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PETROLEUM GEOLOGY OF THE GORM FIELD, DANISH NORTH SEA[1]

C. HURST[2]

ABSTRACT

Hurst, C. 1983 Petroleum geology of the Gorm field, Danish North Sea. In: J. P. H. Kaasschieter & T. J. A. Reijers (eds.): Petroleum geology of the southeastern North Sea and the adjacent onshore areas (The Hague, 1982) – Geol. Mijnbouw 62: 157-168.

The Gorm field is located within the Central Graben of the North Sea. It is a broad, domal, salt-induced structure of 750 ft closure, cut by a major, NNE-SSW striking, normal fault. The downthrown, western A block is dissected by high angle, tensional faults while the upthrown, eastern B block is relatively unfaulted. Downthrow of the A block appears to have been accompanied by a southward tilt relative to the B block.

The reservoir rock comprises high porosity, low permeability, Danian and Maastrichtian chalks which are in pressure and fluid equilibrium. The upper Maastrichtian, with porosities of 30-40%, contains the bulk of the reservoir volume, porous Danian also contributing significant volume in the B Block.

Gorm is an undersaturated oil reservoir with no initial gas cap and an oil column of up to 500 ft. Fluid levels are horizontal in the B block and apparently dipping to the south in the A block. To date, production performance in A block wells is better than that in B block wells.

INTRODUCTION

Location

Denmark's established oil and gas fields are situated in the southern part of the Central Graben of the North Sea (Fig. 1). The area is flanked to the east by the Ringkøbing-Fyn High and to the west by the Dogger High. The sediments of the Central Graben consist of thick sequences of Permian to Recent deposits.

To date, all Danish fields comprise Chalk reservoirs, but hydrocarbon shows have also been encountered in Jurassic sediments penetrated in exploration wells.

Structural closure of the Chalk has been caused by diapirism of Permian salt and Jurassic shale. Salt and shale movement has been extremely active in this area of the North Sea resulting in local stratigraphic and structural variations, superimposed on regional trends.

Two major types of structural configuration can be recognized in Danish Chalk reservoirs, each representing a different stage of diapirism:

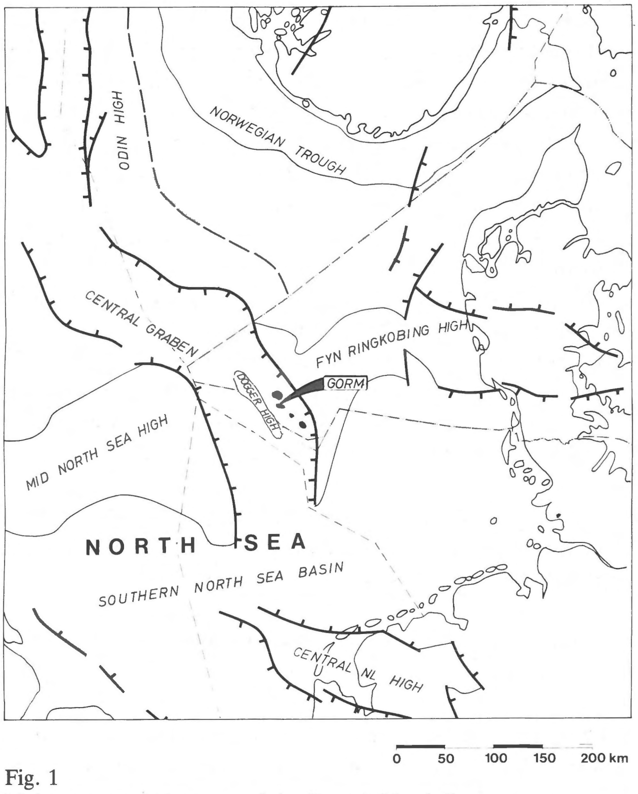

Fig. 1
Main structural elements of the Danish North Sea sector.

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[1] Manuscript received: 1982-11-27.

[2] Dansk Boreselskab A/S, Esplanaden 50, 1263 Copenhagen K, Denmark.

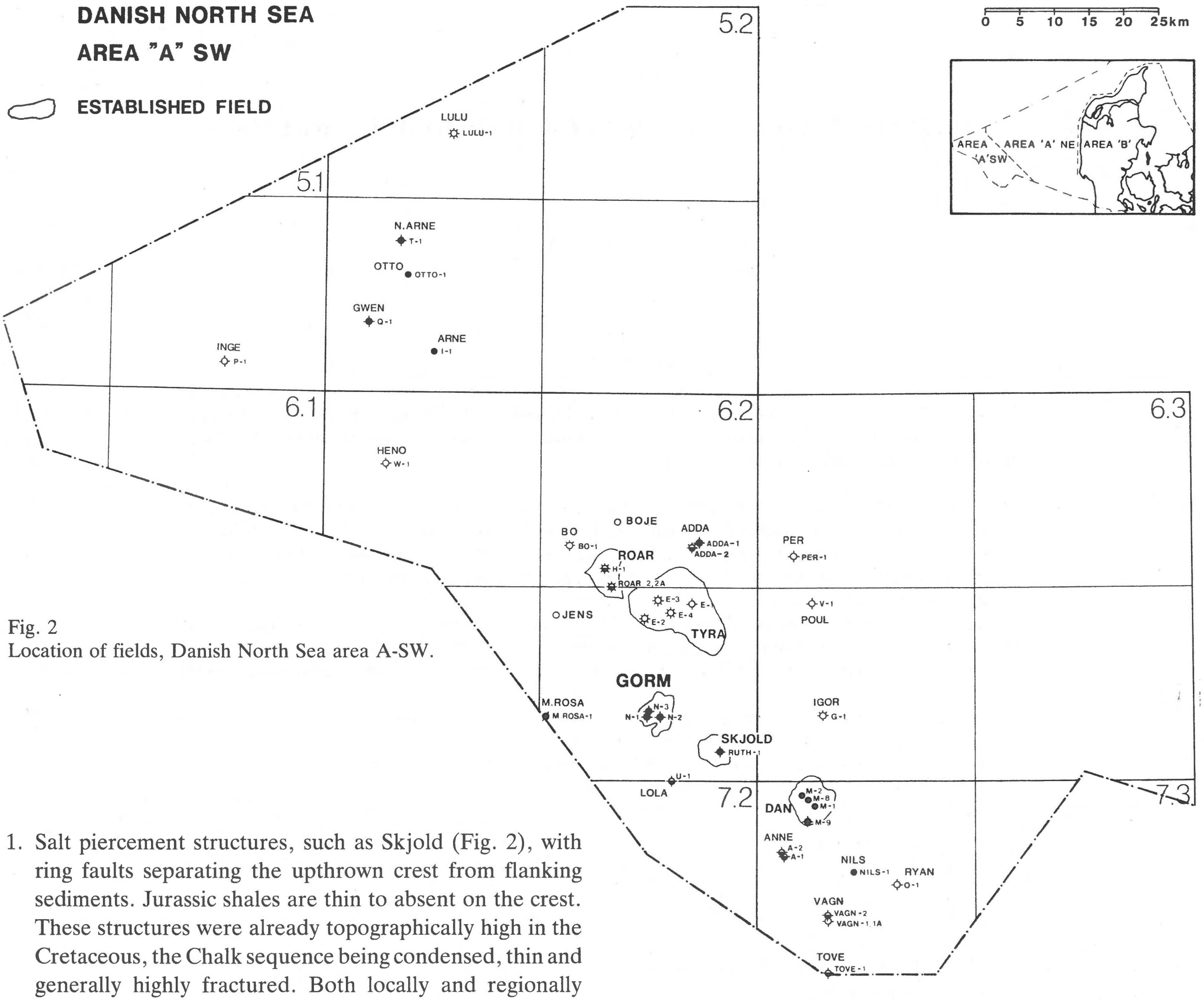


Fig. 2
Location of fields, Danish North Sea area A-SW.

