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Geomorphology of Dungeness Spit, Washington, USA[1]

Maurice L. Schwartz[a], Paolo Fabbri[b] and R. Scott Wallace[a]

[a]Department of Geology
Western Washington University
Bellingham, WA 98225, USA

[b]Facolte di Lettere
Universita di Bologna
Via Zamboni, 38
40126 Bologna, Italy

ABSTRACT

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Since 1855, Dungeness Spit has prograded to the northeast at 4.4 m/yr, with a net shore-drift rate on the order of 14,200 m³/yr. Net shore-drift direction varies with fetch, developing through time and space an unusual spit complex. Tidal currents in the channel between the two lagoon segments attain velocities of 56 cm/sec on the flood and 60 cm/sec on the ebb. A gravel lag deposit is found within the channel, mud within the central lagoon regions, and sand near the spit and mainland shore.

ADDITIONAL INDEX WORDS: *Barrier beaches, coastal geomorphology, Dungeness Spit, net shore-drift, sediment analyses, spits, Strait of Juan de Fuca, tidal currents, Washington State.*

INTRODUCTION

In an obvious attempt to draw a distinction between it and its namesake in England, early maps show a region on the northeast coast of the Olympic Peninsula, Washington, called New Dungeness Point (U.S. EXPLORING EXPEDITION, 1841a, 1841b) and New Dungeness (U.S. COAST SURVEY, 1855). Today the point is named Dungeness Spit (Figure 1), and is located near the small crossroad community of Dungeness.

The spit system is actually composed of complex features: the main, outer, Dungeness Spit; doubly-recurved Graveyard Spit; Cline Spit, on the mainland coast; the Dungeness River delta, and the lagoons of east and west Dungeness Bay (Figure 1). With a county park situated at the spit base, and most of the system area designated as a National Wildlife Refuge, the region remains in a remarkably undeveloped condition. As such, it is an ideal site for geomorphic study.

BORTLESON, CHRZASTOWSKI, and HELGERSON (1980) and DOWNING (1983) have reported recently on some aspects of changes in the spit. In the investigation reported upon here, we have attempted to extend and update available knowledge concerning the geomorphology of Dungeness Spit, Washington.

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METHODS

During August, 1985, we carried out a field research project at Dungeness Spit with a group of students from Western Washington University.

Survey methods undertaken on land included: plane-table and alidade mapping of spit segments; coring on and between beach ridges; tape-measuring from U. S. Coast and Geodetic Survey monuments; profiling the beach at 109 sites; taking a sediment sample in the mid-foreshore at each profile site; and photographing primary sedimentary features on the beach. Utilizing three small, powered boats, bottom-sediment grab-samples were obtained, surface salinity determinations made, and secchi disk readings taken, at 80 stations in the east and west lagoons. In addition, three drogues were tracked through spring flood and ebb tides.

Subsequently, grain size distribution analyses and binocular microscope inspection of sand grain characteristics were carried out at the coastal studies laboratory at Western Washington University. Historical maps were obtained from the university's map library and from NOAA.

OBSERVATIONS AND CONCLUSIONS

Net Shore-Drift

There is ample evidence to ascertain the net

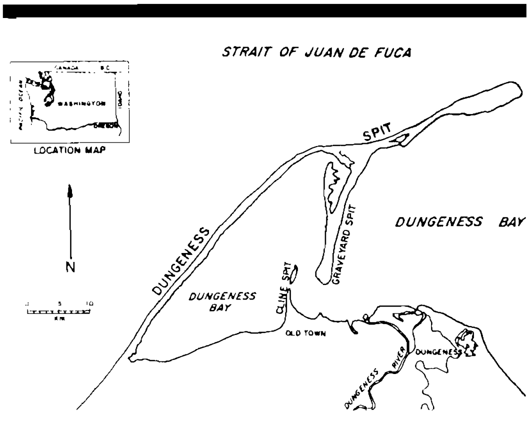

Figure 1. Geographic location map of the Dungeness Spit region.

inution, grain-trend toward rounding, accumulation of sediment at drift obstacles, river channel diversion, and geomorphic changes evidenced in historical maps.

