Sea-level changes, coastal dune building and sand drift, North-Western Jutland, Denmark

Christian Christiansen & Dan Bowman

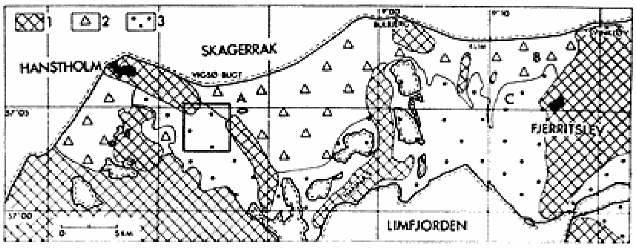

Fig. 1. Locational map showing study areas. 1) Glacial and fluvio- glacial deposits. 2) Blown sand overlaying marine deposits. 3) Marine deposits.

Fig. 1. Oversigtskort visende studielokaliteterne. 1) Glaciale og fluvioglaciale aflejringer. 2) Flyvesand dækkende marine aflejringer. 3) Marine aflejringer.

Christiansen, C. & Bowman, D.: Sea-level changes, coastal dune building and sand drift, North-Western Jutland, Denmark. Geografisk Tidsskrift 86: 28-31. Copenhagen, June 1986.

Two main models linking dune building and sea level changes have so far been proposed. Application of the low sea level model suggests that the major Danish dune building period from 1550 to 1750 need not necessarily be the result of human activity. The dune building period is probably related to a low sea level and the reworking of exposed shallow marine sand.

C. Christiansen, Institute of Geology, Ny Munkegade Bg. 520, 8000 Århus C, Denmark; D. Bowman, Department of Geography, Ben-Gurion University of the Negev, P.O.B. 653, Beer Sheva 84120, Israel.

Keywords: *Sea-level changes, dunes, Denmark.*

There are two main requirements for the formation of coastal dunes: a supply of sand to the littoral zone, and strong on-shore winds for at least part of the year. The form, size and mobility of the dunes is controlled by a number of factors: amount of available sand, directional and seasonal distribution of wind-energy, effectiveness of sand-binding vegetation, amount and distribution of yearly rainfall, and the general physiography of the area.

Sea-level change is generally regarded as a factor which may change dune behavior. Opinions are divided as to the magnitude and direction of the necessary sea-level change (Pye 1984). In the present paper two opposite models of the influence of sea-level changes on dune building and sand drift are applied in the northwestern part of Jutland (fig. 1), where a major aeolian activity took place from 1550 to 1750. Other effects of sea-level change on coastal morphology in Denmark are treated by Christiansen (1985) and Christiansen, Møller & Nielsen (1985).

MODELS OF COASTAL DUNE DEVELOPMENT

Previous work has suggested 2 main models for coastal dune development during the Quarternary. The models are diagramatized in fig. 2.

Model 1 suggests that major dune building takes place in periods with high sea-level (interglacial including late parts of Holocene). Aeolian episodes related to depositional transgressions (marine overlap) occur with a slow rise of sea-level, associated with high rates of sand supply. The sources of sand for aeolian drift may be: residual sands on the upper shelf, long-shore current supply, shore erosion, sea cliff retreat and inundation and reworking of former dunes during the sea-level rise. The aeolian activity designates the front of a transgressive sequence. According to this model low sea-level is associated with dune stabilization, weathering and soil development (Bretz 1960).

A similar interpretation is suggested by Cooper (1958). Rising sea-level leads to beach erosion, destroys the vegetation on dunes and beach ridges, creates blow-outs and results in transgressive dunes. In the southeastern Mediterranean coastal cell sediments from the Nile are during the Holocene transported by a counter-clockwise current. They make up a system of prominent longitudinal cemented sandstone ridges along the Israeli coastal plain, as well as on the shelf, as far as its edge at a depth of 80-110 m. Each ridge represents a lithified former coastal foredune from the last post-glacial transgressive phase (Neev et al. 1973; Nir 1973). Landward migration of barrier islands, triggered by wave erosion, overwash and wind drift, is another form of transgressive dune formation (Sanders & Kumar 1975).

Model 2, proposed among others by Wright (1963) and Ward (1985), presents the opposite interpretation for sea level – dune building relationship. According to this interpretation, major dune building takes place in periods of falling and low sea-level when wide shelf areas are exposed to wind activity. During high sea-level the dunes on the shelf are drowned, while coastal high-lying dunes are deprived of their sand supply and become stabilized. According to Schofield (1975) is major dune development also suggested to take place due to the gradual lowering of the wave base which activates deeper shelf sand that becomes available for landward transport and result in coastal progradation and aeolian deflation.

