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Net directions and rates of present-day beach sediment transport by littoral drift along the East Coast of Peninsular Malaysia

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Abstract: Identification of the shapes of sand spits and beach sediment accumulations at headlands, as seen in a sequential time coverage of aerial photographs, have allowed interpretation of the net directions of present-day beach sediment transport by littoral drift along the East Coast of Peninsular Malaysia. Changes in the shapes of the sand spits with time have, furthermore, allowed determination of the average, annual rates of the beach sediment transport. A dominantly south to southeastward present-day beach sediment transport by littoral drift is identified and interpreted to primarily result from the oblique approach of southwestward directed sea-waves and swell from the South China Sea during the NE monsoon. Deviations from this dominant direction, and variations in the rates, of the beach sediment transport are, furthermore, identified to result from the influence of the orientation of individual coastal segments, the presence of coastline protrusions and nearshore islands and the discharges of rivers at their outlets.

INTRODUCTION

The most important process responsible for the lateral transport of beach sediment is the process of littoral drift (or beach drift) which arises from the oblique approach of waves onto beaches. This oblique approach leads to a net transport of beach sediment parallel to shorelines, as a result of sediment transport perpendicular to wavefronts during 'swash' and sediment transport perpendicular to shorelines during 'backwash'. The process, furthermore, mainly involves sand sized particles and is operative within the swash zone of any beach (Komar, 1976).

The process of littoral drift, operating over a period of time, usually results in the formation of a number of characteristic coastal landforms, as sand spits and tombolos, whose shapes allow for the interpretation of the net directions of beach sediment transport (Longwell and Flint, 1962, p. 316). The shapes of beach sediment accumulations at barriers along the coast, as groynes and headlands, similarly allow interpretation of the net directions of the sediment transport (Komar, 1976, p. 240). Changes in the shapes of the characteristic coastal landforms or of the sediment accumulations, over a period of time can, furthermore, allow determination of the rates of the sediment transport (Zenkovich, 1976). As these landforms and sediment accumulations are easily recognizable on aerial photographs, identification of their changes of shape in a sequential time coverage of such photographs thus allows determination of the rates and net directions of beach sediment transport by littoral drift (El-Ashry and Wanless, 1967).

In this study, the shapes of sand spits and beach sediment accumulations at headlands, as seen in a sequential time coverage of aerial photographs, are used to determine the net directions of the present-day beach sediment transport by littoral drift along the East Coast of Peninsular Malaysia. Changes in the shapes of the sand spits, as seen on the photographs of different dates, are, furthermore, used to determine the average, annual rates of the sediment transport. The main factors, giving rise to, and influencing, these rates and net directions of the present-day beach sediment transport by littoral drift are also discussed.

EAST COAST OF PENINSULAR MALAYSIA

General

The East Coast of Peninsular Malaysia is fronted by the South China Sea and trends in a general northwest-southeast direction over some 675 km between latitudes 6°15'N and 1°20'N. It comprises the entire coastlines of the states of Kelantan, Trengganu and Pahang and the eastern coastline of Johore (Fig. 1). A coastal classification of the entire East Coast has been discussed by Swan (1968), while limited stretches have been geomorphologically studied by Nossin (1961, 1962, 1964 and 1965), Hill (1966), Tjia (1970, 1973), Koopmans (1972), Zakaria (1970, 1975) and Wong (1981). Apart from Koopmans (1972) and Zakaria (1970, 1975) who discussed littoral drift operative in the Sungai Kelantan delta, however, none of the other authors have discussed beach sediment transport by littoral drift.

The coastline of Kelantan state shows general trends of 285°, and 150°, to the west, and south, of Kuala Sungai Besar, respectively (Fig. 2) and is fronted by sandy beaches except at river mouths where sand spits are commonly developed. Tidal swamps are present within the subaerial part of the Sungai Kelantan delta and in some of the larger river mouths. Inland, is found a broad coastal plain that is locally overlain by a number of beach ridges. The nearshore sea-bottom gradient is a gentle one with the 10 fathom line lying 5 to 15 km offshore.

The coastline of Trengganu state shows general trends of 210°, and 150°, to the northwest of Kuala Trengganu, and between Kuala Trengganu and Kuala Dungun, respectively, but to the south of Kuala Dungun the coastline generally trends 180° (Fig. 3). Sandy beaches, whose continuity is interrupted by river mouths and small isolated headlands, front the coastline to the north of Kuala Dungun, while to the south the coastline is formed of small, arcuate bays with sandy beaches that are separated by large headlands. Sand spits, and tidal swamps, are, furthermore, commonly developed at, and within, the larger river mouths. Inland, is found a coastal plain of variable width that is locally covered by a number of beach ridges and backed by a fluvially, dissected hilly terrain. The nearshore sea-bottom gradient is variable, with the 10 fathom line lying more than 4 km offshore between Kuala Besut and Kuala Merchang and to the south of Kuala Paka, but lying between 2 and 4 km offshore between Kuala Merchang and Kuala Paka.

