Changes in the Position of the Zambales Shoreline Before and After the 1991 Mt. Pinatubo Eruption: Controls of Shoreline Change

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ABSTRACT

Shoreline changes along the southern Zambales coast, both short-term — a few to several tens of years — and long-term — hundreds to a few thousands of years — have been determined from bathymetric and topographic maps, satellite images, space shuttle data, and aerial photographs. The dramatic increase of sediment input along the Zambales coast due to the 1991 Mt. Pinatubo eruption resulted in immediate, extensive, and rapid rates of coastal progradation at and adjacent to river mouths. The Bucao River mouth experienced the highest rates of progradation following the eruption, but rapid retreats also occurred. Furthermore, similar advances and retreats of this shoreline were also observed prior to the 1991 eruption; thus, the net change in shoreline position has been minimal. In contrast, progradation has been more pronounced along the discharge area of the Pamatawan and Sto. Tomas Rivers. This is surprising, given that their combined sediment yield is less than that of the Bucao River. Along the more southern segment of the coast, there has been greater progradation which may be attributed to the relatively gentler gradient of the adjacent shelf. Off the Bucao River, a submarine canyon taps the river mouth directly; thus, most of the sediments bypass the coast and shelf.

The deltaic promontory that now characterizes the mouth of Sto. Tomas River was formed only after 1944. The delta formation cannot be due to the shifting of the river mouth because the Sto. Tomas River had been emptying at the same point even before the delta buildup. An increase in precipitation in the early 60's increased the river's discharge, which could have elevated the sediment yield leading to the delta buildup.

Autocyclic changes in the distributary system of the Sto. Tomas alluvial fan redirected the flow of sediment to the Pamatawan River probably during the two episodes of eruption of Mt. Pinatubo prior to 1991. This resulted in the buildup of a delta much larger than the present day Pamatawan River delta.

INTRODUCTION

Of the approximately $7x10^9$ m^3 of pyroclastic material erupted by Mt. Pinatubo in 1991, about 75% was deposited along the western slopes of the volcano (Daligdig et al. 1991). Lahars and normal floods remobilized and redistributed the pyroclastic materials along the alluvial plains of the Bucao and Sto. Tomas Rivers, the two primary river systems draining the western slopes of Mt. Pinatubo. Materials from previous eruptions of Mt. Pinatubo have built alluvial fans where we now find Botolan for the Bucao River and San Rafael, San Marcelino, Castillejos, San Antonio, San Narciso, and San Felipe for the Sto. Tomas River (Newhall et al. 1996).

Remobilization of recently erupted pyroclastic material has delivered huge amounts of sediment along the Zambales coast and more is enroute. The sudden increase in the available sediment should lead to drastic changes in fluvial and coastal morphologies. Recent and current studies (e.g. cf. Umbal 1994; Javelosa 1994; Remotigue 1996; Zambales Lahar Scientific Monitoring Group (ZLSMG) ongoing) have focused on the morphologic changes, as well as processes occurring within the fluvial regime. However, the impact of the eruption on coastal sedimentation has received little attention.

This paper presents the effects of the rapid and massive

Key words: shoreline change, Mt. Pinatubo

input of remobilized pyroclastic material along the Zambales coast by documenting changes in shoreline position. Coastal changes before the eruption are also presented. These short-term and long-term patterns of coastal changes are used to evaluate the role and interplay of sediment yield and shelf morphology in the evolution of the southern Zambales coast.

PREVIOUS STUDIES DOCUMENTING THE IMPACT OF RAPID, MASSIVE INPUT OF SEDIMENT TO COASTAL SEDIMENTATION

Kuenzi et al. (1979) described how an elongate deltaic platform prograded about 7 km into the Pacific Ocean between 1902 and 1922, following the eruption of 5.5 km^3 of pyroclastic material by Santa Maria Volcano in Guatemala in 1902. Roughly 4 km^3 of sediments accumulated in the delta. Nieuwenhuyse and Kroonenberg (1994) concluded that beach ridge formation along the Caribbean coast of Costa Rica prevails during the episodic rapid input of sediment triggered by volcanic eruptions in the Costa Rican Central Cordillera.

Episodic, rapid input of sediment along coasts may also occur during flood events. Hamilton and Anderson (1994) documented the impact in 1992 of a protracted ten-year flood event on the Brazos River Delta along the Texas Gulf Coast. They documented the formation of a new mouth bar approximately 2 km seaward of the previous mouth bar position in less than a year after the flood.

These studies have also shown that, with the return of sediment supply to normal levels, the segment of the coast that experienced the greatest progradation subsequently experienced erosion.

MATERIALS AND METHODS

Bathymetric and topographic maps, low elevation aerial and high elevation NASA Shuttle photographs, Synthetic Aperture Radar (SAR) and Landsat images were reduced or enlarged to the same scale (1:50,000) and were used to establish shoreline changes along the Zambales coast (Table 1). To enhance and apply projection corrections, the images were scanned and digitized. Corrections for distortion were applied to the digitized data using an image analysis program.

Precipitation and wind data from the Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA) stations and a compiled record of river discharge and other parameters of several river systems in the study were gathered and correlated with observed trends of coastal change.

Table 1. List of topographic and geological maps, aerial photographs, SAR and shuttle images used.

Year	Data	Source	Original Scale
1944	Topographic map	US Map Series 812	1:25,000
1977	Topographic map	National Mapping and Resource Information Authority (NAMRIA)	1:50,000
1981	Geological map	Mines and Geosciences Bureau (MGB)	1:50,000
1987	Topographic map	US Defense Mapping Agency	1:50,000
Apr 1991	Synthetic Aperture Radar (SAR)	NAMRIA	1:100,000
Nov 1991	Aerial photograph	NAMRIA	1:15,000
Apr 1994	Shuttle image	National Aeronautics and Space Administration	1:200,000

GENERAL SETTING OF THE STUDY AREA

The Zambales coast is situated within the West Luzon arc system, which is associated with the east-dipping subduction of the Manila Trench beneath the Luzon arc (Cardwell et al. 1983; Karig 1973). The studied coast, stretching northward from Pundaquit, San Antonio to Bangan, Botolan, is linear, has a relatively gentle coastal gradient, and is terrigenous clastic sediment-dominated (Fig. 1). In contrast, the coasts north of Bangan and south of Pundaquit are highly embayed, with steep gradients and are associated with fringing coral reefs.

The principal rivers supplying sediment to the San Antonio-Botolan segment of the coast are the Bucao, Maloma, Sto. Tomas, and Pamatawan. Of these, only the Bucao and Sto. Tomas Rivers drain directly significant areas of the Pinatubo flanks: 270 km^2 or 41% of the Bucao watershed and 132 km^2 or 45% of the Sto. Tomas watershed (Umbal 1994). The western flanks of Mt. Pinatubo received 75% of the pyroclastic materials deposited in 1991; of this, 65% was emplaced within the drainage area of the Bucao River (Daligdig et al. 1991).

