Sequence stratigraphy

The sequence stratigraphic interpretation of the Neill Klinter Group is based on the identification and interpretation of key surfaces, including unconformities, flooding and drowning surfaces, surfaces or levels rich in siderite clasts or conglomerates composed of extraformational pebbles, and surfaces across which there are major landward or seaward shifts in facies (Dam & Surlyk, 1995).

In this way seven regional unconformities, and six regional flooding or drowning surfaces are recognised (Fig. 46). Correct interpretation of systems tracts is difficult due to the near absence of parasequences, and thus of parasequence sets showing well-defined stacking patterns. As a tentative approach it is suggested that aggradational units topped by a sharp drowning surface, draped by a lag conglomerate formed by shoreface erosion, represent lowstand systems tracts, whereas aggradational to slightly retrogradational, strongly bioturbated units represent transgressive systems tracts. We assume that extensive fine-grained units, formed during periods of regional starvation of coarse clastic material in the basin, represent transgressive systems tracts.

The sequences and key surfaces are described below in ascending stratigraphic order, and a tentative systems tract interpretation is presented. The sequences are referred to from below as SQ1, SQ2 etc., whereas sequence boundaries are abbreviated SB1, SB2 etc.

Sequence 1 (SQ1)

SQ1 consists of the lower part of the Lower Pliensbachian Rævekløft Formation (Figs 3, 6, 7).

Transgressive systems tract. In the south-eastern part of the basin the Rævekløft Formation is separated from the underlying delta-plain deposits of the Rhaetian – Sinemurian Kap Stewart Group by a major basin-margin unconformity that conceals a hiatus that in this area corresponds to all of the Sinemurian Stage (Harris, 1935; Pedersen & Lund, 1980; Figs 5, 7). Basinwards it passes into a correlative conformity, and most or all of the Sinemurian is probably represented in the basinal areas and belongs to the Kap Stewart Group, as indicated by recent palynostratigraphic investigations (E. Koppelhus, unpublished manuscript, 1996). In these areas the boundary between the Kap Stewart and Neill Klinter Groups is marked by a change from lacustrine to shallow marine deposits. The change is indicated by the appearance of marine body, micro- and trace fossils, and by a sudden increase in the ratio of total sulphur to total organic carbon (Fig. 4; Surlyk *et al.,* 1973; Dam & Surlyk, 1993; Koppelhus & Dam, in press). The basin-margin unconformity is commonly overlain by a thin conglomerate of fragmented bivalve shells and extraformational clasts (Fig. 5). At Harris Fjeld the delta plain deposits of the Kap Stewart Group are strongly burrowed by *Diplocraterion parallelum* just below the unconformity. The trace fossil assemblage makes up an omission suite and suggests minimal scouring and reworking of the delta plain deposits of the Kap Stewart Group during the Early Pliensbachian transgression (Dam, 1990b). This suggests that the Sinemurian sediments must have been eroded prior to the transgression. The unconformity and its correlative conformity constitutes the basal sequence boundary (SB1) of sequence 1 of the Neill Klinter Group.

The lower cross-bedded sandstone bed of the Rævekløft Formation is up to 7.5 m thick and was deposited in the upper shoreface and foreshore by longshore currents (Fig. 7). It contains a rich invertebrate fauna of European aspect composed of about 140 species of bivalves, gastropods, cephalopods and echinoderms.

Highstand systems tract. The transgressive systems tract is topped by a sharp, erosional drowning surface overlain by offshore transition mudstones in the south-eastern part of the basin at Tancrediakløft and Qupaulakajik (Fig. 7). The surface is interpreted as a transgressive surface of erosion formed by marine shoreface erosion during transgression. In Tancrediakløft and Qupaulakajik the highstand systems tract is represented by a small coarsening-upward mudstone unit, 2 m thick. Further north this highstand systems tract is not preserved.

Sequence 2 (SQ2)

SQ2 consists of the upper part of the Rævekløft Formation and the lowermost part of the Elis Bjerg Member and coincides with palynomorph assemblage 1 of Koppelhus & Dam (in press) at Albuen (Figs 3, 7, 46; Plate 2).

Transgressive systems tract. In the south-eastern part of the basin the lower sequence boundary (SB2) is defined by a sharp, erosional contact between the offshore mudstones of SQ1, and shoreface and foreshore pebbly sandstones of SQ2 (Fig. 7). The boundary represents a major seaward shift in facies, and is interpreted as a sequence boundary. SB2 can be followed northwards from the south-eastern basin margin over at least 50 km and forms a sharp boundary between the lower and upper Rævekløft Formation. At Elis Bjerg shoreface deposits of SQ1 are strongly burrowed by bivalves just below the unconformity (Fig. 8). Further north and towards the basin centre the unconformity passes into the correlative conformity situated about 25 m above the base of the Elis Bjerg Member, which here forms the lowest part of the Neill Klinter Group.

From Harris Fjeld and northwards SB2 is overlain by a pebbly sandstone of debris flow origin (Fig. 7). It is 2–3 m thick, and has a lateral extent exceeding 20 km. It is characterised by well-rounded pebbles scattered in a matrix of muddy sandstones. Rare transported bivalves and belemnites occur at Elis Bjerg, but are absent at Harris Fjeld (Dam, 1991). The shoreface sandstones of the upper part of the Rævekløft Formation is topped by a major drowning surface, suggesting that the sandstones of the Rævekløft Formation belong to a transgressive systems tract.

