

SEDIMENTOLOGY OF MIDDLE AND UPPER JURASSIC SANDSTONE RESERVOIRS OF DENMARK¹

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ABSTRACT

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A regional review is presented of the sedimentology and reservoir parameters of the Middle Jurassic Haldager Formation and J-2 unit, as well as the Upper Jurassic Frederikshavn Member, W-1 and V-1 units from the Danish Subbasin and the Danish Central Graben, respectively. New core data are presented from the Haldager Formation of two D.O.N.G. wells in the Danish Subbasin and from the Upper Jurassic W-1 unit of the D.U.C. W-1 well in the Danish Central Graben.

INTRODUCTION

Hydrocarbon shows have been encountered in several Jurassic sections of the Danish Central Graben. The lack of shows in the Danish Subbasin has, on the other hand, been attributed to the apparent absence of mature source rocks. It is, however, anticipated that the Jurassic plays will attract interest in the new 'first' Danish exploration round in Spring 1983.

Middle and Upper Jurassic sandstone formations are present in the Danish Subbasin and the Danish Central Graben, where the Jurassic sequences generally are thick (Fig. 1). On the Ringkøbing-Fyn High and south of it, in the northern part of the German Basin, the Jurassic sequence is absent or very thin, and it does not contain any sandstones. General outlines of the Jurassic formations in the Danish Subbasin have been given by *SORGENFREI & BUCH* (1964), *LARSEN* (1966), *CHRISTENSEN* (1974), and *MICHELSEN* (1978) while reservoir data were presented by *MICHELSEN* (1981). Likewise a general description of the Jurassic of the Danish Central Graben was given by *KOCH ET AL.* (1982), and reservoir data were presented by *JACOBSEN ET AL.* (1982). The Jurassic onshore sequence of Bornholm was described by *GRY* (1969) and *GRAVESEN ET AL.* (1982). It is a very sandy succession but as no data are as yet available from the offshore Rønne Graben, the Bornholm area is not treated in detail.

In the present paper the Middle Jurassic Haldager Formation in the Danish Subbasin and the Middle Jurassic J-2 unit as well as Upper Jurassic W-1 and V-1 units in the Danish Central Graben are described. The Upper Jurassic sandy Frederikshavn Member will only be treated briefly. The main topic of the paper is to interpret and discuss the sedimentary environments and reservoir parameters of the formations. Detailed core data are presented from the Upper Jurassic W-1 sandstone unit from the D.U.C. W-1 well in the Central Graben, and from the Haldager Formation of two D.O.N.G. geothermal wells in the central part of the Danish Subbasin.

MIDDLE JURASSIC

A regional crustal doming was initiated in the North Sea in Late Toarcian times (*EYNON*, 1981). It was accompanied by extrusion of the Bajocian to Bathonian Rattary Volcanic Formation in the domal centre (*HOWITT ET AL.*, 1975; *DEEGAN & SCULL*, 1977). Renewed normal faulting along the structural highs created an interlinked rift basin system, comprising the Viking Graben, the Central Graben and the Moray Firth Basin. This sequence of events, termed the Mid-Kimmerian tectonic phase, drastically changed the palaeogeographic pattern from the fairly extensive early Jurassic Sea into narrow rift basins, in which continental to deltaic conditions prevailed (*EYNON*, 1981; *ZIEGLER*, 1982).

In the Danish Subbasin the Lower Jurassic Fjerritslev Formation is deeply eroded and unconformably overlain by the Middle Jurassic Haldager Formation (*MICHELSEN*, 1975, 1978). Similarly, the Middle Jurassic J-2 unit unconformably

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GENERALIZED STRATIGRAPHY OF THE DANISH JURASSIC

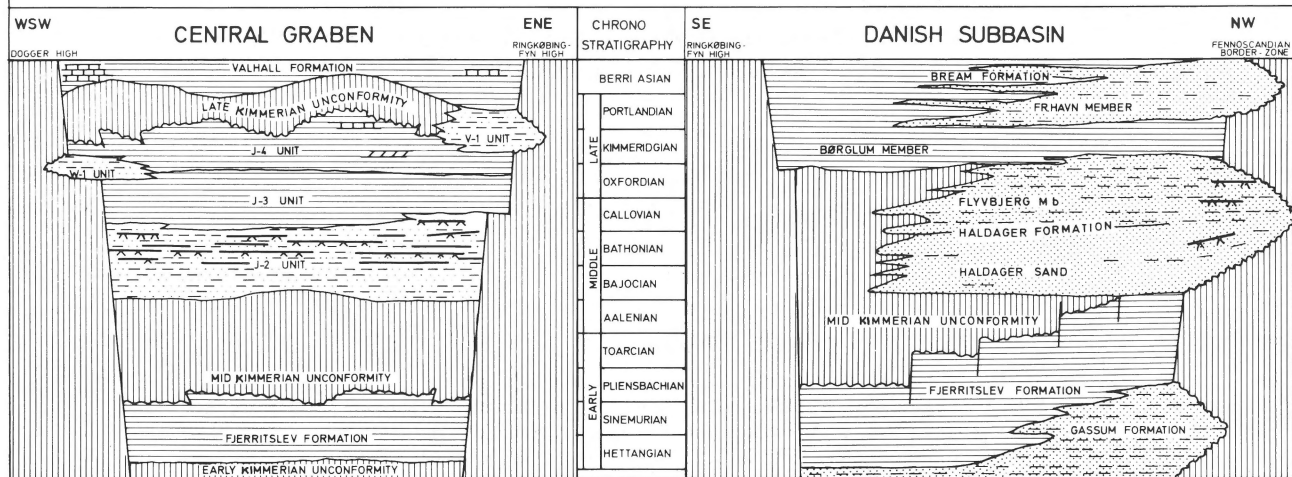


Fig. 1
Generalized stratigraphy of the Danish Jurassic (vertical hatching indicates absence of sediments)

overlies an eroded Fjerritslev Formation in the Danish Central Graben (KOCH ET AL., 1982) (Fig. 1).

Haldager Formation in the Danish Subbasin

The Haldager Formation is a sandy unit, occurring in the central northern part of the Danish Subbasin in Northern Jylland, where it is subdivided into the Haldager Sand Member and the Flyvbjerg Member (Figs. 1 and 2) (MICHELSEN, 1978). The Formation spans the Bajocian to Early Oxfordian (MICHELSEN, 1978). The thickness of the Formation varies from 0-207 m, generally being in the order of 75-200 m in the depocentre, which is located between the Fjerritslev and Børglum faults (Fig. 2).

Southwest of the Børglum fault the Formation is developed in its typical form and the Haldager Sand Member and the Flyvbjerg Member are easily recognizable. This sequence is typified by the Haldager 1 and Vedsted 1 wells (Fig. 2). In the Fennoscandian Border Zone northeast of the Børglum fault, the Haldager Formation apparently grades into a coal-bearing deltaic sequence (ROLLE ET AL., 1979), and the typical Haldager Sand Member and Flyvbjerg Member are not recognizable (Figs. 2 and 4). The typical Haldager Sand Member consists of a number of 10-20 m thick, clean, fine- to coarse-grained sandstone units interbedded with 2-8 m thick claystone units giving the logs a blocky appearance (Fig. 2). The Flyvbjerg Member consists of interbedded, thin, fine-grained sandstones, heterolithic sandstone/claystone layers and thicker claystone beds, which shows frequent root marks. Some thin coal laminae occur, but no autochthonous coal-seams have been reported.

The Farsø-1 cores – Recently D.O.N.G. cored the Haldager

Formation in the Aars 1 and Farsø 1 geothermal wells in northern Jylland. The Farsø 1 cores which were described in detail (KOCH & PRIISHOLM, 1981) will be used to illustrate the sedimentary facies and environments of the Haldager Formation. The Farsø 1 well is located in northern Jylland (Fig. 2), southeast of the depocentre, in an intermodal area. Two continuous cores were cut through the lower part of the Flyvbjerg Member, the entire Haldager Sand Member and the top of the underlying Fjerritslev Formation. Three main facies associations were recognized and are briefly described below (Fig. 3 and Plate 1).

