) was formed 2500 yrs ago by comparing the old and new deltas of the Peusangan river and accepting that the first retreat of the sea occurred 5000 B. P. Obdeyn (1941) found that the S. Sumatran coastal plain is probably 2000 yrs old, judging from its width and the average annual growth of 75 m.

d. Tides and sea currents.

Weeda (1947) found certain relations between the heights of springtides and shapes of the shoreline. North of the Aru Bay (Sumatra's east coast) there are deltas but no estuaries; between this bay and Nangka island (Bangka Straits) large estuaries are typical, while more to the south estuaries are again absent. From Weeda's paper and additional data from the Tide Tables (Hydrographical Survey, Indonesian Navy, 1963) it was found that for Sumatra's east coast estuaries develop if the daily and semi-daily tides are respectively over 20 cm and 40 cm. For Java's north coast estuaries start to form at daily and semi-daily tides of 38 cm and 13 cm, i.e. in the Madura Straits near Surabaja (E. Java). In W. Kalimantan wide river outlets are formed if the daily and semi-daily tides are 31 cm and 25 cm; in S. Kalimantan if the figures are 26 cm and 12 cm or more, while in E. Kalimantan the tides should be equal or more than 26 cm and 86 cm.

The influence of sea currents is convincingly demonstrated by the river mouths and deltas along Java's north coast. There the east wind acts longer (8 months) and occasionally is much stronger than the west wind. Most sediments are transported during the rainy season (west wind).

These factors work together and result in deflecting the river mouths westward, while beach ridges are formed east of the stream outlets. The same conditions also explain the regular, slightly convex eastern outlines of most deltas and quite irregular shorelines along their west sides. Abrasion is locally apparent along the coasts studied and is in the order of 10 – 20 m annually. Its activity is most apparent along delta portions which became deserted by the distributaries, e.g. at the natural outlet of the Tjidurian river (W. Java) and the Djuli river (Atjeh, N. Sumatra).

e. Changes in the watershed.

Natural and artificial changes in the drainage basin may result in drastic changes in the mouth-area. In 1927 several kilometers west of the natural outlet of the Tjidurian river (W. Java) an irrigation canal was constructed. Eighteen years later a delta has been formed in front of the canal extending 2.5 km from the former shoreline (annual growth 139 m), while in the surroundings of the natural mouth abrasion has been active by destroying brackish water fish ponds (Verstappen, 1953).

COASTAL ACCRETION

Shoreline changes in eastern Sumatra and northern Java have been studied from reports, maps and aerial photographs of 1945 – 46. A pantograph was used to compare shorelines shown on maps of different scales and illustrating different times.

A. Sumatra

Table 1 accumulates the known numerical values of coastal accretion for Sumatra. The determination of coastal changes has been based on the following types of evidence.

In the region of Sumatra's East Coast the youthful character of the coastal plain has long been recognized. Witkamp (1920) reported the presence of kitchen middens far from the present shoreline near Bindjai and Serdang, One kitchen midden near Bindjai consists of a 3–4 m high hillock composed of Venus, Arca, and Ostrea shells; it is now located more than 10 km from the sea. Refuse heaps of shells are still common occurrences beneath stilt-houses throughout present Indonesian coastal regions.

Hoekstra (1893, cited by Obdeyn, 1941) found in Deli 8 km from the shoreline black marine clay at a depth of one meter below the surface. He also observed an annual growth of 12.5 m at the coast of Cape Bangsi. The same author even thought that the coastal growth of eastern Sumatra was so rapid that the Riau and Bangka islands will be welded to the main island in not too long a time.

Obdeyn (1941) found coastal accretion data for eastern Sumatra from studying the written history by Chinese, Arab, and European travelers and traders. Anderson (1821) assumed that the shoreline of the Deli

Table 1. Coastal accretion along Sumatra coasts (see also Fig. 2)

Stream/locality	Accretion since	Annual growth	Source
Deli and Asahan	Approx. 45 km (1600-1821).	Approx. 200 m	Anderson in Obdeyn (1941).
Panai and Bila	25 m (2 yrs).	12.5 m	Hoekstra in Obdeyn (1941).
Kuantan	65 km (700-1600) 60 km (1600-1940)	140 m	Figure IV in Obdeyn (1941).
Djambi	Approx. 7.5 km (1821-1922).	Approx. 75 m	Hydrographical maps 1821, 1896-1899, 1900-1901, 1910, 1922.
Tungkal	40 km (700-1600) 20 km (1600-1940)	Approx. 60 m	Figure IV in Obdeyn (1941).
Musi	170 km (1600-1940)	Approx. 500 m	Figure IV in Obdeyn (1941).
Lampung	21 km (in historical time).	15 m	Van Tuyn (1932).
East coast S. Sumatra.	150 km (0-2000).	7.5 m	Obdeyn (1941).
Masangkiri, W. Sumatra.	0.2 km (1883-1935)	3.9 m	Topographic maps in Verbeek 1883 and 1935.
Antokan, W. Sumatra.	0.3 km (1883-1935)	5.8 m	idem.
Gasan Gadang, W. Sumatra.	0.2 km (1883-1935)	3.9 m	idem.
Sirah, W. Sumatra.	0.4 km (1883-1935)	7.7 m	idem.
Manggung, W. Sumatra.	0.5 km (1883-1935)	9.6 m	idem.
Anai, W. Sumatra.	0.15 km (1883-1935)	3 m	idem.
Pandjalinan, W. Sumatra.	0.3 km (1883-1935)	5.8 m	idem.
Arau, W. Sumatra.	0.2 km (1883-1935)	3.9 m	idem.

and Asahan areas was 30 mi more landward in 1600. Beach ridges have been observed far inland : 150 km (Air Melik, Indragiri), 130 km (Pelalawan), 21 km (Komering-hilir, Mesudji, Tulangbawang; Van Tuyn, 1932). The latter occurrence is of historical time, which is indicated by the findings of "batu manik" (ornaments) within those ridges. Valentijn (around 1600, cited by Obdeyn) described the town of Indragiri as being situated close to the sea, while in 1940 the place has to be reached by steamboat by traveling 12 hours (125 km). Figure 1 shows coastal growth in the vicinity of the Djambi river mouth, i.e. 7.5 km in 100 yrs. This would mean that in the last 200 years Sumatra's east coast has widened 150 km. It is interesting to note that the width of the South Sumatra coastal plain is 140 km.

Etymological evidence also indicates the geography of former times. **Lemba** denotes land formed by silting; the word is easily recognized in the place name Palembang. **Lampung** has also a similar meaning, while Sumatra may mean **samudera** or ocean.

Mohnike (in van Bemmelen, 1949, p. 299) reported Palembang (now located 50 km inland) to be a harbour on the coast line 400 years ago; this would indicate an annual growth of 125 m.

