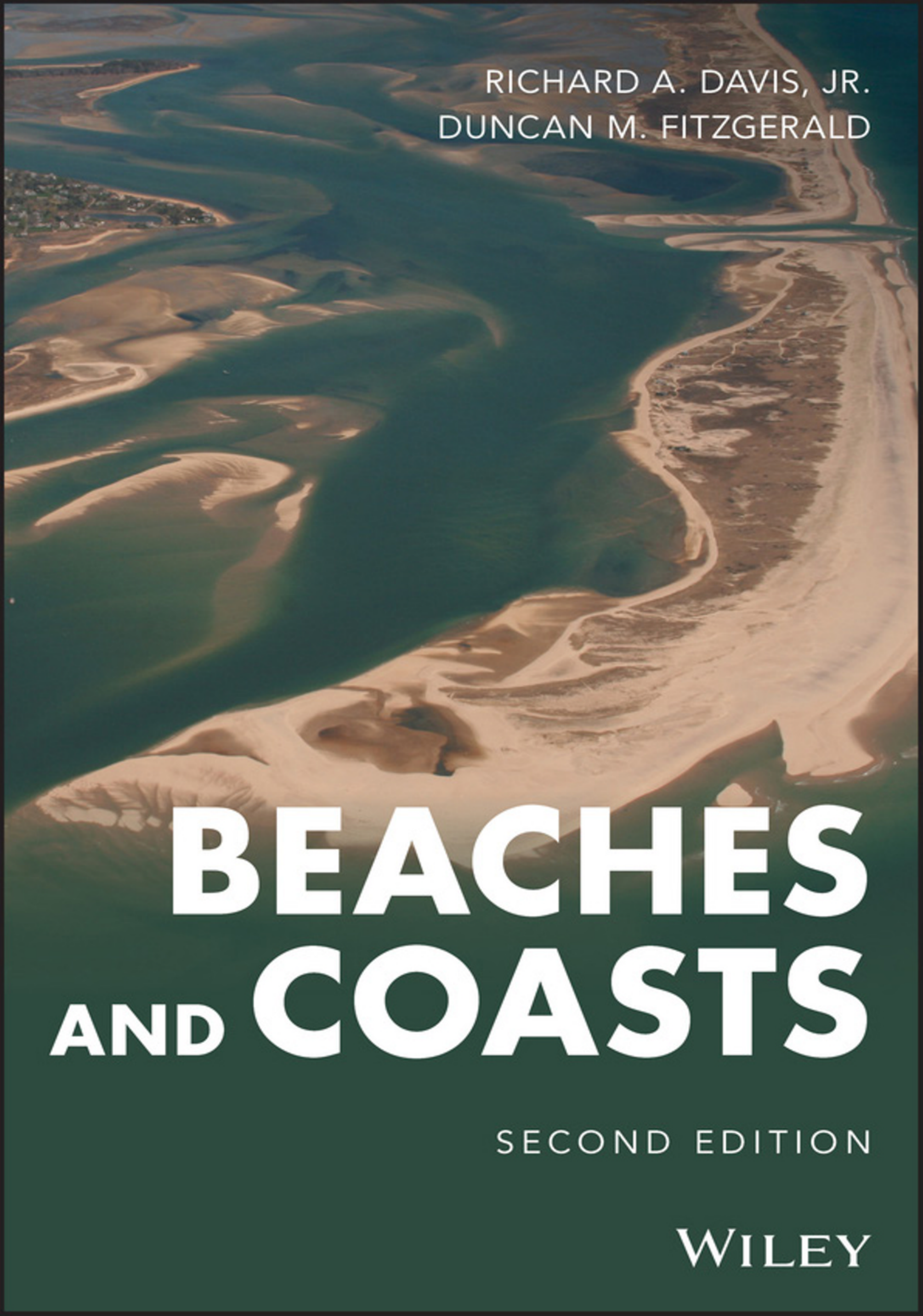

RICHARD A. DAVIS, JR.
DUNCAN M. FITZGERALD

BEACHES AND COASTS

SECOND EDITION

WILEY

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Richard A. Davis, Jr.
University of South Florida,
Texas, USA

