2.0 Structural outline and development

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The Central Graben is a broad, complex trough with a long history of differential subsidence. It was probably initiated in the Permian and was controlled by major rifting during the Mesozoic.

To the south in the Dutch sector the trough is divided into two parts. From here it passes northwards and divides the southern North Sea Basin into the Anglo-Dutch Basin and the Northwest German Basin. It also separates the Mid North Sea High from the Ringkøbing-Fyn High. These highs form broad, east-west trending, relative stable ridges.

The further continuation of the Central Graben is to the northwest, towards the centre of the North Sea, where it passes into the Viking Graben and the Moray Firth Basin at about 58° N.

Where the Central Graben divides the two major highs, there is an elongate central narrow horst, the Dogger High, which is the southernmost of a row of mid-Graben highs. Both sides of the Graben are clearly defined by normal rotational faults that were intermittently active from Triassic to Early Cretaceous times.

2.1 Structural outline

The structural outline of the Central Graben within the Danish North Sea sector is well illustrated by the Bouguer gravity map and by the structural outline map at base Zechstein level (fig. 5).

A number of geo-sections based on the interpretation of seismic sections are given (figs. 7 to 13) in order to illustrate the structural style of various parts of the Danish Central Graben.

On the gravity map the pronounced slope in the eastern part marks the position of the boundary fault zone to the Ringkøbing-Fyn High. The adjacent elongate trend of minima below 260 mgal coincides with the axial depression of the Central Graben. The kink from a north-south orientation of the Graben in the southern part, into a northwest-southeast orientation in the central and northern part, is likewise well illustrated from the gravity picture.

The centre of the Dogger High is indicated by the gravity high above 280 mgal (fig. 5). This maximum is part of a trend of gravity highs extending northwestwards into the very little known part of Central Graben.

The fault pattern of the base Zechstein level (fig. 5) demonstrates the overall picture at this level of pull-apart tectonics, typical of a rift setting.

Partly based on this map, it is possible to subdivide the Danish Central Graben into the following, in part overlapping, structural subunits:

A. A Southern Salt-dome Province south of 55° 40' N, where Zechstein evaporites have undergone halokinesis. Doming of Upper Cretaceous-Danian chalk caused by halokinetic movements of underlying salt is the trap-building mechanism of the declared and established oil fields (Dan, Gorm, and Skjold). It is noteworthy that only few salt domes have actually pierced through and displaced the brittle limestones of the Chalk Group.

The growth of the salt structures appears in some cases to have started late in the Triassic and continued locally into the Quaternary. Development of rim-synclines becomes important during Late Jurassic.

In contrast to the majority of the halokinetic structures which are most certainly caused by migration of Zechstein evaporites, the salt pillow below the Dan field is interpreted as formed by flow of Triassic evaporites. The Ryan structure (O-1) may have a similar genesis.

B. A Northern Salt-dome Province including the area around the North Arne structure in the northeastern part of the Danish Central Graben area, and belonging to the so-called Northern Zechstein Basin.

The southern tip of the Norwegian Hod structure extending into Danish sector is probably also caused by halokinesis.

C. The Tail End Graben forms the axial depression of the Central Graben adjacent to the boundary fault zone of the Ringkøbing-Fyn High and extends into the northern as well as the Southern Salt-dome Provinces. The area is characterized by a pronounced gravity low. The depth to base Zechstein/top Rotliegendes is in the order of 10-11 km. This makes Tail End Graben one of the major depocentres of the whole Central Graben complex (Day et al. 1981). The Jurassic sequence is especially thick in this area, locally exceeding 4000 m (fig. 14).

The structural style in the central part of the Tail End Graben does not appear to have been influenced by salt flowage to any large extent. Differential subsidence, controlled by rotational fault blocks, in the

Mesozoic and especially Late Jurassic, was followed by inversion tectonics in the Cretaceous and Early Tertiary. This was most likely caused by a change into an oblique strike-slip regime, and together the dynamic factors seem to control the present structural configuration in this subarea.

The configuration and development of the boundary fault zone to the Ringkøbing-Fyn High can not be fully evaluated from geophysical data. It is , however, a very prominent feature with depths to base Zechstein in the order of 10 km in the adjacent Graben floor, in contrast to a depth to the basement of about 3 km on the high.

D. The western margin of Tail End Graben is characterized by a major fault zone extending from the South Arne structure southeastwards through the area around the H-1 well into the Southern Salt-dome Province where it is masked by the dominant halokinetic structures. At the Cretaceous levels some of these faults have been interpreted as having reverse components (geo-section, line 5423, fig. 7), believed to be caused by compressional strike-slip. Overpressured shales and shale-flow phenomena appear to be an important element in this zone. Whether it is associated with a flow of deeply seated salt or not is impossible to tell from existing data.

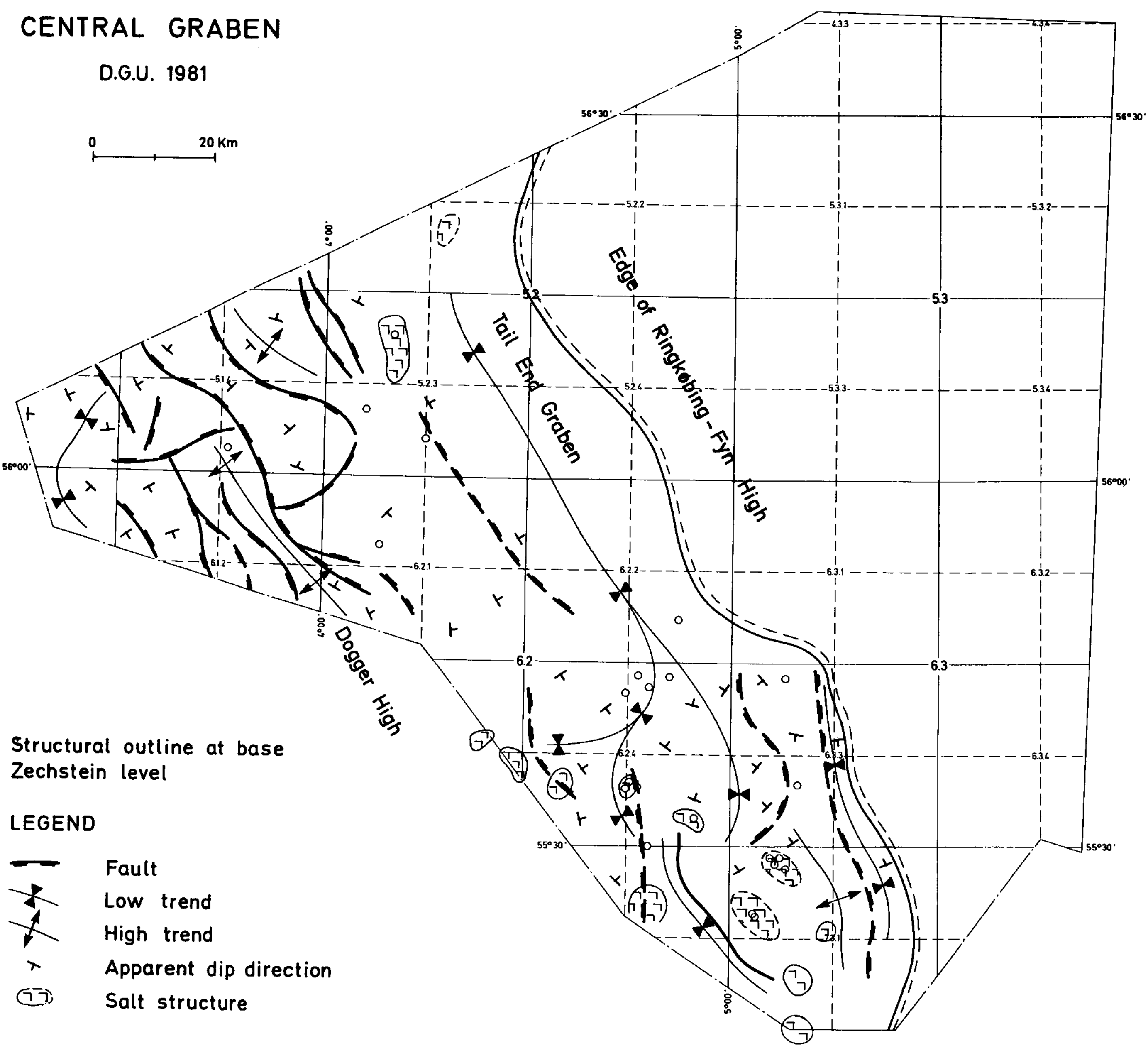


Fig. 5: a) Structural outline of the Danish Central Graben at the base Zechstein level.

E. The region west of the Tail End Graben: Resolution of available seismic data, below the pronounced Late Cimmerian Unconformity to the west of the fault zone just mentioned, is usually poor. Well data from W-1 and Q-1 indicate a relatively thin Triassic-Jurassic sedimentary sequence resting on volcanics of a possible Rotliegendes age.

F. The Dogger High extends northwestwards from the German North Sea sector into the Danish sector up to a position around the P-1 well. It is a rather complex horst structure on which the Mesozoic section below the Late Cretaceous limestones is missing. In P-1 Rotliegendes sediments and volcanics were found immediately below the Chalk Group at about 3100 m b.MSL. Underneath the Rotliegendes, Early Carboniferous sediments, overlying Caledonian greenschists, were encountered. It is uncertain, whether the older Mesozoic sediments were ever deposited on the central part of the Dogger High, or whether they have been removed by erosion during Cimmerian or later tectonic events.

