The Mesozoic Rocks of Andøy, Northern Norway

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The Jurassic–Lower Cretaceous sediments of Andøy are found in a small, down-faulted area on the north-east coast of the island. The Mesozoic sequence is more than 650 m thick, and rests non-conformably on weathered basement rocks. The lower part of the sequence (about 85 m thick) consists of coarse-grained sandstones interbedded with some siltstones, bituminous shales and a few coal layers. The age of this part is Middle Jurassic or earliest Upper Jurassic. On top of this are micaceous sandstones and siltstones of Upper Jurassic age, with a total thickness of nearly 300 m. The next formation consists of calcareous sandstones and siltstones (about 80 m), in part Valanginian in age, and this is followed by a formation consisting of fine-grained siltstones and shales, more than 200 m thick and probably of Lower Cretaceous age.

The Mesozoic sequence is largely marine, except for a few layers of freshwater and brackish-water deposits in the lowest part. The sediments are part of an onlap sequence which rapidly thins towards the NW. The main basin of deposition probably lay somewhere to the east, the sediments coming in mainly from the north-west. Sedimentation started as a consequence of faulting in Middle Jurassic time. Another period of faulting occurred in early Cretaceous time.

The down-faulted structure which we see to-day, with its tight pattern of NNE–SSW-trending vertical faults, probably owes its origin to the Tertiary fault movements which occurred along much of the western part of Norway as a result of continental margin adjustments to sea-floor spreading in the Norwegian Sea.

The rocks and fossils from Andøy show close affinities to the Jurassic–Lower Cretaceous deposits of East Greenland.

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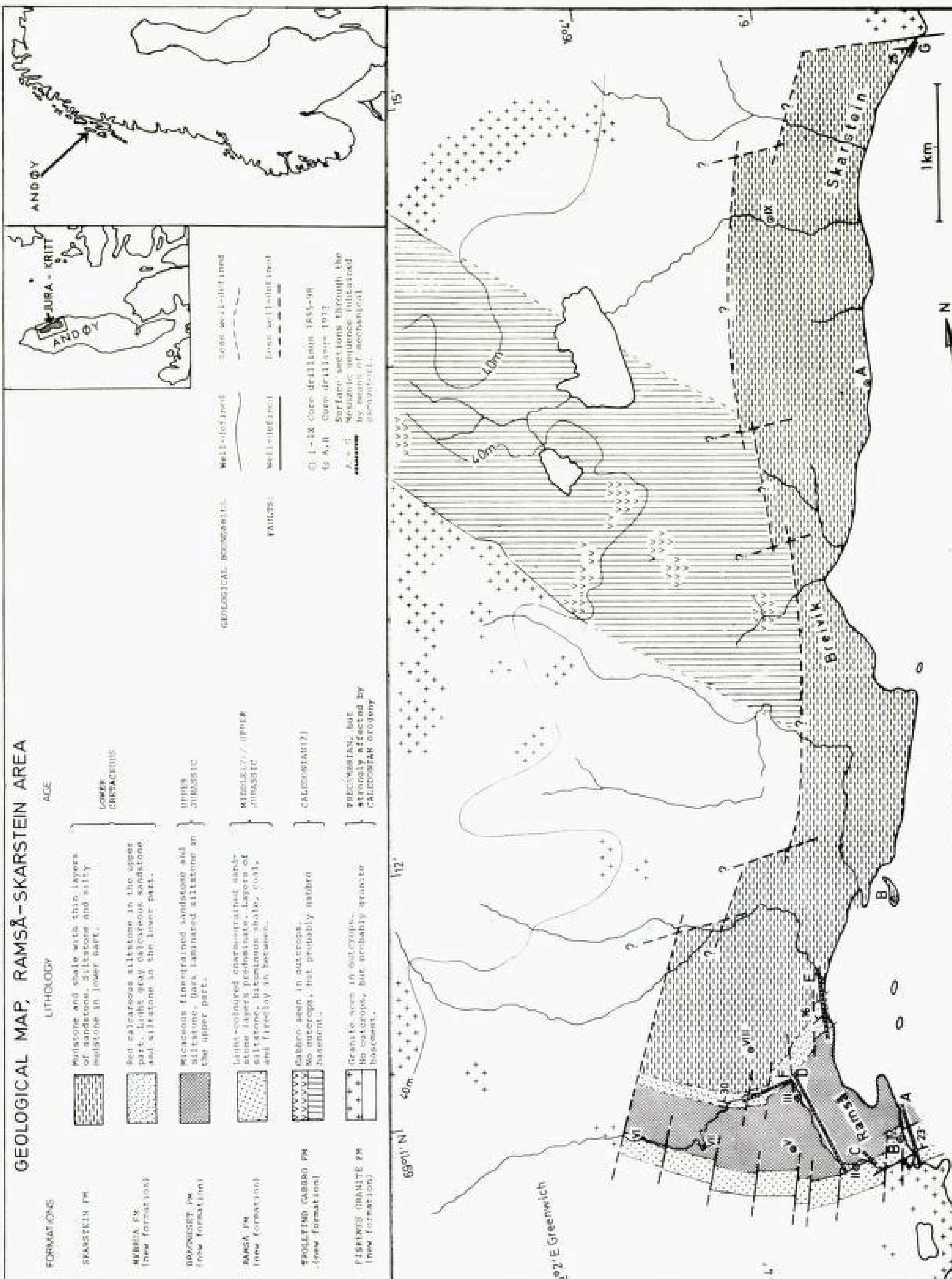
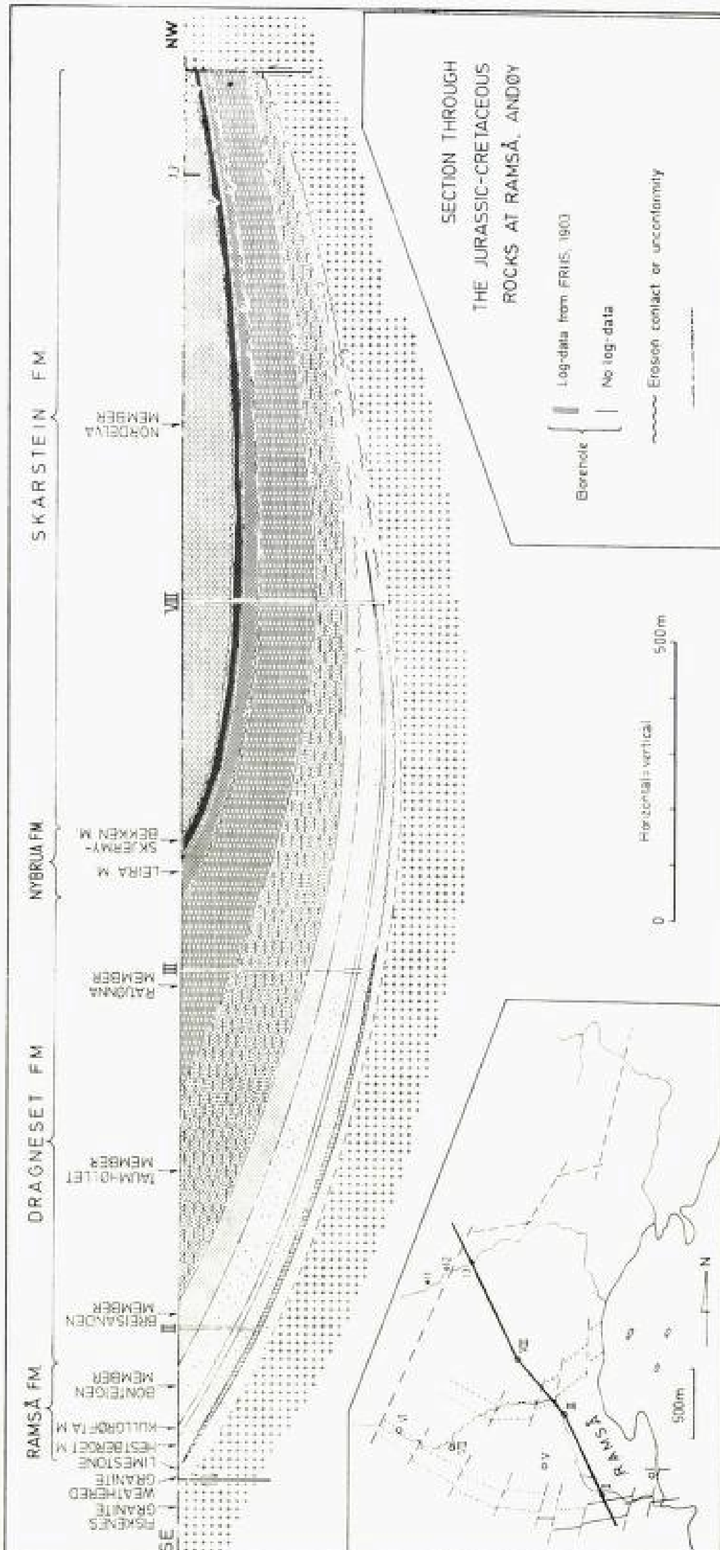
Introduction