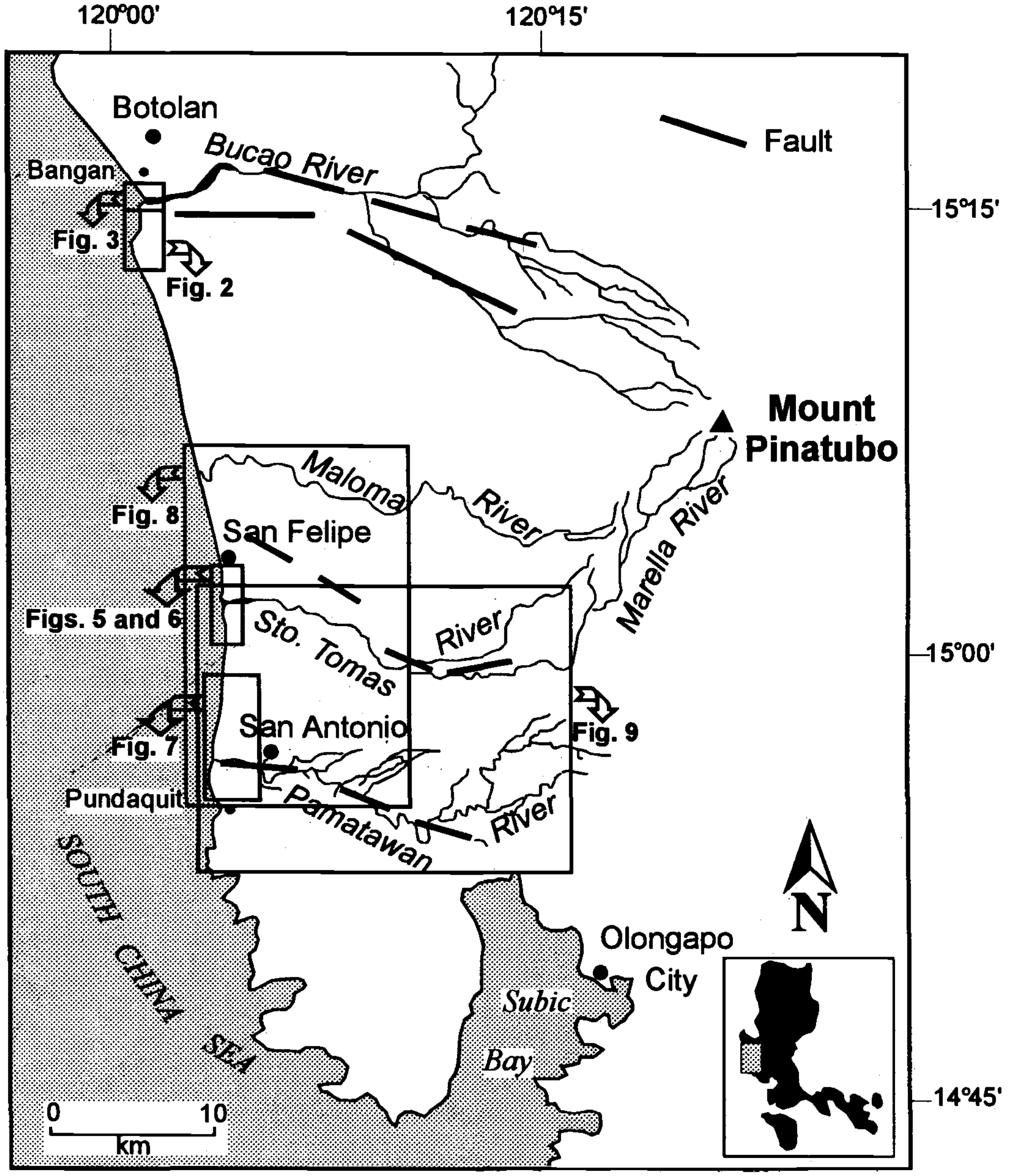


Fig. 1. Location map of the study area. Also shown are the fault traces associated with the Bucao and Sto. Tomas Rivers (data from BED 1986 and Javelosa 1994). Offshore traces of faults are shown in Fig. 11a. The locations of subsequent figures are indicated in the boxed areas.

METEOROLOGICAL AND OCEANOGRAPHIC SETTING

Rainfall data from several stations along the western flank of Mt. Pinatubo show pronounced dry and wet periods. October to May is the dry season and June to September n. A 32-year PAGASA rainfall record (1961-1993) in Iba indicates that August is the wettest month, having a mean rainfall of 1121 mm. Short, intense rainstorms are common during wet season. Most of the annual precipitation is brought about by three to four typhoons and by the enhancement of southwest monsoon flow. During dry season, the average monthly rainfall is less than 100 mm. The driest months are January and February when the mean monthly rainfall is less than 4 mm.

A 21-year PAGASA wind record (1951-1970) in Iba shows that the wind direction, from October to May, is mainly from the northwest, with an average velocity of approximately 4 knots (BHP 1993). From June to September, the winds come from the southwest, with an average velocity of 3 knots.

Regional wave data for the South China Sea indicate that the Zambales coast, during the northerlies, may experience 1.5 m high, with a period of 5s wind waves and 2 m high, 7s swell waves. During the southwesterlies, the wind waves are 1.5 m high with a period of 4s and swell waves are

2 m high with a period of 7s (Sui 1994). The tides are mainly diurnal with a range that is slightly less than 1 m (NAMRIA Tide Tables).

The longer duration and greater velocity of northwesterly winds and the higher wave periods during this time suggest a predominant longshore current direction to the southeast. However, the scarcity of clastic sediments south of Pundaquit and the northward wedging of coastal deposits, suggest greater sediment transport to the northwest. Also, net sediment movement could be to the northwest as a result of a higher discharge during the months of June to September when winds come from the southwest.

SHORT-TERM SHORELINE CHANGES BEFORE THE ERUPTION

The Bucao River

The 1944 to April 1991 data indicate that the shoreline fronting the Bucao River mouth has oscillated landward and seaward, thus, the net shoreline change has been minimal (Fig. 2a-d). However, the 1944 and 1977 maps indicate that at and south of Botolan Point, progradation of as much as 400 m may have occurred. The shoreline position along this segment of the coast remained stable till after 1987. Erosion along most of the coast seems to have transpired prior to the eruption. Associated with the oscillation of the shoreline fronting the mouth of the Bucao River are the lateral shifts in the position of the river mouth. A comparison of the 1977 and the 1944 maps shows that the river mouth shifted southward by approximately 1500 m (Fig. 2a). This shift was also accompanied by progradation of as much as 500 m. Whether the shift occurred slowly or suddenly is not known. However, the terrace that marks the southernmost extent of the channel, based on eyewitness accounts, was cut by elevated floodwaters during the passage of a typhoon in 1972 (Fig. 3). The river mouth is shown to have shifted northward by approximately 750 m in the 1981 map (Fig. 2b) and by another 500 m in the 1987 map (Fig. 2c). In the 1991 SAR image, the main river outlet appears to have shifted back southward by about 500 m (Fig. 2d).

