DELTAIC SEDIMENTATION DURING THE JURASSIC IN THE NORWEGIAN-DANISH BASIN (NORTH SEA)[1]

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ABSTRACT

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In the Norwegian-Danish Basin, several minor Middle to Late Jurassic deltas (Haldager Formation) were built out from the different highs, which acted as local sediment source areas.

The cores studied from well 8/3-1 most probably represent the Middle Jurassic Haldager Formation, while wire-line logs and mineralogical composition indicate that the 17/4-1 core may represent the Late Triassic/Early Jurassic Gassum Formation. The analysed sediments of wells 8/3-1 and 17/4-1 were deposited in delta-front environments, probably as distributary mouth bars. While the 17/4-1 delta had the Utsira High as a major sediment source area, the 8/3-1 delta material was mainly derived from the Sele High. The composition of the Oxfordian marginal-marine deposits of 16/9-1 indicates both the Utsira and Sele Highs as important source areas, reflecting derivation of sediments by reworking of underlying formations. The studied Oxfordian sandstones of well 16/9-1 may represent sandy equivalents to the Egersund Member of the Bream Formation.

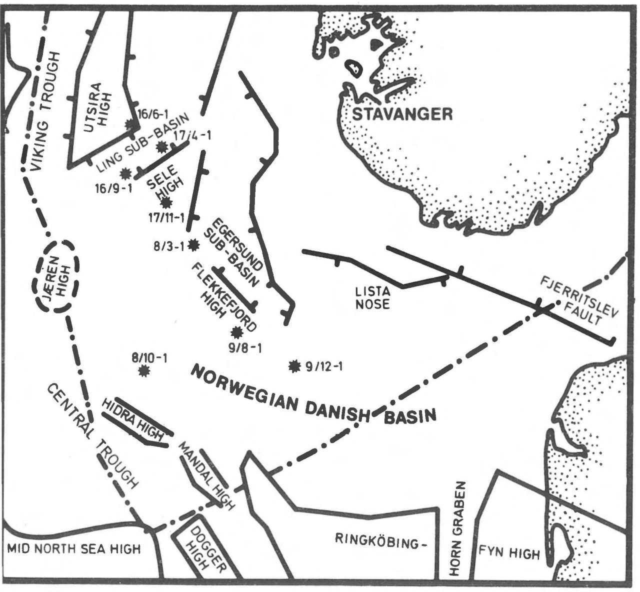

Fig. 1
Tectonic map of the Norwegian Danish Basin and adjacent areas.

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INTRODUCTION

Samples of Jurassic sandstones from the North Sea's Norwegian-Danish Basin (Fig. 1) have been studied in order to get more stratigraphic and sedimentological information. The complicated stratigraphy, the few wells and the paucity of available well data have, however, so far restricted our study. The petrology and diagenesis of these sediments have been described recently by DYPVIK & VOLLSET (1979).

GEOLOGY

In the Danish part of the Norwegian-Danish Basin the Triassic to Early Jurassic deltaic sandstones of the Gassum Formation are generally succeeded by the Early Jurassic marine shales and siltstones of the Fjerritslev Formation (Fig. 2) (DEEGAN & SCULL, 1977; MICHELSEN, 1977, 1978). This formation, which thins out both westwards and northwards (towards Norwegian waters) is overlain by the regressive deltaic to shallow-marine Haldager Formation. The Haldager Formation is transgressed by the dark, shallow-marine shales of the Late Jurassic Bream Formation.

In the Norwegian part of the basin upheaval and erosion at the close of the Early Jurassic probably eroded sediments