Duncan M. FitzGerald
Boston University,
Massachusetts, USA

WILEY

This second edition first published 2020

Edition History
Wiley-Blackwell (1e, 2004)

Registered Office(s)
John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
9600 Garsington Road, Oxford, OX4 2DQ, UK

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Library of Congress Cataloging-in-Publication Data
Names: Davis, Richard A., Jr., 1937– author. | FitzGerald, Duncan M., author.
Title: Beaches and coasts / Richard A. Davis, Jr, Texas, US, Duncan M. FitzGerald, Massachusetts, US.
Description: Second Edition. | Hoboken, New Jersey : John Wiley & Sons, Inc., [2019] |
"Wiley-Blackwell (1e, 2004)"–T.p. verso. | Includes index. |
Identifiers: LCCN 2018061448 (print) | LCCN 2019001886 (ebook) | ISBN 9781119334514
(Adobe PDF) | ISBN 9781119334552 (ePub) | ISBN 9781119334484 (Cloth)
Subjects: LCSH: Beaches. | Coasts. | Coast changes.
Classification: LCC GB451.2 (ebook) | LCC GB451.2 .D385 2019 (print) | DDC 551.45/7–dc23
LC record available at https://lccn.loc.gov/2018061448

Cover Design: Wiley
Cover Image: Courtesy of Duncan M. Fitzgerald

Set in 10/12pt Warnock by SPi Global, Pondicherry, India

10 9 8 7 6 5 4 3 2 1

Brief Contents

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Coastline Variability and Functions in the Global Environment

The surface of the earth is covered by two contrasting media; land and sea. They meet at the coast. There are, of course, glaciers that span parts of both the land and sea such as in Greenland, Iceland, parts of Alaska and the Canadian Arctic, and on Antarctica. Each of these two surfaces may cover millions of square kilometers over continents and oceans or much less in the case of small oceanic islands or some lakes within continental masses. Nevertheless, a narrow coastal zone separates these two major parts of the earth's surface. We are defining the coastal zone as that combination of environments that is influenced by marine waters. Typically this includes barrier-inlet systems, anything that is subjected to astronomical tides, including wetlands and coastal bays.

The world coastline extends for about 440,000 km, but the *coastal zone* comprises less than 0.05 % of the area of the landmasses combined. Because nearly half of the global population lives within less than 100 km of the coastline, the coastal zone has become arguably the most critical part of the earth's surface in terms of global economy and strategies, and management needs. Unfortunately, the coastal zone is also the most desirable property for human development. Much of our development of the coast has had negative impacts on various environments and has caused problems that are very expensive or even impossible to correct.

1.1 Coastal Settings

The coast is global in its distribution but it is limited in width. We cannot give an average width, an average character, or any other average category that adequately typifies the coast. It is much too varied and complicated in its characteristics. In some places the coastal zone might be only a few hundred meters wide, whereas in others it might be more than 100 km wide. Some coastal zones include a wide range of environments that separate the true ocean from the terrestrial environment. In other situations, a single coastal environment may define the land–sea boundary.

In this book we will consider the controlling factors that determine what type of coast develops. The processes that develop and maintain coastal environments, as well as those that destroy the coast, are discussed in order to convey the dynamic nature of all coastal environments. Each of the major environments will be considered in light of these controlling factors and processes. The impact of human activity along the coast has been enormous, especially over the past century. Many examples of this impact appear throughout the book. Most of the emphasis here is directed toward geologic and physical attributes of the coast, although organisms are not overlooked.

