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Shoreface-Connected Ridges in German and U.S. Mid-Atlantic Bights: Similarities and Contrasts

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ABSTRACT

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Shoreface-connected ridges in the German Bight (southern North Sea) and in the U.S. Mid-Atlantic Bight have previously been shown to exhibit some similarities. This report, based on sedimentological investigations in the German Bight, outlines additional similarities as well as significant differences in ridge attributes in both bights. Ridge migration, orientation, and vertical grain size patterns in both bights are identical, although ridge migration rates are up to 200% higher in the German Bight. However, contrasting attributes such as minimum water depth of occurrence and longitudinal grain size trend of ridges in the German Bight are inconsistent with ridge generation models in the Mid-Atlantic Bight.

ADDITIONAL INDEX WORDS: *Shoreface-connnected ridges, German Bight, U.S. Mid-Atlantic Bight, grain size, storm flow.*

INTRODUCTION

Shoreface-connected ridges are well developed features in the German Bight (southern North Sea) and in the U.S. Mid-Atlantic Bight. Since pioneering studies of shoreface ridges were conducted in the Mid-Atlantic Bight, particularly in respect of their characteristics, evolution, and geological significance (*e.g.* DUANE *et al.,* 1972; SWIFT *et al.*, 1972; SWIFT and FIELD, 1981), it was appropriate to compare their attributes with those of their counterparts in the German Bight and elsewhere (SWIFT *et al.*, 1978).

SWIFT *et al.* (1978) documented a number of attributes common to ridges in both bights, namely: (a) shoreline-oblique orientation, (b) shore-acute angle opening into the direction of predominant sediment transport or major storm flow, and (c) out-of-phase coast-normal relationship between mean grain size and ridge topography. Most of these observations are consistent with, and are corroborated by, recent sedimentological investigations of shoreface-connected ridges in the German Bight (ANTIA, 1993a,b).

Such a marked similarity in ridge characteristics from different environments would suggest a similar origin and process of maintenance, although the precise mechanism involved is still a subject of speculation (MCBRIDE and MOSLOW, 1991). A detailed review of the existing models of shoreface ridge evolution is contained in PATTIARATCHI and COLLINS (1987) and MCBRIDE and MOSLOW (1991). A major problem associated with understanding ridge genesis is the difficult task of distinguishing between ridge characteristics which existed at the time of formation vis-à-vis after formation.

The comparative study approach of SWIFT *et al.* (1978) is particularly instructive in the above respect; differences in ridge characteristics caused by local or regional setting and physical processes can eventually be identified leading, ultimately, to a better understanding of mechanisms of ridge development. Until recently, the report of SWIFT *et al.* (1978) was the major source of information on shoreface-connected ridge characteristics in the German Bight. This present study follows the approach of SWIFT *et al.* (1978). However, the main objective here is to update and reevaluate the observations of SWIFT *et al.* (1978) in light of sedimentological investigations of the shoreface ridge of Spiekeroog Island (German Bight).

STUDY AREA

The German Bight is situated at the southeast corner of the North Sea Basin (Figure 1, inset). At the southern margin of the bight is a chain of

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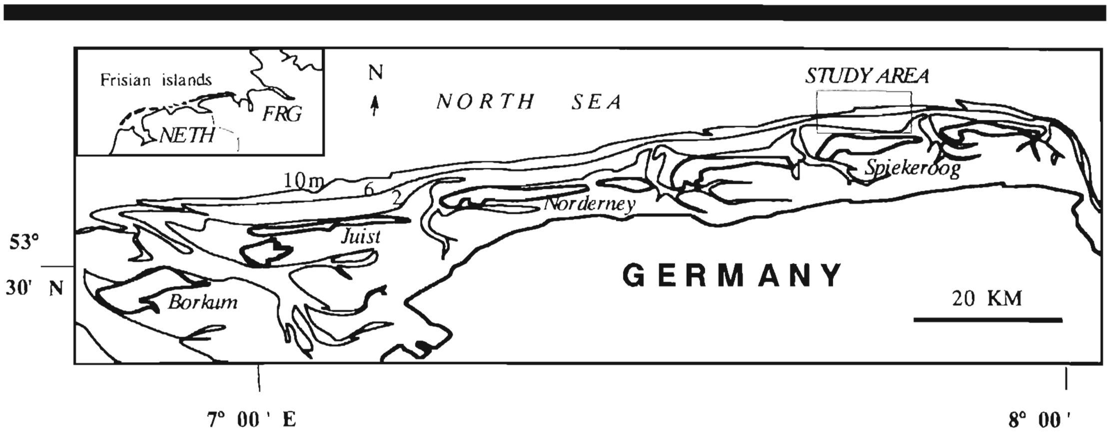

