ENVIRONMENTAL GEOLOGY OF THE COASTAL ZONE

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INTRODUCTION

Although on an international level the field of environmental geology began in the 1970s, it was not until the 1990s that it took on a more formal nature in Mexico. According to Keller (1996), the main environmental problem in the world is excess population, since demographic increases demand a greater amount of resources, principally energy sources, minerals, plants, and spatial resources which, of course, are finite. In Mexico, rapid urban population growth has been concentrated in a few of the country's major cities. But we can assume that, in the long term, the Mexican population will come to be distributed more evenly. We can also expect that in the relatively near future, parts of the population will head toward the coastal zones for the larger share of water resources that will still be found there. The Gulf of Mexico Coastal Zone has a growing oil industry impacting the coastal Mexican states, especially Tamaulipas, Veracruz, Tabasco, and Campeche (Yáñez-Arancibia 1999; Yáñez-Arancibia *et al.* 1999).

The concept of coastal zone may be defined in many different ways. Nevertheless, if one acknowledges that the continent influences the ocean and vice versa, it is essential to consider the coastal zone from the Gulf of Mexico slope to the continental elevation (at the foot of the continental slope). In cases where, by human activity, an endorheic basin (e.g., the Valley of Mexico) becomes exorheic, continental influence on the seas will be even greater. The same is true when a fluvial current is dammed because in that case, sediments and nutrients accompanying it will fail to reach their final destination, i.e., the ocean. Due to anthropogenic inputs, studies of heavy metals in fluvial, lacustrine, and marine sediments are important (Álvarez *et al*. 1986; Rosales-Hoz *et al.* 1986a, b, 1993, 1999; Rosales-Hoz and Carranza-Edwards 1998). In environmental and geochemical studies, granulometric analyses of sediments help us gain a comprehensive understanding of conditions in the source area and in the deposit site (Carranza-Edwards 1997).

The aim of this chapter is to analyze the importance of the Gulf of Mexico coastal zone, with an emphasis on beaches, taking into account the relationships between the beaches and the terrestrial and marine environments surrounding them, and also with the influence of anthropogenic activities.

COMPOSITION OF BEACHES

The principal components of terrigenous or siliciclastic beaches are: quartzes, feldspars, and rock fragments. In the project "Sedimentology of Mexican Beaches," conducted by the Instituto de Ciencias del Mar y Limnología de la Universidad Nacional Autónoma de México (Institute of Marine Sciences and Limnology of the National Autonomous University of Mexico [UNAM]), numerous samples of beach sediments have been collected. Comparing sandy sediments on beaches, beaches on the Atlantic slope are richer in quartz than those of the Pacific (Fig. 18.1). This is because the rivers draining into the Atlantic are longer and, thus, their fluvial sediments have been reworked to a greater extent; consequently, when they discharge onto the coast, they enrich the quartz content of these beaches, since quartz is more resistant to physical

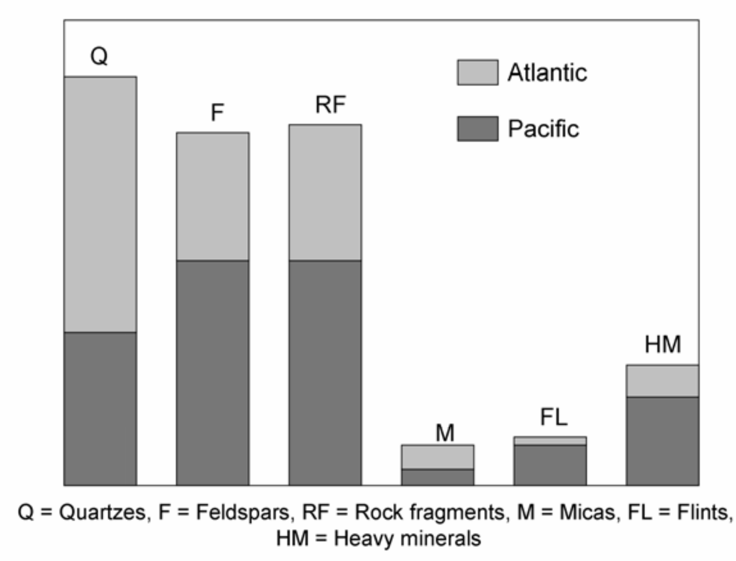

Fig 18.1. Average composition of beach sands in Mexico.

and chemical weathering. At sites where there are no sediment inputs, water turbidity is lower, and if energy conditions are right, then carbonate precipitation is favored (Carranza-Edwards *et al.* 1996).

Rivers have been affected human activities through the dams and canals that have been built for irrigation or general water supplies. In fact, through these actions not only is water held back, but natural sediments and nutrients also fail to reach the coastline. On the other hand, for the last forty years, nutrient concentrations (nitrogen and phosphorus) have been increasing in practically all rivers. According to Berner and Berner (1996), nutrients may have increased by factors of 2 to 3, and it is ever more common to encounter the phenomenon of eutrophication in coastal areas. These same researchers also pointed out that discharges from the Río Pánuco into the Gulf of Mexico have an “artificial source” in Mexico City, as well as potential impact due to drainage inputs of anthropogenic origin or runoff from agricultural fields.

The most important river in terms of sediment discharge in its original condition was the Rio Grande. This river is one of the longest rivers in North America, measuring more than 3,000 km, beginning in the San Juan Mountains in Colorado. Moreover, it acts as a natural boundary between Mexico and Texas. Among its main uses is water for human consumption and agriculture. Urban wastewater and runoff containing agricultural chemicals flow into the Rio Grande. Tamayo (2002) estimated the river’s more recent annual flow rate on the Mexican side of the border at around 5 billion cubic meters. Current measurements of flow in Mexico, plus those in the U.S., can no longer be similar to the original flow rates, i.e., those prior to any kind of damming activity. Nevertheless, we estimate that the Rio Grande’s original (prior to human modifications) annual flow rate was probably on the order of 250 billion cubic meters (Fig. 18.2). The “original theoretical” rate of flow of the Rio Grande was estimated by considering the trend in river flow from the upper part of Figure 18.2, taking into account the basin’s total area. The lack of terrigenous sediments due to human activities causes continuous erosion and, as a result, we can expect the coastline to recede.

