Petroleum geological investigations in East Greenland: project 'Resources of the sedimentary basins of North and East Greenland'

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The multidisciplinary research project 'Resources of the sedimentary basins of North and East Greenland' was initiated in 1995 with financial support from the Danish Research Councils (Stemmerik *et al.*, 1996). In 1996, the hydrocarbon-related studies focused on the sedimentary basins in East Greenland between latitudes 71°N and 74°N (Fig. 1) where nine field teams worked for six weeks in July and August supported by a Hughes 500 helicopter. Within the framework of the project, additional hydrocarbon-related field studies were undertaken in 1996 in western North Greenland, and ore-geological studies were carried out in much of North Greenland (Kragh *et al.*, 1997; Stemmerik *et al.*, 1997).

The 1996 field work in East Greenland concentrated on integrated structural, sedimentological and biostratigraphical studies of the Upper Permian and Mesozoic successions. Two Ph.D. projects focused on the sedimentology of the Lower Triassic Wordie Creek Formation and the diagenesis of the Middle and Upper Jurassic succession. Post-doctorate studies were carried out on the Mesozoic–Tertiary structural development of the basin and the mineralisation of the Upper Permian Ravnefjeld Formation. Three student projects on Lower Triassic and Middle Jurassic ammonite stratigraphy, Upper Permian sedimentology, and fault-associated mineralisation were also included in the work. The most important new results arising from the 1996 field work are:

1) Re-interpretation of the Upper Permian Schuchert Dal Formation as a lowstand turbidite unit within the Ravnefjeld Formation;
2) Recognition of Middle Jurassic deposits and thick lowermost Cretaceous sandstones on Hold with Hope;
3) Interpretation of a full spectrum of scarp-derived coarse-clastic mass movement deposits interbedded with Cretaceous shales on eastern Traill Ø;
4) The presence of a thick sand-rich Cretaceous turbidite succession on eastern Traill Ø;
5) Re-interpretation of the Mesozoic–Cenozoic fault systems on Traill Ø and Geographical Society Ø.

Permian – Jurassic

The Permian to Jurassic succession is thinner and stratigraphically less complete in the Hold with Hope to Traill Ø area than in Jameson Land further to the south (Figs 1, 2; Stemmerik *et al.*, 1993a). It consists of a widespread, siliciclastic-dominated Upper Permian to Lower Triassic marine unit that passes upwards into non-marine Triassic sediments. A major hiatus separates these deposits from overlying Middle Jurassic fluvial to shallow marine sandstones and shales. Block faulting in latest Jurassic time and subsequent erosion of crestal areas led to deposition of Cretaceous sediments unconformably on Jurassic and older rocks. The oldest sediments occurring above this unconformity are of Barremian age in most areas (Nøhr-Hansen, 1993).

Permian

The Upper Permian Foldvik Creek Group is dominated by siliciclastics in northern Scoresby Land and on Traill Ø (Fig. 3). In these areas, the only evidence of carbonate platforms such as those described from Jameson Land (e.g. Stemmerik *et al.*, 1993b) are clasts of carbonate in Lower Triassic conglomerates. The basal Huledal Formation conglomerates show great lateral thickness variations and apparently fill small grabens formed by rejuvenation of older, Carboniferous structures (Surlyk *et al.*, 1984; Stemmerik *et al.*, 1993a). The overlying, restricted marine carbonates and evaporites of the Karstryggen Formation show less pronounced, although still recognisable, thickness variations.

The main focus of 1996 field work was to improve the sedimentological and sequence stratigraphic understanding of the succession corresponding to the Wegener

