PORT AND OCEAN ENGINEERING UNDER ARCTIC CONDITIONS
TECHNICAL UNIVERSITY OF NORWAY

ARCTIC SEDIMENTATION INDUCED BY STORM

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INTRODUCTION

Relatively few sedimentological studies have been completed in Arctic and Sub-arctic regions. Recent observations in these areas suggest that significant and major changes in sedimentary regime often occur during relatively short time. This does not propose cataclasmic theory but suggests that the study of sedimentary processes in these regions must take into account the effects of events which occur in pulses. This paper describes coastal areas of Alaska where storms cause pronounced changes in sedimentation.

Most of the dynamic energy of the ocean is dissipated along its shelf and the coast. It is therefore logical to select near shore areas to study the effects of storms on sedimentation. Point Hope, Alaska, the westernmost tip of Tigarag Peninsula on the shore of the Chukchi Sea was studied because the northern shore of this cuspate is being rapidly eroded while along the southern shore sediments are deposited. The southeastern part of the Bering Sea shelf, on the other hand, a large shallow shelf with long fetch, provides an unparalleled natural laboratory to study the effects of long waves on sediment transport and deposition on the shelf.

CLIMATE

The climate of the Bering Sea is controlled by the geographical position of radiation and the general global circulation of the atmosphere. Geographically most of Bering Sea lies in Sub-arctic climatic zone and only its extreme northern part (north of lat. 64° N) and extreme southern part (south of lat. 55°) can be included in Arctic zone and temperate zone respectively. Cyclonic circulation prevail over the Bering Sea therefore eastern half of the sea is warmer than the western half. Throughout the year the climatic conditions over the Bering Sea is controlled by the Arctic and Honolulu maximums, seasonal influences of the Siberian maximum, the Aleutian minimum and the Asiatic depression is also significant. The dominant control, the Honolulu maximum, changes its position and influence throughout the year. During winter Honolulu maximum occupies a southeastern position and in summer it becomes vigorous and is situated in the northwestern position. Throughout the year Honolulu maximum is a source of heat advection for the Bering Sea and produces strong southeast wind. On the other hand the Arctic anticyclone is the source for cold advection which increases northern and northeastern winds.

The shifting of Honolulu anticyclone to the west northwest leads to an intensification of the cyclonic circulation and increase of the frequency of south winds. The shifting of the Honolulu anticyclone to the east results in simultaneous advance of the Arctic anticyclone to the south thus an intensification of frequency of north winds.

High winds over oceans generally cause storm tides or surge. During the peak of storms the height of surges reaches 3 - 4 m. As a result of these surges water overflows the beaches, accelerating the normal processes of erosion, transportation and deposition. Provided enough fetch, the winds generate wave which travel over long distances. Long and high waves associated with storms generally travel landward and greatly influence sedimentation on the continental shelf.

AREA OF INVESTIGATION

The southeastern Bering Sea shelf is a triangular embayment lying between 54°-59°N latitudes and 157°-167°W longitudes and covering an area of 1.5×10^5 sq km (Fig. 1). At its mouth the bay is about 380 km wide and extends approximately 450 km eastward to the head (apex). The bay floor has an average depth of 70 m. The shelf is extremely flat, with an average slope of only 2.4×10^{-2} percent.

