Predominant Nearshore Sediment Dispersal Patterns in Manila Bay

*Fernando P. Siringan and Cherry L. Ringor
National Institute of Geological Sciences
College of Science, University of the Philippines
Diliman, Quezon City 1101
E-mail: fsiringan@orc.upd.edu.ph

ABSTRACT

Net nearshore sediment drift patterns in Manila Bay were determined by combining the coastal geomorphology depicted in 1:50,000-scale topographic maps and Synthetic Aperture Radar (SAR) images, with changes in shoreline position and predominant longshore current directions derived from the interaction of locally generated waves and bay morphology.

Manila Bay is fringed by a variety of coastal subenvironments that reflect changing balances of fluvial, wave, and tidal processes. Along the northern coast, a broad tidal-river delta plain stretching from Bataan to Bulacan indicates the importance of tides, where the lateral extent of tidal influences is amplified by the very gentle coastal gradients. In contrast, along the Cavite coast, sandy strandplains, spits, and wave-dominated deltas attest to the geomorphic importance of waves that enter the bay from the South China Sea.

The estimates of net sediment drift derived from geomorphological, shoreline-change, and meteorological information are generally in good agreement. Sediment drift directions are predominantly to the northeast along Cavite, to the northwest along Manila and Bulacan, and to the north along Bataan. Wave refraction and eddy formation at the tip of the Cavite Spit cause southwestward sediment drift along the coast from Zapote to Kawit. Geomorphology indicates that onshore-offshore sediment transport is probably more important than alongshore transport along the coast fronting the tidal delta plain of northern Manila Bay. Disagreements between the geomorphic-derived and predicted net sediment drift directions may be due to interactions of wave-generated longshore currents with wind- and tide-generated currents.

INTRODUCTION

Sediment-dispersal pattern information is needed for regional and local planning and management of the coastal zone for fish resources and engineering, and for growth management of sensitive marine-shoreline areas. Sediment transport can be determined directly with detailed current measurements, by sampling the sediment in active transport, and by determining patterns of sediment movement using a variety of tracer materials. These methods, however, are costly and tend to be local in their extent and application.

Tracing of sediment plumes from remotely sensed data can also be employed, but like direct measurements, remote sensing has its drawbacks. The synoptic view afforded by these data is very useful in delineating the sources and dispersion of sediments. However, remotely sensed data are still of too recent acquisition to cover time scales of sufficient duration to identify the processes responsible for net erosion, transport, and deposition of sediments.

Keywords: Manila Bay, sediment transport, coastal geomorphology, longshore current

**Corresponding author*

Table 1. Spatial data set used in this study.

Year	Data	Source	Remarks
1944	Topographic Map (TM) Orion (Bataan) 1:50,000	US Army Map Service (USAMS)	Compiled in 1944 from Luzon, 1:25,000, AMS S812, 1944, which are based on: USC&GS Topographic Field Survey Sheets, 1:20,000 1916; Luzon, 1: 31,680, Office Dept. Engr., Phil. Dept., No. 31 H, 1940. (Rd. and bridge revision 1940, Trail revision, 1942); Vol. I, Commission of Census, Commonwealth of Phil., 1939; USC&GS Chart 4255, 1940, (Special Printing 44-4/21); P. Is., 1:200,000, USC&GS, No. 5, 1940; Communication Map of P. Is., 1:400,000, Hq. M. I., Phil. Dept., No. CM 14-2, 1927 (Tel. and Tel. corrected to 1940, AMS); Revisions from miscellaneous large-scale vertical photography, 1940; Stereo compilation by USGS from vertical and oblique photography, 1944. Hydrography compiled from 1916 surveys by USC & GS, 1944.
1944	TM Balanga (Pampanga) 1:50,000	US Army Map Service (USAMS)	Compiled in 1944 from Luzon, 1:25,000, AMS S812, 1944, which are based on: USC&GS Topographic Field Survey Sheets, 1:20,000 1916-17; Luzon, 1: 31,680, Office Dept. Engr., Phil. Dept., No. 31 E, 1940. (Rd. and bridge revision 1939, Trail revision, 1942); Vol. I, Commission of Census, Commonwealth of Phil., 1939; USC&GS Chart 4255, 1940, (Special Printing 44-4/21); P. Is., 1:200,000, USC&GS, No. 7, 1941; Communication Map of P. Is., 1:400,000, Hq. M. I., Phil. Dept., No. CM 14-2, 1927 (Tel. and Tel. corrected to 1940, AMS); Mobil oil Road Map of the P. Is., 1:1,100,000, Standard vacuum oil Co., P. Is., 1942. Revisions from miscellaneous large-scale vertical photography, 1940; Stereo compilation by USGS from oblique photography, 1944. Hydrography compiled from 1916-1917 surveys by USC&GS, 1944.
1961	Topographic/ Bathymetric Map (TBM) Orion (Bataan) 1:50,000	Authority of the Board of Technical Surveys and Maps (BSTM)	Sources unknown
1961	TBM Balanga (Pampanga) 1:50,000	BTSM	US Army Map Series 711 compiled in 1956 by photogrammetric methods: 1947-1953 photographs and others
1961	TBM Sta. Maria (Bulacan) 1:50,000	BTSM	US Army Map Series 711 compiled in 1956 by photogrammetric methods: 1947-1953 photographs and others
1977	TM Guagua (Pampanga) 1:50,000	National Mapping and Resource Information Agency (NAMRIA)	Map information as of 1977. Sources unknown
1977	TBM Orion (Bataan)	NAMRIA	Map information as of 1977. Sources unknown
1977	TBM Malolos (Bulacan) 1:50,000	NAMRIA	Map information as of 1977. Sources unknown
1977	TBM Corregidor Is. 1:50,000	NAMRIA	Map information as of 1977. Sources unknown
1979	TM Manila 1:50,000	NAMRIA	Produced using the 1979 aerial photographs
1991	High Resolution Synthetic Aperture Radar (SAR) Tagaytay 1:100,000	INTERA/ NAMRIA	
1991	SAR Manila 1:100,000	INTERA/ NAMRIA	

This paper presents the nearshore sediment drift patterns in Manila Bay derived from geomorphological and meteorological data. The term "nearshore" refers to the coastal zone from the shoreline to just beyond the region in which waves break.