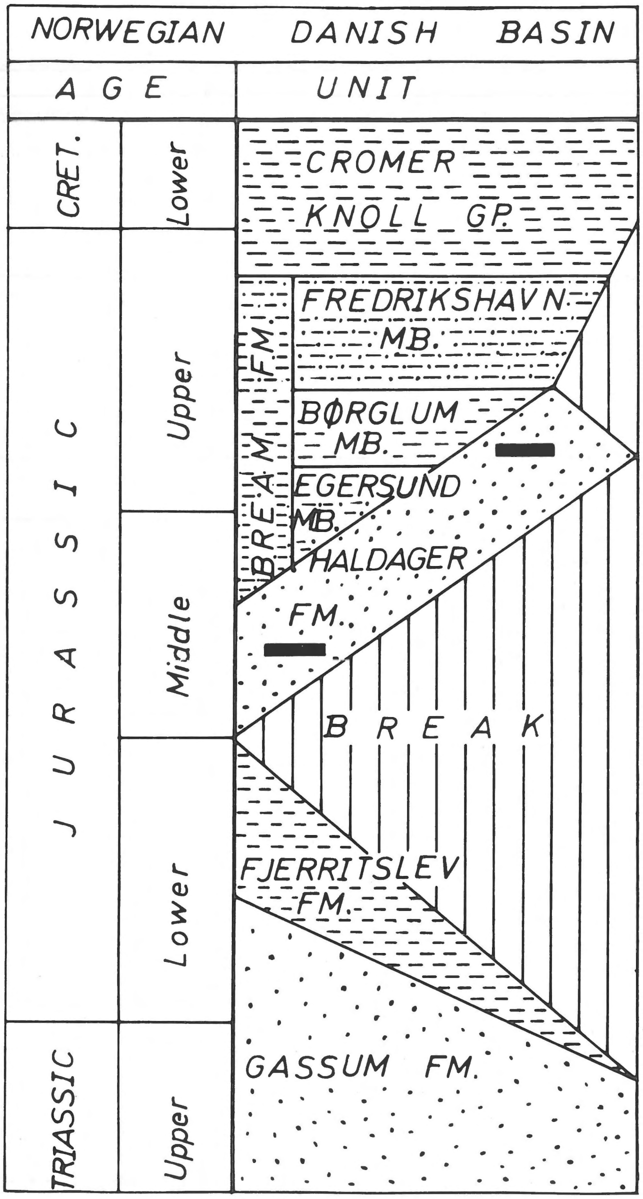


Fig. 2
Jurassic lithostratigraphic nomenclature for the Norwegian Danish Basin. Modified from Deegan & Scull (1977).

equivalent to the Fjerritslev Formation (this formation is present, however, in the Danish part of the Basin). During Middle and Late Jurassic times, western and also southern areas acted as source areas for most of the Haldager Formation. Comparison of available well logs (SP- and γ-ray logs) (NPD-papers 1-14) with those presented by DEEGAN & SCULL (1977) and MICHELSEN (1977, 1978) indicate the presence of parts of this Middle to Late Jurassic Haldager Formation in wells 8/3-1 and 9/8-1 from Norwegian water (Fig. 3). The succeeding Late Jurassic transgression resulted in deposition of clayey sediments over the entire basin, with the largest thicknesses in two depocentres: one east of the Fjerritslev Fault and one in the Egersund Sub-basin (Fig. 1). The Late Kimmerian movements at the time of the Jurassic/Cretaceous transition in the Norwegian part of the basin are very often expressed as an unconformity.

CORE DESCRIPTION

According to NPD-papers 1 and 11, the cores from wells 8/3-1 (cores 1 and 2) and 16/9-1 (core 2) represent the Haldager Formation and are of Dogger and Oxfordian/Kimmeridgian age, respectively. The Oxfordian/Kimmeridgian sandstones are called the 'Unnamed' Formation (NPD-papers 17 and 19). Similarities on wire-line logs, as mentioned earlier, indicate that the core from well 17/4-1 (core 1) (Fig. 3) represents the Late Triassic/Early Jurassic top part of the Gassum Formation.

The cores are generally made up of mottled or homogeneous sandstones of light grey-green colour (NPD-paper 1, Fig. 3; NPD-paper 11, Fig. 2) with cut-and-fill and deformation structures. Interbedded in the sandstone sequences are numerous beds of green, dense shales. Shales are also found as clasts in some parts of the sandstones, indicating erosion of newly deposited, partly consolidated shales. In some horizons of the sandstones thin coatings of brownish clays and organic matter show ripple-like structures. Several fining-upwards sequences, from conglomeratic pebble beds to shaly beds, are found in addition to graded bedding, on a minor scale (5-10 cm thick).

Grains and fragments of coal and bituminous material have been found, but glauconite was not registered. Consequently, the locally green colours of the sediments are due to other green minerals than glauconite, namely chlorites. Limestone breccias or nodules in well 16/9-1 (core 2) probably indicate more marine-dominated sedimentation than represented in the studied cores from 8/3-1 and 17/4-1.

METHODS OF ANALYSES

Grain-size distribution analyses were performed on core samples from wells 17/4-1 and 16/9-1 after ultrasonic and HCl treatments for dissociation. Binocular studies revealed that most of the samples were satisfactorily dissociated by this treatment.

Thin sections were made after impregnating core samples with araldite. In the point countings about 400 points have been counted (Table I).

The X-ray diffraction analyses were carried out on inverted Millipore filtrates. Minerals were determined according to CARROL (1970) and Finx Minerals Index. Semiquantitative estimates were made according to NORRISH & TAYLOR (1962) and DYPVIK (1977) (Table II).

The geochemical analysis of fragments was carried out by atomic absorption analysis by T. Winje, Department of Geology, University of Oslo (Table III).