Sediments of Jurassic–Lower Cretaceous age occupy an area of about 8 km^2 along the north-east coast of Andøy, an island situated just to the north of the Lofoten group of islands (Fig. 1). Total thickness of the sequence is more than 650 metres. The Mesozoic sediments rest unconformably on weathered basement rocks. The outcrop area is bounded by faults except to the south. To the east the sediments extends under the Andfjord and are probably continuous with the thick pile of sediments (about 5 km) proven by seismic studies in the outer part of the fjord (Sundvor & Sellevoll 1969).

The sediments have escaped erosion because of down-faulting and a tight pattern of post-Lower Cretaceous faults has created two small troughs — one in the southern and the other in the northern part of the outcrop area. The depth to basement in the middle of each of the troughs is at least 450 metres. The southern trough contains mainly rocks of Upper Jurassic age (Fig. 2), whereas rocks of Lower Cretaceous age make up the bulk of the sediments


GEOLOGICAL MAP, RAMSÅ-SKARSTEIN AREA
FORMATIONS
LITHOLOGY
AGE
SKARSTEIN FM
Mudstone and shale with thin layers of sandstone. Siltstone and silty mudstone in lower part.
NYBRUA FM (new formation)
Red calcareous siltstone in the upper part. Light gray calcareous sandstone and siltstone in the lower part.
LOWER CRETACEOUS
DRAGNESET FM (new formation)
Micaceous finegrained sandstone and siltstone. Dark laminated siltstone in the upper part.
UPPER JURASSIC
RAMSÅ FM (new formation)
Light-coloured coarse-grained sandstone layers predominate. Layers of siltstone, bituminous shale, coal, and fireclay in between.
MIDDLE(?)/ UPPER JURASSIC
TROLLTIND GABBRO FM (new formation)
Gabbro seen in outcrops. No outcrops, but probably gabbro basement.
CALEDONIAN(?)
FISKENES GRANITE FM (new formation)
Granite seen in outcrops. No outcrops, but probably granite basement.
PRECAMBRIAN, but strongly affected by CALEDONIAN orogeny
GEOLOGICAL BOUNDARIES:
Well-defined
Less well-defined
FAULTS:
Well-defined
Less well-defined
I-IX Core drillings 1895-98
A,B Core drillings 1973
A-G
Surface sections through the Mesozoic sequence (obtained by means of mechanical excavator).
JURA - KRITT
ANDØY
ANDØY
69°11' N
16°2' E Greenwich
12'
15'
16°4'
6'
4'
40m
40m
40m
Ramså
Breivik
Skarstein
ANDFJORDEN
1km
N

. 2. Section through the Jurassic–
wer Cretaceous rocks at Ramså,
døy.



; 1. Geological map of the Mesozoic
diments on Andøy, northern Norway.