Highstand systems tract. The drowning surface at the top of the Rævekløft Formation forms the base of the Elis Bjerg Member of the Gule Horn Formation (Fig. 7; Plate 2). It is overlain by offshore transition zone mudstones showing a slight coarsening-upward trend culminating in a sharply-based tidally dominated shoreface sandstone unit, which may represent a minor forced regression. It is not known if this sharp boundary only has local significance, or if it is of more regional importance. The lower part of the Elis Bjerg Member, where it overlies the Rævekløft Formation, is interpreted as a highstand systems tract. The sharp boundary between the two units is interpreted as a transgressive surface of erosion reflecting a major landward shift in facies.

Sequence 3 (SQ3)

SQ3 includes the main part of the Elis Bjerg Member (Figs 3, 46; Plate 2) and coincides with palynomorph assemblage zones 2 and 3 of Koppelhus & Dam (in press).

Transgressive and highstand systems tracts. Sequence 2 is topped by an erosional surface draped by a quartzite pebble and belemnite conglomerate, which forms the boundary between two distinct facies packages (Plate 2). The size of quartzite pebbles exceeds those of the underlying Elis Bjerg Member, and the formation of the conglomerate appears not to be related to simple transgressive shoreface erosion. The conglomerate may represent a reworked and winnowed fluvial lag, and the erosional surface is accordingly interpreted as an unconformity, forming the third sequence boundary (SB3).

Along the eastern basin margin the overlying part of the Elis Bjerg Member is very difficult to interpret within a sequence stratigraphic framework. The deposits consists of amalgamated tidal channel and subtidal sandsheet facies packages (Plate 2). Well-defined facies cycles are not developed and parasequences can only rarely be recognised. The uppermost part of the Elis Bjerg Member is, however, characterised by the incoming of major tidal channel complexes, forming the best potential hydrocarbon reservoirs in the member (Plate 2). Although they are concentrated in the upper part of the member they can only be lithostratigraphically delineated. The dominant depositional motif seems to be aggradational to progradational. This probably represents moderate rate of creation of new accommodation space and high sediment influx in a flat-bottomed basin. Correlation of siderite clast conglomerates (Fig. 17; Plate 2) gives some clues to the presence of cryptic parasequences and thus to possible relative sea-level fluctuations. Conglomerates are rare to absent in the lowermost *c.* 20 m of SQ3, but become very common in the higher parts of the sequence. Many of the conglomerates form marker beds which can be followed for 10–20 km (Plate 2). The presence of siderite clast conglomerates shows that penecontemporaneous siderite cementation had taken place in the upper sediment layers. Early siderite cementation preferably occurs in marginal marine, brackish and terrestrial environments (e.g. Mozley & Wersin, 1992), and a high content of siderite clasts is thus interpreted as representing shallow water deposition followed by emergence and erosion.

The upward progression from siderite-poor to siderite-rich units in the south-eastern part of the basin, may thus indicate a trend from rare subaerial exposure to common exposure, and a decrease in rate of generation of new accommodation space.

In the north-western part of the basin in Ranunkeldal, the lower part of the Elis Bjerg Member is made up of storm-dominated shoreface deposits. The deposits consist of alternating mudstones and well-sorted fine-grained storm-generated sandstones. The sandstone laminae and beds are arranged in thickening and shallowing-upward units, up to 15 m thick, separated by flooding surfaces, representing well-developed parasequences (Figs 10, 11). This trend and the aggradational to progradational stacking pattern in both the south-eastern and north-western part of the basin suggests that the succession represents a transgressive systems tract overlain by a highstand systems tract.

Sequence 4 (SQ4)

SQ4 consists of the Albuen Member (Fig. 46) and coincides with palynomorph assemblage 4 of Koppelhus & Dam (in press). The Elis Bjerg Member is topped by a major erosional flooding surface (SB4) which forms the boundary to the overlying Albuen Member. SB4 is interpreted as a coalesced sequence boundary and transgressive surface, suggesting the presence of lowstand deposits in more basinal areas. The Albuen Member is about 26 m thick along the south-eastern basin margin; it gradually wedges out towards the north, and is nearly completely removed by later erosion at Nathorst Fjeld in connection with formation of SB5 (Figs 20, 46).

Transgressive systems tract. In detail the lower boundary shows a complex development. The basal few metres of the Albuen Member still have a high content of marine sandstone beds in most sections, and a clear fining-upward trend can be recognised before mudstone becomes the dominant facies (Fig. 20). The fining-upward unit is interpreted as representing the transgressive systems tract. The maximum flooding surface thus occurs a few metres above the transgressive surface in the most fine-grained part of the Albuen Member.

Highstand systems tract. The fining-upward transgressive systems tract is overlain by heteroliths of alternating mudstones and well-sorted, fine-grained storm-generated sandstones deposited in the offshore transition zone. Debris flow deposits, up to 2 m thick, are interbedded with the heteroliths and can be followed laterally for more than 30 km along strike (Fig. 20). The heteroliths form a slightly upwards coarsening unit that is interpreted as a highstand systems tract (Figs 20, 46).

Sequence 5 (SQ5)

SQ5 consists of the Astartekløft, Horsedal, Nathorst Fjeld, Harris Fjeld, Lepidopteriselv and Skævdal Members (Figs 3, 46) and coincides with palynomorph assemblage zone 5 and the lower half of zone 6 of Koppelhus & Dam (in press).

Lowstand systems tract. Along the Hurry Inlet the base of SQ5 is marked by an important erosional unconformity. It truncates the underlying mudstones of the Albuen Member which are almost completely cut out at Nathorst Fjeld (Fig. 46). Further north, the degree of truncation decreases and the unconformity passes into a correlative conformity, separating the Elis Bjerg Member and the overlying Horsedal Member (Figs 3, 46).