G. The area to the north and west of the Dogger High in the direction of the British and Norwegian sectors is the least known part of the Danish Central Graben

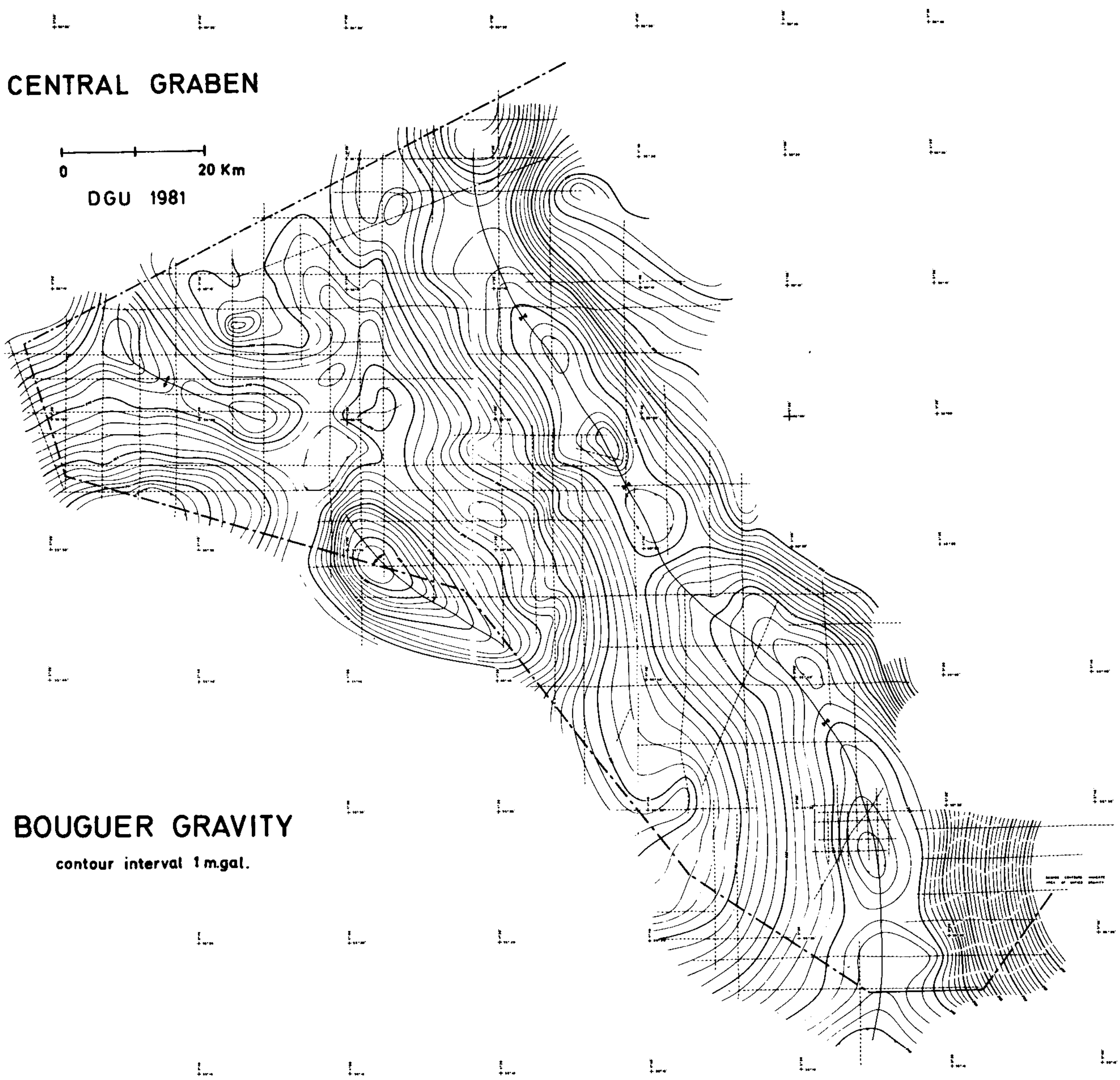


Fig. 5: b) Bouguer gravity map of the Graben area (after Edcon).

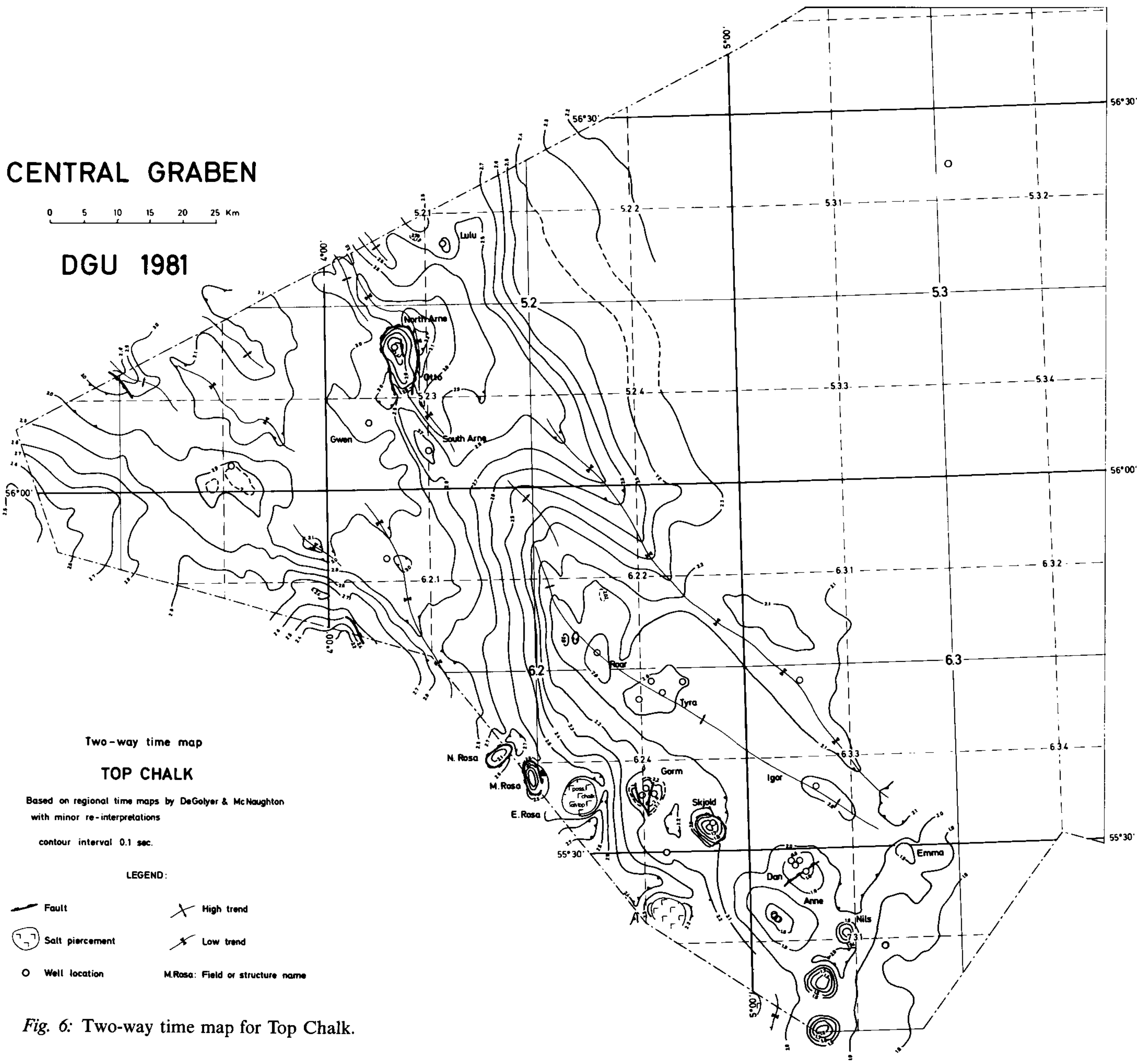


Fig. 6: Two-way time map for Top Chalk.

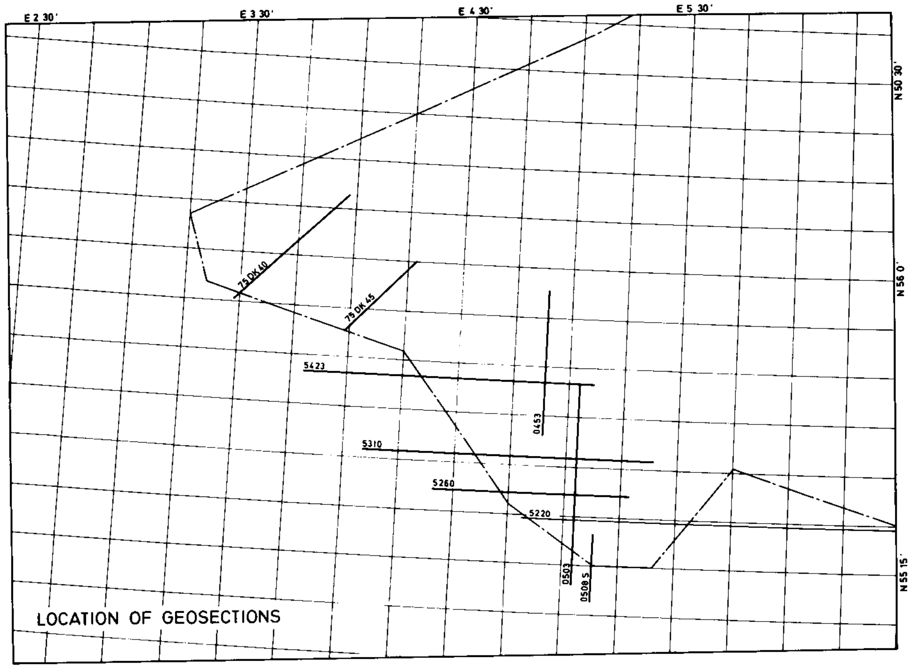
area. There is no well control and only a moderate seismic coverage.

2.2 Structural development

The development of the Central Graben, as presented here, is based on a considerable interdiciplinary reinterpretation of basic data as well as on papers by Bertelsen (1978, 1980), Day et al. (1981), Deegan & Scull (1977), Fyfe et al. (1981), Michelsen (1978), Rhys (1974), and Ziegler (1981) and those cited in the text. The development is treated in stratigraphic order (fig. 2), and referred to the general structural outline on fig. 5. The chapter is focused on the evolution within the area under consideration rather than the history of the entire basin and the major plate tectonic framework.

Knowledge of the structural development of the Danish Central Graben area prior to the Mesozoic rifting is incomplete and the documenting data sparse. Therefore the outline of this part of the section is brief and general. Conversely, far more is known about the Mesozoic-Cenozoic eras.

