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QUESTIONS ON COASTAL PROCESSES: CONTEST OR CO-EXISTENCE WITH NATURE

BY

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U. S. Geological Survey

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INTRODUCTION

<u>Homo Sapiens</u> is, by nature, an adaptive creature. The survival of our species through the climatic rigors of the ice ages almost certainly hinged on our adaptability. This trait no doubt fostered our natural radiation into a remarkable variety of habitats, from barren deserts to arctic wastes, from mountain slopes to coastal lowlands.

The development of technology provided an additional capability. Whereas primitive man could only adapt to his surroundings, civilized man can modify the environment to suit his needs. He alone can generate rapid and significant changes in his landscape. The dual nature of man, adaptor/modifier, is the premise for this paper.

Artificial changes in environmental setting are generally made in the face of the forces of nature. In many places, the contravention of natural processes can be made with impunity. This is not to say that the forces of mountain building and erosion will not, in the next 500 million years, erase all traces of our existence; nor is it meant to imply that catastrophic events such as major floods or earthquakes do not temporarily impede our efforts to reshape the world. But in many of our habitats, these processes are either so slow or so infrequent that they do not significantly retard our progress over the span of several human generations.

Such a generalization does not hold, however, in the coastal environment, where natural processes have sufficient magnitude, rate and recurrence interval to impact significantly upon our occupancy. Environmental modification here may be futile, or worse, lead to unwanted or disastrous consequences. The coastal policy-maker continually faces the question of whether to attempt to change his setting or to adapt to it - whether to contest the natural coastal processes or to coexist with them.

The basis for making such decisions must include a complex array of social and economic factors. But fundamental to judicious policy is a predictive capability of the consequences of any activity relative to the natural setting. This paper explores one of the approaches for providing this capability, and deals with both its advantages and its limitations. It also considers the communication gap between research scientist and policy maker, which may presently be among the more serious limitations.

THE GEOLOGICAL APPROACH

The coastal environment contains a bewildering array of processes that change both spatially and temporally. Surface waves sweep across the nearshore areas, generating oscillatory currents, and interaction with these waves upon the shoreline may drive unidirectional rip and longshore currents. They may also generate standing edge waves normal to the shore that can influence sediment transport and shoreline morphology. Internal waves on a boundary of density contrast in the water column may intrude the surf zone. Astronomic and meteorologic tides change the level of the sea and generate powerful currents within and at the mouths of embayments. Winds remove sand from the beach and carry it inshore or alongshore in the form of coastal dunes. The nature and amount of sediment contributed from rivers or coastal erosion also contribute to the character of a coast.

Storms can greatly increase the magnitude of many of these processes. The vast change in rate (and direction) of sediment transport and in coastal morphology under extreme environmental conditions is well documented (El-Ashry, 1971). The coastal planner must incorporate the potential for the infrequent big event into any long range policy for use of coastal areas.

In order to achieve a desirable level of predictive capability, one must understand the different coastal processes and their long and short term consequences. The question is how to gain this understanding. The direct measurement of the processes (the "engineering" approach) provides information on the character of the processes at one place and at one point in time. With sufficient quantitative data, predictive models can be constructed on either empirical or theoretic grounds. But direct measurement commonly is limited in areal scope and time frame. It may not generate the data required for a true predictive capability.

An alternative to direct measurement is the "geologic" approach whereby the nature of processes is inferred from the character of their products. This approach offers the advantage of integrating the effects of many processes over a specific interval of time. It presently is limited primarily by incomplete understanding of the links between process and response.

This paper considers three different levels of response and the nature of the information that each provide or fails to provide. The first level is that of bedforms and other depositional structures that reflect the nature of process over a time span of a few minutes to several days. The second level consists of analysis of coastal morphology which reflect processes over a span of a few days to hundreds of years. The third level is that of the major storm or flood, which although infrequent, can cause rapid and substantial change in the coastal configuration.

DEPOSITIONAL STRUCTURES

Depositional structures are sedimentary features that derive directly from the processes operative in that environment. They include morphologic features on the sediment bed (bedforms) and internal features such as stratification that occur within the sediment. The structures may be generated by physical processes (e.g. currents) or by biologic activity (e.g. burrowing).

Bedforms have been the subject of much study in recent years because of their direct relationship to the generating dynamics flow (for example, Dalrymple et.al. 1978; Southard, 1975). They range in scale from ripples a few millimeters high and spaced a few centimeters apart to sand waves and dunes up to several meters high and spaced hundreds of meters apart. In the broadest sense, the term "bedform" can be applied to a flat bed devoid of other depositional features.

The presence, size, and shape of bedforms depends directly on sediment grain-size, current velocity and flow depth for unidirectional currents (Southard, 1975) and on sediment grain-size, maximum orbital velocity, velocity asymmetry and wave period for oscillatory (wave-generated) currents (Clifton, 1976). Both types of flow are common to coastal settings.

Bedforms may be active or relict. Where active, they obviously reflect aspects of the processes operating at the time of observation. If they are inactive or relict, however, they may be completely unrelated to subsequent, less energetic conditions. Distinction between active and relict bedforms may be difficult if sand transport is not actually observed. Generally, subsequent small scale movement of the sand by weaker currents or by organisms degrades the form of inactive bedforms. Their presence, however, attests to the occurrence of more energetic conditions in the recent past.

The observation of bedforms may be either direct or remote. Direct observation can be made with scuba or by using underwater camera or television. Data can be gathered remotely from the records of fathometers or side-scanning sonar. With remote methods, the activity of bedforms may be difficult to assess. Moreover the degree of resolution of remote techniques limits them primarily to study of large structures.

Bedforms themselves, although highly useful, provide inferences on processes over a limited period of time. The stratification types associated with bedforms permit an estimate of the nature of processes over a long time span.

Bedforms generated by unidirectional or asymmetric oscillatory flow generally are asymmetric in cross sections; their steeper (slipface) side faces down-current in the direction of the prevailing (or stronger) current (fig. 1). Typically, bedforms migrate in this direction, and preserve within themselves traces of former slipfaces. These traces form ripple lamination or cross-bedding (depending on the scale of the bedform), stratification which is inclined relative to the original sedimentary surface and which indicates the presence of bedforms, something as to their size and geometry, and the direction of their migration. Deposition in conjunction with a flat bed produces planer stratification which, for the same grain-size, bespeaks of more energetic conditions than with ripple lamination or crossbedding.

The study of subaqueous stratification requires cores that may be difficult to obtain in coastal waters where craft size is limited. The collection of cores by divers has proved particularly useful, but is commonly hampered by poor visibility or by intense currents. Peels from the cores or x-radiography generally clearly delineate the stratification type.