1. Salt piercement structures, such as Skjold (Fig. 2), with ring faults separating the upthrown crest from flanking sediments. Jurassic shales are thin to absent on the crest. These structures were already topographically high in the Cretaceous, the Chalk sequence being condensed, thin and generally highly fractured. Both locally and regionally there is great lateral variation in stratigraphy and rock quality, indicating a complex sedimentary and diagenetic history.
2. Broad, flat, salt or shale induced, anticlinal structures, such as Dan, Gorm and Tyra. Thick sequences of chalk were deposited over topographically low structures. Correlation can be made from field to field indicating uniform conditions of sedimentation. Denmark's major established fields are included in this category (Fig. 2).

Overlying Paleocene shales and clays act as cap rock, which in some cases appears to have been fractured allowing escape of light hydrocarbons to shallower horizons.

General characteristics of the Gorm field and brief history of discovery and development

Gorm is a broad, dome shaped anticline which has a maximum closure of 750 ft and is 5 km wide with formation dips of up to 10° (Fig. 3).The structure is dissected by a major, north northeast – south southwest striking fault with downthrow to the west. This fault is used to divide the field into a western A block and an eastern B block. The A block is heavily dissected by high angle, tensional faults while the B block appears relatively unfaulted. Reservoir rock comprises Danian and Maastrichtian chalks. These are informally subdivided in D_1, D_2, M_1, M_2, etc., based on porosity log response (Fig. 4). Figure 5 shows two cross-sections SW-NE and SE-NW, illustrating the structural configuration of Gorm and the lateral variation in reservoir units.

Gorm is an undersaturated oil reservoir with no initial free gas cap. The primary recovery mechanism is solution gas drive. A hydrocarbon column of up to 500 ft is enclosed within the structure. Fluid contacts are parallel and apparently horizontal in the B block while they are approximately 100 ft lower in the southwest than in the northeast of the A block. As is frequently the case, well control is restricted to structurally high locations; unit thickness, rock quality and fluid levels downflank being inferred only.

Gorm was discovered in June 1971 by DUC with the exploration well N-1X drilled in the southwest of the A block (Fig. 3). The well encountered an oil column of 225 ft and reached a total depth of 8048 ft.ss having drilled 1250 ft of chalk. The crests of the B and A blocks were appraised with N-2 and N-3 wells drilled in 1975 and 1976, respectively. These encountered oil columns of 415 ft and 360 ft and confirmed that a significant amount of oil was present in both A and B blocks. Table I summarizes test results for wells N-1, N-2 and N-3. Development drilling from 1980-1982 involved a further 18 wells drilled from two nine-slot platforms. The field has been on full stream since June 1982.

STRATIGRAPHY

General stratigraphy of the area

Formation of the Central Graben was evident in the Triassic, dissecting the Fyn Ringkøbing and Mid North Sea highs (ZIEGLER, 1978, 1982). Sediments in the Graben attain thicknesses of 20 000 ft (RASMUSSEN, 1978).

The nature of basement rock is largely unknown, however, P-1X (Fig. 2), drilled on the Dogger High in 1973, penetrated late Silurian metamorphics at 11 330 ft.

Overlying the Permian, sediments of Triassic and Jurassic age are found. Halokinesis of Permian salts began in the Late Triassic, initiated by thick Triassic sequences overlying Zechstein deposits (CHILDS & REED, 1975; ZIEGLER, 1978, 1982). Regionally, sediments thicken towards the axis of the Graben but local variation is caused by updoming and piercement. Thicknesses of Cretaceous sediments are extremely variable. Isopach maps of the Chalk in the Central Graben indicate thicknesses up to 2500-3000 ft (HARDMAN, 1982), but in places it is found to be absent where diapirism has been severe.

The Chalk is overlain by 6000-8000 ft of Tertiary and Quaternary sediments. Thickness variations reflect the Early Tertiary tectonic and continued salt diapirism.

Stratigraphy of Gorm Chalk

Diapirism under the Gorm field has caused piercement or disturbance of Triassic and Jurassic deposits, these apparently being truncated by the updoming structure (Fig. 6). Cretaceous deposits are seen to thin over the structure, this trend being most marked in the Lower Cretaceous, as interpreted from seismic data. Wells N-1, N-2 and N-3 penetrated the greatest thicknesses of chalk, reaching total depth in Campanian and Santonian chalk. The Campanian is overlain by up to 180 ft of Maastrichtian.

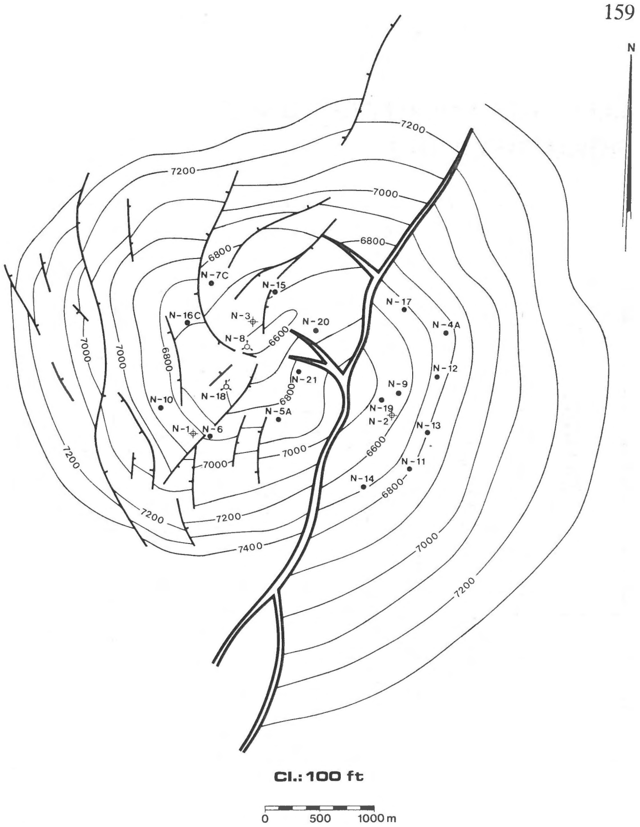


Fig. 3
Structure map on Maastrichtian.

The regional Upper Cretaceous/Tertiary unconformity is marked by advanced lithification and, therefore, considerable porosity reduction. The Danian sequence varies from being thin to absent in places, to thicknesses of 150 ft, reflecting the effect of regional tectonics and topographic expression of the Gorm structure (Fig. 5). Above the unconformity at Top Chalk, a marly section of reworked chalk and Tertiary clays is identified. Approximately 4500 ft of Tertiary siltstones, claystones and limestones overlie the Chalk.

Volcanics are found in Early Tertiary siltstones and claystones and are especially abundant immediately above the Chalk. A Quaternary sequence of 2000 ft is typified by sands and clays, with localised lignite and shell beds.

Table I
Test data for Gorm field exploration and appraisal wells.