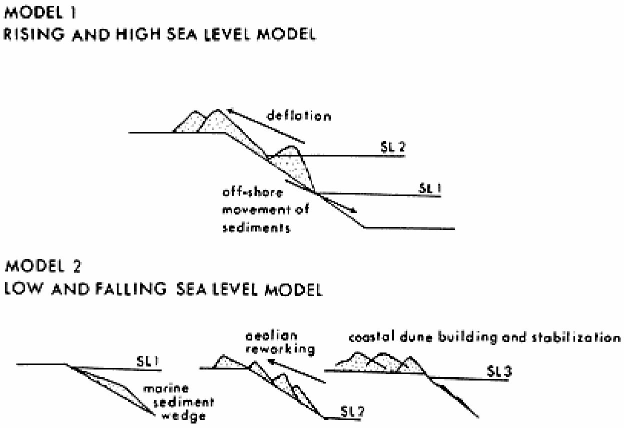

Fig. 2. Two main alternative models of coastal dune development related to sea level change.

Fig. 2. To alternative modeller af kystklitudviklingens afhængighed af vandstandsvariationer.

HANSTHOLM – HJARDEMÅL AREA

The morpho-genetic map covering the area between Hansted knuden (knude=knoll) and Hjardemål knuden shows lineaments (fig. 3) of two main trends. One trend runs N122°E to N172°E indicating beach ridges on the raised former sea floor. These beach ridges show high and low angle planar mega cross-stratification. They have fully developed, topographically concordant, secondary simple humic podzol soils. Fig. 5 shows the cross-section of such a ridge (for locality see fig. 3). The internal structure, with the steep (30°-32°) slip-face towards the south, indicates sand transport from the north. The ridge is thus part of a former coastal dune system, linking the Hansted knude and the Hjardemål knude. This fossil system, as well as others in the area, are signs of considerable aeolian activity related to the post Tapes/Littorina regression. The present form of the ridges is sligthly modified by secondary aeolian activity (Bowman and Christiansen, in prep.).

The second trend of the ridges, N67°E, is shown by patches of aeolian sheets reflecting the eastward advance of coastal sand fields. This trend is dominant in ridges throughout northern Jutland. Most of the dunes with this trend were formed during a period of strong aeolian activity which started about 1550 A.D. The aeolian activity covered areas up to 16 km from the beach. 25% of the former Thisted county was affected by the sand drift. The cause for the drift is generally thought to be human interference. Thus Brüel (1918) suggested deforestation and overgrazing by sheep in the dunes as possible causes. Fig. 4 shows that the sea-level was low during this period of strong aeolian activity. The figure is mainly based on archaeological finds at the Eider in northern Germany (Rohde 1978).

KLIM AREA

In the Klim area coast and dune development has been monitored since 1968 (Christiansen and Møller 1980). During this relatively short period with rising sea-level (Christiansen et al. 1985) the dunes have apparently advanced 80 m to the south (fig. 6). Closer inspection of fig. 6 shows that following beach erosion the beach and dune environment act as one system, i. e., following the November 1981 storm which removed the entire foredune, the next dune grow in height by 0.5 m/Y. Thus the Klim area at present reflects model 1 where weak aeolian activity is triggered by rising sea-level.

DISCUSSION

The Klim data suggest that the present rising sea-level causes beach erosion without the transgressive dune development and sand drift effect characteristic of model 1. The present moderate aeolian activity may be explained in terms of control measures taken by local residents. In contrast, the findings in the Hanstholm area suggest that the ridges are related to the post Tapes/Littorina regression.