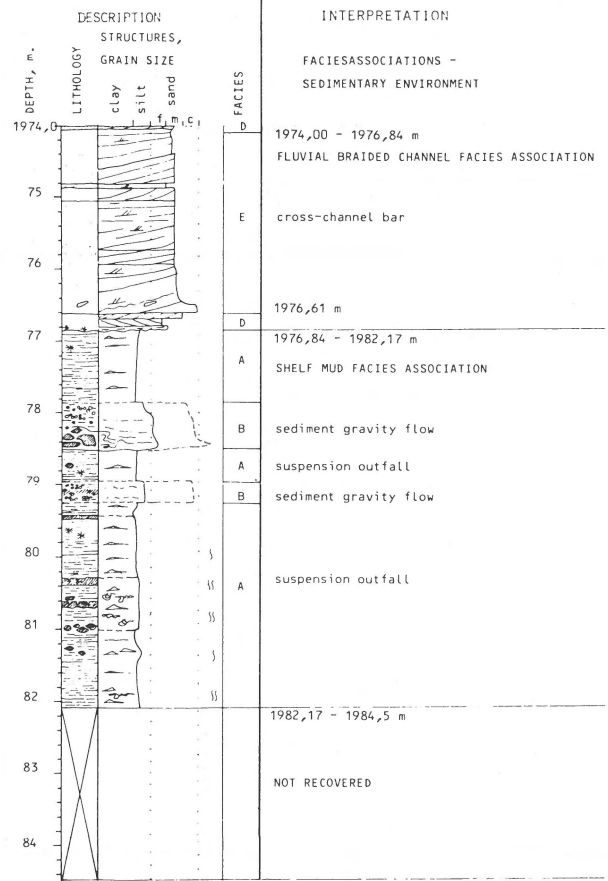
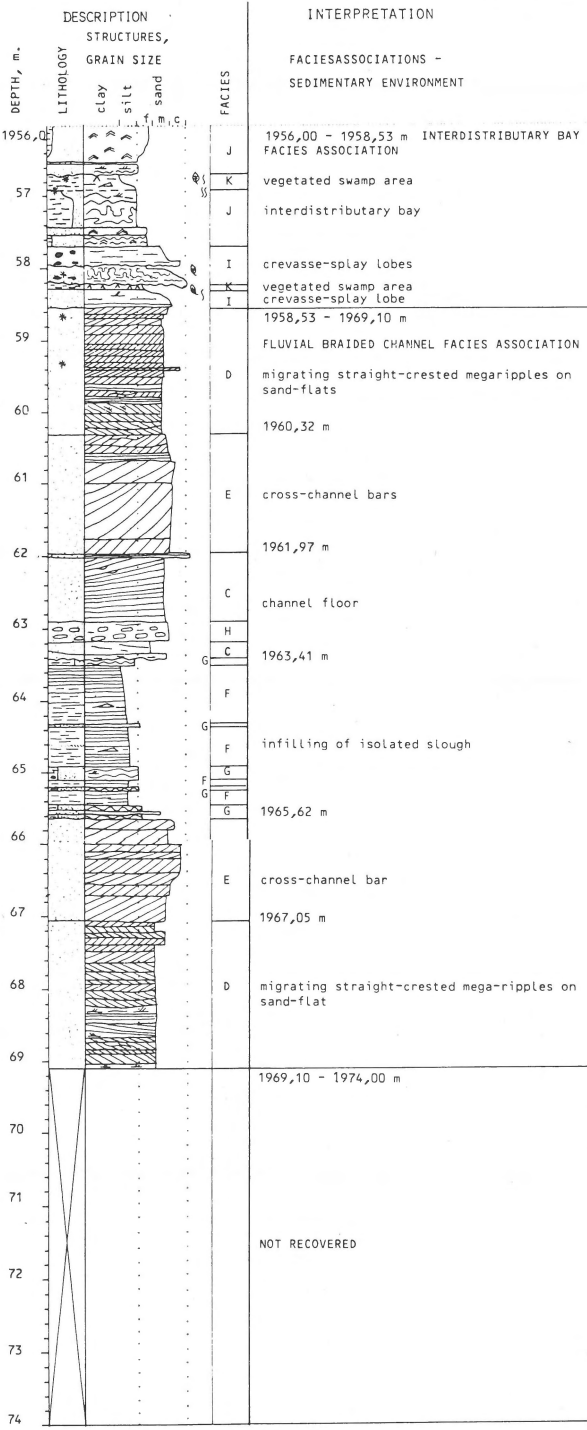
The lower part of core 2 (1976.84-1982.17 m) is recognized as a *shelf mud association*, and is referred to the Fjerritslev Formation. It consists of silt-streaked, occasionally bioturbated black mudstone (facies A) interbedded with two mud-supported clay ironstone conglomerates (facies B). This facies association is interpreted as representing a muddy off-shore marine shelf, where silt and clay settled out of suspension on the sea floor, below wave base. The conglomerates are interpreted as sediments resulting from gravity flows possibly induced by active faulting or halokinesis. The upper boundary of the association is probably erosive.

The central, major part of the cored interval is recognized as a *fluvial channel fill association* (1958.53-1976.84 m), and is referred to the Haldager Sand Member (Fig. 3). The association consists of three sandstone facies, one conglomerate and two silt- and claystone facies. These are (see Plate 1): parallel, laminated, medium-grained sandstone (facies C); thin cosets of large-scale cross-bedded, fine- to medium-grained sandstone (facies D); thick cosets of large-scale cross-bedded, coarse- to medium-grained sandstone (facies E); sand supported mud-pebble conglomerate (facies H); horizontally laminated siltstone grading to claystone (facies F), and cur-

Farsø - 1.

Core 1.

Core 2.



LITHOLOGY

- coal
- clay/claystone
- silt/siltstone
- sand/sandstone/gravel
- pebbles
- heterolith (50% clay & 50% sand)
- conglomerate
- clay/claystone clasts
- clay/ironstone concretions
- rootlets
- carbonaceous material
- limestone

ADDITIONAL SIGNS

- bioturbation (degree indicated by number of signs)
- plant fragments
- bivalve shells

STRUCTURES

- large-scale planar cross-bedding
- large-scale planar cross-bedding with reactivation surfaces
- large-scale trough cross-bedding
- horizontal lamination
- small-scale cross-bedding
- climbing ripples
- wave-ripples
- flaser bedding
- lenticular bedding
- wavy bedding
- thinly rhythmic bedding
- structureless
- rootlets
- mud cracks
- disturbed bedding

BED-INTERFACES

- sharp
- gradual
- erosive

Fig. 3 Farsø-1 well. Core description of the continuously cored interval of the Haldager and Fjerritslev Formations.

rent rippled heterolithic sand and claystone (facies G). The facies are arranged in two sequences of which the lower one (1976.84-1963.41 m) is terminated with an upwards fining interval of facies F with an upwards decreasing number of interbeds of facies G. The upper sequence (1958.53-1963.41 m) has a clearly erosive basis with an intraformational conglomerate bed of facies H in the lower part of the sequence.

The distinctly inversely graded forset laminae of the cross-bedded sandstones (facies D & E) were probably deposited as current induced bed-load avalanches on the lee side of large-scale bedforms. The arrangement in the two erosively based sequences with numerous cross-bedded cosets, furthermore, points towards a fluvial origin. Palynological investigations of a sample from the fine-grained facies F revealed that the sample was barren, possibly indicating a high rate of deposition (KOCH & PRIISHOLM, 1981). The overbank deposits (facies F & G) show, furthermore, no indications of aerial exposure. The absence of root marks, caliche nodules, etc., indicates that the fluvial system tended to have easily erodible banks and frequent channel shifting, rather than more permanent channels with vegetated back-swamp areas. The upwards fining sequences, encountered in the cores, are not very distinctly and rapidly fining upwards, which should be expected if they resulted from lateral accretion on point bars. To the contrary the sequences resemble better the braided fluvial sequences described by CANT & WALKER (1976, 1978). The association is, therefore, interpreted as a braided fluvial system where facies C and H could represent plane-bed vertical aggradation or large sinuous-crested megaripples migrating on the channel floor. Facies E could represent large bars, e.g. cross-channel bars, as described from the Saskatchewan River by CANT & WALKER (1978). Facies D probably represents straight-crested megaripples or sandwaves deposited on sand flats. Facies F and G may represent the infilling of isolated sloughs with fine-grained material.

The top of core 1 constitutes an *interdistributary bay association* (1956.0-1958.53 m) and is referred to the Flyvbjerg Member of the Haldager Formation. The association is composed of 3 facies: wave-rippled heterolithic fine grained sand (facies J); indistinctly laminated or chaotically bedded, coarse- to medium-grained, carbonaceous sandstone (facies I) and silt- and claystone with rootmarks (facies K). The main part of the association is composed of heterolithic sediments (facies J) while sandstones (facies I) are less abundant, and silt- or claystones with root marks (facies K) only occur as two thin beds (Figs. 3 and Plate 1). Two samples from the association, prepared for palynological investigations, contained exclusively terrestrial plant remains.