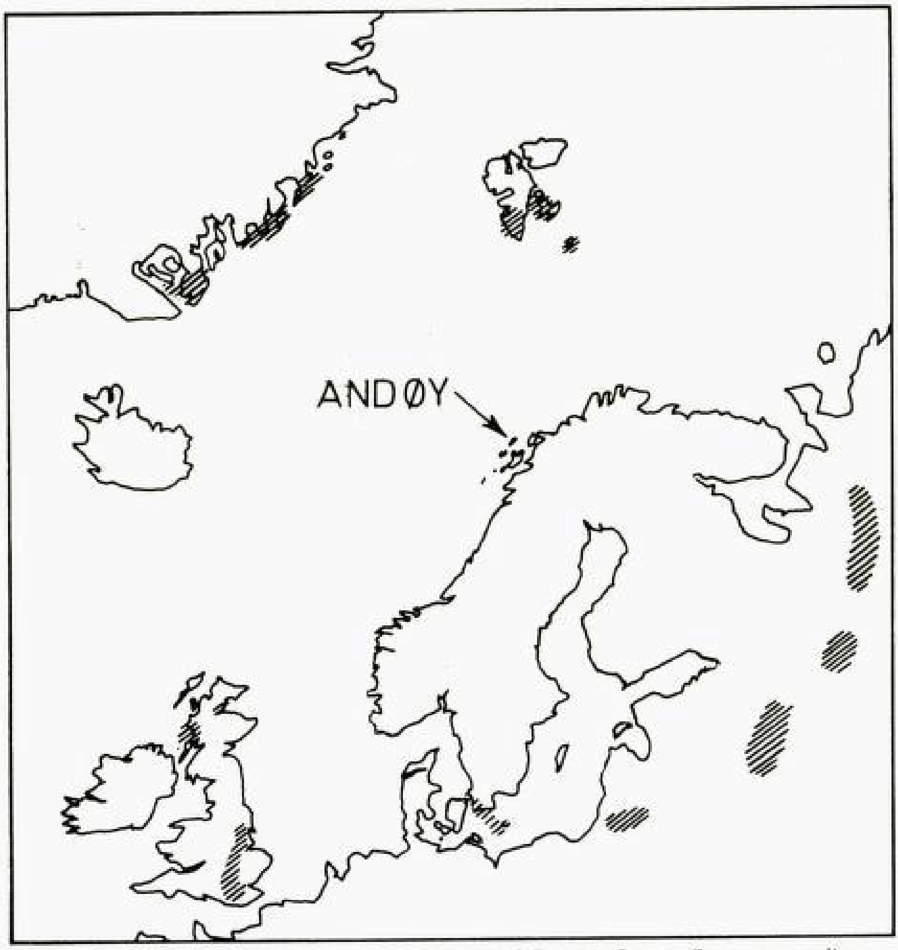


Fig. 3. Andøy in relation to the nearest outcrops of Jurassic–Lower Cretaceous sediments.

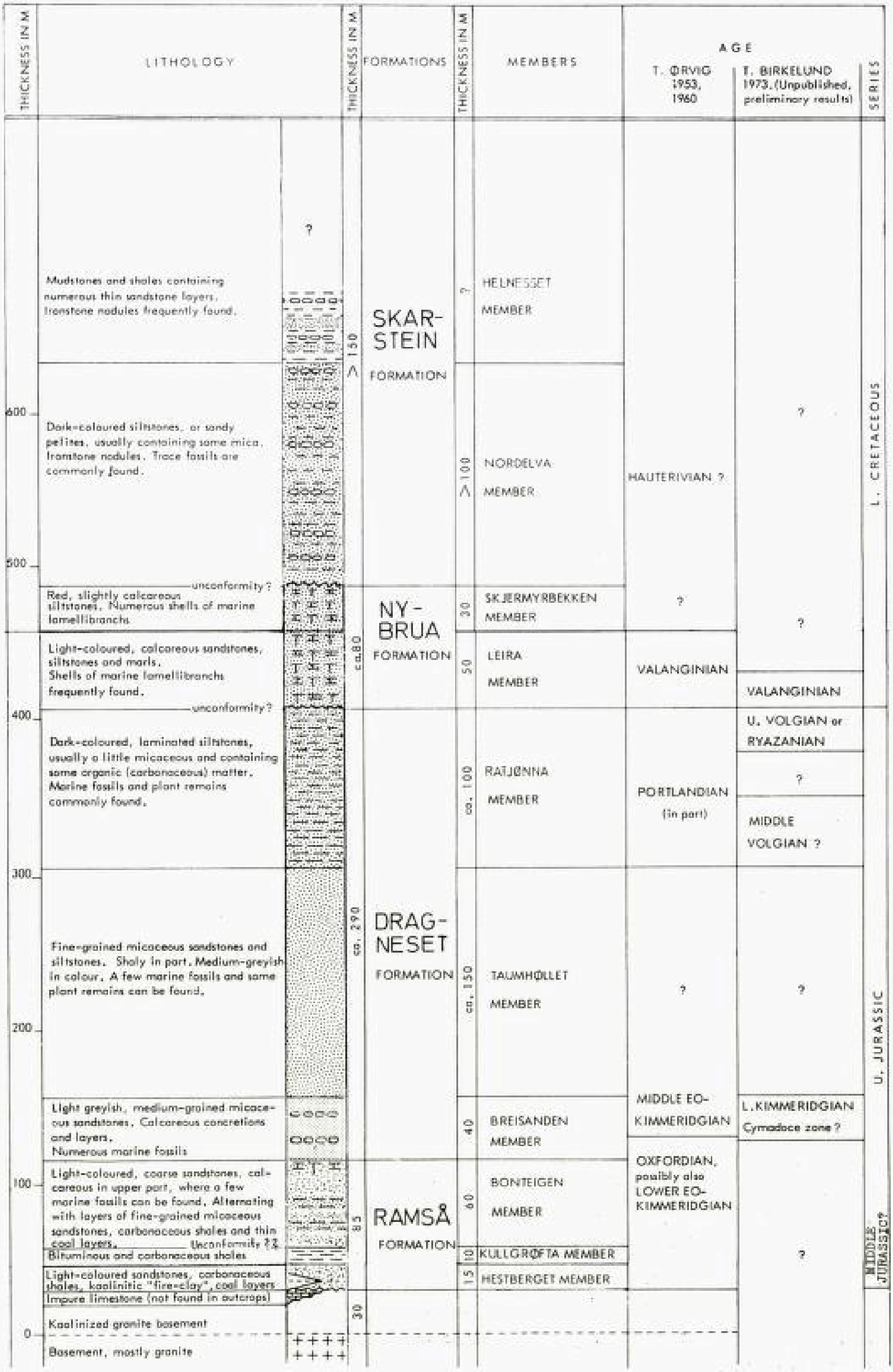
in the northern one. The two troughs are connected by an area with a thinner sedimentary cover extending across a basement high at Breivik (Fig. 1).

Andøy is the only place in Norway where outcrops of Mesozoic rocks are found. The distance to the nearest area of outcrop of sediments of the same age (Fig. 3) makes Andøy a key area for paleogeographic reconstructions, and in recent years the area has developed additional interest because of the possibility of petroleum occurring on the nearby continental shelf.

Exposures are few, and most of them are very small. Because of this, the geological picture of the area has been based mainly on the core drillings made during the late 1890's (Friis 1903; Vogt 1905). The bore-holes were sunk tc investigate the occurrence of coal in the lowest part of the Mesozoic sequence.

Some palaeontological work has been done, but only on samples from restricted parts of the sequence (Heer 1877; Mayer 1877; Lundgren 1894;

Fig. 4. Lithostratigraphy of the Mesozoic rocks of Andøy.