The Sto. Tomas River

A net land gain occurred from 1944 to April 1991 in the Sto. Tomas River Delta area (Fig. 5a-d). In the 1944 map, the segment of the shoreline where the Sto. Tomas River empties into the sea was linear. The deltaic promontory that now characterizes the discharge point of the Sto. Tomas River was not there yet. In the 1987 map, the Sto. Tomas Delta prograded by 750 m.

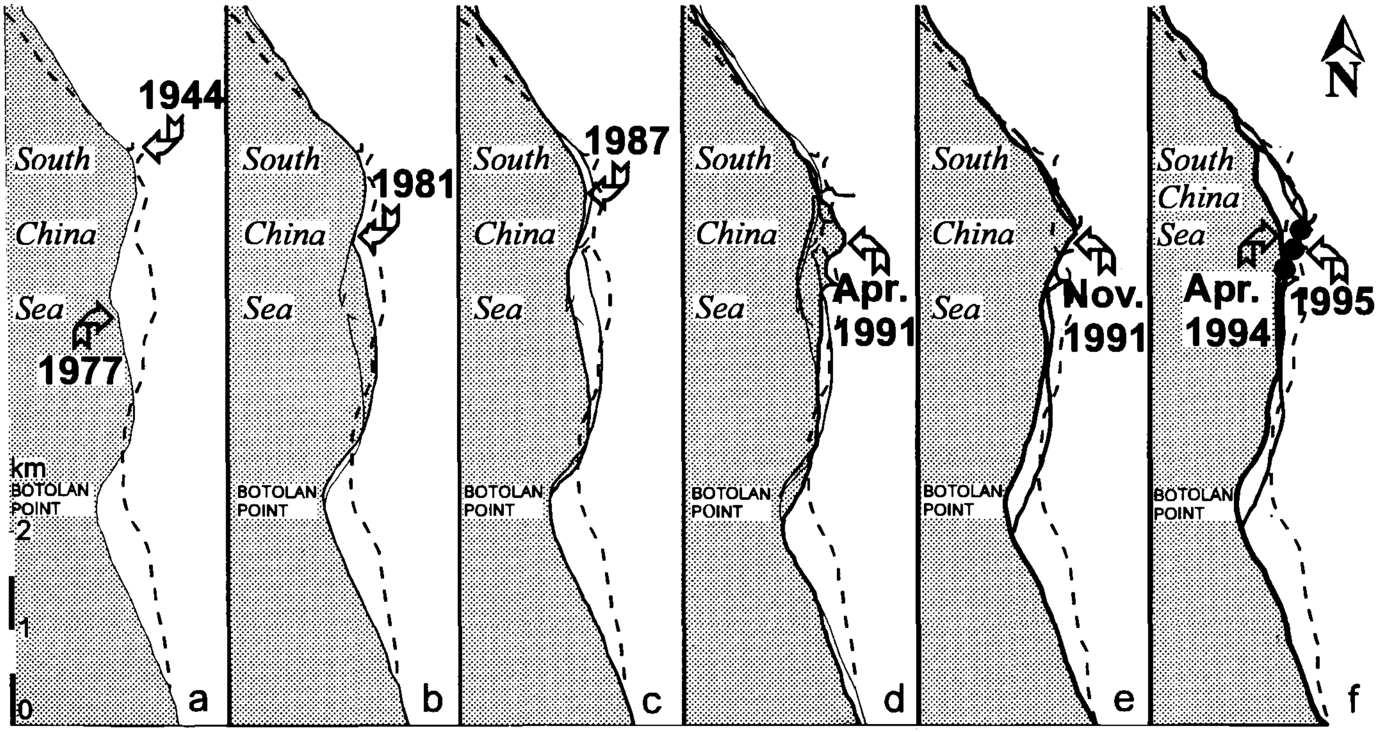


Fig. 2. Changes in the shoreline position along the discharge area of the Bucao River before and after the 1991 Mt. Pinatubo eruption. Also indicated are shifts in the position of the river mouth and the 1995 GPS readings tracing the shoreline (marked by filled circles). The location of the shoreline segment is indicated in Fig. 1.

Fig. 3. Aerial photograph of the Bucao River five months after the 1991 Mt. Pinatubo eruption. Also indicated are the traces of some of the beach ridges (marked by the thin lines) and the northern and southern flanks of the 1944 and 1977 channels respectively (bold lines). The area covered in the figure is indicated in Fig. 1.

The formation of the Sto. Tomas River Delta due to channel mouth shifting can be ruled out because the Sto. Tomas River had been emptying at the same point even before the delta build-up. An increase in the sediment input caused either by an increase in river discharge or sediment availability in the watershed, or by changes in the efficiency of the littoral system in redistributing the coastal sediments, or combinations of these, may have occurred to allow the delta build-up. Man, through increased agricultural activities may have also influenced increased sediment availability. A record of the Sto. Tomas River's mean flow indicates that increase in river discharge could be a probable cause. The mean flow of the Sto. Tomas River, based on a 34-year record (1947-1983), is 277 m^3/s (Fig. 4). In 1961 to 1963, the annual flow ranged from 572 m^3/s to 855 m^3/s. However by 1968, the mean flow dropped precipitously

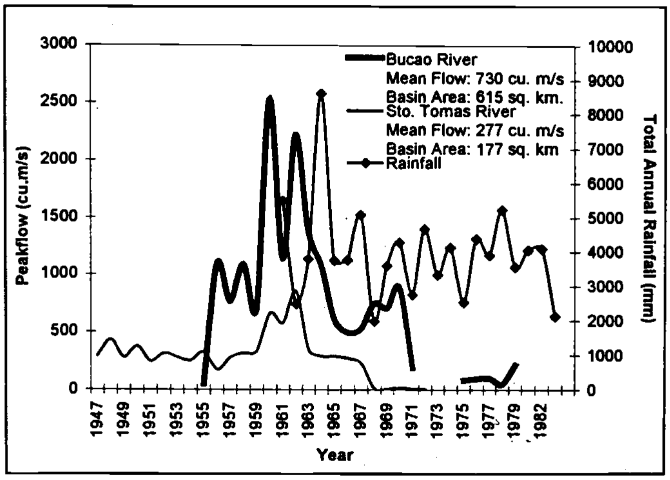


Fig. 4. Annual peakflows of the Bucao and Sto. Tomas Rivers (data from DPWH, 1991) and total yearly rainfall in Iba, Zambales (data from PAGASA).

to below 100 m^3/s. These changes in the river flow might be due to changes in precipitation as suggested by similar trends in the record of the Bucao River and by the precipitation record from Iba.

SHORELINE DISPLACEMENTS AFTER THE 1991 MT. PINATUBO ERUPTION

The Bucao River

Aerial photographs taken five months after the 1991 Mt. Pinatubo eruption show that the Bucao River estuary was immediately filled up. The former meandering-type channel morphology was replaced by a braided pattern, and the average width of the river channel increased by 2000 m. Progradation is observed along most of the adjacent shoreline (Fig. 2e-f). At least 200 m of progradation seems to have occurred north of Botolan Point. However, the shoreline fronting the river mouth receded by as much as 150 m. This shoreline retreat was most likely due to shoreface or delta front collapse. The rapid sedimentation and progradation would have mostly likely resulted in: (1) oversteepening of the shoreface; (2) greater entrapment of pore fluids; and (3) increased overburden. These conditions are favorable to the triggering of mass wasting.