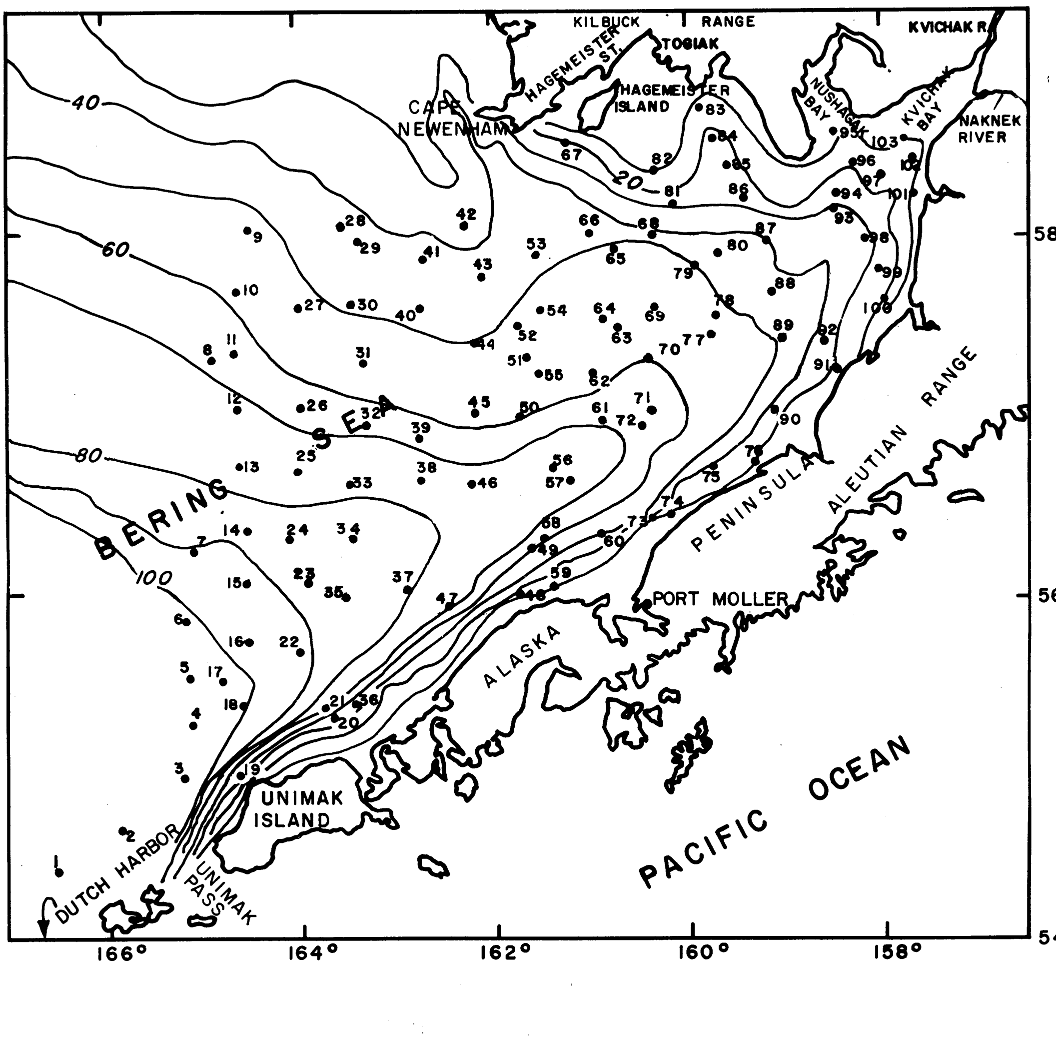

Fig. 1. Location map showing station locations and bathymetry (depth in meters) in Bristol Bay.

Point Hope, Alaska (Fig. 2) is the westernmost tip of the Tigarag Peninsula, on the shores of the Chukchi Sea. The area, part of the Alaskan coastal plain, is a cuspate foreland of unconsolidated Recent and Pleistocene sediments.

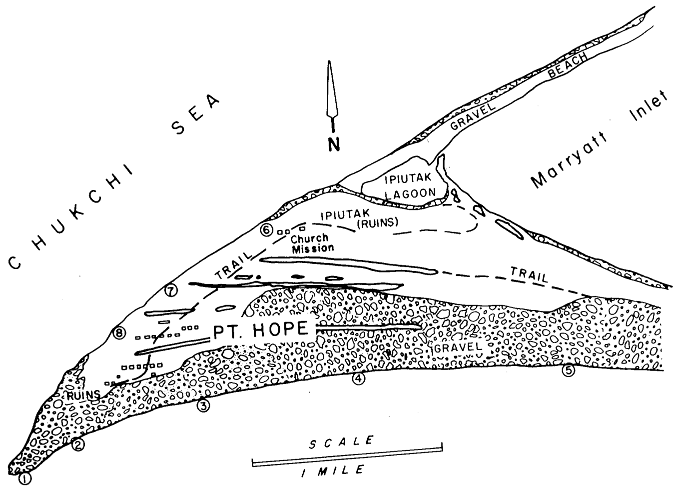

Fig. 2. Index map showing location of beach profiles in Tigarag Peninsula.