The coastline of Pahang state shows general trends of 10°, and 155°, to the north of Kuantan, and between Kuantan and Kuala Pahang, respectively, but to the south of Kuala Pahang the coastline generally trends 180° (Fig. 4). Individual sectors of the coastline do, however, show variable trends. Apart from the isolated stretches of rocky coast forming headlands to the north of Kuantan, the coastline is fronted by sandy beaches except at river mouths where sand spits are commonly developed. Tidal swamps are also found within the larger river mouths, particularly to the south of

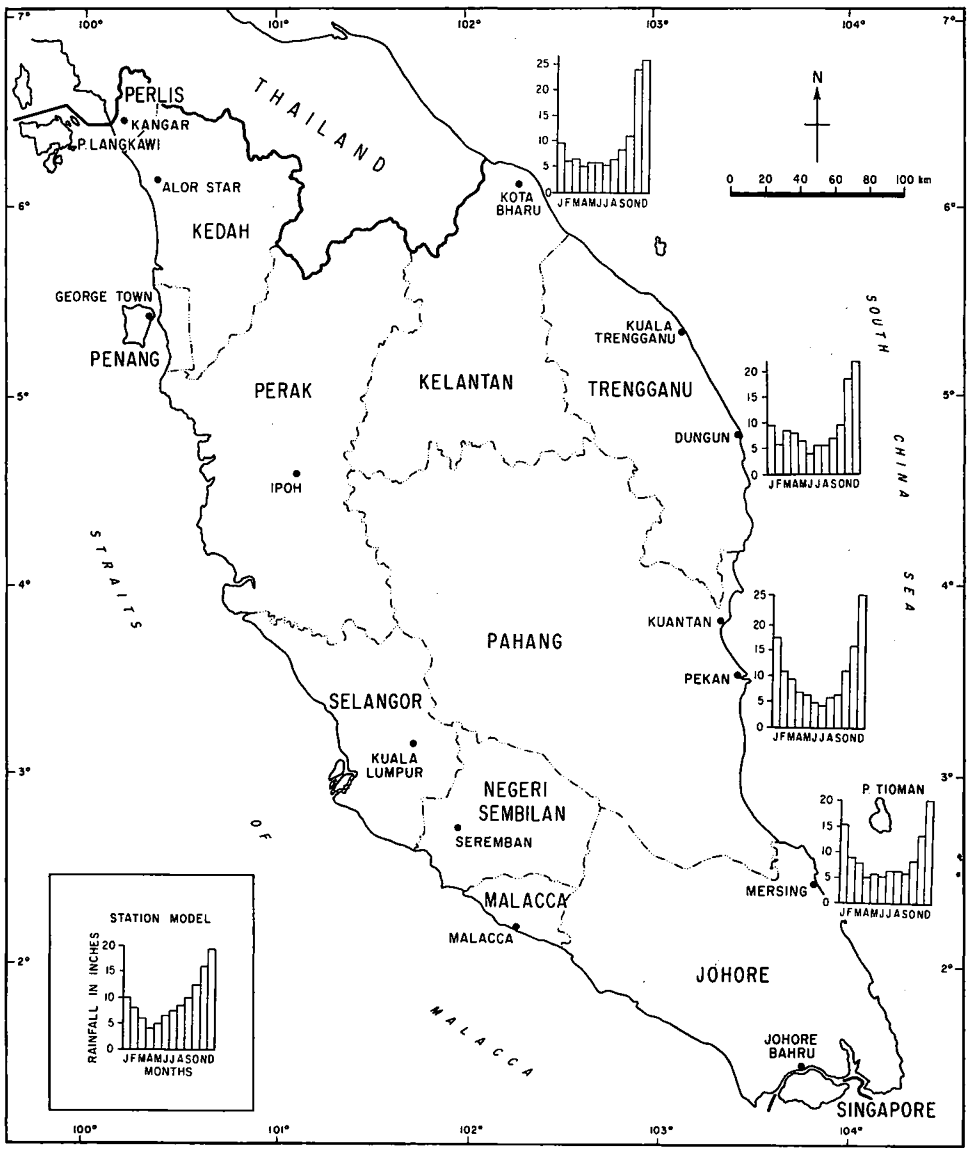

Fig. 1. Mean monthly rainfall along the East Coast of Peninsular Malaysia (after Drainage and Irrigation Department, Malaysia, 1970).