In the 1994 Space Shuttle image, the shoreline fronting the river mouth appears to have readvanced by at least 250 m relative to the November 1991 shoreline (Fig. 2f). This can be attributed to the voluminous amount of loose pyroclastic material made available for reworking by fluvial and lahar processes (Fig. 6). In April 1995, based on GPS-derived locations of the landward limit of the swash zone, the shoreline fronting the river mouth appears to have again receded to the April 1991 shoreline position (Fig. 2f). A decrease in the volume of lahar deposit (Fig. 6) and a general decrease in the precipitation may have caused this retreat. Accounts of local residents point to a regular progradation and recession of the shoreline fronting the river mouth. These post-eruption changes are consonant with those indicated by the pre-eruption data, although the frequency or rates of oscillation may have differed.

The Sto. Tomas River

At the Sto. Tomas River delta, five months after the eruption, progradation of as much as 200 m is observed along the entire adjacent coast (Fig. 5a-f). In the 1994 space shuttle image, there appears to be a slight erosion south of the river mouth and progradation north of the river mouth (Fig. 5f). In 1995, the GPS-derived outline of the delta apex plots along the November 1991 coastline. The subsequent rates of progradation appear to have decreased relative to the

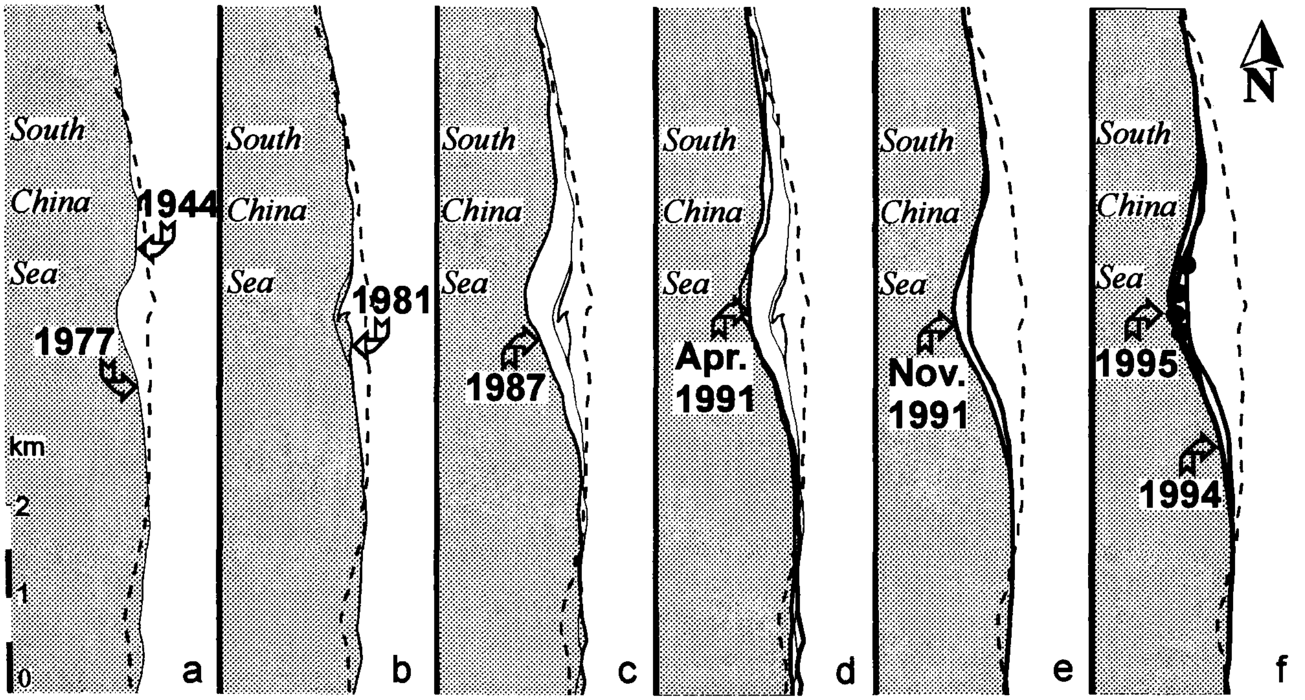


Fig. 5. Changes in the shoreline position along the discharge area of the Sto. Tomas River. Also indicated are the 1995 GPS readings tracing the shoreline (marked by filled circles). Location of the shoreline segment is indicated in Fig. 1.

first few months after the eruption. This decrease in the total amount of progradation might be due to: (1) a reduction in the amount of lahar sediments delivered along the coast; (2) an increase of the accommodation space directly in front of the river mouth due to progradation of the delta in deeper waters; (3) an increase in the offshore and alongshore rates of sediment redistribution; (4) a reduction sediment discharge; or (5) any combination of these three factors. From 1991 to 1993, a general decrease in precipitation is recorded by PAGASA in their Iba, Zambales station. In addition, there is a continuous decline in the volume of lahar deposited along Marella-Sto. Tomas River from 1992 to 1995 (Fig. 6).

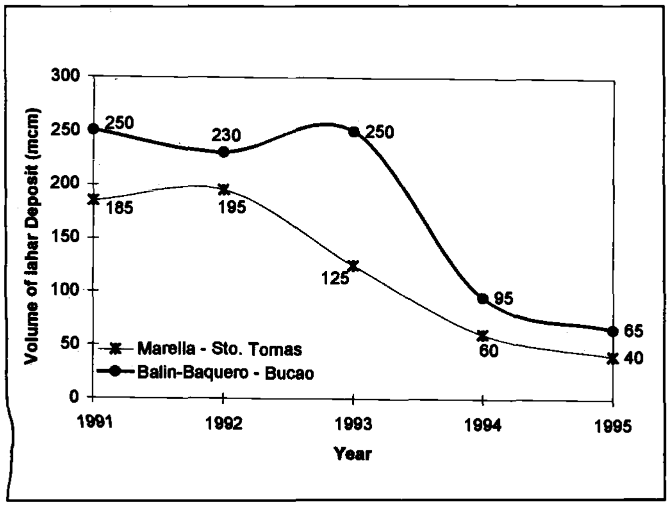


Fig. 6. Annual lahar sediment volumes of the Bucao and Sto. Tomas Rivers (data from PHIVOLCS and ZLSMG).

THE LONGER-TERM RECORD OF SHORELINE CHANGE

The 1991 SAR image, aerial photographs, and topographic maps were interpreted to determine the longer-term changes in shoreline positions. The paleoshorelines are indicated by alternating elevated and depressed linear features along the coastal plain, corresponding to beach ridges (elevated) and swales (depression) (Figs. 3, 7, 8, and 9). South of the Bucao River mouth, the oldest recognizable beach ridge is approximately 700 m landward of the 1991 coastline (Fig. 3). In the Sto. Tomas River Delta area, the oldest recognizable beach ridge and swale topography is more than 1500 m landward of the present delta apex (Figs. 7 and 9).