Well	Test interval	Rate BOPD*	Gravity °API	GOR	Choke 1/64″	Flowing bottom hole pressure (psi)
N-1	Danian	2920	35.6	1418	48	3475
N-2	Maast.	3370	35	530-580	32	3452
N-3	Maast.	4260	32.9	890	56	2203

* Post stimulation.

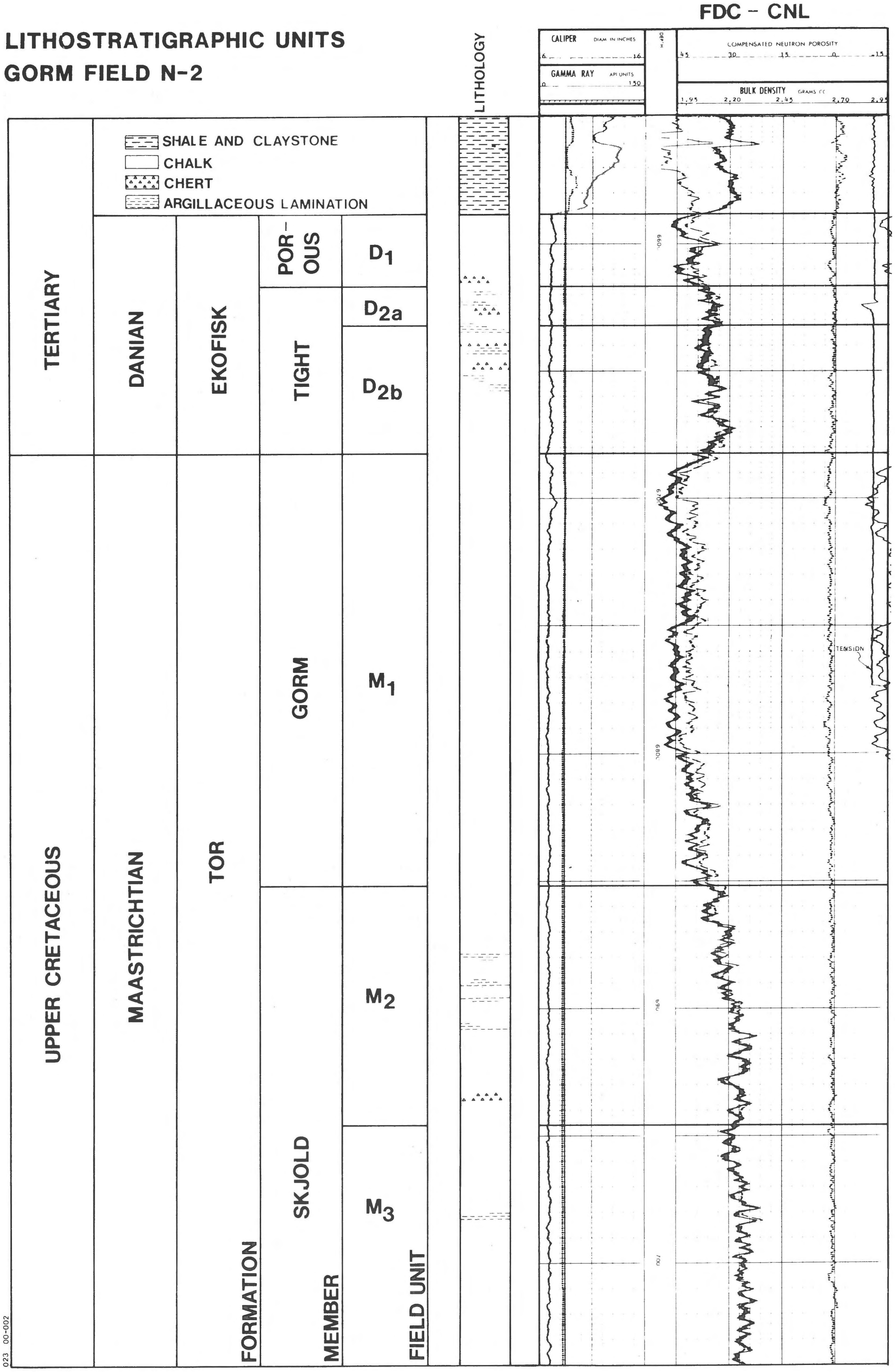


Fig. 4
Lithostratigraphic units, Gorm field.

Danian and Maastrichtian chalk form the reservoir rock. Horizons of limestone and volcanics above the reservoir contain gas but are not commercially exploitable.

The lithostratigraphic units of the Gorm Field and their equivalents are illustrated in figure 4. Subdivision of the reservoir units is based on porosity log response. The use of Danian and Maastrichtian as field units is technically incorrect. These 'time' intervals are established by palaeontology in selected wells and used as a basis for field wide log correlation. The use of letter number unit designation is informal, but allows finer subdivision of the Chalk in Gorm, Dan and Tyra. These units are mappable and can be correlated within a field, but not necessarily on a regional scale. The Danian is subdivided into D_1 and D_2 equivalent to the 'Porous' and 'Tight' Danian members of SVENDSEN (1979). The Maastrichtian porous M_1 unit is equivalent to Svendsen's 'Gorm' Member, the remaining M_2, M_3, M_4, etc. occurring within the 'Skjold' Member.

LITHOLOGY

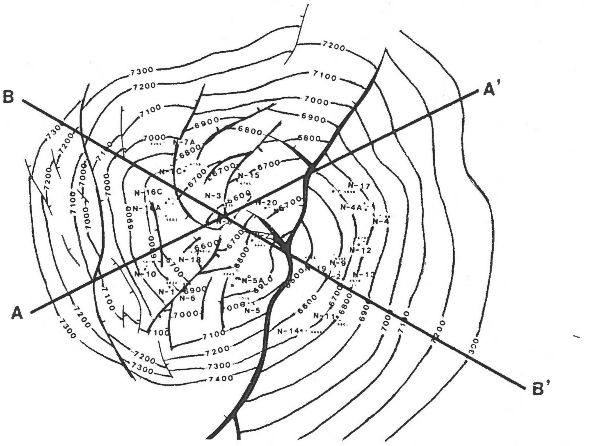
Danian

The Danian D_1 unit is a buff to creamy white and soft chalk becoming moderately hard with depth. Colour variation is mainly attributable to oil staining. The unit is predominantly micritic, but contains a few horizons of biomicrite. The sparse faunal element is dominated by planktonic foraminifera, with occasional macrofossil fragments of echinoids and sponge spicules. Finely disseminated pyrite and trace glauconite are recognized and nodules of grey chert with associated silicified chalk occur sporadically. A conglomerate of chalk clasts in a mud matrix is recognized at the top of D_1 in cores.

The Danian D_{2a} unit is a hard, grey to cream, biomicritic chalk. An abundance of argillaceous material, in places as distinct laminations, is a feature of the unit. Chert is notably abundant forming discrete beds in places.

The D_{2b} unit is similar in character to D_1. The argillaceous component and cherts are still present, but less abundant in D_{2a}. Slump units occur in D_{2b}.