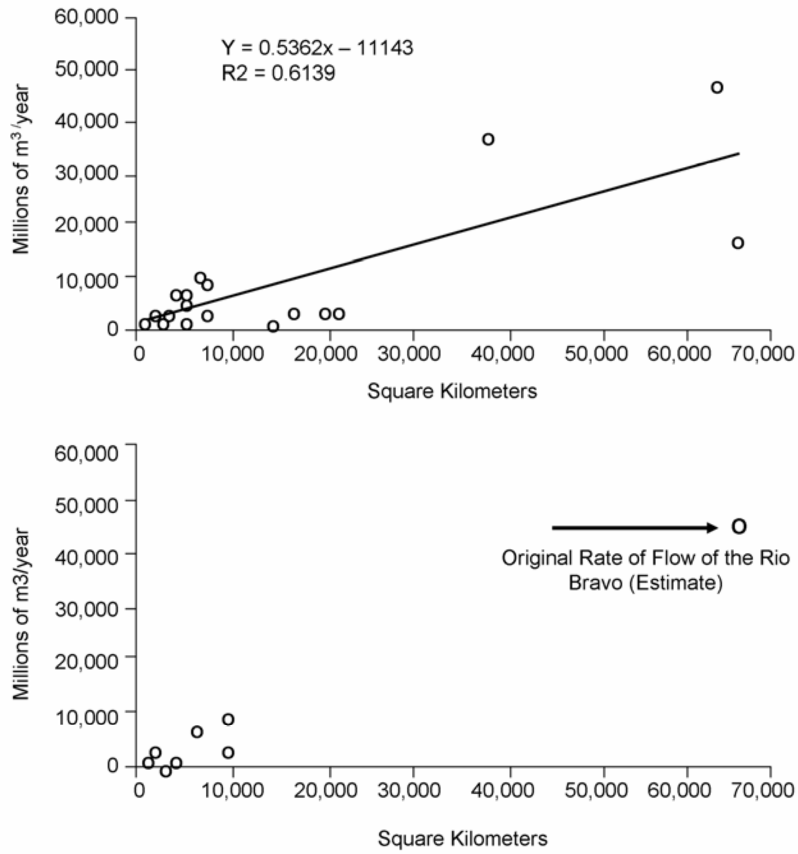

Fig 18.2. Flow rates of the major rivers discharging their waters, sediments, nutrients, and pollutants into the Gulf of Mexico. Data on rates of flow and river basin areas, on the basis of which the above graph was constructed, are for the following rivers: San Fernando, Soto la Marina, Tamesí, Pánuco, Tuxpan, Cazones, Tecolutla, Nautla, Actopan, La Antigua, Jamapa, Blanco, Papaloapan, Coatzacoalcos, Tonalá, Mezcalapa, Alto Grijalva, Macuspana, Usumacinta, Candelaria, and Champotón. From Tamayo (2002).

BEACH PROFILES

In Mexico, as well as in the rest of the Spanish-speaking world (more than 310 million inhabitants), there is no standard terminology for the different features included in beach profiles. The eighteen Spanish-speaking countries have a total of 45,000 km of coasts (considered as a straight line). Taking this into account, Carranza-Edwards and Caso (1994) formulated a proposal on Spanish terminology to be used for beach zones. In view of the fact that beach environments are very sensitive to both natural and anthropogenic changes, it is indispensable to have standard terms for their various traits.

Figure 18.3 is a modified synthesis of that proposal, in which the wave base level (WBL) is included as a point from which the beach arises from the sea inland. According to Komar (1976), a beach is comprised of unconsolidated sediment that starts to move once the waves

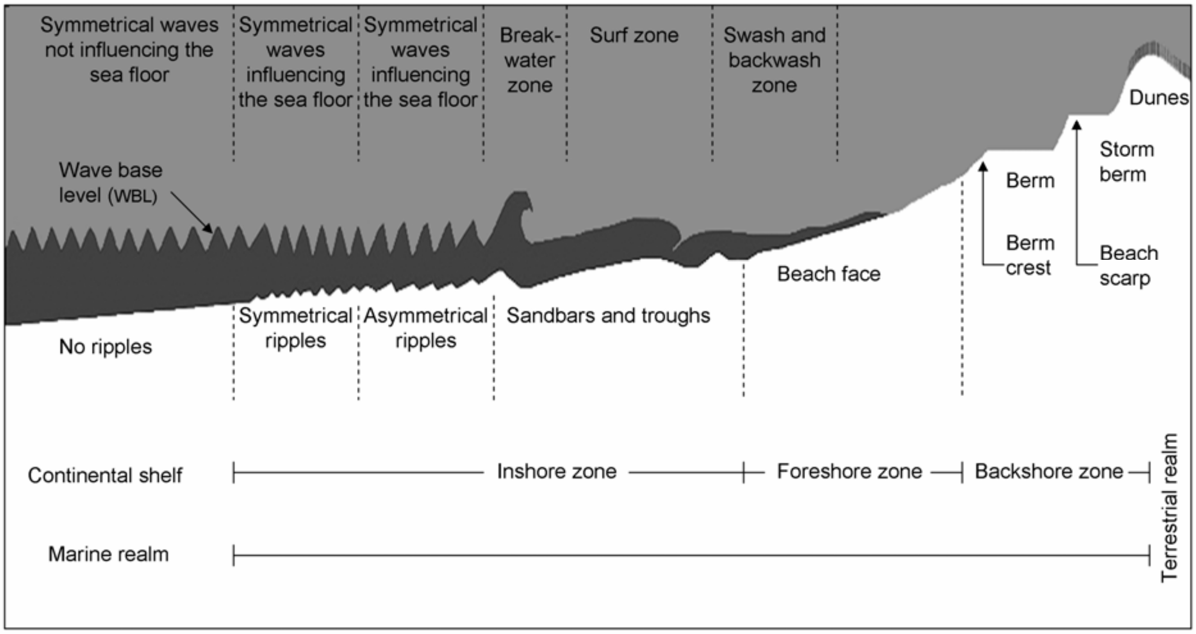

Fig. 18.3. Beach profile. WBL = wave base level. Of the three beach zones, the largest is usually the inshore zone. Modified from Carranza-Edwards and Caso (1994).

begin to touch bottom. It is precisely at the WBL where this occurs, and since the WBL varies greatly, so does the lower limit of a beach. At the other extreme we find the upper limit, which can be determined by the presence of dunes, structures, vegetation, rock outcrops, etc.

MEXICAN BEACHES ON THE GULF OF MEXICO

Beach profiles on the Gulf of Mexico (Figs. 18.4, 18.6 – 18.8, 18.11, 18.12) are very variable. In the following paragraphs we discuss several different beaches of each of the Mexican states bordering the Gulf of Mexico. In the case of Tamaulipas, the profiles are the longest, and are associated with the Rio Grande delta. The largest beach is Playa Bagdad in Matamoros that is over 250 m wide. The color of beach sands ranges from pale brown to light gray and even white, when the content of mollusk shell fragments (gastropods and pelecypods) is high. The composition is mainly subfeldsarenite, reflecting high content of both quartz and feldspar.

Moving farther from the center of the Rio Grande delta, beach widths tend to decrease and beach face slopes increase. Similarly, we observe that particle size is smaller on gentle slopes and becomes larger on steeper ones, except in the case of biogenic fragments, the size of which does not depend on the beach face slope. The predominant classes of terrigenous sediments found are in the size range of fine-grained sands. Sorting of terrigenous sediments tends to vary from well-sorted to moderately well-sorted; however, in sands in the southern portion of Tamaulipas, they tend to be poorly sorted, especially in the sands of La Industria, La Pesca, Barra del Tordo, and Miramar beaches (Fig. 18.4). This is due to the presence of shell

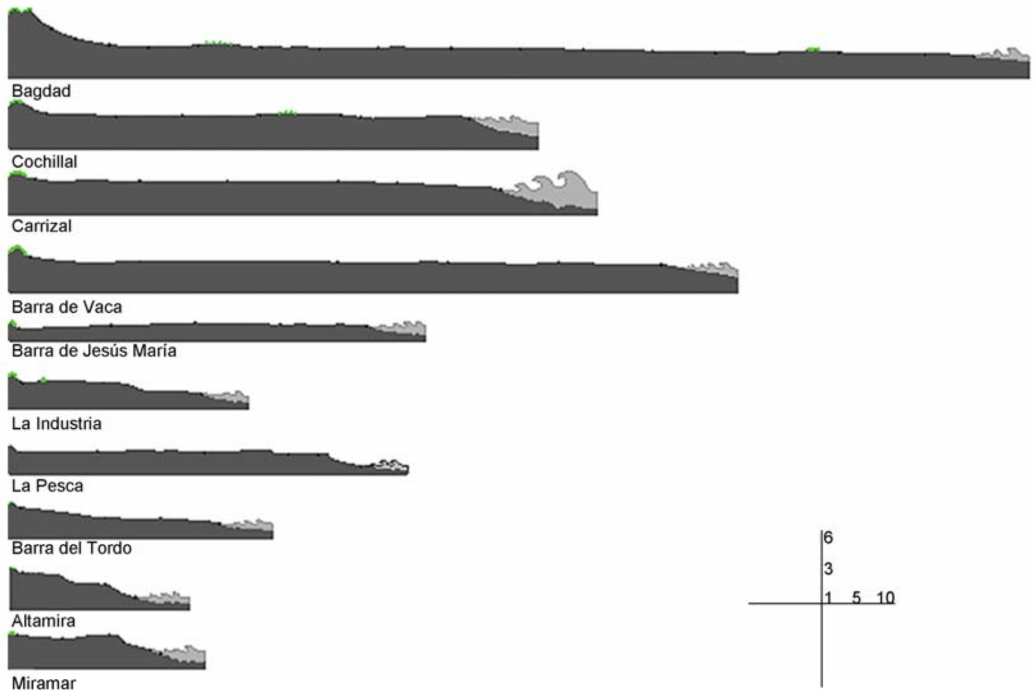

Fig 18.4. Beach profiles in Tamaulipas (2x vertical exaggeration).

fragments which are frequently found when moving towards zones of influence of coastal lagoon environments.