Along the southern segment of the Zambales coast, the rapid convergence of beach ridges located north and south of the Pamatawan River indicates the presence of an older and bigger delta than the present deltas of the Pamatawan and Sto. Tomas Rivers (Fig. 8). The geometry of the beach ridges suggests that the main river mouth was previously located about 1 km north of the present river mouth (within the Dinumagat-Linoron River System) and that the delta could have extended by as much as 1 km seaward. In the SAR image, two major coastal wedges pinching out northward indicate redistribution of sediment from the Pamatawan Delta (Fig. 9). The two wedges indicate at least two episodes of major build up of the Pamatawan Delta; the younger wedge contains the beach ridge sets in Fig.8. The time the present shoreline position was obtained is unknown. It is clear, however, that the present coastal morphology has remained relatively the same since 1944, although a shoreline retreat of approximately 200 m probably occurred between 1987 and 1991. Accounts of local residents indicate that progradation of more than 5 m has occurred since after the 1991 Mt. Pinatubo eruption.

The large Pamatawan paleodelta implies that sediment supply was previously much higher than what is being presently delivered by either the Pamatawan or Sto. Tomas Rivers. The elevated sediment delivery that appears to have occurred in pulses could be associated with the earlier episodes of the Mt. Pinatubo eruption. Six major eruptive episodes, between 400 and 30,000 years BP, have been recognized from radiocarbon dating of charred wood (Umbal 1994). The last two major eruptive periods (occurring between 3,000 to 8,000 and 400 to 800 years BP, respectively), both characterized by multiple episodes of eruption, are represented by pyroclastic flow and lahar deposits exposed along the channels in the southwest sector of the volcano (Umbal 1994). Thus, it is possible that the two episodes of major delta build up correspond to the last two major eruptive periods of Mt. Pinatubo.

The occurrence of this large paleodeltaic promontory along this segment of the Zambales coast suggests that: (1) the Pamatawan River with the Laglaboson-Camachile or the Dinumagat-Linoron River Systems was the primary distributary channel of the Sto. Tomas alluvial plain; and (2) the more likely pathway taken by sediments, especially during periods when the discharge or sediment load is extremely high, correspond to the Laglaboson-Camachile and Dinumagat-Linoron River Systems (Fig. 10). These pathways, being more aligned to the trend of the Marella River, a tributary of the Sto. Tomas River draining the southwest flank of Mt. Pinatubo, appear to be the more natural pathway that will be taken by an unimpeded flow.

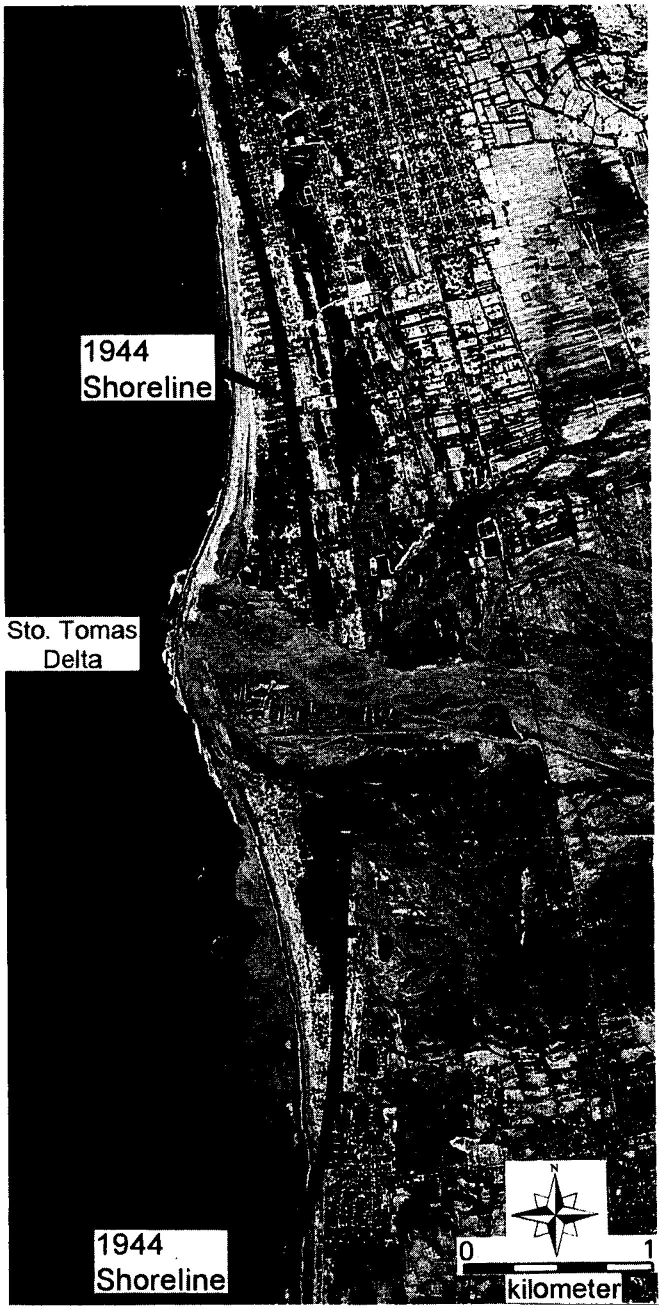


Fig. 7. Aerial photograph of the Sto. Tomas River Delta and adjacent coast 5 months after the 1991 Mt. Pinatubo eruption. The possible trace of the 1944 shoreline is indicated by the thin line. Location of the shoreline is indicated in Fig. 1 (data from NAMRIA).