The Danian chalk is bioturbated, most obviously in laminated sequences. Stylolites become more abundant with depth and are particularly well developed in argillaceous



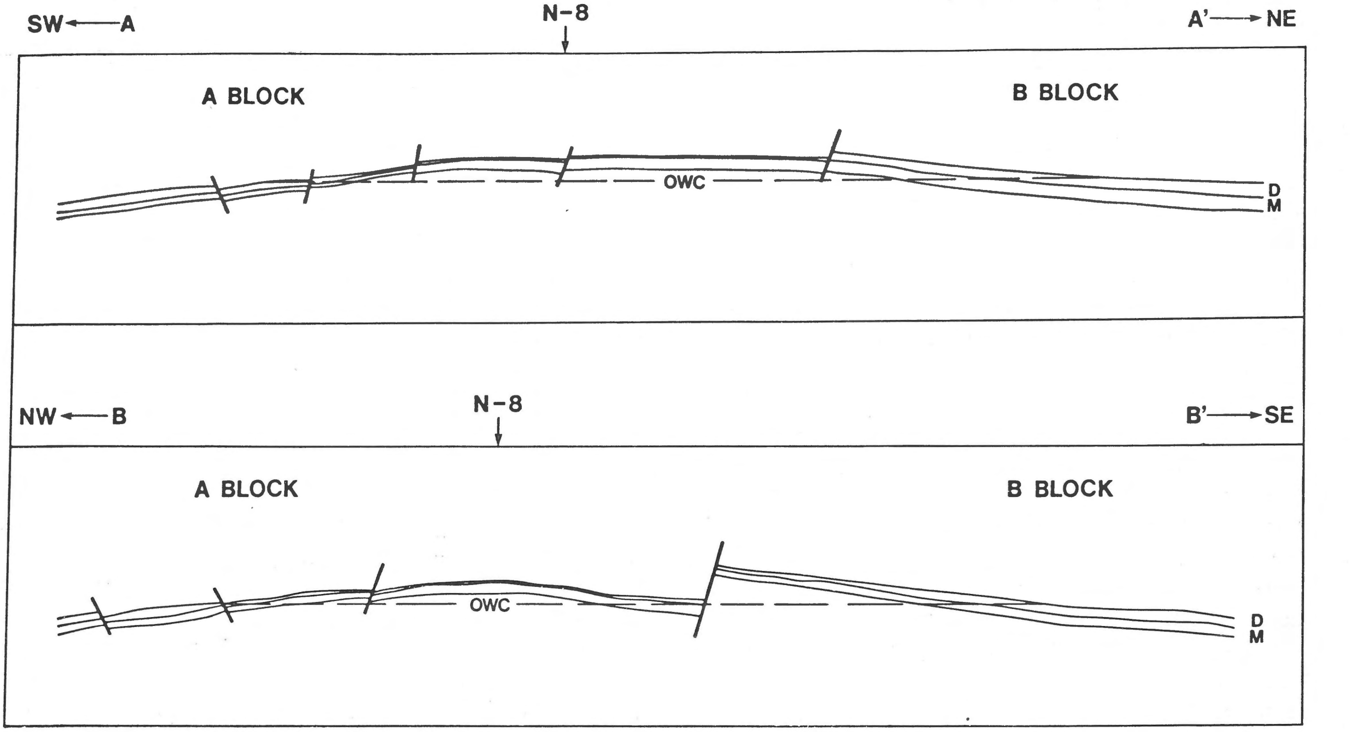


Fig. 5
Cross-sections through A and B blocks.

layers. Stylolite surfaces are coated with argillaceous material and in places, with fine pyrite crystals. Both primary interparticle porosity and secondary porosity due to dissolution and reprecipitation are observed.

Maastrichtian

The Maastrichtian M_1 unit is characterized by white to buff, moderately hard to hard biomicrite. The Chalk appears granular, inferring a larger grain size than observed in the Danian. Planktonic foraminifera are the dominant fauna, but there is also an abundance of macrofossils debris, including sponge spicules, *Inoceramus,* echinoid fragments and occasional bryozoans. Calcispheres are present in the unit and increase in abundance into M_2 below. Occasional white to light grey chert nodules are seen.

The Maastrichtian M_2 and M_3 units consist of biomicrite chalk with a dominance of calcispheres. The macrofossil fraction is similar to that in M_1. Chert abundance generally increases down section and varies greatly from well to well. High porosity (up to 45%) intervals within the Maastrichtian are 20-40 ft thick, laterally discontinuous units, tentatively interpreted as allochthonous chalk.

Bioturbation is common in the Maastrichtian and includes *Thallasinoides* and *Zoophycos* burrows. Stylolite development is more marked than in the Danian and increases in abundance with depth.

The high porosity in the Upper Maastrichtian M_1 is predominantly secondary and the result of recrystallisation. The incidence of primary porosity appears to decrease down section.

STRUCTURE

Structural development

The Lower Cretaceous is mapped as thinning over an underlying dome of salt or shale, diapirism apparently having been initiated at this time. By comparison, attenuation of the Chalk over the structure is not so marked: 1300-1500 ft of Chalk being present over the structure and downflank it is thickening to approximately 2500 ft (Fig. 6). The thin and condensed sequences on adjacent structures, such as Skjold, Middle Rosa and Nils, indicate that there was active updoming in the region during chalk deposition. A topographically low position with respect to these structures is therefore likely for Gorm, allowing for a more complete Chalk section. Allochthonous units probably contribute to the sediment thickness.

Isopach mapping of Maastrichtian M_1 and M_2 units indicates the thinning of these units towards the centre of the structure (Fig. 7a). To the northwest a thickness difference of 75 ft from the centre to the flank can be seen in both M_1 and M_2. Isoporosity maps of these units (Fig. 7b) indicate that highest porosities are preserved in crestal areas. Apparent thinning of the Maastrichtian cannot, therefore, be a compactional feature only. Topographic expression of the structure could also result in crestal thinning of units due to reduced sedimentation or erosion and movement of material downflank. Variation in unit thickness is slightly more marked in the M_1 unit, possibly due to more active crestal erosion at the Cretaceous/Tertiary boundary.

Isopach maps of the Danian D_1 and D_2 exhibit independent trends (Fig. 8a). D_2 varies from being thin to absent in the A block to attaining thicknesses greater than 100 ft in the B block. The A block can be envisaged as a pronounced crest with a steep east-flank, a possible west-flank being outside well control. Distribution and thickness is extremely variable and again higher porosity is to be found in crestal areas. (Fig. 8b). The Danian chalk is largely unfractured while the Maastrichtian is characterised by high angle to vertical fracture planes.

Complex sedimentary relationships in the Chalk reflect active structural growth and tectonic activity in the area during chalk deposition. The Chalk grades upwards into a marl sequence suggesting continued exposure of the Chalk to erosion for periods after chalk deposition had halted. Seismic data indicates that growth ceased by the Oligocene-Miocene and that fault displacement occurred in the Middle to late Eocene. High angle tensional faults are predominantly located in the A block and represent late stages of updoming (Fig. 6).

Downthrow of the A block appears to have been accompanied by a tilting to the south relative to the B block such that 100 ft throw exists to the north (Fig. 5, section A-A_1) and 600 ft to the south at top Maastrichtian level (Fig. 5, section B-B_1).

Sourcing and timing of oil migration

Jurassic shales are indicated to be the source rock for the hydrocarbons of Dan (JEFFREY & BURGESS, 1976). The Upper Jurassic shales in the Dan field are found to be barely mature for oil generation, thus suggesting migration from a source outside the field. A similar situation is thought to exist at the Gorm field. Oil generation from Jurassic shales in the North Sea has taken place since Late Eocene (HARDMAN & KENNEDY, 1980).

Structural formation and oil generation have, therefore, occurred over the same time range. This situation is favourable for oil migration and accumulation in that any fracture systems created by structural deformation provide paths for migrating hydrocarbons. Once the pressure of the oil held within a fracture system exceeds pore entry pressure for a specific chalk type, migration into the matrix will occur (HARDMAN, 1982).

