Coastal progradation as a by-product of human activity: an example from Hoed, Denmark

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Quarry waste (gravel and sand) dumped on the shore at Hoed, Denmark, has been re-worked by wave action and formed into a beach-ridge plain. Progradation of up to 220 metres has occurred on a 9.5 km sector of coastline, extending 5.5 km north and 4 km south from the dumping area. Historical evidence, supplemented by a modern survey, indicates the pattern of coastline progradation, which was most rapid between 1954 and 1971, when waste dumping was at its maximum.

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INTRODUCTION

The east coast of the Djursland peninsula in Denmark has been slowly receding during the past two centuries (Bird, 1974). More resistant sectors, consisting either of glacial drift deposits or Danian Chalk bedrock, are left as promontories, so that the coastline has a characteristic »festoon« form (Christiansen, 1960).

One of the promontories, Glatved-Limbjerg near Hoed (Fig. 1), consists of glacial drift deposits with a high content of chalk boulders and associated gravels, mainly flint. Chalky material has been extracted from the Katholm Quarry here since the late 16th century, and baked in local furnaces to produce lime. Waste material, consisting mainly of flint gravel, but including some sand and finer sediment, has been dumped at the seaward end of the quarry, and since 1900 has extended out across the shore and into the sea. This has resulted in one of the most extensive areas of beach progradation due directly to man's activities anywhere in the world (Bird, 1979): other examples of progradation resulting from waste dumping from coastal quarries have been noted near Peterhead in Scotland and Tintagel in south-west England (Bird and May, 1976) and, farther afield, at Rapid Bay on the coast of South Australia (Bourman, 1975).

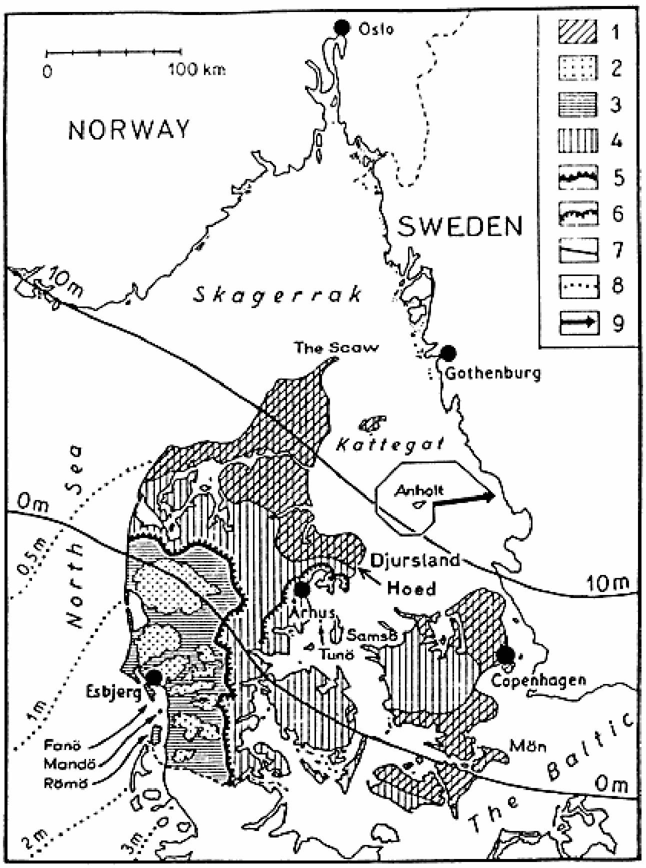

Fig. 1. *The physical-geographical environment of the Djursland peninsula.*

1. Area where limestone rocks form the substratum under the Quaternary deposits.
2. Old moraine landscapes, Riss/Saale glaciation.
3. Outwash plains of the Würm/Weichsel glaciation.
4. Predominant young moraine landscapes, Würm/Weichsel glaciation.
5. Main stationary line of the last glaciation.
6. Terminal moraine in the Djursland peninsula.
7. Lines of equal elevation since the Stone Age (Litorina-Tapes epoch).
8. Lines of equal tidal amplitude.
9. Direction resultant of wind work.

Figur 1. Oversigtskort visende sudielokaliteten ved Hoed.