Along the south-eastern basin margin the unconformity is marked by fine-grained marine heteroliths overlain by subtidal sandsheet and tidal channel deposits of the Astartekløft Member, corresponding to an important and abrupt seaward shift in facies. In central and northern Jameson Land the lower part of SQ5 consists of aggradationally stacked lagoonal parasequences of the Horsedal Member (Figs 24, 25). The parasequences represent more proximal facies than the underlying tidal sandstones of the Elis Bjerg Member, and thus represent an important seaward shift in facies. The unconformity and its correlative conformity is interpreted as a sequence boundary (SB5) because it is erosional, of basin-wide nature, and marks a basinward shift in facies. The abrupt seaward shift in facies, the aggradational parasequence stacking pattern and the flooding surface at the top suggest that the Astartekløft and Horsedal Members represent a thickly developed lowstand systems tract.

Transgressive systems tract. The Astartekløft Member is overlain by an important flooding surface, in places veneered by a thin conglomerate of well-sorted, well-rounded quartzite pebbles, interpreted as a marine transgressive surface of erosion (Fig. 29). The overlying

Nathorst Fjeld Member consists of a single coarsening-upward unit composed of offshore transition zone mudstones grading upward into shoreface sandstones (Fig. 32). The Nathorst Fjeld Member interfingers with seaward prograding low-angle clinoform bedded ebb tidal delta deposits of the Harris Fjeld Member (Figs 34-37).

Further north the offshore mudstones, shoreface sandstones, and ebb-tidal delta heteroliths and sandstones of the Nathorst Fjeld and Harris Fjeld Members pass laterally into cross-bedded tidal channel sandstones of the Lepidopteriselv Member (Fig. 30). The transgressive surface of erosion separating the Astartekløft and Nathorst Fjeld Members, passes northwards into a flooding surface separating the north-eastern lagoonal deposits of the Horsedal Member from the overlying tidal shoal deposits of the Lepidopteriselv Member. Thus to the south this surface forms the boundary between coarse-grained shoreface and tidal channel deposits below and fine-grained offshore deposits above, and represents a landward shift in facies. Towards the north the lithological succession is reversed, relatively fine-grained lagoonal deposits being overlain by much coarser shoreface sandstones, but the boundary still marks a landward shift in facies.

The complex unit composed of the Nathorst Fjeld, Harris Fjeld, and Lepidopteriselv Members is interpreted as representing the transgressive systems tract.

Highstand systems tract. The transgressive systems tract is topped by a second drowning surface overlain by strongly bioturbated shoreface heteroliths of the Skævdal Member showing a slight coarsening-upward trend in several sections (Figs 38, 39). This surface may represent the maximum flooding surface of SQ5, and the basin-wide coarsing-upward shoreface deposits of the Skævdal Member possibly constitutes a thin highstand systems tract.

Sequence 6 (SQ6)

SQ6 consists of the Trefjord Bjerg Member and coincides with the upper part of palynomorph assemblage zone 6 at Astartekløft of Koppelhus & Dam (in press).

Transgressive systems tract. The Skævdal Member forming the top of SQ5 is truncated by a prominent basin-wide erosional unconformity draped by a lag conglomerate (SB6; Figs 41–43). The conglomerate pebbles consist of skeletal fragments, mudstone clasts, and bored siderite clasts. The unconformity marks a basin-wide seaward shift in facies and is interpreted as a sequence boundary (SB6). It is overlain by subtidal cross-bedded sandstones deposited in extensive sandwave fields in a tidal channel complex, and fossiliferous, bioturbated, and wave and storm-dominated shoreface sandstones of the Trefjord Bjerg Member.

Sequence 7 (SQ7)

Sequence 7 consists of the uppermost 3 m of the Trefjord Bjerg Member at Albuen and all of the Sortehat Formation and coincides with palynomorph assemblage zones 7, 8 and 9 of Koppelhus & Dam (in press) and Koppelhus & Hansen (in press).

Transgressive systems tract. The boundary between the Trefjord Bjerg Member and the Sortehat Formation is one of the most prominent lithological boundaries in the Mesozoic succession of East Greenland, and it seems to represent a major landward shift in facies caused by a significant rise in relative sea-level. However, the palynological study of Koppelhus & Dam (in press) shows that the *Botryococcus* assemblage, characteristic of the lower part of the Sortehat Formation, is also present in the uppermost 3 m of the Trefjord Bjerg Member at Albuen, above a thin conglomerate. This suggests that the thin conglomerate at Albuen marks a sequence boundary and that the sandstones above represent a thin transgressive systems tract (Fig. 46).

Highstand systems tract. At other localities the sandstones of the Trefjord Bjerg Member is topped by a locally pebble strewn drowning surface, forming the boundary between the Trefjord Bjerg Member and the black mudstones of the Sortehat Formation (Fig. 45). The boundary has a basin-wide distribution and the conglomerate that locally tops the Trefjord Bjerg Member contains pebble sizes larger than any recorded in the sandstones below. It has the field appearance of a major marine flooding surface formed by marine shoreface erosion during transgression. It is likely that the pebble conglomerate, that in places drape the flooding surface, represents a bypass zone or a reworked lag of a thin lowstand systems tract which had bypassed the Trefjord Bjerg Member. This would explain the very sharp, laterally extensive nature of the surface and the remarkable shift from fully to restricted marine conditions, as suggested by the macrofossil content (Surlyk *et al.*, 1973; Surlyk 1990b, 1991), the organic geochemistry

(Krabbe *et al.*, 1994) and the palynological assemblages (Koppelhus & Dam, in press; Koppelhus & Hansen, in press), accompanying what appears to be a major deepening and transgression. If this interpretation is correct, the Ostreaelv-Sortehat boundary, except for the Albuen section, represents a coalesced sequence boundary and top of a lowstand surface (= transgressive surface). The maximum flooding surface is probably situated in the very dark and organic-rich mudstones just above the formation boundary with the main part of the Sortehat Formation interpreted as a highstand systems tract.