The association is interpreted as deposited in a shallow, wave-agitated, interdistributary bay or floodplain lake. The wave-rippled heterolithic facies J represents the normal lake sedimentation, while the erosively based, upward fining sandstone facies I probably represents fluvially induced crevasse splays into the lake. Silt- and claystones with traces of rootlets, probably were deposited in very shallow, quiet parts of the

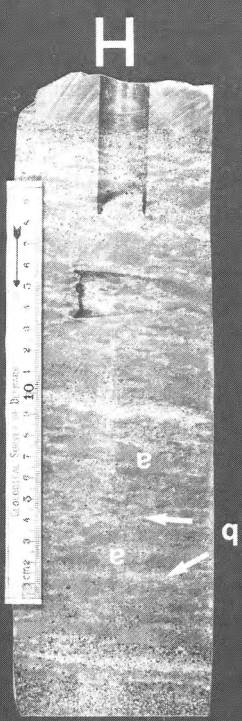
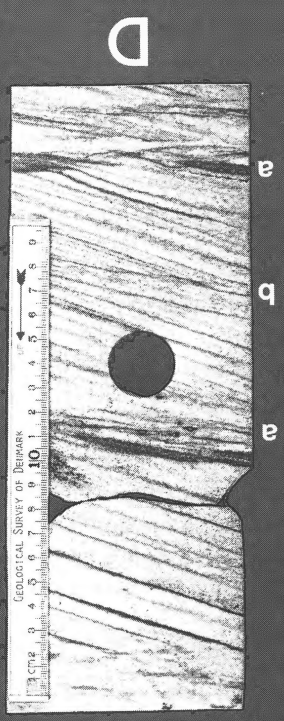
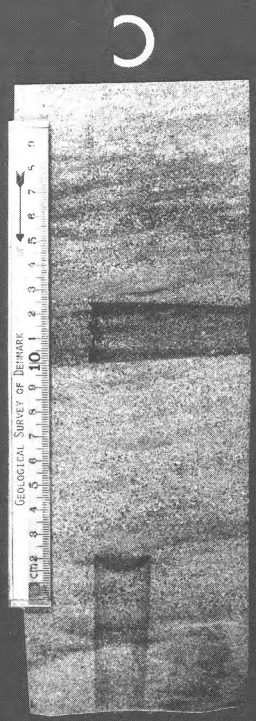
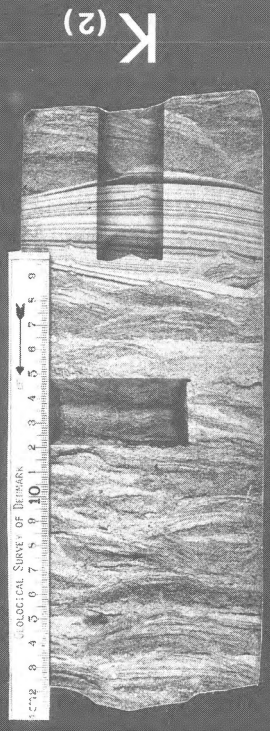
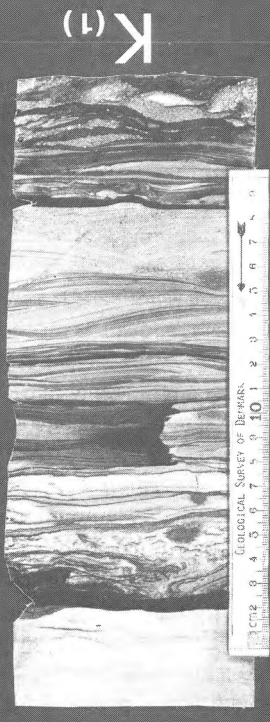
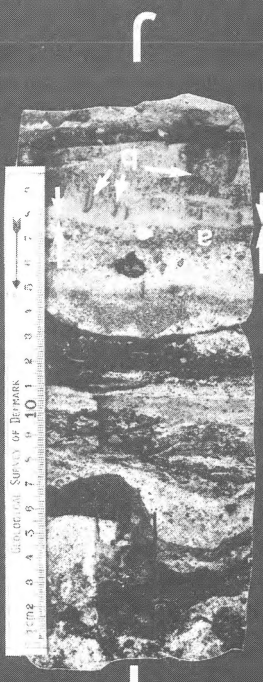
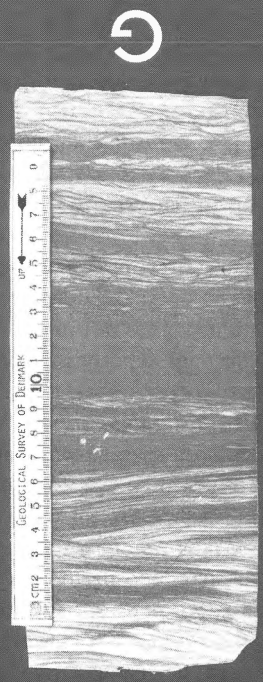
lake which probably were emerged at times and, therefore, could maintain vegetation. The heterolithic nature of the sediments indicates that the environment was either tidally influenced or that fluvial discharge into the lake fluctuated frequently or that both mechanisms were active.

Sedimentary environment – The Aars-1 and Vedsted-1 cores (Fig. 4) fit well with the above interpretation for the Farsø-1 well. It is, therefore, suggested that the Haldager Sand represents a high angle braided river plain over which Permian and Triassic erosion products were shed northeastwards from the Ringkøbing-Fyn High as a result of Mid-Kimmerian uplift (MICHELSEN, 1975, 1978). Denudation reduced the relief and the sedimentary system changed into a low angle meandering flood-plain system, represented by the Flyvbjerg Member.

The Haldager Sand Member and Flyvbjerg Member contain only very thin, possibly allochthonous coal laminae and exclusively terrestrial fossils. The two members grade into a coal-measure sequence to the northeast approaching the Fennoscandian Border Zone (ROLLE ET AL., 1979). In the Skagen and Frederikshavn wells two thin autochthonous coal seams are present (Figs. 2 and 4). A thin marine Aalenian ingression is indicated by abundant occurrence of marine gastropods in the sand interval just below the coal seams in the Frederikshavn-2 well (L. BANKE RASMUSSEN, pers. comm.). The coal bearing sequence can be traced southeastwards along the Fennoscandian Border Zone to the Øresund-Scania area, where it is recognized as the Eriksdal beds and Vilhelmsfalt beds (LARSEN ET AL., 1968; NORLING, 1972). LARSEN ET AL. (1968) reported a minimum of 3 coal-seams from the Øresund 5 & 7 borings. GUY (1971) and NORLING (1972) reported one coal-seam in a clayey sequence in the Vilhelmsfalt well and NORLING (1970, 1972) described 4 coal-seams from the Rydabäck-Fortuna 4 boring (for location see figure 2).

Further to the southeast the Eriksdal beds are exposed in the sand pit near Eriksdal in central Scania (up to 13 coal seams) (NORLING, 1972; ROLLE ET AL., 1979; KOCH, 1979, 1982) and the equivalent Bagå Formation is exposed in the Bagå pit on the west coast of Bornholm, where the sequence also contains a large number of coal seams (GRY, 1969; GRAVESEN ET AL., 1982). Apparently the number and thicknesses of the coal seams increase towards the southeast.

Aalenian sand and coarse silt, with a marine fauna of ostracods, ammonites and foraminifera, have been reported from the Øresund-2 well, structurally below the coal-bearing sequence (LARSEN ET AL., 1968) in a stratigraphic position similar to the marine sand of the Frederikshavn-2 well. In the Rydabäck-Fortuna 4 well NORLING (1970, 1972) reported Aalenian to Late Bajocian foraminifera from thin marine intercalations between the coal seams. Further to the southeast, in the Eriksdal sand pit, the coal-bearing sequence contains several sand beds with dense populations of probably marine *Diplocraterion* burrows (ROLLE ET AL., 1979; KOCH, 1979, 1982).