MATERIALS AND METHODS

Topographic 1:50,000-scale maps and 1:100,000-scale Synthetic Aperture Radar (SAR) images from the National Mapping and Resource Information Agency (NAMRIA; Table 1) were used to delineate the coastal geomorphological features, which, in turn, were used to determine the predominant directions of sediment transport along the coast. Changes in shoreline position over time were also determined from this data set by reducing or enlarging the maps and images to the same 1:50,000-scale and tracing the shorelines manually. Characterization of the morphology of Manila Bay was supplemented by a 1:125,000 U. S. Defense Mapping Agency bathymetric map (DMA 91280 1982). The monthly averages of wind and precipitation data for the area were acquired from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

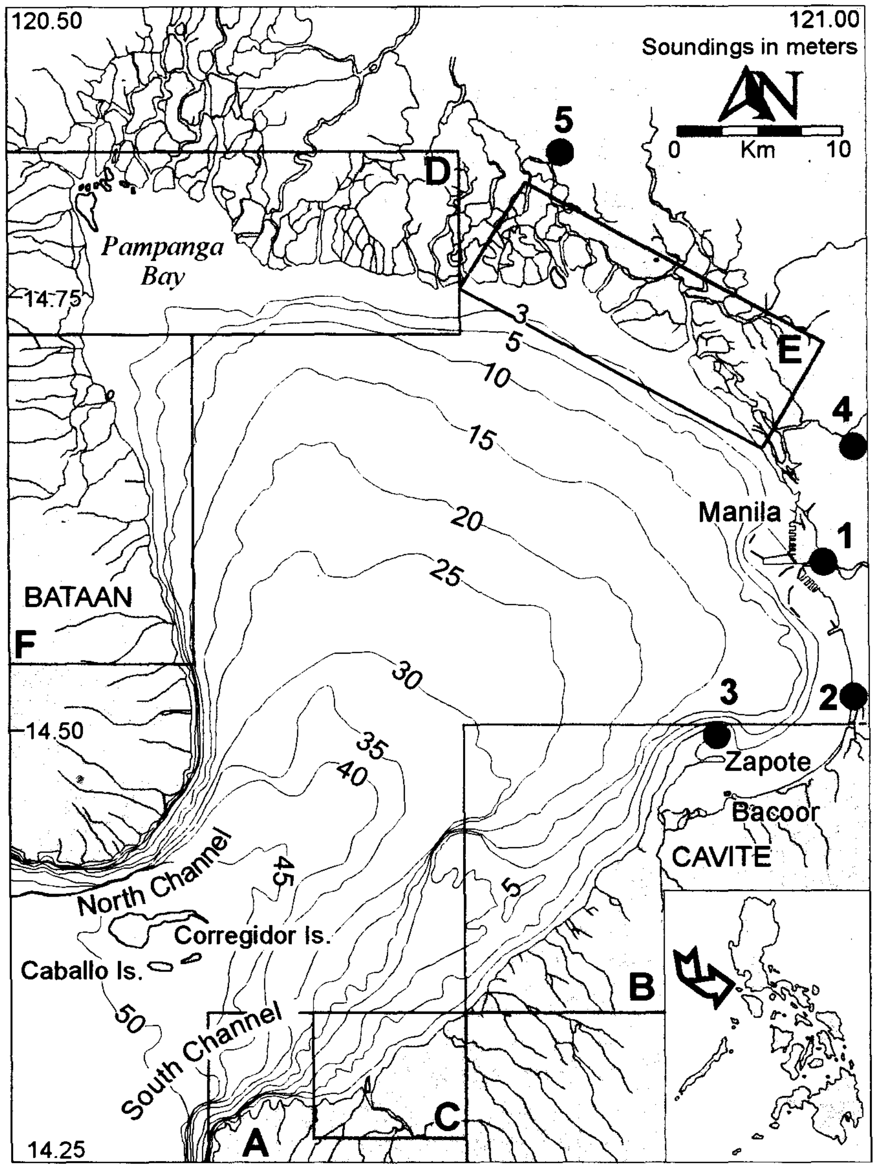

Fig. 1. General morphology and bathymetry of the Manila Bay (bathymetry data came from USDMA 1982). Circles indicate the location of the rainfall stations. Boxed areas show the location of the subsequent figures (A = Fig. 4a; B = Fig. 4b; C = Fig. 6; D = Fig. 9a; E = Fig. 9b; and F = Fig. 9c).

GENERAL CHARACTERISTICS OF THE STUDY AREA

Bay Morphology

Manila Bay has a surface area of 1,800 km^2, contained by a coastline approximately 190 km long (EMB 1992; Fig. 1). It has an average depth of 25 m and is approximately 52 km long, with widths varying from 19 km at its mouth to 56 km inside the bay. However, the mouth is divided into a South Channel and a North Channel by Corregidor and the Caballo Islands, which reduce the net width of the entrance to only about 10 km. Slightly less than 4 km wide, the North Channel has a maximum depth of 71 m, whereas the South Channel, somewhat less than 6 km wide, is no more than 47 m deep. The deepest parts of both channels are adjacent to the intervening islands. Sea floor gradients are gentlest (1m/2.5 km), in the northwest sub-basin, from the northernmost coast of Pampanga Bay out to a depth of 3 m. The steepest gradients occur along the southeastern coast of the Bataan Peninsula, where water depths can exceed 15 m less than 1 km out from the coast.

Catchment Areas

Manila Bay receives runoff from approximately 17,000 km^2 of watershed comprising 26 catchment areas (EMB 1992; Fig. 2). The two major areas contributing fresh water to the bay are the basins of the Pampanga and Pasig Rivers, which respectively contribute about 391 m^3/s (49%) and 170 m^3/s (21%). Other, smaller river systems contribute 205 m^3/s (26%); the balance of 4% comes from the net precipitation over the bay (EMB 1992). The 9,000 km^2 catchment area of the Pampanga River Basin is the largest, and includes the Angat River and other river systems in the provinces of Pampanga, Bulacan, and Nueva Ecija. The Pasig River Basin has a watershed area of 3,900 km^2 and includes the Marikina and Laguna de Bay catchment areas.