THICKNESS IN M
LITHOLOGY
THICKNESS IN M
FORMATIONS
THICKNESS IN M
MEMBERS
AGE
T. ØRVIG 1953, 1960
T. BIRKELUND 1973, (Unpublished, preliminary results)
SERIES
600
500
400
300
200
100
0
?
Mudstones and shales containing numerous thin sandstone layers. Ironstone nodules frequently found.
Dark-coloured siltstones, or sandy pelites, usually containing some mica. Ironstone nodules. Trace fossils are commonly found.
unconformity ?
Red, slightly calcareous siltstones. Numerous shells of marine lamellibranchs
Light-coloured, calcareous sandstones, siltstones and marls. Shells of marine lamellibranchs frequently found.
unconformity ?
Dark-coloured, laminated siltstones, usually a little micaceous and containing some organic (carbonaceous) matter. Marine fossils and plant remains commonly found.
Fine-grained micaceous sandstones and siltstones. Shaly in part. Medium-greyish in colour. A few marine fossils and some plant remains can be found.
Light greyish, medium-grained micaceous sandstones. Calcareous concretions and layers. Numerous marine fossils
Light-coloured, coarse sandstones, calcareous in upper part, where a few marine fossils can be found. Alternating with layers of fine-grained micaceous sandstones, carbonaceous shales and thin coal layers.
Unconformity ??
Bituminous and carbonaceous shales
Light-coloured sandstones, carbonaceous shales, kaolinitic "fire-clay", coal layers
Impure limestone (not found in outcrops)
Kaolinized granite basement
Basement, mostly granite
> 150
SKAR-STEIN FORMATION
ca.80
NY-BRUA FORMATION
ca. 290
DRAG-NESET FORMATION
85
RAMSÅ FORMATION
30
?
HELNESSET MEMBER
> 100
NORDELVA MEMBER
30
SKJERMYRBEKKEN MEMBER
50
LEIRA MEMBER
ca. 100
RATJØNNA MEMBER
ca. 150
TAUMHØLLET MEMBER
40
BREISANDEN MEMBER
60
BONTEIGEN MEMBER
10
KULLGRØFTA MEMBER
15
HESTBERGET MEMBER
HAUTERIVIAN ?
?
VALANGINIAN
PORTLANDIAN (in part)
?
MIDDLE EO-KIMMERIDGIAN
OXFORDIAN, possibly also LOWER EO-KIMMERIDGIAN
?
?
VALANGINIAN
U. VOLGIAN or RYAZANIAN
?
MIDDLE VOLGIAN ?
?
L. KIMMERIDGIAN Cymodoce zone ?
?
L. CRETACEOUS
U. JURASSIC
MIDDLE JURASSIC?

Sokolov 1912; Johansson 1920). Ørvig (1953, 1960) gave a summary of the earlier work in the area.

During the present investigation a mechanical excavator was used in the field work. This enabled us to obtain a nearly continuous surface through the greater part of the sequence, and it also made it easier to correlate the old bore-logs and erect formal lithostratigraphic units (Dalland 1974). The stratigraphic units are shown in Fig. 4, and a short description of each unit is given below.

Basement complex

As Fig. 1 shows, basement in the area consists largely of granite with gabbro cutting through it. The granite is probably of Precambrian age, and has been severely affected by the Caledonian deformation. The gabbro could be of Caledonian age.

Mesozoic system

WEATHERED BASEMENT COMPLEX

The basement was deeply weathered before the sedimentation started, but the weathered granite is preserved only in the southern part of the area. Here it makes up an *in situ* layer, up to 30 metres thick, consisting almost exclusively of kaolin (dickite) and quartz. The weathering profile must have taken a considerable time to form, and stable tectonic conditions and a humid climate must have prevailed. The weathering process could well have started in Early Jurassic time, or even earlier if the tectonic and climatic conditions were suitable, but probably the climate in Triassic time in the area was too dry for weathering of this kind to develop.

BASAL LIMESTONE

This limestone, up to 6 metres thick, rests on the weathered basement in a small part of the area. It is reported only from a few of the old bore-holes, and no samples exist. The age cannot be younger than Middle Jurassic. The limestone unit is poorly described in the old bore-logs. Because of its quite different lithology it is not a natural part of the overlying formation, and it ought to be better known before a formal stratigraphic designation can be given to it.

Ramså Formation (a new formation name; see Dalland 1974)

The deposition of the Ramså Formation was initiated by faulting in the area. A small, down-faulted block served as a local depocentre, and it is only close to this centre that the underlying limestone and weathered basement have escaped erosion. The first sediments to accumulate came from the nearby weathered basement, mainly from the north-west.

Some details of the various members of the formation, which were introduced and described fully in the author's thesis (Dalland 1974), are presented below.

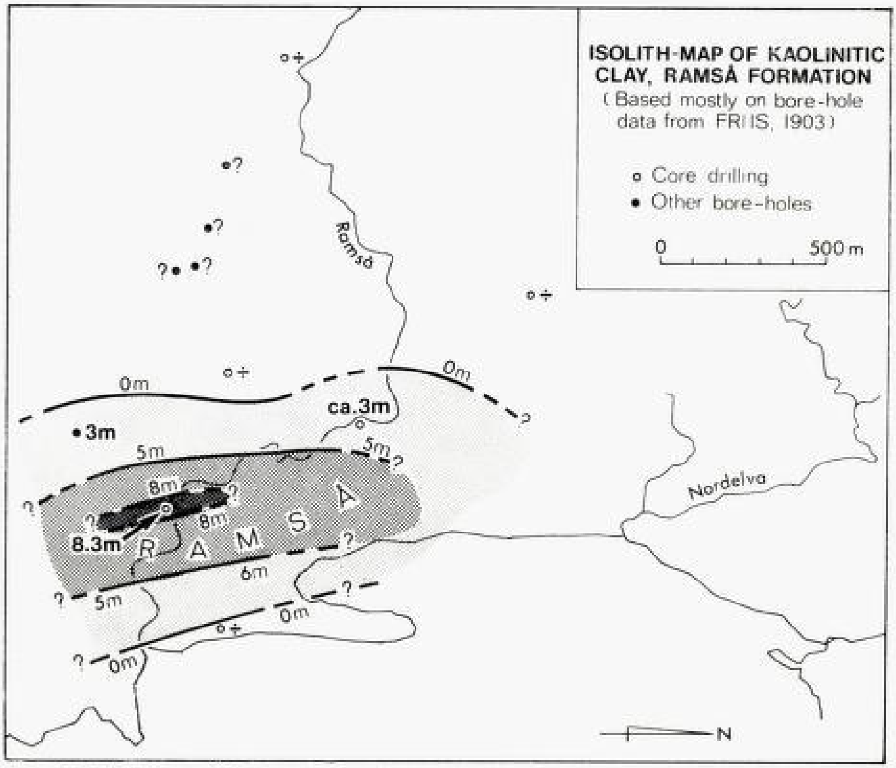


Fig. 5. Isolith map of kaolinitic clay, Ramså Formation.