An application of depositional structures to the problem of delineating transport pathways is shown in an example drawn from Willapa Bay, Washington. This bay, on the southern coast of Washington, is an estuary of complex configuration that is fed by a number of small streams. The southern arm of the bay consists of a north-trending channel 1-2 km wide, bounded by broad, sandy

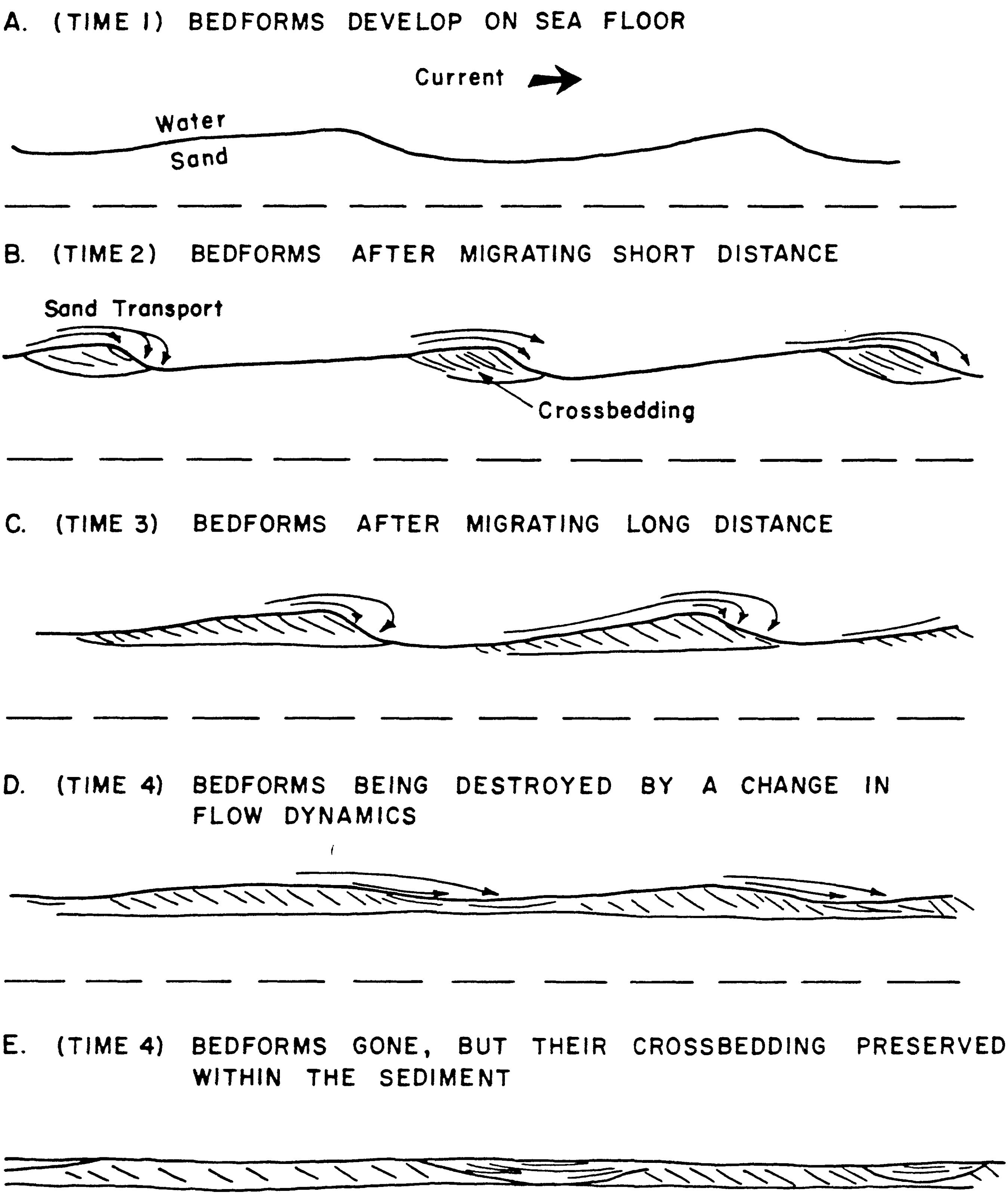

Figure 1. Development and migration of bedforms and production of associated crossbedding.

intertidal flats (fig. 2). Tidal currents in the channel are intense, but highly variable.

In 1974 the channels of Willapa Bay were surveyed using side-scanning sonar, some repeatedly at different stages of the tide. Analysis of the records showed that the bedforms in many parts of the channels retained their orientation through reversals in direction of the tidal currents. The orientation of the non-reversing bedforms suggests the pattern of sand transport throughout the sandy part of the estuary shown in Figure 2. Subsequent coring of the sand by divers confirmed that the orientation of the bedforms reflects their migration pattern and thereby delineates the transport pathways of the material transported across the sediment bed (Phillips et.al., 1976). Such information is of paramount importance for developing policy regarding the removal or addition (i.e. dredge spoils) of sand or other particulate bed material in the channels of the bay. A similar study has subsequently been conducted in San Francisco Bay (Rubin and McCulloch, 1979).

Several factors presently limit the application of depositional structures to environmental problems. These include a need for more precise understanding of the quantitative relationship between structures and process; and a general inability to determine the rate (and in some cases the direction) of sediment transport.

The origin of bedforms has never been clearly delineated. The conditions whereby structures develop under unidirectional flow have been intensively studied in flumes (Simons et.al.,