The foreshore sediment-sample histograms in Figure 2 show a shift toward smaller sediment sizes constituting the bulk, by weight, of the sample, progressing eastward along the outer shore of Dungeness Spit, and then southward and northward on the east and west sides of Graveyard Spit. Though coarser, the same diminution pattern prevails from east and west on the mainland to the tip of Cline Spit.

Binocular microscope inspection of individual sand grains from the same foreshore sediment-samples on Dungeness and Graveyard spits reveals a trend from angular to sub-rounded in the particle shapes, accompanying the same pattern of decreasing grain size on the two spits (Figure 2).

On the west side of Cline Spit a rock groin and concrete boat ramp have sediment prograding to the west and south, respectively. In contrast to this, the residential beach frontage east of the Dungeness

shore-drift patterns within the spit complex. The directional indicators fall into five main categories (JACOBSEN and SCHWARTZ, 1981; SCHWARTZ, MAHALA and BRONSON, 1985): sediment-size dim-

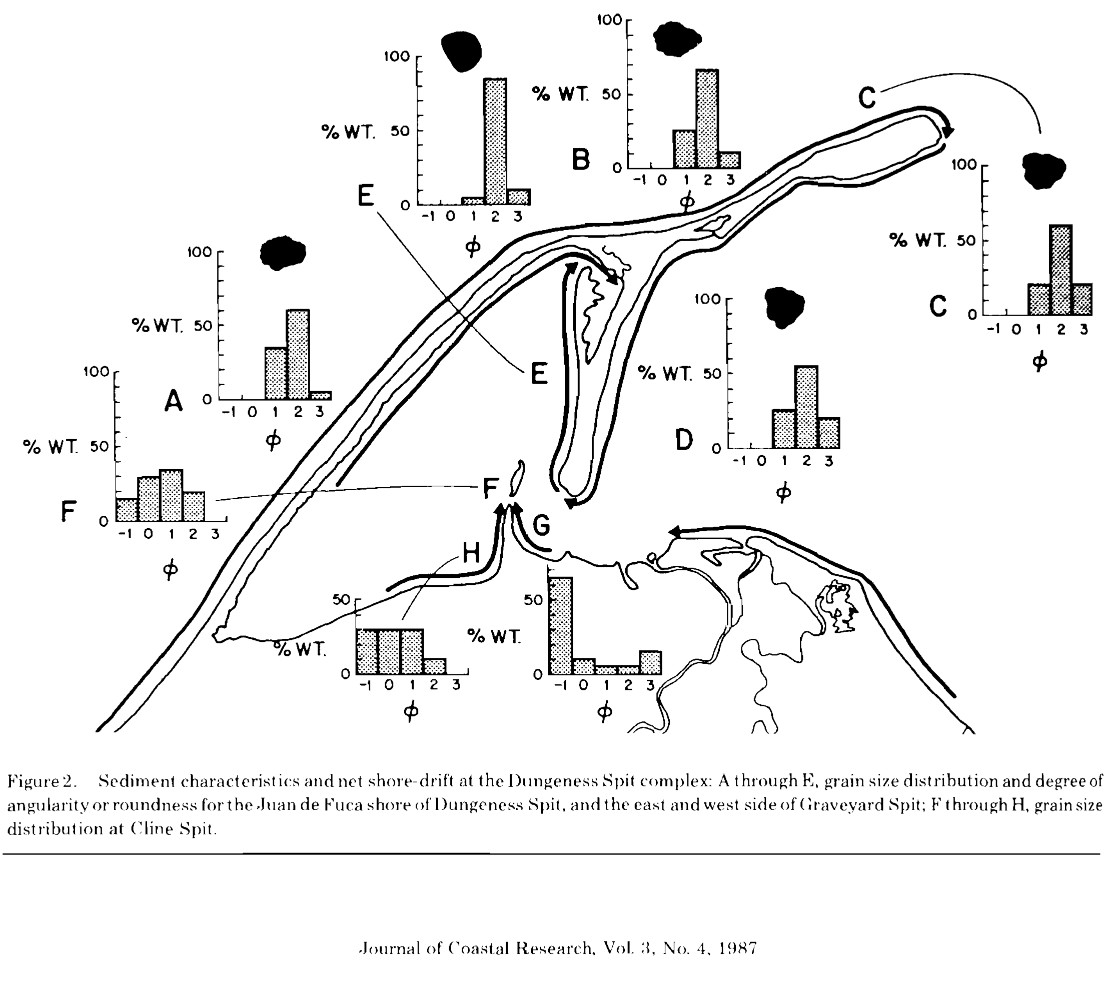

Figure 2. Sediment characteristics and net shore-drift at the Dungeness Spit complex: A through E, grain size distribution and degree of angularity or roundness for the Juan de Fuca shore of Dungeness Spit, and the east and west side of Graveyard Spit; F through H, grain size distribution at Cline Spit.

River delta has numerous groins and boat ramps, all with sediment progradation to the east.

The various distributaries of the Dungeness River, though altered in their courses on the delta through space and time, invariably return to a westerly diversion. Attempts, in the past, to dredge a straight north-south channel have been negated by the subsequent offset to the west.

When comparing recent maps (U.S. GEOLOGICAL SURVEY, 1956, 1976) with present-day conditions on Dungeness Spit, two geomorphic changes have occurred that indicate drift directions. Formerly, there was a small embayment on the west side of the junction between Graveyard and Dungeness spits, partially enclosed by a short southeasterly trending spit branching off from the south side of Dungeness Spit. Today the embayment location is only a grassy hollow, with the continuous beach curving smoothly from the south side of Dungeness Spit to the northwest side of Graveyard Spit. Similarly, there formerly was a small southwesterly trending spit on the south side of Dungeness Spit, just northeast of the junction with Graveyard Spit. It seems likely that this small spit developed into a looped bar that was later breached, because today there is a lagoon at the site connected to east Dungeness Bay by a narrow inlet (Figure 2).