Therefore, it is suggested that the Early Jurassic sea gradually regressed northeastward as a result of the beginning rise of the Ringkøbing-Fyn High, and was restricted to a narrow sea-way trending through the Fennoscandian Border Zone into the Polish Basin to the southeast. In this narrow seaway, Aalenian marine sand was deposited in response to the incipient Mid-Kimmerian uplift. As the Middle Jurassic regional updoming continued the seaway was gradually drained and filled by a system of delta lobes prograding towards the

southeast. Accordingly, the Frederikshavn and Skagen wells in northern Jylland (Figs. 2 and 4) have only a few thin coals. The upper part of the Haldager Formation of these wells can be included in the Flyvbjerg Member and is indicative for an early draining and shift from deltaic to fluvial continental conditions. The Flyvbjerg Member sequence in the wells, however, has relatively thick sand sequences, which possibly represent major channel sands of the Flyvbjerg Member flood-plain, concentrated in the lowlands of the former sea-

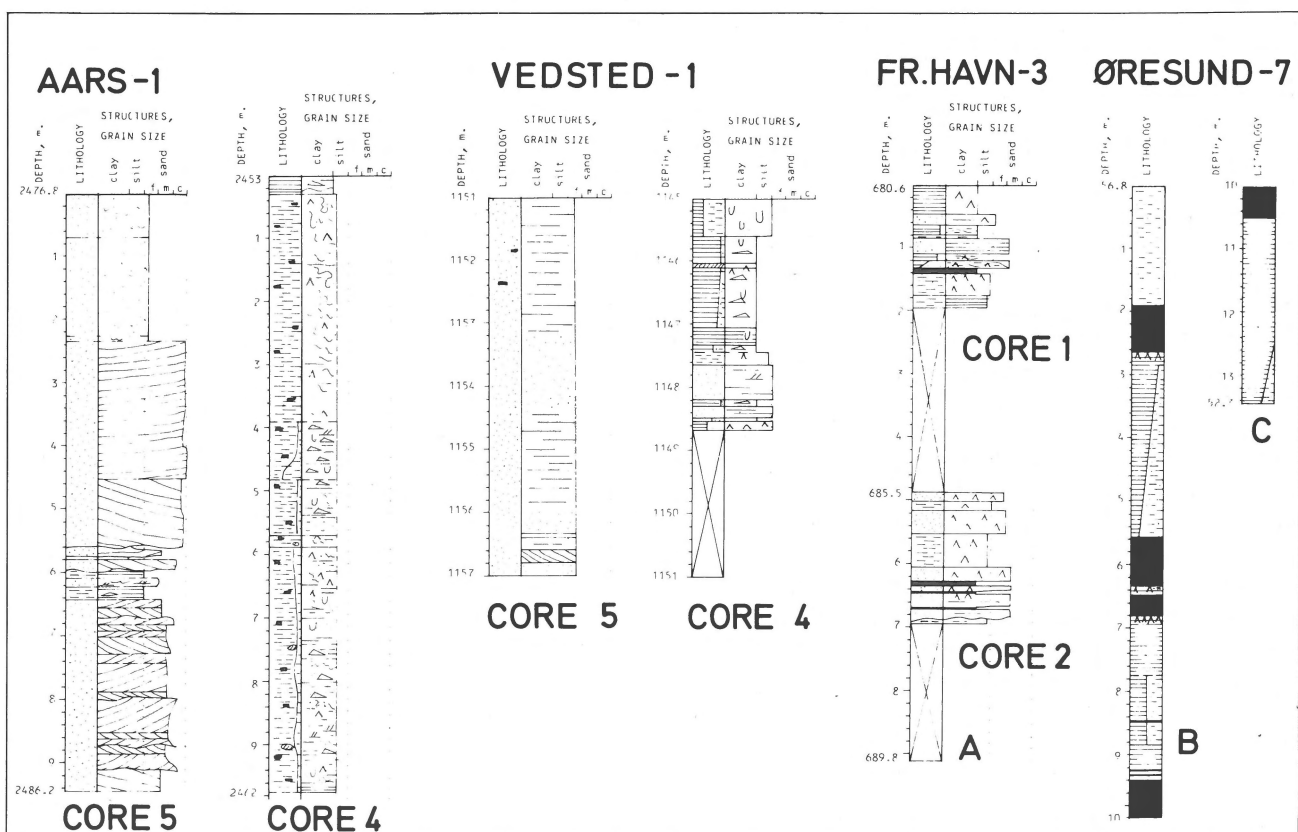


Fig. 4
Description of Haldager Formation cores, from the Aars-1, Vedsted-1, Frederikshavn-3 and Øresund-7 wells. Cores 4 of Aars-1 and Vedsted-1 are from the Flyvbjerg Member and cores 5 of the same wells are from the Haldager Sand Member. For location of the Vedsted-1 cores see figure 2. The section of the Øresund-7 boring is based on vibracore descriptions. The bed thickness has been corrected for 30° structural dip. For legend see figure 3.

Plate 1 (facing page)

Sedimentary facies of the Haldager Formation from the Farsø-1 cores:

- C: Faintly subhorizontally parallel laminated medium-grained sandstone (at 1962.2 m).
- D: Thin sets of large-scale planar cross-bedded fine- to medium-grained sandstone. Two sets with distinctly inversely graded angular foresets and small co-flow ripples in the bottom sets (a). Note the reactivation surface in the lower set at 8.4 cm (b) (at 1969.8 m).
- E: Thick-bedded, large-scale cross-bedded coarse- to medium-grained sandstone. Note the inversely graded foresets which are cemented in the fine-grained parts (a) (at 1966.3 m).
- G: Current rippled heterolith (at 1965.2 m).
- H: Sand supported mud-pebble conglomerate. (a) platy mud pebbles, and (b) sand matrix (at 1963.1 m).
- I: Upwards fining coarse- to medium-grained sandstone with irregular patches of carbonaceous material and highly carbonaceous sand (upper part of photo). Note the coarse-grained base of bed (a) (at 1958.2 m).
- J: Coarse-grained siltstone with traces of rootlets (b) (lower part of photo) (at 1958.2 m).
- K (1): Wave-rippled heterolith with bundlewise upbuilding of wave-ripples between 2.5 and 8.5 cm on lower part of ruler. Single laminae can be followed over the crest of the ripple-form at 3 cm on lower part of ruler (at 1957.9 m).
- K (2): Wave-rippled heterolith with indistinct stratification in the upper part, possibly due to bioturbation (at 1956.1 m).

way. The coal-bearing sequence thickens towards the southeast, indicating that deltaic conditions prevailed in the Danish-Polish Trough throughout Aalenian, Bajocian and Bathonian time.

Reservoir characteristics – The Haldager Sand Member is interpreted as representing a fluvial braided river plain. It has a sheet-like geometry and overlies unconformably the Fjerritslev Formation. The sand bodies are accordingly supposed to coalesce laterally with other sand bodies to form an extensive permeable sand sheet. The fine-grained vertical accretional deposits will probably tend to form patchy, laterally discontinuous bodies, very ineffective barriers to vertical pore fluid migration.

The porosity varies between 10 and 40% (see Fig. 2) and permeabilities up to 2000 mD have been measured on core material (MICHELSEN, 1981). The Haldager Sand Member from the Farsø-1 cores yielded porosities from 5-22%, averaging 17.7%. Permeabilities vary between 1 and 1240 mD to give an estimated minimum transmissivity of 1.7 mD for the 10.2 m recovered Haldager Sand sequence. The sandstones were cemented by authigenic kaolinite varying from some to 25% (volume) (KOCH & PRIISHOLM, 1981).

The crevasse splay sandstones and the interdistributary bay heteroliths of the Flyvbjerg Member, of the Farsø-1 well, are less kaolinite cemented and yield transmissivities up to 3600 mD and porosities up to 37%. These sandstone bodies are, however, expected to have a more limited lateral extension than the Haldager Sand bodies. The 1.1 m recovered crevasse splay sandstone is estimated to have a minimum transmissivity of 0.5 mD (KOCH & PRIISHOLM, 1981).

Although a number of wells have been drilled with Middle Jurassic objectives in the Danish Subbasin, no hydrocarbon shows have yet been discovered in the Haldager Formation. This is mainly attributed to the lack of mature source rocks (THOMSEN ET AL., 1983, this volume).

J-2 unit of the Danish Central Graben

The J-2 unit is a Middle Jurassic sandstone formation deposited during the Bajocian-Bathonian and probably also part of the Callovian (KOCH ET AL., 1982) (Fig. 1). The unit is equivalent to the Haldager Formation (LARSEN, 1966; MICHELSEN, 1978) of the Danish Subbasin, the Brent unit of the northern North Sea (see DEEGAN & SCULL, 1977) and the Lower Graben Sand Formation of the southern North Sea (Nederlandse Aardolie Maatschappij B.V. and Rijks Geologische Dienst, 1980).

The J-2 unit is penetrated by the A-2, O-1, M-8, and U-1 wells in the southern part, and the Q-1 well in the northern part of the Danish Central Graben (Fig. 5). The thickness of the unit varies between 55 m in the Q-1 well and 286 m in the O-1 well.

The J-2 unit consists of interbedded clean sandstone, claystone, heterolithic sand-siltstones and coal seams (Fig. 5).