Some coasts are chronically eroding and others tend to be depositional and are

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accreting. Both situations can take place in any of the coastal environments and even in close proximity to each other. These changes may be cyclical, for instance seasonal, typically with erosion in the winter because of storms and deposition in the summer. There are also places where one or the other is an ongoing process. In addition, coasts are, very rarely, impacted by hugely destructive tsunami (Figure 1.1). The controlling factors tend to be one or more of three factors: energy imparted to the environment, sediment availability, or human impact.

Depositional coasts include a wide spectrum of systems such as river deltas, barrier island systems, strandplain coasts, and glaciated coasts. Each of these may contain numerous distinct environments. The variety of morphologic features and the complex interaction of coastal *morphodynamics* is emphasized in this book.

Climatic differences may cause a wide variety of coastal types in that temperature and rainfall exert a major influence on coastal development. Extreme climates such as those in the very high latitudes can cause coastal areas to be covered with ice; all the time in some places, and for only a few months in others. Parts of Greenland and the Antarctic coast are covered with ice continually whereas some of the coasts of Alaska, Canada, the Scandinavian countries, and Russia have ice cover at least a few months each year. Desert conditions can directly influence coastal environments as well. Few significant rivers and therefore few river deltas are produced from desert areas. Some coastal deserts are dominated by huge sand dunes such as along Namibia on the southwest coast of Africa. Along the Persian Gulf the arid, low-latitude environment produces extensive coastal environments called *sabkhas* that are nearly at sea level and have an almost horizontal surface dominated by chemically precipitated carbonates, salts and other minerals.

The tectonics of the earth's crust also produce a major influence on the coastal zone. Coasts that coincide with or that are near plate boundaries tend to have more relief and are narrow as compared to those that are away from plate boundaries. Collision coasts that are produced by colliding plates provide a particularly rugged coast such as we see along the Pacific side of both North and South America. The opposite situation exists

Figure 1.1 Photograph of an irregular coast with high relief in northern California. (*Source:* NOAA, https://en.wikipedia.org/wiki/National_Oceanic_and_Atmospheric_Administration.)

on trailing edge coasts where sediment is abundant and deposition dominates. Relationships between plate tectonics and coastal development will be treated in detail in Chapter 2.

1.2 Population and the Coast

The coast is many things to many people. Depending on where and how we live, work and recreate, our perception of it varies greatly. Large populations live on or near the coast because it is typically very beautiful and interesting. Many more visit the coast for the same reasons. A large number of people gain their livelihood directly or indirectly from the coast, and some have the task of protecting it from intruders or enemies.

1.2.1 History of Coastal Occupation

The ancient civilizations of the eastern Mediterranean Sea were largely associated with the coast, including the famous Greek, Roman and Phoenician settlements and fortifications of biblical times and before. Many of the great cities of the time were located on the natural harbors afforded by the geologic and physiographic conditions along the coast. These cities provided a setting that was conducive to trade and that could be defended against enemies.

Far to the north, Viking settlements in the Scandinavian countries of Norway, Sweden and Denmark were typically located along the coast as well. Here the great fjords provided shelter and fortification along with ready access to the sea, which was a primary food source and the main avenue of transportation; they were the sites of many battles. At about the same time, the northern coast of what is now Germany and the Netherlands was also occupied for similar reasons but in a very different coastal setting; one of lowlands and barrier islands.

Many centuries later, cities in the New World such as Boston, New York, Baltimore and San Francisco owe their location to the presence of a protected harbor. In their early stages of development many of the major civilizations of the world were either directly on the coast or had important interaction with it.

In the early civilizations, reasons for this extensive occupation of coastal areas were strictly pragmatic. Coasts were essential for harboring ships, a primary means of transporting goods, one of the major activities of the times. The adjacent sea was also a primary source of food. Similar reasons were the cause for the settlement of many of the great cities of Europe such as London, Amsterdam, Venice and Copenhagen. All were settled on the edge of the water because their location fostered commerce that depended on transportation over water.