CHANGES ON THE HOED COASTLINE

The quarries at Hoed existed on a small scale in 1784, as shown on a survey (1:20,000) of that date, now in the archives of the Geodetic Institute in Copenhagen. They had been much enlarged by the time the area was re-surveyed (1:20,000) in 1877, and a revision of this map in 1900 shows that quarry waste was being dumped on the shore from four tramways. Air photographs (1:10,000) taken in 1954 show

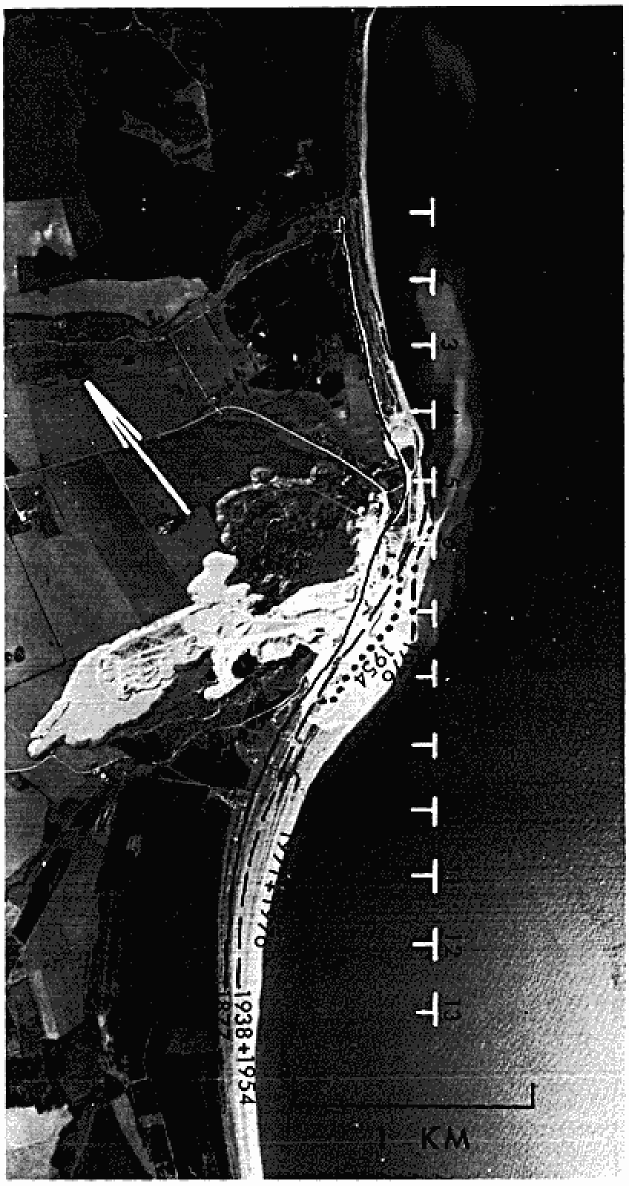

Figure 2. Changes in coastal configuration at Hoed 1877-1976.
Figur 2. Kystfremrykningen ved Hoed 1877-1976. Flyvefotografi: Geodætisk Institut. (Rute 7115 D. Nr. 053. 1971). Gengivet med instituttets tilladelse (A 397/82). Copyright.

further extension of the dumping area, and continued growth is seen on the 1971 air photographs (1:21,000) and from field survey in 1976. Changes in coastal outline deduced from these sources are shown on Fig. 2.

The present sorting works was built in 1967, after which material coarser than 3 mm was deposited in waste heaps up to 12 m high, arrayed in differing size grades so that pebbles and cobbles could be readily extracted for use as required. The seaward flanks of these waste heaps declined directly into the sea (Fig. 3), and were thus subject to re-working and

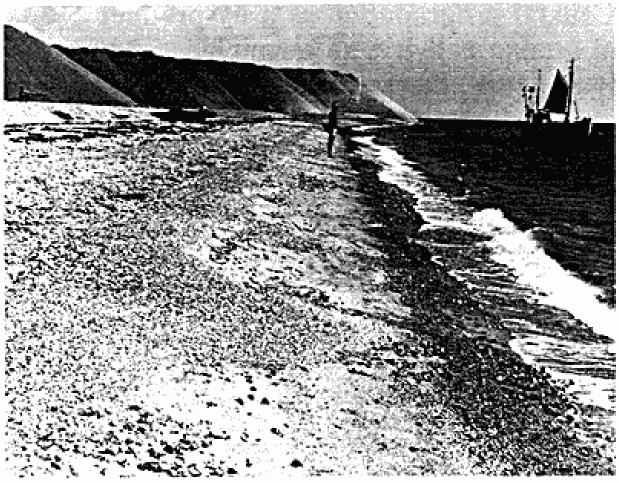

Figure 3. View northward to the waste heaps at Hoed quarry.
Figur 3. Bunker med overskudsmateriale set fra syd. Bemærk strandtakkerne, der består af groft materiale. (Foto: Fl. Hansen).