Porosity preservation within the Gorm reservoir is interpreted as being a function of depth of burial, pressure conditions and timing of oil migration. A chalk normally suffers porosity reduction from 70% to 35% with burial to 3500 ft

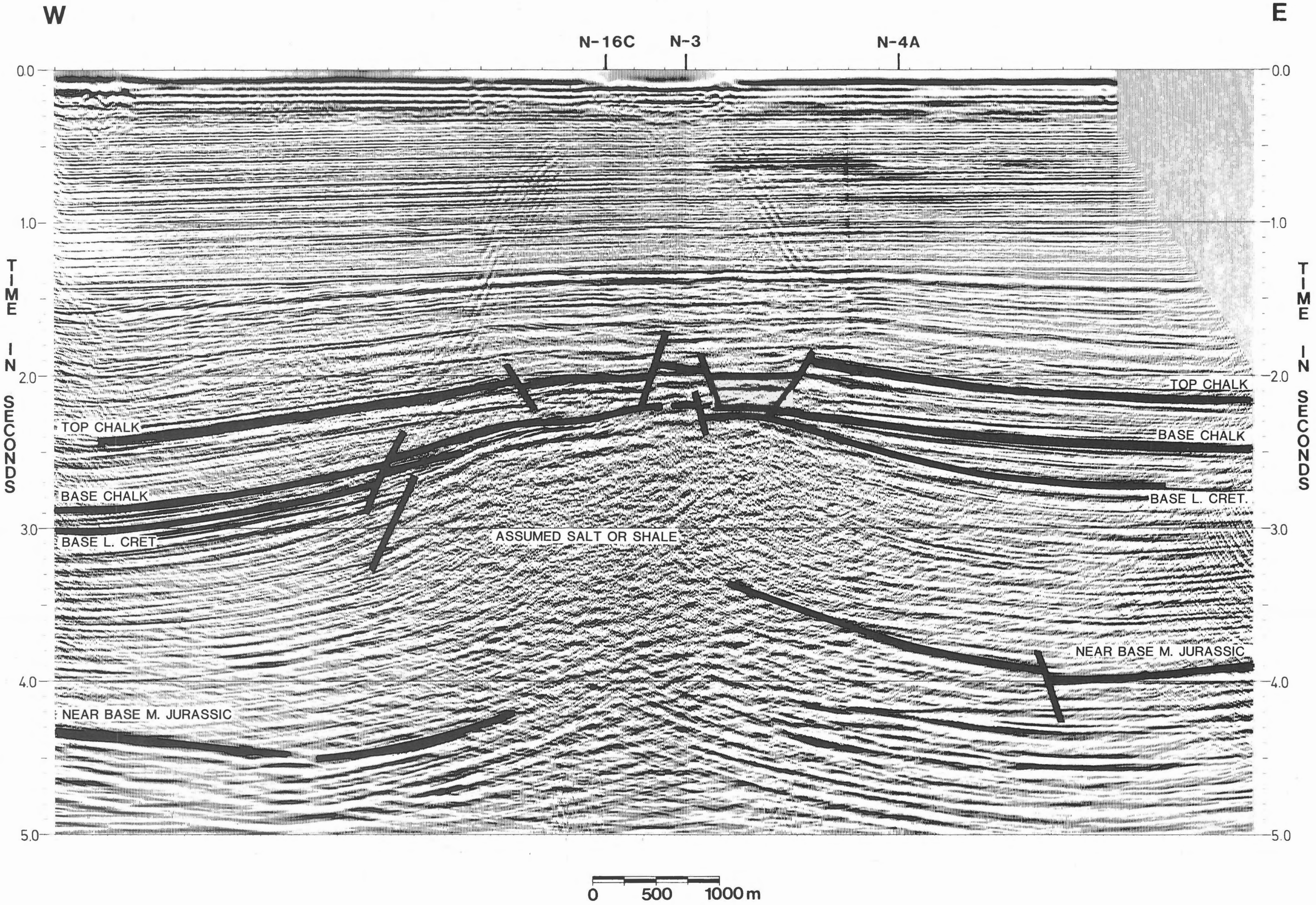


Fig. 6
Seismic profile across the Gorm field.

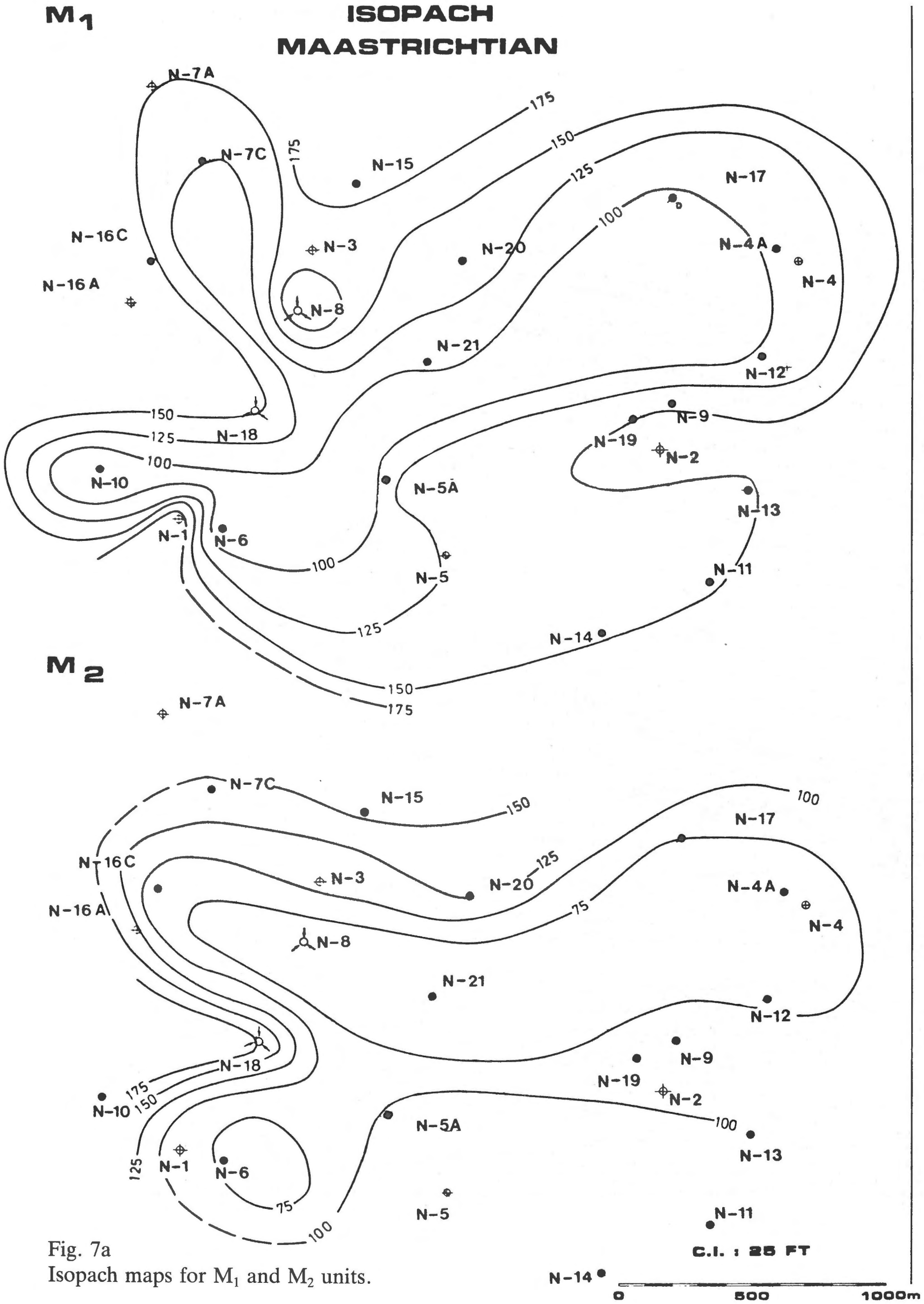


Fig. 7a
Isopach maps for M_1 and M_2 units.