1.3 General Coastal Conditions

Varied geologic conditions provide different settings for the coast, and give variety and beauty to that part of the earth's surface. As a consequence, some coasts are quite rugged with bedrock cliffs and irregular shorelines (Figure 1.2) whereas others are low-lying, almost featureless areas with long, smooth shorelines (Figure 1.3). To be sure, with time, any coast may change extensively but some important relationships continue through geologically significant periods of time, up to many millions of years.

Changes at a given part of the coast are typically slow and continuous, but they may be sporadic and rapid. Rocky cliffs tend to erode slowly but hurricanes can change beaches or deltas very quickly. Overprinted on this combination of slow and rapid processes of change is a fluctuation in sea level, a very slow change throughout time of about 3 mm year^{-1}. In the geologic past this rate has been both much faster and even slower. The

Figure 1.2 Photograph of a depositional coast on the Texas coast.

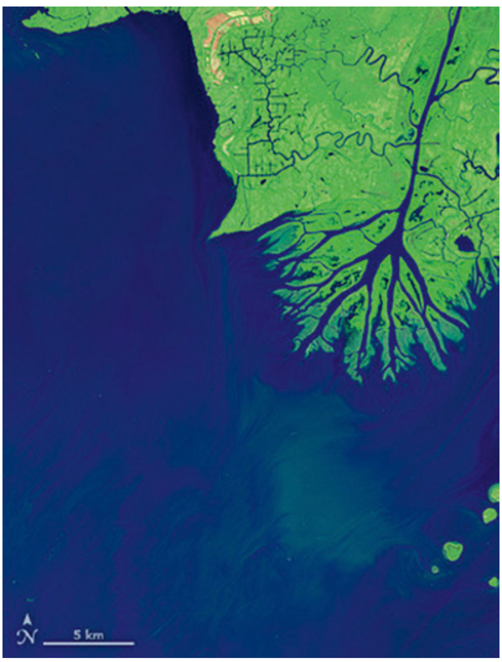


Figure 1.3 Fluvial delta that empties into the Atchafalaya Bay on the Louisiana coast. (*Source:* earthobservatory.nasa.gov.)

point is, as coastal processes work to shape the substrate and the adjacent land, the position of the shoreline changes as well. This translates the processes and their effects across the shallow continental shelf and the adjacent coastal zone, producing long, slow, but relatively steady, coastal change.

Each specific coastal setting, regardless of scale, is unique yet is quite similar to other coastal settings of the same type. Although each delta is different, a common set of features characterizes all of them. The general approach of this book will be to consider the general attributes of each of the various types of coastal environments. Numerous examples of each environmental type will provide some idea of the range available for each. Finally, the overprint of time will demonstrate the dynamic nature of all of these coastal elements.

1.4 Coastal Environments

Coastal environments vary widely. This section will briefly introduce each of the major environments to demonstrate this variety. All of these and more will be discussed in detail in the following chapters.

Rivers carry tremendous quantities of sediment to their mouths, where they deposit it. Much of the sediment is then entrained by waves and currents but commonly there is a net accumulation of sediment at the river

Figure 1.4 River Exe estuary in Devon on the coast of England. (*Source:* Steve Lee, https://www.flickr.com/photos/94466642@N00/178926998/. Licensed under CC BY-SA 2.0.)

mouth—a delta (Figure 1.4). In fact, most of the sediment along all types of depositional coasts owes its presence, at least indirectly, to a river. Deltas range widely in size and shape. Most are dominated by mud and sand but a few have gravel. The primary conditions for delta formation are a supply of sediment, a place for it to accumulate, and the inability of the open-water processes to rework and remove all of the sediment from the river mouth.

Sea level has risen considerably over the past several thousand years as the result of glaciers melting and a combination of other factors. This increase in sea level has flooded many parts of the land and developed extensive and numerous coastal bays. Streams feed most of these bays. These bays are called estuaries (Figure 1.5) and are commonly surrounded by some combination of wetlands; usually either salt marshes or mangrove mangals, and tidal flats.