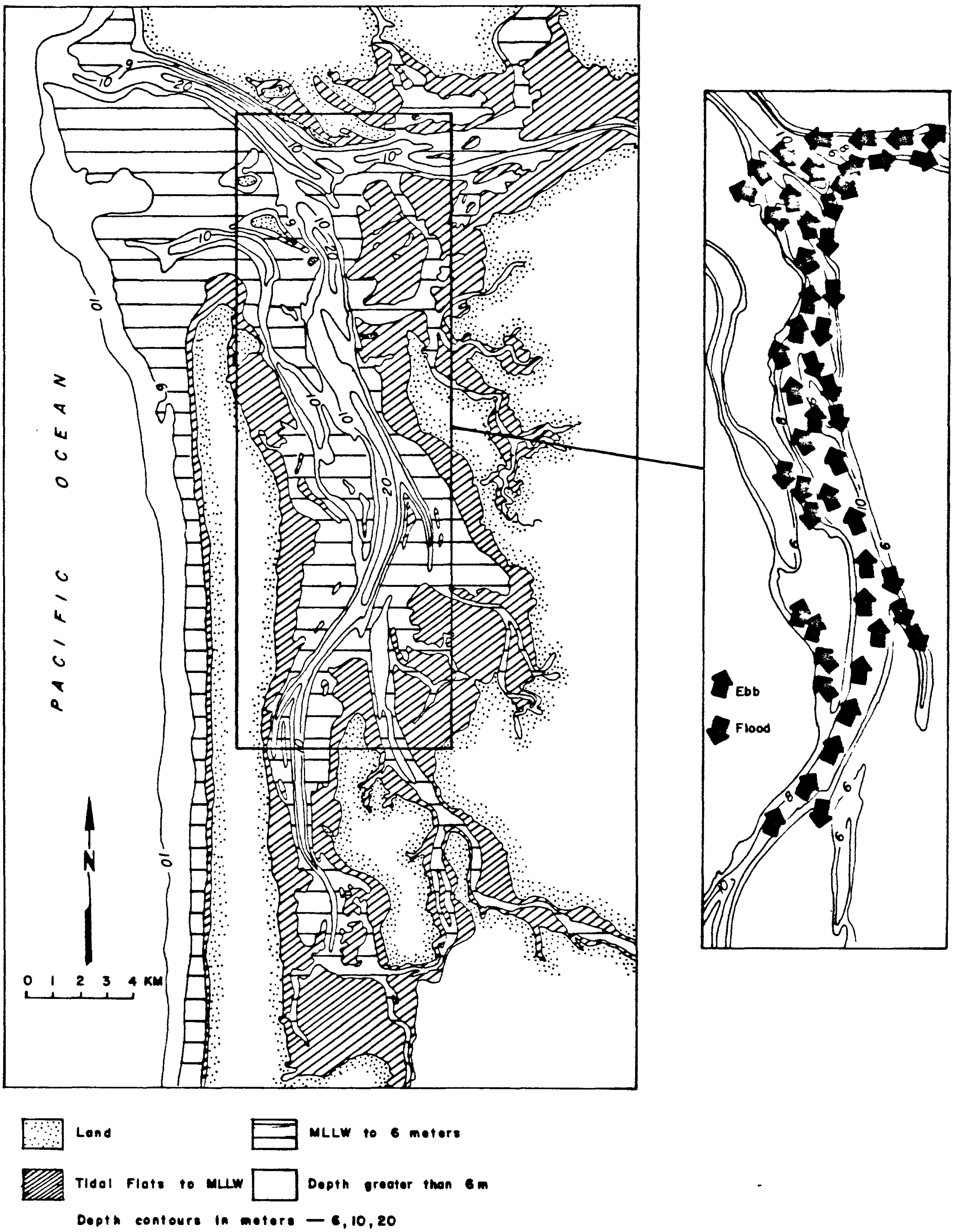

Figure 2. Channel morphology and net sediment transport pattern as indicated by bedforms and internal structure, Willapa Bay, Washington.

1965) and under natural conditions (Coleman, 1969; Collinson, 1970) and are fairly well established. Structures produced by oscillatory flow also have been quantitatively examined in flumes (Carstens et.al. 1969; Mogridge and Kamphis, 1972) and under natural conditions (Dingler and Inman, 1977), but to a far lesser extent. Very little is known about bedform response under the combinations of oscillatory and unidirectional flow that is common in coastal settings. It is not even certain which aspects of a highly variable flow determine the development and morphology of the bedforms. Much research is required before depositional structures in the coastal environments can be used to predict accurately the nature and magnitude of forces here.

Moreover, very little is known about the relationship, if any, between bedform and rate of sediment transport. In some environments, such as within the surf zone the direction of sediment transport may be totally unrelated to the orientation of depositional structures. Figure 3 summarizes a hypothetical situation wherein the strongest currents are the onshore/offshore oscillatory flow generated by passing waves. Bedforms developed here will likely reflect only this flow and be unrelated to a small longshore flux imposed by the same waves. The net sediment transport, in contrast, may be dominated by this flux, which could not be recognized from the depositional structures. Situations have, indeed been documented whereby sand thrown into suspension on the lee side of a bedform is transported in a direction opposite to that of the bedform migration (Tunstall and Inman, 1975).

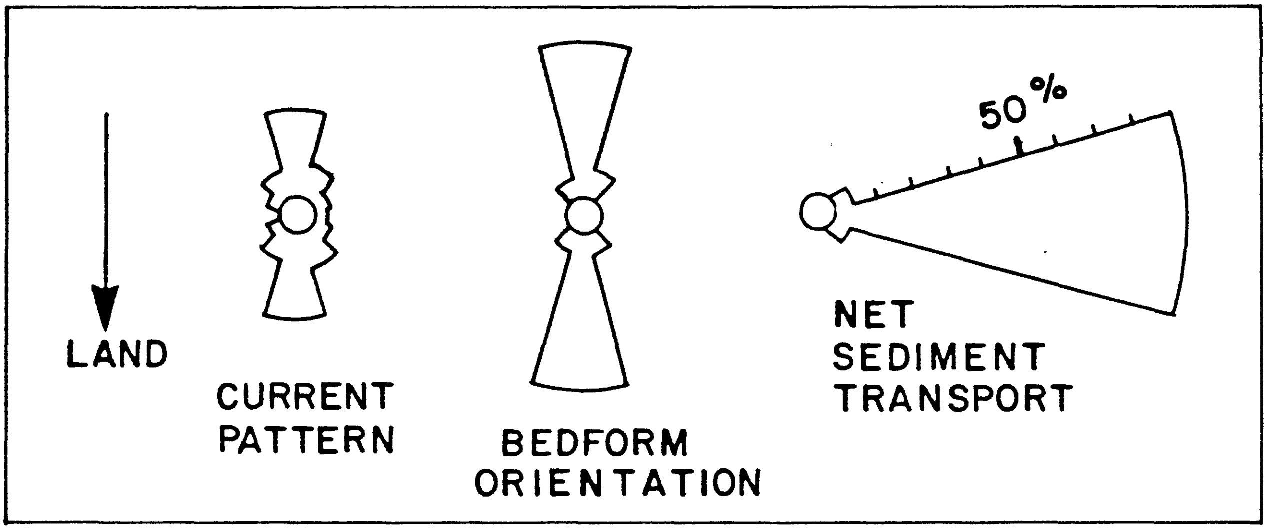

Figure 3. Relation between current pattern, orientation of bedforms, and net sediment transport under a predominantly oscillatory (wave induced) flow with a small longshore current component.