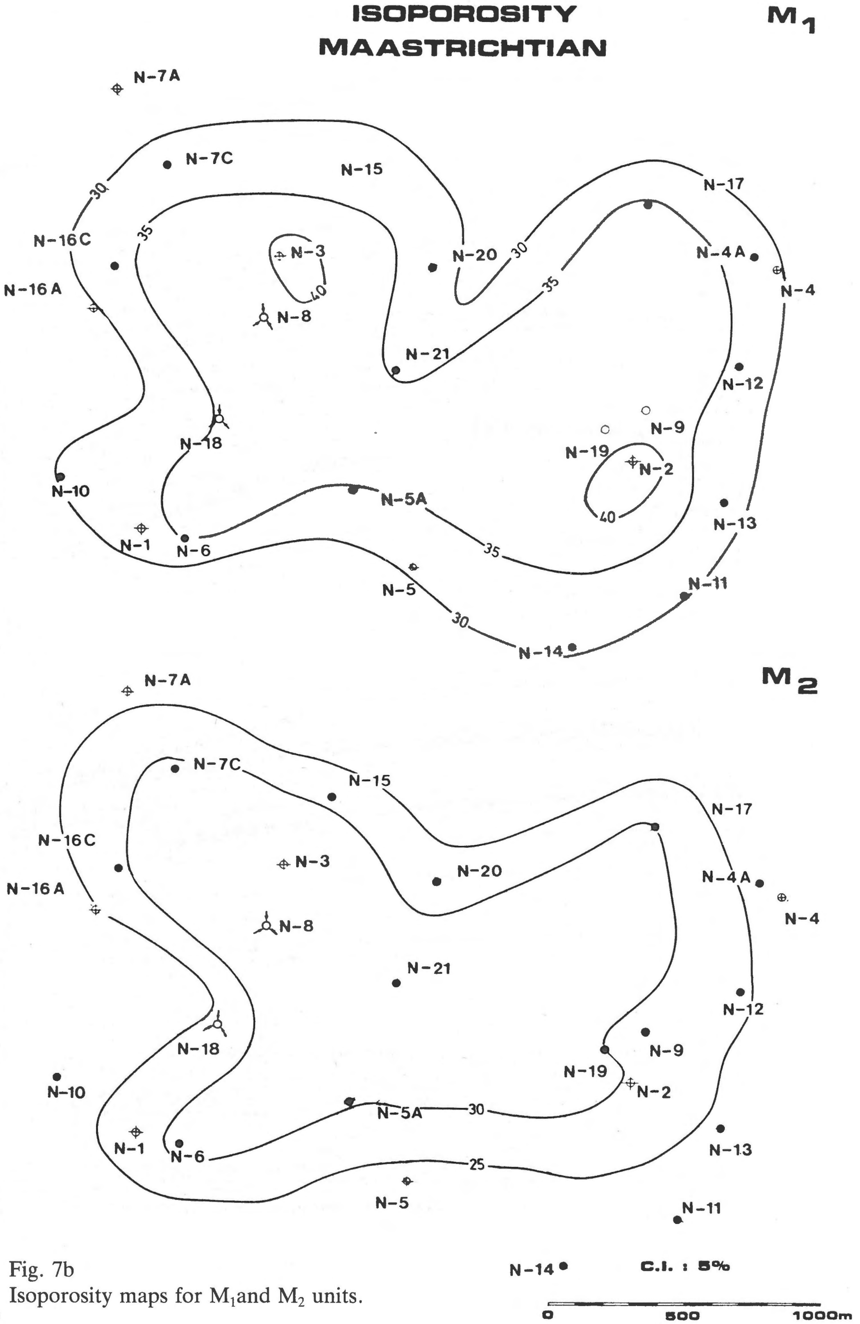


Fig. 7b
Isoporosity maps for M_1 and M_2 units.

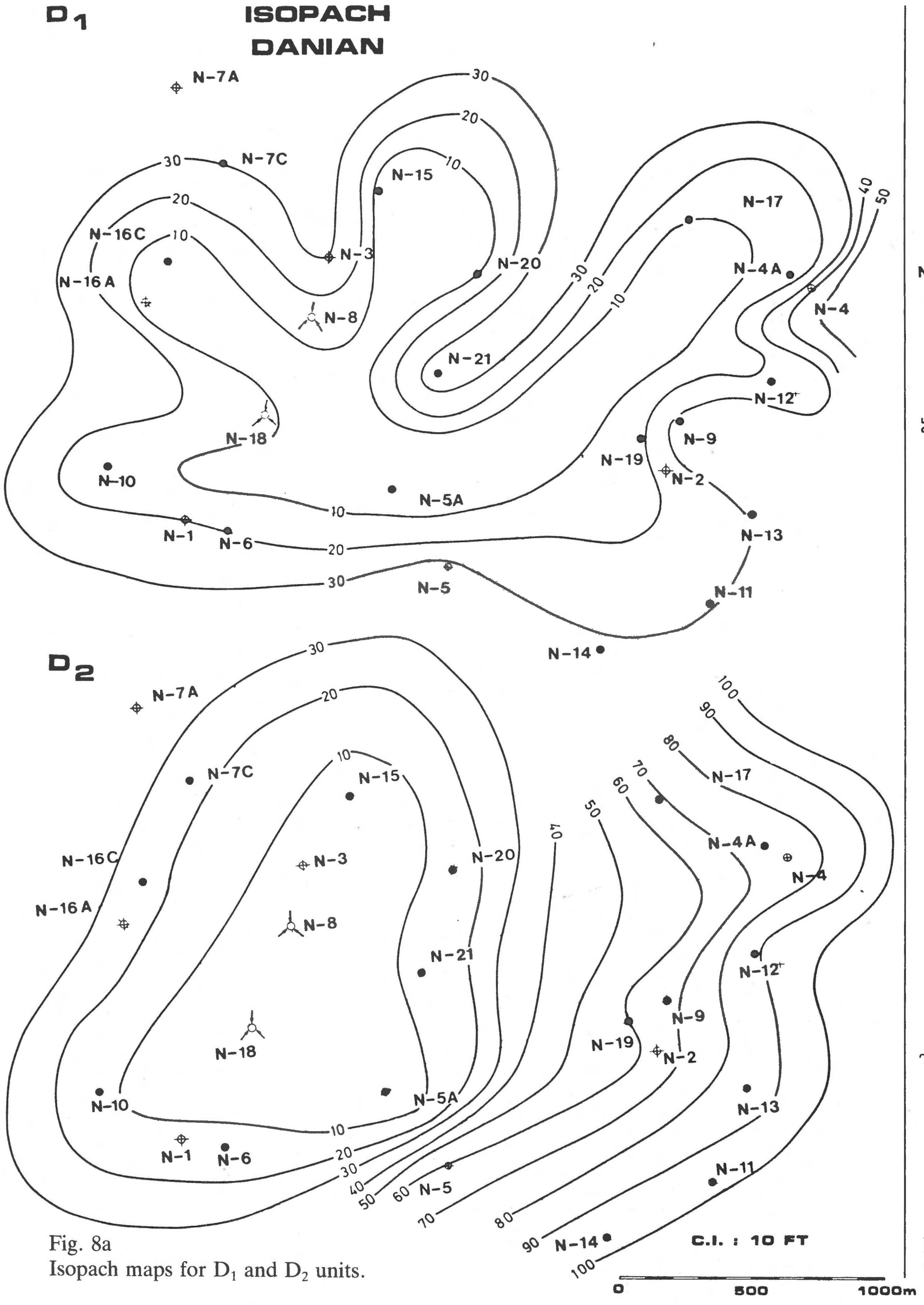


Fig. 8a
Isopach maps for D_1 and D_2 units.