Another common type of coastal bay is one that tends to parallel the coast and is protected from the open ocean by a barrier island. These elongate water bodies—lagoons—have no significant influx of fresh water or tidal exchange. Tidal flats and marshes are uncommon along this type of bay because of an absence of tidal flux. Other coastal embayments that cannot be considered as either an estuary or a lagoon are simply termed coastal bays.

Barrier islands are another important part of the scheme of coastal complexes. They are a seaward protection of the mainland, typically fronting lagoons and/or estuaries. The barriers include beaches, adjacent dunes, washover fans and other environments (Figure 1.6), and wetlands, especially salt marshes, are widespread on their landward side. Barrier islands may be dissected by tidal inlets (Figure 1.7), which are among the most dynamic of all coastal environments. They not only separate adjacent barrier islands, but also provide for the exchange of water, nutrients and fauna between the open-ocean and estuarine systems.

Strandplain coasts are low-relief coastal areas of a mainland that have many characteristics

Figure 1.5 Overview of a barrier island from open-water beaches to washover fans that extend into the estuary behind the barrier.

Figure 1.6 Oblique aerial photo of the North Carolina coast with Drum Inlet bisecting the barrier island on the Outer Banks. (*Source:* Courtesy of A.C. Hine.)

of the seaward side of a barrier island. They contain beaches and dunes but lack the coastal bay (Figure 1.8). Examples include Myrtle Beach, South Carolina and the Nayarit Coast of western Mexico.

The presence of rocky or headland coasts can be present as short isolated sections within extensive sandy depositional coasts, such as along parts of the east coast of Australia or the Pacific Northwest coast

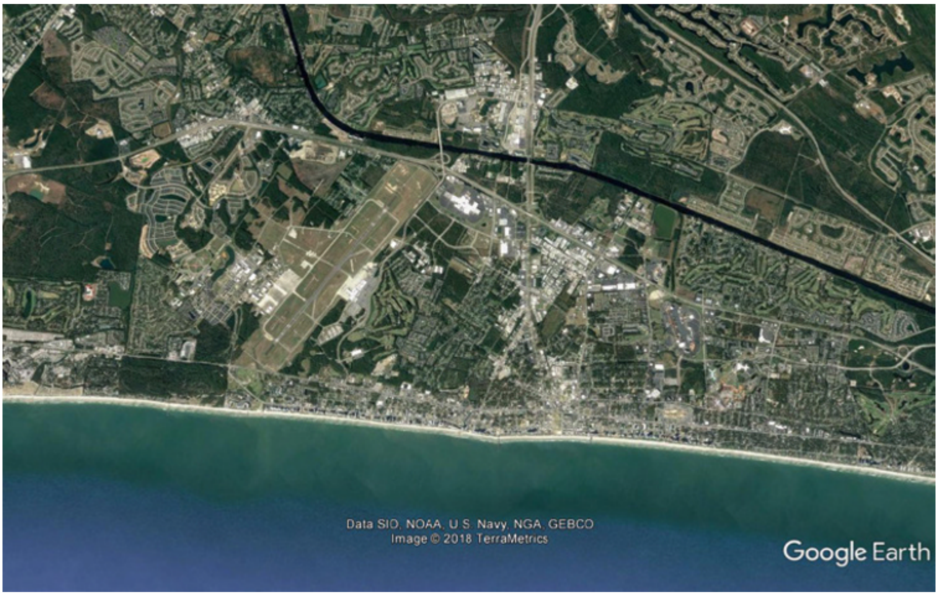


Figure 1.7 Coast of South Carolina near Myrtle Beach which is a strand plain coast without any open water in the backbarrier. (*Source:* Data SIO, NOAA, U.S. Navy, NGA, GEBCO. Image c 2018 TerraMetrics.)

Figure 1.8 Cliff on erosional coast in Oregon with a narrow beach.

Figure 1.9 Large groin to protect the beach from erosion on the North Sea coast of the Netherlands. There is a small dike landward of the dry beach.