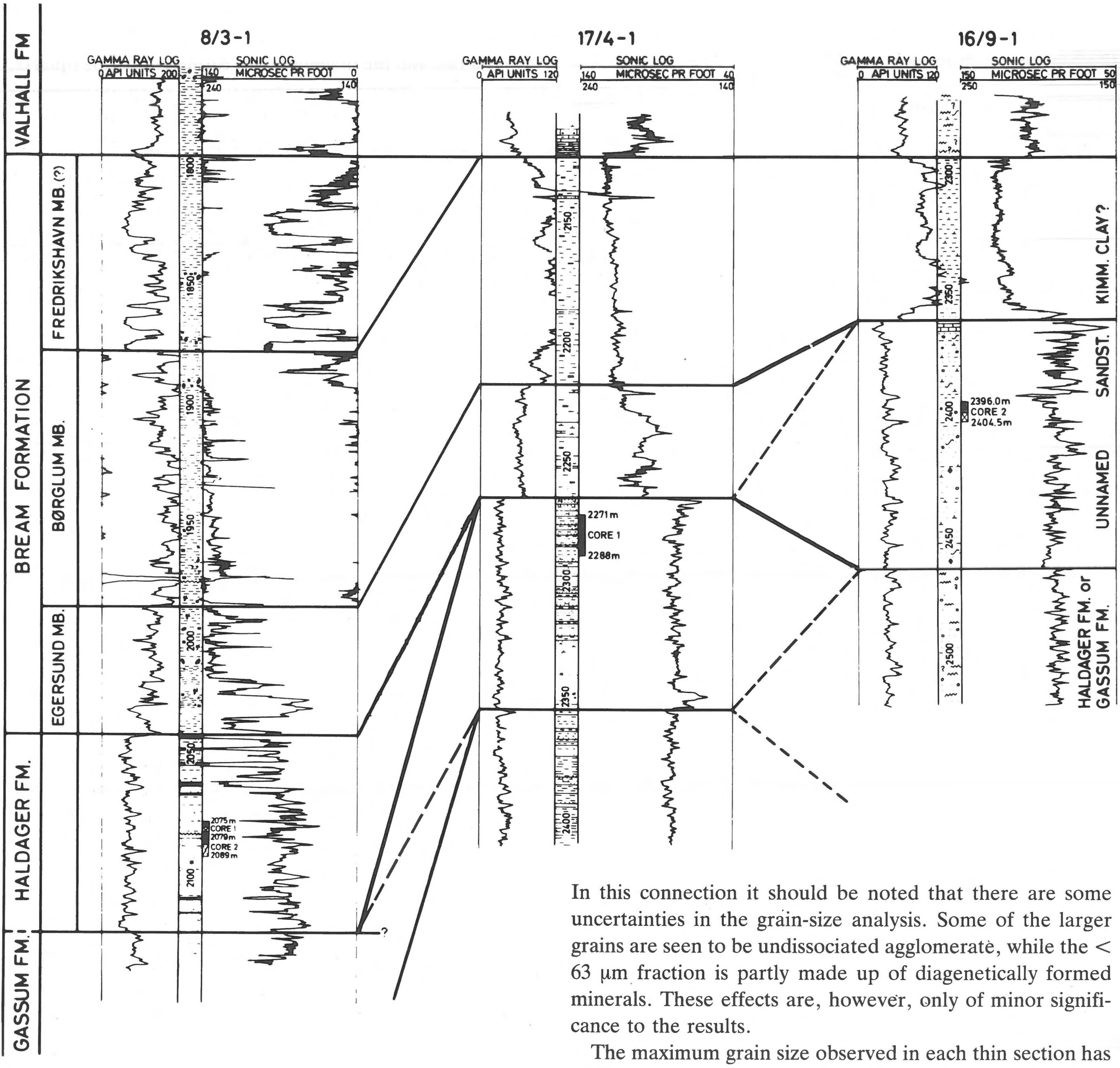


Fig. 3
Stratigraphical correlation of wells 8/3-1, 17/4-1 and 16/9-1. Modified from NPD papers 1, 11 and 14.

RESULTS OF ANALYSES

Texture

In figure 4 different grain-size distributions are shown.

The calculated grain-size parameters (FOLK & WARD, 1957) have, according to GLAISTER & NELSON (1974), some similarities with both fluviatile (point bar, braided stream) and delta-front deposits. Visually, these grain-size distributions resemble the typical delta-front deposits of GLAISTER & NELSON (1974).

In this connection it should be noted that there are some uncertainties in the grain-size analysis. Some of the larger grains are seen to be undissociated agglomerate, while the $< 63\ \mu m$ fraction is partly made up of diagenetically formed minerals. These effects are, however, only of minor significance to the results.