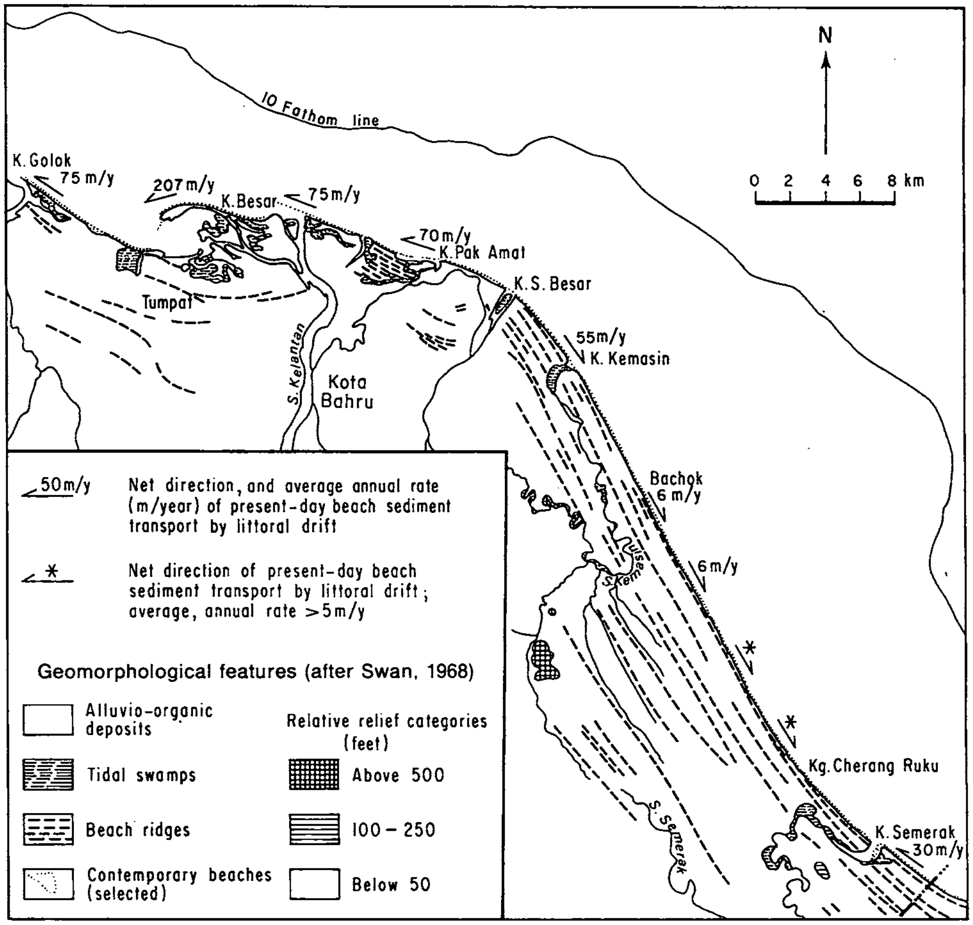

Fig. 2. Net directions and average, annual rates of present-day beach sediment transport by littoral drift along the Kelantan state coastline.

Kuala Pahang. Inland of the rocky coastal stretches are found narrow coastal plains separated by fluvially, dissected hilly terrain, while inland of the other coastal stretches is found a broad coastal plain that is locally overlain by a number of beach ridges. The nearshore sea-bottom gradient is a very gentle one with the 10 fathom line lying between 10 and 20 km offshore.

The eastern coastline of Johore state shows general trends of 320°, and 150°, to the northwest, and southeast, of Tanjong Tenggaroh, respectively, though individual sectors show very variable trends (Fig.5). Apart from the stretches of rocky coast forming continuous headlands with small bays between Tanjong Sekakap and Tanjong Sedili Besar, and to the north of Tanjong Kelesa, the coastline is formed of large arcuate to zetaform bays that are fronted by sandy beaches and separated by small to large, isolated headlands. Inland of these large bays are found narrow coastal

