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NOTE

Relation Between Growth of a Marine Foreland and Sea Level Rise Case: The Skagen Spit, North Jutland, Denmark

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ABSTRACT

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This paper presents the relationship between erosion and deposition at a recurved spit which was generated through thousands of years by a combination of erosion caused by sea level rise, glacial rebound, and littoral drift forces by waves and currents. An unusual combination of peats formed between beach ridges in the process of the extension of the spit and glacial rebounds elevating these formations and later exposing them in eroding dune scarps made it possible to determine growth rates by carbon-dating.

ADDITIONAL INDEX WORDS: *Littoral drift, sea-level rise, glacial rebound, coastal erosion, radio-carbon-dating.*

INTRODUCTION

The generation and behavior of marine forelands is described by many authors (JOHNSON, 1919; GUILCHER, 1990; SCHOU, 1945; ZENKOWICH, 1962; *etc.*). The special feature of the recurved spit is that its growth is associated with the erosion of its root which had built up earlier. The development of the Skagen Spit, the northernmost part of the Danish mainland also called the peninsula Jutland (Figure 1), is an example of such development.

THE DEVELOPMENT OF THE SKAGEN SPIT

The development of the Skagen Spit is described by several authors including JESSEN (1936), STRAND PETERSEN (1990), FREDERICIA and KNUDSEN (1990), HAUERBACH (1990) and BRUUN and TRYDE (1990). Surveys of this particular area of Denmark started in 1695 and have continued since then. Figure 2 (HAUERBACH, 1990) shows how the spit migrated out into deeper water during the last 300 years at a surprisingly high rate of 3 to 10 meters per year. The annual deposition of material is of the order of ¾ to 1 million cubic meters. The growth of the spit for some thousands of years back is documented by old beach ridges (rimmer) with low areas with wetland vegetation (dopper) which are now elevated considerably due to the glacial rebound that has taken place during the period following deglaciation; *i.e.*, after 14,000 BP, and still is active in the northernmost part of Jutland. Old shorelines are found at elevations of about 60 meters above present MSL. The elevated beach ridges with peat formations in between are now exposed in eroding dune scarps on the Skagerrack (North Sea) coast.

STRAND PETERSEN (1990) describes carbon-dating with reference to Figure 3 which shows the location and dating of peats found between the gravel beach ridges along the exposed strongly eroding shore. In the following, the assumption is made that the points indicated in Figure 3 may be identified with the location of the tip of the spit—or rather that the difference along the shore between the points represents the growth during the time intervals indicated by the carbon-dating. This assumption seems reasonable, but it can, of course, not be substantiated by actual facts in the form of geometric survey data.

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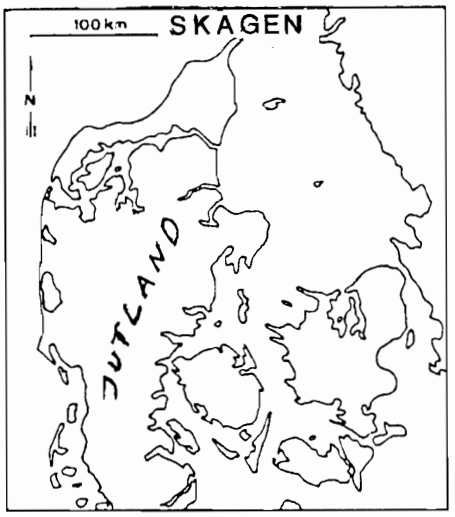

Figure 1. Denmark, peninsula Jutland and Skagen Spit.

PROCEDURE FOR ANALYSES

Table 1 gives figures for growth in meters per year within the time intervals involved based on data from Figure 3. The last column of Table 1 shows by arrows the apparent sea level movements within the time intervals of Figure 3. This information was derived from data integrated from diagrams published by various authors including information by the Danish Museum of Archeology (The National Museum; Figure 4). The arrows shown may be considered common eustatic trends without the glacial rebound for which we do not have a time-history development. The relative sea/land movement has been strongly influenced by glacial rebounds overpowering—until fairly recently—the eustatic sea level movements. Most likely—and based on tide level recordings—the southern part of the Skagen Spit is now in a neutral situation, where sea level rise and glacial rebound are almost equal. In the extreme northernmost part of the spit the situation may be different. We do not know whether any glacial rebound still is active here—or if it was ever there following the last glacial age. All we know is that the spit extended out into the deep water of the Norwegian Trench.