Another limitation of depositional structures lies in their ephemeral nature; they tend to reflect processes operative within a matter of days from the time of observation. Coastal planners must be concerned with longer term patterns of erosion, transport, and deposition. To analyze such long range phenomena, one must take a broader view than is afforded by bedforms and their internal structures alone.

COASTAL MORPHOLOGY

Continued erosion or deposition generally alters the configuration of the shoreline. The analysis of coastal morphology provides clues to long-term trends that may interfere with coastal developments. Such analysis may be conducted either by examining historic changes in the coastline or by drawing inferences from the character of the existing coastline.

Recent changes in coastal morphology can be delineated by comparing contemporary maps, charts, or photographs with those made at an earlier time. This approach not only permits identification of long-term trends within the past several hundred years, but also provides a basis for estimating rates of erosion or deposition. The reliability of the older charts or maps must be established relative to the magnitude of the change. It may also be necessary to recast the maps or charts into the same projection and scale before different sets can be accurately compared.

The inferential analysis of coastal morphology depends on the ability to read correctly the features of a present coastline. Longshore transport directions are indicated by such features as recurved spits (Hunter et.al., 1979), or by asymmetric patterns of sediment accumulation on either side of headlands or a delta. Beach or chenier ridges imply an accretionary shoreline whereas seacliffs or bluffs imply erosion. The character of the coastal morphology commonly suggests trends of erosion or deposition that greatly exceed the duration of historical time.

Three examples of the analysis of coastal morphology are presented here. The first is based solely on an analysis of historical patterns of erosion and deposition. The second illustrates how a problem that is demonstrated by historical change could have been precluded by correctly interpreting the existing morphology. The third brings both historical composition and morphologic analysis to bear on a contemporary coastal problem.

Molnia (1977) provides an analysis of a dramatic example of rapid change on the Alaskan coast and its relevance to proposed developments. Icy Bay, Alaska, provides the only shelter for marine traffic for nearly 300 km on the Gulf of Alaska (fig.4). Its proximity to offshore tracts leased for oil and gas exploration make it a logical location for a staging area for the development of offshore oil and gas, and a feasibility study for such a facility was submitted to the State of Alaska in 1976.

As recently as 1904, however, Icy Bay did not exist; instead the site was occupied by a lobe of Guyot Glacier. As the glacier retreated to its present position (fig. 4), the re-entrant known as Icy Bay was formed. Molnia used three editions of the NOAA

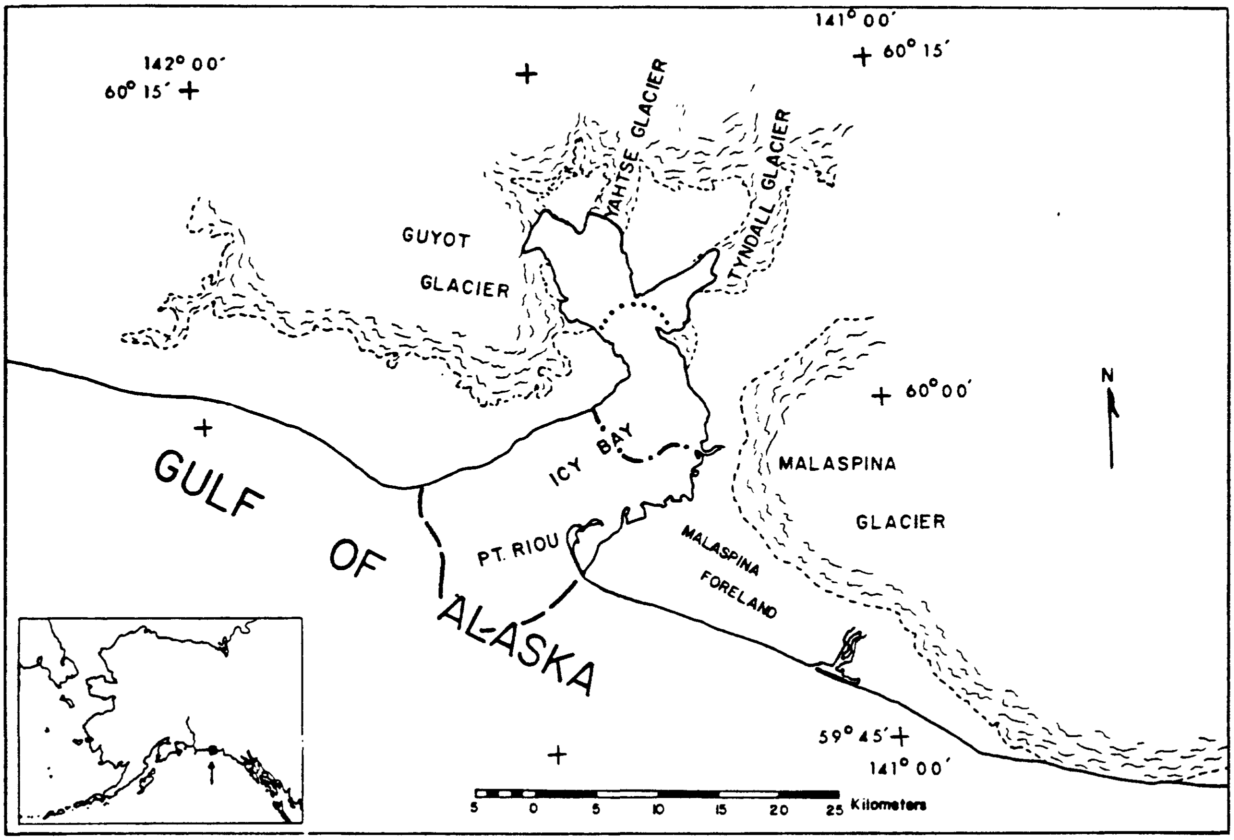

Figure 4. Map of Alaska showing the location of Icy Bay and positions of the ice front of Guyot Glacier in 1904 (----), 1926 (-·-·), and 1957 (.....). After Molnia (1977).

and U. S. Coast and Geodetic Survey 1:40,000 Icy Bay nautical chart (1923, 1964, and 1974) and aerial photographs taken in 1941, 1948, 1957, 1971, and 1975 to chronicle recent changes in the bay and its environs. A comparison of the three editions of the nautical chart and of the five aerial photographs showed that the shoreline east of the bay retreated as much as 1.5 km since 1922, mostly in the past 35 years (fig. 5). The shoreline west of the bay retreated nearly 5 km during the same period. The spit on the eastern shore at the mouth of the bay (Pt. Riou) has grown dramatically from a length of about 3.2 km in 1922 to 6.6 km in 1976 (fig. 5); Molnia calculates that more than 3.56×10^7 m^3 of sediment accreted on the spit between 1922 and 1971.