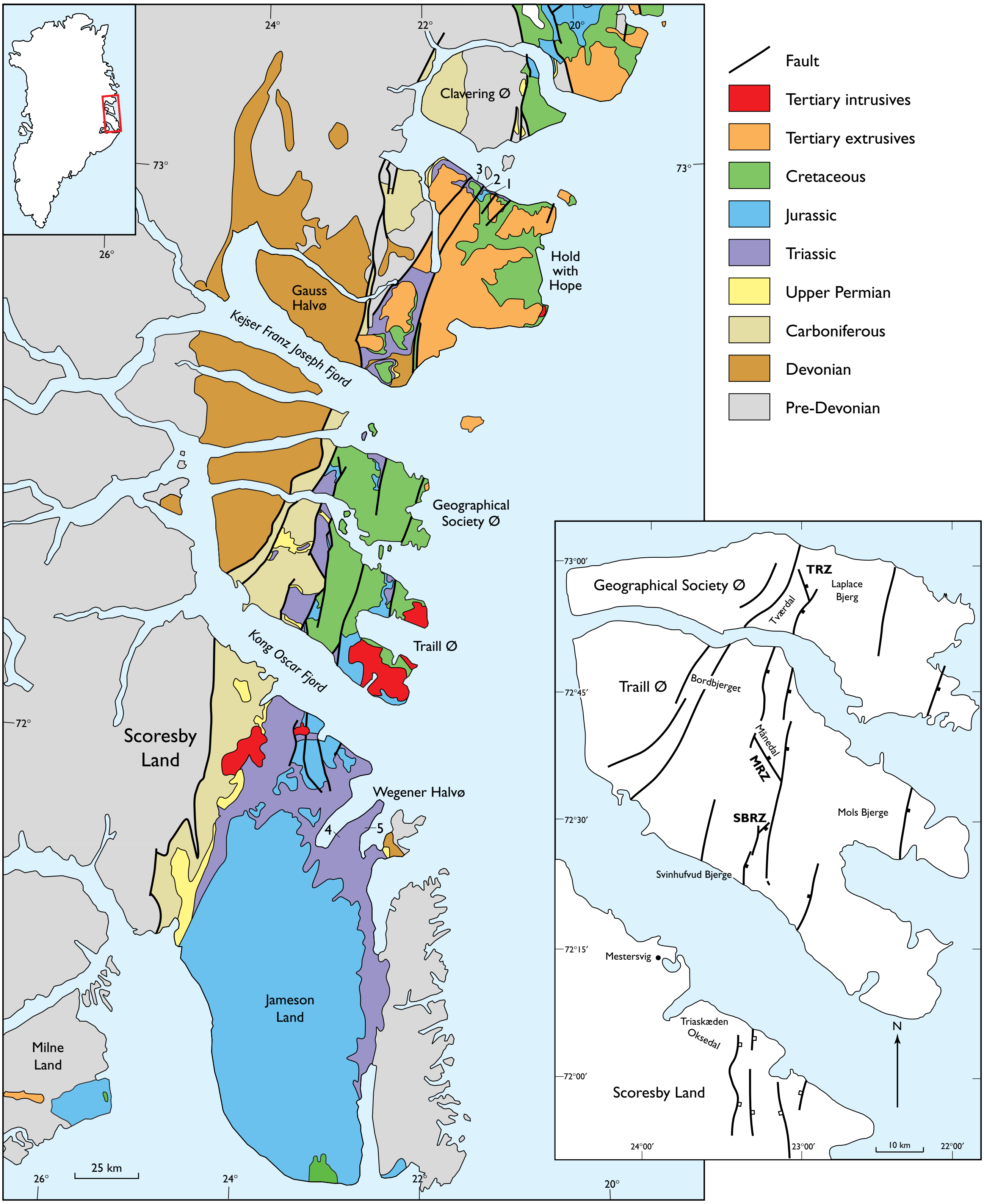

Fig. 1. Simplified geological map of the area between Jameson Land and Clavering Ø. Inset map shows major structural elements in the Traill Ø area. TRZ: Tværdal relay zone; MRZ: Månedal relay zone; SBRZ: Svinhufvud Bjerge relay zone. Localities in northern Hold with Hope: 1, Steensby Bjerg; 2, Gulelv; 3, Stensiö Plateau. Localities in Wegner Halvø: 4, Lille Cirkusbjerg; 5, Paradigmabjerg.

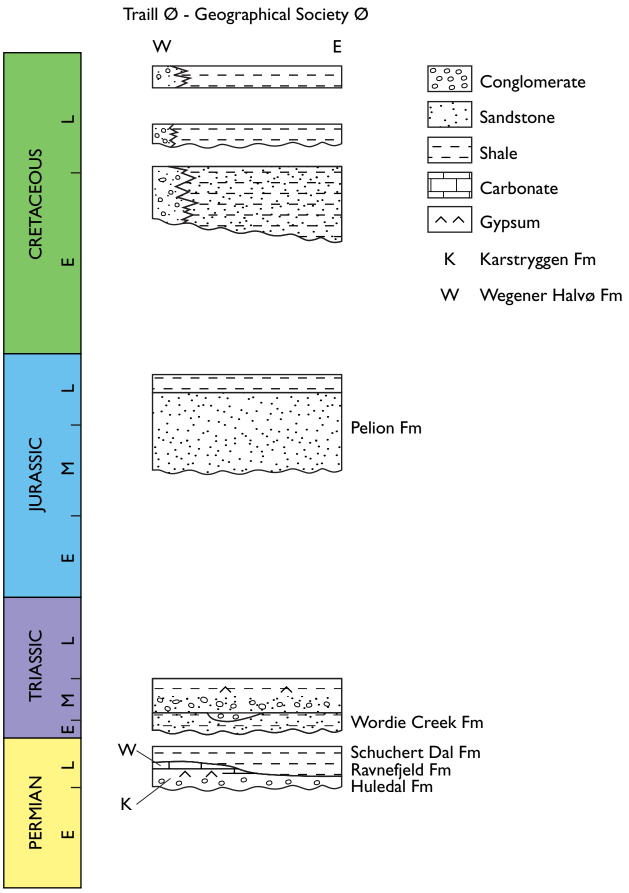

Fig. 2. Stratigraphic scheme of the Upper Permian to Cretaceous succession in the Traill Ø – Geographical Society Ø area (after Stemmerik *et al.*, 1993a). Note that the ?Upper Jurassic – Lower Cretaceous succession described here from Hold with Hope is absent in this area.