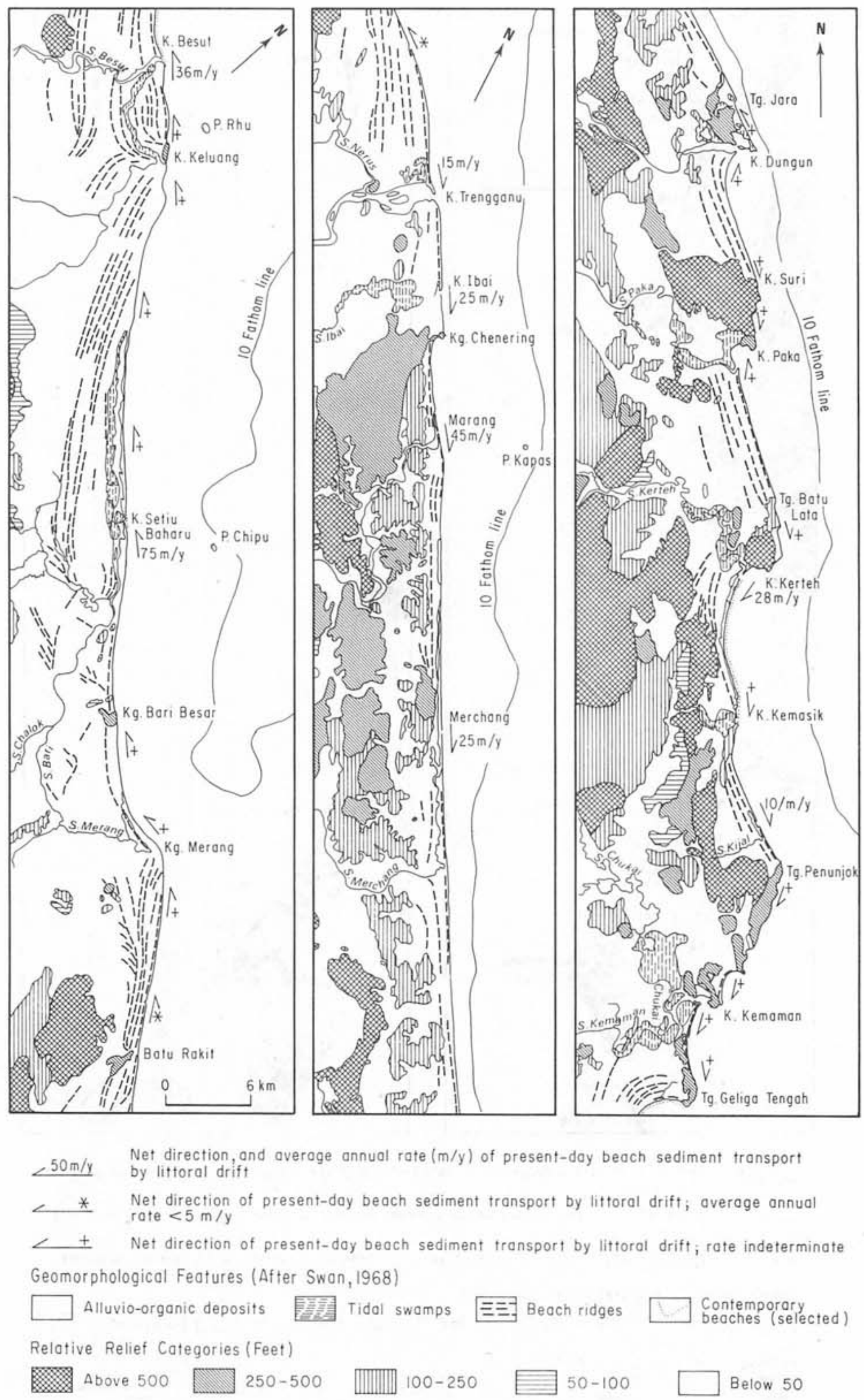

Fig. 3. Net directions and average, annual rates of present-day beach sediment transport by littoral drift along the Trengganu state coastline.