lateral dispersal by wave action. Waste material finer than 3 mm (fine granules, sand, silt and clay) was washed directly into the sea, forming a deltaic plain immediately north of the gravel heaps. According to the quarry company, the coarser material has not accumulated in the heaps since 1975 (demand for gravel having equalled or exceeded production), but the fine material is still washed into the sea.

The direction-resultant of wave work (Christiansen, 1960) is here almost orthogonal to the coastline, and with waves

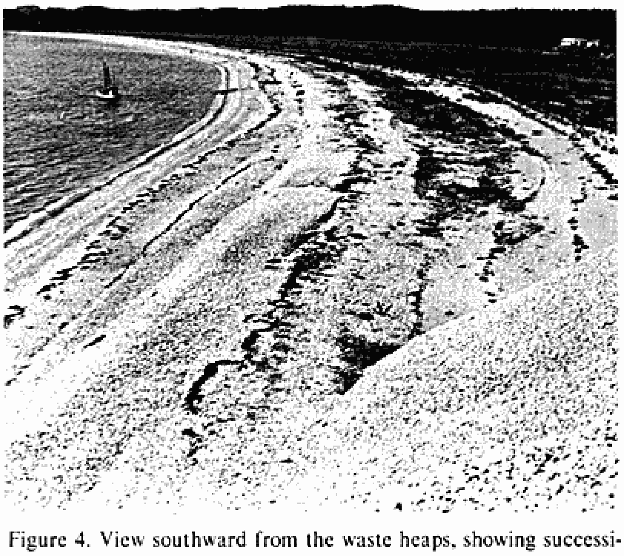

Figure 4. View southward from the waste heaps, showing successively added beach ridges. The forest in the background marks the 1877 coast.
Figur 4. Strandvoldssletten syd for kalkbruddet. Skoven i baggrunden begynder ved 1877 kystlinien. (Foto: Fl. Hansen).

arriving from both the SE-SW and SE-NE quadrants beach material is drifted northward and southward respectively from the dumping area (Fig. 4). Coastal waters are microtidal, mean tide range being only 0.3 m, but more substantial and irregular fluctuations of water level occur, with a range of ± 1 m, in response to meteorological variations, notably barometric pressure and wind effects. The distributed sand and gravel have been built into successive beach ridges, with heights of up to 2.5 m (Schou, 1960). In general, the coarser material has been piled up by storm swash to form ridge crests, the intervening swales having finer sediment, but there is much variation laterally. The present beach usually shows well-developed cusps of coarse material separated by areas of finer gravel or sand (Fig. 3).

The gravels in the waste heaps are subangular to subrounded, while those in the beach ridges are rather more rounded as the result of abrasion during longshore drifting (cf. Berthois, 1951). They are, however, much less rounded than the wave-piled shingle deposits on the coasts of southern England, where the flint gravels have been repeatedly reworked and only minor quantities of »new« flint gravel are being supplied from eroding cliffs.

The prograded area consists of a southern sector, south from the waste heaps, which has up to fifteen successively-formed gravel beach ridges (Fig. 5), a central sector which includes the waste heaps and an »outwash plain« of mainly sandy material, and a northern sector which again consists of parallel beach ridges (Fig. 2). Vegetation (grasses, herbs, shrubs) has become established on the beach ridge plain, colonising the swales first, then spreading across the ridges, it remains sparse on the seaward two or three ridges (Fig. 4). Aided by ditching, a small stream finds an outlet through the beach ridge plain to the south of Katholm Quarry.

In order to trace rates of change, orthogonal survey lines were set up at 250 m intervals along 3 km of the prograded terrain, and measurements made along these lines compared with intercepts on the same alignments on earlier maps and air photographs.