Fig. 3. General view of the Upper Permian – Triassic siliciclastic succession (*c.* 200 m section illustrated) on southern Traill Ø, view towards the east.

Halvø, Ravnefjeld and Schuchert Dal Formations (Fig. 2). Field observations indicate that the earlier concepts of the stratigraphic relationships between the Ravnefjeld and Schuchert Dal Formations require revision. Rather than being a stratigraphically discrete younger unit, the basal part of the Schuchert Dal Formation appears to be a coarse-grained correlative of the Ravnefjeld Formation. In northern Scoresby Land, sandstones assigned to the Schuchert Dal Formation form between two and four laterally extensive, 2–50 m thick units composed of massive to graded sandstone beds separated by laminated and bioturbated shales. The lower three sandstone units are interpreted as lowstand fans, that formed locally in more proximal basinal positions at times when the bioturbated shale units of the Ravnefjeld Formation were deposited in more distal settings (cf. Piasecki & Stemmerik, 1991). This interpretation adds to the hydrocarbon potential of the succession, as it predicts sand-prone facies to occur in basinal positions adjacent to organic-rich source-prone shales.

Triassic

The Permian–Triassic boundary is very complex in northern Scoresby Land and on Traill Ø. In most areas, there is a marked hiatus at the boundary and variable amounts of Upper Permian sediments were eroded away prior to the onset of sedimentation in the Early Triassic. However, in the area around Oksedal, there seems to have been continuous or nearly continuous deposition across the boundary, and Triassic marine shales rest conformably on Permian marine shales without any signs of a hiatus. Further to the south, in the Lille Cirkusbjerg area on Wegener Halvø, the boundary is erosional with fluvial channels, up to *c.* 250 m

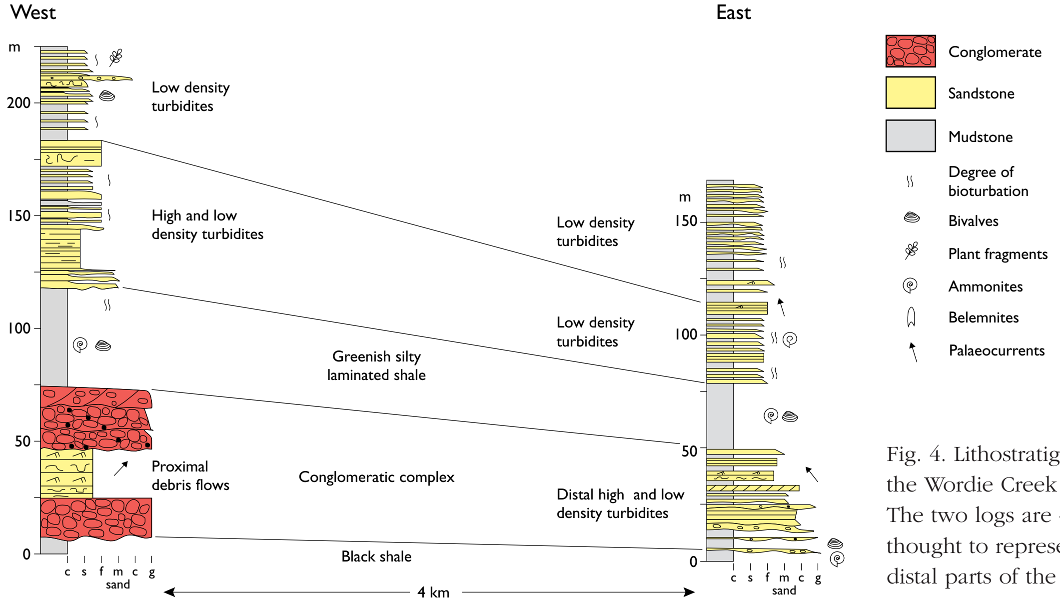

Fig. 4. Lithostratigraphic correlation of the Wordie Creek Formation in Oksedal. The two logs are 4 km apart and are thought to represent the proximal and distal parts of the same debris flow and turbidite system.

wide, incised into the Upper Permian carbonates of the Wegener Halvø Formation. The channels are filled with fluvial sandstones and conglomerates overlain by shales representing a marine transgression in early Scythian times (Surlyk *et al.*, 1986). The remainder of the Wordie Creek Formation invariably consists of marine shales interbedded with thin sandstones deposited mainly by low density turbidity currents. In nearby outcrops at Paradigma Bjerg, the succession is dominated by fine- to medium-grained micaceous sandstones and channel sandstones with structures indicative of tidal influence. The palaeocurrents are bimodal with the main transport direction towards the north. The preliminary interpretation of the Wordie Creek Formation in the Wegener Halvø area is that it reflects a shallow marine, probably estuarine, environment influenced by tidal processes and some wave activity.