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References

Aigner, T. 1985: Storm depositional systems. Dynamic stratigraphy in modern ancient shallow-marine sequences. *Lecture notes in earth sciences* **3**; Berlin: Springer Verlag, 174 pp.

Aigner, T. & Reineck, H.-E. 1982: Proximality trends in modern storm sands from the Helegoland Bight (North Sea) and their implications for basin analysis. *Senckenbergiana Maritima* **14**, 183–215.

Allen, J. R. L. 1980: Sand waves: a model of origin and internal structure. *Marine Geology* **26**, 281–328.

Allen, P. 1981: Pursuit of Wealden models. *Journal of the Geological Society* (London) **138**, 375–405.

Allen, P. A. 1985: Hummocky cross-stratification is not produced purely under progressive gravity waves. *Nature* **313**, 562–564.

Birkenmajer, K. 1976: Middle Jurassic near-shore sediments at Kap Hope, East Greenland. *Bulletin of the Geological Society of Denmark* **25**, 107–116.

Boersma, J. R. 1969: Internal structure of some tidal megaripples on a shoal in Westerschelde estuary, the Netherlands: Report of a preliminary investigation. *Geologie en Mijnbouw* **48**, 409–414.

Brekke, H. & Riis, F. 1987: Tectonics and basin evolution of the Norwegian shelf between 62 and 72 degrees N. *Norsk Geologisk Tidsskrift* **67**, 295–322.

Bromley, R. G. & Asgaard, U. 1972: Notes on Greenland trace fossils. I – III. *Rapport Grønlands Geologiske Undersøgelse* **49**, 30 pp.

Bromley, R. G. & Asgaard, U. 1979: Triassic freshwater ichnocoenoses from Carlsberg Fjord, East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology* **28**, 39–80.

Bukovics, C., Shaw, N. D., Cartier, E. G. & Ziegler, P. 1984: Structure and development of the mid-Norway continental shelf. *In* Spencer, A. M. *et al.* (ed.) *Petroleum geology of the North European margin,*407–425. Graham & Trotman for the Norwegian Petroleum Society.

Cacchione, D. A., Drake, D. E., Grant, W. D. Tate, G. B. 1984: Rippled scour depressions on the inner continental shelf of central California. *Journal of Sedimentary Petrology* **54**, 1280–1291.

Callomon, J. H. 1961: The Jurassic system in East Greenland. *In* Raasch, G. O. (ed.) *Geology of the Arctic* **1**, 258–268. Toronto: Toronto University Press.

Christiansen, F. G., Marcussen, C., Larsen, H. C., Stemmerik, L., Dam, G. & Piasecki, S. 1991: Petroleum potential of Jameson Land, East Greenland. Exploration report. Unpublished internal report, Grønlands Geologiske Undersøgelse, 61 pp.

Clemmensen, L. B. 1976: Tidally influenced deltaic sequences from the Kap Stewart Formation (Rhaetic–Liassic), Scoresby Land, East Greenland. *Bulletin of the Geological Society of Denmark* **25**, 1–13.

Clemmensen, L. B. 1978a: Alternating aeolian, sabkha and shallow-lake deposits from the Middle Triassic Gipsdalen Formation, Scoresby Land, East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology* **24**, 111–135.

Clemmensen, L. B. 1978b: Lacustrine facies and stromatolites from the Middle Triassic of East Greenland. *Journal of Sedimentary Petrology* **48**, 1111–1128.

Clemmensen, L. B. 1979: Triassic lacustrine red-beds and palaeoclimate: the "Buntsandstein" of Helgoland and the Malmros Klint Member of East Greenland. *Geologische Rundschau* **68**, 748–774.

Clemmensen, L. B. 1980a: Triassic rift sedimentation and palaeogeography. *Bulletin Grønlands Geologiske Undersøgelse* **136**, 72 pp.

Clemmensen, L. B. 1980b: Triassic lithostratigraphy of East Greenland between Scoresby Sund and Kejser Franz Josephs Fjord. *Bulletin Grønlands Geologiske Undersøgelse* **139**, 56 pp.

Cook, P. J. 1976: Sedimentary phosphate deposits. *In* Wolf, K. H. (ed.) *Handbook of strata-bound and stratiform ore deposits* **7**, 505–535. Amsterdam: Elsevier.

Crumeyrolle, P., Claude, D., Lesueur, J.-L. & Joseph, P. 1993: The Roda deltaic complex (Spain); reservoir stratigraphy of a low stand prograding wedge. *American Association of Petroleum Geologists Bulletin* **77**, 312 only.

Dam, G. 1990a: Taxonomy of trace fossils from the shallow marine Lower Jurassic Neill Klinter Formation, East Greenland. *Bulletin of the Geological Society of Denmark.* **38**, 119–144.

Dam, G. 1990b: Palaeoenvironmental significance of trace fossils from the shallow marine Lower Jurassic Neill Klinter Formation, East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology* **79**, 221–248.

Dam, G. 1991: A sedimentological analysis of the continental and shallow marine Upper Triassic to Lower Jurassic succession in Jameson Land, East Greenland. Unpublished Ph.D. thesis, University of Copenhagen, Denmark, 243 pp.

Dam, G. & Christiansen, F. G. 1990: Organic geochemistry and source potential of the lacustrine shales of the Late Triassic – Early Jurassic Kap Stewart Formation. *Marine and Petroleum Geology* **7**, 428–443.

Dam, G. & Surlyk, F. 1992: Forced regressions in a large wave and storm-dominated anoxic lake, Rhaetian–Sinemurian Kap Stewart Formation, East Greenland. *Geology* **20**, 749–752.