Any attempt to establish an onshore facility in Icy Bay must obviously contend with rapid erosion and deposition. Molnia estimates that Point Riou Spit, at its present growth rate, will seal off the mouth of Icy Bay in 20 years. Further sedimentation would fill in the harbor for the proposed development fifteen years later. Any economic assessment of the cost of development must include estimates of costs of dredging that would be required to maintain the harbor and its navigation channels. Contesting the forces of nature at Icy Bay might prove prohibitively expensive.

The second example comes from near the town of Adra, Spain, which lies on the Mediterranean coast approximately 130 km east of the city of Malaga. Here, nearly 100 years ago, a modification was made that probably would have been avoided had its consequences been known. An analysis of the coastal morphology

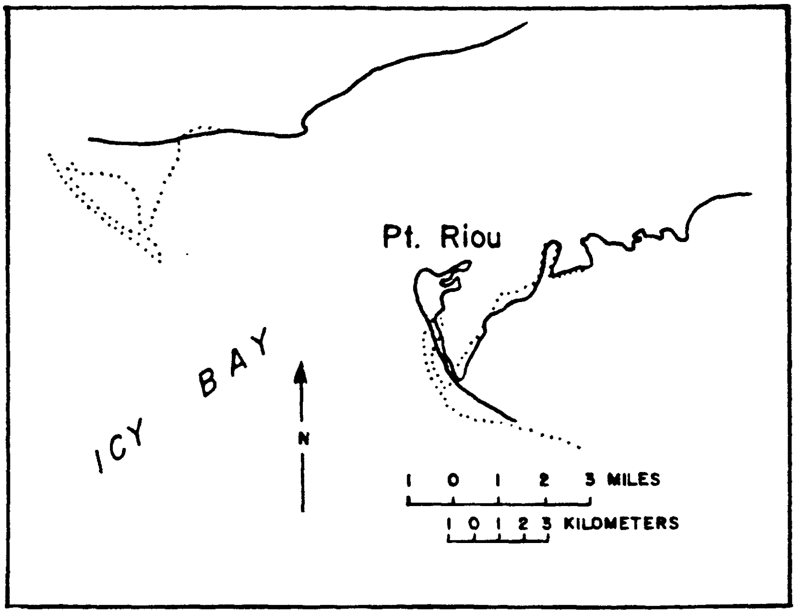

Figure 5. Shoreline retreat on the west coast of Icy Bay and spit growth at Pt. Riou. (1976 shoreline ——— , 1922 shoreline ....). After Molnia (1977).

would likely have led the planners of that time to leave the situation as it was.

Adra, a community with a population of about 8,000, lies within a topographic gap that, as shown on a map published in 1890 (Montojo y Salcedo, 1890), funnelled the intermittently flowing Rio Adra onto a narrow coastal plain (fig. 6). Much of this plain consists of a fan-delta with an area of about 8 km. The delta surface provides an intensely cultivated, fertile platform at the base of an extensive range of barren hills. The 1890 map shows that the delta was markedly asymmetric, protruding abruptly seaward at its western end where the Rio Adra entered the sea (fig. 6).

The 1890 map shows the projected course of the Rio Adra through a cut (La Corta) across the hills about 3 km east of the town of Adra (fig. 6). This cut was made some time before the time the map was published, presumably as a flood control measure. The Rio Adra has flowed through La Corta at least since the turn of the century, and the mouth of the river thereby displaced about 4 km to the east. The consequences to the western end of the delta of diverting the sediment supply were disastrous.

The asymmetric shape of the 1890 delta strongly suggests that it was attacked by waves from the southwest that induced longshore transport toward the east. The coastal engineers of the time seemed to be aware of this situation. The jetty that encloses the harbor at Adra is shown on the 1890 map; it opens to the east and appears to have been constructed to provide