In the Oksedal area of northern Scoresby Land, two localities, *c.* 4 km apart, were investigated. On the western slope of 'Triaskæden', the Wordie Creek Formation consists of *c.* 200 m of mostly marine, greenish silty shales with relatively thin (<1 m) arkosic turbiditic sandstones that record palaeocurrents towards the north-west. Four kilometres to the west, a *c.* 60 m thick complex of conglomerates, interpreted as the deposits of debris flows and high density turbidity currents, forms the lower part of the formation (Fig. 4). Palaeocurrents were towards the north-east. The conglomerates are mainly clast-supported, and clast types include very angular Upper Permian carbonate boulders, granitic pebbles and boulders, and intraformational mud and sandstone clasts. This complex is abruptly overlain by black laminated shales, which gradually become more silty upwards where they are interbedded with turbiditic sandstones. The conglomerates are broadly interpreted to represent a submarine fan system; more work is needed to substantiate this interpretation.

On southern Traill Ø, the Wordie Creek Formation is up to 700 m thick. The marine sandstones and shales in the lower part are overlain with erosional discontinuity by laterally widespread, arkosic fluvial channel sandstones of the Svinhufvud Bjerge Member, which record easterly palaeocurrents (Clemmensen, 1980). The fluvial sandstones are overlain by alternating micaceous marine sandstones and cliff-forming stromatolitic limestones, preliminarily interpreted as having been deposited in a shallow, tidally influenced marine environment.

Jurassic

Outcrops of Middle Jurassic deposits are scarce on Traill Ø and Geographical Society Ø, and prior to the 1996 field work, sediments of this age were unknown from Hold with Hope. However, along the north coast of Hold with Hope, a coarse-grained sandstone succession *c.* 300 m thick is exposed, which was originally described by Koch (1931) and Maync (1949) as being wholly of Early Cretaceous age. During the present study, Middle Jurassic (Callovian) ammonites (J. H. Callomon, personal communication, 1997) were found in the lower part of

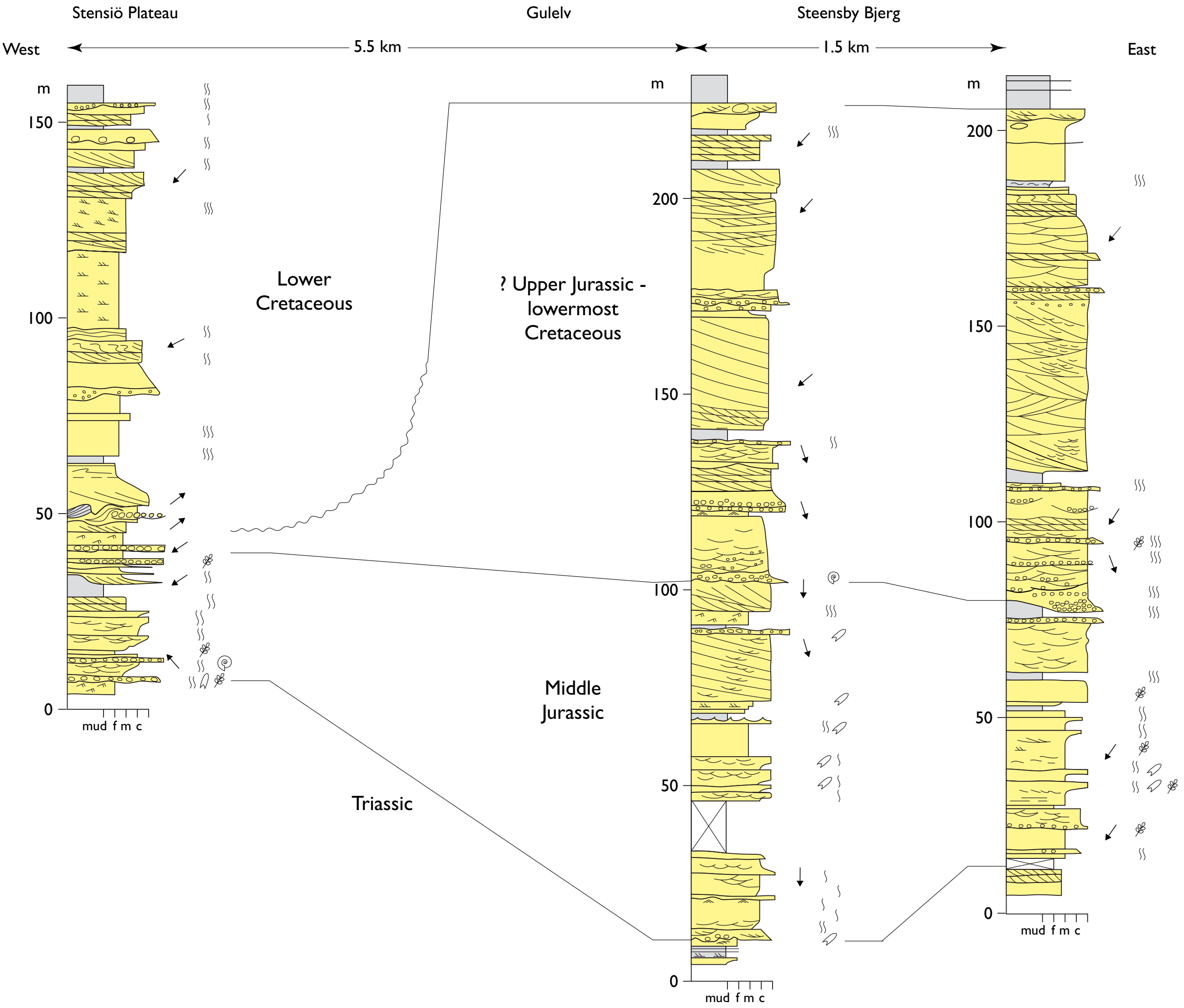

Fig. 5. Simplified cross-section of the Middle Jurassic to mid-Cretaceous succession on the north coast of Hold with Hope. Legend as in Fig. 4.