BEACH DEPOSITS

The Tigarag Peninsula cuspate foreland is formed by unconsolidate gravel ridges. The east west oriented ridges are about 60 m apart and on an average stands 3 m high above sea level. Parts of these ridges are covered with loess. The thickness of top layer of fine sediments on the ridges decreases from north to south. The ridges on the north are older than those on the southern shore. Two vertical profiles characteristic of the older ridges on the northern shore are shown in Figs. 3 and 4. The sediments consist of well rounded sand, pebbles and cobbles. Several horizons of grading and reverse grading are noted. The pebbles and cobbles are well rounded with a flat lying base. The bedded structure and sorting of these sediments undoubtedly indicate marine origin.

The sediments from the southern shore ridges consist of gravel. Bedding at various horizons were observed in the field, however, the stratigraphy could not be studied in detail because the sediments were unconsolidated. Lateral uniformity of grain size throughout these ridges was observed.

The morphology of the northern and southern beaches are shown in Figs. 5 and 6. Beach profiles of northern beach show (Fig. 5) characteristic erosional beach while profiles of southern beach (Fig. 6) a depositonal beach.

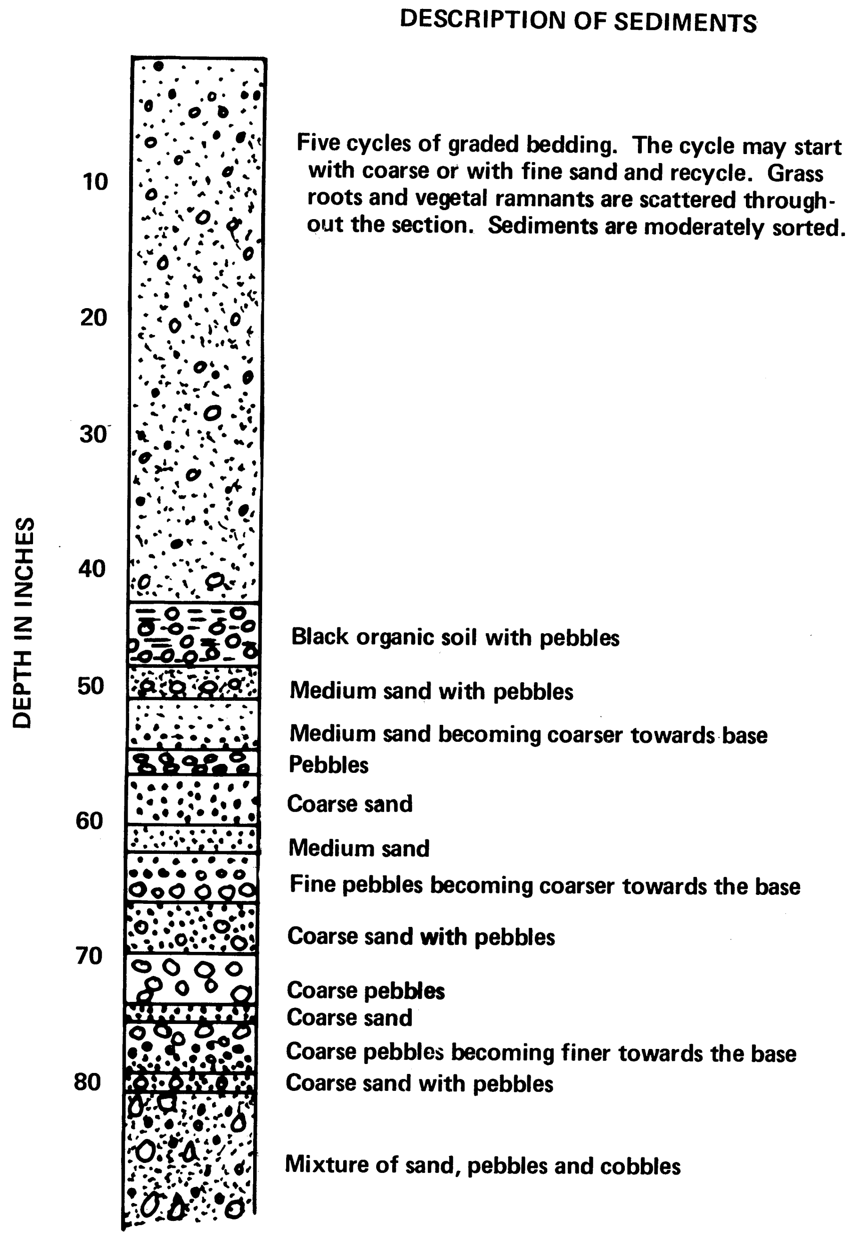

Fig. 3. Ridge profile 1, taken from first exposed ridge northwest of Ipiutak Ruins.