From the foregoing observations*, we conclude that the pattern of net shore-drift in the region of the spit complex is as shown in Figure 2. The predominant waves are through the Strait of Juan de Fuca from the west (DOWNING, 1983), driving the sediment transport to the east and northeast along the outer shore. Wave and fetch orientations within the two segments of Dungeness Bay are the forcing factors behind the many other, complicated, drift directions.

Lagoon Processes

Tidal currents along the Olympic Peninsula coast in the Strait of Juan de Fuca are strongest on the flood to the east. This was tragically demonstrated following a December 21, 1985, spill of 157,376 imperial gallons of heavy crude oil in the harbor at Port Angeles, approximately 20 km to the west. Within a few days, some of the oil washed ashore at Dungeness Spit and the Dungeness National Wildlife Refuge.

Within Dungeness Bay our drogues, patterned after earlier studies in the area (SCHWARTZ *et al.*, 1972; SCRIMGER, 1960), moved inward on the spring flood and outward on the spring ebb tide (Figure 3). More specifically, the drogues placed in the region between northeastern Cline Spit and the southwestern tip of Graveyard Spit, at the beginning of the flood tide, were carried either to the west through the breach in Cline Spit or northward, west of Graveyard Spit, well into the western part of Dungeness Bay. Flood tide velocities ranged from 48 to 56 cm/sec. Drogues placed at similar locations, at the beginning of the ebb tide, were carried to the east through the Cline Spit breach, or northeasterly past the east side of Graveyard Spit. Ebb tide velocities ranged from 54 to 60 cm/sec.

Except for the vicinity around the distributaries of the Dungeness River, the water in west and east Dungeness Bay appears to be well-mixed by tidal action; with surface salinities in both sections of the bay ranging from 28 to 32 ppt. Away from the delta, salinities dropped to 12 to 25 ppt. Water clarity was best in the deeper eastern part of Dungeness Bay, whereas the western part, though shallower, had

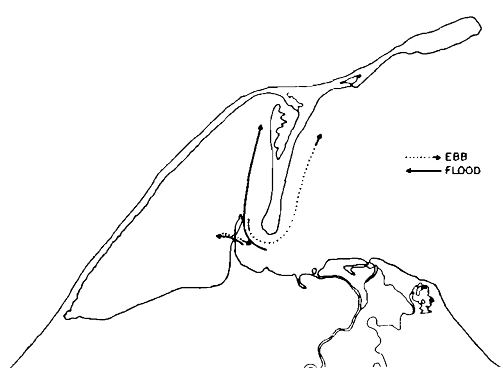

Figure 3. Flood and ebb tidal currents in Dungeness Bay.