(Figure 1.9). Other geomorphically different coasts may have their origin in glacial deposits, with New England being a good example.

1.5 Historical Trends in Coastal Research

Early systematic efforts for studying the coast in the early twentieth century were made by *geomorphologists*, scientists who study the morphology or landforms of the earth. Geomorphologists also investigate mountains, deserts, rivers, and other earth features. Their studies produced various classifications, maps, and reports on coastal landforms. Some scientists focused on the evolution of coasts and the processes responsible for molding them. For example, Douglas W. Johnson, a professor at Columbia University, wrote a classic and pioneering book in 1919 entitled *Shore Processes and Shoreline Development*, a monograph that is still commonly referenced. Another more recent individual who has contributed a great deal to our knowledge and terminology of coastal dynamics is Dr. Miles O. Hayes, who had spent his career in both academia and private enterprise.

Engineers have also given special attention to the coast over many centuries. Their interest has been directed toward construction of dikes, harbors, docks, and bridges, on one hand, and stabilization of the open coast on the other (Figure 1.10). Although geomorphologists and engineers direct their efforts toward different aspects of the coast, their interests overlap in many circumstances.

Ancient people recognized that the coast is potentially dangerous during storms and is continually changing due to processes associated with wind, waves and storms. They understood that the shoreline is one of the most dynamic areas on the earth. Erosion was a particularly important problem, and settlements were lost or threatened as the shoreline retreated. For centuries, dikes have been constructed along the North Sea coast of Holland and Germany, both for protection (Figure 1.10) and for land reclamation. In many other areas, however, construction on the open coast was designed to slow or prevent erosion. As a result, various types of structures were emplaced at critical locations along densely inhabited areas of the coast in

Figure 1.10 South end of the Galveston sea wall on the Texas coast showing how it is protecting the shoreline from erosion.

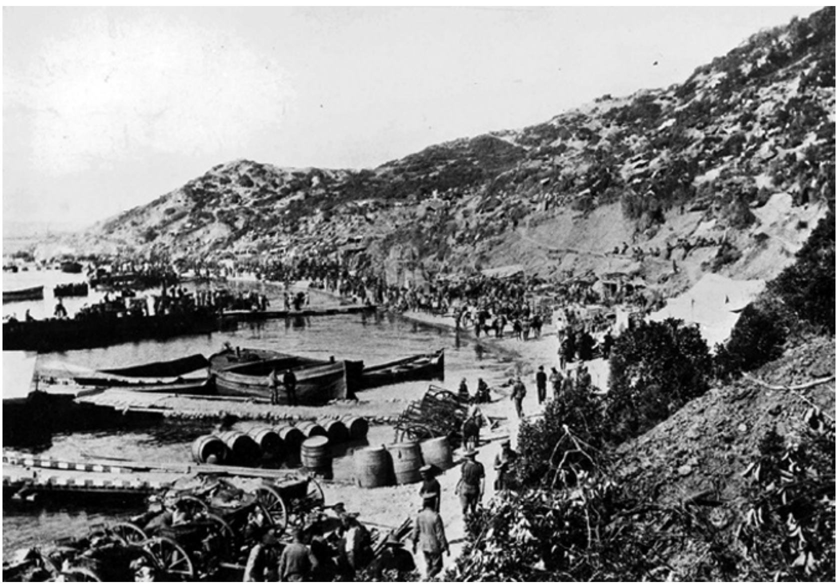


Figure 1.11 Allied troops landing on a steep and narrow beach at Gallipoli during the early stages of World War I. (*Source:* Courtesy of Australian War Memorial.)

attempts to stabilize the beach and prevent erosion (Figure 1.11).

For decades these activities represented the major efforts of science and technology to understand, and in some respects, to control the response of the coast to natural processes. World War II was also an important period in furthering our understanding of the coast. Major war efforts took place along the coast, particularly the landing of troops

Figure 1.12 Photograph of the late Douglas L. Inman, famous professor at Scripps Institution of Oceanography and major contributor to research on the coast of southern California. (*Source:* Scripps Institution of Oceanography, UC San Diego. Reproduced with permission of Scripps Institution of Oceanography, UC San Diego.)