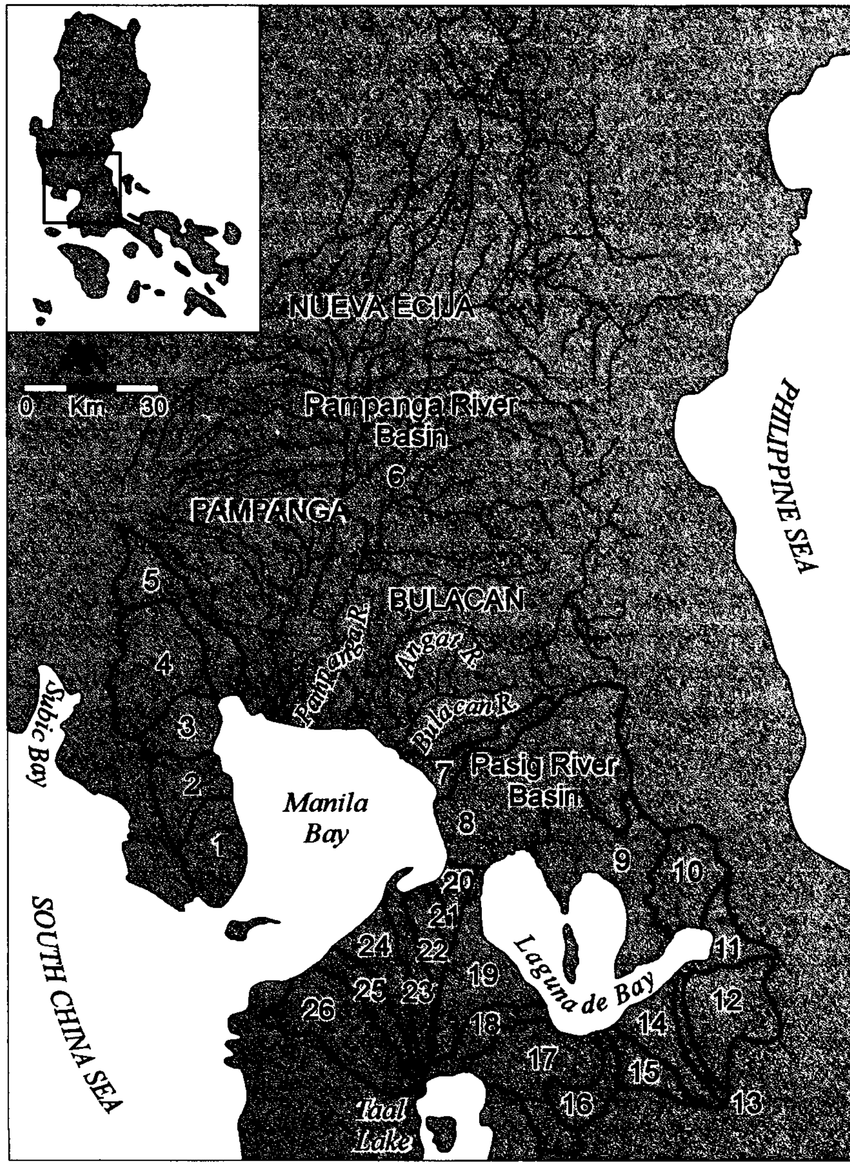

Fig. 2. Catchment areas draining into Manila Bay (modified from EMB 1992).

Precipitation, Wind, and Tides

Rainfall in the Manila Bay catchment area is characterized by two pronounced seasons: dry from November to April and wet during the rest of the year (Fig. 3). August is the rainiest month, with an average rainfall of over 400 mm (except in Malolos, Bulacan where the average precipitation is about 240 mm) while February is the driest, with less than 10 mm average monthly rainfall.

The Manila Bay region is influenced by at least three major wind regimes (De las Alas and Sodusta 1985). From October to January, steady northeasterly winds blow with speeds averaging about 5 m/s. The dominant winds from February to May are southeasterly, with speeds ranging from 3 to 6 m/s. Steady southwesterly winds with speeds of 5 to 7 m/s dominate from June to September. Other wind directions also occur, but much less frequently.

Tides along the coast of Manila Bay are predominantly diurnal and within the microtidal range. The estimated mean tidal range for Port Lamao, Bataan is 1.09 m (NAMRIA 1996). A tidal range of 1.8 m was recorded at the Manila South Harbor Station in January 1984 (Maunsell Phils. Inc. 1996).

RESULTS AND DISCUSSION

General Coastal Morphology

Manila Bay is fringed by a variety of coastal sub-environments. The southern coastlines of Cavite and Bataan are rocky and highly embayed, with local pockets of sand forming thin strips

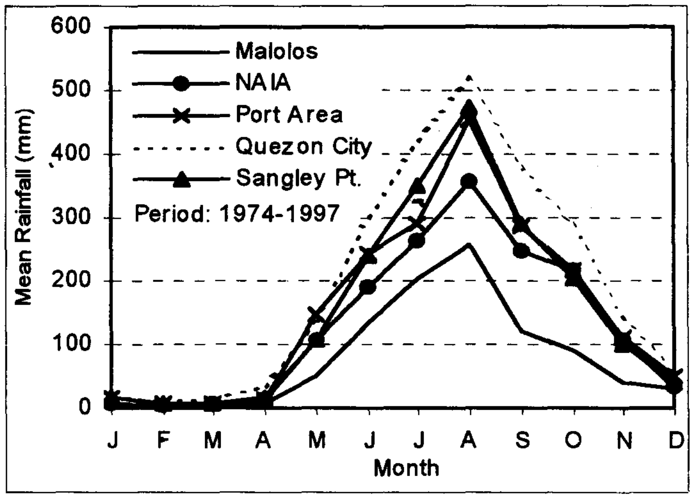

Fig. 3. Precipitation patterns along the fringes of Manila Bay. Location of the stations are indicated in Fig. 1.

of beach at the heads of coves (Fig. 4a). Along the northern coasts of Cavite to Bulacan the shoreline becomes more linear, and two or more beach ridges can be recognized. The most prominent geomorphic feature along this coast is the spit where Cavite City is located. "Cavite Spit" is approximately 10 km long, 1.25 km wide at its broadest portion, and has two recurved terminations at its northeast end (Fig. 4b).

The Cavite coastline directly facing Manila Bay is interrupted by several rivers. Wave-dominated deltas, as indicated by a series of arcuate strandplain ridges and by a lack of major distributaries, are present at the mouths of the larger rivers such as the Maragondon, Labac, and Cañas Rivers, whereas spits mark the mouths of the smaller rivers (Figs. 4 and 5). Along the northwest facing coastline, fluvial-dominated deltas have formed at the mouths of the San Juan and Imus Rivers, shielded from wave impact in the lee of Cavite Spit (Fig. 4b).