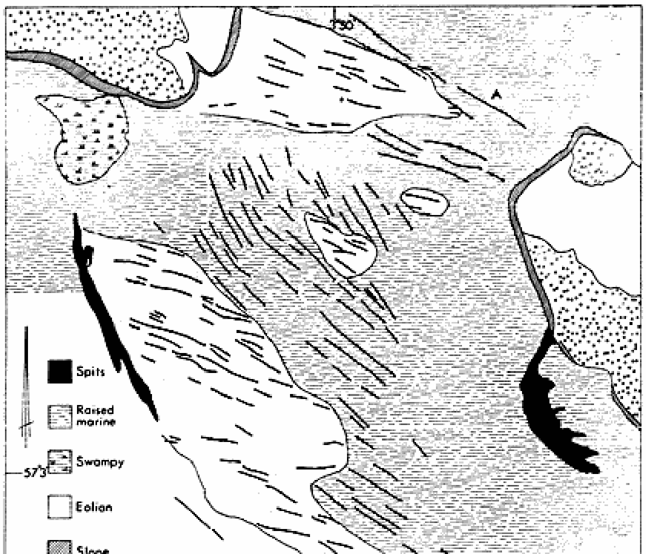

Fig. 3. Simplified morpho-genetic map showing trends of morphological lineaments in the Hanstholm area. Based on air photoes and 1:20000 topographic map, 1942. Cross-section of ridge 'A' is further discussed in the text and shown in fig. 5.

Fig. 3. Simplificeret morfo-genetisk kort visende retningen af morfologiske lineamenter i Hanstholm området. Baseret på luftfotografier og 1:20000 topografisk kort, 1942. Tværsnitsprofilet af ryggen 'A' diskuteres i teksten og vises i fig. 5.

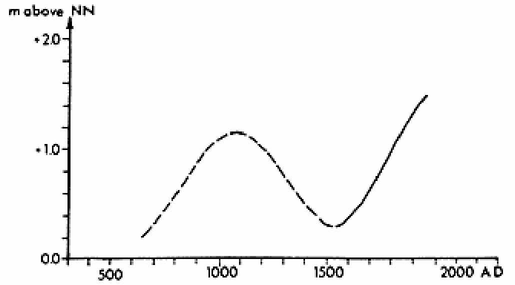

Fig. 4. Probable co-tidal line of HWNT from about 650. Constructed from archaeological excavations on the Eider. (NN= German Ordnance Datum). (After Rohde (1978)).

Fig. 4. Middelhøjvandets variation fra ca. år 650. Baseret på arkæologiske udgravninger ved Eideren. (NN= Tysk normal nul). (Efter Rohde (1978)).

According to fig. 4 the sand drift period 1550-1750 can be explained by model 2 sea-level drop. The high sea-level around 1100 A.D., like the present one, caused extensive beach erosion (Christiansen et al. 1985). Material was deposited and stored in bays and coves and partly in deeper water according to Bruun's rule (Bruun 1962). During the low sea-level around 1550 A.D. these deposits were reexposed to aeolian activity. The low sea-level also lowered the ground water table which contributed further to sand drift. Rather similar theories have been proposed by Andersen (1947).

The sand drift can thus be explained by geological processes. We therefore suggest that the effect of a fall in sea-level and onshore blowing winds is at least as great as any antropogenic effects. The low sea-level in the sand drift period coincide with 'the little ice age' (Sugden & John 1976). The cold climate partly deprived the oceans of some of their water, which was stored on land in glaciers and partly lowered the sea-level because of the higher water densities in the oceans due to low water temperatures (Christiansen 1985).

Brüel (1918) quotes several examples in which the sand drift apparently stopped by itself in the late 17 the century. This implies that the sea-level rise which started in

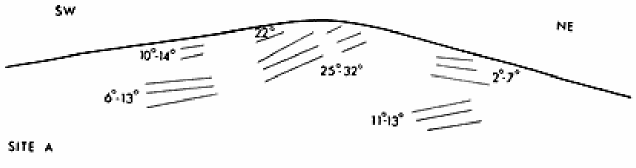

Fig. 5. Line drawing of main internal structures in cross-section of fossil coastal ridge in the Hanstholm area. Localization of stratigraphic sets is approximate. Dips and stratigraphic relations are accurate. For localization see 'A' in fig. 3.

Fig. 5. Rids af interne strukturer i ryggen 'A' på fig. 3. Lokaliseringen af lagfølgerne er tilnærmet. Hældningerne og deres stratigrafiske forbindelser er akkurate.

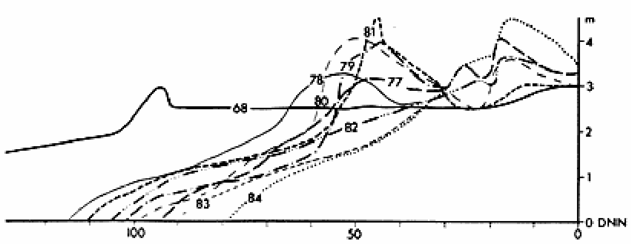

Fig. 6. Changes in coastal profile during the period 1968-1985 along line 600 in the Klim study area. (For localization see Christiansen and Møller (1980)).