The maximum grain size observed in each thin section has been measured (Table I). They show upward fining sequences and partly confirm similar mesoscopically observed sequences.

Petrology

The diagenetic history of the sediments has been described in detail by DYPVIK & VOLLSET (1979). The authors found the immature sand- and siltstones to have an early-diagenetic quartz cement which subsequently had been augmented by the formation of kaolinite and calcite. During a later diagenetic stage, minor amounts of kaolinite were formed from alteration of feldspar by porewater.

In the 17 thin sections from wells 8/3-1 (core 1 and 2), 16/9-1 (core 2) and 17/4-1 (core 1), several fragments of andesite,

Table I
Mineralogical composition of core samples from wells 17/4-1, 16/9-1 and 8/3-1. Based on 400 points counted in thin section.

Well	Sample	Quartz Feld-spar	Mica	Ande-site Fragm.	Rock Fragm.	Cement matrix	Max. Grain Size (in mm)
17/4-1	1	41	10	7	7	35	—
	2	49	5	20	1	25	0.70
	4	62	15	6	2	15	0.80
	9	37	4	19	10	30	1.05
	11	65	8	9	3	15	1.83
	18	61	21	0	0	18	0.25
	20	44	2	20	3	31	1.15
	21	62	18	4	0	16	0.60
16/9-1	2	58	4	2	2	34	2.15
	5	35	—	—	—	65	0.20
	8	32	7	4	6	51	0.45
	9	66	3	5	6	20	0.85
	10	61	2	2	4	31	1.00
8/3-1	4	61	0	0	0	39	1.65
	13	61	1	0	0	38	0.60
	18	43	1	0	0	56	0.85
	22	61	1	0	0	38	0.75

granite, gneiss and mylonite have been observed in addition to grains of mono- or poly-crystalline quartz, feldspar, mica and clay minerals and the diagenetically formed minerals (quartz, calcite, kaolin, siderite and pyrite) (Table I). In the generally badly sorted, mineralogically immature sands and siltstones (Fig. 5) varying amounts of the different fragments have been observed.

In cores 1 and 2 from well 8/3-1 the Jurassic sandstones are mainly composed of angular quartz grains and mica flakes. Whereas the samples from core 2 of well 16/9-1 on average contain 3-4% andesite fragments and about 5% of other rock grains, the samples from core 1 of well 17/4-1 contain 5-20% grains of andesite and 1-10% of other rock fragments (gneiss, mylonites etc.: Table I). In addition, sandstones from wells 16/9-1 and 17/4-1 contain large amounts of quartz and weathered feldspar grains.

In thin section the green andesite fragments are seen to have suffered advanced secondary alteration to quartz, feldspar and chlorite. Marked alteration is also indicated by the rugged outline of some feldspars. The presence of feldspar

Table II
Semiquantitative mineralogical determinations from X-ray diffractograms. 14Å peak are mainly chlorite in 17/4-1, while smectite dominates the 14Å peak in 16/9-1 and 8/3-1. The 10Å peak are illite and mica in all wells while 7Å represent chlorite and kaolinite.

Well	Sample	Quartz	K-feldspar	Plagioclase	Calcite	Dolomite	Siderite	Pyrite	14Å	10Å	7Å
17/4-1	1	5	—	5	46	—	—	—	11	5	28
	4	4	—	6	8	—	—	—	10	17	55
	6	11	4	11	9	—	—	—	14	13	38
	7	8	+	7	—	—	(+)	—	18	20	47
	10	3	—	9	46	—	—	—	9	3	30
	11	6	—	7	6	—	—	—	15	18	48
	12	3	—	5	—	—	—	—	19	30	43
	14	4	—	6	—	—	—	—	20	22	48
	15	6	—	9	—	—	—	—	18	20	47
	16	9	—	7	—	—	—	—	14	21	49
	17	6	—	36	16	—	—	—	8	4	30
	19	5	—	11	14	—	—	—	16	18	36
	21	6	—	7	6	—	—	—	21	17	43
	23	6	—	7	6	—	2	—	26	25	28
16/9-1	1	13	9	5	7	15	—	+	14	5	33
	2	13	6	3	—	11	4	2	13	10	38
	3	7	3	2	28	—	—	—	17	25	18
	4	5	3	1	—	—	—	—	45	21	25
	6	2	2	2	—	—	—	—	58	8	28
	7	12	14	18	6	4	—	1	25	6	14
	8	10	8	8	12	—	—	—	20	10	32
	9	13	14	14	11	—	—	—	10	10	28
	10	11	9	5	47	—	—	—	11	5	12
8/3-1	1	9	2	+	—	—	—	—	7	6	76
	2	32	6	5	2	—	2	1	16	6	30
	4	100	—	—	—	—	—	—	—	—	—
	6	38	2	2	—	—	—	—	8	11	39
	7	17	6	+	—	—	—	+	14	15	40
	9	11	+	—	—	—	—	—	+	7	82
	13	6	—	—	—	—	—	—	—	10	84
	15	10	+	—	—	—	—	—	3	4	83
	17	16	2	—	—	—	—	—	9	4	69
	19	15	3	—	—	—	—	—	7	3	72
	21	3	—	—	—	—	—	—	—	4	93
	23	10	—	—	—	—	—	—	—	12	78