Along the coastal plain of the Manila-Navotas area is a series of beach ridges that fans out towards Bulacan (Fig. 6). In the Bulacan River area, a possible beach ridge is traced as far as approximately 7 km landward of the shoreline. Another possible ridge can be traced to Malolos, Bulacan. Field observations indicate that the ridges are sandy, but the fishpond areas enveloping them are muddy. Thus, these ridges in the coastal plains of Bulacan are better referred to as chenier ridges.

The northern coastal plain of Manila Bay, including areas from Navotas, Bulacan to Orani, Bataan, is the wide, low-lying surface of a tidal-delta plain, as strikingly indicated by a myriad of anastomosing tidal distributary channels (Fig. 6). Furthermore, northward tidal incursion of more than 20 km into the northwestern delta plain is indicated by the landward limits of Nipa palms (*Nipa fruticans*) and fishponds.

Major streams enter the tidal delta plain: the Bulacan-Meycauayan, Angat, and Pampanga Rivers (Fig. 6). Along the coast, the channels are generally spaced less than 1.5 km, and, large or small, have funnel- to trumpet-shaped morphologies, as is typical for tidal distributaries. Bathymetry reveals offshore, sub-tidal extensions of the Pasag, Malubag, and Orani Channels (Fig. 7).

The Bataan shore from Samal to Limay is linear and has a narrow coastal plain. Narrowing to the south, the plain becomes irregular and rocky between Orion and Limay. Based on the 1944 maps, the coastal plains from Navotas to Bataan used to be occupied by mangroves. Very few of these remain because almost the entire Bataan coastal plain has been converted to fishponds.

Locally Generated Waves and Predominant Longshore Currents

Waves, generated by the seasonably variable prevailing wind and modified by the morphology of the bay, drive longshore current with temporally and spatially varying directions (Fig. 8). Southwesterly winds produce longshore currents that generally flow up the bay along Bataan and to the northeast along Cavite (Fig. 8a). Wave refraction may produce divergence of longshore currents along the Manila-Bulacan coast. Similarly, refraction at the tip of Cavite Spit causes southwesterly longshore currents along the Las Piñas-Kawit coast. Under southeasterly winds, longshore currents move to the northwest along the Manila-Pampanga coast and to the north along Bataan (Fig. 8b). Northeast winds generate longshore currents that move towards the mouth of the bay (Fig. 8c). Wind-driven currents may amplify the wave-generated longshore currents, especially when wind and longshore-current directions coincide (Komar 1976), a condition that occurs along the Cavite coast with the southwest winds.

The predominance of southwest and southeast winds, combined with their greater velocities (5-7 m/s and 3-6 m/s, respectively), determine that the predominant sediment

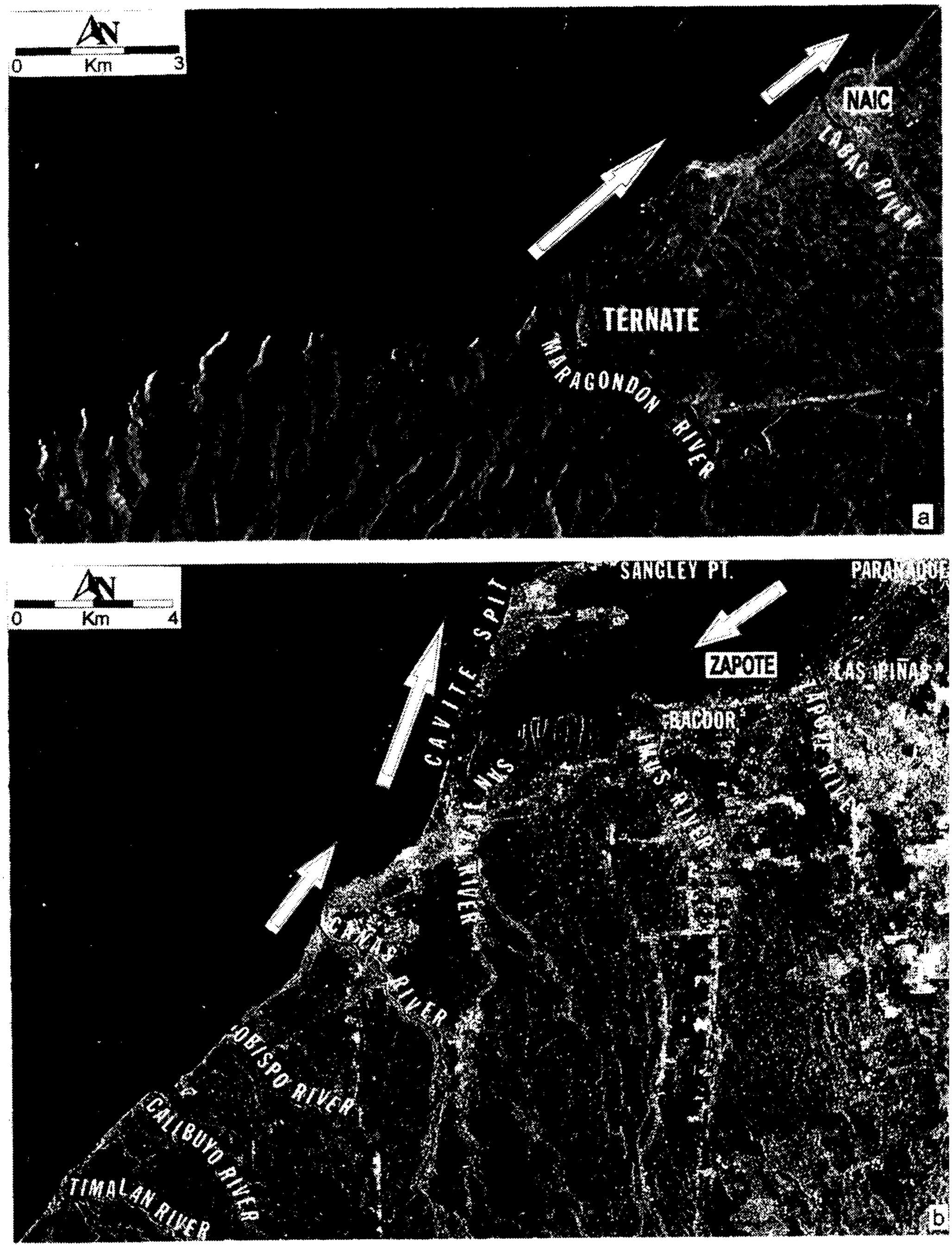

Fig. 4. Geomorphological features along the: (a) southeastern; and (b) eastern coast of Cavite. Arrows indicate net sediment drift direction derived from coastal morphology (data from NAMRIA). The areas covered in the figures are indicated in Fig. 1.

movement is to the northeast along the Cavite coast; to the northwest along the Manila-Pampanga coast; and to the north along the Bataan coast. Furthermore, greater input of river sediment into the bay during the rainy season, when winds are mainly from the southwest, causes a large amount of fine sediment to be transported to the northeastern parts of Manila Bay.