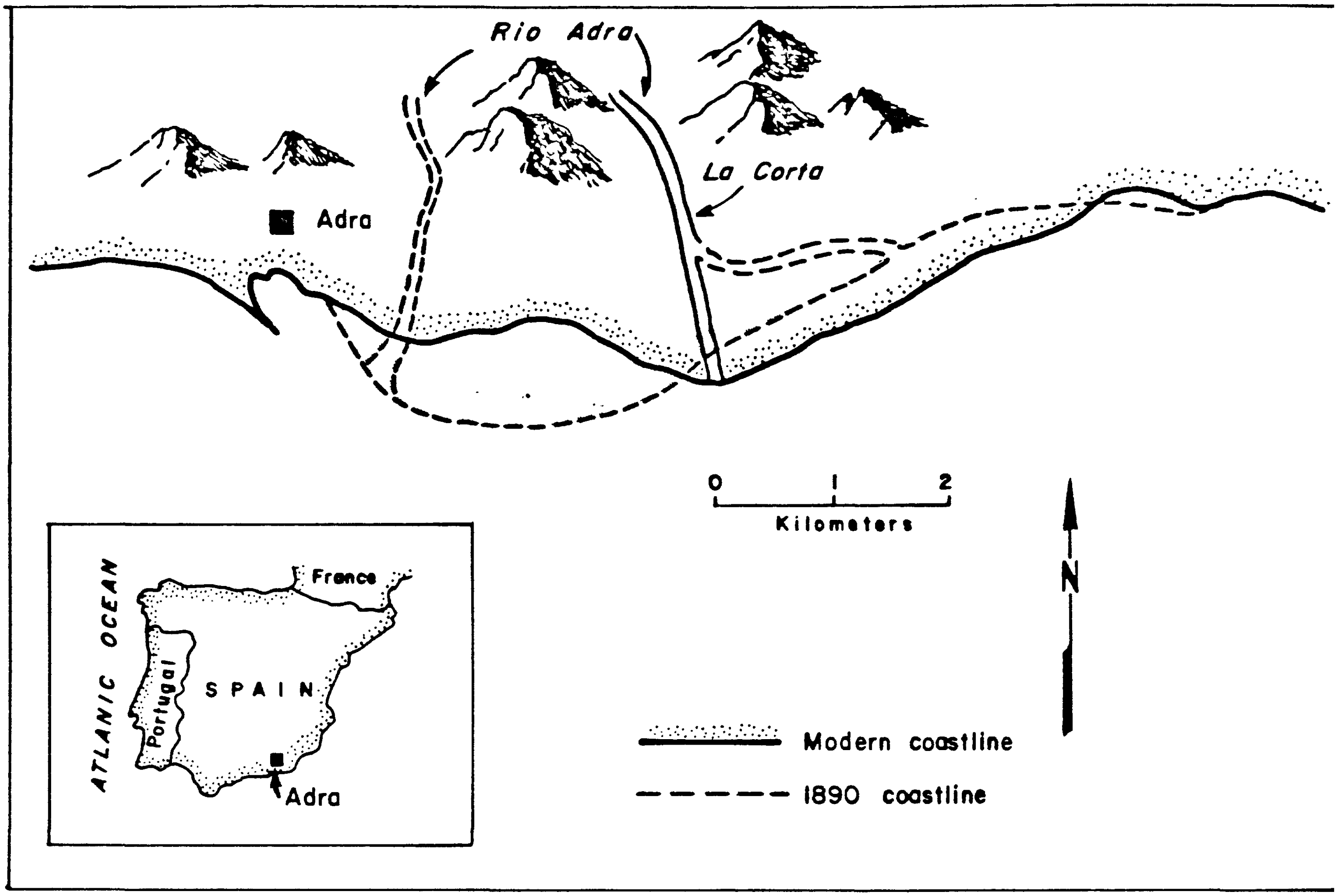

Figure 6. Location of Adra, Spain, and 1890 and 1957 positions of the coastline and the Rio Adra.

protection from southwesterly waves. A jetty at Puerto de Motril, 45 km to the east, is similarly built and the orientation of both jetties is consistent with the pattern of eastward longshore transport that is implied by extensive beach ridge systems on the eastern side of large promontories along the coast between Adra and Puerto de Motril.

The planners who diverted the Rio Adra may have been aware of the direction of longshore transport; they seemed not to recognize the erosional character of the coast at Adra. Cliffs front the sea along most of the shoreline-they are absent only on depositional features like the Adra delta.

Although seemingly not recognized at the time, the effect on the Adra delta of diverting the river was predictable. Once sediment was no longer fed to the delta front, it retreated under the attack of the waves. Comparison of the 1890 map with one published in 1957 indicates that in six decades, more than 1.5 km^2 of land was lost (fig. 6). At present the margin of the old Adra delta is marked by a scarp that locally exceeds 3 m in height. The foundations of buildings are exposed in the cliff and collapsed ruins lie on the beach and in the surf zone.

The modern Adra delta, like the ancient delta, is an asymmetric feature. Approximately .35 km^2 of new land has accreted since 1890 on the eastern flank of the delta. This land is presently cultivated, but it replaces only a small part of that eroded.

The delicate balance between deposition on the delta by the Rio Adra and erosion by waves could be further disturbed. If the

Rio Adra were dammed for flood control or irrigation purposes, sediment input to the delta would be further reduced. Under these circumstances it is likely that considerably more valuable agricultural land would be lost to coastal erosion.

The third example is drawn from Willapa Bay, Washington, where an erosional problem has existed on the north side of the entrance to the estuary for a number of years. Since the mid-1950's, the entrance to the channel has migrated northward about 1 kilometre. As the channel shifted 10 km^2 of land, containing a number of dwellings, a Coast Guard Station and several roads were lost. Several questions are pertinent: Can the erosion be stopped? Is it induced by man's activities? How far will the erosion proceed if unchecked? Partial answers to these questions can be gleaned by analyzing the historical changes at the bay's entrance, as well as by studying morphologic features near the entrance.

Willapa Bay was the site of relatively early settlements in the Pacific Northwest. The native oyster, Ostrea lurida, was harvested and shipped to San Francisco in the days of the gold rush (Swann, 1857). The earliest charts of the bay were made in 1852 (Alden, 1852). The oldest reliable chart of the bay dates from 1887 (Burnett, 1887). This chart indicates that the main channel into the bay was located some 3 km south of the present channel (fig. 7). Subsequent charts show it shifting progressively northward with time.

A series of profiles (fig. 8) across the entrance as the channel shifted north suggests that the northward shift was