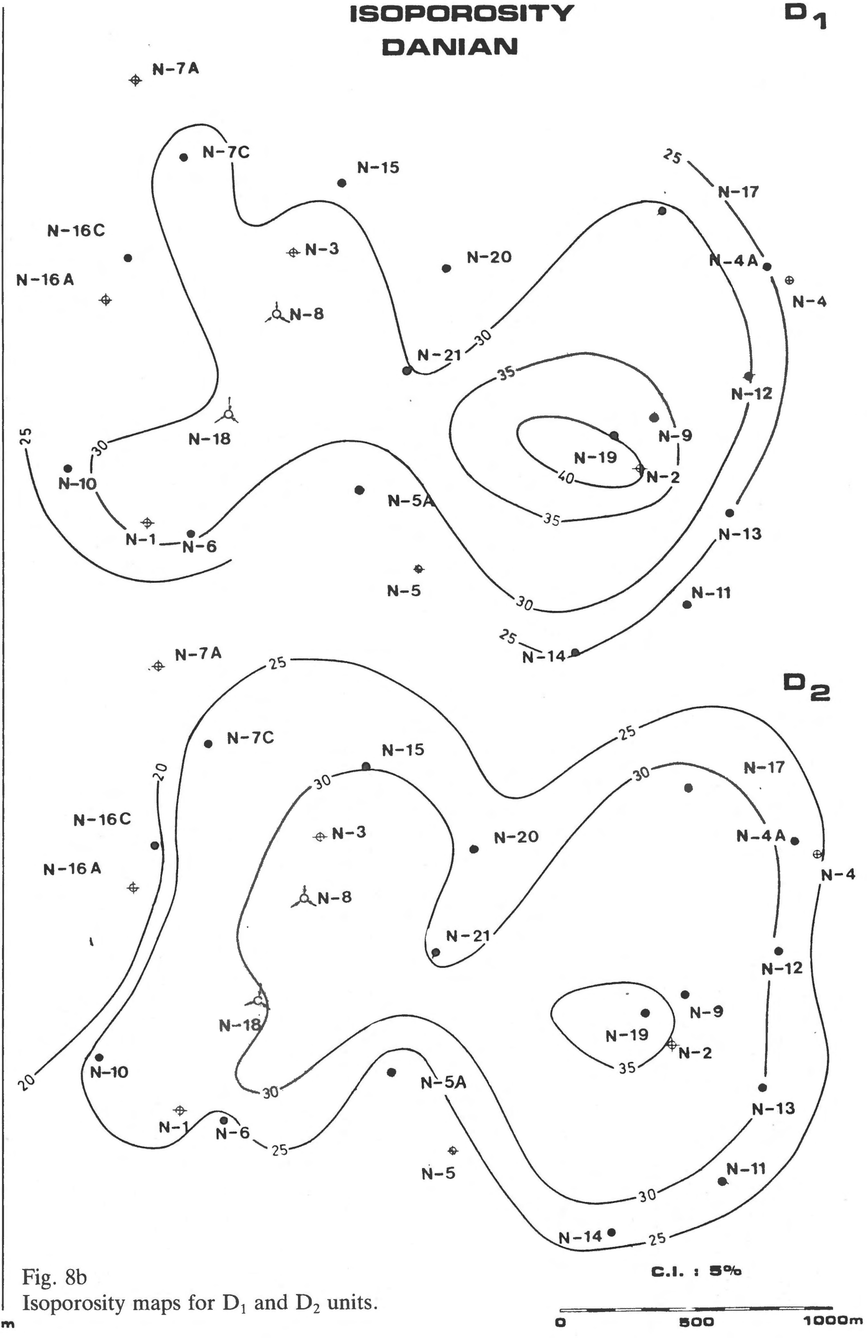


Fig. 8b
Isoporosity maps for D_1 and D_2 units.

depth and 15% at 7000 ft depth (SCHOLLE, 1977). The Gorm structure was formed by the Oligocene-Miocene with an overburden of approximately 1500 ft of Tertiary shales. At that time porosity reduction by burial diagenesis cannot have been too profound and was possibly counterbalanced by overpressuring in the chalk. Migration of hydrocarbons into the structure and current reservoir pressures of 1200 psi in excess of hydrostatic pressure have offset increasing overburden pressures and maintained high porosities.

MATRIX CHARACTERISTICS

Hydrocarbons are contained within Danian D_1 and D_2 and Maastrichtian M_1 and M_2 and also in crestal areas M_3. Table II presents average log derived porosity and water saturations for the above intervals. Danian and Maastrichtian chalk is typified by porosities of 25-48% and low matrix permeabilities of less than 10 mD. The D_1 is characterised by porosities ranging from 25% to 40%. The lower porosities of the tight D_{2a} are due to the presence of argillaceous layers. The porous D_{2b}, thickly developed in the B block, is similar in character to D_1. Porosities in excess of 45% are seen in the Upper Maastrichtian M_1, but average at 35-40%. Porosity gradually decreases down section through M_2, there being no sudden porosity reduction into the aquifer. The M_1 unit comprises the greater part of the reservoir volume. A porosity reduction of 5% to 10% is seen in the reservoir units (Figs. 7b and 8b) from crest to flank.

Figure 9 illustrates the relative pore volume contribution of the Danian and Maastrichtian units for each block computed from an average thickness (h) and average porosity (ø). In the A block reservoir volume is mainly confined to Maastrichtian units, the Danian sequence being thin. A slightly lower average Danian porosity is observed in the A block also. The B block is characterised by thick development of porous D_{2b} contributing significant pore volume in this block. The total Danian and Maastrichtian pore volume is greater than in the A block.

Within the reservoir, saturation profiles largely reflect porosity distribution. The presence of argillaceous material in the Danian, especially D_2, results in a high water saturation due to large quantities of bound water in clay layers. Differences in pore throat configuration for Danian and Maastrichtian chalks may also result in varying immobile water saturations. The oil to water transition zone in Gorm is typically long. Mapping the 50%-100% Sw indicates a very general thickening off structure corresponding to downflank porosity reduction and increased capillary action.

Table II
Log derived porosity and water saturation data for Gorm reservoir units.