Obdeyn (1941) concluded the following on the geographical development of South Sumatra. Until the Middle Ages a vast bay existed in the Palembang-area, a fact which led travellers from different countries to believe that North Sumatra was an island separated from South Sumatra. At that time the Sunda Straits was not yet known, for it was mentioned for the first time in 1554 by the Turkish traveller Sidi Ali Celebi. Suvar-

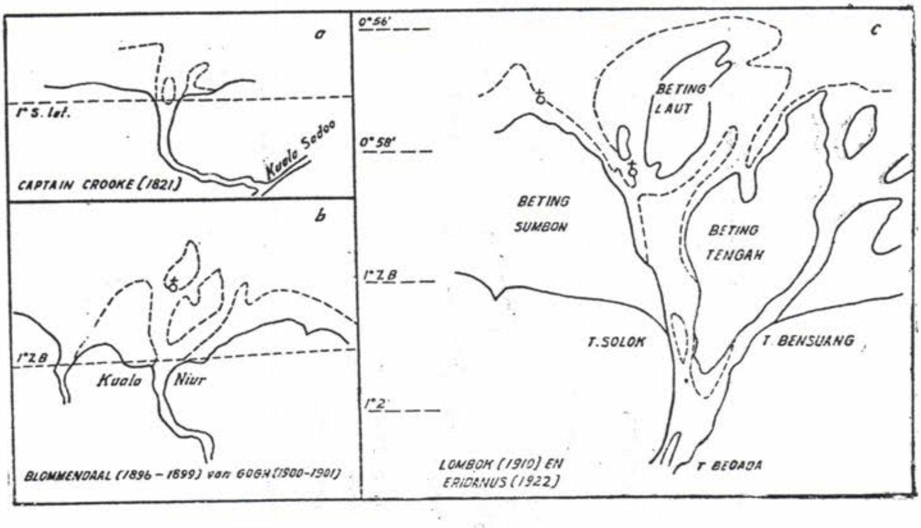

Fig. 1. Coastal growth near the Djambi river mouth, Sumatra (From Obdeyn, 1941, p. 212).

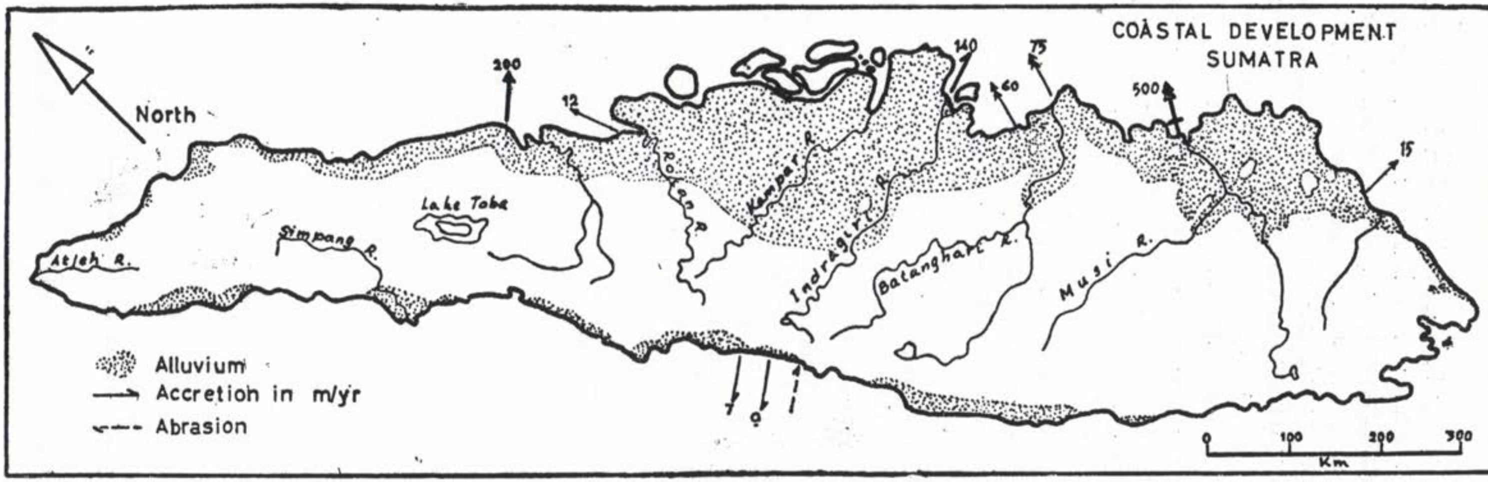

Fig. 2. Coastal development and extent of alluvium in Sumatra.

nadvipa (especially South Sumatra) and Yavadvipa or Djawa (Java) were considered to form one island up to that time. It appears that the Sunda Straits was poorly navigable for sailing ships on account of its strong currents and winds. After the straits became known, South Sumatra was called Java-minor and Java proper became known as Java-major. The shoaling of the Palembang Bay convinced people at last that South and North Sumatra form one island.

Recent active uplift is only proven for several localities in Sumatra, e.g. in Atjeh where stream terraces ranging in heights to 100 m have been observed (Oppenoorth & Zwierzycki, see Van Bemmelen, 1949). On the other hand Hondius van Herwerden (1910) noticed subsidence along the east coasts of the Mentawai island group.

Recent negative eustatism has been investigated by Van Tuyn (1931, 1932) and he found three series of features of rejuvenation at heights of $1-2$ m, $3-6$ m, and 10 m above sea level.

B. Java

a. Rate of denudation, tectonics, and volcanism.

Tectonic and volcanic activity render high denudation rates in Java, which are reflected by the sediment load transported by the streams. The Brantas river, draining an area of 11,000 km^2, carries 1.3 kg silt per cubic meter water; the Solo river carries 2.75 kg/cu. m. According to Mr. Moh. Jahja, civil engineer of the Hydraulics Institute, Ministry of Public Works (personal communication), the Tjimanuk river transported 5.10^6 tons silt in the period July 1963 - July 1964, while during one flood (January 22–23, 1964) an estimate of 371,000 tons of sediment were transported. The large silt content of the Tjimanuk river originates from an important tributary watershed – Tjilutung – where extensive deforestation and cattle-grazing have occurred. Van Dijk & Vogelzang (1948) reported the annual denudation to have increased from 0.98 mm (1911–1912) to 1.97 mm (1934–1935). Annual denudation rates in other watersheds have been published by Rutten (1927, 1932, 1938);

Drainage area	Yearly denudation (mm)
Pengaron (Semarang)	3.7 – 5
Djragung (Semarang)	1.6 – 2.5
Tjilamaja (W. Java)	1.4 – 1.8
Seraju (Tjilatjap)	1.4 – 1.8
Lusi (Semarang)	1.0 – 1.4
Tjimanuk (W. Java)	over 0.4
Banjuputih (E. Java)	0.4
Brantas (Surabaja)	0.3
Tjiliwung (Bogor)	0.1

A denudation of 1 mm was measured in the Pengaron river during only 24 hours. This river and the Djragung, Seraju, and Lusi rivers drain areas of Tertiary rocks, especially clay, marl, and limestone but little volcanic soil (latosol). The Tjilamaja and Tjimanuk rivers flow through predominantly volcanic sediments with occasional outcrops of weak Tertiary sediments. The other streams mentioned above almost entirely flow through volcanic rocks.

Three examples suffice to illustrate young uplift in Java. Between the Ungaran volcanic sediments and the underlying folded Neogene is found an erosion surface, which is now 100–150 m above sea level. Kemmerling (1915) and Mohr (1909) reported stream terraces resting upon Pliocene or younger sediments at altitudes till scores of meters above the present streams in the Pekalongan, Tegal, and Tjirebon areas (West and Central Java). A similar situation was observed along the Tjiasem and other rivers in the Subang area, where gravels and flat surfaces are located till at least 65 m above the streams (Tjia, 1964). Pannekoek (1949) noticed terraces, possibly of Pleistocene age, at 250 m, 125 m, and 50 m above sea level in the Patjitan area of the Southern Mountains.