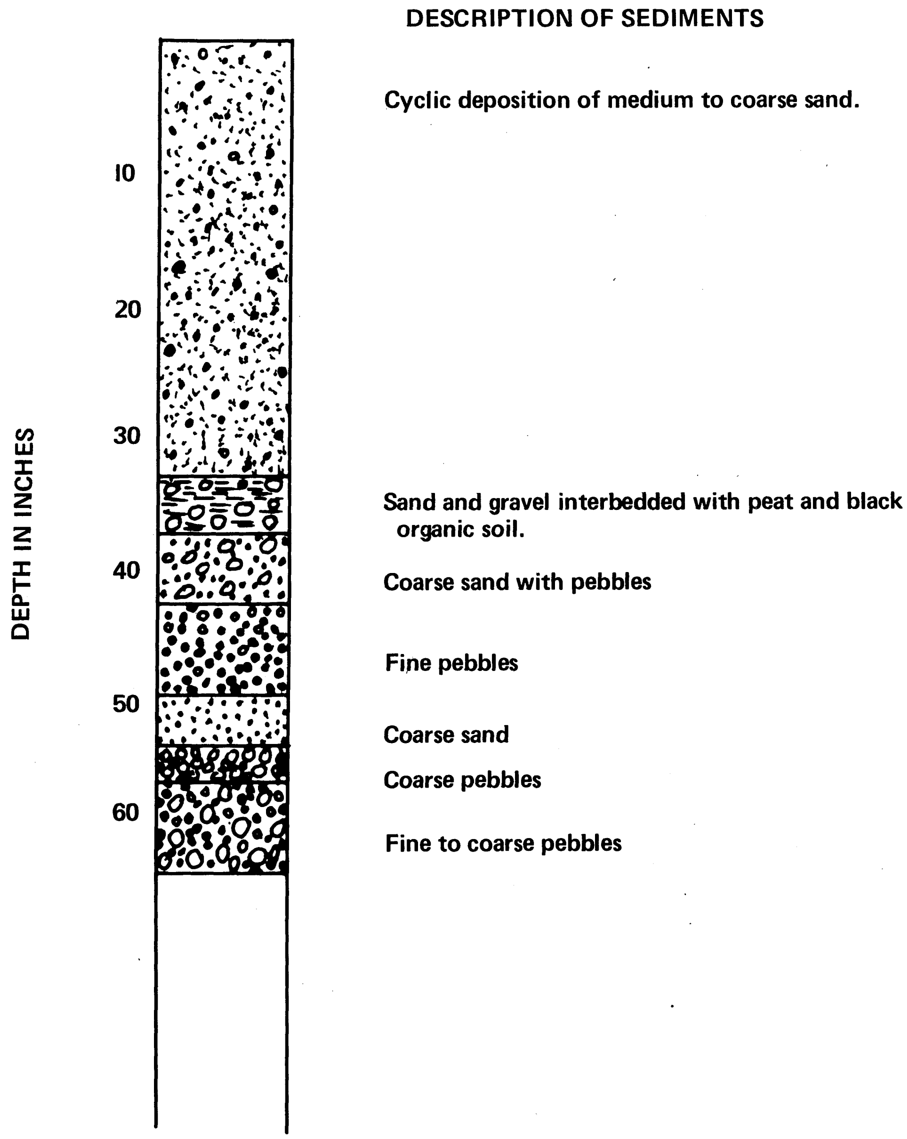

Fig. 4. Ridge profile 2, taken from second exposed ridge northwest of Ipiutak Ruins.