Fig. 6. Ændringer i kystprofilet gennem perioden 1968-1985 på linie 600 i Klim studie området. (For lokalisering se Christiansen and Møller, 1980).

the sand drift period did not trigger model 1 dune building and sand drift. On the contrary, the dunes became stabilized partly because of a rising ground water table in coastal areas and partly because wide previously subaerial areas were again covered by the sea.

There is another point of geological interest in fig. 4. According to the Snorres saga the Norwegian king Harald escaped 1061 A.D. for the Danish king Svend Estridssøn. During one night he took his ships across a small barrier from the Limfjord and out into the North Sea. The location of this route has been eagerly debated in Danish Geology and History for many years. Stenstrup (1975) and Jessen (1920) suggested the Aggertangen as a possible crossing-point. Later Pedersen (1976) and Møller (1980) suggested that there was an open connection to the North Sea across Hanherred and northern Thy. Fig. 4 shows that sea-level was high at the time of the Vikings. This is further evidence of a possible northerly route. Pedersen (1976) has pointed out that Jessen (1920) was probably thinking in terms of the present distribution of land and sea when he suggested that is was impossible 'even for Norwegian Vikings' to cross the rough beach ridge terrain in Hanherred with their ships.

ACKNOWLEDGEMENTS

We thank C. Aub-Robinson for help with the English text and G. Larsen and J. T. Møller for critically reading the manuscript.

Sammendrag

I Hanstholm-Hjardemål området findes to generationer af klitter. 1) Kystklitter dannet under post Tapes/Littorina regressionen. 2) Indlandsklitter dannet i sandflugtsperioden 1550-1750. Begge sæt af klitdannelser påvises at have fundet sted i perioder med faldende/lav middelvandstand i havet. Nutidens stigende/høje vandstand medfører i Klim området ingen transgressiv klitdannelse. Det foreslås derfor, at den lave vandstand i sandflugtsperioden har hovedansvaret for sandflugten. Antropogene effekter som skovfældning og overgræsning i klitterne tillægges sekundær betydning.

References

Andersen, S. A. 1947: Hvorledes landet blev til. In: Brunsgaard, C. & Pedersen, H. E. (Eds.): Landet mod Nordvest, 1, 7-32.

Bretz, J. H. 1960: Bermuda, a partially drowned, late mature, Pleistocene karst. Bull. Geol. Soc. Amer., 71, 1729-1754.

Brüel, J. 1918: Klitterne i Vestjylland og paa Bornholm. København, 133 pp.

Bruun, P. 1962: Sea level rise as a cause of shore erosion. Am. Soc. Civ. Eng. J. Water Har. Div., 88, 117-130.

Christiansen, C. 1985: Nutidige ændringer i middelvandstand. Dansk geol. Foren., Årsskrift for 1984, 15-20.

Christiansen, C. & Møller, J. T. 1980: Beach erosion at Klim, Denmark. A ten-year record. Coast. Eng., 3, 283-296.

Christansen, C., Møller, J. T. & Nielsen, J. 1985: Sea-level fluctuations and associated morphological changes: Examples from Denmark. Eiszeitalter u. Gegenwart, 35, 89-108.

Cooper, W. S. 1958: Coastal sanddunes of Oregon and Washington. Mem. Geol. soc. Amer., 72, 169 pp.

Møller, J. T. 1980: Kollerupkoggen. Opmåling og beskrivelse af et middelalderskib og nogle tanker om fundstedet. Antikvariske Studier, 4, 143-160.

Neev, D., Almagor, G., Arad, A., Ginsburg, A. and Hall, J. K. 1973: The geology of the southeastern mediterranean sea. Israel Geol. Surv. Rep. MG/73, 43 pp.

Nir, Y. 1973: Geological history of the recent and subrecent sediments of the Israel mediterranean shelf and slope. Israel Geol. Surv. Rep. MG/2/73, 179 pp.

Pedersen, K. S. 1976: Om Limfjordens postglaciale marine udvikling og niveauforhold, belyst ved mollusk-fauna og C-14 dateringer. Danm. Geol. Unders., Årbog 1975, 75-103.

Pye, K. 1984: Models of transgressive coastal dune building episodes and their relationship to Quarternary sea level changes: a discussion with reference to evidence from eastern Austalia. In: Clark, M. (ed.): Costal Research: U. K. perspectives. Geobooks, 81-104.