Subsidence of the land surface is shown by unfolded, black marine clays at 108 m depth in the Brantas river delta (Duyfjes, 1938). Craandijk (1911) found that the Sedulang islands (off the north coast of West Java) subsided. In 1867 one of the island, Pulau Pagak, had its bench mark S. 231 above sea level, while in 1906 the triangulation pillar only emerged at low tide. Two years later it stood 5 m below sea level. Six other islands of the group also showed signs of subsidence, where trees became partially submerged at high tide.

In spite of its subsidence (Duyfjes, 1938; Pannekoek, 1949) the Brantas delta still adds 50–100 m land annually through the huge quantities of its transported sediment. Corroborating evidence of delta growth is shown by the fact that sea going vessels could reach Modjokerto till 1396.

b. Eustatism.

Postglacial drops of sea level are well demonstrated along the coasts of Java. Verbeek & Fennema (1896) reported raised coral reefs of several meters altitudes on Java's south coast; terraces at 3 to 6 m from the north coast. Van Tuyn (1932 a) concluded that during the Postglacial evidence supports a sea level drop of 5–10 m. Umbgrove (1928, 1930) mentioned terraces in the Djakarta Bay area at 2–3 m altitude. Umbgrove & Cosijn (1931) supplied similar observations from Tjilauteureun (south coast). The lowest and youngest series of terraces appears to be 0.5–1 m above sea level. Field experience of the authors in northern West Java indicates that the 5 m and 2–3 m terraces can be traced at similar relative heights till the middle reaches of the larger streams.

These Postglacial sea level drops should be regarded as absolute lowerings of sea level, for the foregoing elevated strand lines are distributed throughout the Indian and Pacific oceans.

c. Tides and sea currents.

Only in the vicinity of Surabaja occur daily and semi-daily tides of such degree as to result in wide river mouths. Elsewhere along Java's north coast large rivers invariably possess cuspate or digitate deltas. The only fan-shaped delta belongs to the Brantas river.

From Table 2 we may conclude that the destructive effect of tides upon the north coast is very small compared to the rate of coastal accretion.

Along the same coast one also observes many stream mouths to have been deflected westward on account of a dominant sea current westward during 8 months of the year.

d. Changes in the drainage area.

Eighteen years after an outlet was dug 4 km west of the natural Tjidurian mouth, a 2,500 m long delta has formed at the artificial mouth, while during the same period more than 100 m of the shoreline has been abraded from the area of the old mouth. (Verstappen, 1953).

A natural course shift occurred in the Tjomal river between surveys in 1870 and in 1920. Earlier the river built its delta at the western outlet, later its load has been deposited at its eastern distributary. At the same time abrasion has carved 1600 m in 26 years from the west side of the delta, amounting to a decrease of more than 60 m annually.

Field studies and aerial photographs show the Tjimanuk river below Kertasemaja to have shifted progressively westward (Tjia, 1965).

Map of coastal growth of Java.

The rates of coastal changes shown on the map of Java have been collected from topographic maps and aerial photographs. The actual measurements are listed in Table 3. Growth rates may attain annual values of over 400 m or 2.52 km^2 as is indicated by the Solo delta between 1882–1896 (Fig. 3). The average accretion rates are listed below.

Table 2. Annual rates of coastal accretion.

West Java	Large deltas 56 – 204 m; 0.62 – 1.26 km^2; small deltas 7 – 117 m.
Central Java	Large deltas 55 – 160 m; 0.13 – 0.42 km^2; small deltas 8 – 30 m.
East Java	Large deltas 136 – 214 m; 0.46 – 2.52 km^2; small deltas 9 – 22 m.

Abrasion along deltaic coasts is conspicuous in the vicinity of abandoned channels, like near the west Bangkaderes outlet which receded 21 m annually in the period 1922–1946. In the environment of the Rambatan mouth – a distributary of the Tjimanuk river – a recession of 300 m/yr occurred in 1940–1946. In general the abrasion rates along Java's north coast vary between 10–20 m each year. Although no figures are available, we may safely assume the abrasion rates along the south coast to be much higher, on account of the more powerful wave action of the Indian Ocean. Outside bay-areas and coastal marshes, coastal accretion of the south coast is not apparent. The wide zone of beach ridges in th Bagelen area, C. Java probably also indicates the influence of Postglacial sea level lowerings.

Abrasion on the east coast is demonstrated by the disappearance of bench mark Q.03, which in 1925 was at 2 m above sea level while the 1941 topographic map reported it missing.

On the north and south coasts, and also to a lesser degree on the west coast, beach ridges are distinct phenomena. These ridges vary in heights from a score of centimeters to approximately 20 m like in the Parangtritis dunes of Central. Java. The largest ridges are occupied by settlements, while the swales between the ridges serve as paddy fields or fish ponds. On the north coast the maximum distance onshore amounts to 12 km for beachridges in the Tjitarum delta near Rengasdengklok. The farther inland, and presumably older, beachridges are located, the bigger they are in size. One may explain the evidence as representing stronger wave action in older times and decreasing wave energies through gradual climatic changes more recently. An elaboration of this assumption is given in the text dealing with the coastal development of the Tjiasem Bay area.

The map under discussion also shows the extent of the alluvium in Java which is derived from geological maps by the Mining Survey issued between 1915 and 1929. Near the Tjimanuk mouth the widest alluvial belt is recorded to be 42 km. Here the alluvium probably started 2000–2500 years ago, if we assume the growth rate to be similar as that averaged in Table II. A sea level lowering may have assisted the development of the coastal alluvium.

Discussion of Figs. 3, 4, and 5.

Several conclusions are apparent from the graphs depicted by Figs. 3, 4, and 5.

Fig. 3 indicates the frowth of the Solo delta since 1882 (since 1885 the Solo river mouth has been deflected northward). In Fig. 4 is shown the areal increase for 9 deltas on the north coast. Annual coastal growth rates of 12 rivers debouching into the Java Sea are shown on Fig. 5. The three diagrams indicate that since about 1910 the rate of coastal accretion has increased significantly less some exceptions. Several factors may account for the increased growth.

1. Large scale deforestation on account of the population boom, the Japanese occupation, and the armed revolution resulting in higer erosion rates.
2. Lowering of sea level in the beginning of the 20th century.
3. Warping or uplift of the land surface.

The authors regard factors 1 and 2 as very probable, while the third cause lacks evidence.

Increased erosion rates have been demonstrated by Van Dijk & Vogelzang (1948) for the Tjilutung watershed. Lowering of sea level is apparently indicated by the evidence that beachridges of 1900 or younger are smaller than the older ones (see discussion on Tjiasem Bay). It appears that since 1900 sea level lowering occurs at a faster pace and therefore preventing the formation of larger ridges, and/or waves have decreased in size through climatic change.

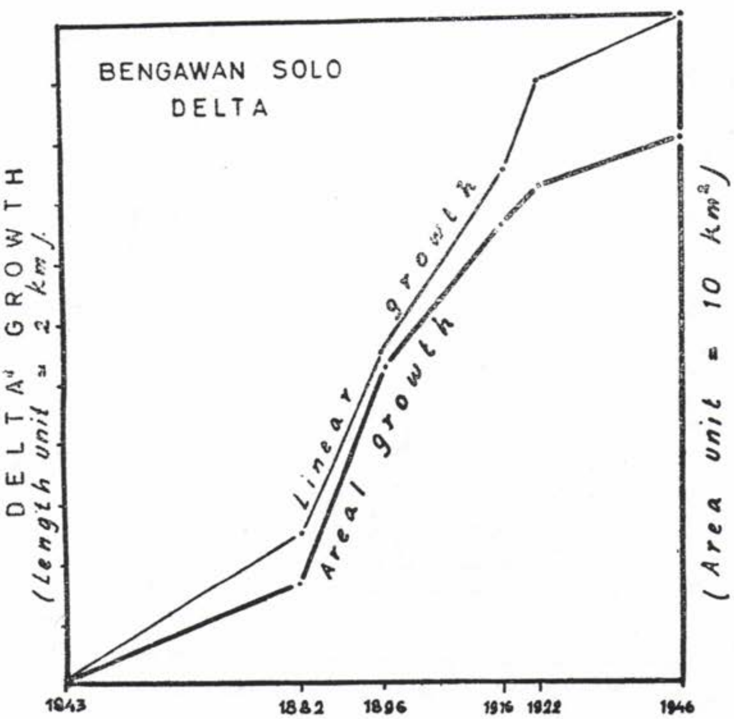

Fig. 3. Linear and areal growth of Bengawan Solo delta. Explanation in text.