Hestberget Member

The Hestberget Member consists of coarse-grained sandstone interbedded with layers of kaolin-rich shale ('fireclay'), bituminous shale, micaceous siltstone and a few layers of cannel-coal. The kaolin shales are concentrated in a very small area in the middle of the basin, and must represent outwash from the kaolin-rich weathered basement (Fig. 5). The lowest sandstone layers consist of irregular quartz grains; they contain surprisingly little feldspar, and must also be derived from the nearly feldspar-free weathered layer. There is a tendency for roundness to increase upwards throughout the member. Feldspar and garnet content also increases upwards. Garnets are common in the basement, but have not escaped the intense weathering. There is also a marked upward decrease in fireclay. This points to a gradual erosion through the weathered crust in the source area, and suggests that the source area itself moved a little further away from the depocentre as the basin became filled up. Deposition of this member could have occurred over a relatively short period of time, and there might also have been some syn-sedimentary faulting activity.

The thickness of the Hestberget Member is about 30 m in the centre of the basin, but this decreases rapidly out in all directions, especially towards the north-west. Deposition probably took place in coastal swamps with the down-faulted area acting as a lagoon for part of the time. Palynological investigations indicate a Middle Jurassic age (J. Os Vigran, pers. comm. 1973).

Kullgrøfta Member
This is a sequence consisting mainly of brownish-black bituminous shales. It also contains a few layers of micaceous siltstones and fine-grained sandstones. Except for the higher clay content, the shale layers have about the same composition as the layers of cannel-coal. The maximum thickness of the Kullgrøfta Member is about 12 m, and it thins out away from the depocentre in the same way as the underlying Hestberget Member. During the time of deposition the area was probably a shallow fresh- or brackish-water lagoon with a high accumulation of sapropel-rich mud. The age of the member is probably Middle Jurassic.

Bonteigen Member
The Bonteigen Member consists of medium- to coarse-grained sandstones, interbedded with shaly micaceous siltstones. A few layers of bituminous shale and thin coal layers are found in the middle and lower part. The sandstones in the upper part are calcareous and contain marine fossils (bivalves and belemnites). Near the top of the member a few glauconite-rich layers are present. The local depocentre can still be recognized, but the reduction in thickness outwards from this centre is not as marked as in the lower parts of the formation. Even so, the Bonteigen Member seems to thin out in all directions, and as with the lower members the thinning is especially rapid towards the north-west. The member is about 55 m thick at the depocentre, while the thickness 1 km to the north-west is only 25 m. According to Ørvig (1953, 1960) the Bonteigen Member is probably of Oxfordian age.

Conditions of deposition for the lower part of the Bonteigen Member must have been fairly similar to those suggested for the Hestberget Member. The upper part seems to represent more open marine conditions — this was probably in part high-energy shore-line sedimentation, and in part sedimentation in somewhat deeper sea-water.

An isopach map of the Ramså Formation is shown in Fig. 6, together with other distribution maps of the same sequence. Fig. 7 presents an interpretation of the local paleogeography during the deposition of the formation. The main basin probably lay to the east, in the area to-day occupied by the Andfjord. The small, down-faulted block which became the local depocentre must have been subsiding continually during deposition. The source area for much of the sediment was located at a short distance to the north-west of this small basin, and the entire outcrop area seems to be part of an onlap sequence marginal to the larger basin to the east.

Dragneset Formation
The lowest part of Dragneset Formation (Dalland 1974) consists of medium- to fine-grained sandstones. The middle part is a fairly monotonous sequence

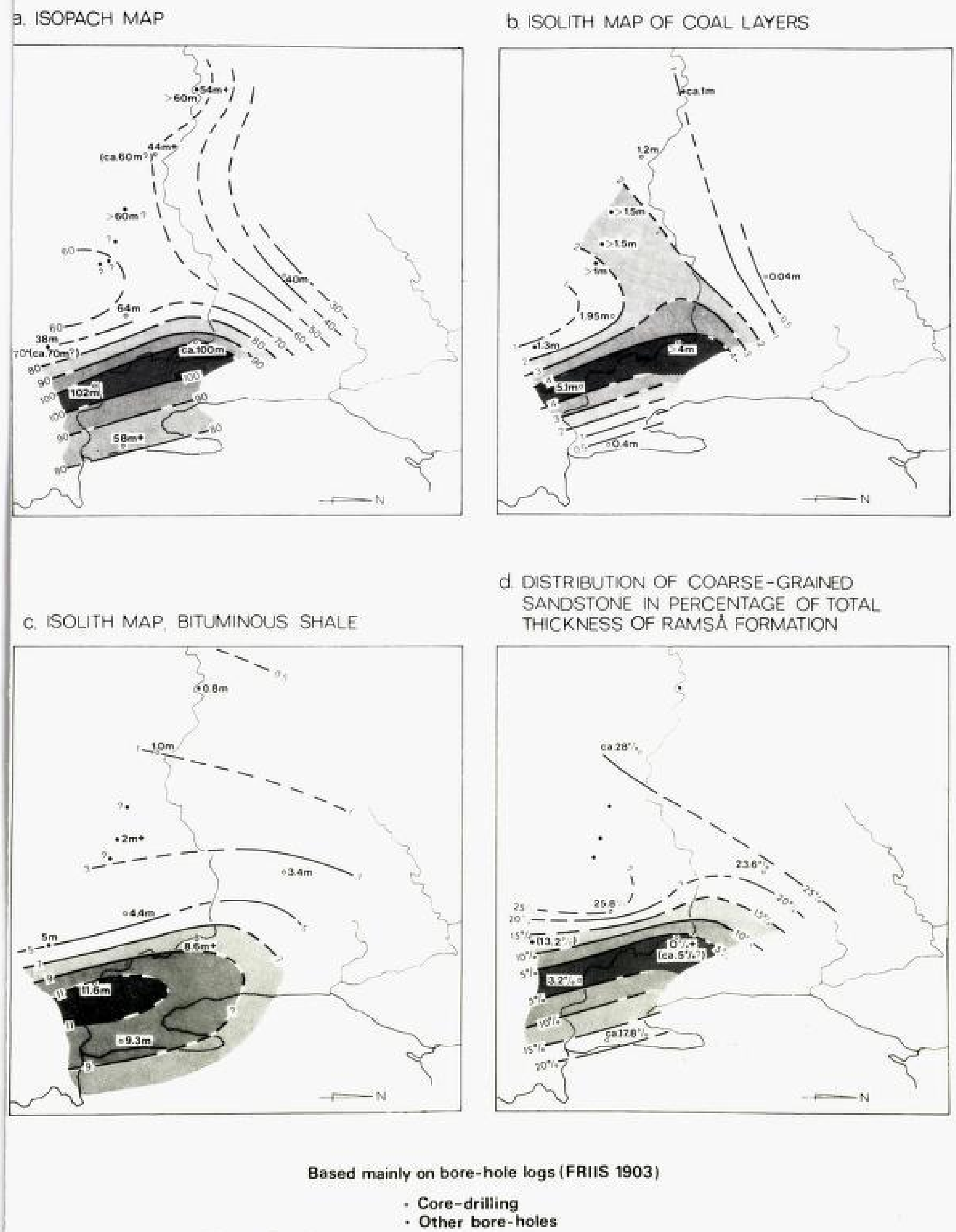


Fig. 6. Distribution maps, Ramså Formation.