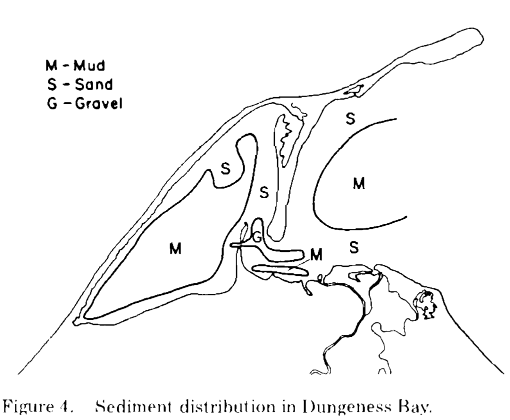

Figure 4. Sediment distribution in Dungeness Bay.

* *Footnote: No significant trends were discerned in reviewing the beach profiles; presumably due to the greatly varying combinations of fetch orientation, wave energy, and sediment size.*

more turbid water. The strong tidal currents through the inlets would seem to play a major role in causing this difference.

It should be noted here that the Cline Spit breach-inlet (Figures 1 and 3) does not appear on the 1979, or earlier, maps cited here The inlet was formed, and a small island developed, when Cline Spit was breached around 1978 (WRAY and CASEY, 1985, personal communication).

The 80 bottom samples, taken from the west and east lagoons, were analyzed and classified in the manner of FOLK's (1974) marine sediments, based on proportions of mud (silt and clay), sand, and gravel. There are 15 categories in the system, and because our journal figure-page format is limited in size, Figure 4 was prepared on the basis of the predominant sediment trait: *i.e.*, mud (silt and clay), sand, gravel.

In general, the nearshore bottom along the inner lagoon shores of the spit complex are composed of sand This comes from erosion of the mainland bluffs, alongshore sediment transport (shore-drift), and washover deposits where Dungeness Spit is narrow enough for overwash processes (LEATHERMAN, 1981). The visibly crenulated, lagoon-side basal portion of Dungeness Spit (Figures 1 and 4) is ample evidence that copious amounts of sediment are transported to the lagoons in this fashion. Mud (silt and clay) settles out in the central portions of the east and west lagoons, where depths are mostly between 2 and 4 m. Another patch of mud parallels the shore just west of the most westerly, and largest, Dungeness River distributary. Gravel is only present in the 4 to 6 m deep channel between Graveyard Spit and Cline Spit, and in the Cline Spit inlet; presumably as a lag deposit under the strong tidal currents that flow through those channels.

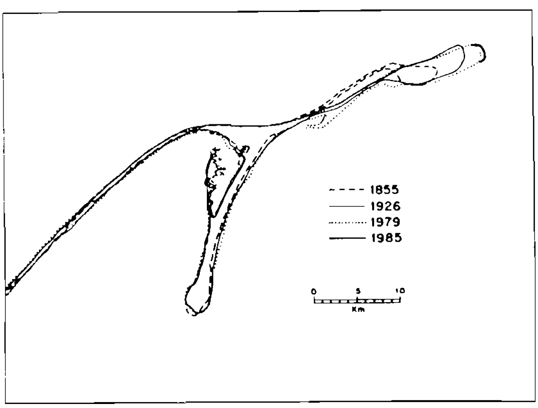

Figure 5. Composite map of the Dungeness Spit, 1855-1985.

Spit Progradation

Progradation of the distal end of Dungeness Spit can be traced over the past 130 years by utilizing historic and recent maps and our plane-table mapping. A composite of these is shown in Figure 5.

As is evident in Figure 5, there has been very little change in the position of Graveyard Spit or the western half of Dungeness Spit during this time. The greatest changes have been in the position and length of the rather bulbous distal portion of Dungeness Spit, and the southeasterly migration of that narrow portion of Dungeness between Graveyard Spit and the tip of Dungeness Spit.