In beach sands in the State of Veracruz, changes in composition are greater than in Tamaulipas, since there are four distinct geological domains: a) the southern portion of the Tamaulipan Basin; b) the eastern end of the Trans-Mexican Volcanic Belt (Kasper-Zubillaga *et al.* 1999); c) the Veracruz Basin; and d) the Los Tuxtlas Volcanic Massif. Due to this state's volcanic provinces, there are many more rocky outcroppings along the Veracruz coast than in the rest of the states bordering the Gulf. According to Carranza-Edwards and Rosales-Hoz (1995), beach sands in Veracruz can be subdivided into two major groups: a) sands associated with a volcanic rock source; and b) sands associated with non-volcanic areas. These domains can be distinguished by using maturity and provenance indexes.

On the other hand, as volcanic realms become more distant, beach sands are richer in quartz due to long fluvial transport. According to Méndez-Ubach *et al*. (1986), the type of coastal benthic fauna found is associated with distinct types of sediments. Towards the mid-section of Veracruz and in the Los Tuxtlas region, both the coastal plain and the continental shelf are narrow, and are associated with Quaternary volcanic activity. Watersheds draining into the ocean cross lands dominated by sedimentary outcrops (with high maturity and provenance indexes) and volcanic outcrops (with low maturity and provenance indexes), as reported by

Carranza-Edwards and Rosales-Hoz (1995). The profile of Playa de la Barra presents a concave beach face suggesting an erosive state (Fig. 18.5). This beach is also the narrowest of those sampled along the Veracruz coast (Figs. 18.6 and 18.7).

The beach profiles in the State of Tabasco are narrower than those of Tamaulipas and Veracruz (Fig. 18.8). The composition of Tabasco beach sands are more terrigenous than in other states along the Gulf coast. The large sediment load from the Grijalva, Usumacinta, and Tonalá rivers makes coastal waters turbid, inhibiting carbonate precipitation. On the other hand, sand grain size varies from fine to very fine. Thus, these sands are of interest thanks to their economic potential because heavy minerals are concentrated in smaller and more well-sorted sediments (Carranza-Edwards 1991) such as ilmenite and magnetite (Cabrera-Ramírez and Carranza-Edwards 2002). We should also mention that on the beaches in Tabasco, sea turtle nesting sites have not been found. Perhaps this may be explained by the presence of excess fine sandy and muddy fluvial sediment loads. On Pailebot Beach, an asphalt horizon was found in the backshore zone (Fig. 18.9), which may be attributable to a spill from the Ixtoc oil well located offshore.

In contrast, beaches in Campeche exhibit coastal sediments that are more enriched in carbonates as the distance from the mouths of the Grijalva and Usumacinta rivers increases. The carbonate region of beaches in this state forms part of the coast of the Yucatán Peninsula. A coast with terrigenous material is part of Continental Morphotectonic Unit No. III defined by Carranza-Edwards *et al.* (1975) because that unit goes from Coatzacoalcos, Veracruz up to the eastern portion of Laguna de Términos in Campeche. In the eastern part of that lagoon, Ayala-Castañares (1963) described an increase in calcium carbonate inputs (Fig. 18.10).

Subsequently, Carranza-Edwards *et al*. (1993) defined the limit of sediments with 50% carbonate content just opposite the mid-section of Isla del Carmen. Nevertheless, according to Carranza-Edwards (2001), the limit between carbonate and terrigenous sands was located towards the west, at the Playa La Gloria (Fig 18.11). This means that onshore transport of carbonate sands has an influence on the area west of Boca del Carmen and, as coastal bathymetry increases, the limit shifts eastward. Sandy sediments on Playa Campechito are terrigenous, those of Playa La Gloria are biogenic and terrigenous, and from Playa Norte to Playa Bonita, sediments are rich in calcium carbonate. Playa Campechito suffers from erosion and palisades are used to protect it. In fact, this beach is located in the erosive zone of the former delta of the San Pedro and San Pablo rivers, and apparently due to a geological trend, the course of the Río Usumacinta has migrated west. The current delta of the Río Grijalva is a constructive feature, while the delta located immediately east of it is undergoing erosion, as can be observed in different satellite images. In general, beaches in Campeche are narrower than those of Tabasco.

The six beach localities profiled in the State of Yucatán vary in width; the narrowest is Playa Dzilam de Bravo and the widest Playa Chicxulub (Figure 18.12). All have carbonate sands, and often contain shell fragments, mainly of gastropod and pelecypods.

Sediments of beaches with carbonate sands in Campeche and Yucatán are composed of calcirudites and calcarenites. Sediments are usually poorly sorted in the inshore zone, and are more well-sorted in the foreshore and backshore zones. In Yucatán, medium- and fine-grained calcarenites predominate, are moderately well-sorted, and most of the sediments range from symmetrical to coarse, due mainly to the influence of shell fragments (Nolasco-Montero and Carranza-Edwards 1988). Sediments in Yucatán are well-sorted when they are finer grained. Strong northerly winds, known locally as *nortes*, produce extremely intense turbulence, and may be one reason why beach profiles in Yucatán are narrow.

Fig. 18.5. Beach erosion in La Barra, Veracruz.

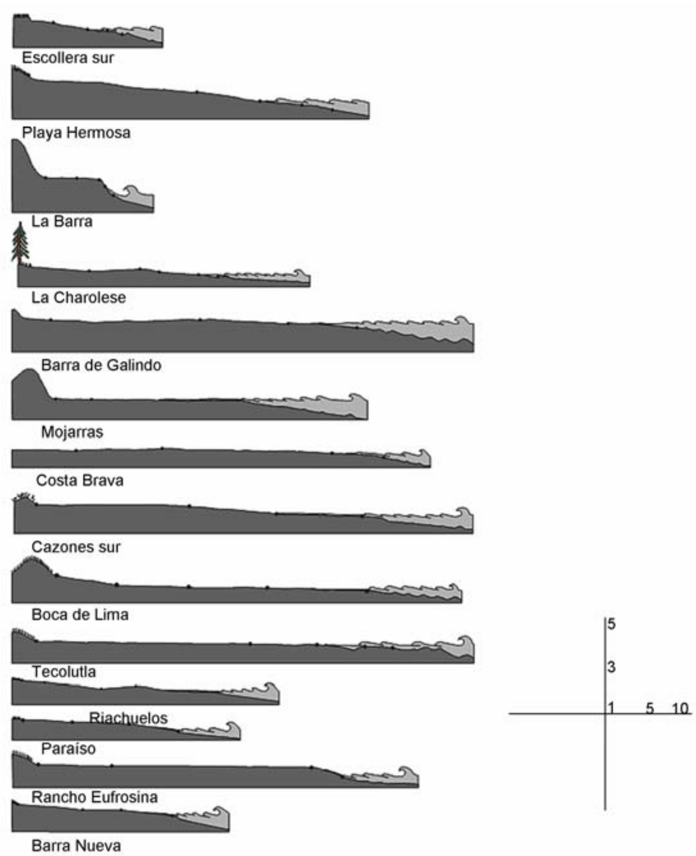

Fig. 18.6. Beach profiles in northern Veracruz (2x vertical exaggeration).