Penetration of Waves from the South China Sea

Entering Manila Bay from the South China Sea, waves should produce longshore currents that flow northeastward along the Cavite coast and northward along the Bataan shore. The South Channel being the wider opening, wave penetration is likely to be more pronounced there, and so the resulting sediment drift should be larger along the Cavite side. This

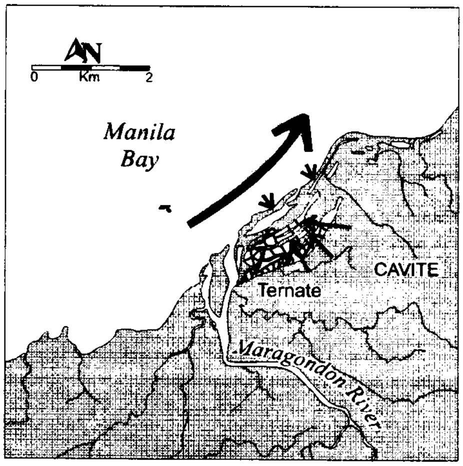

Fig. 5. Asymmetric wave-dominated Maragondon River Delta indicating a net sediment drift to the northeast (modified from NAMRIA 1977). Small arrows point to beach ridges. Location of the shoreline segment is indicated in Fig. 1.

may also be due to gentler bottom slopes which result in higher wave refraction. Waves from the South China Sea may also intensify or degrade locally generated waves. Those generated by southwest and southeast winds are likely to be intensified whereas those generated by northeast winds should be degraded. The sandy strandplains, spits, and wave-dominated deltas attest to the predominance of wave processes along the coast of Cavite.

Predominant Sediment Drift from Coastal Geomorphology and Changes in Shoreline Position

It is widely known that spits grow in the direction of the predominant longshore sediment drift. Along the coast of Cavite, wave-dominated river deltas and spits, especially the prominent Cavite Spit, point to a northeastward net sediment

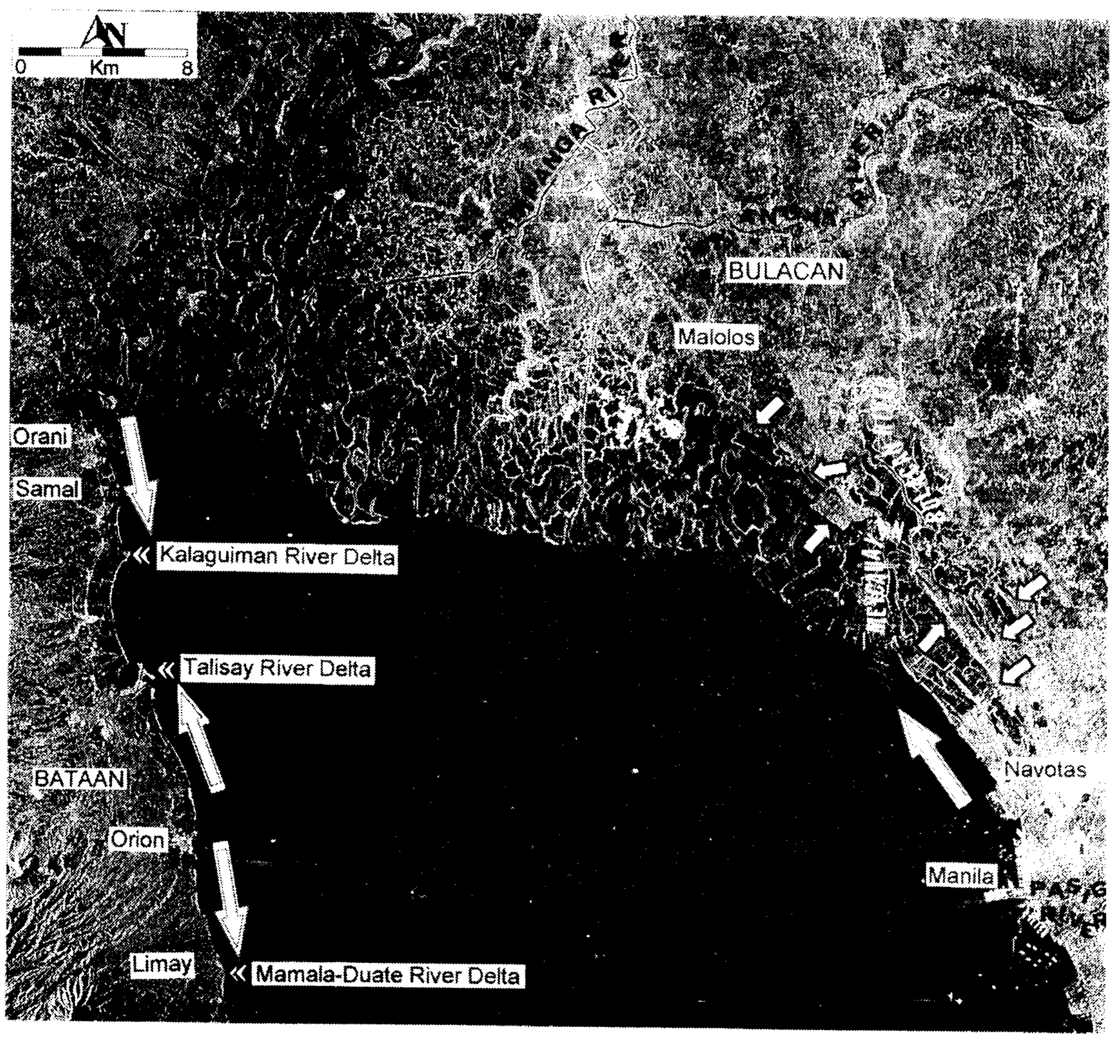

Fig. 6. Tidal delta plain fringing the coast of Pampanga and Bataan (data from NAMRIA). Large arrows indicate longshore current direction derived from coastal morphology. Small arrows point to the chenier ridges along the Bulacan coastal plain.