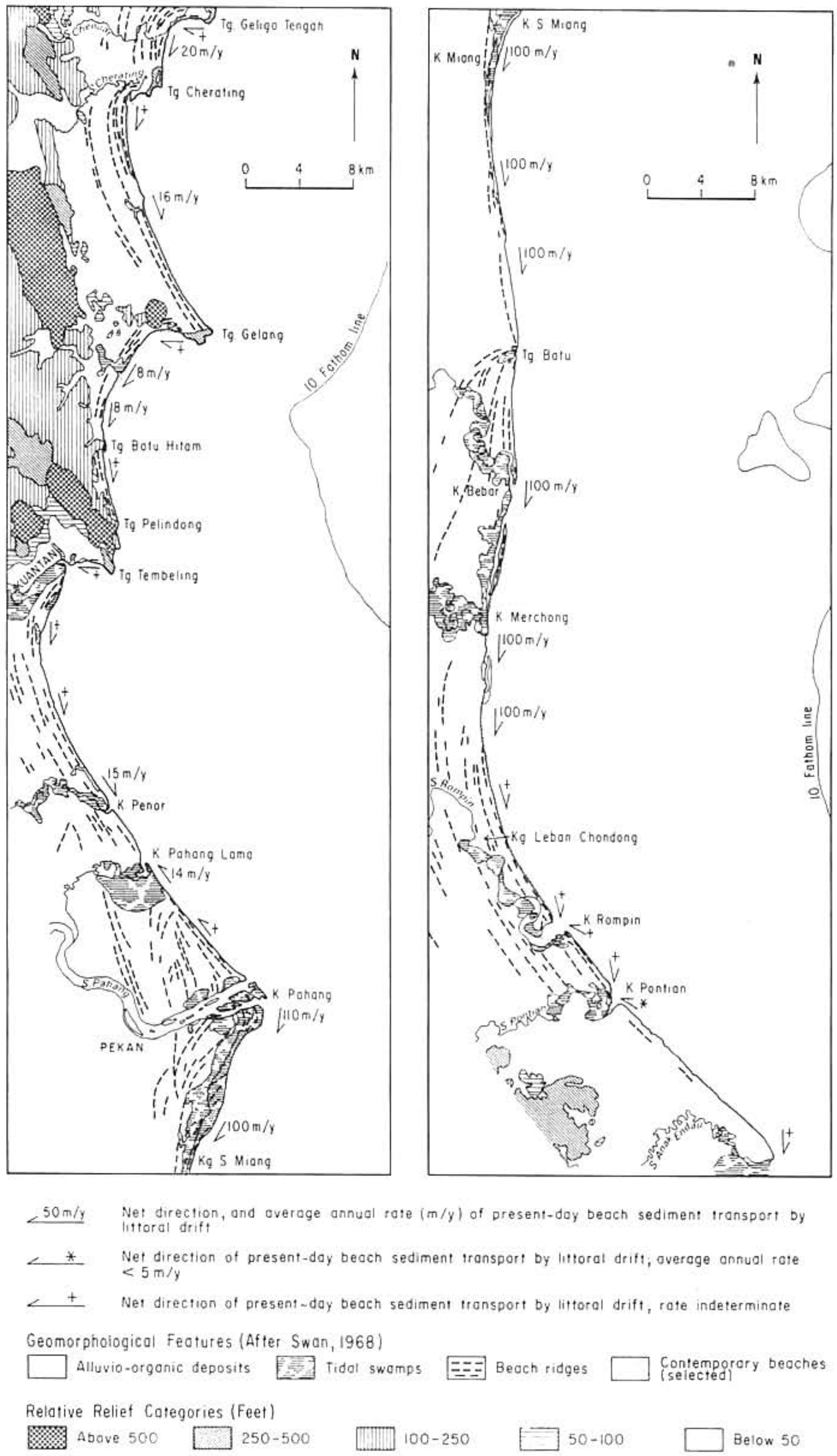

Fig. 4. Net directions and average, annual rates of present-day beach sediment transport by littoral drift along the Pahang state coastline.

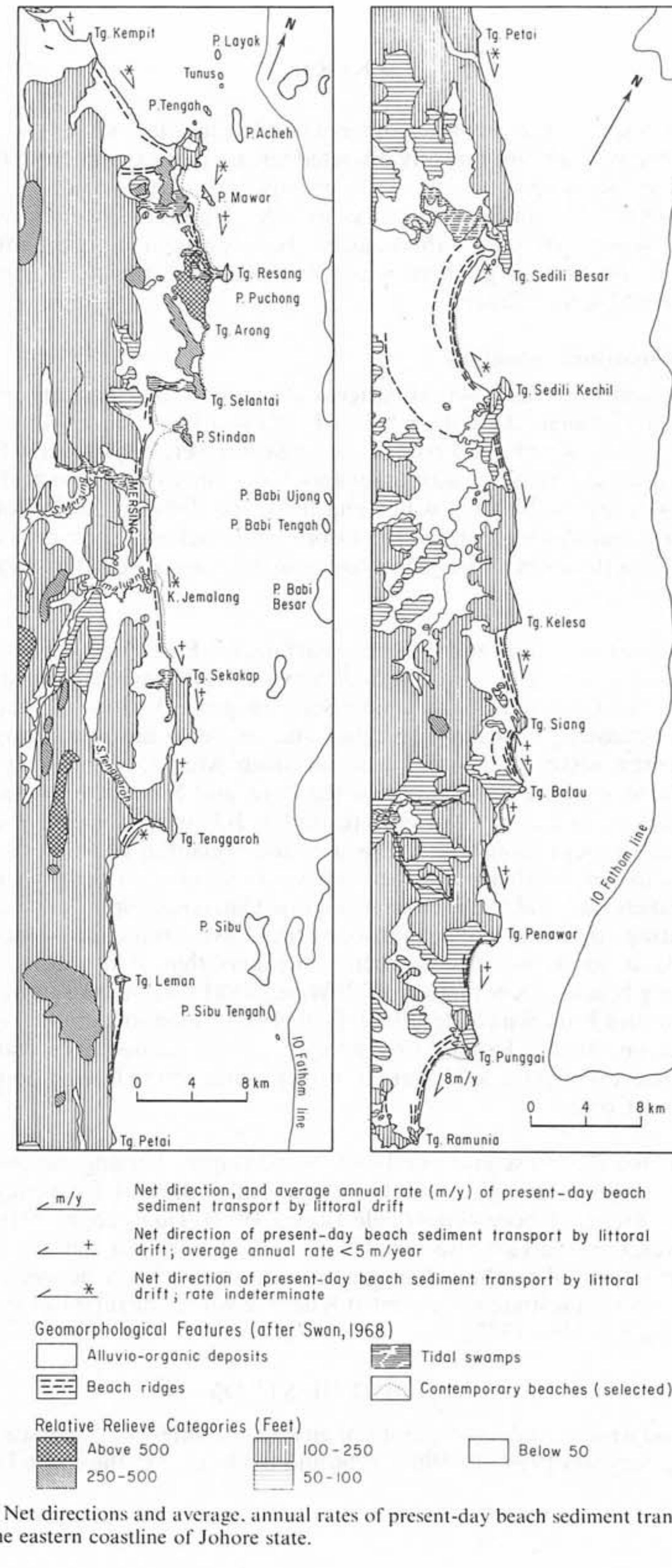

Fig. 5. Net directions and average. annual rates of present-day beach sediment transport by littoral drift along the eastern coastline of Johore state.

plains that are locally overlain by a number of beach ridges and backed, or surrounded, by the hilly to mountainous, fluvially dissected terrain that extends from the stretches of rocky coast. Sand spits are not well developed along this coastline, while tidal swamps are only found in the larger river mouths. Numerous nearshore islands are found along the northern part of this coastline but are absent along the southern part. The nearshore sea-bottom gradient is a gentle one, with the 10 fathom line lying between 5 and 15 km offshore.