the section. The Jurassic part of the succession is up to 130 m thick, unconformably overlies shallow marine sandstones of the Triassic Wordie Creek Formation and, in turn, is unconformably overlain by strata of assumed ? Late Jurassic – earliest Cretaceous age (Figs 5, 6).

The Middle Jurassic sandstones are coarse-grained, white to yellowish in colour and quartz-dominated. They commonly form stacked coarsening upwards units, 4 to 20 m thick, topped by fossiliferous conglomerates with an open marine fauna of bivalves, belemnites and rare ammonites. These units are interpreted as having been formed by shoreface progradation in a shallow marine environment. The top part of the coarsening upward units contains common *Diplocraterion habichi*. A sparse but diagnostic Middle Jurassic dinoflagellate cyst assemblage has been recovered from silty shales interbedded with the sandstones. In general, the sedimentary facies of the Hold with Hope sandstone succession closely resemble those of the Middle Jurassic Pelion Formation further to the south on Traill Ø, Scoresby Land and Jameson Land (Donovan, 1953, 1955, 1957; Surlyk *et al.*, 1973; Engkilde & Surlyk, in press) as well as to the north in Wollaston Forland (Maync, 1949; Surlyk, 1977; Surlyk & Clemmensen, 1983). The presence of coarse-grained Middle Jurassic shallow marine sandstones on northern Hold with Hope shows that the area did not form a high in the Middle Jurassic as previously thought. Further studies are needed to fully clarify these relationships.

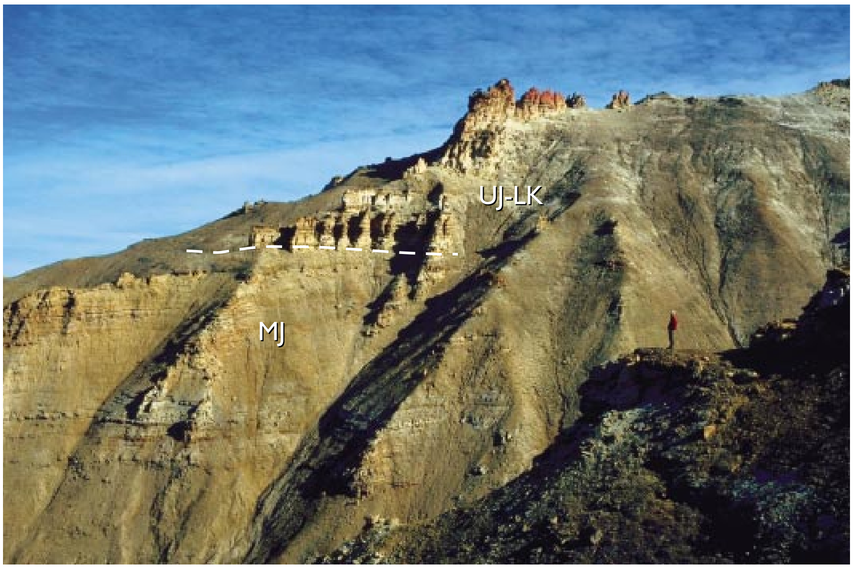

Fig. 6. Middle Jurassic sandstones (MJ) unconformably overlain by ? Upper Jurassic – Lower Cretaceous sandstones (UJ-LK); Steensby Bjerg, north coast of Hold with Hope. Exposed section is *c.* 200 m thick.

Fig. 7. Middle Jurassic sandstones (MJ) faulted (F) against Triassic sediments (T), and unconformably overlain by Cretaceous strata (K). S, Tertiary sills. Southern Traill Ø. Approximately 800 m of vertical section is shown.

Elsewhere in the study area, the Middle Jurassic deposits are dominated by medium to coarse-grained, white and yellowish sandstones with subordinate conglomerates, mudstones and thin coal seams. At Svinhufvud Bjerge on southern Traill Ø, the *c.* 450 m thick Jurassic succession (Fig. 7) starts with a lower fluvial unit (110 m thick) of trough cross-bedded, coarse-grained, pebbly sandstones and interbedded mudstones, formed in a braided river. It is followed by a fine-grained paralic unit (90 m thick) with thin coal seams and root horizons, and an upper shallow marine unit (240 m thick). The upper marine unit includes cross-bedded, strongly bioturbated and structureless medium- to coarse-grained sandstones with several transgressive lag surfaces in the lower part. The ichnofauna is dominated by *Diplocraterion habichi* and *Ophiomorpha*, the former concentrated on omission surfaces in the lower part of the unit. The sandstones contain a sparse marine fauna of bivalves, belemnites and ammonites with four well-defined horizons containing more abundant *Cranocephalites*.