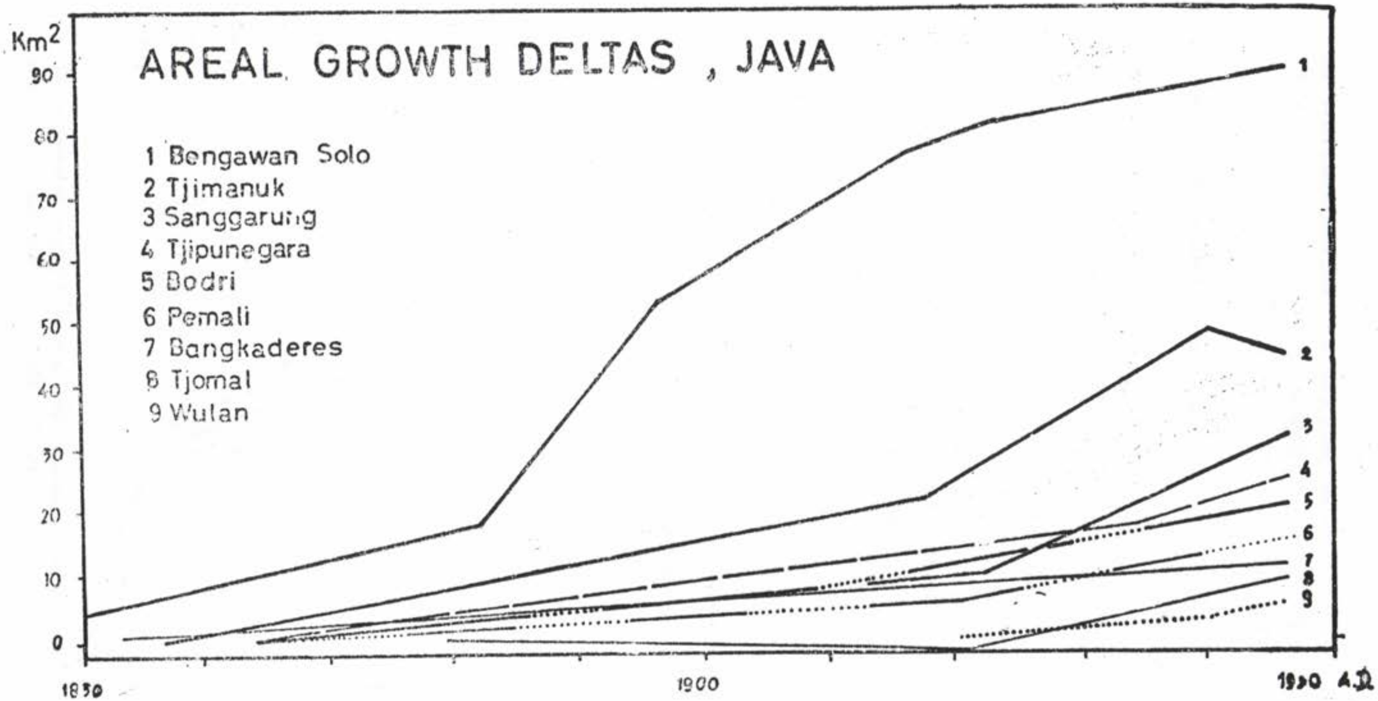

Fig. 4. Areal development of nine deltas on Java's north coast. Explanation in text.

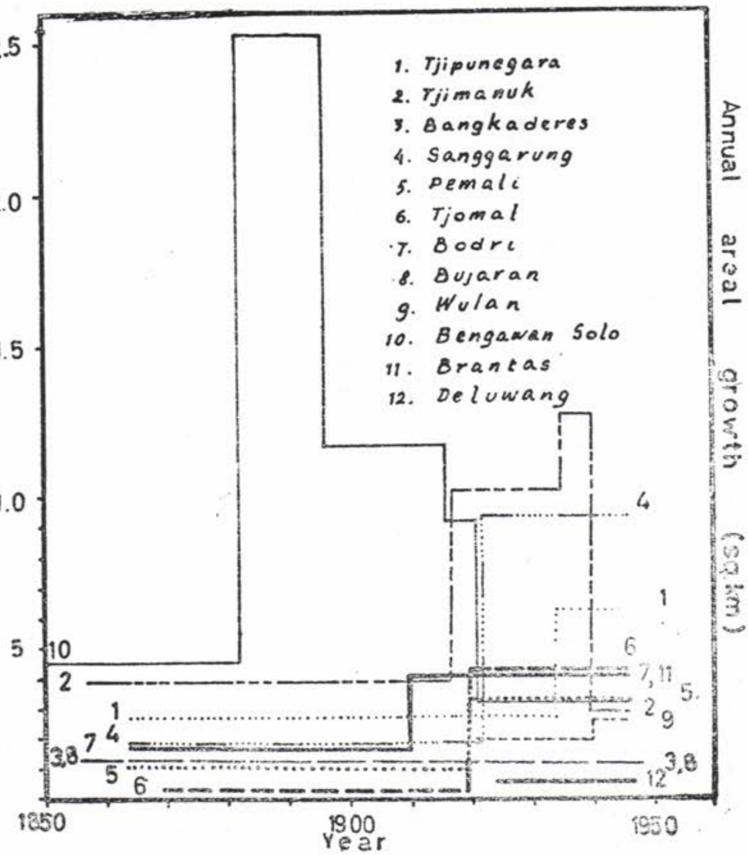

Fig. 5. Annual areal growth of twelve deltas on Java's north coast, explanation in text.