(Figure 1.12), supplies and equipment, whether on the European mainland or on Pacific islands (see Box 1.1). All branches of the military were involved in studying coastal geomorphology, coastal processes including waves, tides and currents, and the analysis of weather patterns along the coast. Much of the world's coast was mapped in detail during this period. The Beach Erosion Board, a research committee of the U.S. Army, Corps of Engineers, made many very important contributions to our knowledge of coasts. This group conducted extensive research on beaches, waves, erosion and other important aspects of the coast using both their own staff and academic researchers from many of the best universities. Francis P. Shepard and Douglas L. Inman (Figure 1.13) of the Scripps Institution of Oceanography were prominent contributors to the research programs of this group and later became among the most prominent coastal researchers in the world.

Box 1.1 Why is the Coast so Important?

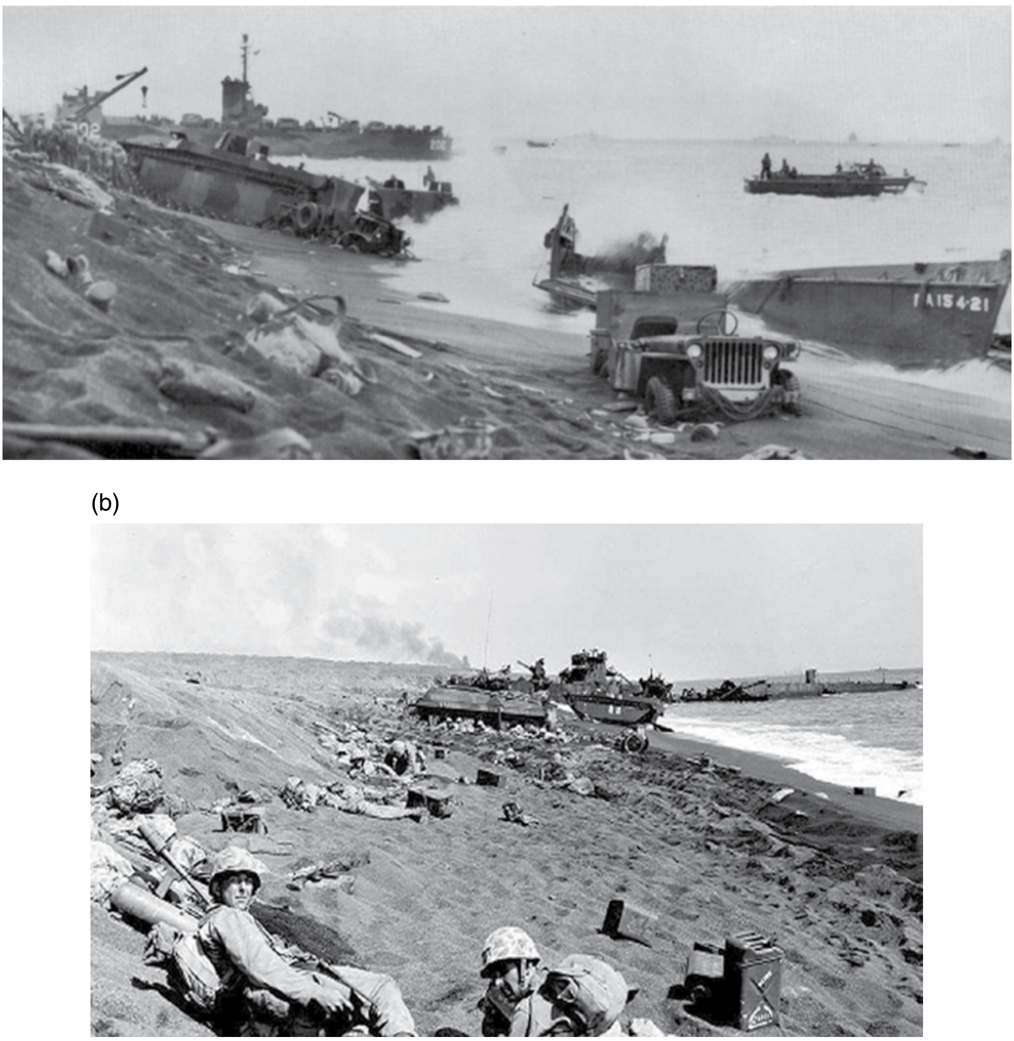
This seems like a pretty stupid question but maybe there are some reasons that you have not considered before. Most of us think about the beach and swimming or surfing; maybe fishing. All of these are important but they pale in comparison to some of the huge economic benefits of the coast. All of our ports and harbors are on the coast. Many of the major cities of the world are on the coast. These account for many trillions of dollars in economic benefit. Coastal tourism is also a huge business in many countries, with the United States leading the pack.