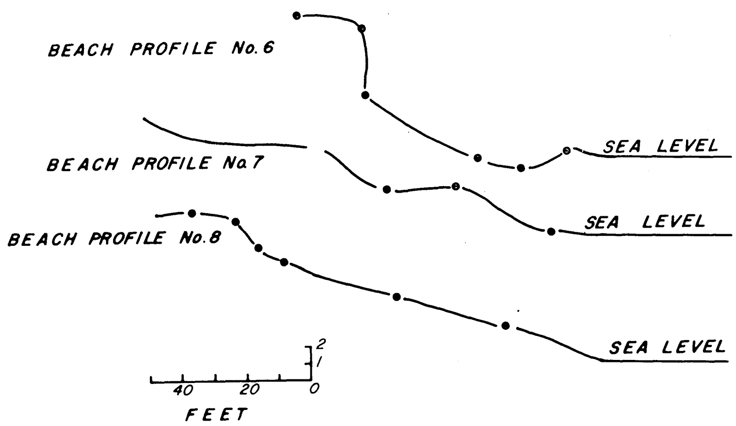

Fig. 5. Beach profiles of northern shore near Point Hope.

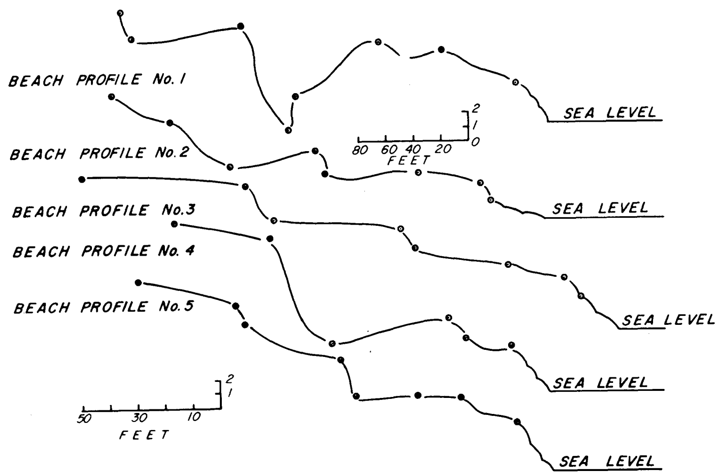

Fig. 6. Beach profiles of southern shore near Point Hope.

EVOLUTION OF TIGARAG PENINSULA

It has been estimated that the sea level during Sangamon time was about 8 m above the present sea level. Two beaches of Sangamon time are exposed near Point Hope. During Wisconsin glaciation the water withdrew from the Chukchi Sea, thus exposing a broad tundra-covered plain around Point Hope. The waning continental glaciers resulted in rise of sea level which reached approximately its present position about 5,000 years ago. The oceanographic condition at that time were similar to those prevailing at present. The longshore current moving westward along the south shore set in. Sediments orignating from the sea cliffs around Cape Thompson were deposited as a spit or the first ridge. Moore (1966)[1] calculated the amount of sediment currently transported by longshore currents along the south shore of Point Hope. His calculations are based on wind velocity, wave height and the angle between wave front and shoreline. The computation give a net longshore, sediment transport to the east for nine months of the surf year, but storms in late September and October reversed the directions so that by the end of the year a net of 28,000 m^3 of sediment moved to the west. These sediments deposited in nearshore environment are redistributed occassionally by storms. Severe storms generated by high winds from the west and northwest cause storm surges. Increase in energy as a result of rise in sea level results in migration of beach line landwards, and deposition of material brought by currents as beach ridges.

SHELF DEPOSITS

The sediments on Bristol Bay shelf consist of coarse sand and gravel, but they become progressively finer toward the mouth of the bay (Fig. 7). The mean size of the sediments, which gradually decreases from the head of the bay and the adjacent shores to the deeper portions of the bay has a general relation with depth (Fig. 8).

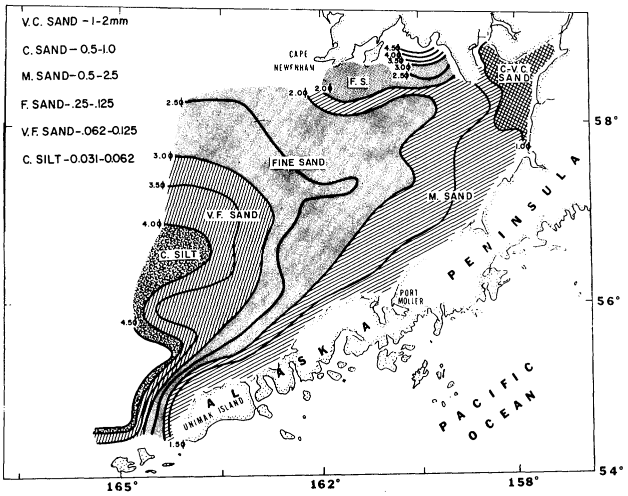

Fig. 7. Sediment distribution in Bristol Bay.