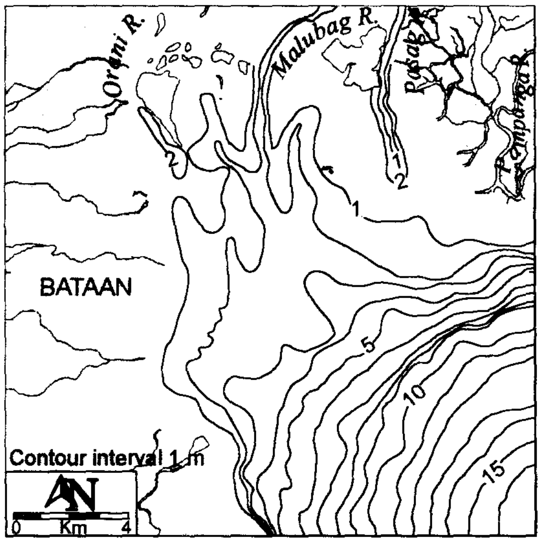

Fig. 7. Bathymetric map of the Pampanga sub-basin showing the sub-tidal continuations of the Pasag, Malubag, and Orani channels (from BTSM 1961).

drift, which is consistent with the predicted predominant longshore current direction for this area (Figs. 4 and 5).

Southwest of the Cavite Spit are several smaller spits that are associated with a northeast deflection and elongation of river mouths. From southwest to northeast, the deflected river mouths are those of the Maragondon, Labac, Timalan, Calibuyo, Obispo, and Cañas Rivers (Figs. 4, 5, and 6). Growing to the northeast, the spits deflect the mouths of the rivers and elongate them in the direction of longshore sediment drift. The morphologies of the wave-dominated deltas of the Maragondon River in Ternate and the Labac River in Naic, skewed to the northeast, are consistent with a predominant northeast sediment drift.

Along the northwest-facing coast from Zapote to Bacoor behind Cavite Spit, a southwesterly sediment drift is indicated by the southwest deflection of the western distributary of the Zapote River and the southwest skewed fluvial-dominated delta of the Imus River (Fig. 4b). This southwesterly sediment drift along this coast, as mentioned earlier, could be due to wave refraction at the tip of the Cavite Spit.

From the mouth of the Pasig River to the mouth of the Meycauayan-Bulacan River, the northwesterly deflection of rivers and divergence and termination of chenier ridges indicate the predominance of northwest sediment drift (Fig. 6). Thus, a divergence of predominant sediment drift direction occurs along the Parañaque-Las Piñas area. Again, this also results from the wave refraction.

Alongshore sediment transport may not be important along the highly irregular coastline fronting the tidal delta plain from Navotas, Bulacan to Orani, Bataan, as indicated by the numerous funnel- to trumpet-shaped channels, and their lack of preferred deflection (Fig. 6). Instead, these characteristics indicate the greater importance of onshore-offshore directed currents. This seems to be supported by the changes in the position of the shoreline and river mouths along this coastal

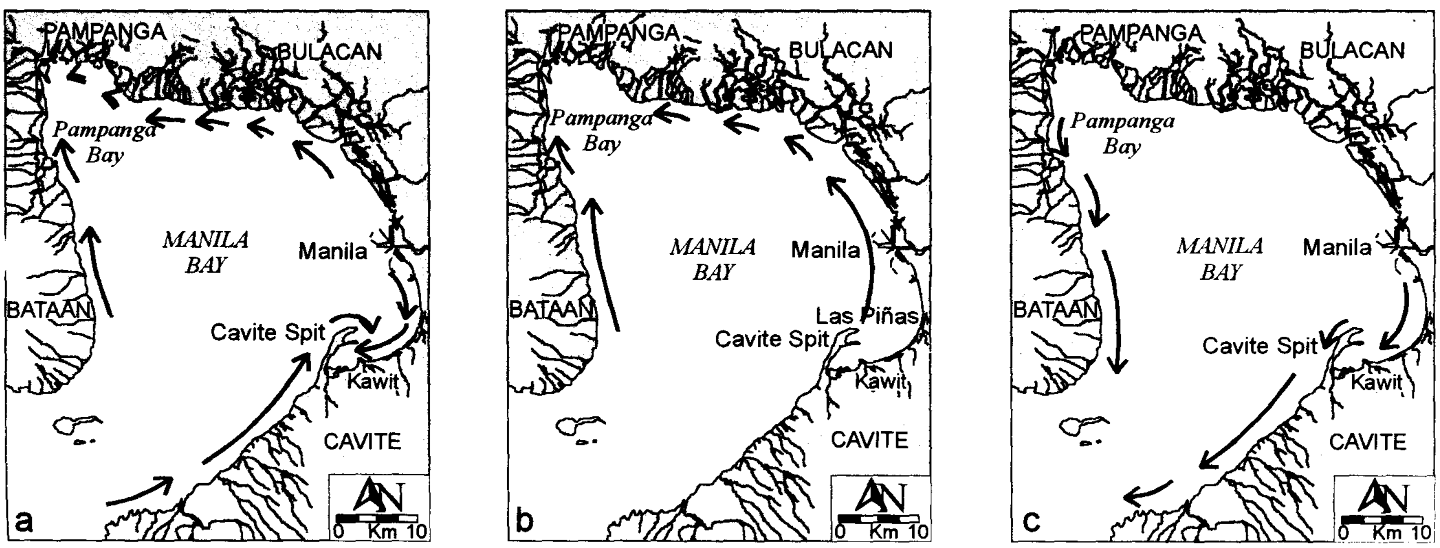

Fig. 8. Longshore currents associated with locally generated waves: (a) southwesterlies; (b) southeasterlies; and (c) northeasterlies.