Dam, G. & Surlyk, F. 1993: Cyclic sedimentation in a large wave and storm-dominated anoxic lake; Kap Stewart Formation (Rhaetian–Sinemurian), Jameson Land, East Greenland. *In* Posamentier, H. W., Summerhayes, C. P., Haq, B. U. & Allen, G. P. (ed.) Sequence stratigraphy and facies associations. *Special Publication International Association of Sedimentologists* **18**, 419–438.

Dam, G. & Surlyk, F. 1995: Sequence stratigraphic correlation of Lower Jurassic shallow marine and paralic succession across the Greenland–Norway seaway. *In* Steel, R. J., Felt, V. L., Johannessen, E. P. & Mathieu, C. (ed.) Sequence stratigraphy of the Northwest European margin. *Norwegian Petroleum Society Special Publication* **5**, 483–509.

Dam, G., Surlyk, F., Mathiesen, A. & Christiansen, F. G. 1995: Exploration significance of lacustrine forced regressions of the Rhaetian–Sinemurian Kap Stewart Formation, Jameson Land, East Greenland. *In* Steel, R. J., Felt, V. L., Johannessen, E. P. & Mathieu, C. (ed.) Sequence stratigraphy of the Northwest European margin. *Norwegian Petroleum Society Special Publication* **5**, 511–527.

De Raaf, J. F. M., Boersma, J. R. & Gelder, A. van 1977: Wave generated structures and sequences from a shallow marine succession, Lower Carboniferous, County Cork, Ireland. *Sedimentology* **4**, 1–52.

Diem, B. 1985: Analytic method for estimating palaeowave climate and water depth from wave ripple marks. *Sedimentology* **32**, 705–720.

Dingwall, R. G. 1987: Ocean-floor spreading and the Mesozoic deltaic systems of the North Atlantic rim. *In* Brooks, J. & Glennie, K. (ed.) *Petroleum geology of North West Europe*, 1177–1188. London: Graham & Trotman.

Donovan, D. T. 1957: The Jurassic and Cretaceous systems in East Greenland. *Meddelelser om Grønland* **155**(4), 214 pp.

Doré, A. G. & Gage, M. S. 1987: Crustal alignment and sedimentary domains in the evolution of the North Sea, north-east Atlantic margin and Barents shelf. *In* Brooks, J. & Glennie, K. (ed.) *Petroleum geology of North West Europe*, 1131–1148. London: Graham & Trotman.

Dott, R. H. Jr. & Bourgeois, J. 1982: Hummocky stratification: Significance of its variable bedding sequences. *Geological Society of America Bulletin* **93**, 663–680.

Doyle, P. 1991: Belemnites from the Lower Jurassic of East Greenland and their biostratigraphical and biogeographical significance. *Bulletin of the Geological Society of Denmark* **39**, 123–141.

Dreyer, T. 1992: Significance of tidal cyclicity for modelling of reservoir heterogeneities in the Lower Jurassic Tilje Formation, mid-Norwegian shelf. *Norsk Geologisk Tidsskrift* **72**, 159–170.

Duke, W. L. 1985: Hummocky cross-stratification, tropical hurricanes, and intense winter storms. *Sedimentology* **32**, 167–194.

Ekdale, A. A. & Mason, T. R. 1988: Characteristic trace-fossil associations in oxygen-poor sedimentary environments. *Geology* **16**, 720–723.

Engkilde, M. 1994: The Middle Jurassic Vardekløft Formation, East Greenland: Depositional environments and sequence stratigraphy of shallow marine sandstones deposited in a low-gradient epeiric seaway. Unpublished Ph.D. thesis, University of Copenhagen, Denmark, 207 pp.

Engkilde, M. & Surlyk, F. in press: Sequence stratigraphy of shallow marine sandstones of the Middle Jurassic Pelion and Fossilbjerget Formations, East Greenland. *In* Surlyk, F. & Ineson, J. R. (ed.) The Jurassic of Denmark and Greenland. *Geology of Denmark Survey Bulletin*.

Fürsich, F. T. 1975: Trace fossils as environmental indicators in the Corallian of England and Normandy. *Lethaia* **8**, 151–172.

Fürsich, F. T. 1982: Upper Jurassic bivalves from Milne Land, East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **144**, 126 pp.

Fürsich, F. T. 1984: Benthic macroinvertebrate associations from the Boreal Upper Jurassic of Milne Land, central East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **149**, 72 pp.

Goldring, R., Bosence, D. W. J. & Blake, T. 1978: Estuarine sedimentation in the Eocene of southern England. *Sedimentology* **25**, 861–876.

Hallam, A. 1988: A reevaluation of Jurassic eustasy in the light of new data and the revised Exxon curve. *Society of Economic Paleontologists and Mineralogists Special Publication* **42**, 261–273.

Hamblin, A. P. & Walker, R. G. 1979: Storm dominated shallow marine deposits: the Fernie-Kootenay (Jurassic) transition, southern Rocky Mountains. *Canadian Journal of Earth Sciences* **16**, 1673–1690.

Haq, B. U., Hardenbol, J. & Vail, P. R. 1987: Chronology of fluctuating sea levels since the Triassic. *Science* **235**, 1156–1167.

Harris, T. M. 1926: The Rhaetic flora of Scoresby Sound, East Greenland. *Meddelelser om Grønland* **68**, 45–147.

Harris, T. M. 1931a: Rhaetic floras. *Biological Review* **6**, 133–162.

Harris, T. M. 1931b: The fossil flora of Scoresby Sound, East Greenland. 1. Cryptogams. *Meddelelser om Grønland* **85**(2), 102 pp.

Harris, T. M. 1932a: The fossil flora of Scoresby Sound, East Greenland. 2. Descriptions of seed plants *incertae sedis* together with a discussion of certain cycadophyte cuticles. *Meddelelser om Grønland* **85**(3), 112 pp.