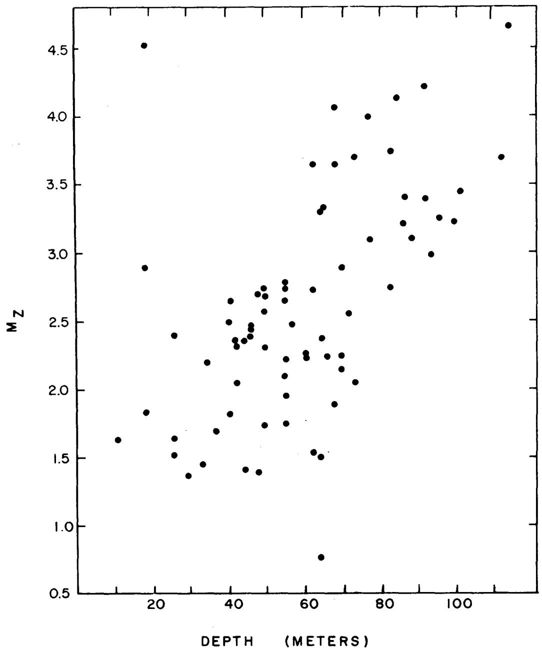

Fig. 8. Sediment phi mean size (Mz) - depth (meter) plot.

The sediments in Bristol Bay are predominantly sands, in particular, fine sands are relatively more widely distributed than coarse and medium sands. It is interesting to note that fine sands along with other size grade are distributed throughout the shelf and decrease abruptly near the 100 m isobath. Winnowing of fine sand and its offshore transport requires high energy environment over the entire shelf. Such an environment over large area can be provided by storms.

To asses the influence of storm waves on the transport and dispersal of sediments in the Bristol Bay the meteorological observations gathered sporadically over the past one hundred years were analysed using computer. Theoretical wave heights and periods for severe annual storms in Bristol Bay have been developed from synoptic surface windcharts. These considerations and wave forecast theory give for the Bristol Bay significant wave height (H) of approximately 10 m and significant wave period (T) of about 11 seconds. This would result in a wave-length (L) of approximately 200 m sufficient to move sediments at a depth (d) of about 94 m. At this depth the maximum water particle velocity u would be:

$$u = \frac{\pi H}{T \sinh \frac{2\pi d}{L}} = 30 \text{ cm}/_{\text{sec}}$$

Consequently, the motion of the water at 94 m would be sufficient to cause incipient motion of fine sand due to the water particle velocity resulting from the wave (Hjulstrom, 1939)[2]. The absence of silt and clay-sized sediments in areas with water depth less than 80 m strongly suggest that these size grades are not deposited due to storm waves effective to these depths. It seems, therefore, the waves are among the most powerful factors controlling sedimentation in most parts of the Bristol Bay shelf.

EVOLUTION OF BRISTOL BAY SHELF

The mean grain-size of sediments in the Bristol Bay displays a good relationship with the water depth. Such relationship indicates that the energy of deposition to a large extent is controlled by the depth of water. In other words, the sediment size and its movement by wave disturbance depends on water depth. Concurrent to the sediments movement on the shelf, the profile (gradient) of the bottom is modified. The profile alteration will naturally affect the type of wave distortion, in consequence of which the external parameters of the waves and their internal properties will also vary with depth. Equilibrium will be reached only when the sediment particle size on the bottom would conform to the available wave energy properties. It is also evident that as the dimensions of wave increase, the specific energy of the waves, per unit of bottom area or length of profile, will also increase. This would result in marked increase in the amount of bottom sediment movement in the zone of wave distortion and more sediments would be moved to adjacent areas where the energy potential is not so high. During period of stationary sea level this process would lead to extension of the zone of wave energy dissipation or flattening of the shelf profile. The Bristol Bay shelf is presently undergoing a leveling of the bottom profile and extension of the shelf as the continental slope.

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2. Hjulstrom, Filip, 1939, Transportation of detritus by moving water. *In*: Recent Marine Sediments, Editor Parker D. Trask. Amer. Assoc. Petroleum Geologists, Tulsa, Oklahoma. pp. 3-31.

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