CHAPTER 13

THE GEOLOGICAL ASPECTS OF COASTAL ENGINEERING

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INTRODUCTION

A natural beach system is in equilibrium when there is a balance between sand supply and erosion such that the volumes of material entering and leaving the system are just equal. If the erosion rate exceeds the supply rate, a beach retrogrades; if the erosion rate is less than the supply rate, a beach progrades. Unfortunately, coastal engineering works, which are meant to improve the shore for commerce or recreation, often upset this delicate balance with very deleterious results: great accretions of sand and high dredging costs, accelerated beach erosion and much property damage. It is the task of the geologist to determine the secular equilibrium conditions of a beach system and to supply the coastal engineer with the information he needs to control the natural forces acting on the shore in such a way that this equilibrium is maintained. In order to accomplish this task, the geologist needs to make a thorough study of the source, transportation, and deposition of beach sediment. He must determine the stable position of the shore line and the profile of equilibrium of the beaches through detailed physiographic investigations. The geological report can and should close with the prediction of just what will happen to a natural beach system if man introduces a disturbing element.

CONTINENTAL GEOLOGY OF TRIBUTARY WATERSHEDS

If an investigation of sediment sources reveals that the principal sources of beach-building material are the drainage basins tributary to the shore under consideration, as is the case in southern California for example, then it is necessary to make a detailed study of the continental geology of these basins. Such a study includes hydrology, physiography, stratigraphy, and sediment supply (Handin, 1951).

In order to make an estimate of the quantities of sediment supplied to the beaches, the geologist first measures or estimates the rate of terrestrial sedimentation. Quantitative estimates are impossible without direct measurements of silting rates in reservoirs or catch basins or empirical equations based upon such measurements. The Forest Service makes use of such equations in determining sedimentation rates in mountainous watersheds (Anderson, 1949). The equations used are of course applicable to a specific area of known geologic characteristics, but the results are valid for other areas if corrections are made for several variables: vegetation, hydrology, rock type, etc. In the absence of direct measurements or applicable equations only qualitative estimates can be made. In southern California for example, the hydrologic data indicate that rainfall is appreciable during a limited time only, but that during this time intermittent streams can become torrential and can then transport enormous quantities of sediment. Such knowledge at least permits the geologist to say that the sediment supply is discontinuous and that significant amounts of material are moved to the shore only once in several years, whenever there is a major flood. On the other hand, there may be evidence that there is never much runoff in, say, a region underlain by very pervious rocks.

Consideration must be given to the types of rocks being eroded in the source areas. Only sand-sized material remains on the beaches; silt and clay are lost in deep water offshore. A careful stratigraphic study is necessary to determine the relative abundances of sand and fine sediment in the source rocks. In the case of

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crystalline rocks particularly, the geologist must know what sort of weathering processes are active in the region so that he can determine how much of the weathered rock remains in the form of sand grains and how much is lost in solution or decomposed into clay and silt. Weathering depends largely upon climatic conditions which are then another factor to be considered.

Even if there are excellent data on terrestrial sedimentation rates, it may be very difficult to estimate how much material reaches the shore. How much sediment is lost along the way between the mountains and the stream mouths? It is now extremely difficult to measure directly the total load of a stream. The measurements of losses in transit must be indirect. If the streams are degrading or appear to be at grade, one can assume that all the source material ultimately reaches the shore. But if the streams are aggrading, deposition rates along the channel must be measured and the losses subtracted from the estimate of sediment supply to the beaches.

It is sometimes possible to use coastal engineering data on accretion rates to determine the contributions of sediment by tributary streams. The rate of accretion of sand at the Santa Monica breakwater has been used to estimate sedimentation rates in the Santa Monica Mountains (Handin and Ludwick, 1950a). The quantity of material deposited by the Santa Clara River during the great flood of 1938 was determined from the volume of sediment in the delta.

In summary, a study of tributary watersheds should reveal terrestrial sedimentation rates, percentages of sand-sized material, and percentages of source sediment ultimately reaching the shore. Both direct and indirect methods can be applied to the measurements.

BEACHES AND COASTAL PHYSIOGRAPHY

A detailed study of beaches and the physiography of the adjacent coastal areas can solve a great many local problems. Some of the following features might be included in such a study: foreshore slope, berms, cusps, sediment type, nature of the backshore, general shape of the beach, presence of seacliffs, seawalls, or dunes, general shape of the beaches, terraces and wave-cut benches, inlets, offshore bars, spits, headlands, and many more. An example of the application of such a study to the solution of a particular problem is the establishment of the fact that in southern California a negligible quantity of sediment has its source in the sea cliffs bordering the coast (Shepard and Grant, 1947). In general the cliffs are protected from direct wave attack by narrow "buffer" sand beaches even along rugged, mountainous beaches of the coast. In regions where coast land is being eroded by wave action, another purpose of the physiographic investigation is to determine the rate of supply of sediment from that source. This is usually accomplished by measuring the rate of retreat of sea cliffs.