Two members can be recognized in the wells A-2, U-1, M-8 and Q-1 from the western part of the Graben. The lower member consists of interbedded thick sandstones and claystones. The upper member comprises interbedded claystones, thin sandstones, heteroliths and coal seams; in most wells showing an upward decreasing occurrence of sandstone beds (KOCH ET AL., 1982). This two-fold subdivision, which is well displayed in the U-1 well (Fig. 5), but with thick coals in the upper member, resembles the subdivision into Haldager Sand and Flyvbjerg Members of the Danish Subbasin. The J-2 unit is thickest in the eastern part of the Danish Central Graben, in accordance with its Jurassic half graben nature (MICHELSEN & ANDERSEN, 1983, this volume). Here, it does not display the two-fold subdivision but has thick sand beds in the upper part of the unit and coals also in the lower part (Fig. 5).

Sedimentary environment – The J-2 unit yielded long ranging sporomorphs along with very few ostracods and arenaceous foraminifera. The coal seams in the upper member were probably formed by autochthonous accumulation of plant material in a swamp environment in a warm, humid climate. The heterolithic nature of the silt- and claystones indicate regular fluctuations in flow regime, such as caused by deposition in the intertidal zone or by deposition from fluctuating river currents. Dipmeter analyses of sandbeds from the upper part of the O-1 well show a concentration of low-angle dips centering around a dip axis of 215 degrees (Fig. 5). This indicates the presence of cross-bedded sands, deposited predominantly from southwest trending currents.

The lower of the two thick cross-bedded sandstone sequences in the upper part of the O-1 sequence (Fig. 5), is distinctly coarsening upwards while the upper sandstone interval is clearly fining upwards. The lower sequence may be a progradational sequence grading from interdistributary bay heteroliths to distributary mouth-bar sands capped by two coal seams, representing overgrowth of a deltalobe on the delta plain. The upper sequence could represent a section of a delta distributary on the delta plain.

Although the number of deep wells in the Danish Central Graben is still rather limited, the following interpretation of the sedimentary history is attempted. The lower member in the western part of the Graben with sandbeds and interbedded claystones could represent a braided river plain. The sediments were shed from the Mid-North Sea High and the Dogger High into the low-lying downfaulted eastern half-graben margin along the Ringkøbing-Fyn High, where the braided river plain merged into a meandering river plain or lake, represented by the lower part of the J-2 unit in the O-1 well (Fig. 5). The relief was gradually reduced and marine invasions occurred, probably from the south whereby the Central Graben was changed into a delta plain. Marine incursions alternated with southward progradation of delta lobes, probably into the West Netherlands-Sole Pit Basin. Major distributary channels were possibly concentrated along the eastern downfaulted margin of the Central Graben.

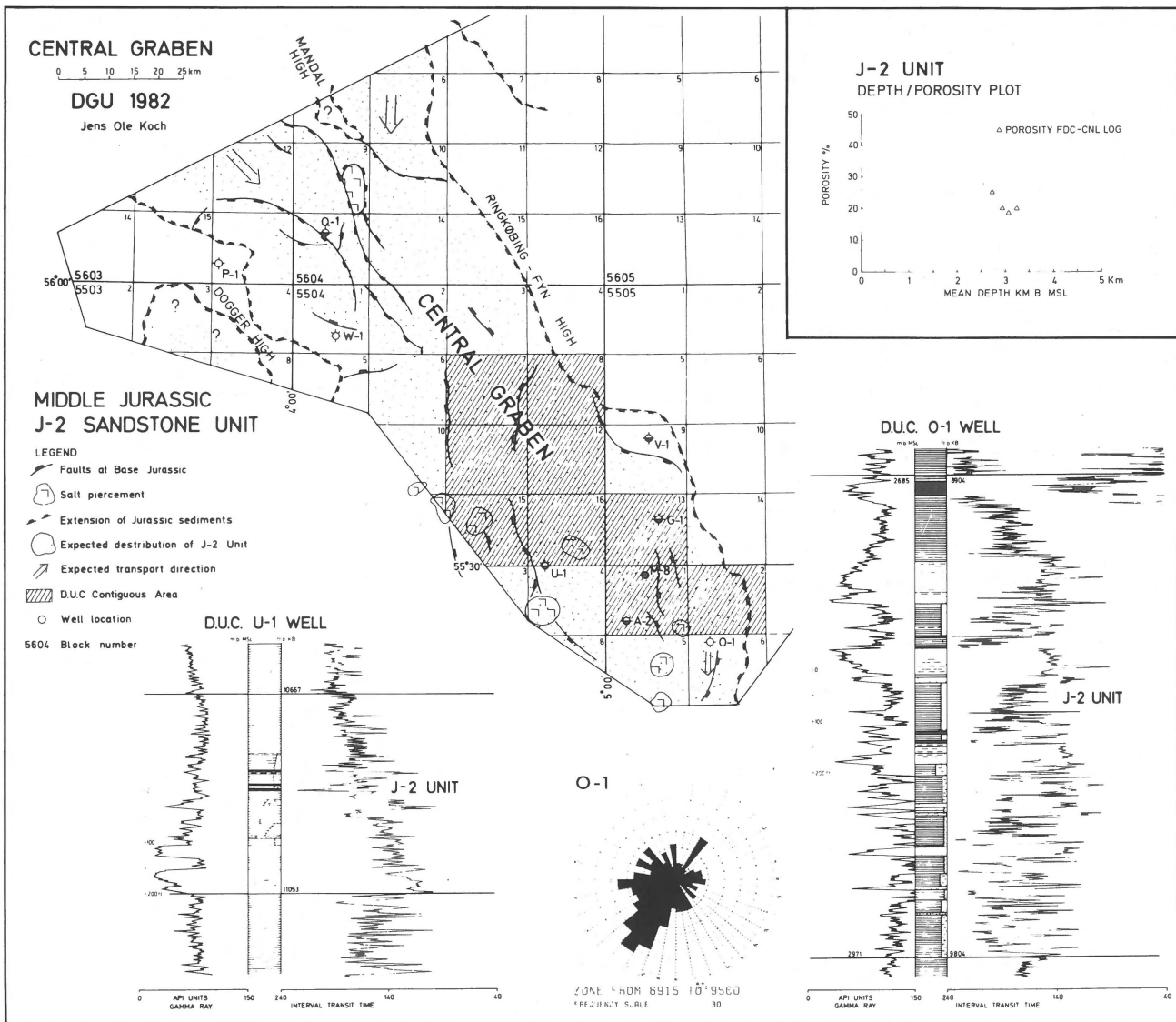


Fig. 5 Middle Jurassic J-2 Sandstone unit of the Danish Central Graben.

Reservoir characteristics – The J-2 unit contains several thick sand- and siltstone beds with log porosities varying between 4 and 45%, with an average around 20% (Fig. 5).

The J-2 unit is seen as blanketing the Central Graben floor overlying Lower Jurassic shales of the Fjerritslev Formation in the deepest part of the basin. The unit is apparently not found on the marginal blocks along the Ringkøbing-Fyn and Dogger High (Fig. 5). If the sandbodies represent fluvio-deltaic distributary channel sands, the active channels would tend to flow through areas with the highest rate of relative subsidence. Therefore, the sandbodies can be expected to be concentrated in areas of Middle Jurassic active downfaulting. In contrast, sandbodies would be expected to be relatively scarce in areas characterized by Middle Jurassic active updoming, e.g. over a salt induced domal feature.

Middle Jurassic hydrocarbon shows were encountered in the U-1, A-2, M-8 and Q-1 wells. Petrophysical log-evaluation of the U-1 section suggests the presence of approximately 14 m of net hydrocarbon zone (K. LIEBERKIND, pers. comm.).

UPPER JURASSIC

Denudation of the high Middle Jurassic relief and continued subsidence of the rift basins coupled with the global Late Jurassic eustatic sea level rise (VAIL & TODD, 1981) resulted in prevailing marine conditions in the former continental North Sea rift basins (ZIEGLER, 1982). In the Danish-Polish Trough the Callovian Fortuna Marl with a diverse marine fauna reflects the first major transgression from the Polish Trough in

the south (NORLING, 1970, 1972). The Danish Subbasin was apparently not flooded until the Late Oxfordian when sedimentation changed from the floodplain deposits of the Flyvbjerg Member into the marine claystones and shales of the Børglum Member of the Bream Formation (Fig. 1). The Danish Central Graben was flooded in Early Callovian times and sedimentation changed to marine claystones of the J-3 unit (Fig. 1).

Renewed Late Jurassic fault activity along the Ringkøbing-Fyn and Dogger High resulted in high clastic influx. The shallow marine sands of the W-1 and V-1 units were deposited along the highs in Late Oxfordian to Kimmeridgian times, wedging into or overlying the J-4 unit (Kimmeridge Clay equivalent) of the Central Graben (Fig. 1).