Rohde, H. 1978: The history of the German coastal area. Küste, 32, 6-29.

Sanders, J. E. and Kumar, N. 1975: Evidence of shoreface retreat and in place 'drowning' during Holocene submergence of barriers, shelf off Fire Island, New York. Bull. Geol. Soc. Amer. 86, 65-76.

Schofield, J. C. 1975: Sea level fluctuations cause periodic postglacial progradation, South Kaipara Barrier, North Island, New Zealand. NZ. J. Geol. Geophys., 18, 295-316.

Steenstrup, J. 1875: Harald Haarderaads Tog til Limfjorden og Limfjordens Tilstand i 11. Aarhundrede. Kjøbenhavn, 81 pp.

Sugden, D. E. and John, B. S. 1976: Glaciers and landscape. Arnold, London. 376 pp.

Ward, W. T. 1985: Correlation of East Australia Pleistocene shorelines with deep sea core stages: A basis for coastal chronology. Bull. Geol. Soc. Amer. 96, 1156-1166.

Wright, H. E. 1963: Late Pleistocene geology of coastal Lebanon. Quarternaria, 6, 525-539.

Analyse af den morfologiske udvikling på strandplanet nord for indsejlingen til Torsminde havn 1947-85.

H.A. Olsen

Olsen, H.A.: Analyse af den morfologiske udvikling på strandplanet nord for indsejlingen til Torsminde havn 1947-85. Geografisk Tidsskrift 86: 31-45. København, juni 1986.

Abstract: Movement of bars on the off-shore by Torsminde harbour on the west coast of Jutland, Denmark is described and connected with structures of moles and sedimentation in the port entrance.

H.A. Olsen, ingeniør, Toften 25, DK-6780 Skærbæk ex - chief hydraulic enginieer by state ports administration, Esbjerg, Denmark.

Keywords: *Movement of bars, west coast of Jutland, Denmark.*

LANDSKABET

På fig. 1 ses beliggenheden af Torsminde på den smalle landtange, der adskiller Nissum Fjord fra Nordsøen.

Nissum Fjord har et areal på 70 km^2 og er i århundredernes løb blevet adskilt fra Nordsøen ved en tangedannelse forårsaget af den kraftige materialvandring langs kysten. Tangen var tidligere gennembrudt af et smalt udløb med varierende tværsnit og skiftende beliggenhed. I 1479 optræder dette under navnet Torskemynnæ (torskemunding), der siden er blevet til stednavnet Torsminde. Det upålidelige afløb fra Nissum Fjord gav en dårlig afvanding af det omkringliggende land. Derfor blev tangen gennemgravet i 1870 og forsynet med en afvandingssluse ved Torsminde, så afløbet fra fjorden blev fikseret.

Nord for Torsminde ligger Bovbjerg, der er resterne af en endemoræne fra sidste istid. Den danner indtil 30 m høje klinter ud mod Nordsøen på en strækning af ca. 6 km. Disse klinter begynder 12 km fra Torsminde og leverer en stor del af materialet (sand, grus og sten) til litoralstrømmens materialetransport.

Fig. 2 er et flyfoto fra 1981 orienteret med nord opad og viser en del af Torsminde by og havn med sluseanlæg og ydre havneværker. Revlens beliggenhed foran kystlinien markeres tydeligt af brådzonen, der fremkaldes af de indløbende bølger fra nordvest.

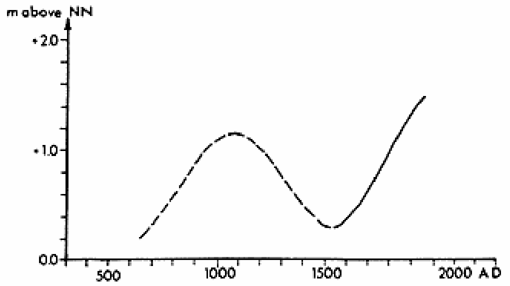

Fig. 4. Probable co-tidal line of HWNT from about 650. Constructed from archaeological excavations on the Eider. (NN= German Ordnance Datum). (After Rohde (1978)).

Fig. 4. Middelhøjvandets variation fra ca. år 650. Baseret på arkæologiske udgravninger ved Eideren. (NN= Tysk normal nul). (Efter Rohde (1978)).