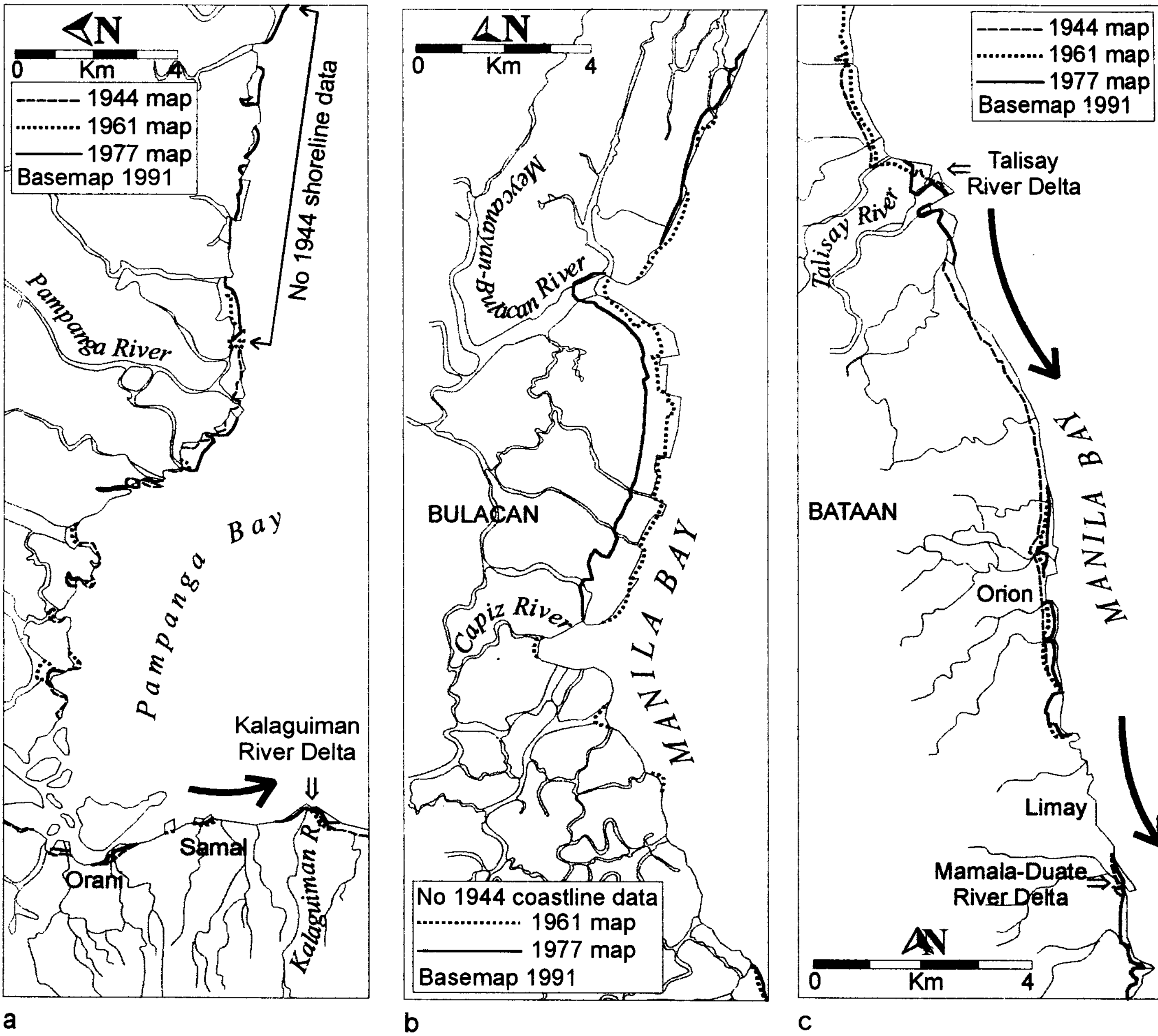

Fig. 9. Changes in shoreline position along the coast of (a) the tidal-delta plain in the Pampanga - Bataan area; (b) Bulacan; and (c) Bataan. Large arrow indicates net sediment drift direction derived from coastal morphology. The areas covered in the figures are indicated in Fig. 1.

segment (Fig. 9). In general, the position of the river mouths has not changed much. However, a slight westward shift of river mouths, maximally 350 m, can be gathered from the 1944 and 1961 topographic maps, indicating net westward sediment drift (Fig. 9b).

The changes in the shoreline position in the Meycauayan-Malabon River area are also consistent with a net westward drift (Fig. 9b). A very slight progradation occurred along the eastern side of the river mouth while progradation of as much as 1 km occurred along the western side from 1977 to 1991. This may indicate that sediments issuing out of the river are displaced to the northwest.

Along the coast of Bataan, using the skewed morphologies of the deltas, the Kalaguiman River Delta located south of Samal indicate a predominant sediment drift to the south, the Talisay River Delta in Balanga indicates drift to the north while the Mamala-Duate River Delta in Limay indicates a southerly drift (Figs. 6, 9a and 9c). The directions of net sediment drift derived from shoreline position changes are consistent with the above. Greater progradation has occurred at the northern flanks of the Mamala-Duate River and the Talisay River Deltas and along the southern parts of the Kalaguiman River Delta. Coastal progradation observed between the Kalaguiman River and the Talisay River Deltas could be attributed to the convergence of longshore currents between the two deltas.

The above geomorphic-derived net sediment drift patterns appear to be inconsistent with the predicted predominant longshore current direction; the latter predicts a predominant northerly drift for the entire Bataan coast (Fig. 8). The disagreements between the two results might be due to the interaction of the longshore currents with other nearshore current systems such as wind- and tide-driven currents. Along the Pampanga sub-basin, amplification of tidal influence can be expected from the very gentle sea floor gradient (Figs. 1 and 7). Ebb-tidal flow, as well as the river outflow from the Orani Channel might be influencing the Kalaguiman River Delta. The wide shallow platform within the Pampanga Sub-basin is also favorable to the enhanced generation of wind-driven currents (De las Alas and Sodusta 1985; Villanoy and Martin this volume). In the wind-driven circulation models of De las Alas and Sodusta (1985) and Villanoy and Martin (this volume), northward movement along the Bataan coast and a clockwise gyre of strong currents in the Pampanga sub-basin are generated during southwest winds. In contrast, counterclockwise gyres and southward moving currents are generated during the southeasterlies and northeasterlies (De las Alas and Sodusta 1985).