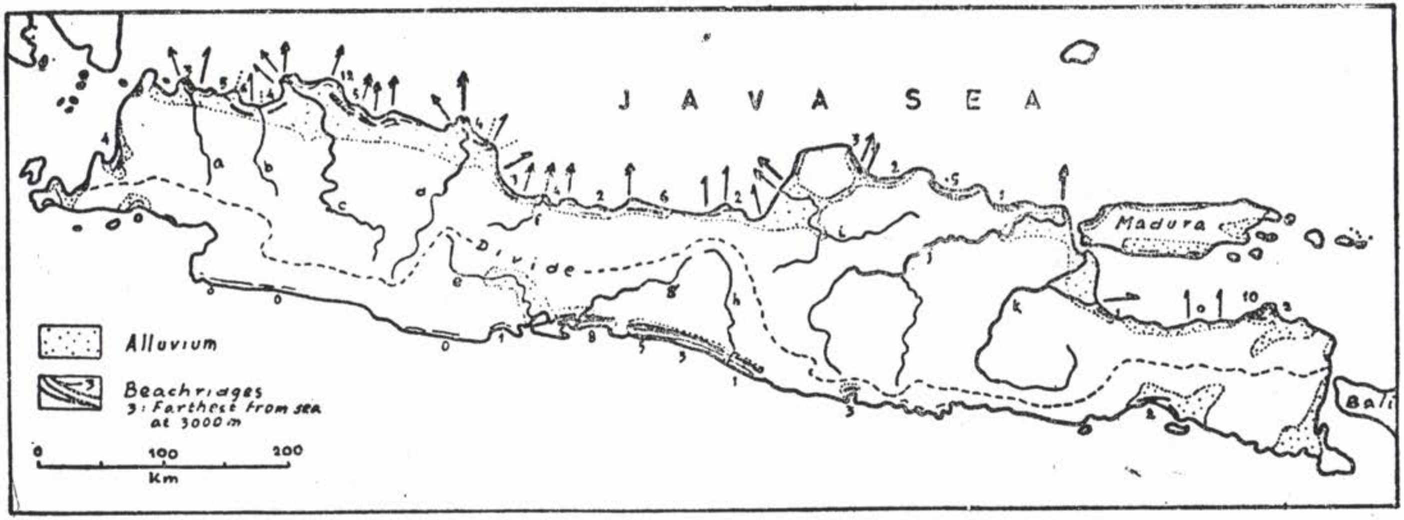

Fig. 6. Coastal development of Java. Linear dots indicate abrasion, usually less than 20 m/yr. Arrows indicate accretion.

Thin arrow with	1 feather :	less than 25 m/yr	Heavy arrow with	1 feather :	100 - 149 m/yr.
	2 feathers :	25 - 49 m/yr.		2 feathers :	150 - 199 m/yr.
	3 feathers :	50 - 74 m/yr.		3 feathers :	200 m/yr and more.
	4 feathers :	75 - 99 m/yr.			

a. Tjiudjung river, b. Tjiliwung river, c. Tjitarum river, d. Tjimanuk river, e. Tjitanduj river, f. Sanggarung river, g. Seraju river, h. Progo river, i. Bengawan Solo river, k. Brantas river.

Table 3. Coastal accretion in Java.

Locality	Change in km for period	Annual change in m	Remarks
TJIUDJUNG	0.2 1940 - 1946	32	Map 1 : 50,000 (1940) and aerial photo (1946)
TJIDURIAN natural outlet	0.5 1912 - 1927	33	Map 1 : 100,000 (1912) and 1 : 50,000 (1927).
channel	2.5 1927 - 1945	139	Verstappen (1953).
DJAKARTA BAY	1. Abrasion	—	Milius (1949) : Second World War pill-boxes destroyed
	2. Growth 1869-1874 until 1936 - 1940	—	Verstappen (1953) : Areal growth about 25 km^2.
	3. Deposition in Bay.	—	Verwey (1931/1932) & Vestappen (1953) : 1.5 m in 32 yrs; 2.5 m in 87 yrs.
A N G K E	0.1 1873 - 1888	6.6	Vestappen (1953) : Total accretion 465 m or annually 7.2 m.
	0.2 1888 - 1901	15.4	
	0.125 1901 - 1927	5.0	
	0.04 1927 - 1938	3.6	
B E K A S I	0.25 1873 - 1901	8.9	Verstappen (1953) : Total accretion 1000 m or annually 15 m.
	0.5 1901 - 1927	19.9	
	0.25 1927 - 1938	22.7	
TJITARUM western outlet	1.9 1873 - 1901	68.0	Verstappen (1953) : Total accretion 2950 m or annually 45.4 m.
	1.1 1901 - 1927	42.3	
	- 0.05 (?) 1927 - 1938	- 4.5	
TJITARUM central outlet	0.5 1873 - 1901	18	Total accretion 3000 m or annually 55.6 m.
	2.5 1901 - 1927	96.1	

Locality	Change in km period	Annual change in m	Remarks
TJITARUM eastern outlet	0.25 (?) 1873 - 1901	8.9	Total accretion 1000 m or annually 18.5 m.
	0.75 1901 - 1927	29	
OLD TJITARUM near Gembong	1.0 1874 - 1906	31.3	Niermeyer (1908) : old map issued between 1869 - 1879.
CAPE BALUKBUK	1.5 1874 - 1906	46.9	
WEST OF TJITA-RUM DELTA.	0.1/0.6 1874 - 1906	3.1/18.8	
CAPE SADARI	1.0 1892 - 1907	66.7	Niermeyer (1908).
TJILAMAJA CANAL	1.2 1924 - 1938	80	Map 1 : 100,000 (1924) and 1 : 50,000 (1938).
TJIASEM	0.2 1924 - 1939	13	Map 1 : 100,000 (1924) and 1 : 50,000 (1939).
TJIPUNEGARA	- 0.8 1865 - 1934	- 11.6	Hollerwöger (1964). Total accretion between 1865 - 1934 : 18.3 km^2 or annually 0.263 km^2;
	- 0.2 1934 - 1946	- 16.6	between 1934 - 1946 : 7.45 km^2 or 0.62 km^2 annually.
PANTJERKULON	3.35 1865 - 1934	48.5	Veth (1903) and aerial photos (1946) : annual growth 0.81 km^2.
	0.8 1934 - 1946	66.5	(1865 - 1880), 0.08 km^2 (1880 - 1940) 1.04 km^2. (1940 - 1946).
PANTJERWETAN	4.8 1865 - 1934	69.5	Average linear growth : 64 m/yr.
	0.7 1934 - 1946	58.5	
WEST END TJIPUNEGARA DELTA	0.7 1865 - 1934	10.1	
	0 1934 - 1946	0	

Locality	Change in km for period	Annual growth in m	Remarks
TJIMANUK CAPE NORTH OF INDRAMAJU	- 0.9 1857 - 1917	- 15.0	Map 1 : 100,000 compiled by "Tjimanuk Project", Public works.
	- 0.3 1917 - 1935	- 16.6	Areal delta growth : 1857 - 1917 : 22.3 km² or 0.371 km²/yr. 1917 - 1935 : 20.8 km² or 1.155 km²/yr. 1935 - 1940 : 6.3 km² or 1.260 km²/yr. 1940 - 1946 : 1.7 km² or 0.283 km²/yr.
	0.15 1935 - 1940	30	
	0 1940 - 1946	0	
TJIMANUK OUTLET	2.5 1857 - 1917	41.7	
	2.2 1917 - 1935	122.2	
	0.5 1935 - 1940	100	
	1.2 1940 - 1946	200	
ANJAR OUTLET	0.5 1857 - 1917	8.3	Average annual accretion 204 m.
	6.0 1917 - 1935	333.3	
	0.3 1935 - 1940	60	
	2.5 1940 - 1946	416.6	
RAMBATAN OUTLET	3.5 1857 - 1917	58.3	
	- 0.5 1917 - 1935	— 27.7	
	0 1935 - 1940	0	
	— 2.0 1940 - 1946	— 333.3	
TJEMORO OUTLET	1.7 1857 - 1917	28.3	
	0.8 1917 - 1935	44.4	
	0 1935 - 1940	0	
	0.4 1940 - 1946	66.6	
COAST OF INDRAMAJU	4.0 37 yr.	108	't Hoen (1929).