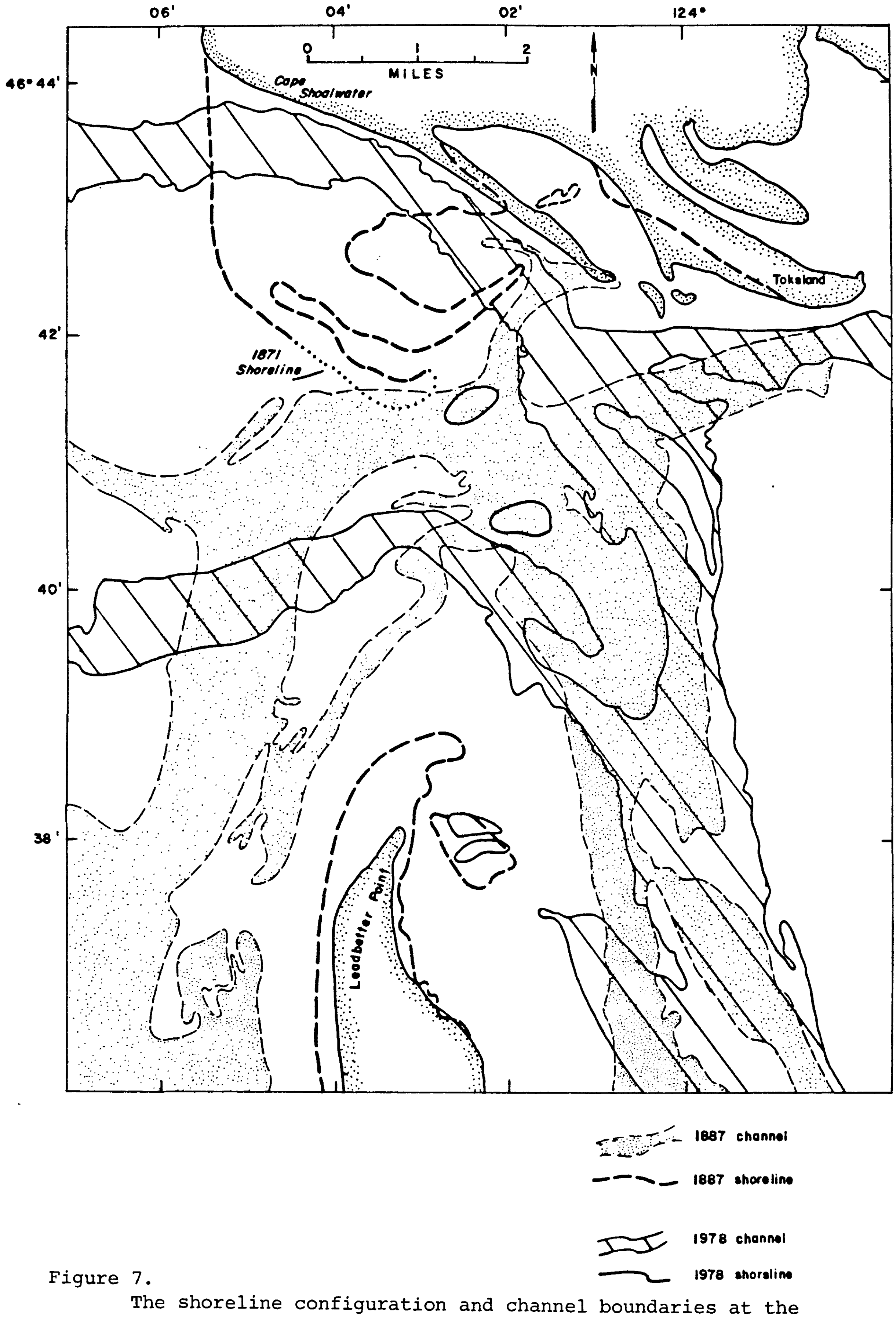

Figure 7.
The shoreline configuration and channel boundaries at the entrance to Willapa Bay in 1887 and 1978.

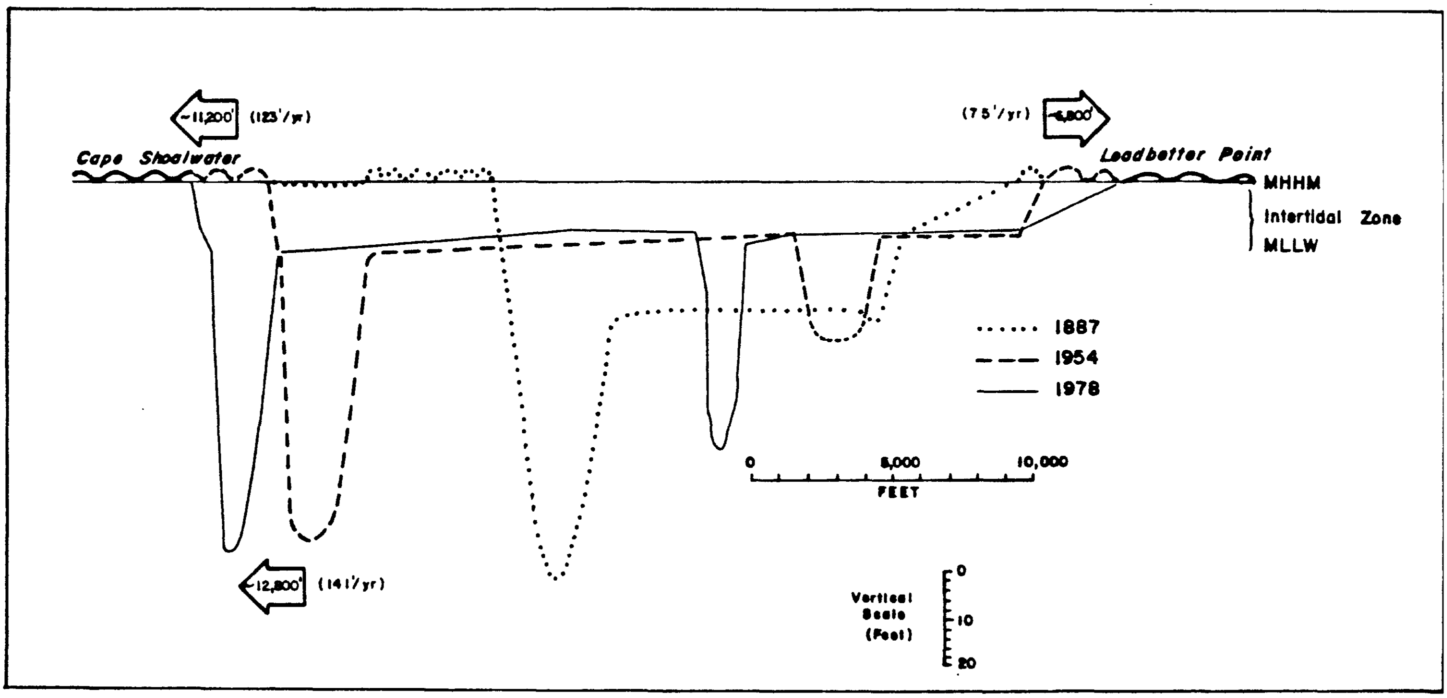

Figure 8. Profiles across the entrance to Willapa Bay in 1887, 1954, and 1978. The broad flat areas are zones of breaking waves for which no bathymetric data is available.

driven by tidal currents. As the channel became progressively more curved, both the ebb and flood currents, which flow with considerable strength at the entrance, were focussed on the northward bank. Most of the visible erosion of the shore is caused by waves during winter storms. It is, however, the erosion of the channel wall by the tidal currents that drives the northerly shift of the channel system.

In the early 1970's, consideration was given to a proposal to protect the shoreline with riprap. Fortunately this course was abandoned; although it might have impeded the destructive effects of the waves, the erosion due to the tidal currents would have continued. That erosion might be checked if the entire northern face of the tidal channel were reinforced. Such a measure would probably be prohibitively expensive, for it would require a wall of riprap 20-25 m high and as much as 7 1/2 km long.

The northerly shift of the channel seems to be unrelated to any human interference, such as the building of dams on the Columbia River. The migration of the channel has been evident since 1852, long before dams were built on the Columbia River. The rate of erosion has clearly increased during the past 20 years, but this is probably attributable to the decrease in the radius of curvature of the channel during this time. As the channel becomes more sharply curved, the tidal currents are increasingly thrown by centrifugal force against the outer bank.

If this model is correct, the channel will continue to migrate north for some time. Ultimately its length will become so great as to limit its effectiveness as a conduit for tidal flow in and out of the estuary. A distinct secondary channel has developed near the southern side of the bay entrance. Over the past 30 - 40 years, this subsidiary channel has been migrating northward (figs. 7,8). Presumably it will someday replace the northern channel as the main pathway into the bay. At that time, the northern channel will cease to erode further and will probably fill rather rapidly.

The configuration of the shoreline at the northern edge of the entrance suggests that this is not the first time in the history of the bay that an erosional tidal channel impinged upon it. A large sand spit has presently developed east of the channel where it bends to the southeast into the estuary (fig. 7). Just east of the area of present erosion, the shoreline has a broad arcuate bend. On the eastern side of the projection of the bend is a large spit (on which lies the small community of Tokeland). The arcuate part of the shoreline is cut into Pleistocene terrace deposits and clearly seems to be an erosional feature. The radius of curvature here closely resembles that of the present channel, suggesting that it was the margin of an earlier channel that cut into the north bank of the bay. The Tokeland spit appears to be a bay-entrance spit associated with this channel.