Table III
Geochemical composition of red (1A), green (samples 1B & 1C) fragments separated from sample 17/4-1, 1. IE is bulk sample. Analysed by atomic adsorption.

% main elements

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	Ign. loss	
1A	75.9	0.14	13.5	1.27	0.6	0.9	6.2	2.6	1.07	102.18
1B	75.5	0.44	10.9	4.08	2.1	1.2	4.0	0.8	2.36	101.38
1C	62.9	1.12	14.0	6.91	3.2	1.6	5.1	0.8	2.12	97.75
1E	54.0	0.44	9.3	2.35	1.0	16.1	2.7	0.7	13.71	100.3

ppm trace elements

Sample	Co	Cr	Cu	Mn	Mo	Ni	Sr	Zn	Ba
1A	37	16	102	240	50	53	70	11	294
1B	68	74	53	437	50	95	26	45	105
1C	146	85	122	740	50	146	60	91	182
1E	80	117	106	954	50	80	95	13	186

laths makes an extrusive formation most probable (Fig. 5).

Red coloured grains are also found in the samples and are rather easy to separate. In thin section they are seen to consist of quartz, plagioclase and potash feldspar, probably reflecting a granitic to granodioritic composition. Thin sections reveal a possibly intrusive or metamorphic texture (Fig. 5).

X-ray diffraction analyses

X-ray diffraction analyses have been performed on both shales and sandstones from the three wells (Table II). In table II plagioclase is seen to be present in wells 17/4-1 and 16/9-1 as well as potash feldspar in wells 16/9-1 and 8/3-1. The plagioclase probably reflects the presence of andesitic fragments in wells 17/4-1 and 16/9-1.

Most of the shales from the three wells studied contain chlorite, illite, kaolin and mixed-layer clay minerals. In addition, smectite has been detected in core samples from well 16/9-1 (Table II). The smectite may indicate limited influx from a different source area, or (more probably) diagenetic smectite formation. DYPVIK & VOLLSET (1979) described occurrences of minor amounts of diagenetic smectite in some of the samples. Lack of smectite in the other analysed cores makes a diagenetic origin most probable.

Geochemistry

One sample from well 17/4-1 was dissociated and red and green grains separated. These fractions, in addition to the bulk sample, were analysed by atomic adsorption for both main and trace elements (Table III).

Katanorm calculations show the red fragments to have a granitic affinity and the green ones to be related to andesitic rocks.

The fragments have been compared geochemically with volcanics of adjacent regions to get information concerning geochemical classification and composition compared with adjacent volcanic provinces. No major geochemical similarities have been established between the fragments and the Permian volcanics from the Oslo Region (LARSEN, 1977; NEUMANN, 1977; RAMBERG & LARSEN, 1977; WEIGAND, 1975; Segalstad, 1978, pers. comm.) or Jurassic igneous rocks from the North Sea, Scania and Western Norway (GIBBS & KANARIS-SOTIRION, 1976; HJELMQVIST, 1939; FÆRSETH ET AL., 1976). The red grains have some geochemical similarities with Tertiary rhyolites from Scotland and Iceland (GROOME & HALL, 1974; CHARMICHAEL, 1964) and granitic rock data as published by TURNER & VERHOOGEN (1960). The green fragments seem to have some similarities with Tertiary Icelandic andesites (CHARMICHAEL,