Figure 1. The general geomorphology of the German Bight showing the Frisian barrier islands and inlet ebb-tidal deltas as well as the main study area of Spiekeroog Island (after FitzGerald *et al.* 1984).

drumstick- and linear-shaped barrier islands, referred to as Frisian islands (Figure 1). These islands are seperated, respectively, from each other by inlets which are 15–20 m deep and about 2 km wide, and from the mainland coast of Netherlands and Germany by up to a 7 km wide backbarrier region or Wadden Sea. Most of the inlets are characterized by well-developed ebb-tidal deltas protruding 3 km seawards (into water depth of 6 m) from the E-W oriented barrier island shoreline.

The maximum water depth in the German Bight is about 30 and its seabed gradient varies between 1:600 and 1:1000. According to Streif (1989), the East Frisian barrier islands have retreated at a rate of 1 m/yr over the last 1500–2000 years.

The physical oceanography of the southern North Sea is detailed by Otto *et al.* (1990). Residual currents attain a velocity of 10–15 cm/s (Neumann, 1966) and flow eastward, but gradually veer offshore along the Frisian islands. Tides in the German Bight are semidiurnal and show mean tidal range increasing eastward along the Frisian islands from about 1.4 m at the extreme west to about 2.7 m around Wangerooge. Fair-weather peak tidal current velocities (varying between 30-60 cm/s) measured at 1 m above sea bed and in water depths < 20 m showed the easterly flood currents to be 30-50% stronger than their westerly ebb counterparts (Antia, 1993a). Klein and Mittelstaedt (1992) reported a peak (flood) current velocity of 78 cm/s at 1 m above the bottom on the shoreface-connected ridge of Norderney Island during a violent storm.

Storms occur at least 10 to 30 days annually during winter months in the inner German Bight, most of which originate from NW to SW. Significant wave height (H_{sig}) of 2.3 m and periods of 6 secs are considered typical for the shoreface of Norderney at 20 m water depth (Klein and Mittelstaedt, 1992). In 10 m water depth off Norderney, H_{sig} of 1.8–4.5 m was documented by Niemeyer (1979), which under extreme storm conditions may reach a height of 9 m and period of 12 secs (Niemeyer, 1976).

DATA BASE

The main data from the German Bight shoreface-connected ridges were obtained offshore of Spiekeroog Island. In addition to repetitive current measurements and analyses of detailed sounding charts, sediment size statistical parameters were studied using 690 grab, 9 vibrocore and 60 boxcore samples. The boxcores were taken repetitively along two coast-normal transects. Field logistics and laboratory procedures are detailed in Antia (1993a). Preliminary results of surficial and vertical grain size patterns are given in Antia (1993b) and Antia (1994), respectively.

RIDGE CHARACTERISTICS

For clarity, ridge characteristics are detailed under two subheadings: morphology and sediments.

Ridge Morphology

The shoreface-connected ridges in the German Bight are at least 10 km long, 1–2 km wide, 3–5 m high, 0.5–1° steep, and are mainly composed of

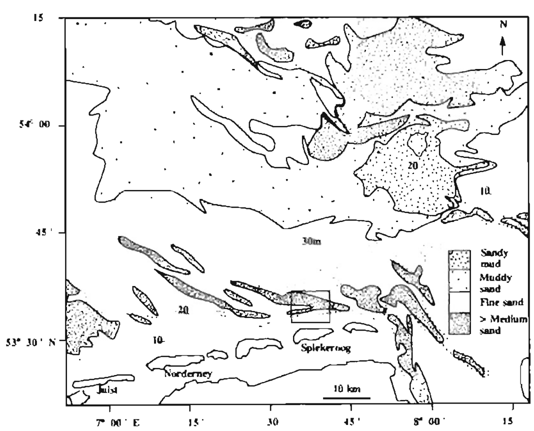

Figure 2. The German Bight showing the shoreface-connected ridges in 10–25 m water depth. The ridges are typically linear in shape, oblique to the coastline trend and are composed of medium- to coarse-grained quartz sands (modified after the DEUTSCHES HYDROGRAPHISCHES INSTITUT chart No. 2900, 1:250 000, 1981). Contours are in meters. Studied ridge is boxed.