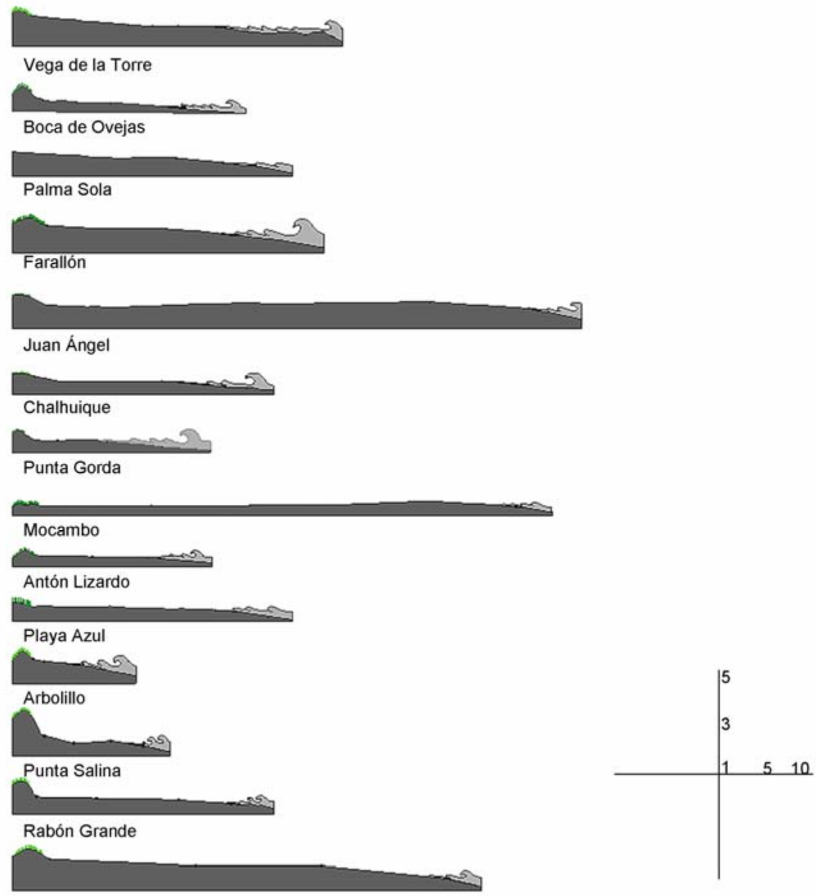

Fig. 18.7. Beach profiles in southern Veracruz (2x vertical exaggeration).

One of the most important features of beaches is their relationship with turtle nesting sites. According to Márquez (2004), the following turtles lay their eggs on the shores of the Gulf of Mexico: green sea turtle (*Chelonia mydas*); Atlantic loggerhead (*Caretta c. caretta*); Atlantic hawksbill (*Eretmochelys i. imbricata*); Kemp's ridley (*Lepidochelys kempi*); and Atlantic leatherback (*Dermochelys c. coriacea*). In all Mexican states bordering the Gulf except Tabasco there are sea turtle nesting sites. In Tabasco, only turtles indigenous to marshes nest. In Yucatán there are beaches with carbonate-rich sands, and there are reports that green, Atlantic loggerhead, Atlantic hawksbill, and Atlantic leatherback sea turtles nest there. Evidently, the presence of beaches with sands rich in carbonates is important for some of these species in terms of nesting. One of the primary sites of nesting by Kemp's ridley sea turtles is Rancho Nuevo, Tamaulipas, where eggs of this turtle have been successfully transplanted to Padre Island (USA) because this island's geological conditions are similar to that of the Cabo Rojo in Laguna Tamiahua. Yet aside from geological conditions, undoubtedly we need to consider other parameters such as climate, physiography, beach slope, carbonate content, etc. Hence interdisciplinary research is very important.

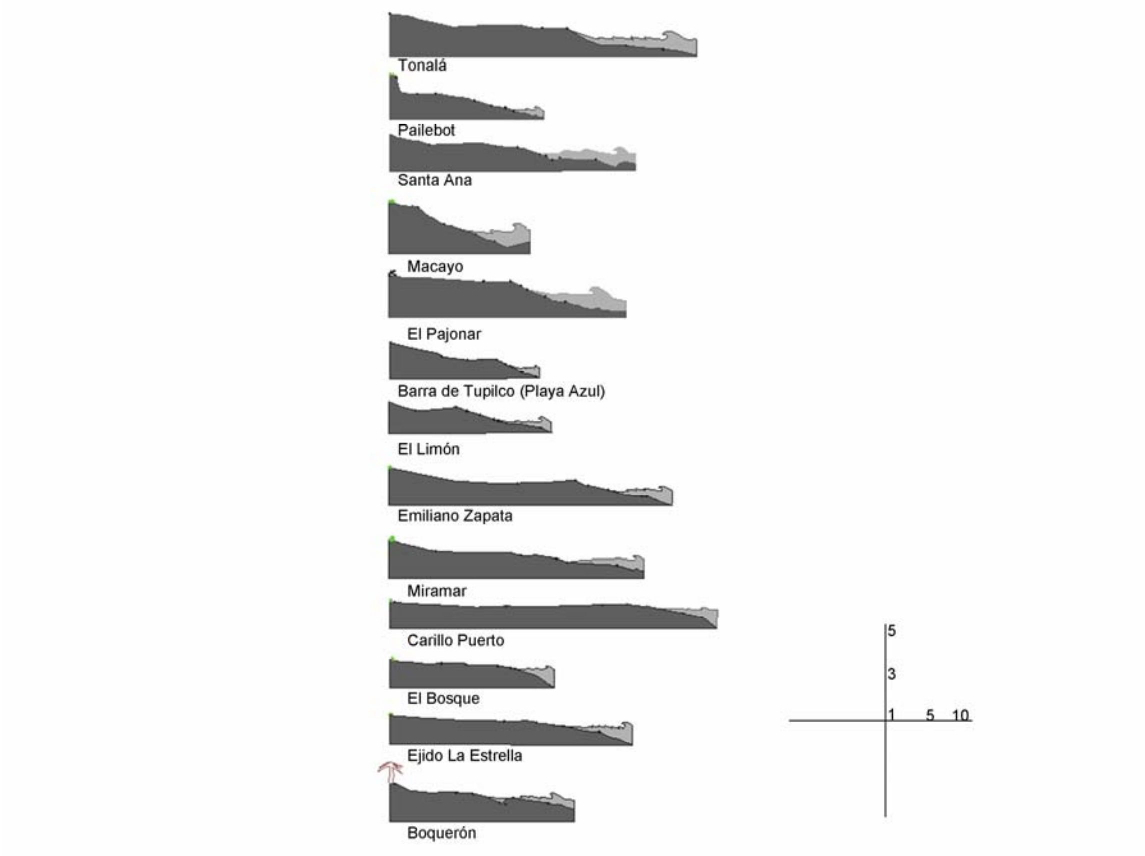

Fig. 18.8. Beach profiles in the state of Tabasco (2x vertical exaggeration).

Fig. 18.9. Asphalt horizon on a beach in Tabasco located opposite the Ixtoc oil well.

Fig. 18.10. Mass stratification with a shell horizon in Canchec, Campeche.