Locality	Change in km for period	Annual growth in m	Remarks
DADAP VILLAGE	Abrasion 1855 - 1941	- 6 / - 12	Pannekoek (1941) : Belt of land disappeared 12 × (0.5/1.0) km^2 plus three villages.
SIGEDANG	0.05 1920 - 1946	2	Map (1920) and aerial photo (1946), 1 : 50,000.
BOBOS CAPE TANAH	- 0.1 1920 - 1946	- 4	Map (1920) and aerial photo (1946), 1 : 50,000
PONDOK NEAR TUGU	0.7 1940 - 1946	117	Map (1940) and aerial photo (1946), 1 : 50.000
TJIWARINGIN	0.5 1940 - 1946	63	As above.
TUMARITIS	0 1940 - 1946	0	As above.
COAST EAST KARANG SAMBUNG.	0.2 1940 - 1946	33	As above.
BONDET	0.7 1940 - 1946	117	As above.
WEST BANGKADERES	2.5 1853 - 1922	36.2	Map by Hollerwöger (1964). Delta growth 1853 - 1922 : 8.62 km^2 or 0.125 m/yr.
EAST BANGKADERES	- 0.5 1922 - 1946	- 20.8	Delta growth 1922-1946 : 3.0 km^2 or 0.932 km^2/yr.
	2.0 1853 - 1922	29	
	1.8 1922 - 1946	75	
SANGGARUNG	3.52 1864 - 1922	60.7	Map by Hollerwöger (1964). Delta growth 1864-1922 : 10.88 km^2 or 0.188 km^2/ r.
SANGGARUNG EAST.	3.04 1922 - 1946	126.5	Delta growth 1922-1946 : 22.25 km^2 or 0.932 km^2/yr.
	3.2 1864 - 1922	50.2	
	1.44 1922 - 1946	60	

Locality	Change in km for period	Annual change in m	Remarks
BOSOK	0 1864 - 1922	0	
	0.8 1922 - 1946	33.3	
PEMALI WEST	2.2 1865 - 1920	40	Map by Hollerwöger (1964).
	0.2 1920 - 1946		Delta growth 1865-1920 : 6.5 km² or 0.119 km²/yr.
		7.7	Delta growth 1920-1946 : 8.75 km² or 0.336 km²/yr.
PEMALI EAST	1.5 1865 - 1920	27.3	Average growth 66 m/yr.
	2.7 1920 - 1946	104	
TJOMAL WEST	1.6 1870 - 1920	31.5	Map by Hollerwöger (1964). Delta growth 1870 - 1920 : - 1.76 km² or - 0.035 km²/yr.
	- 1.6 1920 - 1946	- 61.5	Delta growth 1920-1946 : 11 km² or 0.423 km²/yr.
TJOMAL EAST	- 0.64 1870 - 1920	- 12.8	Average growth 66 m/yr.
	2.72 1920 - 1946	145	
BODRI	1.5 1864 : 1910	32.6	Hollerwöger (1964). Delta growth 1864-1910 : 7.4 km² or 0.16 km²/ r.
	- 0.4 1910 - 1946	- 11	Delta growth 1910-1946 : 14 45 km² or 0.402 km²/yr.
KENTJENG	0.5 1864 - 1910	10.9	Average growth 65 m/yr.
	4.0 1910 - 1946	110.1	
KENTJENG	3.3 1913 - 1929	206	Van Bemmelen (1941).

Locality	Change in km for period	Annual growth in m	Remarks
GARANG (SEMARANG)	0.08 1695 - 1719	3.3	Maps in Van Bemmelen (1941). Average growth 1695-1940 : 2000 m or 8.2 m/yr.
	0.72 1719 - 1847	5.6	Coast of Semarang 4000 m wide; it is highly possible that the shoreline marks the foot of Tjandi Hills 500 yrs ago. Since 1847 the annual accretion is 13 m.
	0.7 1847 - 1892	15.6	
	0.5 1892 - 1940	10.5	
SEMARANG CITY	0.4 - 0.55 1892 - 1907	26.7	Niermeyer (1908).
DEMAK	12.0 approx. 1550 - 1940	30	Van Bemmelen (1949). In the 16th century Demak was a port, now it lies 12 km inland.
BUJARAN CANAL	1.1 1920 - 1946	55	Map 1 : 100,000 (1920) and aerial photo 1 : 50,000 (1946). Delta growth 3.3 km^2 or 0.125 km^2/yr.
WULAN CANAL	2.0 1920 - 1940	100	Map 1 : 100,000 (1920) and aerial photo 1 : 50.000 (1946).
	2.2 1940 - 1946	367	Areal growth 1920-1940 : 3.8 km^2 or 0.19 km^2/yr. Areal growth 1940-1946 : 1.5 km^2 or 0.25 km^2/yr. Average growth 160 m/yr.
KUTA	0.3 1909 - 1923	21	Map 1 : 100,000 (1909) and 1 : 50,000 (1923).
DJUWANA	0.6 1909 - 1933	25	Map 1 : 100,000 (1909) and 1 : 50,000 (1933).

Locality	Change in km for period	Annual growth in m	Remarks
DELOK	0.2 1909 - 1933	8	As above.
BENGAWAN SOLO (Canal used since 1885).	5.0 1843 - 1882	128	Map in Atlas Tropisch Nederland (1938), map 1 : 50,000 (1922) and aerial photo (1946). Delta growth :
	6.0 1882 - 1896	428	1843 - 1882 : 17.5 km^2 or 0.45 km^2/yr.
	6.0 1896 - 1916	300	1882 - 1896 : 35.5 km^2 or 2.53 km^2/yr. 1896 - 1916 : 23.5 km^2 or 1.175. km^2/yr
	3.0 1916 - 1922	500	1916 - 1922 : 5.5 km^2 or 0.918 km^2/yr. 1922 - 1946 : 8.0 km^2 or 0.332 km^2/yr.
	2.0 1922 - 1946	83	Average annual growth 214 m.
	5.0 approx. 1890 - 1930	125	't Hoen (1929).
BRANTAS	3.0 1924 - 1946	136	Map 1 : 50,000 (1924) and aerial photograph (1946). Delta growth 10 km^2 or 0.455 km^2/yr.
		50 - 100 7	Pannekoek (1949). Van Bemmelen (1949) : Brantas outlet.
		9 - 15	Van Bemmelen (1949) : Porong outlet.
DELUWANG	0.2 1924 - 1946	9	Map 1 : 50,000 (1924) and aerial photo (1946). Delta growth 1.19 km^2 or 0.054 km^2/yr.

TJIASEM BAY, WEST JAVA.

Below is examplified the use of morphological studies to some engineering problems.

a. Evaluation of the various morphologic features.

The morphologic map of figure 8 shows areas underlain by incompetent rock and with poor drainage conditions in the coastal plain *sensu stricto* and several depressions farther inland. Relief is usually less than 10 m and the area has a general northward slope. The valleys of the larger rivers like the Tjilamaja, Tjiasem, and Tjipunegara are 3 to 5 m deep.

The entire area consists of fine grained sediments : fine grained sandstone, silt, and clay except parts of the natural levees and beachridges where coarse grained material is an important constituent. Volcanic material predominates in the sediments, which through weathering has been transformed into red latosol. Fresh parent rock is only exposed in valley walls consisting of : tuff, tuffaceous breccia, and pumiceous tuff. Structures indicate these sediments to have been deposited subaqueously (Tjia, 1964—1965). Shell and coral fragments are the main constituents of the arenaceous beaches.

In this area dense rock like andesite, basalt, and consolidated sediment are unavailable for construction purposes. Sand should be looked for in the natural levees.

b. Flood susceptibilities.

According to susceptibility to flooding the various morphologic elements can be classified into two groups :

Group I : High degree of flood susceptibility.