Now think back into history and see if the coasts have always been important to civilization. In early historical times eastern Mediterranean countries such as Greece, Turkey, Egypt and Italy all had established coastal cities that functioned both as important economic centers and as places to protect their countries from invaders. In those days invasion by vessel was the most common way to conduct such activities. Ships were small and required little water to float, so attackers could beach their transport ships to unload the invading armies. This type of activity was also common in the Scandinavian countries when the Vikings were invading the high-latitude parts of Europe.

As time marched on, coastal invasions continued but in somewhat different fashions. During World War I some invasions were launched large transport ships from which soldiers made their way to the coast in small landing craft. This left the invading troops exposed and vulnerable to well-placed defenders on land and, as a result, landing troops were often destroyed. More recently in World War II there were examples of how the coast, and the beach in particular, played an important role in famous military events. The first to be considered is the landing of US troops at Iwo Jima in the Pacific. We all know of the famous picture and statue of the marines raising the flag on the island. Here the landing craft and submarines could proceed right to the shore because of the steep nearshore bottom (Box Figure 1.1.1), meaning that deep water extended very close to the beach. Tides on Pacific islands are low; less than a meter. This steep beach of volcanic sand posed some difficulty for the landing troops but they managed. Eventually the US troops prevailed, which led to the raising of the flag, but more US military were killed in

(a)

(b)



Box Figure 1.1.1 (a) Boats carrying troops right up to the beach at Iwo Jima and (b) marines on the steep beach of volcanic sand. (*Source:* U.S. Department of Defense.)

this battle in a few hours than in more than a decade of the wars in the Middle East and Afghanistan in this century.

The other famous landing of World War II was the Normandy Invasion on the north coast of France (Box Figure 1.1.2). The beach here is quite the opposite of that on Iwo Jima. It is wide and flat with tides of near three meters in magnitude. Bad weather was predicted for the invasion, which included hundreds of aircraft as well as vessels. Tides also had to be considered because the Germans had placed various

(a)

(b)

Box Figure 1.1.2 (a) Aerial view of the huge task force landing on Normandy Beach, France (*Source:* Wikipedia, https://commons.wikimedia.org/wiki/File:NormandySupply_edit.jpg); and (b) troops making their way across the shallow nearshore to the wide, gently sloping beach. (*Source:* U.S. War Department/ National Archives, Washington, D.C.).

obstacles in the shallow water to hinder the landing craft. The weather cleared and the decision was mad to land at low tide which would help to see the obstacles. It was the largest seaborne invasion in history, with 150,000 participants. Fewer were killed than at Iwo Jima.

These are just a couple of examples of extreme activities that benefited from the military knowing the nature of the coast that they were invading. Knowledge of tides, wave climate, nearshore bottom and other environmental parameters helped in these invasions.

Figure 1.13 Photograph of the devastation near the coast of Japan where the 2011 tsunami came ashore.

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