Climatic and maritime influences

Rainfall and wind distribution patterns along the East Coast are of a seasonal character, being influenced by the northeast, and southwest, monsoons which blow from November to March, and from June to September, respectively (Dale, 1956). During the northeast monsoon, strong (of about 3 to 7 m/s; Climatological Summaries 1949 to 1974), onshore blowing winds and heavy rainfalls occur all along the East Coast, whereas during the southwest monsoon and inter-monsoon periods, variable and weak (of less than 4 m/s), frequently offshore blowing winds and low rainfalls are present.

The trends of sea waves and swell approaching the East Coast are also influenced by the monsoon and inter-mansoon periods for they are dependent upon surface winds prevailing in the Java and South China Seas. In general, from October to April, prevailing northeasterly winds in the South China sea result in southwestward directed approaching sea waves and swell, whereas from May to September, prevailing southeasterly to southwesterly winds in the Java and South China Seas result in northward directed sea waves and swell (except in July when southward directed sea waves are also present along the Trengganu and Kelantan coastlines). During the northeast monsoon, furthermore, the high velocity, northeasterly winds result in plunging breakers that lead to the erosion and rapid lateral transport of beach sediment, whereas during the southwest monsoon the lower velocity, southeasterly to southwesterly winds result in constructive breakers that lead to the accretion of sediment along beaches (Koopmans, 1972; Wong, 1981). Variations in water stowage within the South China Sea (Dale, 1956), furthermore, lead to a gradual rise of mean sea-level from late July to January (to a maximum rise of about 20 cm) and a gradual fall of mean sea-level from late January to July (to a maximum fall of about 15 cm), all along the East Coast.

Tides are mainly of a semi-diurnal frequency along the Pahang and eastern Johore coastline throughout the year, but are largely of a diurnal frequency along the Kelantan and Trengganu coastlines (Tide Tables, 1977). Tidal ranges, between higher, high and lower, low levels are also variable along the East Coast, being less than 1.5 m along the Kelantan and northern Trengganu coastline, but being between 1.5 and 2 m along the other coastal stretches, except at Kuantan where the tidal range is between 2 and 2.5 m (Tide Tables, 1977).

METHOD OF STUDY

Black and white aerial photographs of an approximately 1:25,000 scale have been flown during the years 1946–49, 1965–1966 and 1974–75 over the entire East Coast as

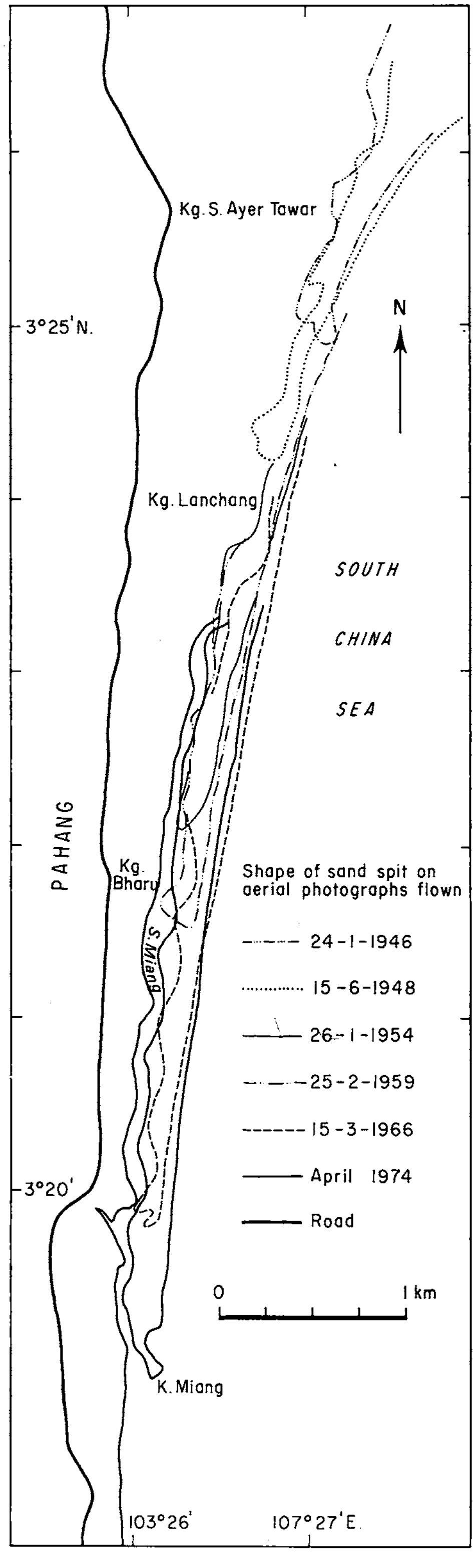

Fig. 6. Sequential changes with time of the sand spit at K. Miang, Pahang.