Group II : Low degree of flood susceptibility, i.e. flooding only occurs under exceptional conditions, like heavy rains.

1. S t r e a m s. In this area streams occupy the entire valley bottom and flow 3—5 m below the surrounding land surface. In streams close to the shoreline, the rivers Djarong, Tjilamaja, Tjiasem, Pantjerkulon and Pantjerwetan distributaries of the Tjipunegara, and Sewo are liable to breach their undercut banks during high river levels and cause inundations of the neighbouring areas.

2. A b a n d o n e d s t r e a m c h a n n e l s. Abandoned river channels near existing streams, like meander cut-offs, are easily flooded during high water stages. Such old valleys are abundant along the Tjiasem and Tjipunegara rivers.

Abandoned river valleys located some distance from the parent streams are less liable to flooding than the former type. Re-flooding of these valleys may occur through course changes or exceptionally heavy rains.

3. D e p r e s s i o n s o n l a n d s u r f a c e. In the area south of line A — 1 on figure 7 darker colour tone indicates depressions with difficult drainage conditions; part of these depressions are marshes.

4. Depressions on coastal plain. North of line A–J on figure 7 depressions are extremely susceptible to flooding by springtides. Beachridges provide refuge under such conditions. The depressions on the coastal plain serve as brackish water fishponds except the swampy Tjipunegara delta shore which is left to the mangroves (aerial phtograph of 1946).

5. Natural levees. Natural levees in the lowland areas of Java are usually occupied by villages. Even large abandoned channels may be flanked by rows of settlements. Most levees are free from flooding, except those located on the coastal plain.

6. Beachridges. Neutral shorelines are usually indicated by beachridges.

Two size-classes of beachridges are distinguished in the Tjiasem Bay. The ridges farthest inland are invariably larger than those nearer to the shoreline. Settlements on the back of the larger beachridges imply them to be free from inundations. Near the present shoreline the ridges are only as high as the high water level.

7. Offshore banks. Banks of predominantly muddy material form the initial stage of land accretion. Eventually these banks will become permanent land. On aerial photographs of 1946 no offshore banks have risen sufficiently to bear trees in the Tjiasem Bay.

Following is a summary of the flood susceptibility according to groups. To Group I belong : Abandoned channels close to parent streams, inland depressions, coastal plain depressions, sand banks. Group II comprises : Abandoned channels remote from streams, natural levees, beachridges.

c. Harbour conditions.

On account of the high rate of accretion, averaging 60 m annually and the "open" nature of its shore, the Tjiasem Bay is unsuitable for harbouring ocean-going ships.

d. Coastal development of Tjiasem Bay.

Topographic maps issued in 1924 (scale 1 : 100.000) and 1938 - 1940 (scale 1 : 50.000), and aerial photographs flown in July and August 1946 (scale 1 : 50.000) were consulted to study the coastal changes of the Tjiasem Bay. Old shorelines are indicated by beachridges, which in part are occupied by villages, and photographic tone differences. Figures 7 and 8 show the shoreline development in Tjiasem Bay, while on figure 7 the interpreted ages of the shorelines are also depicted.

Verstappen (1953) once again emphasized that beachridges on the north coast are predominantly located east of large river mouths. During the wet monsoon, when the sea currents are directed westward, the rivers carry most of their sediment load, therefore resulting in deposition east of the stream outlets. In the dry monsoon the currents in the Java Sea flow westward, but then the rivers transport only little sediment.

The rates of coastal accretions in the Tjiasem Bay area are as follows :

	1924–1940	1940–1946
Tjilamaja river	1200 m (80 m / yr)	500 m (83 m / yr)
Tjiasem river	200 m (13 m / yr)	400 m (67 m / yr)
Tjipunegara river	averaging 64 m / yr since 1924	

Coastal development in vicinity of Tjilamaja outlet. On figure 7 coastal development near the Tjilamaja river is shown by shorelines A through I, 1924, 1938-1940 and 1946. Bearing in mind that most beachridges lie east of river mouths, therefore the beach ridges indicating shorelines C through H should belong to the Tjitarum river, i. e. west of the map area. Assuming a constant rate of accretion at 50 m / yr, then ages can be interpreted for the various shore-lines. The oldest recognizable shoreline dates from about 1770 A. D.

Coastal development of Tjipunegara delta. Beachridges and photographic colour tone indicate former shorelines 1 through 6, 1940, and 1946 on figure 7. From the orientations of the beachridges the writers have interpreted the river to have debouched farther west when the coastlines were at 4 and 5. Underfit distributaries still mark the course of its western outlets.

By using a constant rate of coastal growth at 50 m/yr, provisonal ages have been assigned to the older strandlines. The oldest recognizable shoreline dates from approximately 1725.

The authors emphasize that the age values assigned to the older should be considered as provisional, for it is uncertain whether accretion rates have been constant during the last 200 yrs or so.

The younger beachridges in the Tjiasem Bay area are considerably smaller than those before 1900. The evidence may imply weaker wave action through climatic change and/or acceleration of sea level lowering has occurred since that time

SUMMARY AND CONCLUSIONS

Coastal development in western Indonesia, especially on Sumatra's east coast and Java's north coast, has been studied from topographic maps surveyed in different years and from aerial photographs.

1. Factors which definitely enhance coastal growth are :
   a. Strong denudation in the watershed through high relief, scanty vegetation, and exposure of weak rocks.
   b. Tectonic uplift of the land.
   c. Volcanic activity, especially which produces pyroclastic rocks.