The location of the Caledonian basement is indicated by wells in Poland, Danish onshore, North Germany, and the North Sea. The boundary between



LEGEND FOR GEOSECTIONS AND SEISMIC LINES

TMM	Top Middle Mirocene
TCh	Top Chalk Group
BUC	Base Upper Cretaceous
TLC	Top Lower Cretaceous
BLC	Base Lower Cretaceous
TJ	Top Jurassic
inJ	Internal Jurassic
BJ	Base Jurassic
TT	Top Triassic
TZ	Top Zechstein
BZ	Base Zechstein

(a)	Potential structural arch trap
(f)	Potential structural fault trap
(p)	Potential primary stratigraphic trap.
(s)	Potential secondary stratigraphic trap.

The off-set of wells from seismic lines is given in Km.

GEOSECTION, LINE 5423

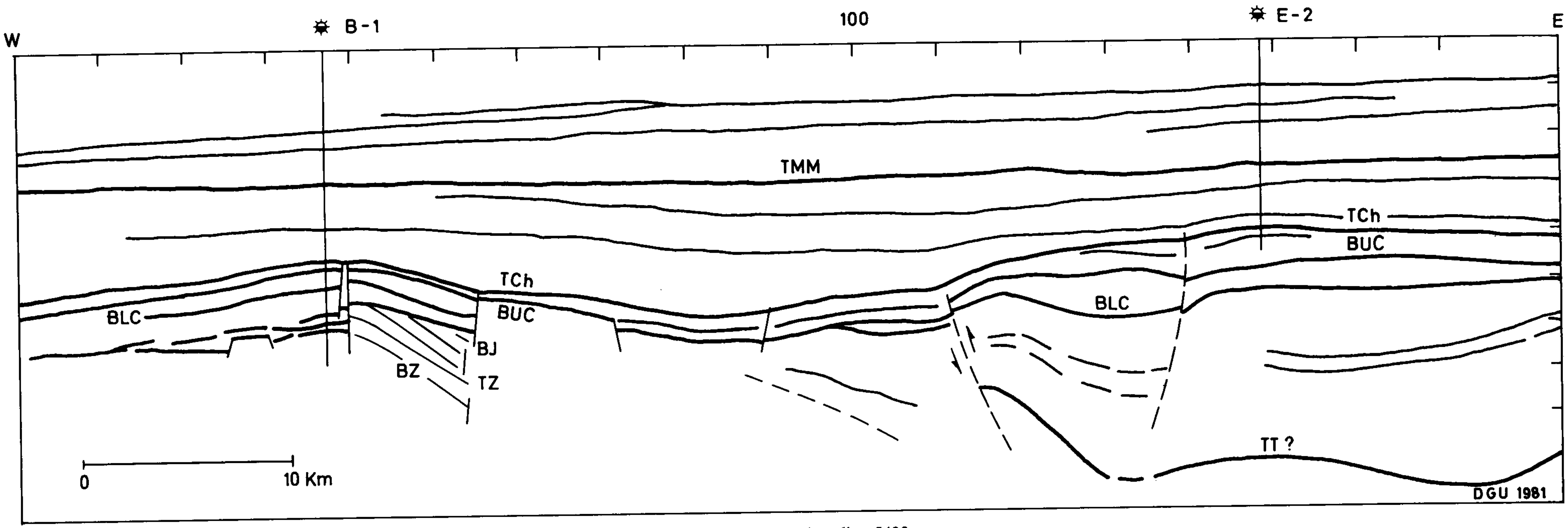
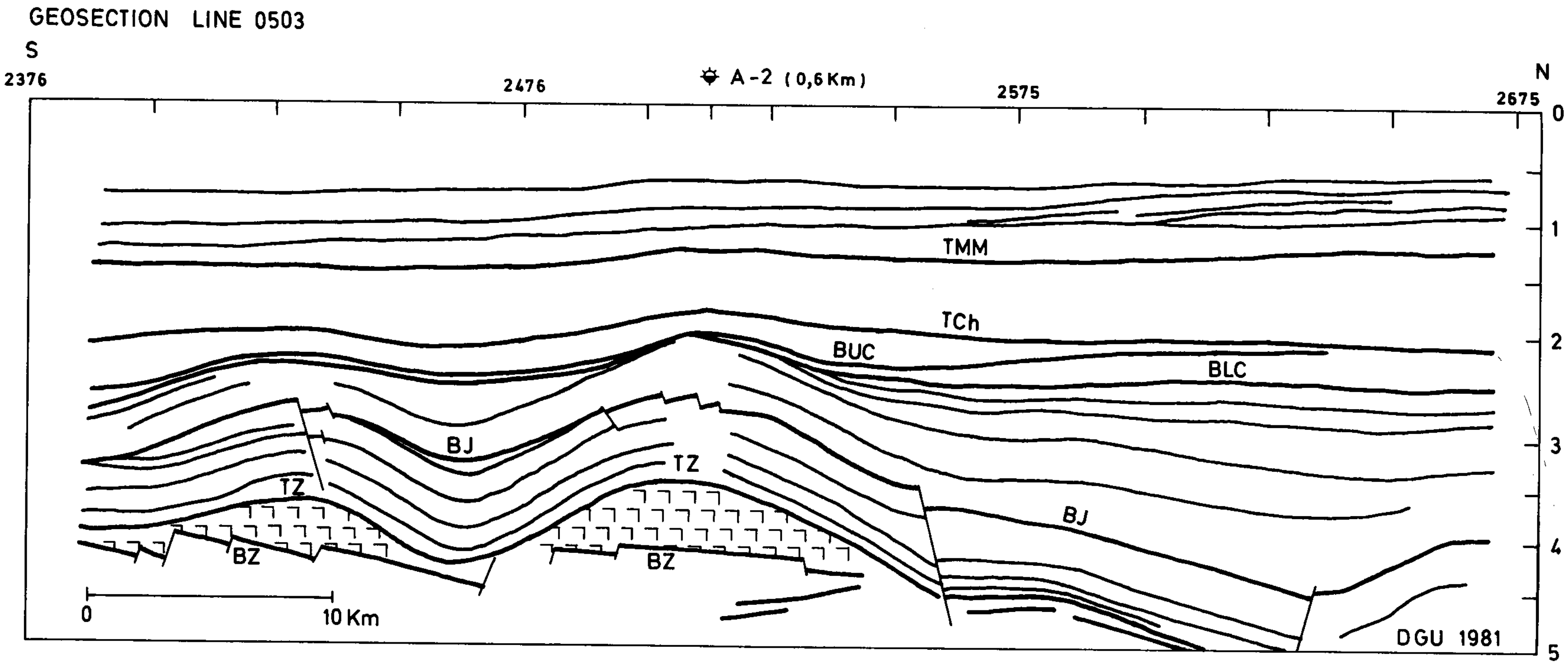


Fig. 7: a) Location map and legend of geosections presented in figs. 7 to 13 and b) Geosection, line 5423.



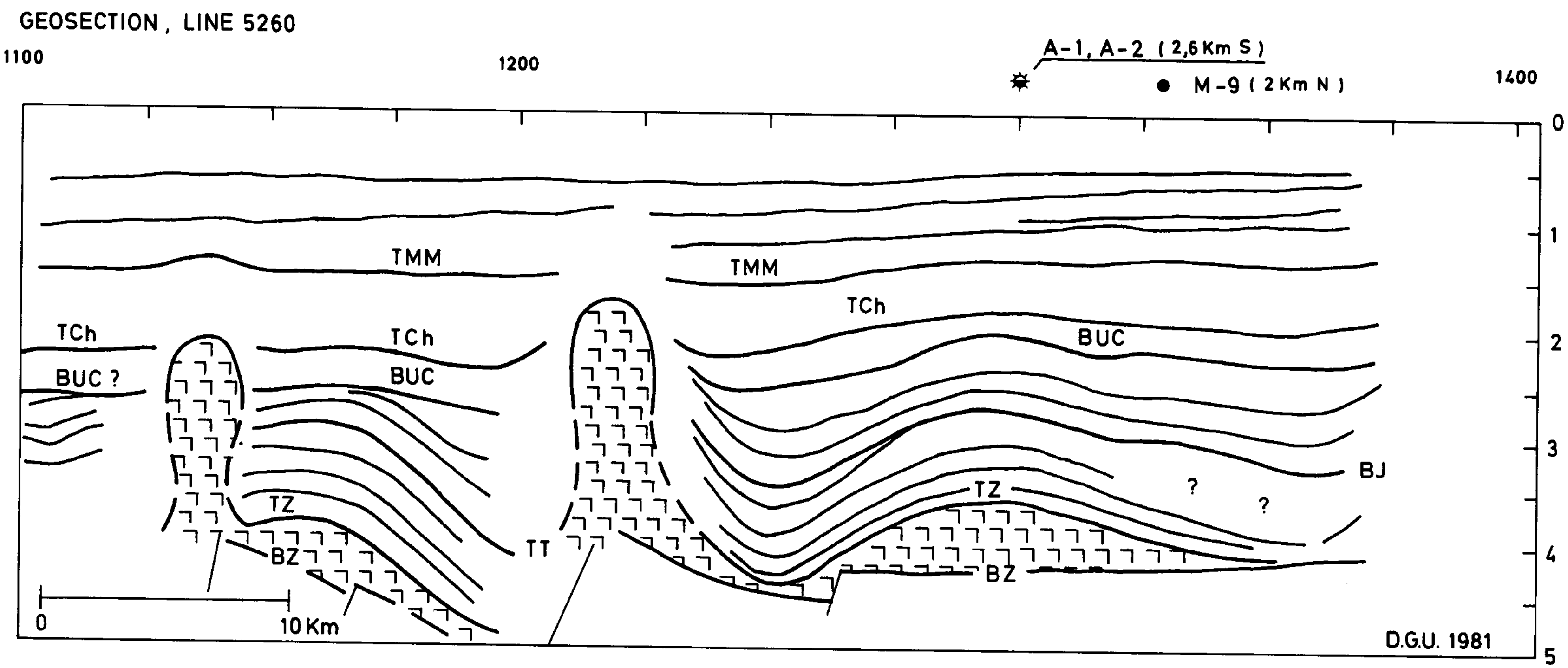
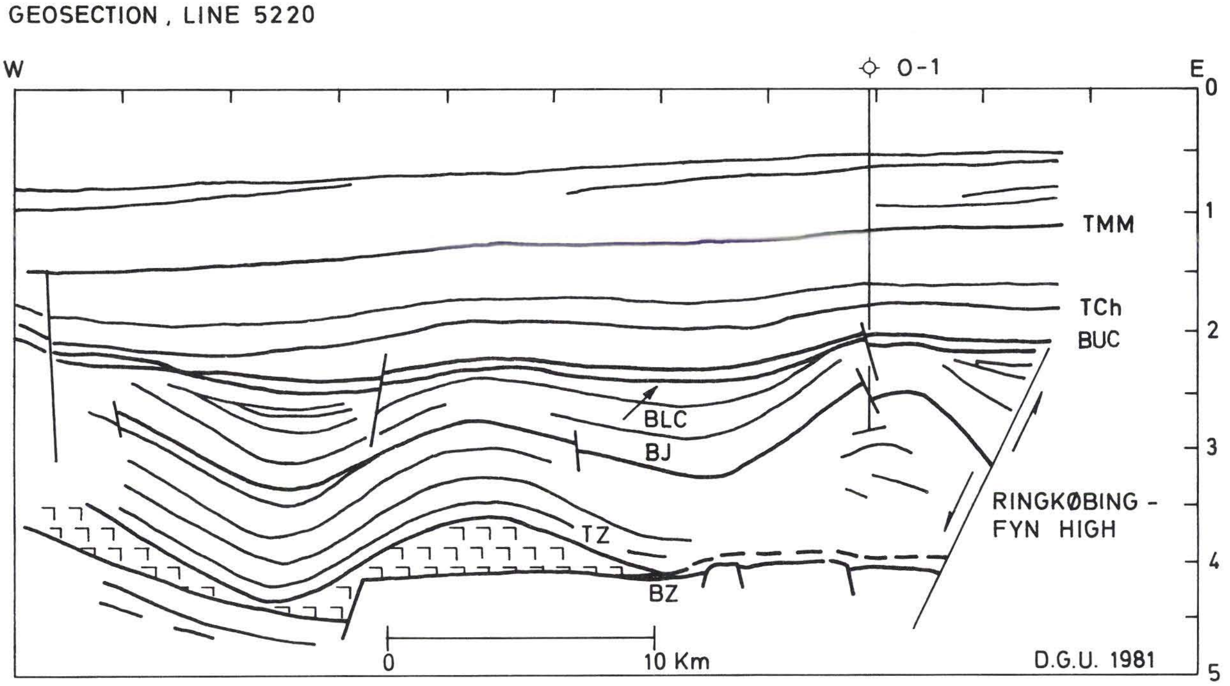