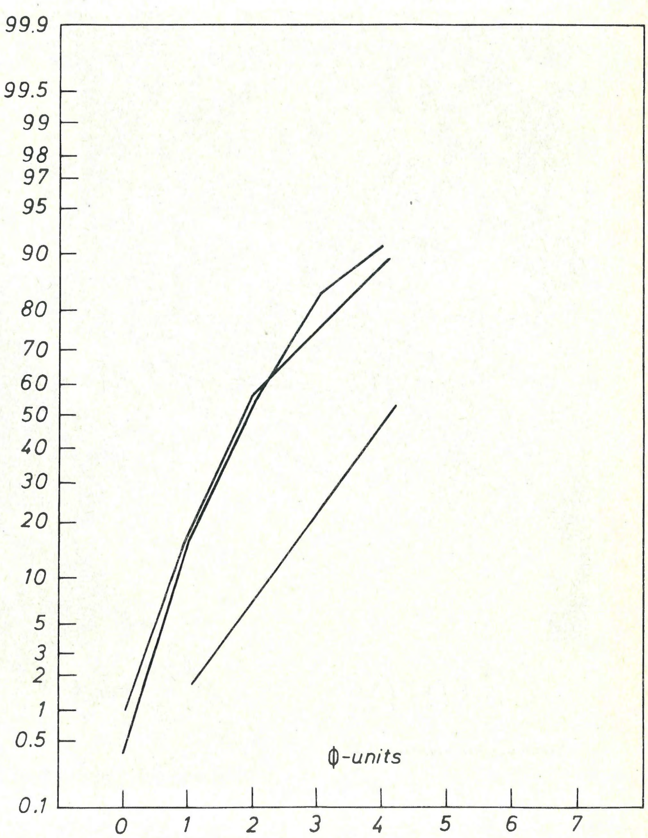
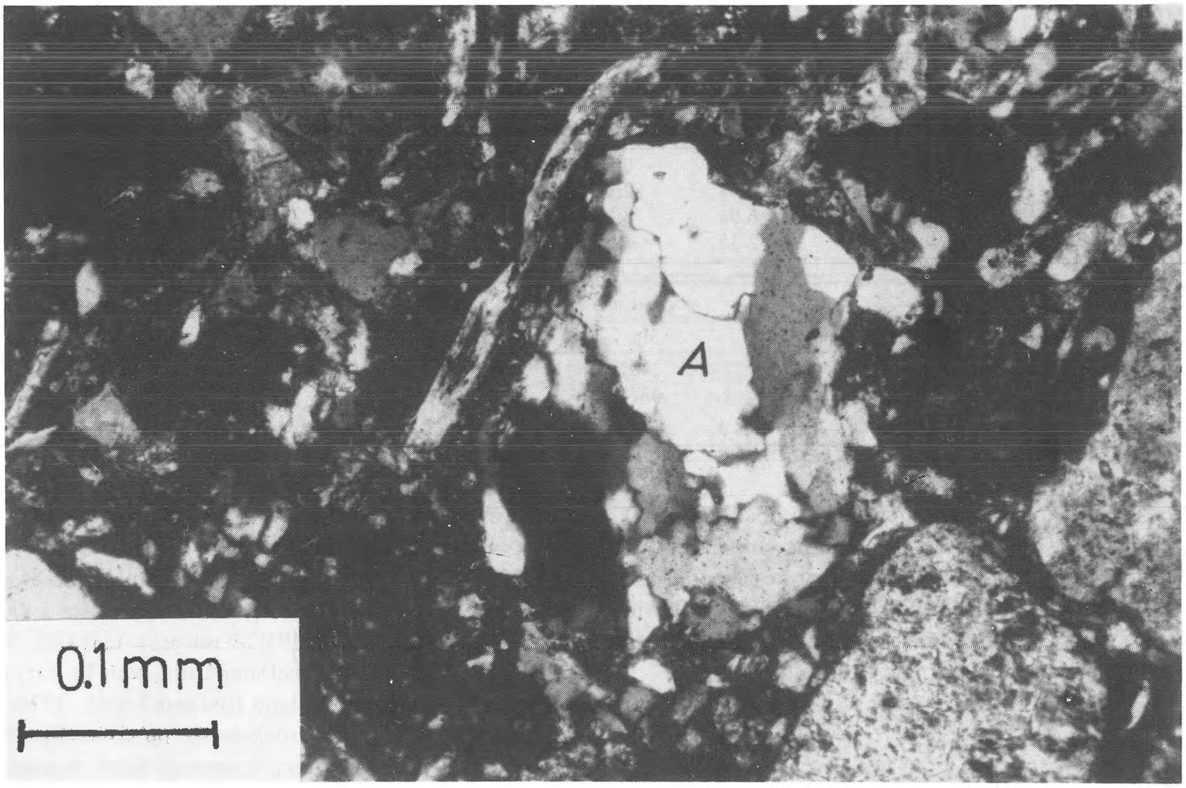


Fig. 4
Grain size distributions of samples from core 1 of well 17/4-1.