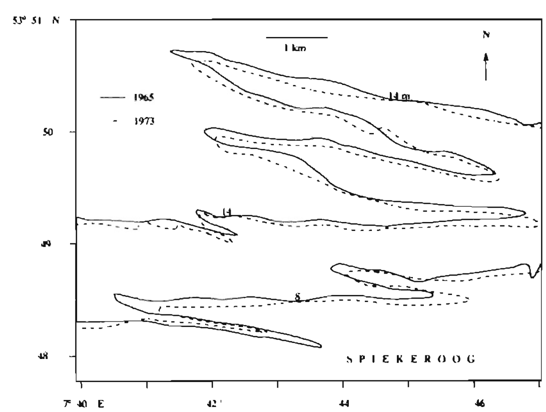

Figure 3. Headward trough erosion and coastward migration of a shoreface-connected ridge morphology, Spiekeroog Island.

coarse- to medium-grained quartz/feldspathic sands (Figure 2). SWIFT *et al.* (1978) noted that the acute angles of shoreface ridges relative to the adjacent coastline open into the direction of major storms or mean flow in both the German and U.S. Mid-Atlantic Bights. The shore-acute angle increases in a northerly direction in the Maryland sector of Mid-Atlantic Bight from 10° to 40° (SWIFT and FIELD, 1981). However, DUANE *et al.* (1972) reported a decrease in shore-acute angle in a southerly direction over a larger area, from 50° to 20° between Delaware Bay and Chincoteague Shoals. In the German Bight, the shore-acute angle decreases in a westerly direction from about 14° near Spiekeroog to 40° near Juist (*cf.*, Figure 2). On a regional scale, the shore-acute angles of the ridges decrease down-current of the major storm in both bights.

Shoreface ridges in the German Bight do not occur shoreward of the distal margin of the ebb-tidal deltas, i.e., their proximal or shallower (ESE) end can hardly be traced above the 8–10 m depth contour; by contrast, ridges in the U.S. Mid-Atlantic Bights are recognizable in water depths as shallow as 2 to 4 m (SWIFT *et al.*, 1973; SWIFT *et al.*, 1978).

Ridge migration in the German Bight proceeds through both trough headward erosion as well as coast-normal translation (Figure 3), like their U.S. Mid-Atlantic Bight counterparts reported by SWIFT and FIELD (1981). A fundamental difference, however, is the much higher rate (as much as 200–500%) of ridge migration in the German Bight, over comparable time intervals, than in the U.S Mid-Atlantic Bight (ANTIA, 1993a).

Ridges in the latter environment, based on existing literature reports such as DUANE *et al.* (1972), SWIFT and FIELD (1981), rarely exhibit long-term coastwise and coast-normal mean migration rates > 5 m/yr; whereas, coast-normal ridge migration rates of 20–30 m/yr and coastwise counterparts of > 100 m/y are common in the German Bight (ANTIA, 1993a). An additional difference in the coast-normal migration pattern of shoreface ridges in both bights was noted. In the Mid-Atlantic Bight, the coast-normal migration of shoreface ridges is predominantly offshore (SWIFT *et al.* 1978; SWIFT and FIELD, 1981). By contrast, a diabathic (oscillatory) pattern of migration is typical of shoreface ridges in the German Bight (ANTIA, 1993a; in press).

Ridge Sediments

The out-of-phase relationship between the cross-shore profiles of mean grain size and ridge topography noted by STUBBLEFIELD and SWIFT (1981) in the U.S. Mid-Atlantic Bight and by SWIFT *et al.* (1978) off the East Frisian islands of Norderney and Baltrum (German Bight) has been confirmed to be temporally consistent off Spiekeroog Island (ANTIA, 1993b; see Figure 4). On Spiekeroog shoreface-connected ridges, as in oth-