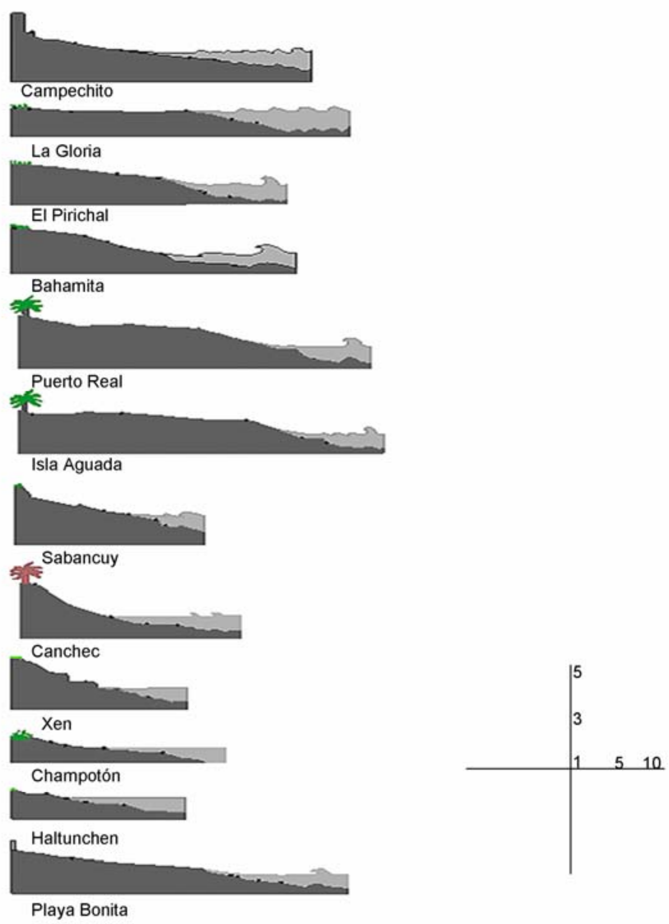

Fig. 18.11. Beach profiles in Campeche (2x vertical exaggeration).

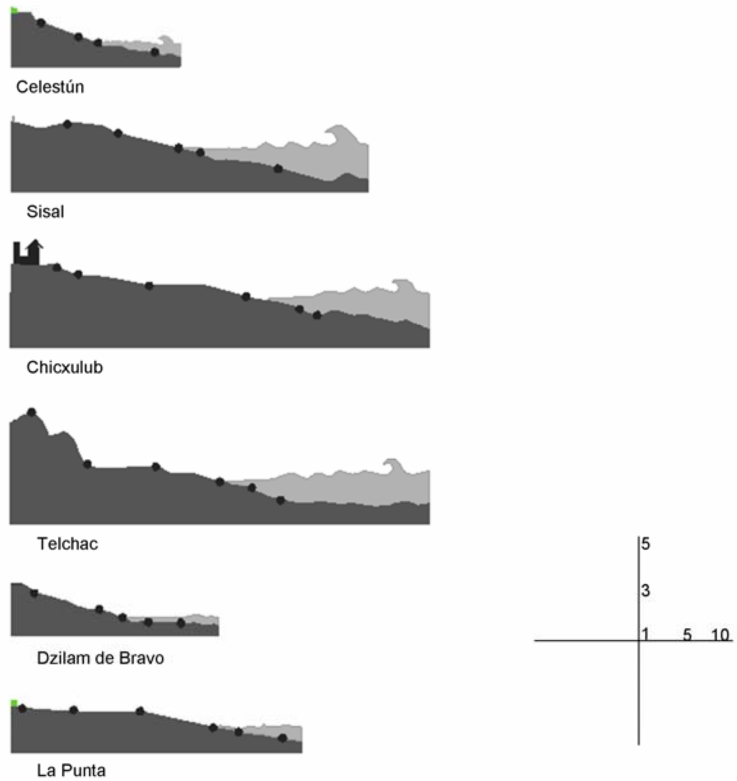

Fig. 18.12. Beach profiles Yucatán (2x vertical exaggeration).

CARBONATE SEDIMENTS

Figure 18.13 shows carbonate content (Carranza-Edwards *et al.* 1996) of beach face sands at 68 beach localities sampled in the project "Sedimentology of Mexican Beaches." The beach face sediment samples range from the Rio Grande in Tamaulipas to the Río Hondo in Quintana Roo. On the northeastern coastal plain carbonate content is highly variable, which seems to be due to the influence of the coastal lagoon environment. The deltaic area of the Rio Grande contains few carbonates, but sandbars bordering Laguna Tamiahua, also formed by deltaic sedimentation, are occasionally interrupted, producing conditions favoring carbonate enrichment due to the influence of marine sedimentation. If we compare the composition of coastal sediments with terrigenous sedimentation on the proximal shelf (Fig. 18.13), we observe some degree of correspondence, since the continental shelf is characterized by silts and sands in regions with a terrigenous influence. On the contrary, in reef zones or in the region of carbonate sediments on the Yucatán Shelf, the upper part of the shelf contains sediments varying from silts and sands to carbonate gravels.

Figure 18.13 also shows that sediments on the sea floor of the Gulf of Mexico are richer in carbonates than those of the Mexican Pacific. This is due in part to the influence of the

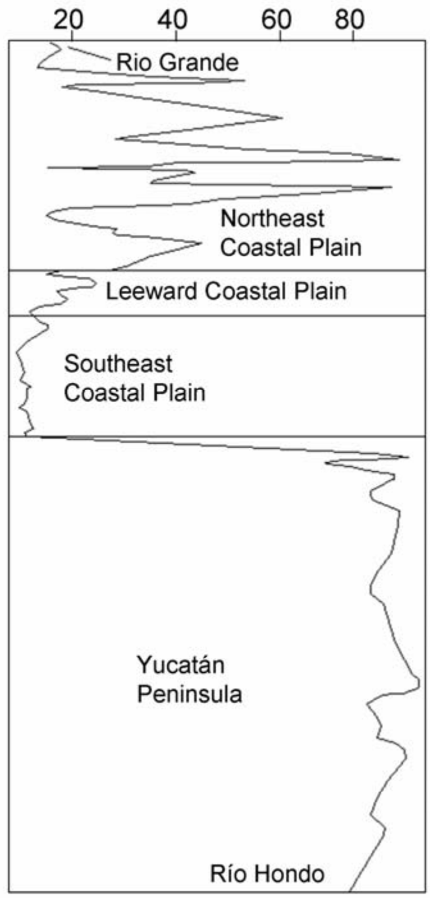

Fig. 18.13. Percentage of carbonates in beach sands from the Rio Grande, Tamaulipas to the Río Hondo, Quintana Roo. Modified from Carranza-Edwards *et al.* (1996).

carbonate province of the Yucatán Peninsula and to the fact that carbonate rock outcroppings in the Sierra Madre Oriental contribute to carbonate inputs through lixiviation. In addition the deltaic zone of influence of sediments from the Rio Grande can also be seen.

Particle size is very variable in coastal sediments (Fig. 18.14). Even though there is greater abundance of coarse-, medium-, and fine-grained sands, some of the samples may contain sediments that fall between very coarse or very fine. Toward the bottom of Figure 18.14 (Caribbean end of Morphotectonic Unit No. IV; Carranza-Edwards *et al.* 1975), there are very fine-grained sands associated with the south-north current in Quintana Roo which, due to high energy, favors calcarenite formations. In contrast, terrigenous sediments in the Rio Grande delta are homogeneous, as can be noted towards the top of Morphotectonic Unit No. I. In general, sediment content of coarse grains usually seems to be determined by the influence of biogenic sediments, which are also associated with high carbonate values.