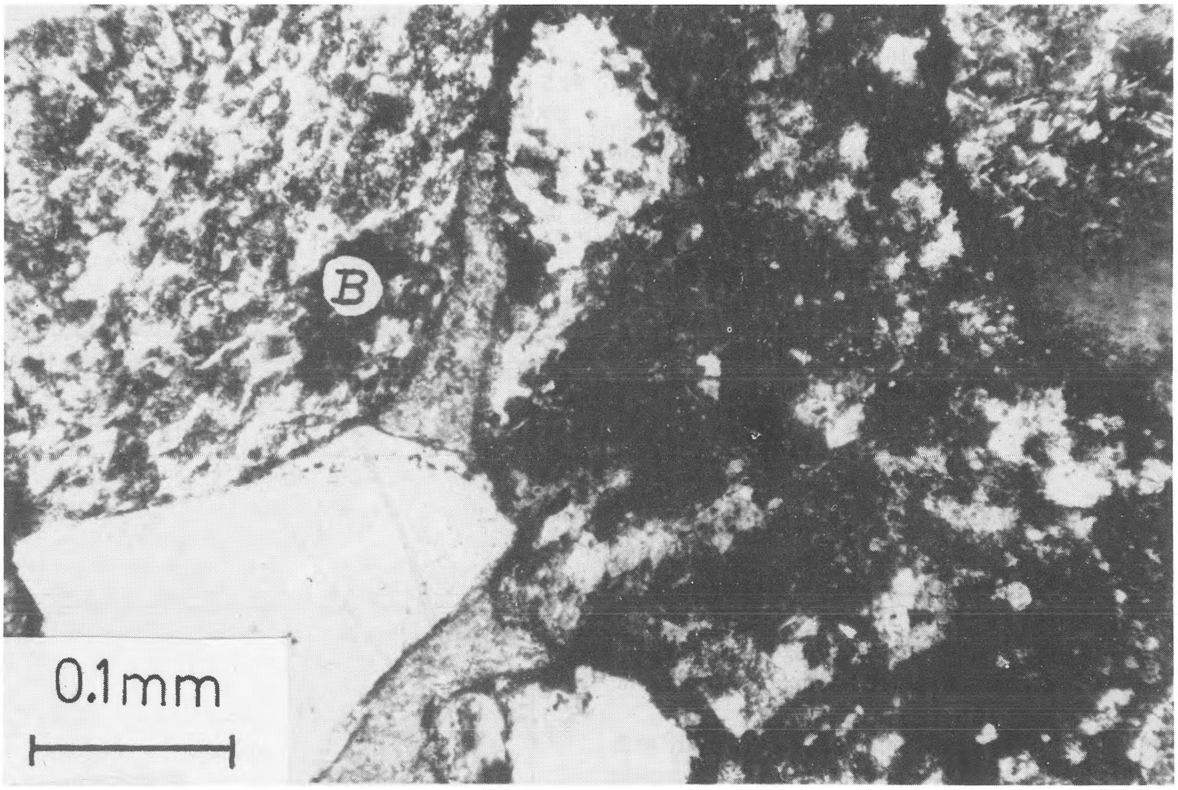


Fig. 5
Photomicrograph of thin section. The upper photo shows a granitic to granodioritic fragment (A), while an andesitic grain (B) is seen in the lower photo.

1964), New Zealand andesites (EWART ET AL., 1968) and andesites and quartz keratophyres from other areas of the world (TURNER & VERHOOGEN, 1960, p. 262, 281, 285).

However, of the possible source rocks, the geochemical analysis agree best with data for Devonian and Carboniferous volcanic rocks from England and Western Germany (TURNER & VERHOOGEN, 1960), where Devonian andesitic lavas are intruded by Carboniferous granitic dykes (DEWEY & FLETT, 1911).

DISCUSSION

Depositional environment

In the often badly sorted, immature sandstones studied, cut-and-fill, load structures and graded bedding are frequently observed. Fragments of lignite and clay clasts are often present. Lack of both root structures and typical fluviatile depositional sequences argue against a purely fluviatile environment, while lack of glauconite indicates either high sedimentation rates in a marine environment or non-marine sedimentation. These observations point towards a marginal marine, deltaic depositional regime, which also was claimed in NPD-papers 1, 11 and 14.

Sand and sandstones with the above mentioned characteristics have been found in delta-front environments in both constructive and destructive deltas (ALLEN, 1965; FISHER ET AL., 1974; KANES, 1970; MATTHEWS & SHEPARD, 1962; MORGAN, 1970; VAN STRAATEN, 1959). In these regimes, however, generally two different kinds of sands are deposited; distributary mouth bar and delta-front sheet sands. The sands from distributary mouth bars are typically badly sorted (MORGAN, 1970), while the delta-front sheet sands are well sorted because of prolonged reworking and the removal of finer grained material by marine winnowing processes (FISHER ET AL., 1974; KANES, 1970). Cut-and-fill, load cast, slumping structures, convolute bedding and turbidite-like deposits have often been observed in delta-front environments (ALLEN, 1965; KANES, 1970; MATTHEWS & SHEPARD, 1962; VAN STRAATEN, 1959). Several authors also describe occurrences of lignite fragments from such environments (COLEMAN ET AL., 1970; DONALDSON ET AL., 1970; FISHER ET AL., 1974).