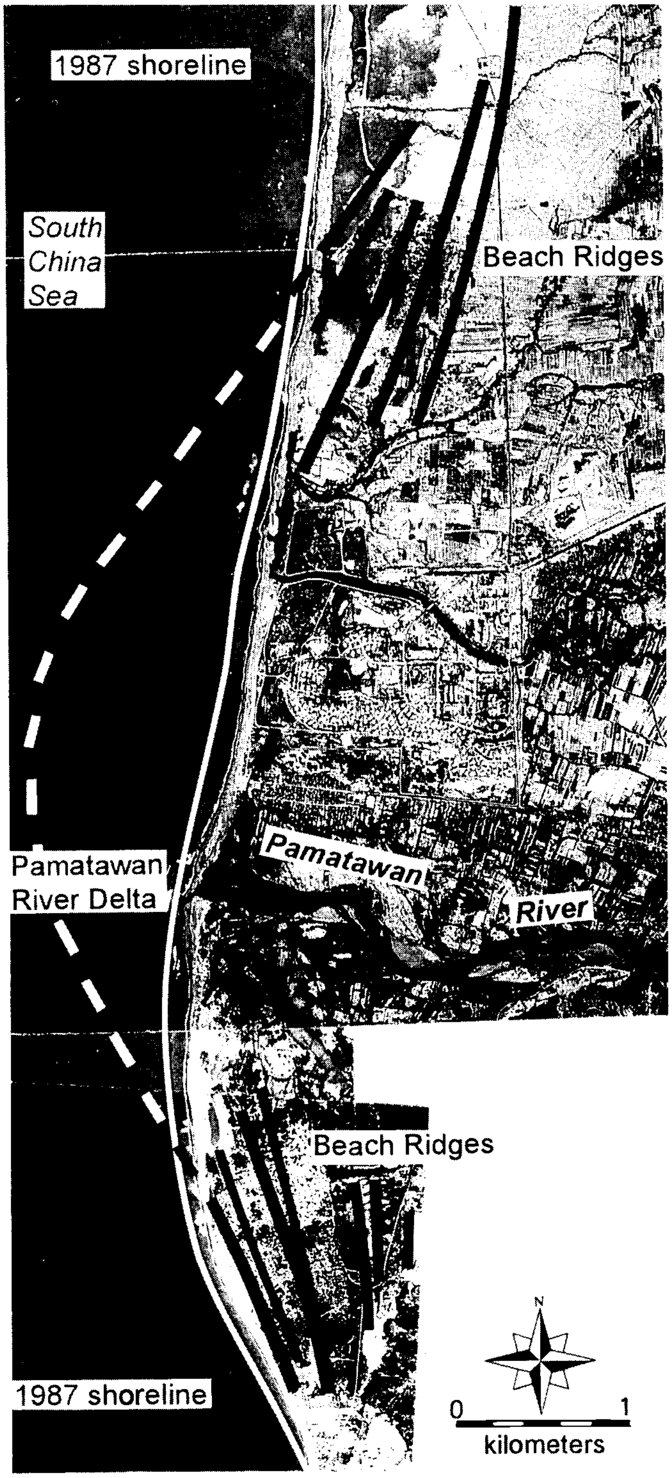


Fig. 8. The Pamatawan Delta and the beach ridges (red lines) defining a larger than present Pamatawan paleodelta (broken line). Also indicated is the 1987 shoreline. The area covered in the figure is indicated in Fig. 1 (aerial photographs taken in Nov. 1991; source: NAMRIA).

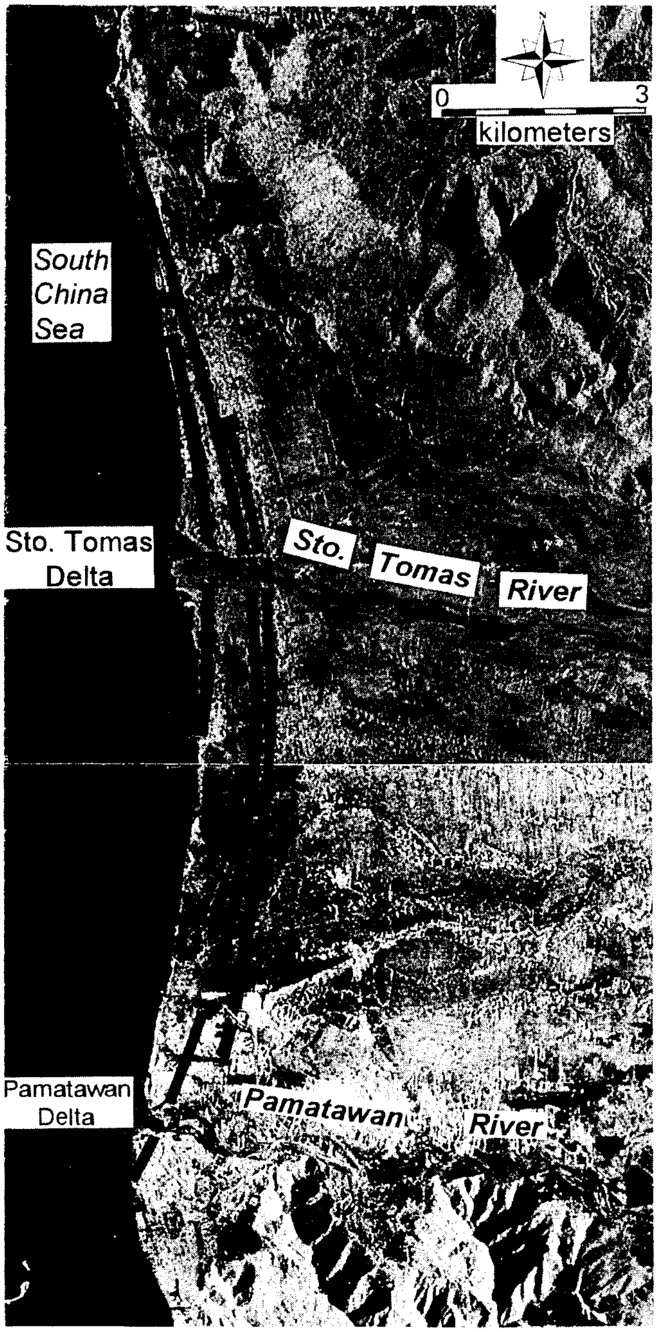


Fig. 9. Beach ridge trends defining a northward wedging of coastal deposits in the SAR image. The area covered in the figure is indicated in Fig. 1.

These shifting and possible branching out downdip of the Marella River partly defines the alluvial fan landscape, herein called the Sto, Tomas River Alluvial Fan, within the Sto. Tomas plain. Aggradation at the head of this alluvial fan, at the San Rafael area where the stream gradient is drastically reduced and the alluvial plain widens, may shift the flow to a more southerly direction (towards Castillejos) or to an easterly flow (along Sto. Tomas River). The aggradation presently occurring along the Sto. Tomas River System, if not fot the Sto. Tomas Dike and its tributary, the Marella River, would have probably already redirected the flow towards the Laglaboson-Camachile or the Dinumagat-Linoron River Systems. However, the Sto. Tomas Dike, confining and even amplifying the aggradation, may just make the shift more catastrophic. This is consistent with the prognostications made by Rodolfo et. al. (1993) on the possible fate of the Sto. Tomas Dike.

RATE OF SEDIMENT INPUT AS A FACTOR IN COASTAL SEDIMENTATION

The changes in the shoreline position along the Zambales coast, before and after the 1991 Mt. Pinatubo eruption, attest to the influence of sedimentation rate on coastal evolution — that an increase in the rate of sediment input would lead to coastal progradation. The vast volume of loose sediment still available for fluvial and lahar reworking indicates that the elevated rates of sediment input may still persist for several years. Projections of Mt. Pinatubo's sediment delivery yield, using an exponential decay function, point to the year 2010 as the time during which sediment yield of fluvial systems will return to normal (Newhall 1994). At this time, erosion is most likely to ensue, especially for those segments that will experience the greatest amount of progradation (e.g., the Sto. Tomas River Delta) similar to what have occurred along the Guatemala, Costa Rica, and Texas coasts (Kuenzi et al. 1979; Nieuwenhuyse and Kroonenberg 1994; Hamilton and Anderson 1994).