have been approximately 1:60,000 scale photographs flown in the years 1957–59. Limited stretches are also covered by approximately 1:10,000, and 1:25,000, scale black and white aerial photographs flown in the years 1951–54, and 1977, respectively. Identifications of the shapes of, sand spits, and beach sediment accumulations at headlands, as seen on the photographs of different dates, thus allowed interpretation of the net directions of the present-day beach sediment transport by littoral drift, while changes in the shapes of the sand spits with time allowed calculation of the average, annual rates of the sediment transport. These changes of the spits were determined by superimposing the shapes of different dates, after they (the shapes) had been transferred onto 1:25,000 scale topographic base maps (series L8010, Jabatan Ukur Malaysia) through the use of a stereo-sketchmaster.

As an illustration of the use of the sequential aerial photographs for the determination of the rates and net directions of the present-day beach sediment transport by littoral drift, Fig. 6 is presented which shows the changes with time of the sand spit at Kuala Miang in Pahang. The continuous southward extension of the spit, between the years 1946, 1948, 1954, 1959, 1966 and 1974, clearly indicates a present-day net southward transport of beach sediment at an average, annual rate of 100 m/year (based on the 1966/1974 changes).

It should be noted that the aerial photographs used in this study have been flown at widely spaced time intervals and thus only allow determination of average, annual rates and net directions of beach sediment transport by littoral drift. This aspect needs to be emphasized in view of the seasonal nature of the climatic and maritime influences on the East Coast which may lead to different directions and rates of beach sediment transport by littoral drift at different times of the year. The directions and rates that have been determined, however, represent the overall, net directions and average, annual rates of the present-day beach sediment transport by littoral drift along the East Coast.

PRESENT-DAY BEACH SEDIMENT TRANSPORT BY LITTORAL DRIFT ALONG THE EAST COAST OF PENINSULAR MALAYSIA

Kelantan state

Fig. 2 shows that there are two net directions of present-day beach sediment transport by littoral drift along the Kelantan state coastline; a northwestward transport, and a southward transport, to the west, and south, of Kuala Sungai Besar respectively. Average, annual rates of the sediment transport are, however, variable and dependent upon the trends of individual coastal segments. An extremely rapid rate (of 207 m/year) of sediment transport is seen opposite Tumpat, while moderate rates (of 30 to 75 m/year) are seen along other coastal segments. Very low rates (< 10 m/year) are, furthermore, seen between Bachok and Kampung Cherang Ruku.

Trengganu state

Fig. 3 shows that there two net directions of present-day beach sediment transport by littoral drift along the Trengganu state coastline; a northwestward transport, and a southward transport, to the northwest, and south, of Kuala Trengganu respectively.

Average, annual rates of the sediment transport are, however, variable with moderate rates (of 30 to 75 m/year) at Kuala Besut, Kuala Setiu Baharu and Marang, but low to very low rates (<30 m/year) along other coastal segments.

Pahang state

Fig. 4 shows that present-day beach sediment by littoral drift along the Pahang state coastline is predominantly southward, except at Kuala Pahang Lama, Kuala Rompin and Kuala Pontian where northwestward transport directions are seen. On the lee sides of some large headlands in the northern part of this coastline, furthermore, a present-day westward beach sediment transport is seen. Average, annual rates of the sediment transport are, furthermore, variable with rapid rates (of about 100 m year) between Kuala Pahang and Kampung Leban Chondong, but low to very low rates (<20 m/year) along the other coastal segments.

Eastern coastline of Johore state

Fig. 5 shows that present-day beach sediment transport by littoral drift along this coastline is predominantly southeastwards, except at Kuala Jemalung and Tanjung Sedili Kecil where northwestward transport directions are seen. The development of tombolos on the lee sides of Pulau Mawar and Pulau Setindan, furthermore, indicates divergent beach sediment transport directions caused by wave refraction at these islands. Average, annual rates of the sediment transport are all of very low values, being less than 10 m/year. It should be noted that these rates of the sediment transport are only determinable at a few sites due to the large stretches of rocky coast where sequential changes in the shapes of sand spits cannot be monitered.

FACTORS GIVING RISE TO, AND INFLUENCING, THE PRESENT-DAY BEACH SEDIMENT TRANSPORT BY LITTORAL DRIFT ALONG THE EAST COAST OF PENINSULAR MALAYASIA