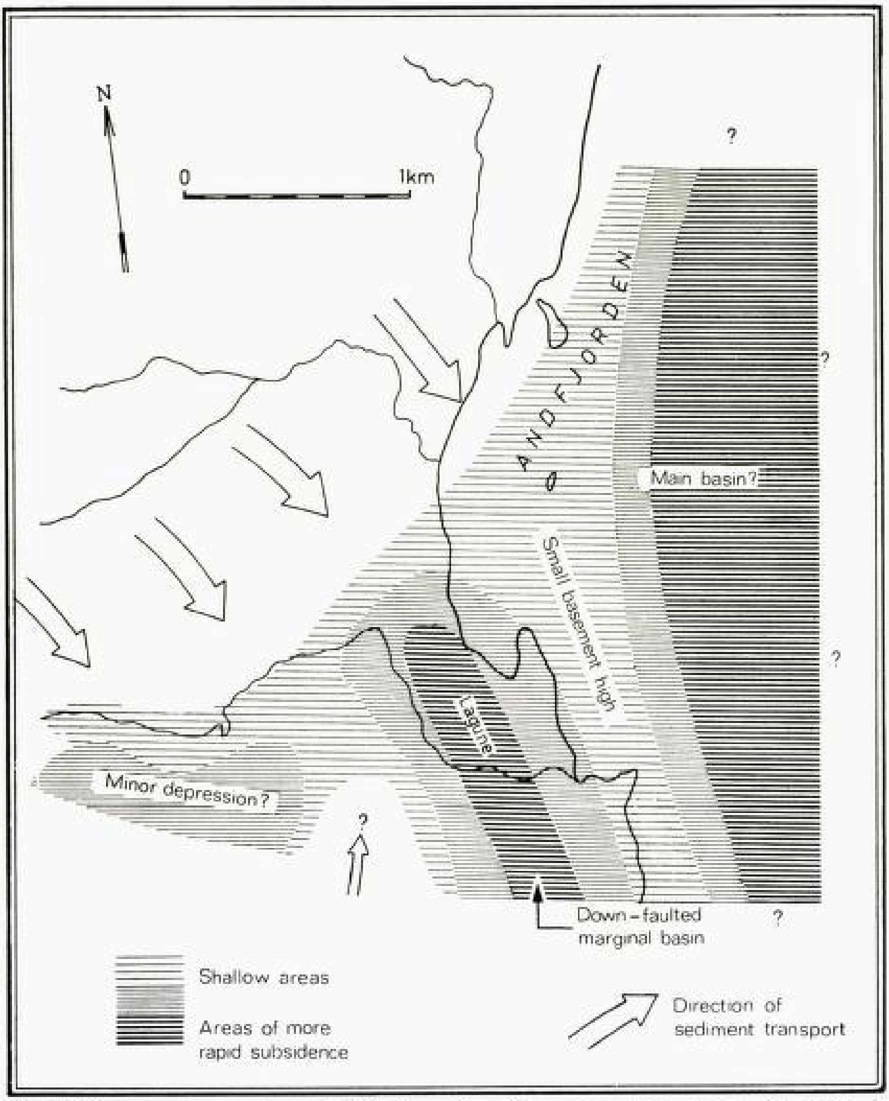


Fig. 7. Basement topography and directions of sediment transport during deposition of the Ramså Formation.

of siltstone and fine-grained sandstone layers, while the upper part is dominated by layers of shaly siltstones. A high content of muscovite is typical for the whole formation. No coarse-grained sandstones are found. The thickness of the formation is up to 290 m. The Dragneset Formation is divided into 3 members.

Breisanden Member

The Breisanden Member consists of layers of medium- to fine-grained sandstone. Some of the layers are a little calcareous and large concretions are common. Many beds contain abundant marine fossils — bivalves, ammonites and belemnites are the most common. A few vertebrate remains have been found. Glauconite-rich layers occur in the lower part. The thickness is up to 40 m, the member thinning out north-westwards as with the underlying members.

Deposition of the lowest part of the member probably took place in an open marine environment, a little below the limit of the littoral zone. The upper part seems to have been deposited in a bay or lagoon with a connection to the sea.

The Breisanden Member may be correlated with the *Rasenia cymodoze* zone of the Lower Kimmeridgian (T. Birkelund, pers. comm., 1973).

Taumhølet Member

The Taumhølet Member consists of micaceous siltstones and fine-grained sandstones. Some of the layers are shaly, but lamination is not common. The colour is dark grey, due to the presence of finely dispersed plant material. A single thin layer, which seems to contain volcanic material, is observed in the lowest part. Marine fossils are found throughout the member, but there is a very limited number of different species. The maximum thickness of the Taumhølet Member is about 150 m in the outcrop area.

Conditions of deposition are not quite certain. The fossil fauna suggests a somewhat restricted marine environment, possibly brackish water. It could perhaps be a mud-flat deposit, or alternatively the member may have been deposited in a shallow, brackish-water lagoon.

The age is also a little uncertain; the whole sequence could have been deposited within Kimmeridgian time, but it is not unlikely that at least the upper part is younger than that (Lower Tithonian or Lower Volgian). It has not been possible to detect any major sedimentological break or unconformity either within or at the bottom or top of the Taumhølet Member, but the very bad exposure in the area makes observation difficult.

Ratjønna Member

Dark, partly laminated, siltstone layers predominate in this member. The dark colour is mainly due to the presence of dispersed plant material. The Ratjønna Member contains abundant marine fossils. Ammonites, bivalves (especially *Aucella* forms) and belemnites are common. The thickness of the sequence in the Ramså area is about 100 metres. Layers of hard, light sandstone occur in the upper part. These layers are slightly calcareous. Small-scale cross-bedding and concentrations of transported shell material are common within the layers. This, together with the lense-shaped cross-section of most of the layers, suggests that these sandstones represent infill deposits of small tidal channels. The dark, shaly siltstone that characterizes most of the sequence was probably deposited in somewhat deeper water. The laminated parts could indicate a deficiency in oxygen at the bottom of the basin during deposition.

According to T. Birkelund (pers. comm. 1973) the age of the lower part of the Ratjønna Member could be Middle Volgian, while the upper part is of

Upper Volgian age; the uppermost layers of the member may also contain sediments of Berriasian age, but this is still uncertain.