Fig. 8: Geosections a) line 0503 and b) line 5260. – For location and legend, see fig. 7.



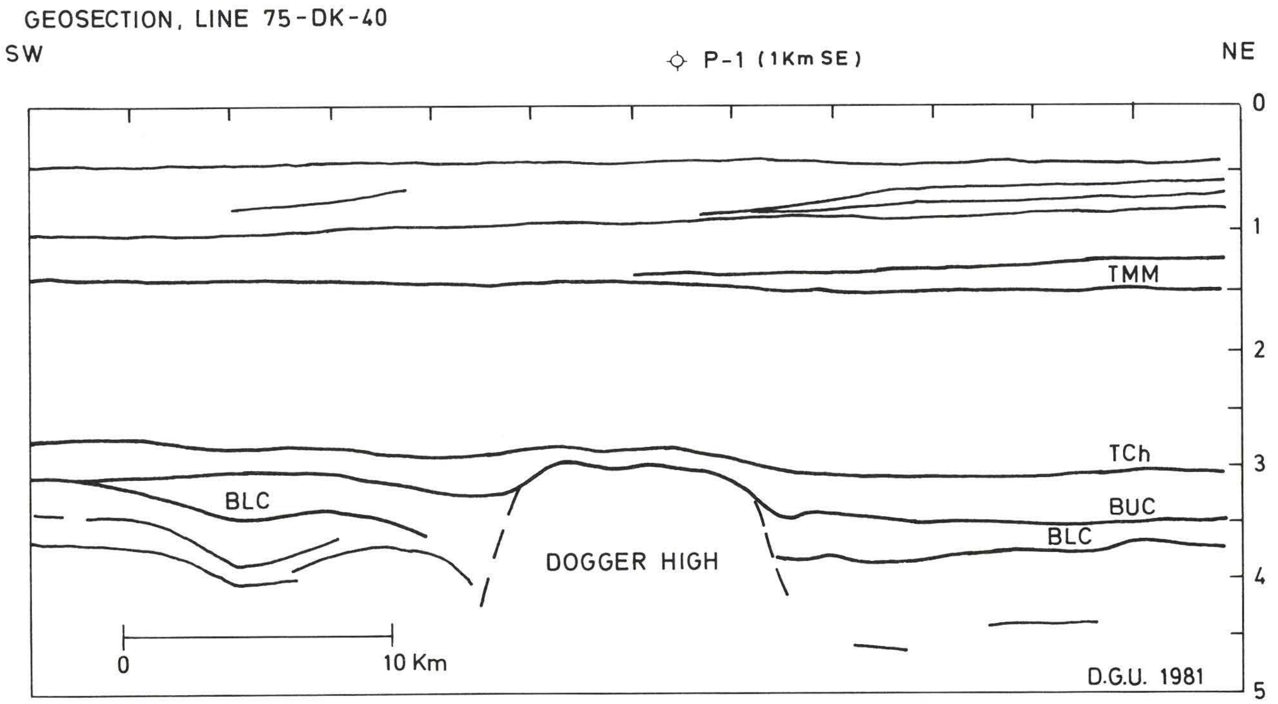


Fig. 9: Geosections a) line 5220 and b) line 75-DK-40. – For location and legend, see fig. 7.

CENTRAL GRABEN

Geosection, line 0453

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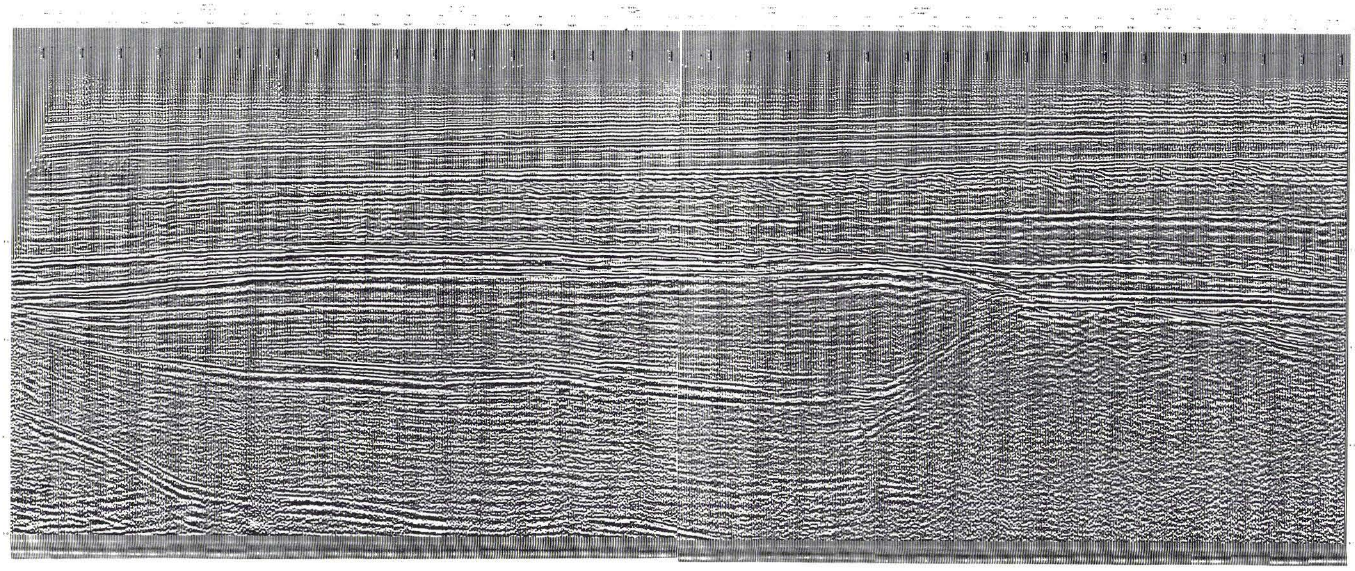

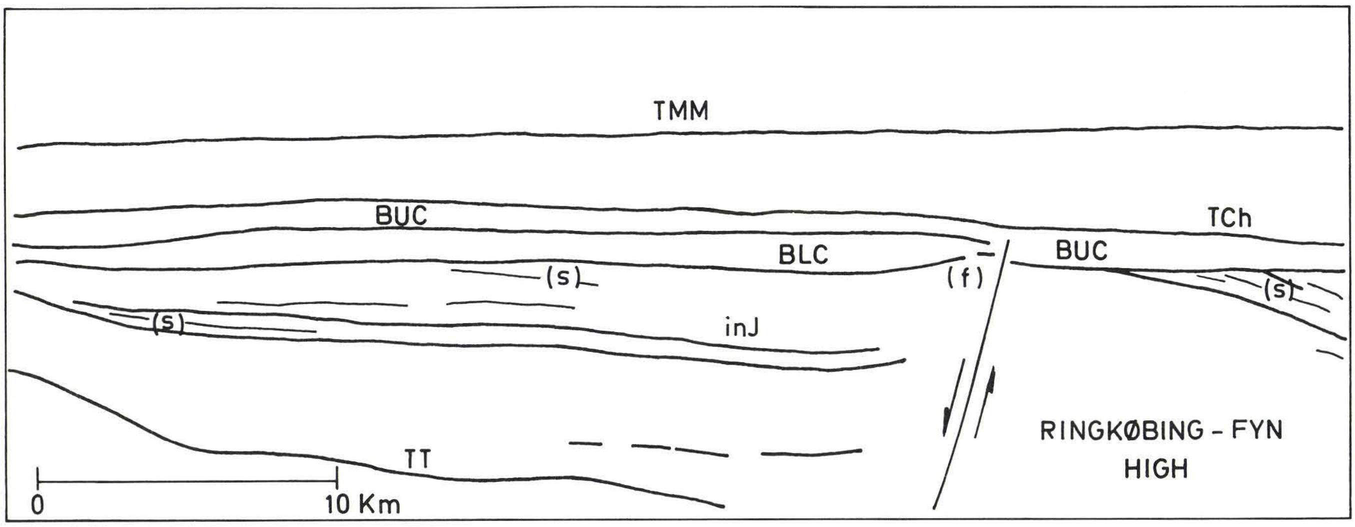

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Fig. 10: Line 0453 a) seismic section b) geosection. – For location and legend, see fig. 7.