Similarly, shallow marine sands and silts of the Frederikshavn Member of the Bream Formation were shed southwest-

wards from the Fennoscandian Border Zone into the Danish Subbasin (Fig. 6) (CHRISTENSEN, 1974; MICHELSEN, 1978; BIRKELUND & PEDERSEN, 1979). The Frederikshavn Member probably grades into the Kimmeridgian-Portlandian Nytorp Sand of Scania (NORLING, 1981). Very little core material has been redescrbed from the Frederikshavn Member which therefore will not be treated in further detail.

W-1 and V-1 units of the Danish Central Graben

The D.U.C. W-1 well, drilled some 6-7 km off the Dogger High on its northeastern flank (Fig. 7), penetrated 97 m of a Lower Kimmeridgian to Upper Oxfordian sandstone formation, informally named the W-1 unit (KOCH ET AL., 1982). Additionally, the D.U.C. V-1 well, drilled approximately 6 km southwest of the Ringkøbing-Fyn High (Fig. 7) encoun-

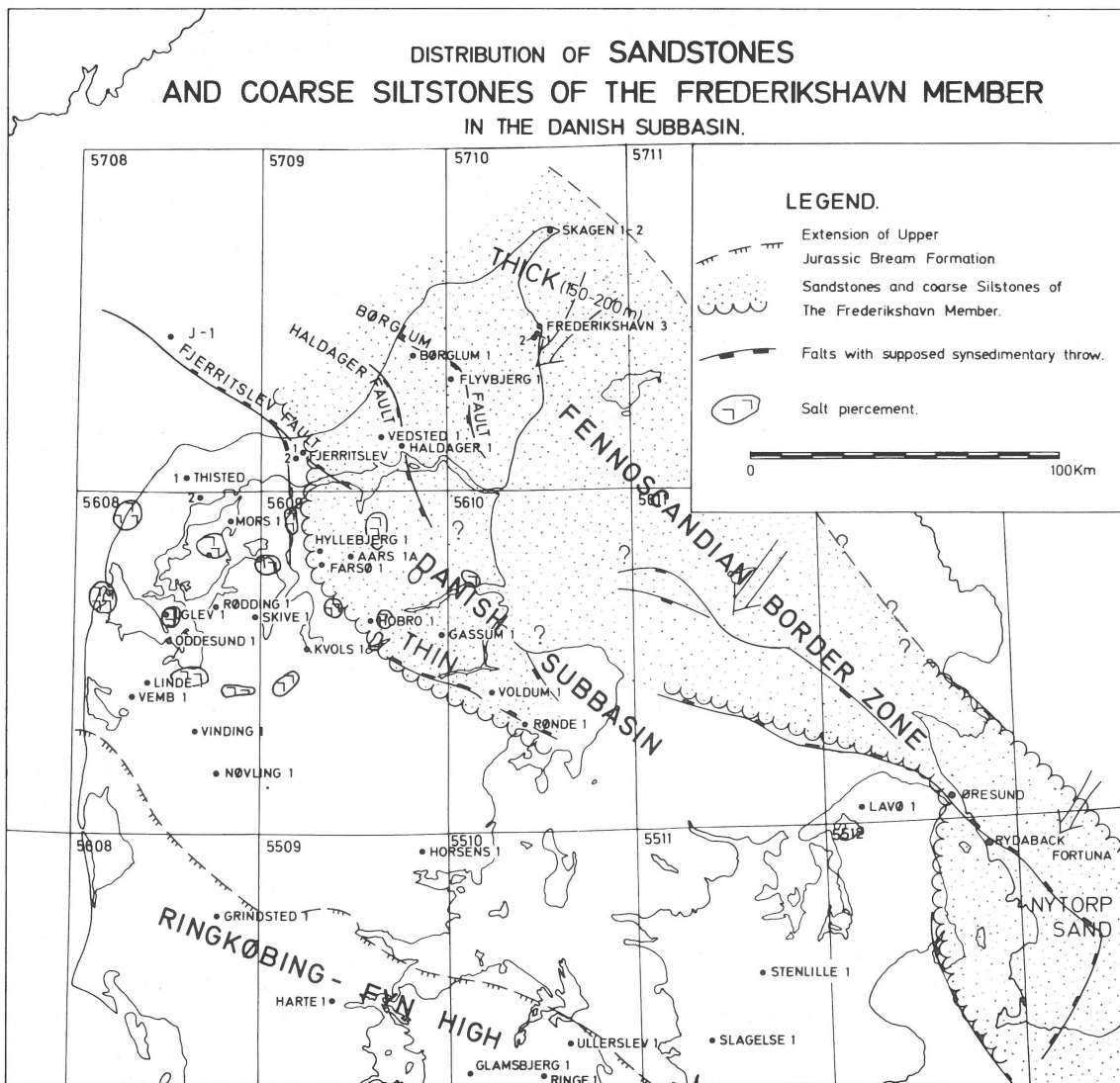


Fig. 6
The Frederikshavn Member of the Danish Subbasin.

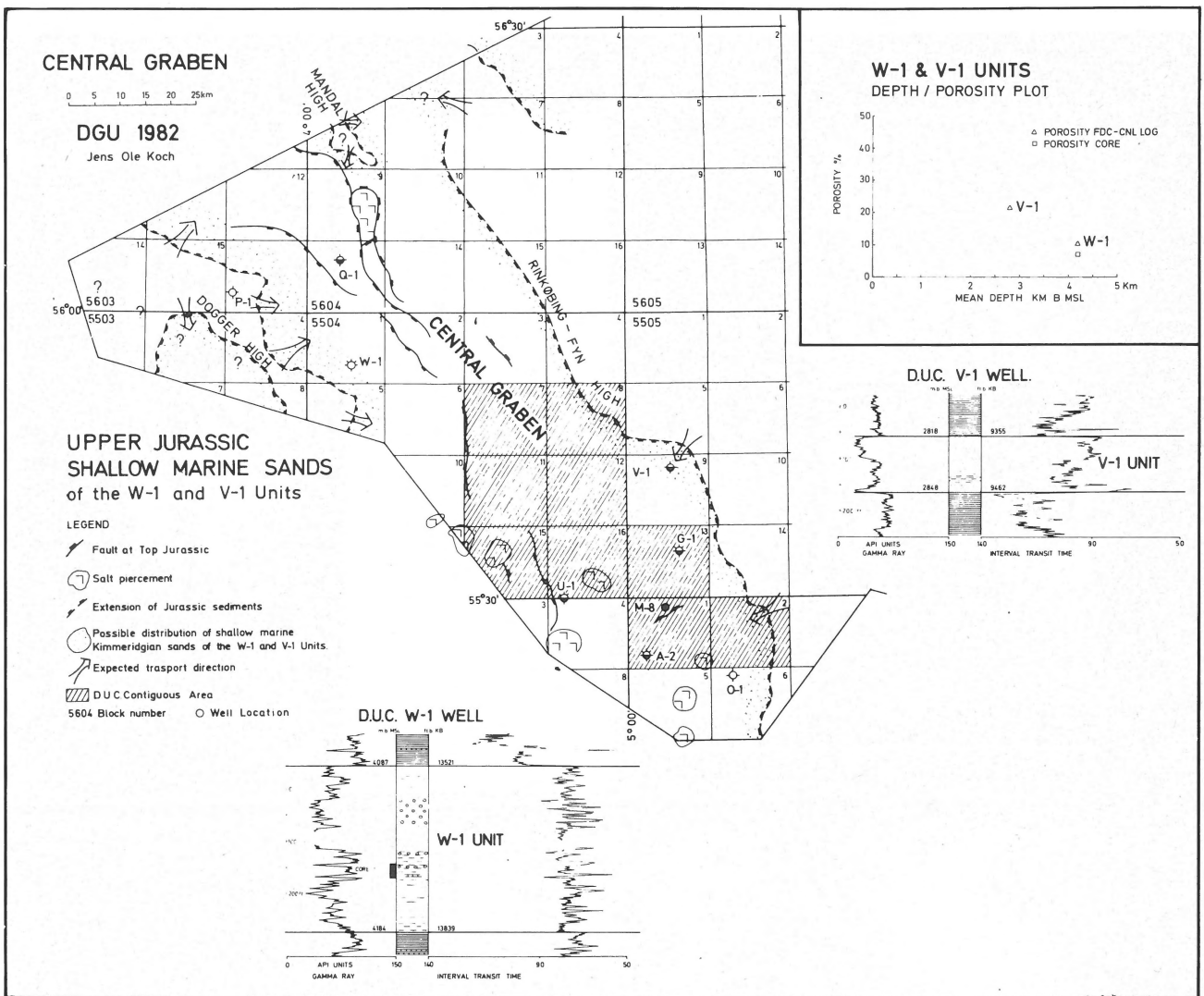


Fig. 7
Upper Jurassic shallow marine sands of the W-1 and V-1 units in the Danish Central Graben. Porosity depth plot after Michelsen (1981).