Some depth contours are indicated in Figure 3. The faint line below the line indicating elevations in Figure 3 shows that peat elevations follow similar patterns. From Table 1 it may been seen that the growth of the spit and the trend of the sea level rise apparently are compatible.

The magnitude of the glacial rebound is not available in detail. We know that it presently keeps pace with the sea level rise at the root of the Skagen Spit. The outermost part of the spit grew out into deep water. Today, the 50 meters depth contour is only 4 kilometers from shore and the

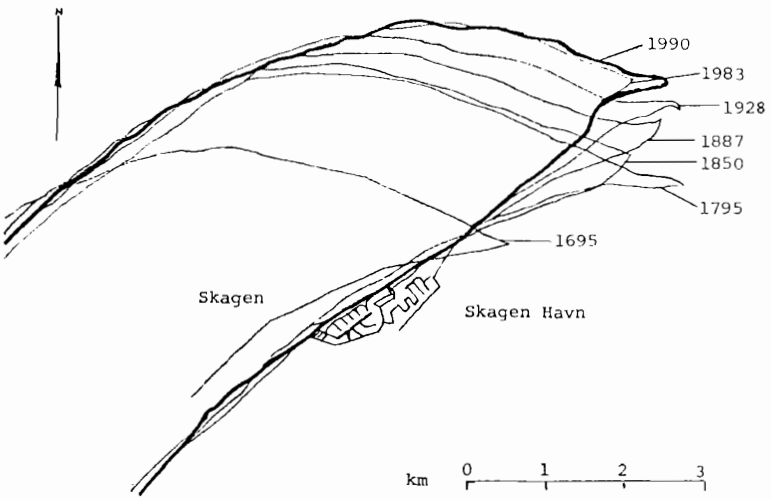

Figure 2. The development of the Skagen Spit by the location of shorelines during the period 1695–1990 (Hauerbach, 1990).

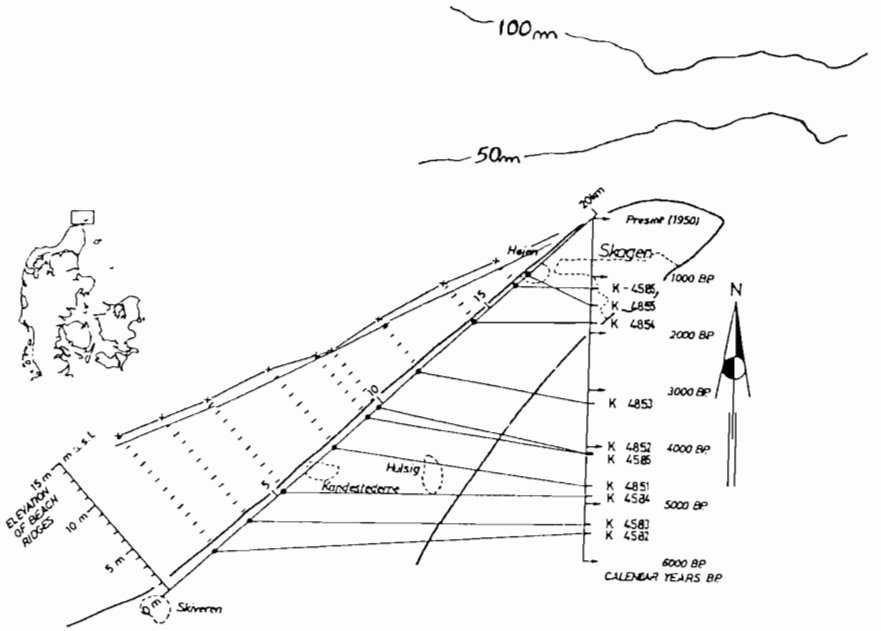

Figure 3. Carbon-dating of peats along the West Coast of the Skagen Spit with matching elevations above MSL for beach ridges as found in the dune scarp (STRAND PETERSEN, 1990).