Harris, T. M. 1932b: The fossil flora of Scoresby Sound, East Greenland. 3. Caytoniales and Bennettitales. *Meddelelser om Grønland* **85**(5), 133 pp.

Harris, T. M. 1935: The fossil flora of Scoresby Sound, East Greenland. 4. Ginkgoales, Coniferales, Lycopodiales and isolated fructifications. *Meddelelser om Grønland* **112**(1), 176 pp.

Harris, T. M. 1937: The fossil flora of Scoresby Sound, East Greenland. 5. Stratigraphic relations of the plant beds. *Meddelelser om Grønland* **112**(2), 114 pp.

Harris, T. M. 1946: Liassic and Rhaetic plants collected in 1936–38 from East Greenland. *Meddelelser om Grønland* **114**(9), 41 pp.

Hartz, N. 1896: Planteforsteninger fra Cap Stewart i Østgrønland. *Meddelelser om Grønland* **19**, 215–247.

Haug, E. 1926: Fossiles du Lias recueillis par mission Charcot au cap Stewart. *Compte Rendu hebdomadaire des séances de l'Académie des Sciences, Paris* **182**, 353–355.

Heinberg, C. & Birkelund, T. 1984: Trace fossil assemblages and basin evolution of the Vardekløft Formation (Middle Jurassic, central East Greenland). *Journal of Paleontology* **58**, 362–397.

Hunter, R. E., Thor, D. R. & Swisher, M. L. 1982: Depositional and erosional features of the inner shelf, northeastern Bering Sea. *Geologie en Mijnbouw* **16**, 49–62.

Hunter, R. E., Dingler, J. R., Anima, J. & Richmond, B. M. 1988: Coarse-sediment bands on the inner shelf of southern Monterey Bay, California. *Marine Geology* **80**, 81–98.

Koch, L. 1939: Zur geologischen Erforschungsgeschichte Ostgrönlands. *Mitteilungen des Naturforschenden Gesellschaft Schaffhausen* **16**, 70–81.

Koppelhus, E. B. & Dam, G. in press: Palynostratigraphy and palaeoenvironments of the Lower – lower Middle Jurassic Neill Klinter Group, Jameson Land, East Greenland. *In* Surlyk, F. & Ineson, J. R. (ed.) The Jurassic of Denmark and Greenland. *Geology of Denmark Survey Bulletin.*

Koppelhus, E. B. & Hansen, C. F. in press: Palynostratigraphy and palaeoenvironment of the Aalenian – ?Bajocian Sortehat Formation, Jameson Land, East Greenland. *In* Surlyk, F. & Ineson, J. R. (ed.) The Jurassic of Denmark and Greenland. *Geology of Denmark Survey Bulletin*.

Krabbe, H., Christiansen, F. G., Dam, G., Piasecki, S. & Stemmerik, L. 1994: Organic geochemistry of the Lower Jurassic Sortehat Formation, Jameson Land, East Greenland. *Rapport Grønlands Geologiske Undersøgelse* **164**, 5–18.

Larsen, H. C. 1984: Geology of the East Greenland shelf. *In* Spencer, A. *et al.* (ed.) *Petroleum geology of the North European margin*, 329–339. Graham & Trotman for the Norwegian Petroleum Society.

Larsen, H. C. & Marcussen, C. 1992: Sill-intrusion, flood basalt emplacement and deep crustal structure of the Scoresby Sund region, East Greenland. *In* Storey, B. C., Alabaster, T. & Pankhurst, R. J. (ed.) Magmatism and the causes of continental break-up. *Geological Society Special Publication* (London) **68**, 365–386.

Larsen, P.-H. 1988: Relay structures in a Lower Permian basement-involved extension system, East Greenland. *Journal of Structural Geology* **10**, 3–8.

Leckie, D. A. 1988: Wave-formed, coarse-grained ripples and their relationship to hummocky cross-stratification. *Journal of Sedimentary Petrology* **58**, 607–622.

Leithold, E. L. & Bourgeois, J. 1984: Characteristics of coarse-grained sequences deposited in nearshore, wave-dominated environments – examples from the Miocene of southwest Oregon. *Sedimentology* **31**, 749–775.

Lund, J. J. & Pedersen, K. R. 1985: Palynology of the marine Jurassic formations in the Vardekløft ravine, Jameson Land, East Greenland. *Bulletin of the Geological Society of Denmark* **33**, 369–400.

Lundgren, B. 1895: Den østgrønlandske Expedition, udført i Aarene 1891–92 under ledelse af C. Ryder. VII. Anmærkninger om några Jurafossil från Kap Stewart, Ost-Grønland. *Meddelelser om Grønland* **19**, 189–214.

Masuda, F. & Makino, Y. 1987: Palaeo-wave conditions reconstructed from ripples in the Pleistocene palaeo-Tokio Bay deposits. *Journal of Geography* **96**, 23–45.

Mozley, P. S. & Wersin, P. 1992: Isotopic composition of siderite as an indicator of depositional environment. *Geology* **20**, 817–820.

Newton, R. S. & Werner, F. 1972: Transitional-size ripple marks in Kiel Bay (Baltic Sea). *Meyniana* **22**, 89–96.

North American Commission on Stratigraphic Nomenclature 1983: North American stratigraphic code. *American Association of Petroleum Geologists Bulletin* **67,** 841–875.

O'Brien, G. W., Milnes, A. R., Veeh, H. H., Heggie, D. T., Riggs, S. R., Cullen, D. J., Marshall, J. F. & Cook, P. J. 1990: Sedimentation dynamics and redox iron-cycling: controlling factors for apatite-glauconite association on the East Australian continental margin. *In* Notholt, A. J. G. & Jarvis, I. (ed.) Phosphorite research and development. *Geological Society Special Publication* (London) **52**, 61–86.