The presence of the old channel scar implies erosion to this point in the past. It suggests that the present channel may be approaching a natural limit to its northerly migration. Whether or not this migration will continue until the channel consumes the recently constructed, rerouted highway on the north side of the bay is open to conjecture. It might have been wise to have built the highway a few miles further north as a safety factor.

The Willapa Bay example illustrates the advantage of using both comparative study of historical change and interpretive analysis of morphology to address a coastal problem. Historical variations can provide estimates of rates of change but generally do not indicate the nature of the end result. Interpretation of morphology can permit prediction of the end result but is less valuable for assessing the rates of change. The combination of the two permits inferences of both end result and the rates involved in reaching it.

ANALYSIS OF STORM EFFECTS

Conditions in most coastal settings are far from uniform through time. Generally three levels of intensity can be defined. Mild conditions, typified by the absence of storms, occur most of the time. Intense conditions, produced by storms typical for the area, are likely to occur several times or more each year. Extreme conditions are vastly more energetic and reoccur on the order of tens or even hundreds of years.

Extreme events can rapidly change the coastal morphology and bear a potential for great destruction to human dvelopment. Coastal planners can ill-afford to ignore the potential consequences of the major storm. A predictive capability is not easy to obtain, however, owing to the infrequency of such events.

The geological approach provides information regarding certain aspects of prior major storms. Primarily, the approach consists of identifying evidence of sediment transport in locations in which transport would not ordinarily occur. This evidence may exist at the surface, be found in cores through the sediment, or lie in exposures of ancient deposits formed in a similar environment.

The effectiveness of the geologic approach for predicting the consequences of major storms depends in part upon the general spectrum of energy with time. In an area where the energy spectrum is naturally broad, as on the open California coast, it may be difficult to separate the effects of the truly unusual event from those produced under more common, somewhat less energetic conditions. In areas where the general energy level is more uniform (as for example, the Gulf Coast), the results of the extreme events stand out in the sedimentary record.

The environmental setting also controls the degree to which the effects of major events are engraved in the record. Within estuaries, the effect of normal winter storms and floods are modulated and the energy level is fairly uniform. Extreme events have a pronounced immediate effect, but tend subsequently to be obliterated by the day to day processes. Tropical storm Agnes in 1972 generated major flooding in the Chesapeake Bay area. The magnitude of the flood approached the level expected at an interval of 100 years (U. S. Army Engineer District, Baltimore, 1975) and clearly formed a major event in the depositional history of the bay. Nonetheless, analysis of the effect a few years later indicated that the effect of the flood in the geologic record was probably obscure (Nichols, 1977).

Of particular significance to coastal planners is the store surge, a rise in water associated with a storm. The surge results primarily from wind stresses on the sea surface (U. S. Army Coastal Engineering Research Center, 1973). The rise can exceed 8 m and can lead to great destruction and loss of life. A storm surge at Galveston, Texas, associated with a hurricane in 1900, raised the water level along the coast by approximately 3 meters (Bascom, 1964). Superimposed on top of this rise were storm waves on the order of 8 m high that demolished the city and caused some 5,000 people to be drowned.

Several factors contribute to a storm surge, including the characteristics of the storm, the configuration of the basin, the initial state of the system and external factors such as astronomical tides or rainfall (U. S. Army Coastal Engineering Research Center, 1973). In areas such as the Gulf of Mexico, enough data exist to permit a prediction of the potential surge associated with a particular storm. Hurricane Carla, in 1961, created a surge similar to that which devastated Galveston a half century earlier. Because of the predictive capability, the area was evacuated and loss of life and destruction was minimal (Bascom, 1964).

In areas that are less well known, however, the predictive capability of the "engineering" approach is limited. The geological approach may be of substantial value in such situations.

An example can be drawn from an analysis made by A. H.

Sallenger, Jr. of storm surge effects along the coast of the northern Bering Sea (1979, written communication). In November, 1974, a severe storm swept toward the northeast across the Bering Sea and caused extensive damage to coastal communities. Winds associated with the storm had a peak velocity of 111 km/hr (Fathauer, 1975), and waves 3 - 4 m high were reported at Nome, Alaska. Much of the damage, however, was attributable to a substantial rise in sea level as the storm passed.

The following summer, Sallenger examined the northern Bering Sea coast and measured at 30 places the elevation of the debris line left by the surge. He found that the sea level had risen between 3 and 5 m along most of the coast. He also noted that the debris line associated with the 1974 storm destroyed older debris lines reported by earlier workers in this area.

The northern Bering Sea shelf is presently scheduled for an oil and gas lease sale in 1981. Hydrocarbon exploration, if successful, will almost certainly lead to the development of nearby coastal areas. The potential for storm surges up to 5 m high must be taken into account in the planning of this development.

The geological approach, at best, generally indicates only the presence of certain effects of prior storms. It provides little information regarding the actual character of any storm. The approach therefore is of limited value for developing contingency plans in the face of a particular storm. Its primary use is for assessing certain maximum consequences (such as sea level rise) in a particular area.

THE TRANSFER OF KNOWLEDGE

The coastal planner must choose continuously between contesting coastal processes or co-existing with them. He can choose wisely only if the processes are adequately understood. The geologist can contribute to this understanding by drawing inferences on the basis of physical features. Unfortunately, this contribution is not made as often as it might be.

The primary limit to the "geologic approach" is the degree of understanding of the connection between process and response. In most areas, much basic research is needed to bridge the gap. Where the coastal planner faces the question of whether to modify a particular situation or to adapt to it, the research geologist faces the question of how to allocate the available time and fiscal resources.

The coastal planner generally deals with very specific questions: Will the mining of sand in offshore areas lead to a depletion of sand on the beaches? The coastal geologist is rarely willing to answer such questions unequivocally. First they must be translated into geologic terms: What is the exchange of sediment between offshore area and surf zone and surf zone and beach? If the answer is uncertain, the geologist can be of little use to the planner.

Such situations can lead to a sense of frustration. The geologist may feel that the planner is asking impossible questions; the planner may feel that the geologist's time is wasted on irrelevant issues.

Good communications can decrease the chance for such an impasse.

It will help the planner to know which questions can be answered on the basis of available information, and which require further research. An awareness of the planner's problems can permit a scientist to adjust a research program to improve the chances for solving these problems. Workshops and meetings between planners and scientists allow them to become familiar with the other's needs and broaden the basis for developing wise coastal policy.

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