According to fig. 4 the sand drift period 1550-1750 can be explained by model 2 sea-level drop. The high sea-level around 1100 A.D., like the present one, caused extensive beach erosion (Christiansen et al. 1985). Material was deposited and stored in bays and coves and partly in deeper water according to Bruun's rule (Bruun 1962). During the low sea-level around 1550 A.D. these deposits were reexposed to aeolian activity. The low sea-level also lowered the ground water table which contributed further to sand drift. Rather similar theories have been proposed by Andersen (1947).

The sand drift can thus be explained by geological processes. We therefore suggest that the effect of a fall in sea-level and onshore blowing winds is at least as great as any antropogenic effects. The low sea-level in the sand drift period coincide with 'the little ice age' (Sugden & John 1976). The cold climate partly deprived the oceans of some of their water, which was stored on land in glaciers and partly lowered the sea-level because of the higher water densities in the oceans due to low water temperatures (Christiansen 1985).

Brüel (1918) quotes several examples in which the sand drift apparently stopped by itself in the late 17 the century. This implies that the sea-level rise which started in

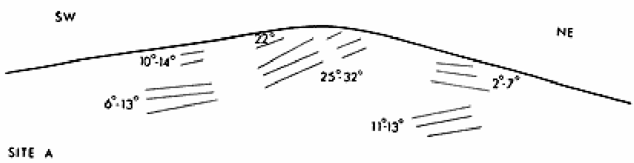

Fig. 5. Line drawing of main internal structures in cross-section of fossil coastal ridge in the Hanstholm area. Localization of stratigraphic sets is approximate. Dips and stratigraphic relations are accurate. For localization see 'A' in fig. 3.

Fig. 5. Rids af interne strukturer i ryggen 'A' på fig. 3. Lokaliseringen af lagfølgerne er tilnærmet. Hældningerne og deres stratigrafiske forbindelser er akkurate.

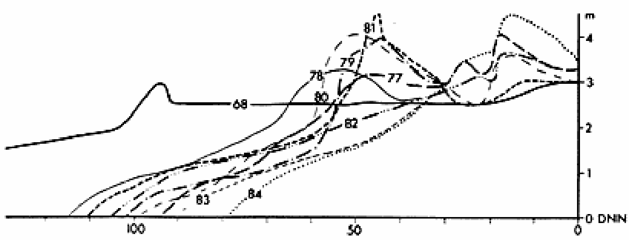

Fig. 6. Changes in coastal profile during the period 1968-1985 along line 600 in the Klim study area. (For localization see Christiansen and Møller (1980)).

Fig. 6. Ændringer i kystprofilet gennem perioden 1968-1985 på linie 600 i Klim studie området. (For lokalisering se Christiansen and Møller, 1980).

the sand drift period did not trigger model 1 dune building and sand drift. On the contrary, the dunes became stabilized partly because of a rising ground water table in coastal areas and partly because wide previously subaerial areas were again covered by the sea.

There is another point of geological interest in fig. 4. According to the Snorres saga the Norwegian king Harald escaped 1061 A.D. for the Danish king Svend Estridssøn. During one night he took his ships across a small barrier from the Limfjord and out into the North Sea. The location of this route has been eagerly debated in Danish Geology and History for many years. Stenstrup (1975) and Jessen (1920) suggested the Aggertangen as a possible crossing-point. Later Pedersen (1976) and Møller (1980) suggested that there was an open connection to the North Sea across Hanherred and northern Thy. Fig. 4 shows that sea-level was high at the time of the Vikings. This is further evidence of a possible northerly route. Pedersen (1976) has pointed out that Jessen (1920) was probably thinking in terms of the present distribution of land and sea when he suggested that is was impossible 'even for Norwegian Vikings' to cross the rough beach ridge terrain in Hanherred with their ships.

ACKNOWLEDGEMENTS

We thank C. Aub-Robinson for help with the English text and G. Larsen and J. T. Møller for critically reading the manuscript.

Sammendrag

I Hanstholm-Hjardemål området findes to generationer af klitter. 1) Kystklitter dannet under post Tapes/Littorina regressionen. 2) Indlandsklitter dannet i sandflugtsperioden 1550-1750. Begge sæt af klitdannelser påvises at have fundet sted i perioder med faldende/lav middelvandstand i havet. Nutidens stigende/høje vandstand medfører i Klim området ingen transgressiv klitdannelse. Det foreslås derfor, at den lave vandstand i sandflugtsperioden har hovedansvaret for sandflugten. Antropogene effekter som skovfældning og overgræsning i klitterne tillægges sekundær betydning.