Pedersen, K. R. & Lund, J. J. 1980: Palynology of the plant-bearing Rhaetian to Hettangian Kap Stewart Formation, Scoresby Sund, East Greenland. *Review of Palaeobotany and Palynology* **31**, 1–69.

Reineck, H.-E., Gutmann, W. F. & Hertweck, G. 1968: Sedimentologie, Fanenzonierung und Faziesabfolge vor der Ostküste der inneren Deutschen Bucht. *Senckenbergiana Lethaea* **49**, 261–309.

Rhoads, D. C., Boesch, D. F., Tang Zhican, Xu Fengshan, Huang Liquiang & Nilsen, K. J. 1985: Macrobenthos and sedimentary facies on the Changjiang delta platform and adjacent continental shelf. *Continental Shelf Research* **4**, 189–213.

Rizzini, A. 1975: Sedimentary sequences of Lower Devonian sediments (Uan Caza Formation), south Tunisia. *In* Ginsburg, R. N. (ed.) *Tidal deposits*, 187–199. New York: Springer-Verlag.

Rosenkrantz, A. 1929: Preliminary account of the geology of the Scoresby Sund district. *Meddelelser om Grønland* **73**(2), 135–154.

Rosenkrantz, A. 1934: The Lower Jurassic rocks of East Greenland. Part I. *Meddelelser om Grønland* **110**(1), 150 pp.

Rosenkrantz, A. 1942: The Lower Jurassic rocks of East Greenland. Part II. The Mesozoic sediments of the Kap Hope area, southern Liverpool Land area. *Meddelelser om Grønland* **110**(2), 56 pp.

Rosenkrantz, A. 1956: A large Velata from the Lower Jurassic of East Greenland. *Meddelelser fra dansk Geologisk Forening* **13**, 79–84.

Salvador, A. L. (ed.) 1994: *International stratigraphic guide*. 2nd edition. Geological Society of America, 214 pp.

Smith, A. G. & Briden, J. C. 1977: *Mesozoic and Cenozoic paleocontinental maps*. Cambridge: Cambridge University Press, 102 pp.

Snedden, J. W., Nummedal, D. & Amos, A. F. 1988: Storm- and fair-weather combined flow on the central Texas Continental Shelf. *Journal of Sedimentary Petrology* **58**, 580–595.

Stauber, H. 1940: Stratigraphisch-geologische Untersuchungen in der ostgrönländischen Senkungszone des nördlichen Jamesonlandes. *Meddelelser om Grønland* **114**(7), 34 pp.

Straelen, V. van 1929: Sur les Crustacés décapodes jurassiques du Groenland oriental. *Bulletin de l'Académy royale de Belgique*, class sci. **15**, 741–745.

Surlyk, F. 1977a: Mesozoic faulting in East Greenland. *In* Frost, R. T. C. & Dikkers, A. J. (ed.) Fault tectonics in NW Europe. *Geologie en Mijnbouw* **56**, 311–327.

Surlyk, F. 1977b: Stratigraphy, tectonics and palaeogeography of the Jurassic sediments of the areas north of Kong Oscars Fjord, East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **123**, 56 pp.

Surlyk, F. 1990a: A Jurassic sea-level curve for East Greenland. *Palaeogeography, Palaeoclimatology, Palaeoecology* **78**, 71–85.

Surlyk, F. 1990b: Timing, style and sedimentary evolution of Late Palaeozoic – Mesozoic extensional basins of East Greenland. *In* Hardman, R. F. P. & Brooks, J. (ed.) Tectonic events responsible for Britain's oil and gas reserves. *Geological Society Special Publication* (London) **55**, 107–125.

Surlyk, F. 1991: Sequence stratigraphy of the Jurassic – lowermost Cretaceous of East Greenland. *Bulletin American Association of Petroleum Geologists* **75**, 1468–1488.

Surlyk, F. & Noe-Nygaard, N. 1986: Hummocky cross-stratification from the Lower Jurassic Hasle Formation of Bornholm, Denmark. *Sedimentary Geology* **46**, 259–273.

Surlyk, F., Callomon, J. H., Bromley, R. G. & Birkelund, T. 1973: Stratigraphy of the Jurassic – Lower Cretaceous sediments of Jameson Land and Scoresby Land, East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **105**, 76 pp. (Also *Meddelelser om Grønland* **193**(5)).

Surlyk, F., Clemmensen, L. B. & Larsen, H. C. 1981: Post-Paleozoic evolution of the East Greenland continental margin. *In* Kerr, J. W. & Fergusson, A. J. (ed.) Geology of the North Atlantic borderlands. *Canadian Society of Petroleum Geologists Memoir* **7**, 611–645.

Surlyk, F., Piasecki, S., Rolle, F., Thomsen, E. & Wrang, P. 1984: The Permian basin of East Greenland. *In* Spencer, A. *et al.* (ed.) *Petroleum geology of the North European margin,* 303–315. Graham & Trotman for the Norwegian Petroleum Society.

Surlyk, F., Hurst, J. M., Piasecki, S., Rolle, F., Scholle, P. A., Stemmerik, L. & Thomsen, E. 1986: The Permian of the western margin of the Greenland Sea – a future exploration target. *In* Halbouty, M. T. (ed.) Future petroleum provinces of the world. *American Association of Petroleum Geologists Memoir* **40**, 629–659.

Surlyk, F., Noe-Nygaard, N. & Dam, G. 1993: High and low resolution sequence stratigraphy in lithological prediction – examples from the Mesozoic around the northern North Atlantic. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe. Proceedings of the 4th conference,* 199–214. London: Geological Society.