SHELF MORPHOLOGY AS A FACTOR IN COASTAL EVOLUTION

The short-term (pre- and post-eruption) and longer-term (based on paleoshoreline trends) changes in shoreline position show that coastal progradation in the Sto. Tomas River area is more pronounced compared to that which occurred in the Bucao River area, despite an expected greater sediment yield in the latter. Compared to the Sto. Tomas River, the Bucao River has: (1) a mean flow that is 2.6 times greater, (2) a drainage area that is 3.5 times greater, (3) steeper channel gradients, and (4) a higher percentage of watershed within the flanks of Mt. Pinatubo (Figs. 5 and 11).

Less progradation in the Bucao River area is probably attributable to the occurrence of a submarine canyon directly offshore of the Bucao River mouth (Fig. 12a). Similar submarine channel features are found off San Antonio and San Felipe, but a 3 to 4 km-wide shelf separates them from

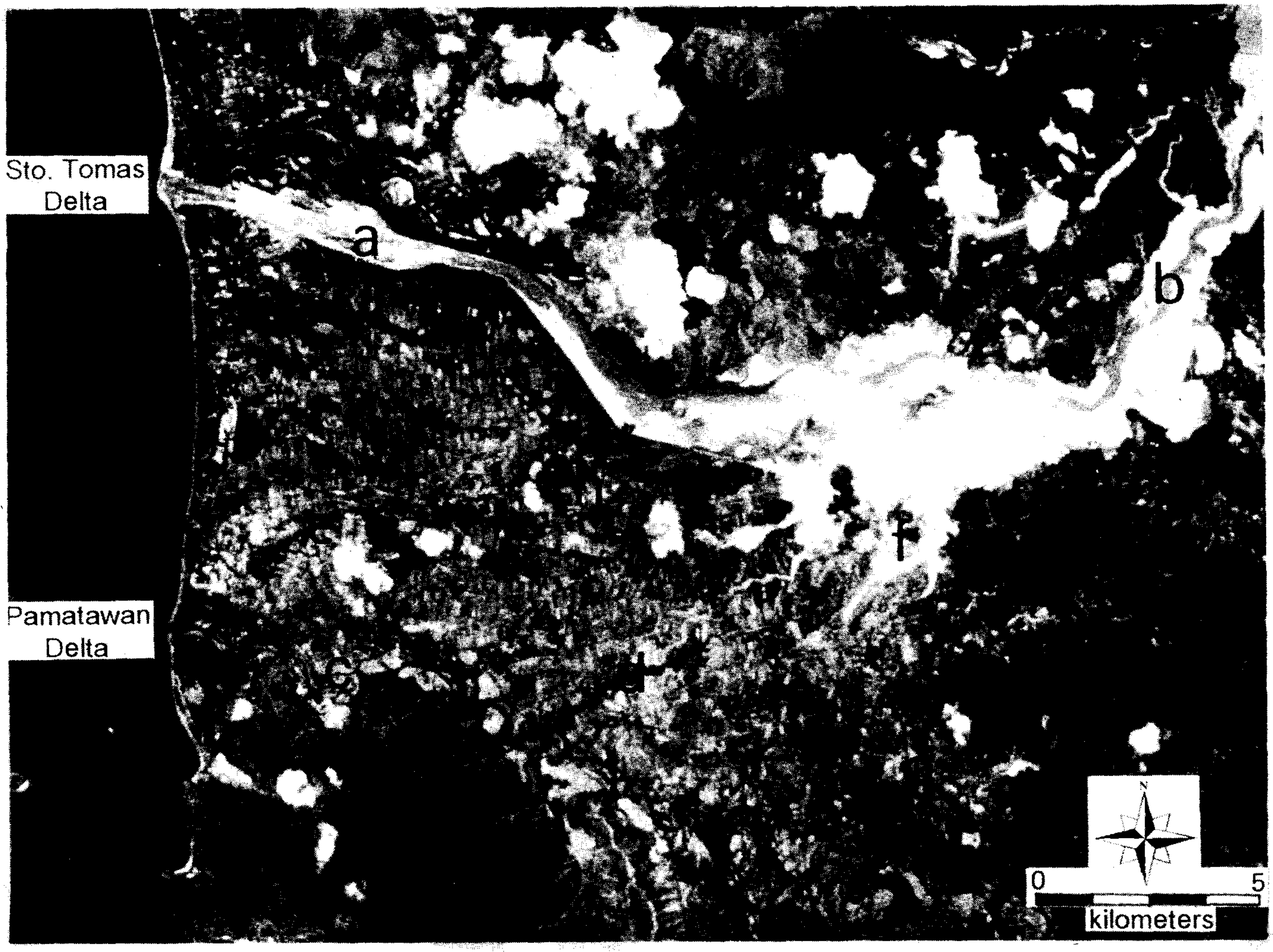


Fig. 10. 1994 space shutle image of the Sto. Tomas alluvial plain. The distributary river from the confluence of the Marella and Sto. Tomas Rivers defines the Sto. Tomas Alluvial Fan. (a) The Sto. Tomas River; (b) The Marella River; (c) The Pamatawan River; (d) The Laglaboson-Camachile River System; (e) The Dinumagat-Linoron River System; (f) The San Rafael; (g) The Castillejos; (h) The Sto. Tomas Dike; and (i) The Mapanuepe River. The area covered in the figure is indicated in Fig. 1.

the coast. These submarine channels appear to be related to the faults bounding the Sto. Tomas alluvial plain. Reflection seismic data off the Zambales coast (BED 1985) indicate that the continuation of these faults coincides with the channels. Similarly, the submarine channel tapping the Bucao River, henceforth referred to as the Bucao Canyon, appears to follow the southern fault bounding the Bucao valley.

The oscillating nature of the shoreline at the mouth of the Bucao River is most probably related to the presence of the Bucao Canyon. The very narrow and steep shelf off the Bucao River mouth is very conducive for the oversteepening of the shoreface (Fig. 12b). Thus, any progradation of the river mouth would eventually trigger a shoreface collapse. The collapsed material may then be deposited or moved along the canyon. Direct transport of river-borne sediment beyond the shelf through the Bucao Canyon might also occur specially during a flood stage. It might also be possible that even the sediment entrained by longshore current are trapped and transported down the canyon. The bathymetry downdip of the Bucao Canyon indicates the presence of a submarine fan system that is approximately 500 m thick, 30 km long and 16 km wide. (Fig. 12). The volume of sediment within this submarine fan system, assuming a water content by volume of 50%, is 1.2 x10^{11} m^3, roughly 17 times the amount of material erupted by Mt. Pinatubo in 1991. Most of the sediment within this submarine fan could have come directly from the Bucao River a large amount of which probably originated from Mt. Pinatubo.