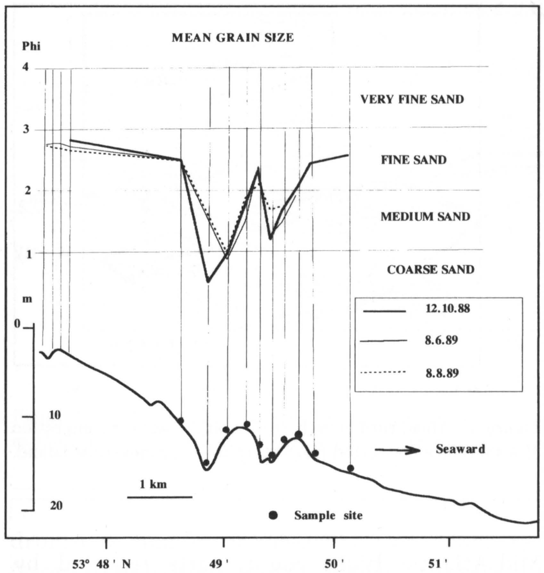

Figure 4. Mean grain-size trend across a shoreface ridge (long. 7° 44.50′E), off Spiekeroog Island, Germany (after ANTIA, 1993b).

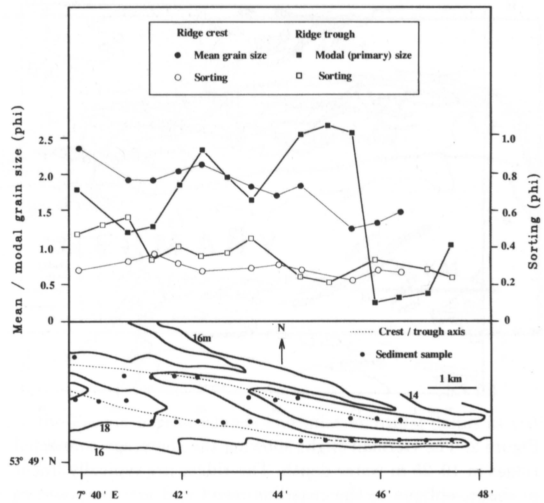

Figure 5. Mean grain-size trend along a shoreface ridge morphology, off Spiekeroog Island, Germany (after ANTIA, 1993b).

er localities, the sediments are finest on the seaward flank and coarsest either on the landward flank or in the troughs.

SWIFT *et al.* (1972) showed that sediments in the ridge field off the Virginia coast fine southerly, a trend which was considered to be a response to the south-setting storm currents in the region. In the case of the German Bight, the results from Spiekeroog is the opposite of the aforementioned, in that sediments fine northwesterly, *i.e.*, upcurrent of the major storm flow direction (Figure 5).

The vertical variation in mean grain size of the shoreface-connected ridges in the German Bight (ANTIA, 1994a, Figure 6) also displays a coarsening-upward pattern in some of the cores, as described by RINE *et al.* (1986) for the uppermost lithologic unit of ridges off the New Jersey coast as well as many fossil analogs of the shoreface ridges (*e.g.,* SWIFT and RICE, 1984).

DISCUSSION

The observations noted in the preceding section are discussed under three aspects, namely: grain size pattern, ridge morphology and ridge formation.

Grain Size Pattern

The implication of the noted longitudinal grain size trend (fining northwesterly) on Spiekeroog is that the major storm flow direction, which is E to ESE, is inconsequential to the origin of the ridges (ANTIA, 1993b). DUANE *et al.* (1972) reported that, irrespective of the presumed direction of net sediment transport in the U.S. Mid-Atlantic Bight, the shoreface ridges open northerly.

The coarsening of Spiekeroog shoreface ridge sediments toward the proximal, shallower, ESE end as a consequence of more intensed winnowing by the easterly to southeasterly-setting storm currents is plausible. However, this process is considered to play a secondary role in determining the observed sediment size trend. This is because near-bottom fairweather tidal current velocities in the ridge region, combined with the maximum horizontal wave current (U_{max}) counterparts (56–147 cm/s), will mobilize and entrain all medium and finer sands (ANTIA, 1993a); these constitute > 90% of the ridge surface sediments (*cf.,* Figure 4). Consequently, the stronger flood currents should cause an eastward fining of the ridge sediments, as is the case for sediments shoreward of the ridge region (ANTIA, 1993a). By comparison to the German Bight, shoreface ridge sediment transport in the U.S. Mid-Atlantic is effected mostly by storm currents (SWIFT *et al.,* 1973).