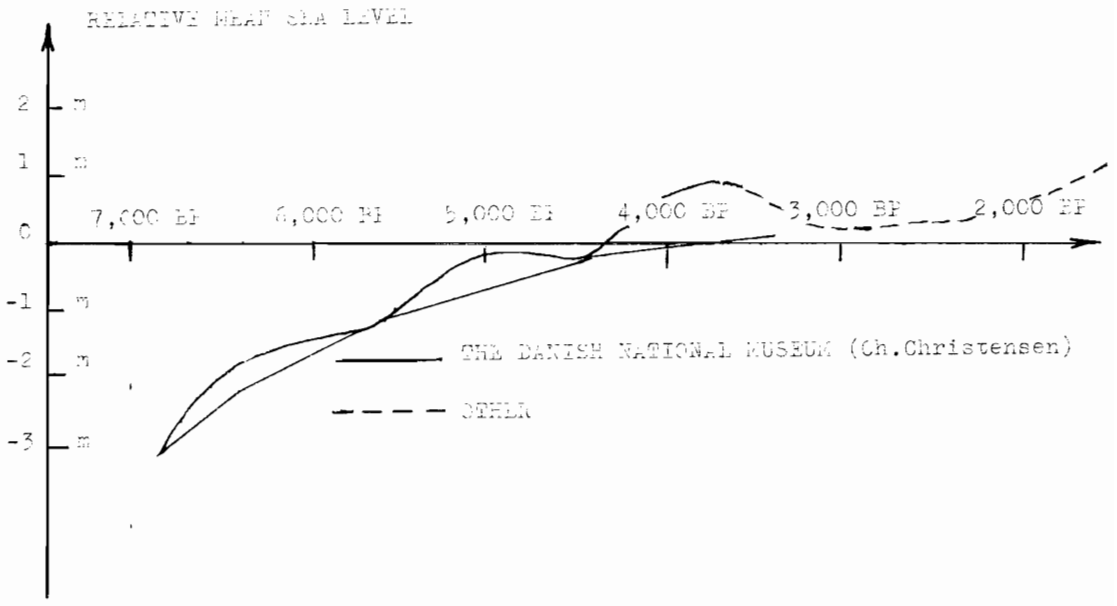

Figure 4. The relative MSL from selected site in Denmark (selected site on the Great Belt. Danish Nat. Museum).

Table 1. *Time intervals of growths of the Skagen Spit in relation to common movements of sea level. Period of 5,585 BP up to present. Basis material from Figure 3.*

Years BP	Intervals Years	Total Movement (m)	Movement/ Year (m)	Tendency of Sea Level Rises
5,585/4,910	675	3,200	4.6	
4,910/4,200	710	4,600	6.5	5.7 → Up glb.
4,200/3,265	935	2,500	2.6	→ Up slowly
3,265/1,860	1,405	2,900	2.1	→ Up *slowly*
1,860/1,390	470	2,200	4.7	
1,390/0,000	1,390	8,000	5.8	5.6 → Upturn

glb. = glacial rebound

100 meters contour is 6–8 kilometers from shore. These distances only represent about 1,000–1,500 years of growth by the spit. The bottom of the Norwegian Trench is almost 100 meters of very soft silt or mud. No glacial materials have been found.

Due to the glacial rebound, the development of the Skagen Spit is very unique. The relative sea/land movement at Skagen is now being observed by a very accurate tide level recording associated with the Global Observation System (GLOSS). A deep core boring will observe the geological development and the possible existence of a glacial rebound in the deeper layers as found in the shoals of the North Sea and on the continental platform off Norway where the glaciers have left pressures still not adjusted to the pressure of present elevations. This means that they are higher than they should be in accordance with the weight of the soil which now covers the bottom.

CONCLUSION

The growth of the Skagen Spit as described by the development of beach ridges (rimmer-dopper) seems to be related to the relative sea/land movements which have taken place.

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