The relatively wider and gentler shelf off the Sto. Tomas River favors the retention of sediment. Thus, the smaller

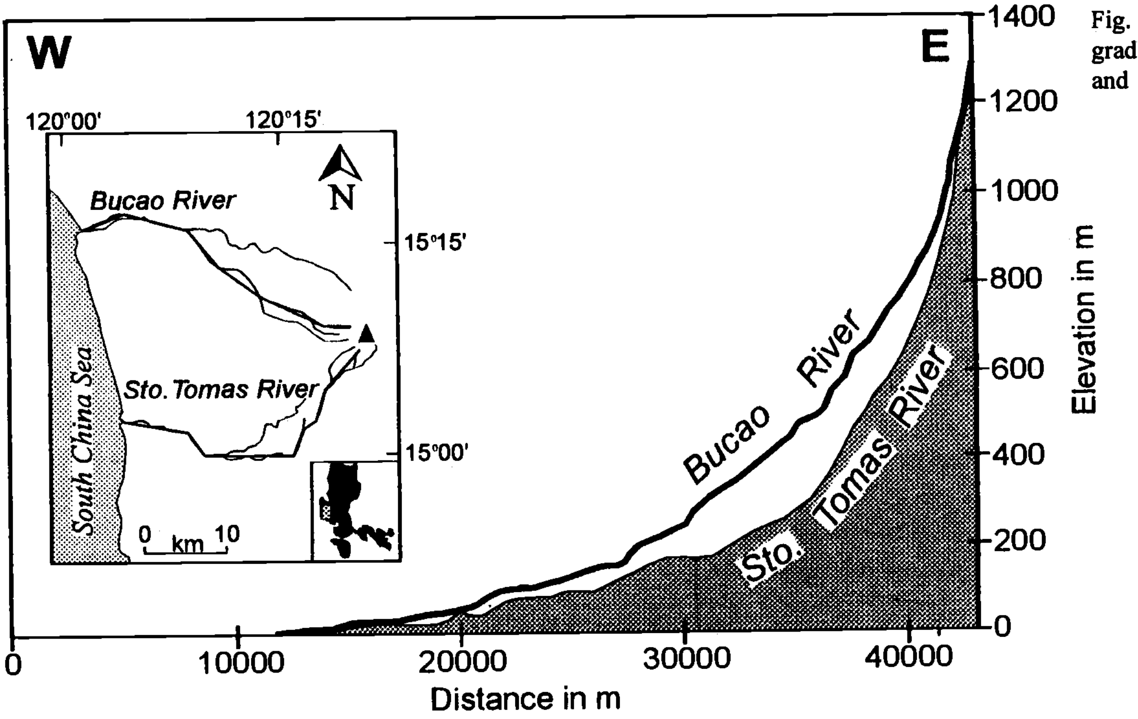
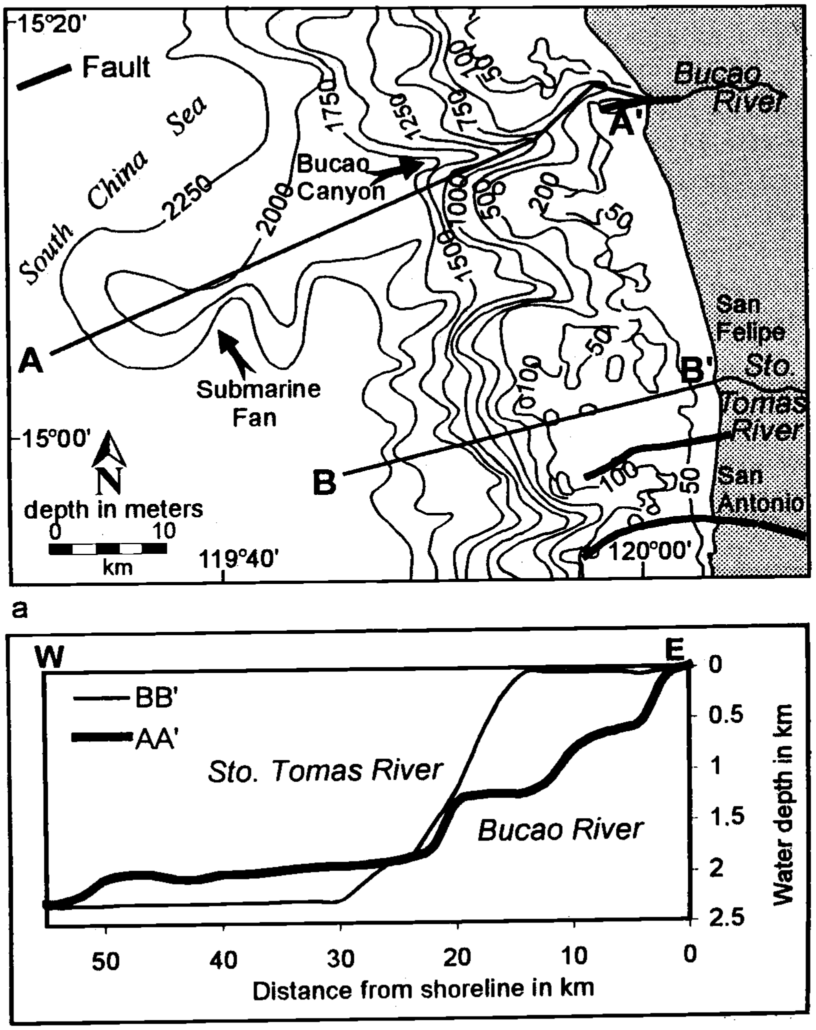


Fig. 11. Channel gradients of the Bucao and Sto. Tomas Rivers.

Fig. 12. (a) Bathymetry off the Southern Zambales coast indicating the presence of a submarine fan system (bathymetric data is from the West Luzon Coast bathymetric map, National Mapping Agency Hydrographic/Topographic Center, USA, 1986). Also shown are the offshore traces of faults associated with the Bucao and Sto. Tomas Rivers (data from BED, 1986).
(b) Bathymetric profiles off the Bucao and Sto. Tomas Rivers. The wide and gentle shelf off the Sto. Tomas River favors the retention of sediment, resulting in the delta development at the mouth of the river.



sediment yield of the Sto.Tomas River still resulted in greater shoreline progradation.

CONCLUSIONS

Changes in the rate of sediment input and morphology of the adjacent shelf are major controls of the long- and short-term shoreline changes along the Zambales coast. Greater progradation along the southern segment of the coast can be attributed to the relatively gentler gradient of the adjacent shelf. The oscillating shoreline position at the mouth of the Bucao River is caused by the presence of a submarine canyon directly tapping the river mouth. Thus, even with a higher sediment yield, progradation is minimal because sediments are able to bypass the coast and the shelf. The submarine fan of the Bucao Canyon attests to the voluminous amount of sediment that have bypassed the shelf. It is possible that most of the sediment within the fan came directly from Mt. Pinatubo. Thus, it is also probable that the submarine fan contains an excellent record of Mt. Pinatubo's evolution.

The occurrence of the large Pamatawan River paleodelta suggests that the Marella River, the upper extension of the Sto. Tomas River, has in the past, taken a more southwesterly pathway. This channel shift appears to be part of the autocyclic changes within the Sto. Tomas Alluvial Fan. The erosion of the Pamatawan paleodelta which may have ensued after the watershed's sediment yield returned to its pre-eruption level shows that shoreline retreat is also likely to occur along the now highly progradational Sto. Tomas River Delta.

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