The upward-coarsening sediment pattern of sand bodies on shelves, also observed on the shoreface-connected ridges of Spiekeroog, was explained by SWIFT and RICE (1984) as a response to the increased perturbation of the near-bottom flow associated with the growth of the morphology. The above explanation can not be unequivocably extrapolated to the German Bight because the ridge surface sediments are markedly coarser than those of the upper shoreface (< 7 m) (cf., Figure 4). Based on the proposition that there is no extraneous source of coarse sediments onto the shoreface, one would have expected that the ridge sediments which are situated in deeper waters to be finer than the sediments landward of the ridge region. This is because of decreasing intensity of near-bottom flow with depth.

The above observation, coupled with the genetic relationship between grain-size statistical parameters of the ridge and inlet/ebb-tidal delta sediments, led to the suggestion that the coarser sediments on the ridge morphology could not be a consequence of winnowing in-situ; rather, they are transported obliquely onto the shoreface from the adjacent inlets during the ebbing phase of storms (ANTIA, 1993a,b, 1994a,b).

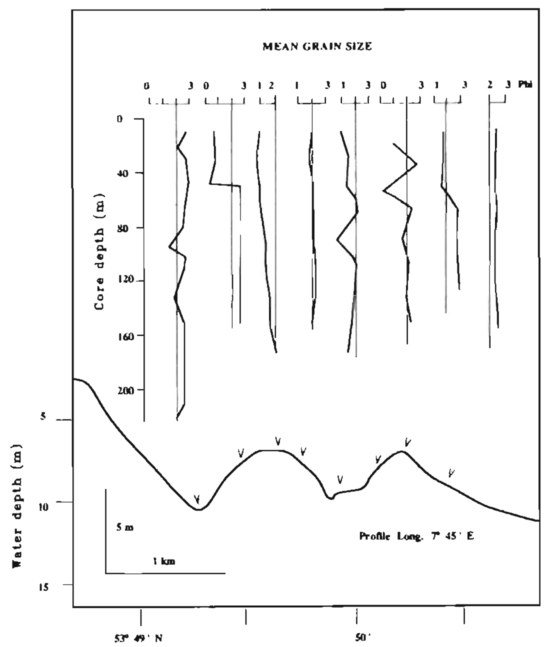

Figure 6. Vertical pattern of mean grain-size of a shoreface ridge, off Spiekeroog Island, Germany (after ANTIA, 1994b). Most cores are characterized by sediments < 2 phi in mean size above 60 cm core depth.

Ridge Morphology

In spite of the high sediment transport potential of shoreface ridge sediments in the German Bight, the morphology and orientation has not changed dramatically within the last 3–4 decades (ANTIA, 1993a), suggesting that the ridges are in equilibrium with the day-to-day hydrodynamic regime. Higher rates of ridge migration observed in the German Bight probably reflect the higher intensity of the hydrodynamic regime. Being a much smaller and shallower basin than the Mid-Atlantic Bight, water column response to wind forcing is likely to be faster and more intense.

SWIFT and FIELD (1981) reported ridges at various stages of development in the U.S. Mid-Atlantic Bight. Assuming that ridges closest to the coastline are the youngest and age with offshore distance, then the disparity in the minimum water depth of ridge occurrence in both bights (> 8 m water depth in the German Bight and 2–4 m in the U.S. Mid-Atlantic counterpart) may imply that ridges are not forming in the German Bight at the present time. This calls to question the applicability, in the German Bight, of the ridge generating models postulated for the Mid-Atlantic Bight.

CONCLUSIONS

The results of this study corroborate, to a very large extent, the observations of SWIFT *et al.* (1978) that shoreface-connected ridges in the German and U.S. Mid-Atlantic Bights have much in common. The higher migration rates of ridges in the German Bight, compared to their U.S. Mid-Atlantic counterpart, is probably indicative of the more intense nature of the flow regime in the former bight.

Based on the models of ridge genesis invoked for the Mid-Atlantic Bight, there is no fundamental reason for the non-occurrence of shoreface ridges in the German Bight in water depths as shallow as 2 m, as observed in the Mid-Atlantic Bight. This disparity invariably implies that these models of ridge origin are not entirely applicable to the German Bight.

The grain-size gradient along the ridge morphology does suggest that the major storm and mean flow direction to which the shore-acute angle of the ridges open is inconsequential to the genesis and maintenance of the morphology. Such currents may, if flow direction veers appreciably from that of the ridge orientation, contribute to the out-of-phase relationship between the cross-shore ridge morphology and the grain-size pattern as postulated by SMITH (1970).

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