The boundary between the Dragneset Formation and the overlying Nybrua Formation seems to represent an unconformity or at least a period of non-deposition.

Nybrua Formation

The Nybrua Formation (Dalland 1974) consists of calcareous sandstones and siltstones. The thickness of the formation is a little less than 80 m; it is divided into two members.

Leira Member

Layers of hard, calcareous sandstone with softer intercalations of siltstone predominate in this member. The siltstone layers are also a little calcareous and commonly contain concretions. Fossils of marine pelecypods are common (*Aucella* types dominate). The shell material is often fragmentary and shows signs of transportation. Deep vertical burrows are common in many of the sandstone layers. Very little plant material has been found.

The age of the Leira Member is Valanginian. Many of the sandstone layers seem to have been deposited on a shore, exposed to the open sea, while most of the siltstone layers may have been deposited just below the littoral zone.

Skjermyrbekken Member

The Skjermyrbekken Member consists of brownish-red siltstone. In addition to the colour, slump structures are the most characteristic feature, and these are found throughout the sequence in the outcrop area. Because of the presence of these slump structures, original layering is difficult to find. A few, often fragmented belemnites and badly preserved lamellibranch shells are present. Plant material has not been observed. The thickness of the sequence is up to 30 metres.

The age of the Skjermyrbekken Member is uncertain, but as there seems to be a gradual downward transition at the lower boundary, it is probably fairly close to that of the Leira Member (?Valanginian–Hauterivian).

Deposition must have taken place in a marine environment, not very different from that in which the siltstones of Leira Member were deposited. Small relics of greenish-grey coloration can be found within the rock, and these parts very much resemble the siltstones in the underlying Leira Member. The red colour is almost certainly secondary; this could probably have originated during a very short period of uplift and weathering. Oxidizing conditions within the bottom sediment shortly after deposition could also have caused the change in colour (by oxidizing Fe^{++} minerals), and the process of slumping could perhaps have played a role here. The slump structures are indicative of faulting activity in the area shortly after deposition.

Skarstein Formation (Ørvig 1960)
The Skarstein Formation, which lies probably unconformably upon the Skjermyrbekken Member, consists of dark, fine-grained rocks — siltstones and silty shales in the lower part, mudstones, shales and thin beds of sandstones in the upper part. The total thickness is unknown, although it must exceed 200 m. The formation is divided into two members.

Nordelva Member
Dark siltstones and silty shales and mudstones predominate in the Nordelva Member (Dalland 1974). Most of the beds contain a few per cent of white mica (muscovite/sericite). Sideritic concretions, most of which display an internal system of carbonate-filled cracks, are common. Besides finely dispersed plant remains, a few imprints of small leaves have been observed. Trace fossils are common, and belemnites, ammonites and bivalve fossils have been found. The thickness of the Nordelva Member is at least 70 metres.

The sequence was deposited in a marine environment; perhaps in somewhat deeper water than for most of the underlying formations. The plant remains indicate that the distance to the nearest shore-line was short. The precise age of the Nordelva Member is not known (?Hauterivian–Aptian).

Helnesset Member
The Helnesset Member (Dalland 1974) consists of dark shale and mudstone with a few interlayers of sandstone. The sandstone layers show graded bedding and other structures commonly found in turbidity current deposits. Concretions of the same type as those found in the Nordelva Member are common. The fine-grained rocks contain a fairly large amount of dispersed organic material. A few marine fossils are found, and trace fossils are common. The thickness of the member is at least 125 metres.

Microfossils indicate an Aptian age, at least for the upper part of the member (Bergsaker 1973, information given at the Bergen Oil Conference). The sediments were probably deposited in deep water, in part by turbidity currents.

Structure

BASEMENT COMPLEX

Brecciated zones, most of them approximately vertical and trending N–S, have been observed in the basement close to the Mesozoic outcrops. The age of the deformation which produced these zones is unknown.

MESOZOIC SYSTEM

Sedimentation during this time was tectonically controlled. Faulting probably began in late (?) Middle Jurassic time, and lasted perhaps until early Late Jurassic. Another period of faulting occurred in the area in Early Cretaceous time (?Hauterivian–Aptian).

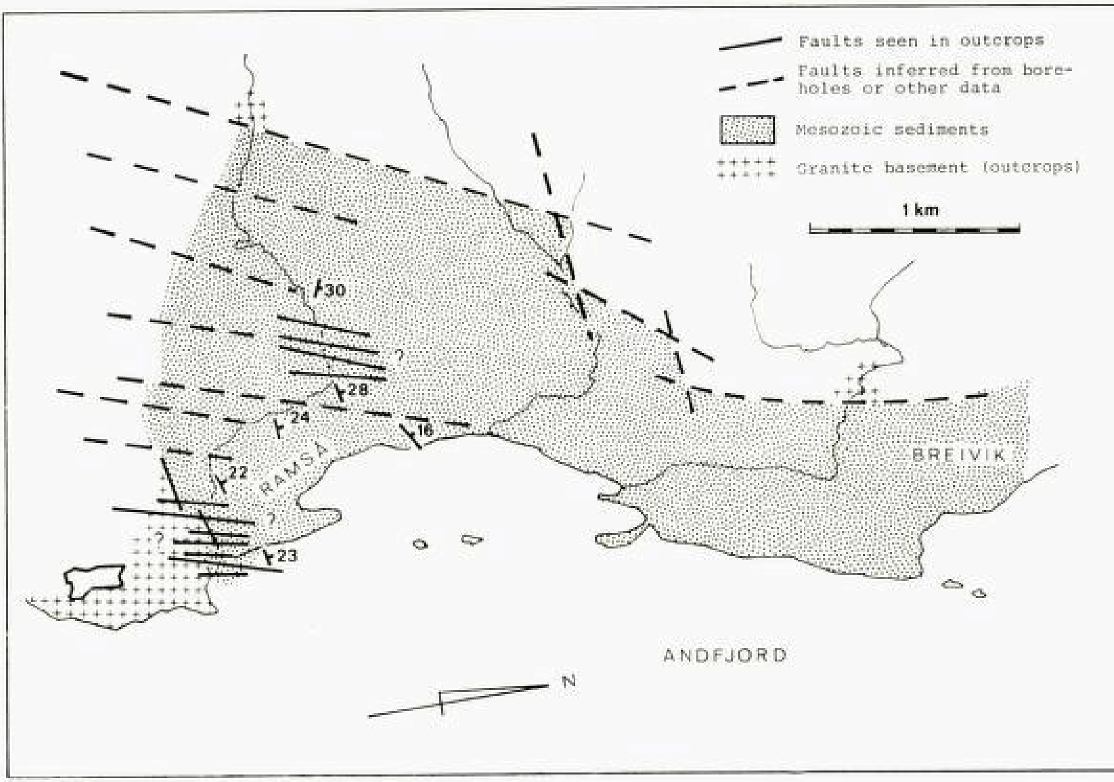


Fig. 8. Fault pattern, Ramså area, Andøy.