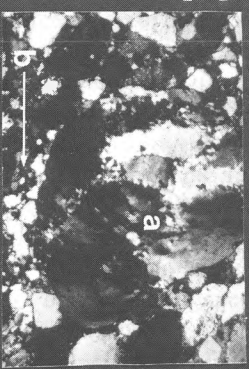
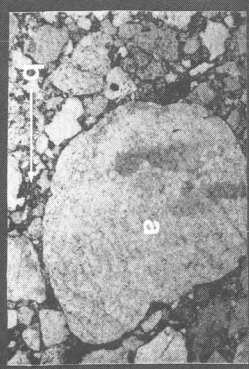
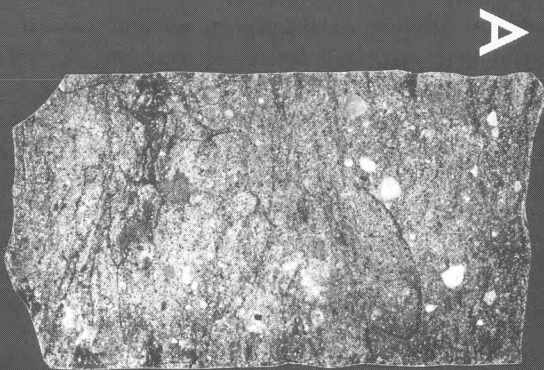
tered 33 m of a Kimmeridgian sandstone-siltstone interval, here informally named the V-1 unit. In HANSEN & BUCH (1982) this sand was included in the LC-1 unit. Both the W-1 and V-1 units consist of marine sands believed to be deposited along the margin of the Dogger and Ringkøbing-Fyn Highs at approximately the same time. The units seem to be equivalent to the Piper Sandstone (MAHER, 1981) and the Fulmar Formation from the UK offshore and possibly the Ula Formation from the Norwegian offshore (BAILEY ET AL., 1981).

The W-1 unit consists of grey to white sandstones, siltstones and conglomerates interbedded with dark grey claystones and heterolithic siltstones and claystones (KOCH ET AL., 1982) (Fig. 7). The V-1 unit consists of dark grey siltstones and light grey very fine-grained sandstones (Fig. 7). At the base of the interval there is 2 m of very fine-grained sand. The rest of the interval displays one 30 m thick coarsening upwards sequence of siltstone, with minor shale, grading upwards into sandy

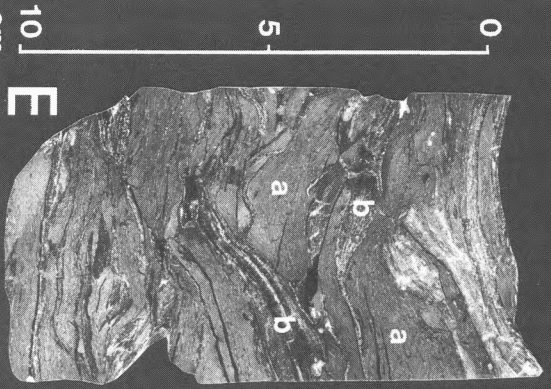
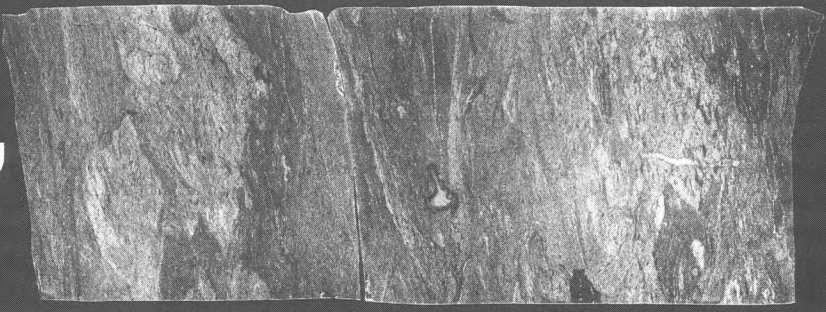
siltstone and further into 14 m of very fine-grained sandstone.

The W-1 core

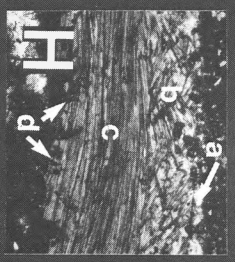
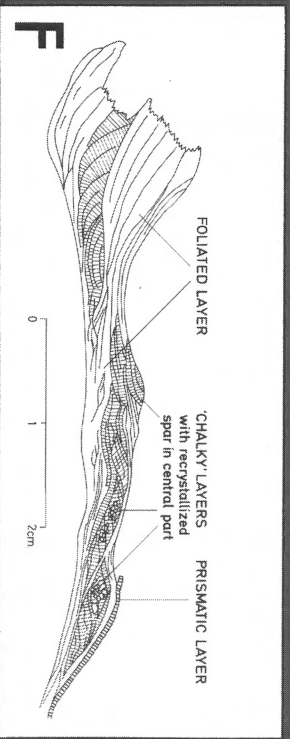
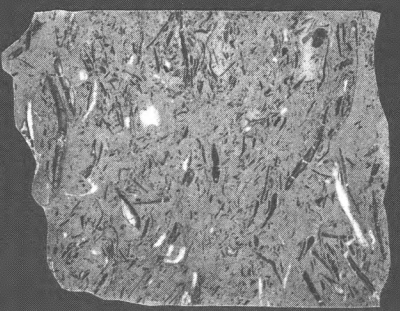
A core was cut in the W-1 unit encountering less than 1 m conglomeratic sandstone and 7 m of siltstone with a calcareous interval containing numerous large bivalve shells (Fig. 8). The conglomeratic sandstone (facies A) is a moderately to poorly sorted fine-grained, calcite-cemented silty orthoquartzitic sandstone, with rounded milky granules of lithic quartzite, with an interlocked mosaic texture. It shows indistinct lamination, grading into massive, structureless conglomerate (Plate 2). The siltstone (facies B1, Plate 2) is intensively bioturbated making it difficult to identify any primary sedimentary structures. The lower part of the siltstone (facies B2) contains agglutinating foraminifera, abundant dinoflagellates (J. M. HANSEN, pers. comm.) and numerous large bivalve



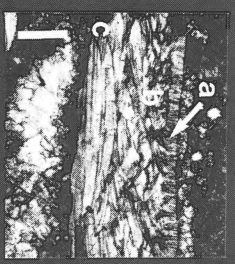
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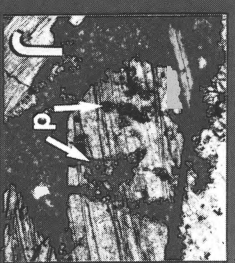
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0 0.6mm

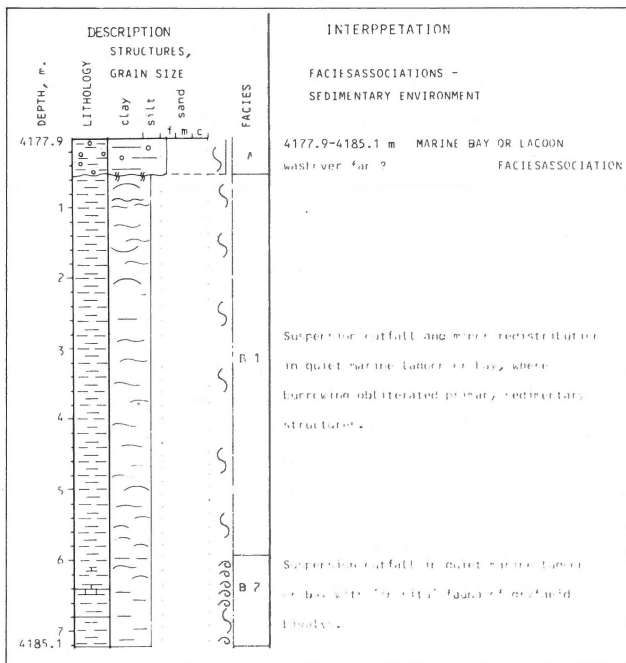


Fig. 8
Description of core 1 from the W-1 well. For legend see figure 3.

shells with algal micro-borings (Plate 2). A cross section of one of the large shells showed a structure very similar to the structure of recent *Ostrea edulis*. In the shelly interval (facies B2) the siltstone grades into a brown grey argillaceous limestone. The cored interval is cemented with calcite and has a low porosity.