At Mols Bjerge on eastern Traill Ø, the Middle Jurassic deposits consist entirely of coarse-grained fluvial sediments. Comparable deposits occur further to the north at Laplace Bjerg, where a *c.* 200 m succession of medium- to coarse-grained sandstones and conglomerates unconformably overlies fine-grained Triassic sandstones. The succession shows an overall fining upward motif with basal conglomerates overlain by trough cross-bedded and channel-filling coarse-grained

Fig. 8. Cretaceous turbidites, northern Traill Ø. Person (centre right) for scale.

pebbly sandstones. The upper part often lacks sedimentary structures, presumably due to diagenetic processes, and is generally finer grained.

? Upper Jurassic – Cretaceous

On Steensby Bjerg, northern Hold with Hope, shallow marine Middle Jurassic sandstones are unconformably overlain by an up to 170 m thick sandstone-dominated succession of post-Middle Jurassic but pre-Aptian age (Figs 5, 6). This succession is much reduced in thickness in the western outcrops at Stensiö Plateau where it has been largely removed by Aptian valley incision. The deposits consist of large scale cross-bedded, coarse-grained sandstones showing a general south to south-western palaeocurrent direction. Giant scale cross-bedding has been recognised in up to 60 m thick units in well-exposed parts of the succession, whereas tidally influenced cross-bedding is limited to the uppermost 30–40 m (Fig. 5). It is most likely that the entire succession was deposited in a tidally influenced delta. The sandstones are overlain by dark grey silty shales, which probably form the base of a several hundred metres thick shale succession known as the 'Home Forland beds' (Frebold, 1934; Maync, 1949). Dinoflagellate cysts indicate an early Aptian age for these shales (H. Nøhr-Hansen, personal communication 1997), in contrast to the middle to latest Albian age obtained in down-faulted sections east of the sandstone outcrops (Nøhr-Hansen, 1993).

Towards the west, at Stensiö Plateau, Aptian sediments fill an incised valley cut into the undated post-Middle Jurassic – pre-Aptian sandstones described above. The valley fill comprises pebble conglomerates, contorted shales and coarse-grained pebbly sandstones; the succession generally fines upwards, and grades into tidally influenced sandstones and silty shales.

In the Traill Ø area, the occurrence of Cretaceous resedimented breccias and conglomerates adjacent to the fault systems of the Svinhufvud Bjerge relay zone, the Månedal relay zone, and the major fault segment just north of the Månedal relay zone (Fig. 1) indicate a close relationship between the structural development and depositional patterns during the Cretaceous. Fault displacements created palaeoslopes that dipped away from the major faults, as indicated by clast imbrication in the conglomerates and soft sediment deformation of Cretaceous sediments.

Cretaceous basinal sediments are dominated by dark mudstones, although coarse-grained resedimented breccias, conglomerates, and sandstones occur interbedded with mudstones on the downthrow side of major faults at several stratigraphic levels. These coarse clastic deep-water deposits are normally rather chaotic, without any pronounced organisation in the form of vertical facies trends. Clasts vary in size from pebbles to blocks more than 10 m across, and in composition from carbonate and sandstone to metamorphic quartzite, granite and gneiss. Several of the clast lithologies are sufficiently characteristic to determine provenance; clasts derived from Upper Permian carbonates, Carboniferous and Middle Jurassic pebble conglomerates and pebbly sandstones have all been identified with varying degrees of certainty. The clast ages allow determination of the stratigraphic levels that were exposed in the fault scarps at the time of deposition of the resedimented coarse-grained clastics, and thus of the minimum height of the scarps.

A number of sections exposing coarse clastic synrift deposits were studied. The most proximal locality is situated in the hanging wall of the Månedal fault, 6 km north of Månedal. This section is at least 25 m thick and consists of very poorly bedded chaotic breccias with a great variety of block sizes and lithologies. The coarse clastic sediments are overlain by black mudstones with abundant inoceramid bivalves suggesting an Albian age (preliminary identification by K. A. Tröger, personal communication, 1996). Distally the breccia unit gives way to large isolated blocks embedded in mudstone or to small groups of blocks.

A succession of resedimented conglomerates is exposed in Månedal, 8–10 km from the Månedal fault. These are the only resedimented deposits well known from the literature (Donovan 1953), for which a Turonian age was suggested on the basis of a single inoceramid bivalve. This age has now been confirmed by collections of ammonites and belemnites from the uppermost conglomerate unit (preliminary identifications by W. J. Kennedy and W. K. Christensen, respectively; personal communications, 1996). The succession consists of sandstones and conglomerates deposited from sandy debris flows and high-density turbidity currents. Bedding is highly lenticular, and several sedimentary detachment planes have been identified.

A mudstone-dominated succession occurs immediately adjacent to the Månedal fault in an E–W trending valley on the eastern side of Svinhufvud Bjerge. It contains abundant deformed sandstone beds which have undergone repeated phases of downslope sliding, folding and thrusting. The age of this succession is not known at present.