Unit		Average porosity %	Average water saturation %
Danian	D_1	32	38
Danian	D_{2a}	27	45
Danian	D_{2b}	30	42
Maastrichtian	M_1	35	19
Maastrichtian	M_2	29	53
Maastrichtian	M_3	28	87

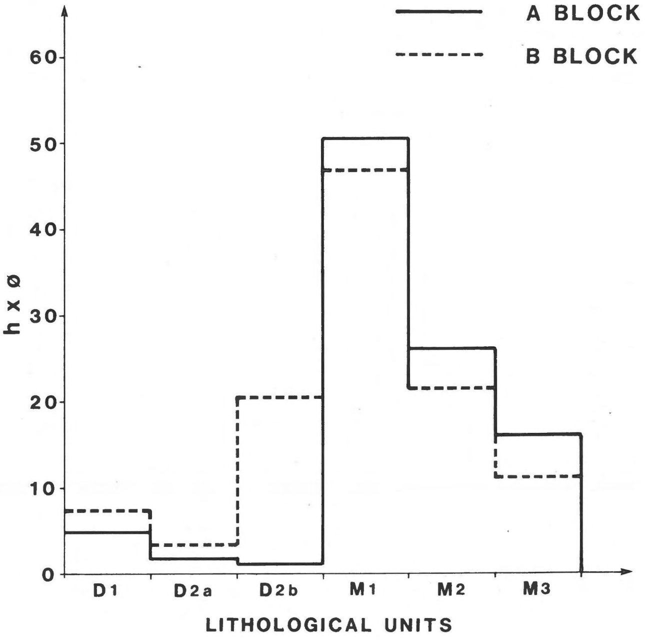


Fig. 9
Reservoir pore volume distribution.

A composite of core derived porosities and permeabilities (Fig. 10) indicates that Danian and Maastrichtian chalk exhibit individual trends, the Danian being less permeable than the Maastrichtian for the same porosity range. Maastrichtian chalk from block A displays a higher average core derived matrix permeability than that of the B block. Separation of the two trends in figure 10 amounts to an average permeability difference of 0.5-1.5 mD for the 24-44% porosity range. The same distinction can be seen in averaged test derived permeabilities of 10 to 6.5 mD for the A and B block, respectively. This is interpreted as due to a greater fracture contribution to permeability in the A block.

OIL DISTRIBUTION

Gorm is an undersaturated oil reservoir, thus an initial gas cap is absent. Oil gravity is 33.5 API. Initial reservoir pressure in the A block is 4290 psi and in the B block, 4340 psi, i.e. a difference of 50 psi. Although reservoir fluid and pressure conditions are seen to vary between blocks, vertical reservoir continuity is assumed to exist between the Danian and the Maastrichtian in both blocks, as no permeability barriers are apparent from logs and cores. No initial gas contacts are present. Water-oil contacts are identified in most wells and subsequently defined from petrophysical evaluation. Fluid

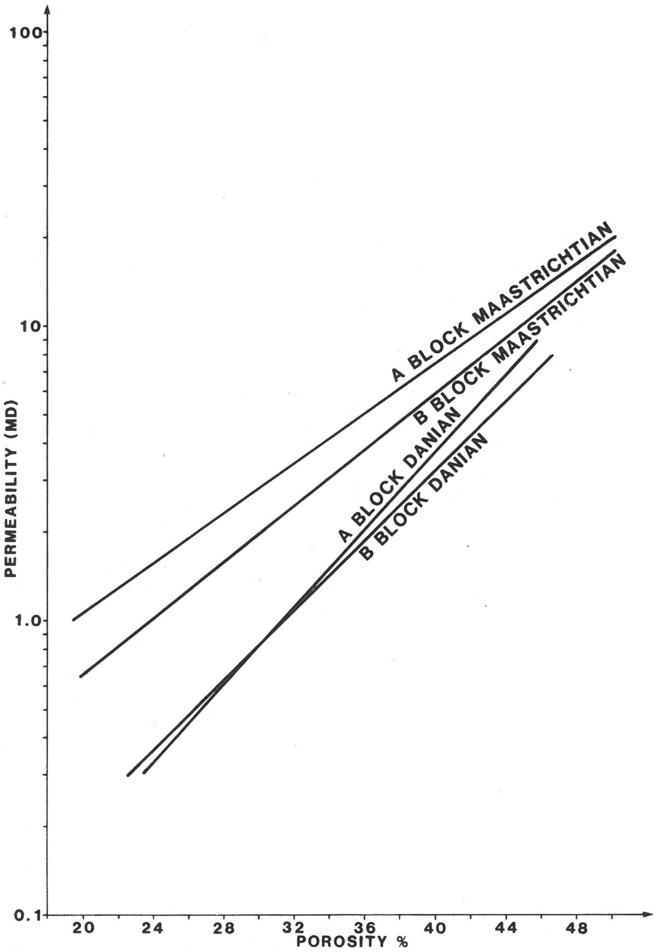


Fig. 10
Core derived porosity and air permeability.

saturations of 50% and 100% water saturation are used as reference levels for field wide comparison.

Various assumptions have to be made regarding fluid contact configuration within the structure outside of well control. A Danian oil-water contact (100% Sw) has not been penetrated in Gorm, but it is reasonable to assume that elevation will differ from a Maastrichtian contact due to differences in rock quality. In the A block a difference in elevation of fluid levels from northeast to southwest has been identified. In the northeast 50% Sw is at 6900 ft.ss and 100% Sw at 6950 ft.ss. These surfaces are lower to the southwest by 100 ft in N-1, N-5A, N-6 and N-10. This same condition does not appear to exist in the B block, but control in the south is restricted to one well (N-14).

FIELD DEVELOPMENT

Following discovery and field appraisal, two nine slot drilling platforms were positioned above the A block southeast of the crest. Production facilities have been developed on a third platform. The Gorm production configuration is currently 2 gas injectors and eight producers in the A block and eight producers in the B block. Although some wells from the A platform were available for production in May 1981, full production began only in June 1982. The field produced ca. 40 000 b/d in October 1982.

CONCLUSIONS

Gorm reservoir rock comprises Danian and Maastrichtian chalk. The thick Maastrichtian M_1 unit exhibits the highest porosities and permeabilities and contributes the bulk of the reservoir volume.

The structure is interpreted as originating from updoming of Zechstein salt, Tertiary shales forming a cap rock to the Chalk reservoir.

Structural development occurred as a single unit, until the late NNE-SSW trending fault cut the Gorm structure into two blocks which developed independently during late stages of structural growth. Some differences in structural position, stratigraphical, matrix and production characteristics are therefore apparent:

1. Structure. From at least the Early Tertiary the A block has occupied a crestal position with respect to the underlying domal structure, and it is dissected by many high angle tensional faults. The B block is positioned 'downflank' and is relatively unfaulted.
2. Stratigraphy. Lateral variation in sequences reflects structural location at the time of deposition. Condensed or absent sequences represent crestal areas where erosion was active and flank areas are characterised by thicker and fuller sequences, possibly including sediment derived from upslope. This pattern is well marked in the Danian, the crest being located on the A block. These variations are superimposed on regional stratigraphic variations.
3. Matrix Quality. In both blocks, highest porosities are preserved in current crestal areas decreasing downflank. There is no marked difference in porosity distribution between blocks. Maastrichtian matrix permeabilities are higher in the A block than the B block, a similar trend being identified from test derived permeabilities. Higher test permeabilities are interpreted as reflecting the more fractured nature of the chalk in the A block and matrix permeability differences in grain size distribution and diagenesis.
4. Production wells in the A block have a higher productivity than those in the B block.

The apparent differences seen in the two Gorm field blocks can be attributed to growth history in relation to their relative structural locations. The crestal position and updoming of the A block area from the Early Tertiary accounts for the thin sedimentary sequences relative to the B block. Late fracturing and possibly also diagenetic history are responsible for the superior production characteristics of the A block.

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