The dominantly south to southeastward net directions of present-day beach sediment transport by littoral drift all along the East Coast indicates that the domineering littoral drift is generated by the oblique approach of the southwestward directed sea-waves and swell from the South China Sea during the months of October to April. This domineering littoral drift is, furthermore, of greatest intensity during the northeast monsoon when the high velocity, onshore blowing winds result in plunging breakers that lead to the erosion and rapid lateral transport of beach sediment (Koopmans, 1972). During the other months of the year, however, although different directions of beach sediment transport by littoral drift may be present (particularly during the southwest monsoon when northward directed sea-waves and swell occur along the East Coast), their effects are overshadowed by the littoral drift generated during the northeast monsoon. This interpretation of the southwestward directed sea-waves and swell during the northeast monsoon as being responsible for the present-day beach sediment transport by littoral drift along the East Coast can be verified by calculating the average, monthly rates of the beach sediment transport by littoral drift along the coastal stretch between Kuala Besar and Kuala Sungai Besar (Fig. 2) as this stretch is covered by aerial photographs flown in October 1948 and Feburary 1949 (a period covering a single season of the northeast monsoon). The monthly rate of sediment transport calculated for this period from the formation of a sand spit at Kuala Semut Api is about 75 m/month, whereas the average monthly rate of sediment transport for this coastal stretch between the years 1966 and 1974 (a period covering several monsoon and inter-monsoon periods) is only about 6 m/month. These vastly different rates clearly indicate that the maximum rates and dominant directions of the present-day beach sediment transport by littoral drift along the East Coast are generated during the northeast monsoon period.

Various factors have, however, influenced the approach of the southwestward directed sea-waves and swell during the northeast monsoon and it is the modifying influence of these factors that results in the actual net directions and average, annual rates of the present-day beach sediment transport by littoral drift along the East Coast.

One of the more important factors is the presence of protrusions of the coastline, for through wave refraction different net directions of sediment transport have been developed. This influence is clearly seen in Figs. 2 and 4, where the protrusions of the coastline at Kuala Sungai Besar, and Kuala Pahang, have led to northwestward, and southward, transport directions to the northwest, and south, of these sites, respectively. Wave refraction, at protrusions of the coastline formed by large headlands, as at Tanjung Geliga Tengah, Tanjung Gelang and Tanjung Tembeling in Fig. 4, have similarly led to westward sediment transport directions on their lee sides.

Another important factor is the orientation of individual coastal segments relative to the southwestward directed sea-waves and swell approaching from the South China Sea during the northeast monsoon. This factor has mainly influenced the present-day rates of beach sediment transport by littoral drift, for the length of sediment movement during 'swash' will, in part, increase with increasing obliquity of the trends of approaching wavefronts relative to the coastline trend (Davies, 1977). This influence of coastline orientation is clearly seen in Fig. 2, where variations in the average, annual rates of beach sediment transport to the northwest of Kuala Sungai Besar are directly due to differences in orientation of individual coastal segments. The rapid average, annual rates of sediment transport to the south of Kuala Pahang in Fig. 4, are also due to the influence of the coastline orientation, for this coastal stretch trends at large obliquity (of about 45°) to the general trends of the approaching wavefronts during the northeast monsoon.

The presence of nearshore islands along the East Coast has only influenced to a minor extent the net directions of beach sediment transport through the effects of wave refraction. This influence is only clearly seen in Fig. 5, in the development of tombolos on the lee sides of Pulau Mawar and Pulau Setindan..

The nearshore sea-bottom gradient is a factor that may be expected to influence average, annual rates of the present-day beach sediment transport along the East Coast, for where waves break far from the shoreline (due to gentle nearshore sea-bottom gradients) little uprush (swash) of water onto beaches is expected, whereas where waves break close to the shoreline (due to steep nearshore sea-bottom gradients) a large uprush of water onto beaches is expected. The nearshore sea-bottom gradient, however, appears to be a negligible factor in influencing rates of the present-day beach sediment transport, for along the similarly southeast trending coastal stretches at Marang and Merchang in Fig. 3, the more gentle nearshore sea-bottom gradient (of about 1:370) at Marang results in a more rapid average, annual rate of sediment transport than at Merchang with a steeper nearshore sea-bottom gradient (of about 1:200).

Another influencing factor is the discharge of rivers at their outlets along the coast, for these discharges can not only breach sand spits, but can also sometimes flush out sediment accumulating at the outlets to prevent the extension of sand spits. This would thus influence the calculations of the rates of the beach sediment transport based on the extensions of the spit with time. In this study, therefore, care has been taken to ensure that calculations of the average, annual rates of the sediment transport were only carried out at sand spits that appeared to show clear and continuous extensions between the different dates of photography. The influence of river discharge on the rates of beach sediment transport by littoral drift along the the East Coast can only be evaluated for the large spit opposite Tumpat in Fig. 2, for prior to 1966 river discharge was via the tip of the spit and the mainland, though after 1972 the discharge was both across the spit and between the tip of the spit and the mainland as a result of the breaching of the spit sometime between 1966 and 1972. The influence of the river discharge is clearly reflected in the different average, annual rates of the beach sediment transport by littoral drift of 150 m/year, and 207 m/year, calculated from the extension of the spit between the years 1957 and 1966, and 1966 and 1974, respectively.

CONCLUSION

In conclusion, it can be stated that the present-day beach sediment transport by littoral drift along the East Coast of Peninsular Malaysia primarily results from the oblique approach of southwestward directed sea-waves and swell from the South China Sea during the northeast monsoon, as modified by the influence of the orientation of individual coastal segments, the presence of coastline protrusions and nearshore islands and the discharge of rivers at their outlets.

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