The deposits at these three localities were all derived from linear fault scarps, and transport directions are at high angles to the scarps. The depositional environments can be characterised as fault scarp slope aprons dominated by deposition from a wide variety of sediment gravity flows.

A further sandstone-dominated turbidite succession was identified in the Månedal gorge just west of the river delta (Fig. 8). It occupies the most distal position with respect to the fault scarps compared to the other coarse clastic systems. The turbidites are of medium thickness, parallel-sided, graded, and consist of medium- to fine-grained sandstone. The exposed part of the succession is several tens of metres thick, but the top and base are not exposed. The high degree of organisation and the uniform, monotonous nature of the succession suggest a deep-water outer fan lobe environment. This is one of the very few classical turbidite successions known from the Cretaceous of the rifted seaway between Greenland and Norway, which finds its only onshore equivalent in the Kangerlussuaq basin far to the south (Larsen *et al.*, 1996).

Structural development

The main Mesozoic rift event in East Greenland was initiated in Middle Jurassic times and reached a climax in the latest Jurassic with the formation of strongly tilted fault blocks (Surlyk, 1978); tectonic activity ceased in early Cretaceous, Valanginian times. Deposits and structures associated with this event are well exposed and form the basis for an extensive literature (e.g. Surlyk, 1978). This Jurassic rift event has, however, to some extent overshadowed the importance of subsequent Cretaceous rift phases. Field work in 1995 and 1996 has provided new data on a number of Cretaceous rift events, and the associated coarse clastic deep water deposits.

A number of fault lines, including the Traill Ø segment of the post-Devonian main fault and the most prominent faults in the Mesozoic basin, were mapped during field work; follow-up photogrammetric studies have also been made (Fig. 1). A common characteristic of many of the faults is the occurrence of fault breccias. These are often associated with dramatic, upstanding knolls with well-developed striated slip surfaces, often weathered to a characteristic buff or red-brown colour. The rock types range from fault breccias to quartz mylonites. Many fault rocks have been through several phases of brecciation so that some breccias contain fragments of older fault breccias. These fault rocks are considered to be excellent hydrocarbon seals.

The fault system bounding the Cretaceous sediments to the west consists of a number of overlapping fault segments, with a lateral E–W offset of approximately 2–4 km (Fig. 1). The segments generate a number of relay zones: the Svinhufvud Bjerge relay zone, the Månedal relay zone and the Tværdal relay zone (Fig. 1). Each of the fault segments is composed of a number of overlapping minor faults that generate minor relay zones; the distance between the fault segments is approximately 300–500 m. The internal geometry of the minor relay zones is not well exposed, but the orientation of joints suggests the presence of relay faults striking at approximately 60° to the general strike of the major fault segments, as is often observed in such relay zones (e.g. Trudgill & Cartwright, 1994).

Where the major relay zones involve Jurassic sediments, these typically dip parallel to the fault trend that defines the relay ramps, whereas Cretaceous silty shales onlap onto the relay ramps. There are, however, marked differences in the internal structure of the major relay zones. The Svinhufvud Bjerge relay zone and the Månedal relay zone both have a normal fault transecting the relay ramp (relay faults), while the ramps dip to the south and to the north respectively. This contrast in dip directions arises from the alternating right-stepping and left-stepping character of the major fault segments across Traill Ø. The Tværdal relay zone is characterised by left-stepping major fault segments, but here the relay fault is associated with intense folding of the Jurassic sediments located in the footwall. Structural analysis suggests that the difference in deformational style of the relay zones may be related to variations in strain rates during the Cretaceous.

The major fault segments were first active as individual faults in post mid-Jurassic time since the bedding of the Middle Jurassic deposits is rotated passively in the major relay zones. Erosion of the Middle Jurassic sandstones, progressive onlap of Cretaceous shales onto the relay ramps and the presence of various types of resedimented conglomerates, all indicate that the ramps were topographic features and that the major fault segments were tectonically active during the Cretaceous. Accumulated displacement in the major fault segments introduced strain within the relay zones, which was accommodated by ductile deformation (Walsh *et al.*, 1996) until a critical amount of strain was reached and a relay fault was generated. Fault intensity appears to have increased during the Cretaceous, with the collapse of the ramps during Late Cretaceous time. This resulted in linkage of the fault segments, and the resulting major fault acted as a single coherent structure during later movements in Late Cretaceous – Early Tertiary time. The presence of fine-grained offshore, relatively deep water Lower Cretaceous sediments immediately east of the fault indicates that the Cretaceous shoreline was located west of the fault line, and that most of the footwall was originally covered by Cretaceous sediments. However, the presence of Permian and Triassic clasts in the debris flows indicates that these older successions were exposed to erosion along at least the fault scarps, perhaps due to footwall uplift, or local uplift due to accommodation strain at the relay structures. The present distribution of sedimentary rocks is thus a result of Cenozoic down-faulting along the linked fault trend and erosion of the uplifted footwall sediments down to the level of Triassic rocks. The presence of Triassic sediments in the footwall immediately adjacent to Lower Cretaceous deposits in the hanging-wall indicates that Cenozoic down-faulting was substantial, and that the Cretaceous rocks in the hanging-wall east of the fault line may overlie Jurassic deposits, which are otherwise only poorly exposed within the relay structures and have been eroded in the footwall.