The bioturbated siltstones, facies B-1 of the W-1 core, indicate a shallow marine, but rather low energy environment, where silt and clay could settle from suspension. Sedimentation rates were moderate, enabling burrowers to obliterate primary sedimentary structures. Furthermore, the presence of oysters could indicate a slightly brackish environment. Thus, the siltstone facies (B1 + B2) of the W-1 core was probably deposited in a shallow marine bay or a lagoon. The 1 m of conglomeratic sandstone (facies A) of the W-1 core is interbedded in a sequence of the lagoonal or bay siltstone (facies B) (Fig. 7 and Plate 2). This conglomeratic sandstone is immature and it is not likely to represent a high energy shoreface environment, but could represent part of a washover fan spilled into and rapidly deposited in a lagoon, represented by the siltstone facies (B1 & B2). The rounded

lithic quartzite clasts in the conglomeratic sandstone (facies A) have an interlocked mosaic texture (Plate 2) indicative for low grade metamorphism. These clasts possibly originated from erosion of Carboniferous strata, similar to the CA-1 unit from the P-1 well (LARSEN & MICHELSEN, 1982), which probably were exposed on the Dogger High in Late Jurassic times.

Sedimentary environment

The microfauna, the pervasive bioturbation, the shell debris with algal microborings and the presence of glauconite clearly demonstrate a shallow marine origin for the W-1 core. The basal part of the W-1 unit shows a coarsening upward trend, whereas no obvious patterns are seen in the rest of the unit (Fig. 7). Considering the large variability of grain size from siltstone to coarse-grained conglomerates, a submarine fan origin may be suggested. A shallow marine origin is, however, also possible and in the opinion of the author more likely in view of the Late Jurassic tectonic setting as well as the above core data. The approximately 30 m thick coarsening upward sequence in the V-1 well may represent the distal part of a prograding shoreline or submarine fan.

Reservoir parameters

The W-1 unit contains unconsolidated loose sand and the log porosity was estimated at an average of 11% (JACOBSEN ET AL., 1982) (Fig. 7). Four horizontal plugs from the calcite cemented fine-grained core yielded the porosities and air permeabilities given in Table I.

The V-1 unit has an estimated average log porosity of 22% (JACOBSEN ET AL., 1982). An optimistic log interpretation may indicate the presence of 12 m net hydrocarbon zone in the top of the V-1 unit (K. LIEBERKIND, pers. comm.).

Table I
Well W-1: core measured porosities and permeabilities.

Facies	Porosity %	Permeability mD
sandstone (A)	6	0.5
siltstone (B-1)	9	16
siltstone (B-1)	4	1.1
siltstone (B-1)	9	0.06

Plate 2 (facing page)

Core 1 from the W-1 well.

A. Conglomeratic sandstone with granules of milky quartz (facies A).

B. & C. Thin sections of A, showing the poorly sorted sandstone with rounded lithic clasts of quartzite with interlocked mosaic texture (a) and calcite cement (b). C is taken with crossed nicols.

D. Bioturbated siltstone (facies B1).

E. Argillaceous siltstone (a), with oyster shells (b) (facies B2)

F. Cross section of one shell from E.

G. Silty limestone of facies B2, with shell debris.

H, I & J. Thin sections from the rock shown in G. Note prismatic layer (a), and foliated layers (b) & (c) and algal microborings (d).

CONCLUSIONS

The present study suggests that the Early Jurassic sea of the Danish Subbasin regressed northeastwards as a result of the incipient Mid-Kimmerian uplift of the Ringkøbing-Fyn High and was restricted to a narrow marine strait in Aalenian time, extending from northern Jylland through the Fennoscandian Border Zone into the Polish Trough (Figs. 2 and 9). In response to further uplift of the Ringkøbing-Fyn High the Haldager Sand Member was shed northeastwards, as a steep slope braided river plain grading into the marine strait. The latter was gradually filled by delta lobes prograding through the border zone (Figs. 2 and 9). As denudation reduced the topographic relief, the steep slope barren braided Haldager Sand Member floodplain evolved into a low slope vegetated meandering floodplain of the Flyvbjerg Member.

In the Danish Central Graben the J-2 unit coal-bearing sequence suggests the presence of a Middle Jurassic fluvial-deltaic system prograding southwards, possibly into the West Netherlands and Sole Pit Basins of the southern North Sea (Fig. 5 and 9).

The Upper Jurassic shallow marine sands of the W-1 and V-1 units, possibly extend along the margins of the Dogger and

Ringkøbing-Fyn Highs, as stratigraphic equivalents of the Fulmar and Ula Sands (Fig. 7). The W-1 and V-1 units seem to wedge into or overlie the J-4 unit which is thought to be the main hydrocarbon source rock of the Danish Central Graben. These reservoirs when drilled in optimum position may prove to be very prolific.

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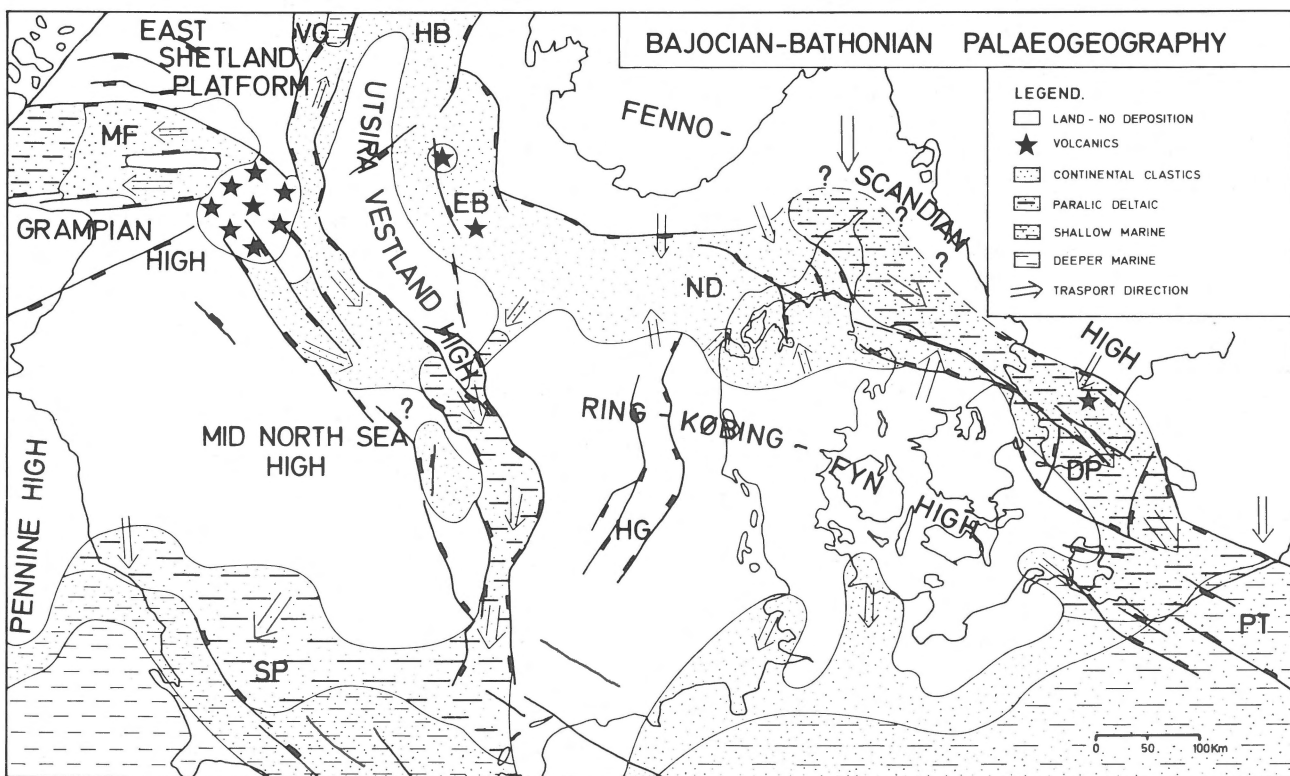


Fig. 9 Bajocian-Bathonian palaeogeography. Key: DP = Danish Polish Trough, EB = Egersund Basin, HB = Horda Basin, HG = Horn Graben, MF = Moray Firth Basin, ND = Norwegian Danish Basin, PT = Polish Trough, SP = Sole Pit Basin, VG = Viking Graben. Modified from Eynon (1981) and Ziegler (1982).

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