Most of the faults shown in Fig. 8, however, must be of post-Early Cretaceous age. These faults are probably part of the Tertiary fault system which occurs along much of the western part of Norway, and which is thought to have developed as a consequence of continental margin adjustments following sea floor spreading in the Norwegian Sea area. Nearly all the faults are of small displacement and are nearly vertical; their main direction is NNE–SSW, but E–W trending faults are also observed. Limited exposure makes it difficult to trace the faults, but judging from their concentration in the Ramså area (Fig. 8) where they are easiest to detect, the pattern must be extremely dense.

The faults, of course, are not restricted to the Mesozoic sediments, but they are much more difficult to detect in the basement rocks. The tight fault pattern suggests that the outcrop area at Andøy is situated within a NNE–SSW-trending zone of very intense Tertiary faulting.

The Tertiary faults to some extent are likely to follow earlier fault lines, as there are indications that the approximate N–S direction was also dominant for older fault systems.

As mentioned, the faulting has produced two small graben or trough structures in the outcrop area. The numerous fault blocks make the structure complicated, but in general the sediments seem to be dipping with angles of 15°–30° towards the centres of the troughs.

A section through the southern trough is shown in Fig. 3. This section also shows the rapid north-westward pinching out of the lower part of the sequence. Almost all the faults are omitted in this diagram.

Relationship to other areas

The Mesozoic rocks and fossils of Andøy show closer affinities to the Jurassic–Lower Cretaceous deposits and fossils of East Greenland (Aldinger 1935; Spath 1935, 1936; Donovan 1957; Surlyk et al. 1973) than to any other of the outcrop areas shown in Fig. 3, but as Norway and Greenland were juxtaposed in the pre-drift situation, this is really no surprise. Most of the outcrop areas of East Greenland were originally situated just a little to the south-west of Andøy. As on Andøy, most of the faults which affect the Mesozoic rocks of East Greenland trend in about N–S direction.

Fig. 9 shows the possible relationships of the outcrop area on Andøy to the nearby shelf sediments. Sediments are about 5 km thick in the outer part of Andfjord and probably continue into the fjord (Nysæther et al. 1969; Sundvor & Sellevoll 1969, 1971; Sellevoll 1972, Fig. 4). Little is known about the structures and sedimentary thicknesses along the submerged part of the section, and the structural interpretation presented in Fig. 9 must therefore be considered as tentative.

Petroleum prospects

Potential hydrocarbon source rocks on Andøy are the bituminous shales near the base of the sequence (Fig. 6c). The much thicker Lower Cretaceous shales and mudstones are also of interest as possible source rocks.

Porosity measurements of Jurassic sandstones give values between 12 and 30%, but the porosity of the samples has probably been affected by weathering.

The fine-grained Cretaceous rocks in the upper part of the sequence could act as sealing horizons.

Signs of gas have been reported from bore-holes (core-drillings, 1972–73, by the local company Norminal — at least one of the holes was drilled down to below 500 metres), but the fault pattern and the small size of the outcrop area do not favour the occurrence of hydrocarbons on land.

Nevertheless the area is important, as it provides some idea of the rock-types and structures that one can expect to find on the nearby shelf. Especially in Andfjord and in the area just to the north of the fjord, the depositional and structural history of Jurassic–Lower Cretaceous times could be very similar to that known from Andøy. Sedimentation was probably controlled by the same pattern of mainly N–S trending fault lines. The faults probably dissected the area into long, troughlike basins, with considerable

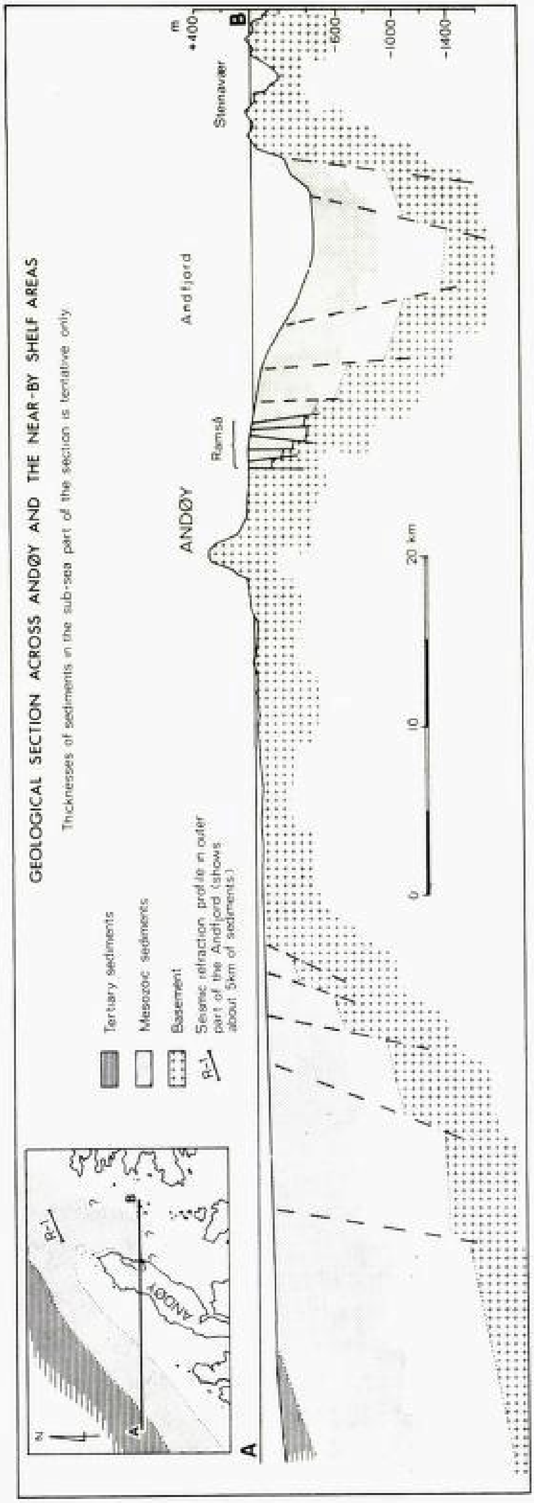


Fig. 9. Geological section across Andøy and the nearby shelf areas.

thicknesses of Mesozoic and perhaps also older sediments occurring just to the north of Andfjord.

If the Jurassic–Cretaceous sediments in this area of the shelf are of the same types as those occurring on Andøy, and if the structural conditions are favourable, than the area could be highly prospective.

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