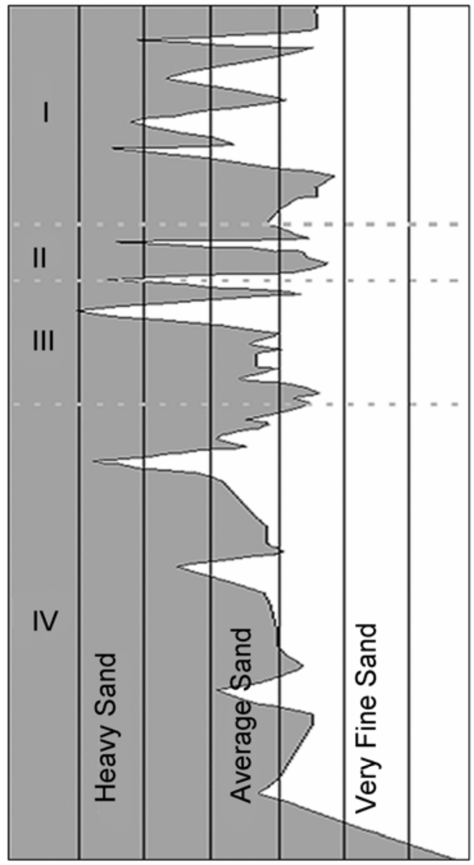

Fig. 18.14. Size of beach sand grains from the Rio Grande, Tamaulipas to the Río Hondo, Quintana Roo. Modified from Carranza-Edwards *et al.* (1996). The Roman numerals indicate morphotectonic units defined by Carranza-Edwards *et al.* (1975).

MAJOR NATURAL DISASTERS AFFECTING THE GULF

Due to natural phenomena, materials of different sizes and compositions may be transported suddenly towards beaches, resulting in environmental disturbance. In the Gulf there are hurricanes the paths of which have been recorded by SARH (1981) and CNA (2003) (Fig. 18.15). Hurricanes have not entered the southern portion of the Gulf of Mexico or the area surrounding the Los Tuxtlas Volcanic Massif. In more than 20 years there has been no direct hit by a hurricane between the Port of Veracruz and the Los Tuxtlas region, however, hurricane landfalls may occur when appropriate local meteorological conditions are in place.

When the path of a hurricane reaches the coast, the deepening of the wave base level produces a sharp rise in wave energy and a zone with major erosion (represented by point B on Fig. 18.16). This can lead to serious damage for the exposed beach, because under non-hurricane conditions, accumulation of very fine sediments occurs at wave levels lower than the average wave base level.

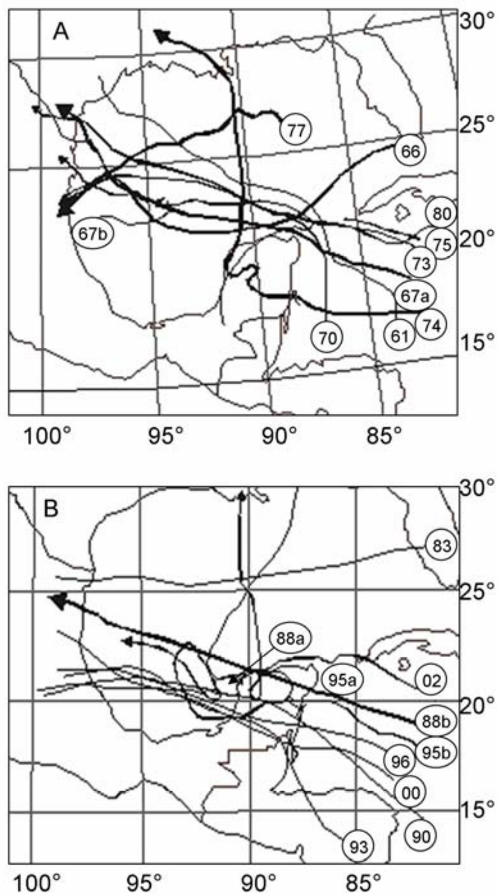

Fig. 18.15. Hurricane paths. A) Occurred between 1960 and 1980 (modified from SARH 1981): 61.- Carla (Sept. 5-12), 66. - Inez (Sept. 27 - Oct. 10), 67a.- Beulah (Sept. 8-23), 67b.- Fern (Oct. 2-4), 70.- Ella (Sept. 10-12), 73.- Brenda (Aug. 18-22), 74.- Carmen (Aug. 29 - Sep. 8), 75.- Caroline (Aug. 26 - Sept. 1), 77.- Anita (Aug. 29 - Sept. 2), 80.- Allen (Aug. 1-11). B) Occurred between 1981 and 2002 (modified from CNA 2003): 83.- Barry (Aug. 23-29), 88a.- Debby (Aug. 31 - Sept. 8), 88b.- Gilbert (Sept. 8-13), 90.- Diana (Aug. 4-8), 93.- Gert (Sept. 14-21), 95a.- Opal (Sept. 27 - Oct. 6), 95b.- Roxanne (Oct. 8-20), 96.- Dolly (Aug. 19-24), 00.- Keith (Oct. 3-5), 02.- Isidore (Sept. 18-25). Note: 61 = 1961, 02 = 2002.

The presence of fine muddy sediments favors settlement and concentration of heavy metals. A phenomenon of this type can alter natural conditions in turtle nesting sites. On the contrary, at point C of Fig. 18.15, there may be silting due to excess terrigenous sedimentation, with a modification of the kind of sedimentation to which benthic fauna are adapted. This causes stress on marine organisms.

One of the consequences of hurricanes is flooding. However, coastal zones frequently suffer from flooding with sudden increases in rainfall, which is often the case in coastal states bordering the Gulf of Mexico and in Quintana Roo. For this reason, we need to have information on coastal zone relief and to use topographic maps in which areas that may be flooded are estimated under maximum runoff conditions, which may arise even in the absence of hurricanes.

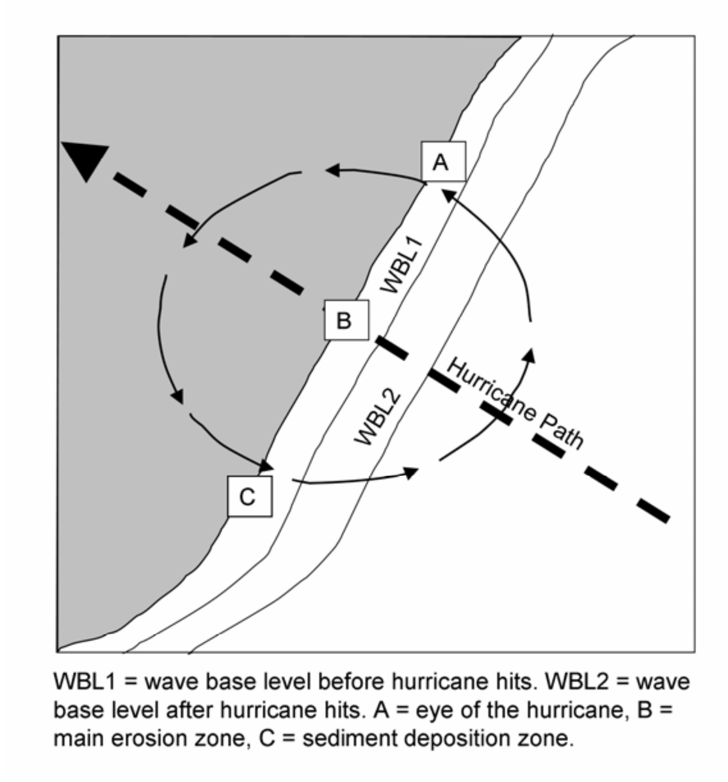

Fig. 18.16. Sedimentological effects associated with the arrival of hurricanes.WBL1 = wave base level before hurricane hits. WBL2 = wave base level after hurricane hits. A = eye of the hurricane, B = main erosion zone, C = sediment deposition zone.

A preventive measure to mitigate flooding disasters is to build two-story houses in which the ground floor is left empty and the upper floor has an exit onto the roof in the event that rescue operations are necessary (Fig. 18.17).

PORT DEVELOPMENT

According to Carranza-Edwards (2002), due to Mexico's economic development and population growth rate, we need maritime ports with greater capacities. It is even possible that in the near future, water will have to be transported by ships or piped in from high-precipitation regions to arid ones. In addition, imports and exports of commodities are being transported in increasingly larger volumes and also oil tankers are continuously raising their tonnage.