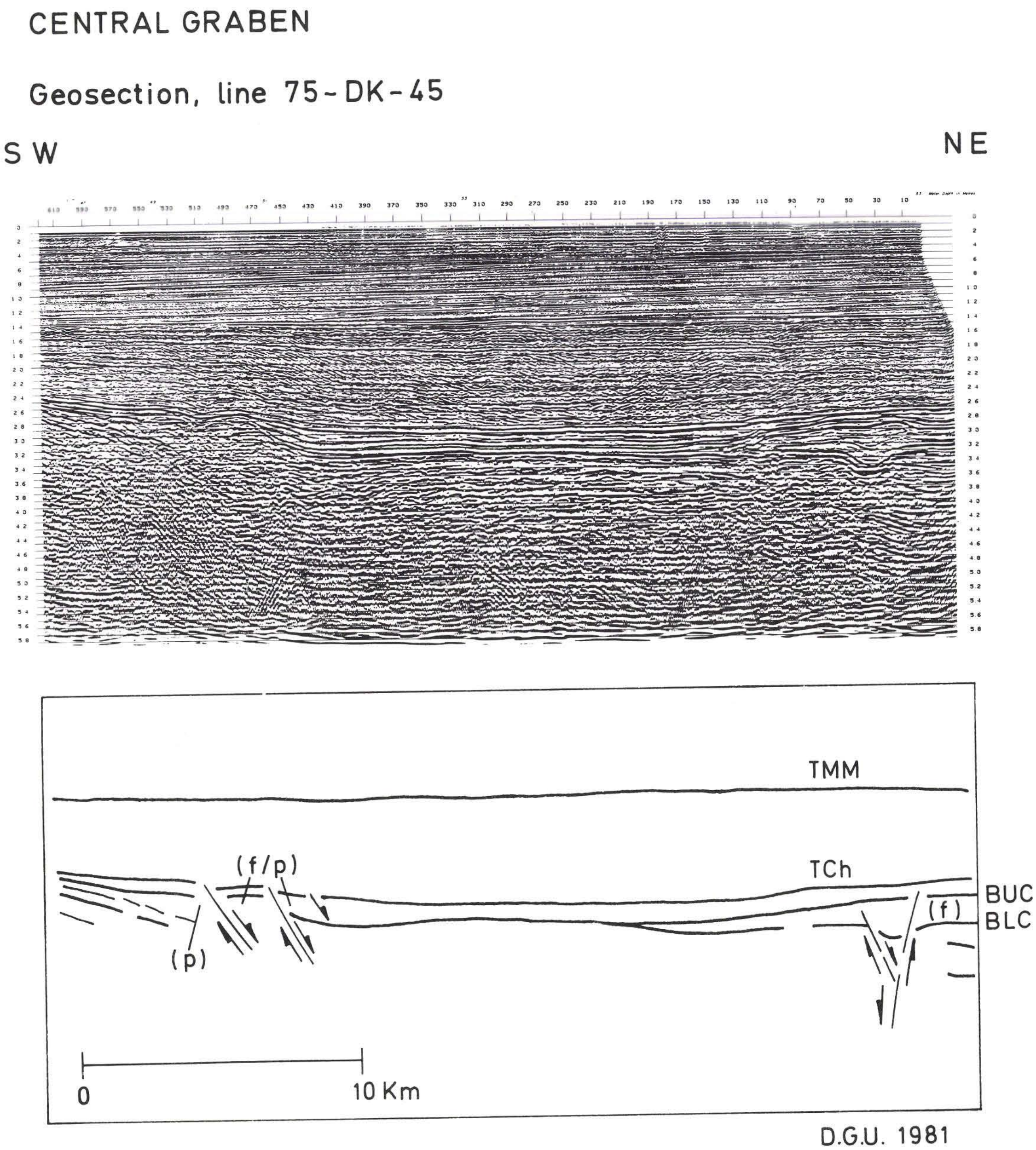

Fig. 11: Line 75-DK-45 a) seismic section b) geosection. – For location and legend, see fig. 7.

this Caledonian fold belt and the undeformed foreland to the north and east is not well defined. The Ringkøbing-Fyn High is known to be Precambrian basement, in parts covered by Lower Palaeozoic sediments which also cover Sjælland, Kattegat, and Jylland.

The greenschists found in the P-1 well, located on the northern part of the Dogger High, have Caledonian radiometric ages (Frost et al. 1981). Thus the Polish-German Caledonian deformation front , linking up with the Scottish-Norwegian Caledonian Mobile Belt, appears in the Danish sector to be located more or less at the same position as the later formed Central Graben.

Devonian and Carboniferous

So far Devonian deposits have not been drilled in Danish areas, whereas Carboniferous is present in the P-1 well. The palaeogeographic pattern based on wells elsewhere in the North Sea suggests the presence of Devonian strata. During the Devonian an extensive basin covered large parts of the North Sea including the Central Graben. The sediments that can be expected in the Danish sector are dominated by redbeds but, centrally, deposits of Limestones , in a possible fault controlled sea arm extending northwards from the Rhenish Basin, are likely to be present.

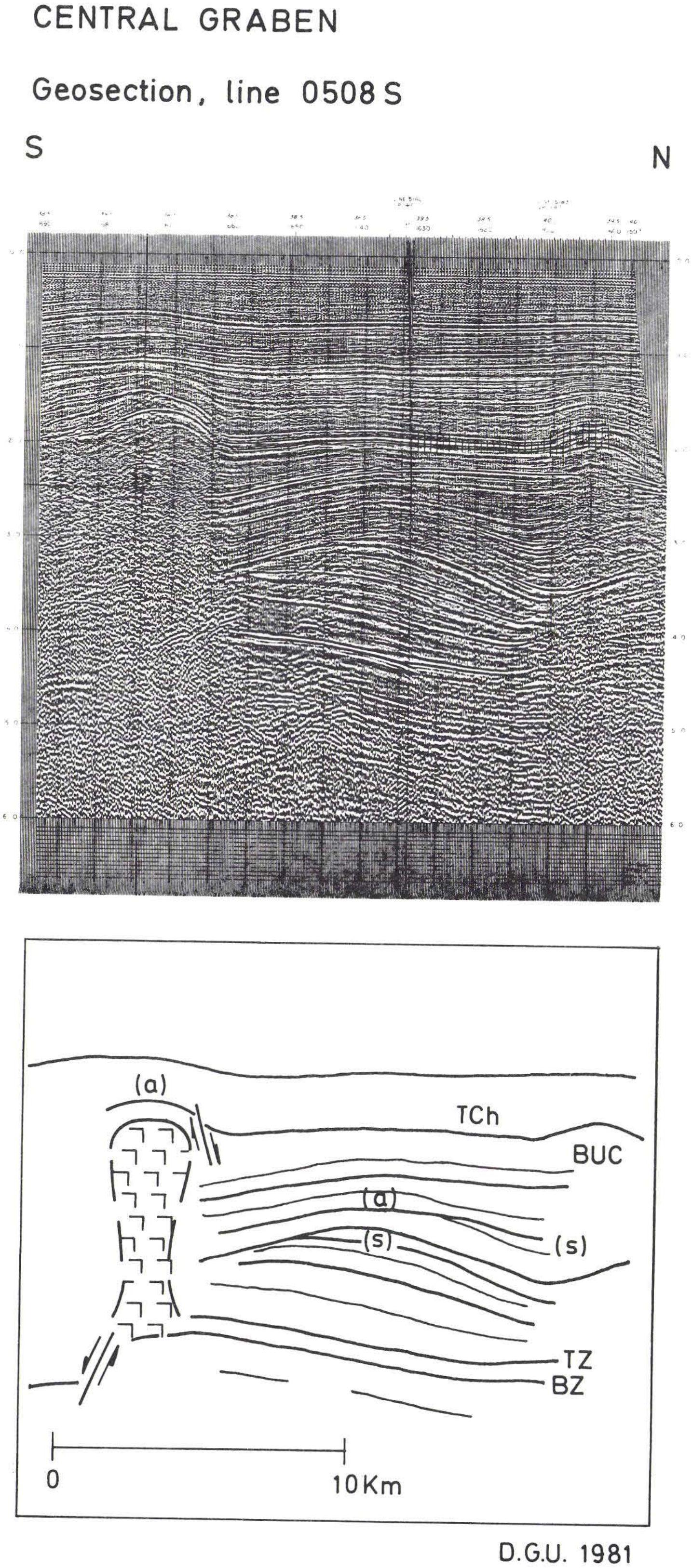

Fig. 12: Line 0508S a) seismic section b) geosection. – For location and legend, see fig. 7.