Importance of Tidal Processes along the Pampanga Sub-basin Coast

The interaction among the tidal-, fluvial-, and wave-processes, akin to the Galloway (1975) and Coleman and Wright (1975) delta classification, resulted in the formation of the wide tidal-river delta plain along the northern coast of the Manila Bay. The very gentle gradient, both onshore and offshore, is probably a major contributing factor to the apparent importance of tidal processes along the northern coast. A gradient of 1:20,000 occurs along the northwest coastal plains. Also, at the Pampanga sub-basin, nearshore gradients of as low as 1:5,000, from the coast to 3-m water depths, are exhibited. Thus, the lateral extentof the influence of a 1 m tidal range is amplified. Partitioning of fluvial discharge into the tidal-river delta plain distributaries will lead to a more diffused fluvial input along the coast, which will result in the lessening of the fluvial signature, as in a fluvial-dominated delta.

The relatively low energy waves reaching the northern coast is another possible contributing factor to the apparent stronger tidal influence. The formation within of large waves is precluded by the shallow, small, and protected nature of the Manila Bay. Intrusion of large waves originating from outside of the bay will be limited also because of the constricted and shallow depths of the bay mouth. If there are large waves that are able to penetrate, they will be refracted probably more towards Cavite.

Net Sediment Drift and Human-Induced Changes Along the Coast

It was shown earlier that the bay's morphology exerts a very strong control on sediment drift; changes in bay morphology will likely lead to changes in sediment dispersal. Without the Cavite Spit, wave refraction leading to the southeast sediment drift along the Zapote-Bacoor coastal segment will probably not occur. Siringan et al. (1997) proposed that prior to the growth of Cavite Spit, longshore transport was relatively uninterrupted in its northeastward movement from Cavite to Bulacan. They suggested that the sands of the chenier ridges were sourced from Cavite. With the development of the spit, the northeastward transport of sediment was cut-off, turning the Bulacan coast into a muddier environment. Furthermore, they proposed that the growth of the spit shielded the mouths of the San Juan and Imus Rivers from waves, transforming the once wave-dominated to fluvial-dominated deltas. Plans to extend the land reclamation area in the Manila Bay to almost the tip of the Cavite Spit (Maunsell Phils. Inc., unpubl.) may help in re-establishing the previous continuous northeastward sediment drift from Cavite to Bulacan. The gap between the reclaimed land and the Cavite Spit will likely experience rapid shallowing and eventual closure, unless maintained through dredging. But with or without the gap being closed, Bacoor

Bay will likely experience rapid siltation and eventually be filled-up. With the closure of the gap between the reclaimed land and the Cavite Spit, sediment from Cavite can then again march towards Bulacan. Channels along the way, natural or man-made, will likely have to be dredged to keep it open.

CONCLUSIONS

The geomorphology of the Manila Bay attests to the role of the balance among fluvial, wave, and tide processes in the formation of coastal subenvironments. Along the northern coast, despite the ~1 m tidal range in the bay, tidal processes are important, as attested by the formation of a tidal-river delta plain. The importance of wave-processes along the Cavite coast is manifested by the predominantly sandy strandplains, spits, and wave-dominated deltas. This wave-dominance is due mainly to the intrusion of waves from South China Sea.

The results show the utility of depositional geomorphological features along the coast as indicators of net sediment drift. Combining approaches in the establishment of sediment dispersal patterns allows for cross-checking and possible better definition. Interaction of wave-generated longshore currents with wind- and tide-generated currents may result in disagreements between the predicted and the geomorphic-derived net sediment drift directions. Changes in the bay's morphology, natural or man-induced, will lead to changes in the sediment dispersal patterns.

ACKNOWLEDGMENTS

Funding for this project was provided by the Office of Research Coordination of the University of the Philippines, Diliman to F. P. Siringan (Project No. 09505 Ns). Credit is also due the National Institute of Geological Sciences for providing laboratory and field facilities. A lot of thanks to Joseph M. Foronda, Cesar Villanoy, and Kelvin Rodolfo for their critical and helpful review of the final report.

REFERENCES CITED

BTSM, Board of Technical Surveys and Maps. 1956. Topographic map of Manila Bay and vicinity, 1:50,000, BTSM and Department of National Defense, Manila, 6 sheets.

Coleman, J. M. & L. D. Wright, 1975. Modern river deltas: variability of processes and sand bodies. In M. L. Broussard (ed.), Deltas, Models for Exploration. Houston Geological Society, Houston, USA: 99-149.

de las Alas, J. G. & J. A. Sodusta, 1985. A model for the wind driven circulation of Manila Bay. *Nat. and Appl. Sci. Bull.* 37(2): 159-170.

EMB, Environmental Management Bureau. 1992. Manila Bay Monitoring Program. Environmental Management Bureau, Department of Environment and Natural Resources, Quezon City, 87 pp.

Galloway, W. E., 1975. Process framework for describing the morphologic and stratigraphic evolution of deltaic depositional systems. In M. L. Broussard (ed.), Deltas, Models for Exploration. Houston Geological Society, Houston, USA: 87-98.

Komar, P. D., 1976. Beach Processes and Sedimentation. Prentice Hall Inc., New Jersey, USA, 429 pp.

Maunsell Phils., Inc., unpubl. Manila Bay land reclamation project. Environmental Impact Statement, 88 pp.

NAMRIA, National Mapping and Resource Information Authority. 1977. Topographic map of Manila Bay and vicinity, 1:50,000. Department of Environment and Natural Resources, Manila, 6 sheets.

NAMRIA, National Mapping and Resource Information Authority. 1991. Synthetic Aperture Radar of Manila, 1:100,000. Department of Environment and Natural Resources, Manila.

NAMRIA, National Mapping and Resource Information Authority. 1996. Tide and Current Tables. The Coast and Geodetic Survey Department, National Mapping and Resource Information Authority, Department of Environment and Natural Resources, Manila, 243 pp.

Siringan, F. P., K. L. Queaño, E. M. Francisco, & C. L. Ringor, 1997. Long-Term and Short-Term Shoreline Changes Along the Coast of Manila Bay. In F. Casareo & M. N. R. Casareo (eds.), GEOCON '96 Proceedings. Geological Society of the Philippines: 95-103.

US AMS, United States Army Map Service. 1944. Topographic map of Manila Bay and vicinity, 5 sheets, 1.50,000. Chief of Engineer, Army Map Service, US Army, Washington, D.C..

US Defense Mapping Agency Hydrographic Topographic Center. 1982. Bathymetric map of Manila Bay and Approaches, Sheet 91280, 1:125,000. US Defense Mapping Agency, Washington D.C..

Villanoy, C. & M. Martin, 1997. Modeling the circulation of Manila Bay: Assessing the relative magnitudes of wind and tide forcing. *Sc. Dil.* 9(1/2): 26-35.