Surlyk, F., Arndorff, L., Hamann, N.-E., Hamberg, L., Johannessen, P. N., Koppelhus, E. B., Nielsen, L. H., Noe-Nygaard, N., Pedersen, G. K. & Petersen, H. I. 1995: High-resolution sequence stratigraphy of a Hettangian–Sinemurian paralic succession, Bornholm, Denmark. *Sedimentology* **42**, 323–354.

Surlyk, F., Dam, G., Engkilde, M., Hansen, C. F., Larsen, M., Noe-Nygaard, N., Piasecki, S., Therkelsen, J. & Vosgerau, H. in press: Jurassic stratigraphy of East Greenland. *In* Surlyk, F. & Ineson, J. R. (ed.) The Jurassic of Denmark and Greenland. *Geology of Denmark Survey Bulletin*.

Swift, D. J. P., Figueiredo, A. G., Jr., Freeland, G. L. & Oertel, G. F. 1983: Hummocky cross-stratification and megaripples: A geological double standard? *Journal of Sedimentary Petrology* **53**, 1295–1317.

Sykes, R. M. 1974: Sedimentological studies in southern Jameson Land, East Greenland. II. Offshore-estuarine regressive sequences in the Neill Klinter Formation (Pliensbachian–Toarcian). *Bulletin of the Geological Society of Denmark* **23**, 213–224.

Taylor, A. M. & Gawthorpe, R. L. 1993: Application of sequence stratigraphy and trace fossil analysis to reservoir description: examples from the Jurassic of the North Sea. *In* Parker, J. R. (ed.) *Petroleum geology of Northwest Europe. Proceedings of the 4th conference,* 317–335. London: Geological Society.

Tessier, B. & Gigot, P. 1989: A vertical record of different tidal cyclicities: an example from the Miocene Marine Molasse of Digne (Haute Provence, France). *Sedimentology* **36**, 767–776.

Underhill, J. R. & Partington, M. A. 1994: Use of genetic sequence stratigraphy in defining and determining a regional tectonic control on the 'Mid-Cimmerian Unconformity' – implications for North Sea basin development and the global sea level chart. *In* Weimer, P. & Posamentier, H. (ed.) Siliciclastic sequence stratigraphy. Recent developments and applications. *American Association of Petroleum Geologists Memoir* **58**, 449–484.

Visser, M. J. 1980: Neap-spring cycles reflected in Holocene subtidal large-scale bedform deposits: a preliminary note. *Geology* **8**, 543–546.

Vossler, S. M. & Pemberton, S. G. 1989: Ichnology and paleoecology of offshore siliciclastic deposits in the Cardium Formation (Turonian, Alberta, Canada). *Palaeogeography, Palaeoclimatology, Palaeoecology* **74**, 217–239.

Yang, C.-S. & Nio, S.-D. 1985: The estimation of palaeohydrodynamic processes from subtidal deposits using time series analysis methods. *Sedimentology* **32**, 41–57.

Yang, C.-S. & Nio, S.-D. 1989: An ebb-tide delta depositional model – a comparison between the modern eastern Scheldt tidal basin (southwest Netherlands) and the Lower Eocene Roda Sandstone in the southern Pyrenees (Spain). *Sedimentary Geology* **64**, 175–196.

Ziegler, P. A. 1988: Evolution of the Arctic – North Atlantic and the Western Tethys. *American Association of Petroleum Geologists Memoir* **43, 1–198.**

Legend to sedimentary logs

Plate I

Lithology

- Mudstone
- Sandstone
- Pebbly sandstone
- Coal
- Volcanic intrusive
- Concretion
- Siderised rip-up mudstone clasts/conglomerate
- qz Quartzite clasts/conglomerate

Bed contacts

- Sharp/erosive or irregular
- Sharp/planar
- Gradational

Sedimentary features

- Parallel lamination
- Lenticular bedding
- Wavy bedding
- Flaser bedding
- Planar cross-bedding
- Trough cross-bedding
- Cross-bedding with pebbles along foresets
- Structureless
- Structureless (with quartzite pebbles)
- Slumping
- Cross-lamination
- Incipient wave ripple lamination
- Wave ripple cross-lamination
- Hummocky and swaley cross-stratification
- Coarse-grained ripples

Biota

- Rootlets
- Plant fragments
- Drifted plant stems/logs
- Bivalves
- Gastropods
- Ammonites
- Belemnites
- Brachiopods
- Crinoids
- Echinoderms
- Fish
- Undifferentiated shell fragments

Trace fossils

- Weak, Moderate, Intense } bioturbation
- *Arenicolites* isp.
- *Curvolithos multiplex*
- *Diplocraterion habichi*
- *Diplocraterion parallelum*
- *Gyrochorte comosa*
- *Ophiomorpha nodosa*
- *Phoebichnus trochoides*
- *Planolites beverleyensis*
- *Taenidium serpentinum*
- *Thalassinoides* isp.
- Unidentified burrow

Miscellaneous features

- Current direction from cross-bedding and cross-lamination
- Crestline orientation of wave ripples
- Cone-in-cone structures
- Ooids
- Basement boulder

The accompanying legend is applicable to all sedimentological logs in this paper. Due to different drawing techniques the signatures may not entirely match the individual figures.

Plate 2 (in pocket). Sedimentological logs through the Elis Bjerg Member showing interbedded offshore transition, tidal channel, subtidal sand sheet and storm-dominated sandy shoal deposits. Sequence boundaries and correlatable siderite clast conglomerates are indicated. Logs are measured along a south–north trending profile line from the south-eastern to the northern parts of the basin. See Plate 1 for legend. Modified from Dam & Surlyk (1995).