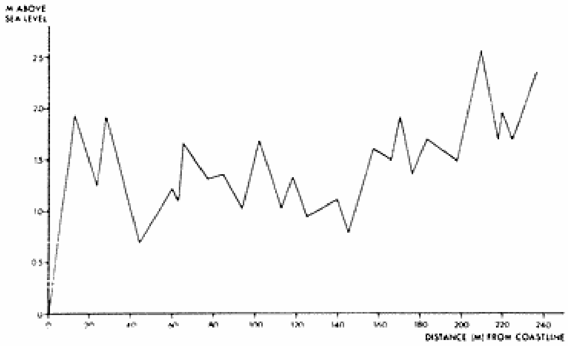

Figure 5. Beach ridge topography along line no. 8.
Figur 5. Strandvoldstopografien langs linie 8.

Survey results (Table 1 and Fig. 2)
There was little change between 1784 and 1877, probably because the dumped quarry waste was then too small to cause progradation, but from 1877 to 1900 mean coastline advance was about 15 m (0.7 m per year), varying from 0 to 40 m along the 3 km of studied coastline. In this period, progradation was mainly south of the waste heaps, indicating a predominance of southward drifting, and the extent of land gained was 0.8 ha.

From 1900 to 1938 mean coastline progradation was 33 m (0.9 m per year), with an areal gain of 6.6 ha. During this period, progradation was more rapid in the central and northern sectors than to the south.

Between 1938 and 1953 progradation was measurable only in the central sector, the areal gain being 2.6 ha. From 1953 to 1971, however, there was rapid progradation in the central and southern sectors, the coastline advancing by up to 9 m per year, giving an areal gain of 25.7 ha in only 18 years. Since 1971 progradation has declined. Between 1971 and 1976 the only gains were in a sector between two artificial promontories made in 1967 in an attempt to build a loading jetty: an experiment that was abandoned in 1971 because of intervening sand accretion.

	Progradation (m) on line no.													increase
	1	2	3	4	5	6	7	8	9	10	11	12	13	(ha)
1877-1900	0	0	0	0	30	15	15	15	10	40	20	20	20	0.8
1900-1938	35	40	55	100	0	100	50	15	25	0	5	5	5	6.6
1938-1953	0	0	0	0	0	70	50	10	0	0	0	0	0	2.6
1953-1971	20	20	0	0	0	20	60	165	170	135	135	120	105	25.7
1971-1976	0	0	0	0	0	12	10	0	0	0	0	0	0	0.8
1877-1976	55	60	55	100	30	217	185	205	205	175	160	145	140	36.5

Table 1. Coastal progradation along lines at intervals of 250 m, and areal increase 1877-1976.

The overall pattern of progradation has been greatest in the central sector, close to the waste heaps, tapering off northward and southward. However, the measurements along the survey lines indicate considerable variation in rates of change over time, a pattern that has also been demonstrated by repeated surveys on an eroding coastline in northern Jutland (Christiansen and Møller, 1980). The nearshore of the prograded sector at Hoed has steepened (the 2 m depth contour having moved landward by more than 70 m), and it is expected that progradation will consequently slow down, a tendency already found in 1971-76.

Measurements in the 1976 survey permit an approximate calculation of the volume of material deposited to form the beach-ridge plain. Over the 9,5 km sector of prograded coastline, the average advance has been about 100 metres, and the mean thickness of deposited material (1 metre above and 2 metres below mean sea level) 3 metres, giving a total volume of about 2.85 million cubic metres. In 1975, 420,000 m^3 of material was extracted from Katholm Quarry, and of this 200,000 m^3 was discharged as waste material on to the shore. The total volume of material removed from Katholm Quarry is about 10 million cubic metres, so that, allowing for some waste material deposited inland, for the volume of material in the remaining waste heaps, and for dispersal, especially of fine-grained material (note the plumes of chalky sediment flowing northwards from the »outwash plain« in Fig. 2) it appears that some 60 per cent of the waste material deposited on the coast has been re-worked and incorporated into the prograded beach ridge plain.

This relatively high proportion is related to the fact that the bulk of material in the waste heaps is coarser than the natural beach material which previously existed on this coastline, and which can still be seen north and south of the study area. This is consistent with the experience from artificial beach nourishment projects in various parts of the world, which is that losses from nourished beaches are reduced if the sediment added is coarser than the original natural beach material (Willis and Price, 1975; Walton and Purpura, 1977; Clayton, 1980). The progradation at Hoed indicates the potential value of quarry waste for beach building: a technique that has been applied on parts of the Soviet Black Sea coast (Pyasetskiy, 1979; Shuisky and Schwartz, 1979).

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