For example, in the case of an alternate port for Veracruz, goods should be able to arrive and leave expeditiously thus loading and unloading operations should not be carried out within or near the city. Moreover, spreading out port facilities diminishes the risk of pollution of drinking water by saline intrusions, as well as the risk of pollution by wastewater, which is undesirable for both the health of humans and that of corals occurring in the reef zone east-southeast of the Port of Veracruz (Fig. 18.18).

Because strong northerly winds (*nortes*) blow every year, they must be taken into consideration when selecting the site for an alternate port so that those winds, which are frequent

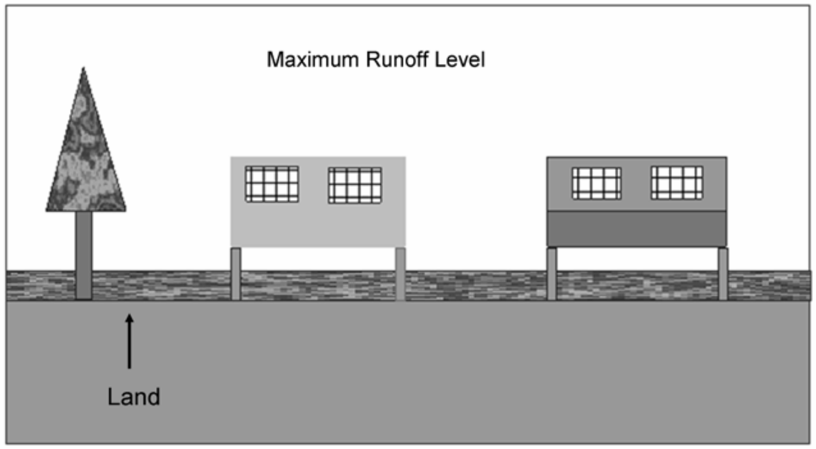

Fig. 18.17. Idealized diagram of buildings suggested for regions vulnerable to flooding in coastal zones, in which maximum water levels are taken into account.

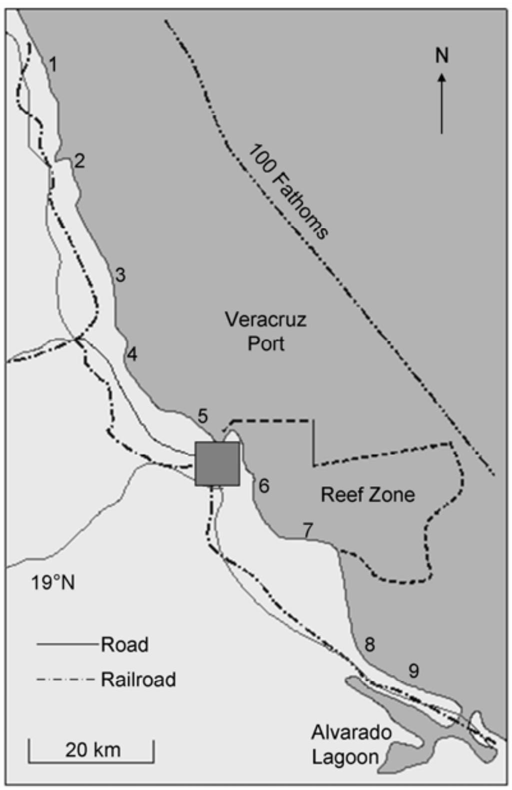

Fig. 18.18. Port area in Veracruz. In this figure, numbers represent localities that were previously sampled, and are used here as points of reference. An alternative for the new port of Veracruz could be located somewhere between points 7 and 8, attempting to achieve protection of the reef zone and rapid entry and exit of imports and exports

in this area, do not affect the coasts. The most impacted coasts will be those having an east-west orientation and the least impacted, ones with a north-south orientation. The latter will have a lower effect involving the accumulation of water masses than when there are storm tides, which can lead to flooding. Wave effects will also be lower on the north-south oriented coastal areas. In other cases, greater beach face slopes and also greater erosion will occur (Carranza-Edwards 2002). Therefore, an alternative worth analyzing could be located somewhere between points 7 and 8 on Fig. 18.17, where a point of equilibrium between erosion and deposition should occur. Breakwaters of the alternate port should "follow the current" of strong northerly winds, i.e., their orientation should pose minimum resistance to pounding by the strongest winds.

The proposed site is located south of the reef zone, and is a natural barrier that produces a "shadow area" favoring deposition of sandy sediments (Carranza-Edwards 2002). In addition, it would keep the reef zones from being threatened by shipping routes, since these zones are are very sensitive to anthropogenic alterations. For instance, boats that have not been able to dock during a strong *norte* at the alternate port suggested by Carranza-Edwards (2002) could anchor outside it and, in the case of an accident or disaster, would not crash against the reef zone because they would be south of it. To sustain economic development in the Gulf of Mexico, there is a need for a new awareness of the capacity of ports in Tampico, Tuxpan, Veracruz, and Coatzacoalcos, that will likely require enlargement or alternate sites in the near future.

PROTECTION OF NATURAL AREAS

The reefs along the Gulf of Mexico must be protected from urban or industrial wastewater discharges because there are drainage pipes near the reef zone (Figure 18.19). Waters must be treated to ensure that bacteria or suspended organic or inorganic solid matter does not cause irreversible damage to corals in the Gulf. The care we take regarding the quality of the water discharged into the marine environment should not be underestimated. From an environmental and economic standpoint, it is less expensive to prevent the problem than to have to mitigate it. Similarly, dredging to the north of the city of Veracruz constitutes a latent threat for corals, since one of the essential conditions for their survival is the transparency of the waters surrounding them.

According to the Ley General de Equilibrio Ecológico y la Protección al Ambiente (LGEEPA; General Law on Ecological Balance and Environmental Protection) "the environment is the set of natural and artificial or human-induced elements that make possible the existence and development of human beings and all the other living organisms that interact in a specific space and at a specific time." Therefore, comprehending that set of elements is a major challenge and in order to fully grasp its multiplicities, we must first gain greater familiarity with the factors and elements involved. Carranza-Edwards *et al.* (2003b) suggested that in order to promote care of the environment, different areas of knowledge (humanities, natural sciences, social sciences, economy, and health) must be integrated.

GLOBAL CLIMATE CHANGE AND SEA LEVEL RISE

Increases in greenhouse gas concentrations have led to a rise in atmospheric temperatures which, in turn, causes melting of polar ice caps resulting in sea level rise. Although sea level rise may not be dangerous for high-relief coastal areas, it represents a major threat in low-relief areas (Ortiz-Pérez *et al*. 1996). There are at least two potentially harmful effects: a) recession of the