But by far the most important purpose of this study is to establish the natural equilibrium of the beach system. The facts gathered in the investigation are used to interpret the recent geologic history of the coast. The shore line changes which have taken place during historic time are determined from a study of old maps and charts. It is then possible to establish whether or not the present shore line is stable, and, if not, what the trend of further changes is likely to be.

PETROGRAPHIC STUDIES

A petrographic study, including mechanical and mineral grain analyses, can be a powerful tool to use in the solution of the problem of the source, transportation, and deposition of beach sediment. Sediment samples to be analyzed are collected from selected sites in the source areas, along the channels of source streams, on the beaches, on dunes, and on the shelf offshore. If the source rocks contain distinctive diagnostic minerals, it is possible to trace sediments from the source areas to the shore. One can show, for example, that much of the beach sand of Santa Monica Bay is derived from the Santa Monica Mountains; whereas the beach sands of Ventura County to the northwest are not (Handin, 1951). By comparing the mineral content of sand samples taken along the shore line, it is possible to determine the direction of the prevailing littoral drift. Finally one can show where the coastal sands are ultimately deposited by investigating the mineral content of dune sands and submarine sediments.

Much can be learned about the nature of the sediment transporting agents by using the concept of the "variation series." Several samples taken along a shore line generally have different median grain sizes and different percentages of mineral constituents. The changes from sampling point to sampling point along the shore line may show a progressive trend. Along the Ventura County coast, for instance, there is an increase in median grain size of the beach sands with distance away from the source streams, which is ascribed to a progressive loss of fine material from the littoral zone. On the other hand, there is a decrease in grain size along the shore of Santa Monica Bay, which is probably due to a progressive decrease in the competency of longshore currents. Heavier minerals seem to settle out of suspension to remain on the beaches, while the lighter ones are carried out beyond the plunge zone to be lost in deep water. Therefore there is an increase in the heavy mineral content of many beach sands as the sediment is transported away from the source areas (Handin, 1951).

Still another use of the petrographic study is to determine the characteristics of the beach sediment which is in equilibrium in its natural environment. Such information is valuable to the engineer who must bring in material with which to construct an artificial beach. If his material is finer than the sand which would be found on a natural beach in the same environment, it is quickly removed by the waves and lost in deep water. If his material is too coarse, the artificial foreshore is likely to be so steep that the beach is useless as a recreational facility.

SUBMARINE GEOLOGY

An investigation of the offshore submarine topography is important since one must have detailed knowledge of bottom contours for wave refraction studies. The history of changes in the bottom topography are of course as significant as changes in the position of the shore line in determining the natural profile of equilibrium and the stable configuration of the shore line. Successiv soundings may indicate that sediment is being deposited or that material is bei; g removed.

In solving the problem of the ultimate deposition of beach sediment, a study of bottom deposits is indispensable. The petrography of submarine samples may reveal the source of the sediment, and in so doing establish whether the bottom sediments are residual or are being deposited now.

In southern California there are unique features which require special consideration: the submarine canyons which head very close to shore. In the first place, these canyons exert a powerful influence on incoming waves. Erosion at Redondo Beach is greatly intensified by wave convergence resulting from refraction over the canyon just offshore. In the second place the canyons very probably trap much sediment moving in the littoral zone. At Port Hueneme the jetties are built out almost to the head of a canyon, and it is very unlikely that littoral drift can bypass the harbor entrance. The inevitable result is serious depletion of down coast beaches.

GEOLOGICAL ASPECTS OF WAVE STUDIES

The geologist is most concerned with average wave conditions prevailing for a long time. The prevailing waves have much to do with shaping the coast line. The source of the majority of swells reaching the California coast is in the North Pacific Ocean, so that waves approach the shore from the northwest much of the time (Scripps Institution of Oceanography, 1947). The result is that headlands are asymmetric with long western tangents and short northeast trending re-entrants.

The direction of wave approach determines the direction of littoral drift, which is of course of prime interest to the coastal geologist, as well as the coastal engineer. Unfortunately, the direction of the littoral drift can be determined analytically with the aid of wave refraction diagrams only when very complete meteorologic data are available. In the absence of such data, the geologist must look to physiographic and petrographic evidence.

Wave heights are probably the most important factor determining the grain size of beach sands. Foreshore slopes in turn depend upon grain size among other things, so that it is well for the geologist to make a study of prevailing wave heights. He should also observe the period and angle of approach of waves, since together with height, these factors largely control longshore current velocities. Seasonal changes in wave heights and angles of approach are responsible for seasonal variations in longshore current capacity and competence (Handin and Ludwick, 1950b).

CONCLUSIONS

There has been time to touch upon only a few of the more generally important functions of the geologist in the coastal engineering program. Indeed, it is difficult to differentiate between problems typically handled by a geologist or by an engineer. For the study of sediment sources, the engineer furnishes the hydrologic data; the geologist provides the stratigraphic evidence. For the beach studies, the geologist makes the petrographic analyses; the engineer measures the profiles. But perhaps the greatest contribution the geologist can make is a philosophical one. He always asks himself: what will be the effect of an engineering structure upon a natural equilibrium that was established long before man came along, an equilibrium man can upset so easily.

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