In 1855 (U.S. COAST SURVEY), the distal end of Dungeness Spit was oriented, essentially, in an east-west fashion. By 1926 (U.S. COAST AND GEODETIC SURVEY), this feature had evolved to a northeast-southwest orientation, and prograded to the northeast. Further progradation, and a slight shift to the southeast, had occurred by 1979 (U.S. GEOLOGICAL SURVEY). The only change noted in our 1985 survey, was a slight progradation to the northeast.

Taken all together, the tip of Dungeness Spit has prograded 575 m to the northeast between 1855 and 1985, an average progradation rate of 4.4 m/yr. This is in line with the 4.5 m/yr, calculated by BORTLESON, CHRZASTOWSKI and HELGERSON (1980) for the period between 1855 and 1976. Evidently, Dungeness Spit has continued to prograde at about the same rate during the past decade.

To a rough approximation, there has been a volumetric growth in the upper portion of the distal end of about 1,850,000 m^3 from 1855 to 1985. This would translate into an average shore-drift rate of 14,200 m^3/yr. However, this calculation is based only upon quantification of that portion of the spit (referred to here as upper) on the 10 m depth spit platform (MEISTRELL, 1972), and we do not know how much sediment has been contributed to the progradation of that platform in the past 130 years.

It would be tempting to extrapolate an overall net shore-drift rate for Dungeness Spit since its origin, based on age and volume (SCHWARTZ, 1983). But there is no way of calculating the amount of sediment lost into the deep channel of the Strait of Juan de Fuca that closely borders the outer side of Dungeness Spit. A more accurate quantification of the net shore-drift rate will have to wait upon further studies in the region.

SUMMARY

Net shore-drift patterns at the Dungeness Spit complex are driven primarily by fetch exposure. Sediment eroded from the glacial bluffs to the west is transported to the east, around the end of Dungeness and then along the recurve of Graveyard Spit. On the mainland, shore-drift converges from the east and west upon Cline Spit.

During the past 130 years, the distal portion of Dungeness Spit has prograded to the northeast at a rate of 4.4 m/yr. A first approximation of the rate of nt shore-drift can be given as 14,200 m^3/yr.

Sediment distribution within the lagoons consists of mud in the central areas, and near the delta; sand along the shore perimeter; and gravel in the scoured tidal channels, where tidal currents reach 56 cm/sec in flood and 60 cm/sec in ebb.

ACKNOWLEDGEMENTS

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□ RESUMEN □

Desde 1855, el Puntal de Dungeness ha progresado hacia el Nordeste a razón de 4.4 m/año en un arrastre neto de sedimentos del orden de 14.200 m^3/año. La dirección del arrastre neto varia con el fetch, desarrollando en el tiempo y espacio un inusual y complejo puntal. Las corrientes de marea en el canal existente entre los dos segmentos de la albufera alcanzan velocidades de 56 cm/seg en el flujo y 60 cm/seg en el reflujo.--*Miguel A. Losada, Universidad de Cantabria, Santander, Spain*

□ ZUSAMMENFASSUNG □

Seit dem Jahrgang 1855 ist Dungeness Spit nordostens zu 4.4 m/Jahr progradiert, mit einer reinen Küstengeschiebeverhältnis zu 14.200 m^3/Jahr. Die Geschieberichtung ist abhängig von der Holung und entwickelt endlich ein besonderes Landzungenkomplex. Ebbe- und Flutströme im Kanal zwischen den Lagunenteile erreichen Geschwindigkeiten von 56 cm/sec (Flut) und 60 cm/sec (Ebbe).--*Stephen A. Murdock, CERF, Charlottesville, Virginia, USA*

□ RÉSUMÉ □

Depuis 1855, la Dungeness Spit a avancé de 4,4 m/an vers le NE, avec une dérive littorale nette de l'ordre de 14.200 m^3/an. La dérive littorale varie avec le fetch et développe dans l'espace et le temps un complexe de flèche inhabituel. Entre les deux segments du lagon, les courants de marée atteignent, dans le chenal des vitesses de 56 cm/s pendant le flot et de 60 cm/s pendant le jusant.--*Catherine Bressolier, EPHE, Montrouge, France*