Consequently, we believe the sandstone deposits of the 17/4-1 (core 1) and 8/3-1 (cores 1 and 2) wells to represent delta-front deposits, probably deposited in distributary mouth bar environments. Such a depositional environment matches well the diagenetic processes put forward by DYPVIK & VOLLSET (1979). We consider that deposition from more or less hyperpycnal currents have often taken place rather rapidly and resulted in unsorted sediments with graded bedding. Clays were deposited in periods of lower energy activity. Subsequently, such clay beds may have been eroded and then redeposited as clay clasts in later sands. In such a depositional environment glauconite is not expected because of high rates of clastic sedimentation, in contrast to deposition in holomarine environments. Wood fragments also indicate a continental affinity for the deposits. Loading phenomena and mottling of sediments may partly be the result of rapid deposition and compaction. During a transgression such delta-front deposits are succeeded by clays and silts of pro-delta slope and shelf environments. This was interpreted to be the case in the investigated area. Presence of probably marine limestone breccias or nodules in well 16/9-1 (core 2) makes a dominantly marine origin more probable here than in wells 17/4-1 and 8/3-1.

Provenance

In well 16/6-1, on the edge of the Utsira High (NPD-paper No. 9), Late Jurassic sediments (Bream Formation) are found directly on top of albite prophyres of andesitic composition. The chemical, mineralogical and petrological compositions of the albite porphyres resemble to some extent those of the green fragments. Ordovician ages were obtained by Rb/Sr dating of the albite porphyres (NPD-paper No. 9). In well 16/6-1 and also in well 8/3-1 (on the Sele High), gneiss datings giving Silurian ages (K/Ar, Rb/Sr) are present and may represent the gneissic, mylonitic and/or granitic source rocks (NPD-papers 1 and 9). These results, combined with the presence of andesite grains and with the feldspar distributions in the wells investigated, indicate that sandstones in 17/4-1 and 16/9-1 had a detritus supply from Utsira High. The potash feldspar enriched gneisses found in well 8/3-1 (NPD-paper No. 1) presumably represent a possible potash feldspar source for the overlying Mesozoic sediments. Outcrops of such gneisses on the Sele High resulted in potash feldspar enrichments in sediments derived from this area. Consequently, it seems reasonable to suppose that the sandstones from well 16/9-1 and 8/3-1 have derived some of their potash feldspar and gneiss fragments from the erosion of such rocks at the Sele High. Only minor amounts of potash feldspar have so far been detected by X-ray diffraction analysis of core samples from well 17/4-1. Therefore, probably only a minor part of those sediments were derived from such gneiss sources at the Sele High.

The 17/4-1 sandstones had probably the Utsira High as a major source, while the Sele High was probably the main source area for the 8/3-1 sandstones. The Oxfordian 16/9-1 sandstones consist of reworked older material from both the Haldager and Gassum Formations and consequently contain both plagioclase and potash feldspar. Similar mineralogic relationships seem to exist between equivalent formations in well 9/8-1 (Dypvik & Vollset, in prep.).

CONCLUSION

Based on the rather few cores studied, new information concerning the Jurassic of the Norwegian-Danish Basin has been provided. In Early Jurassic times and during and after the Middle Jurassic upheaval and erosion in the Norwegian-Danish Basin area, deltaic sedimentation probably took place.

The postulated deltaic sediments of wells 17/4-1 and 8/3-1 were built out by sedimentation in delta-front environments in Early Jurassic (17/4-1) and Middle Jurassic times (8/3-1) respectively. In such environments varying current conditions led to rapid deposition of often unsorted, water-saturated sediments. The marine reworking processes on these sediments seem to have been only of minor importance. At the adjacent Utsira and Sele Highs albite porphyres, gneisses, granites and mylonites of at least Ordovician/Silurian age, in addition to younger sedimentary rocks, outcropped and provided the source areas for these Jurassic sediments.

The 8/3-1 delta was built out mainly from the Sele High and the 17/4-1 delta from the Utsira High. The younger, probably marginal marine sands of well 16/9-1 were mainly formed by the reworking of underlying sediments, e.g. from the adjacent Gassum and Haldager Formations, resulting in the observed 'mixed' mineralogy of 16/9-1 sandstones. The sediments were later transgressed by the pro-deltaic and marine clays of the Bream Formation.

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