Geosection, line 5310

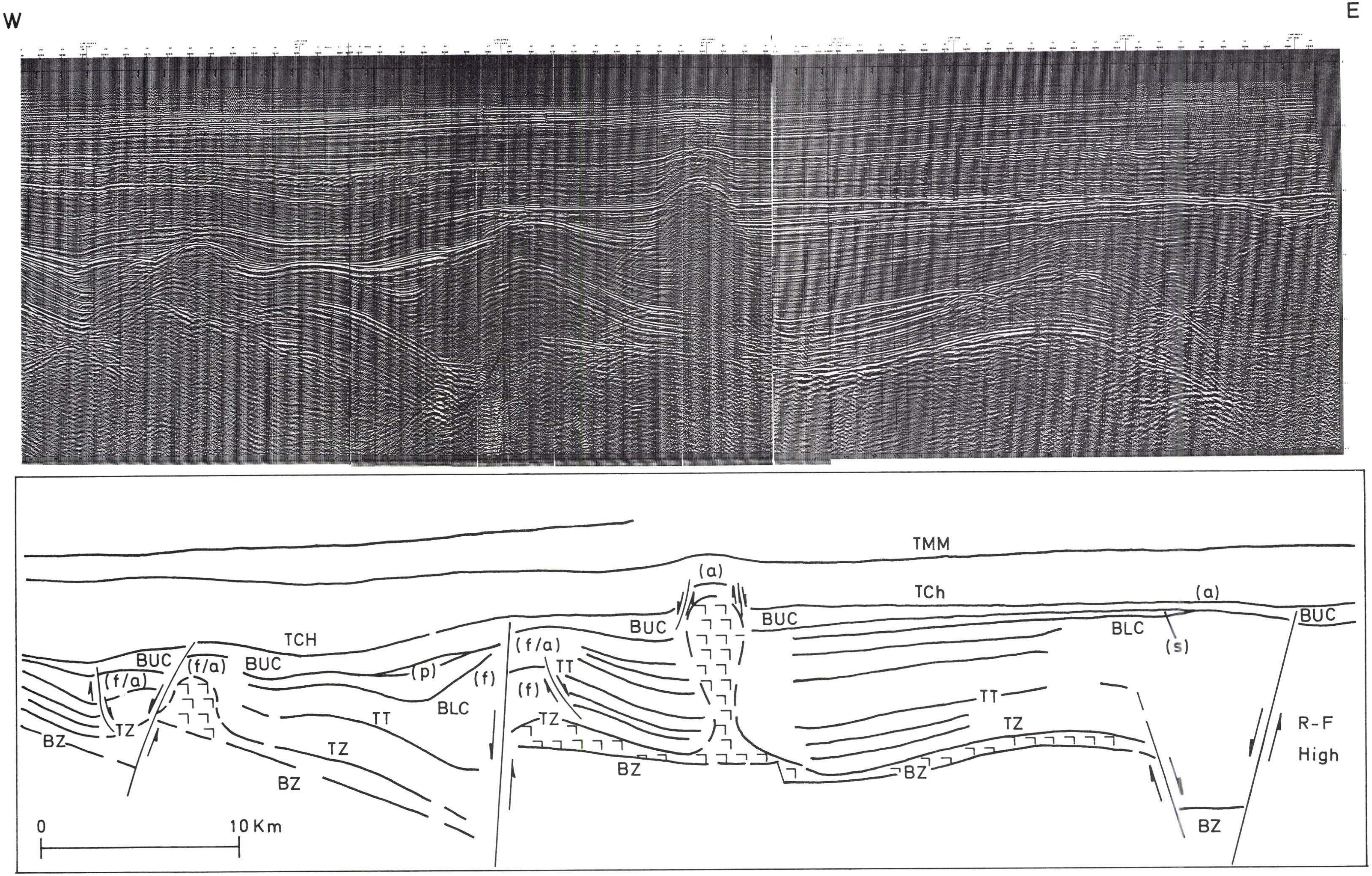

Fig. 13: Line 5310 a) seismic section b) geosection. – For location and legend, see fig. 7.

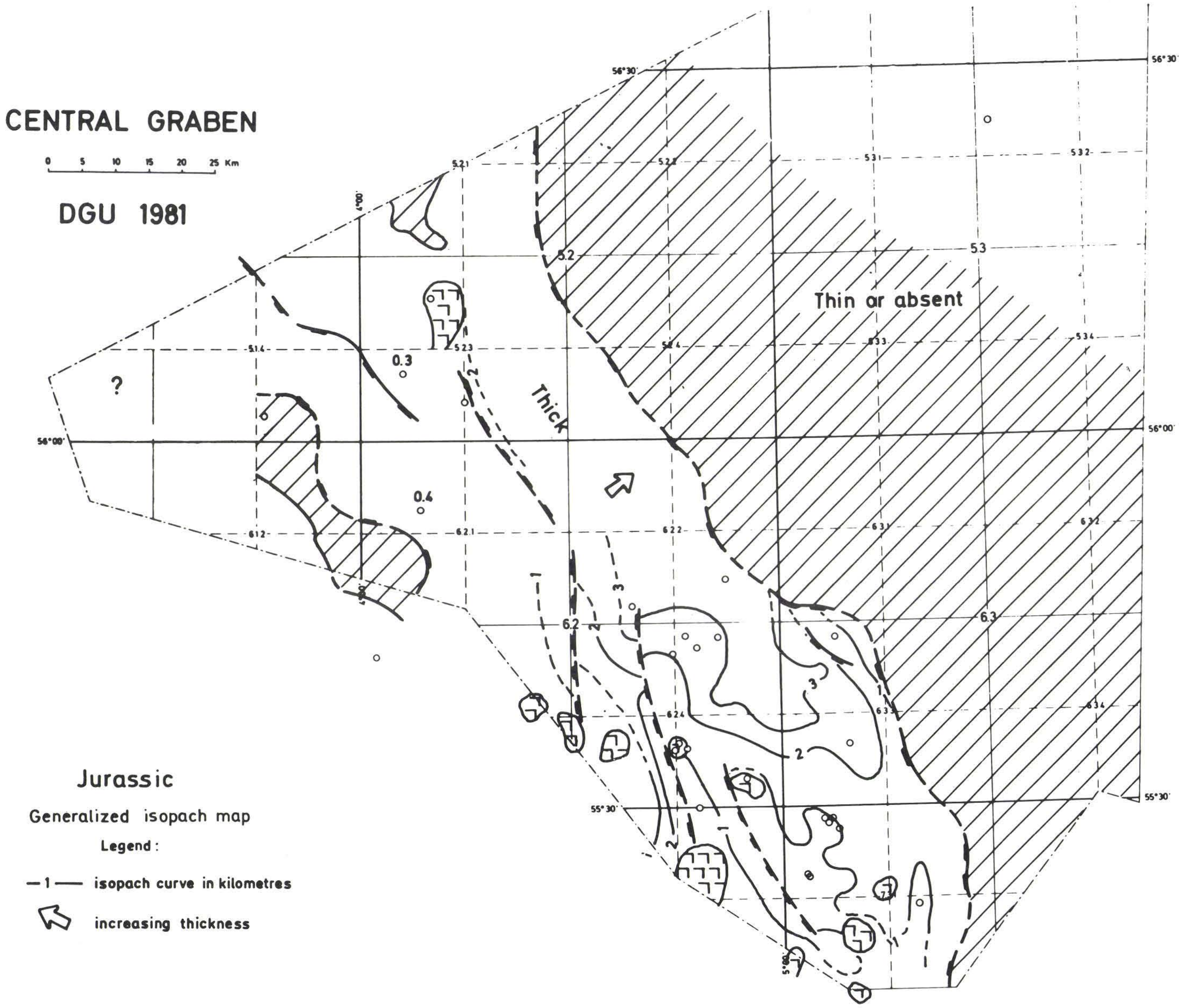

Fig. 14: Generalized isopach map of the Jurassic sequence.

Marine Early Carboniferous platform deposits are known as far north as the Danish P-1 well in the Central Graben, and the Moray Firth Basin. P-1 may well be located in a marginal belt which, together with the North British and the North German occurrences, delimites the occurrence to the north.

Late Carboniferous coal bearing series were until recent only known from the southern North Sea, where they form an east-west depositional belt. The central North Sea and the Danish onshore area is generally accepted as the source region for clastic supply to this depositional basin. The new discovery of marine Late Carboniferous sediments in the Oslo Graben area (cf. Olaussen 1981) gives valid reasons for changing the palaeogeographic picture. Of two postulated connecting sea arms (Eva Paproth 1981, pers. comm.) the one passing Kattegat, Skåne, and the Baltic may be preferred to the other through Skagerrak and northwards through the North Sea. Until further data are available , the conclusion will be that Carboniferous sediments, might be present in the Kattegat, Skagerrak, and the Central Graben, and even on the westernmost block of the Ringkøbing-Fyn High.

The structural understanding of the Carboniferous in the study area will be likewise rather poor. Dipping seismic reflections in the Dogger High area (fig. 11) below the Chalk Group may tentatively be correlated with Devonian-Carboniferous events. Similar dipping reflectors are seen on the Ringkøbing-Fyn High and in the area north of the Adda structure (fig. 10).

Permian

Late Carboniferous to Early Permian tectonic movements strongly affected the Northwest European region.

Following the uplift after the Variscan Orogeny in central West Europe, formation of horsts, basins, and grabens were initiated in Northwest Europe by right-lateral faulting. Thick volcanic piles usually accumulated at intersections of fault trends (i.e. northern Germany), and dyke swarms were intruded in Scania and the northern part of the British Isles. A part of this system may have been the WNW-ESE trend of highs across the North Sea, including the Mid North Sea High and Ringkøbing-Fyn High, which probably already existed in Late Carboniferous-Early Permian times. It also seems reasonable to relate the formation of both the Oslo Graben, the Horns Graben and the associated volcanism to the same tectonic phase. The Rotliegendes sequence in the Danish part of Central Graben is dominated by volcanics with subordinate intercallated sediments, and it has been drilled in the B-1 and P-1 wells and possibly in Q-1 and W-1. Possible Rotliegendes volcanics occur in the adjacent parts of the British and Norwegian sectors. The tectonic activity in the early part of Early Permian created a separate Southern and a Northern Permian Basin. In these basins red beds with interbedded sand and clay were deposited later in Rotliegendes. Due to missing well-control, neither the geometry of the northern basin nor the distribution and thickness of the red beds in the Central Graben are well known. Red beds are likely, however, to be rather widely spread both on the Dogger High and on the Graben floor.

In Late Permian, Zechstein time, the sea transgressed into the Northern and Southern Permian Basins mentioned above.

South of 57° N, the Zechstein facies in the North Sea are clearly structurally related. Shallow water carbonates and anhydrites predominate around the basin margins particularly on the Mid North Sea High and the Schillbank High, whereas thick evaporite sequences were deposited in the subsiding Northern and Southern Zechstein Basins. Evaporites were also deposited in the subsiding Central Graben. Day et al. (1981) propose that the evaporite sequence is continuous through the Central Graben although probably thin over the median part.

Ziegler (1981) in contrast is in favour of a model where the central part of the Danish Central Graben is dominated by deposition of thin carbonate and anhydrite shelf sequences similar to the deposition pattern of the adjacent structural highs.

No proof for selecting the right model is as yet at hand since Zechstein, because of its depth, is not recorded on available seismic sections and therefore cannot be traced in the Tail End Graben area. The absence of the Zechstein evaporites in the W-1 and Q-1 wells is, following the arguments of Day et al. (1981), explained by salt withdrawal associated halokinetic movements.