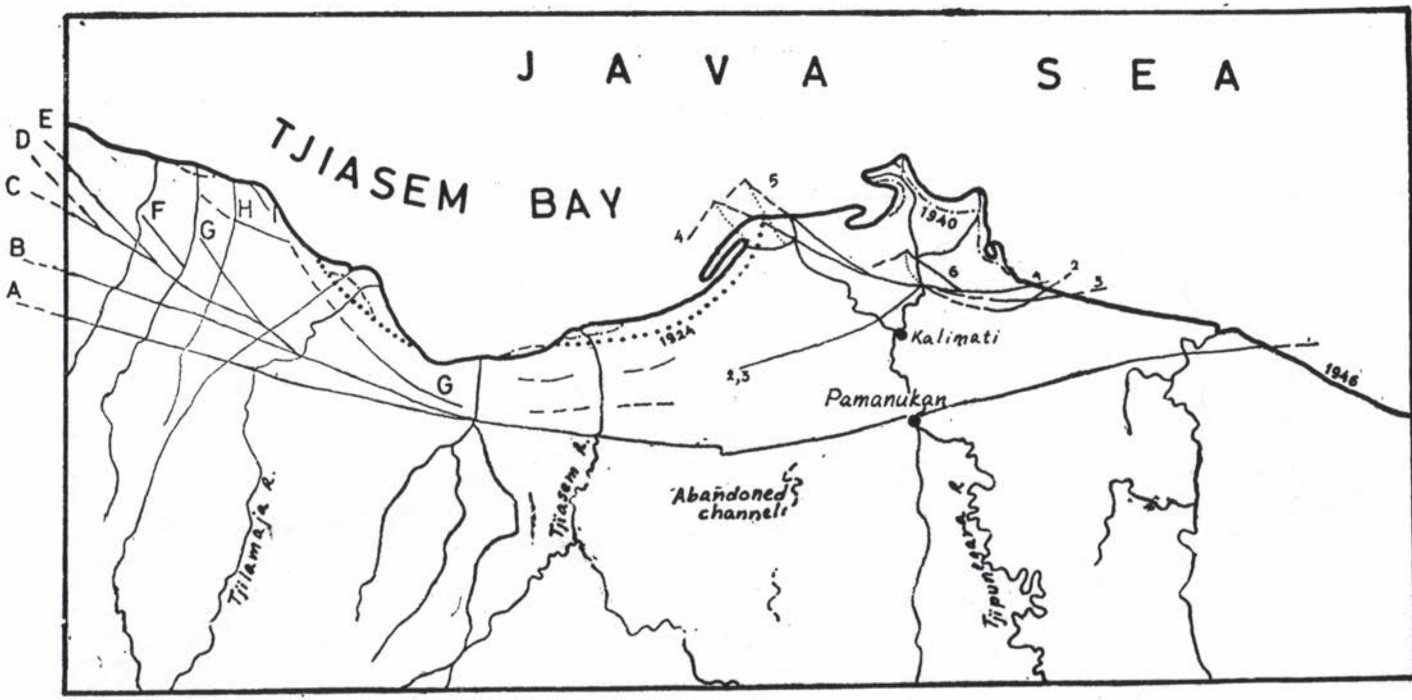

Fig. 7. Coastal development of Tjiasem Bay. Older shorelines are indicated by A through I and 1 through 6. Estimated ages of these shorelines assuming a rate of accretion at 50 m annually:

Tjilamaja area	I approx. 1910 A. D.	F ?	C approx. 1820	Tjiasem area	6 approx. 1970 A. D.	3 approx. 1820
	H ,, 1890	E ?	B ,, 1805		5 ?	2 ,, 1805
	G ,, ?	D ?	A ,, 1770		4 approx. 1830	1 ,, 1725

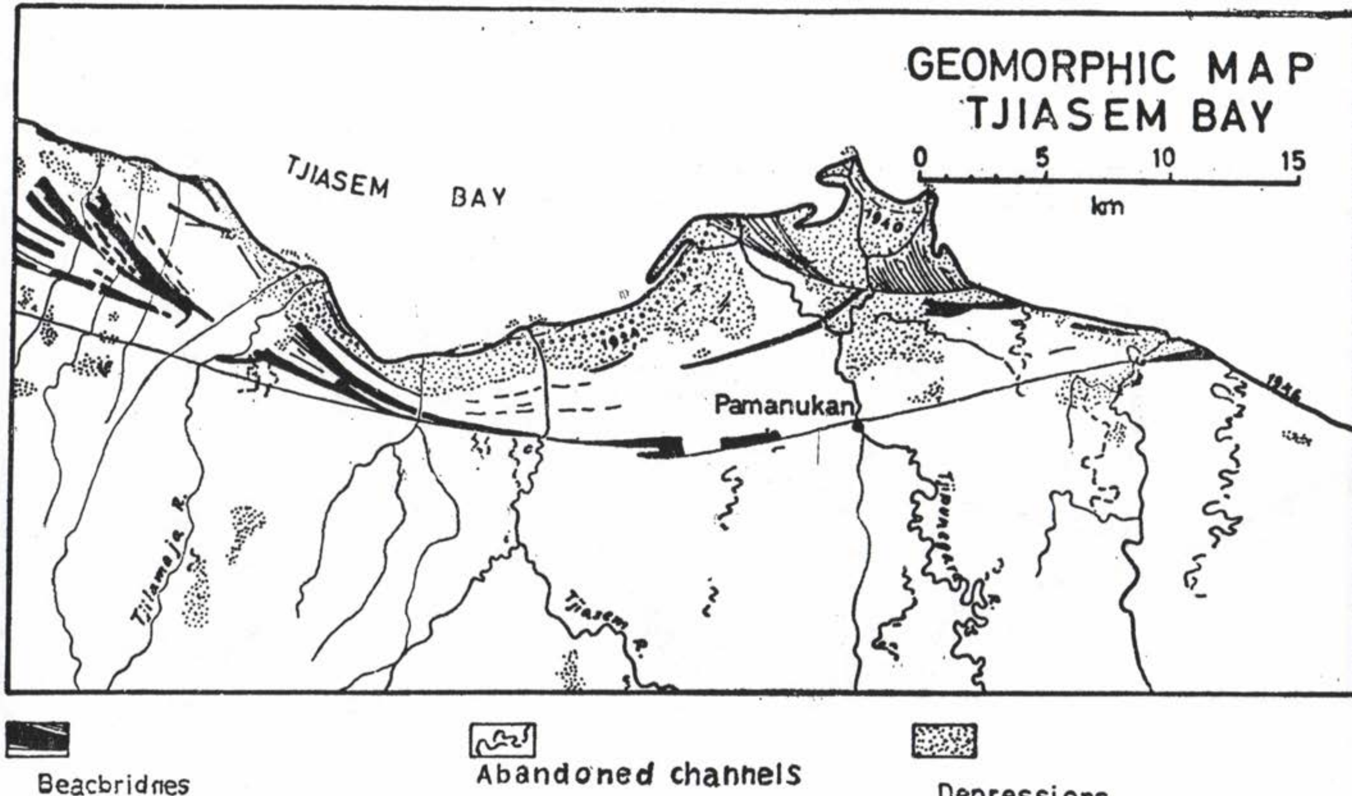

Fig. 8. Geomorphic map, Tjiasem Bay.

d. Rhizophora growth in the coastal marshes.
e. Quiet marine conditions and shallow sea.
f. Eustatic lowering of sea level.

2. Significant coastal growth only occurs in the vicinity of large rivers.

3. Coastal accretion is not always indicated by the presence of deltas, for the shape of river outlets is also governed by combinations of daily and semi-daily tides.

4. Abrasion is particularly apparent on shorelines recently abandoned by large rivers.

5. Sumatra's east coast between Deli and Musi rivers aggradates at a rate of 60–500 m/yr; the east coast of Lampung grows at a rate of 15 m/yr. The coast of Padang on Sumatra's west coast extends at less than 10 m/yr. No abrasion rates are known for Sumatra.

6. Java's north coast possesses accretion rates varying from 55 to 214 m/yr (averaging 75–150 m/yr) in the vicinity of large rivers or rivers draining Neogene rocks, while the smaller streams contribute about 30 m land annually.

Abrasion on the north coast averages less than 20 m/yr. Abrasion rates on recently abandoned delta shorelines are much higher.

On the south coast accretion appears to be considerable only in Central Java, where the zone of beachridges attain a maximum width of 8 km. The authors suspect that this evidence of exceptional growth is due to tectonic uplift rather than to sedimentary aggradation alone.

7. After approximately 1910 linear as well as areal coastal growth has accelerated, which is due to extensive deforestations and possibly also to uplift of the land surface.

8. A detailed investigation of the Tjiasem Bay area reveals that beachridges older than 1900 are considerably larger than the younger ones. Weaker wave action in recent times appears to be the cause. Climatic change and/or accelerated sea level drop may account for this phenomenon.

9. Flood susceptibilities of various landforms are predicted through morphological studies. Extremely susceptible to flooding are: flood plains, abandoned channels close to large rivers, inland and coastal depressions. Less susceptible to inundations and easier-to-drain areas comprise abandoned channels remote from large streams, natural levees, and beachridges.

10. Rapid accretion renders Tjiasem Bay unsuitable for harbours.

11. Sedimentation occurs predominantly east of river outlets debouching into the Java Sea as is indicated by the distribution of beachridges. During the wet monsoon rivers are transporting most of their annual load when the sea currents are eastward.

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