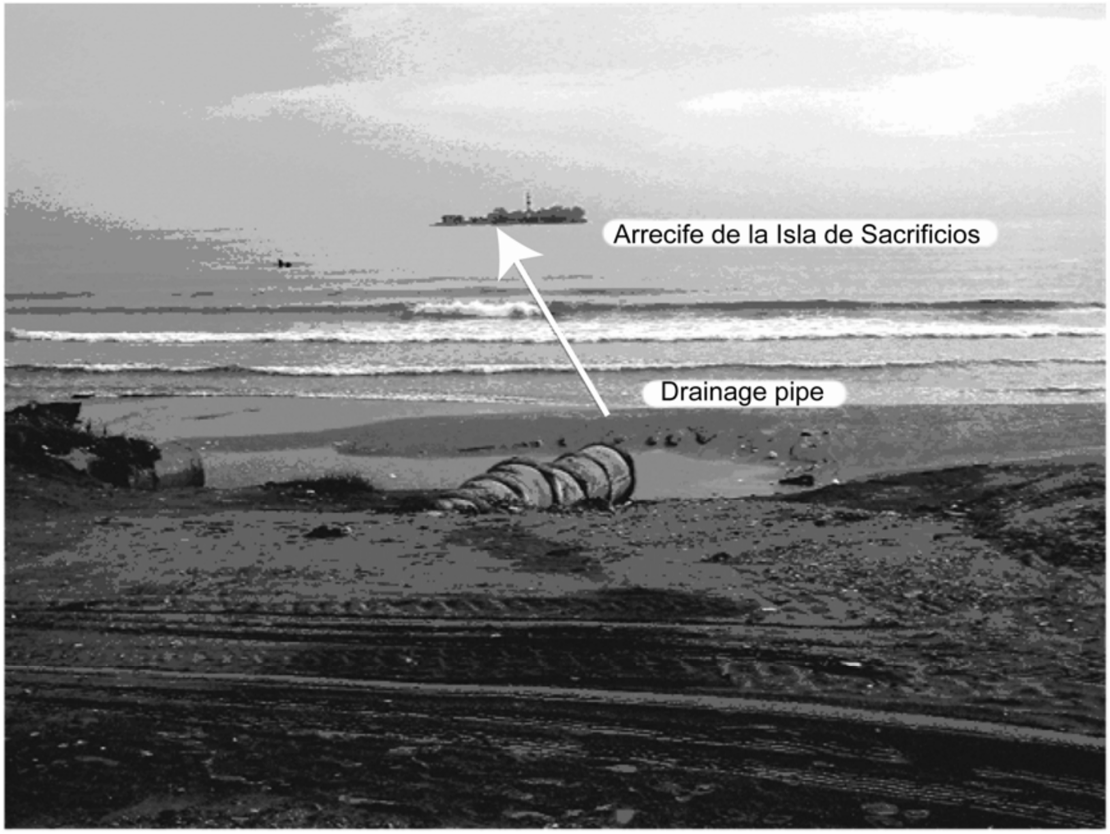

Fig. 18.19. View of Isla Sacrificios from the outfall of a wasterwater drainage pipe. Wastewater drainage poses a potential hazard for coral reefs due to its turbidity and pathogenic bacterial content.

coastline; and b) saline intrusions into water tables near the coastline. An increasein sea level of a few centimeters may have repercussions, causing the coastline to recede as much as tens of meters, depending on the slope of the coastal plains in question (Carranza-Edwards *et al.* 2003a).

Figure 18.20 shows the regions of the Gulf of Mexico with the greatest vulnerability due to global climate change. These are precisely places where the 100-m (or 200-m) elevation moves farther away from the coastline. In particular, given the low degree of their slopes, the northern portion of the Yucatán Shelf and the zone of influence of the Rio Grande delta are areas in need of greater attention and planning with regards to the development of infrastructure because of their low relief. Nevertheless, due to damming operations, currently there are other vulnerable areas such as those of the deltas of the Grijalva-Usumacinta and Papaloapan rivers (Ortiz-Pérez *et al.* 1996).

CONCLUSIONS

1. Population concentration and growth in coastal zones exacerbate the risk of saline intrusion in groundwater due to excessive drawdowns of the water table.

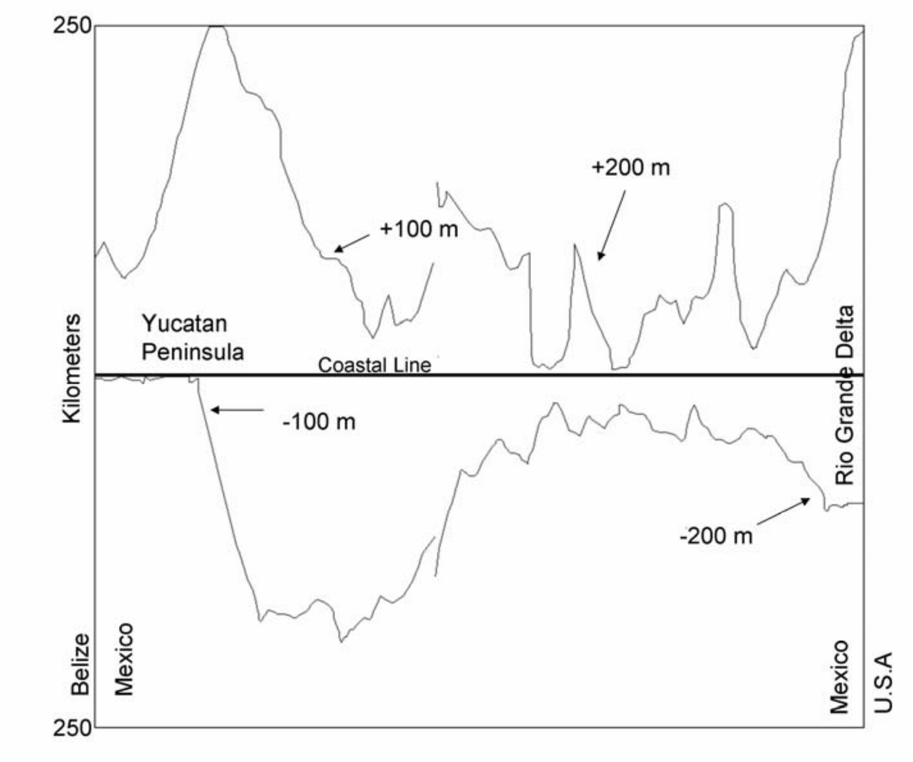

Fig. 18.20. Topographic/bathymetric elevations in the Gulf of Mexico and the Caribbean.

2. Population growth jeopardizes the Veracruz Coral Reef System if suspended solids and pathogenic bacteria are not monitored and controlled, since these are common in municipal wastewater.
3. Sediment retention in the dams of the principal rivers draining into the Gulf causes erosion of the coastline. Due to this and to global warming, the zones expected to undergo the greatest degree of coastline recession are those with gentle slopes, such as the areas around the Rio Grande and Río Papaloapan.
4. Damming also causes retention of natural nutrients to which the local flora and fauna have adapted. Pollutants reaching the shores of the Gulf can come from places as far away as the Valley of Mexico.
5. Inshore zones merit greater attention because on their boundary with the continental shelf, finer sediments begin to be deposited, and these sediments are potential pollutant recipients. Since this boundary is dynamic, when subjected to storms or hurricanes sediments can be resuspended and transported to the coast, where they may impact the coastal ecosystem.
6. The most frequent natural disasters on the Gulf of Mexico are caused by hurricanes, which make the wave base level deepen, generating both erosion and sedimentation.
7. Among the beaches studied, the Playa Bagdad (Tamaulipas) is widest (>250 m) and the narrowest, Playa Dzilam de Bravo (Yucatán) is about 15 m wide. This is due to the influence of terrigenous inputs, which are greater on wider beaches.
8. On the coastal zone, the limit between beaches with carbonate sands and terrigenous sands is marked by Playa La Gloria (Campeche). West of this beach terrigenous sands or

sands that are both terrigenous and carbonate are found, but to the east sands are predominantly carbonate.

9. Sediments in the Gulf of Mexico are richer in carbonates than those of the Mexican Pacific due to the influence of the Yucatán Peninsula and to fluvial inputs coming from the Sierra Madre Oriental, where there are abundant calcareous outcroppings.
10. Frequently associated with hurricanes and tropical storms are floods. It is essential to design two-story houses for coastal residents in which the ground floor contains no furniture or other objects of value.
11. Given the complexity of the coastal environment, interdisciplinary studies are a top-priority, especially because natural and anthropogenic phenomena often exceed the carrying capacity of coastal ecosystems.
12. Mexico's economic development is linked to the need to build new ports or enlarge existing ones. Cutting corners now may mean greater losses in the future thus it is wiser to prevent problems than to have to mitigate them.
13. Protection of sea turtles must begin at nesting sites and there needs to be interdisciplinary research on the relationship of these sites with the substrate and with pollutants that may be transported towards backshore zones during hurricanes.
14. The oil wealth of the Gulf of Mexico will not last forever and therefore, investments for research into clean, renewable energy sources deserve top priority.

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