Triassic

The structural framework, created during the Late Palaeozoic, which made up the fundament for the Triassic, Jurassic, and Early Cretaceous sedimentation, suffered rifting during the Triassic. In the Northern and Southern Permian Basins in Northwest Europe the onset of the Triassic was marked by a regional regression and a return to a continental depositional regime. Continued subsidence caused a gradual burial of the Mid North Sea High and the Ringkøbing-Fyn High. Generally the continental sedimentation rates kept pace with subsidence and rising sea level.

The Triassic depositions in the North Sea may generally be divided into two parts, a northern and a southern. The Danish Central Graben seems to be located in a transition zone between these. The northern area is dominated by accumulations of heterogenuous and rather coarse-grained material shed into the basin from the northeast. The southern region is characterized by more fine-grained material deposited in a cyclical succession reflecting regressions and transgressions from the south. Well control in the Danish Central Graben is limited to the Southern Salt-dome Province and the B-1 and Q-1 wells.

The thickness of the Triassic sequence in the south is 1500-2000 m, but rather wide variations caused by erosion during the Early Cimmerian or perhaps the Mid Cimmerian tectonic events, do occur. This observation is in accordance with well information, indicating that Rhaetian sandstones of the Winterton Formation, normally present in the Netherlands part of the Central Graben, are missing in the Danish sector. The base Jurassic seismic reflection is often developed as a rather distinct unconformity surface.

Variations in thickness of the Triassic sequence in the Southern Salt-dome Province may locally be explained by the onset of halokinesis of Zechstein evaporites in the Late Triassic. Towards the German part of the Dogger High the thickness of the Triassic sequence is generally reduced and the angular unconformity on top becomes much more distinct.

In the northern parts of the Danish Central Graben, very little can be said about distribution and structural setting of the Triassic. This is due to scarcity of data, both with respect to well control and to resolution of the seismics.

Jurassic

The thickness of the Jurassic sequence, predominantly Late Jurassic shales, exceeds 4000 m in parts of Tail End Graben. In the Southern Salt-dome Province the thickness rarely exceeds 1600 m and usually only in connection with development of rim-synclines around salt structures. West of the fault zone delineating the Tail End Graben, the Jurassic is much reduced in thickness, and it is totally absent on the crest of the Dogger High. An understanding of the Jurassic in the northern area adjacent to the Norwegian sector is difficult to obtain due to lack of well control and released seismic sections. A generalized isopach map of parts of the Central Graben is given in fig. 14.

Unconformities are rather frequently recorded in the Jurassic sequence especially on seismic sections from the northern part of the Southern Salt-dome Province.

It is tentatively suggested that the major part of the Tail End Graben subsided as one large rotational fault block in the Late Jurassic with the boundary fault zone of the Ringkøbing-Fyn High acting as a major synthetic fault.

The Early Jurassic sedimentation of Northwest Europe took place during a sea-level rise. In the North Sea region relatively shallow-water marine clay- and marlstones were deposited. Deposition of sand and silt took place only in marginal regions, e.g. along the northeastern margin of the Danish Subbasin and in the East Shetland Basin.

The Early Jurassic sediments are preserved only in local basins within the North Sea region, probably as a result of the Mid Cimmerian events (see below). It is believed that the Early Jurassic sea covered the entire Danish area, and that the main depocentres were primarily in the Danish Subbasin and secondarily in the southern Central Graben. In the Danish Central Graben, the claystone series is referred to the Fjerritslev Formation, which is known from the Danish Subbasin, equivalent with the Dunlin Unit in the northern North Sea.

At the end of the Early Jurassic a rifting phase, the Mid Cimmerian phase, took place. It affected the Northwest European Graben systems by renewed block faulting, and it was accompanied by a general lowering of the sea level and subsequent erosion. In the central North Sea a large rift dome was uplifted, and volcanic activities took place north of the Danish area. In the Central Graben the erosion is not yet known to have affected strata older than Early Jurassic. Due to the accentuated relief, clastic sediments were shed into the basins. Generally the deposition took place in fluviatile and deltaic environments. Interbedded sand, clay, and coal, equivalent to the Haldager Sand in the Danish Subbasin and the Brent Sand to the north, were deposited in the Central Graben.

During the Middle Jurassic, the Central North Sea rift dome began to subside and a general sea level rise took place. The area was flooded and, except for certain highs, the sea covered the main part of the North Sea region. The rate of subsidence in the Central Graben exceeded the rate of sedimentation, so clay-dominated sediments were laid down in a deep water marine environment. The Late Jurassic period is a main subsiding period for the Central Graben. The thickness of the Late Jurassic claystone series within the Graben varies, due to differentiation of the subsidence and deposition on individual rotational fault blocks, but it markedly exceeds that of the equivalent series on the surrounding flanks.

At the transition Jurassic to Cretaceous, a tectonic pulse, the Late Cimmerian phase, affected the entire Northwest European region, and it was accompanied by a sea level drop. A regional unconformity was developed in the Graben system, and shallow marine arenaceous sediments were deposited in marginal areas, e.g. the Frederikshavn Member in the Norwegian-Danish Basin. The unconformity is believed to be largely of sub-marine nature, and continuous sedimentation in the deeper parts of the Graben systems is found elsewhere in the North Sea. In the Danish Central Graben, the unconformity hiatus represents varying parts of the Late Jurassic-Early Creaceous.

In the Southern Salt-dome Province, the distinction of separate subsiding Late Jurassic fault blocks is attenuated by contemporaneous salt movements.

The sand of the W-1 Unit shows indications of having originated from a near source. It is therefore suggested that the Dogger High horst block remained partly elevated during Late Jurassic times and acted as a source area for clastic deposits along the margins of the graben floor.

The Late Cimmerian rifting phase gave rise to an unconformity which can be mapped in most of the North Sea area. This unconformity is diachronous due to a complex interplay of tectonic activity and eustatic changes (Fyfe et al. 1981).

In the Danish Central Graben, the top of the Jurassic sequence frequently shows an angular unconformity to the overlying Early Cretaceous in the area to the east of the Dogger High. In a zone along the Ringkøbing-Fyn High stretching from Tyra and Adda to the south of Igor, the top Jurassic is difficult to map seismically. Distinct unconformities are usually not observed and there appears to be very little contrast in acoustic impedance between the shales of Late Jurassic and Early Cretaceous ages.

The depth to the Top Jurassic marker is usually less than 2500 m in the southeastern part of Central Graben. Minimum depth to the Top Jurassic (about 2200 m) is recorded on top of the Anne structure, while the maximum depth (more than 4500 m) is found towards the north close to the Norwegian sector.

Early Cretaceous

The Late Cimmerian tectonic phase led to a framework of differentially subsiding rotational fault blocks which was only little changed during Early Cretaceous. The general transgressional sedimentation lead to onlap sequences and maximum deposition in the graben floor.

In the central North Sea sedimentation of marine clay, well known from the Norwegian sector, was the dominating feature. In the Danish Central Graben this sedimentary sequence is referred to as the Valhall Formation, which is time equivalent with the Vedsted Formation and the upper part of the Frederikshavn Member in the Norwegian-Danish Basin. Along the highs, sand bodies or sandy marl fans were deposited which are interpreted as beds deposited by density currents activated by fault activity. The LC-1 Unit in the Danish area is probably equivalent to the Devils Hole Formation. A minor regression associating the Asturian tectonic phase, seems to have broken the general transgressional trend. In the Danish region this could be indicated by minor unconformities. As the Cretaceous transgression continued the highs were drowned. The Rødby Formation, dominated by reddish marl, covers large parts of the North Sea area, as well as the Ringkøbing-Fyn High.

The distribution and thickness of the Early Cretaceous sequence within the Danish Central Graben is illustrated on the generalized isopach map of the Early Cretaceous (fig. 15). The thickness of the Early Cretaceous sequence exceeds 500 m in the central and northern parts in the elongated, partly fault-controlled troughs. A maximum thickness more than 900 m is found in a trough at the northern extension of a major Cimmerian normal fault.

The thickness of the Early Cretaceous sequence is less than 250 m in the Southern Salt-dome Province, except for a few peripheral sinks around salt diapirs in the southernmost part.

Early Cretaceous is thin or absent on the Ringkøbing-Fyn High and there is a gradual decrease in thickness in the Graben towards the boundary fault zone.

Likewise Early Cretaceous is thin or absent in the Dogger High area.

'Onlap sequences' are characteristic features on seismic sections and internal unconformities occur locally close to the fault zone at the western margin of Tail End Graben suggesting that this zone was active during Early Cretaceous times.

In the northern part of the Danish Central Graben area and around Dogger High, the top of the Early Cretaceous sequence is marked by an unconformity. The area around the P-1, W-1, Q-1, and I-1 wells was uplifted and part of the Early Cretaceous eroded prior to the deposition of the Late Cretaceous Chalk Group.

Late Cretaceous

The dominating factor for the Late Cretaceous sedimentary evolution in Northwest Europe was a global sea level rise during which the marginal areas, such as Scania, were transgressed. Due to the transgression and changes in climatic conditions, the influx of clastic material was radically reduced, and chalk was deposited.

In Late Cretaceous times the active central North Sea rift system ceased to exist. More than 1500 m of the chalk was deposited in the Norwegian part. On the Graben flanks the chalk thicknesses usually are in the order of 250-500 m.