References

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

Donovan, D. T. 1953: The Jurassic and Cretaceous stratigraphy and paleontology of Traill Ø, East Greenland. *Meddelelser om Grønland* **111**(4), 150 pp.

Donovan, D. T. 1955: The stratigraphy of the Jurassic and Cretaceous rocks of Geographical Society Ø, East Greenland. *Meddelelser om Grønland* **103**(9), 59 pp.

Donovan, D. T. 1957: The Jurassic and Cretaceous systems in East Greenland. *Meddelelser om Grønland* **155**(4), 214 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. *et al.* (ed.) The Jurassic of Denmark and Greenland. *Geology of Denmark Survey Bulletin.*

Frebold, H. 1934: Obere Kreide in Ostgrönland. *Meddelelser om Grønland* **84**(8), 33 pp.

Koch, L. 1931: Carboniferous and Triassic stratigraphy of East Greenland. *Meddelelser om Grønland* **83**(2), 99 pp.

Kragh, K., Jensen, S. M. & Fougt, H. 1997: Ore geological studies of the Citronen Fjord zinc deposit, North Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. *Geology of Greenland Survey Bulletin* **176** (this volume).

Larsen, M., Hamberg, L., Olaussen, S. & Stemmerik, L. 1996: Cretaceous – Tertiary pre-drift sediments of the Kangerlussuaq area, southern East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **172**, 37–41.

Maync, W. 1949: The Cretaceous beds between Kuhn Island and Cape Franklin (Gauss Peninsula), Northern East Greenland. *Meddelelser om Grønland* **133**(3), 291 pp.

Nøhr-Hansen, H. 1993: Dinoflagellate cyst stratigraphy of the Barremian to Albian, Lower Cretaceous, North-East Greenland. *Bulletin Grønlands Geologiske Undersøgelse* **166**, 171 pp.

Piasecki, S. & Stemmerik, L. 1991: Late Permian anoxia of central East Greenland. *In* Tyson, R. V. & Pearson, T. H. (ed.)

Modern and ancient shelf anoxia. *Geological Society Special Publication* (London) **58**, 275-290.

Stemmerik, L., Christiansen, F. G., Piasecki, S., Jordt, B., Marcussen, C. & Nøhr-Hansen, H. 1993a: Depositional history and petroleum geology of the Carboniferous to Cretaceous sediments in the northern part of East Greenland. *In* Vorren, T. O. *et al.* (ed.) Arctic geology and petroleum potential. *Norsk Petroleum Forening Special Publication* **2**, 67–87.

Stemmerik, L., Scholle, P. A., Henk, F. H., Di Liegro, G. & Ulmer, D. S. 1993b: Sedimentology and diagenesis of the Upper Permian Wegener Halvø Formation carbonates along the margins of the Jameson Land basin, East Greenland. *In* Vorren, T. O. *et al.* (ed.) Arctic geology and petroleum potential. *Norsk Petroleum Forening Special Publication* **2**, 107–119.

Stemmerik, L., Jensen, S. M., Korstgård, J., Schønwandt, H. K., Surlyk, F., Clausen, O. R., Fougt, H., Kragh, K., Langdahl, B. R. & Therkelsen, J. 1996: Resources of the sedimentary basins of North and East Greenland – an integrated petroleum and ore geological research project. *Bulletin Grønlands Geologiske Undersøgelse* **172**, 32–36.

Stemmerik, L., Sønderholm, M. & Bojesen-Koefoed, J. A. 1997: Paleo-oil field in a Silurian carbonate buildup, Wulff Land, North Greenland: project 'Resources of the sedimentary basins of North and East Greenland'. *Geology of Greenland Survey Bulletin* **176** (this volume).

Surlyk, F. 1977: 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. 1978: Submarine fan sedimentation along fault scarps on tilted fault blocks (Jurassic–Cretaceous boundary, East Greenland). *Bulletin Grønlands Geologiske Undersøgelse* **128**, 108 pp.

Surlyk, F. & Clemmensen, L. B. 1983: Rift propagation and eustacy as controlling factors during Jurassic inshore and shelf sedimentation in northern East Greenland. *Sedimentary Geology* **34**, 119–143.

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.

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

Surlyk, F., 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.

Trudgill, B. & Cartwright, J. 1994: Relay-ramp forms and normal-fault linkages, Canyonlands National Park, Utah. *Geological Society of America Bulletin* **196**, 1143–1157.

Walsh, J. J., Watterson, J., Childs, C. & Nicol, A. 1996: Ductile strain effects in the analysis of seismic interpretations of normal fault systems. *In* Buchanan, P. G. & Nieuwland, D. A. (ed.) Modern developments in structural interpretation, validation and modelling. *Geological Society Special Publication* (London) **99**, 27–40.

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