Comparing the generalized isopachs of the Lower Cretaceous sequence and the Chalk Group, one observes that areas of thick Lower Cretaceous are often overlain by relatively thin Upper Cretaceous and vice versa. This phenomenon is associated with a system of antiformal and synformal gentle flexures arranged in en echelon pattern. These are believed to be the effects of Late Cretaceous and Early Tertiary inversion tec-

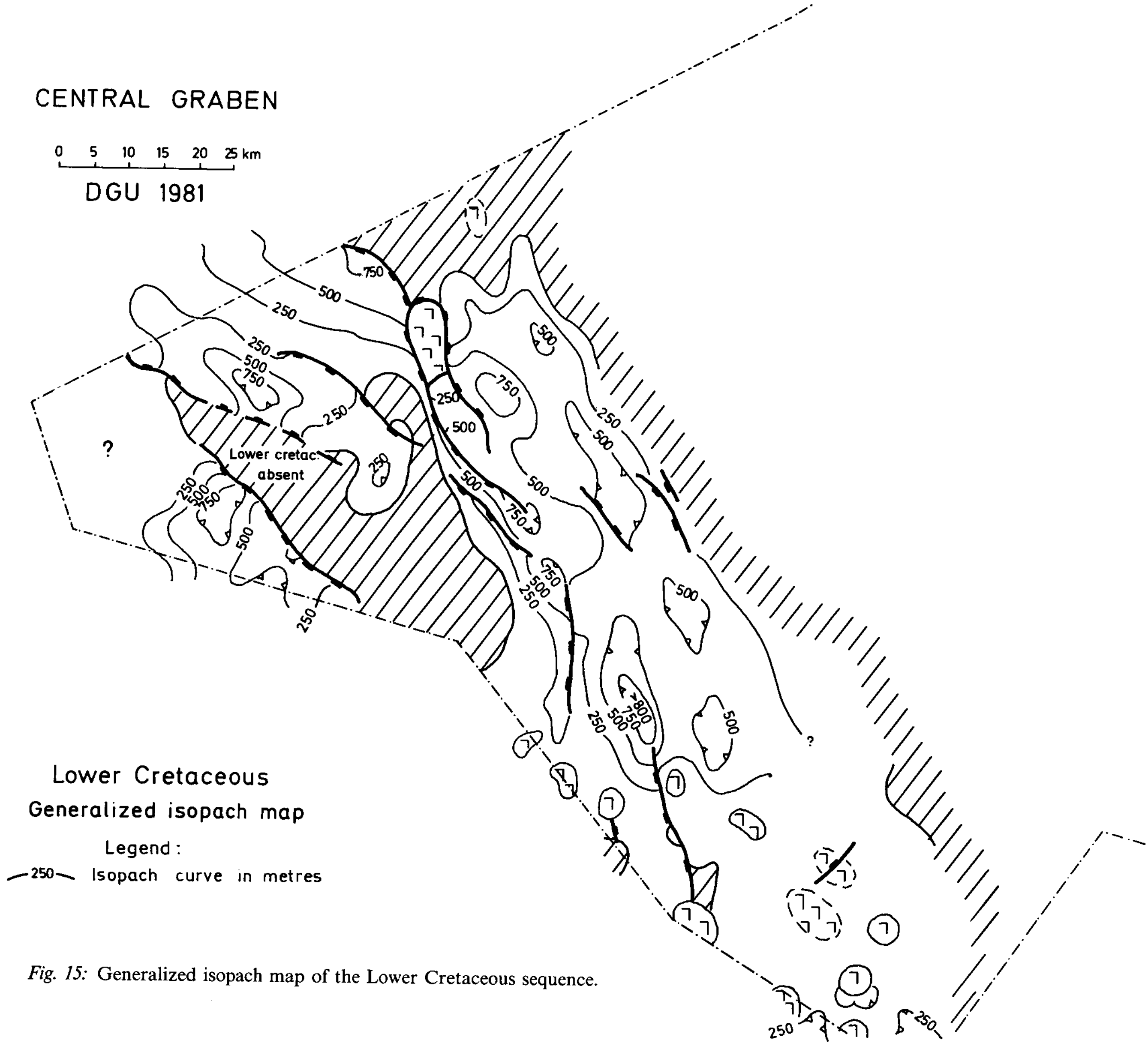

Fig. 15: Generalized isopach map of the Lower Cretaceous sequence.

tonics caused by a compressional strike-slip stress regime.

The change from rifting to a phase of gradual subsidence was thus accompanied by inversion tectonics whereby previously tensional basins were deformed by compressional and wrench forces. The basin fill was folded and uplifted and may even have been subjected to erosion.

The inversions are believed to be caused by Sub-Hercynian or possible Laramide orogony.

A generalized isopach map of the Chalk Group is given in fig. 16, and a two-way time map to Top Chalk is given in fig. 6.

The thickness of the Chalk Group outside the halokinetic structures varies considerably, from less than 250 m in the south, to more than 1250 m in the northern part of the Danish Central Graben, close to the Late Cretaceous regional depocentre in the Norwegian sector.

The effect of active Late Cretaceous salt diapirism and possible shale flow along the western margin of the Tail End Graben can be read from the generalized isopachs and the fault pattern.

The relative thickness distribution of the various chalk units, based on well information, shows a complicated depositional pattern throughout the Central Graben area (fig. 26). This indicates a differential structural evolution of the Graben subunits. The well data seem to indicate that the Dogger High area and the western margin of the Tail End Graben were

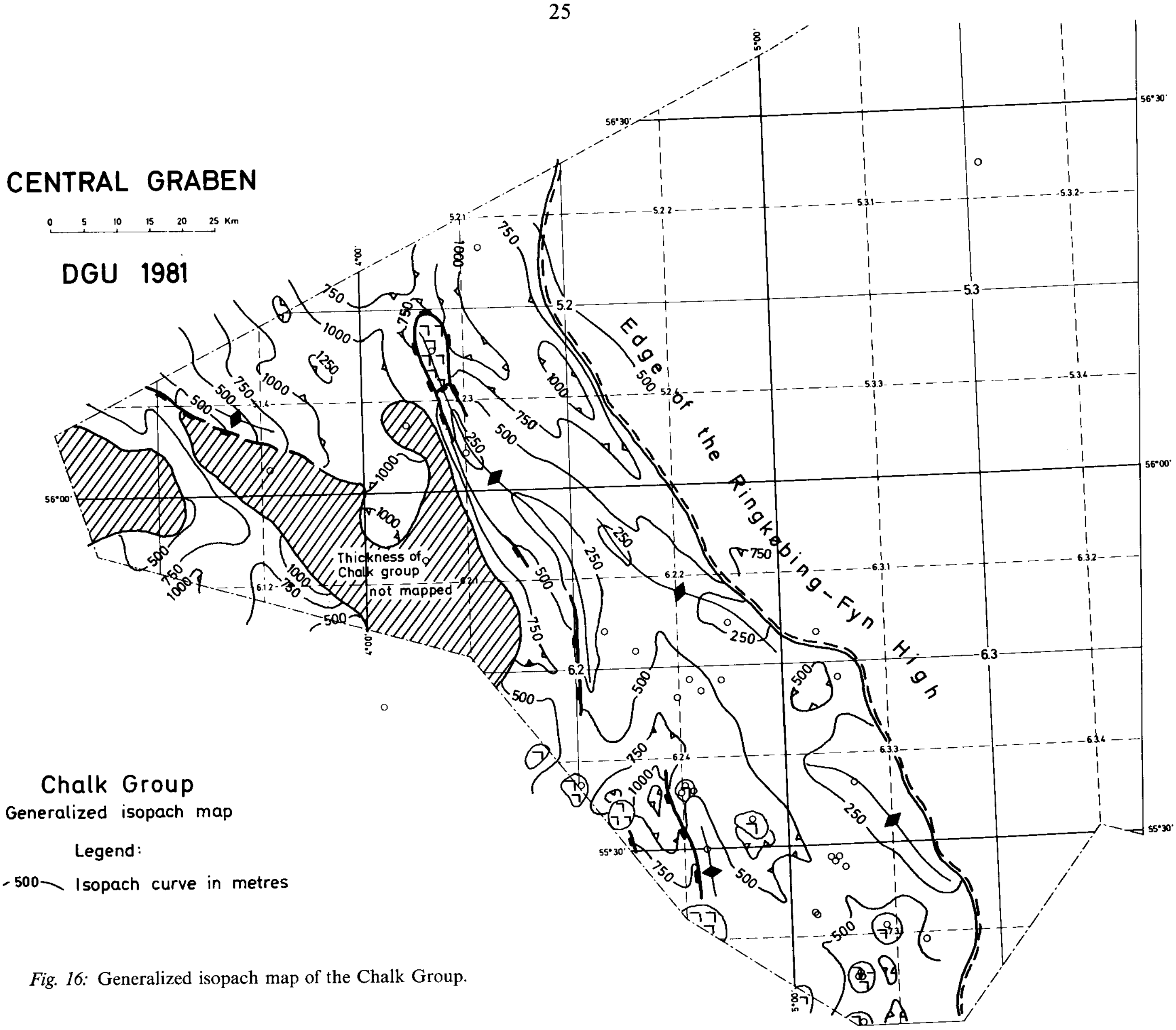

Fig. 16: Generalized isopach map of the Chalk Group.

uplifted during deposition of the Chalk-1, 2, and 3 Units. The Chalk-4 Unit was deposited all over the Central Graben although it is thin at the eastern margin of the Tail End Graben close to the boundary fault zone. This area may have remained relatively uplifted during deposition of this Unit.

The Chalk-5 Unit is also relatively thin in the Tail End Graben and its western margin. These areas probably became inverted during deposition of this Unit.

The Chalk-6 Unit of Danian age was probably deposited throughout the Central Graben area. It has its maximum thickness along the flank of the Ringkøbing-Fyn High and may be absent locally along the western margin of the Tail End Graben.

Tertiary and Quaternary

In the beginning of the Tertiary, the Laramide tectonic phase, associated with a regression in the marginal areas and a change of the climate, altered the sedimentary pattern into a clastic dominated regime. After this event the North Sea Basin became a part of a large Northwest European sedimentary basin, the main sedimentary source region of which was situated to the east. During the Tertiary the basin subsided evenly and rapidly, and was affected only by minor tectonic events and locally by halokinetic movements. In the Early Tertiary, sedimentation clay dominated, while sand and silt intercalations characterize the Late Tertiary accumulation.

During the entire Cenozoic, characterized by a gradual and rapid subsidence pattern in the Central North Sea area except for mild Laramide inversions in the former Graben areas, more than 3000 m of sediments accumulated in the northern part of the Central Graben. Only the Early Tertiary lithological units vary significantly in thickness, and these deposits become thicker in the northern part.

The central part of Dogger High showed a separate subsidence pattern during the Early Tertiary. Fig. 11 shows that sediments prograded eastwards from this high into the basin to the east. The base of the Upper Miocene is locally developed as a weak angular unconformity and marks the shift from an Early Tertiary, predominant-shale sedimentation into a more sandy, Late Tertiary sedimentation. This indicates that sedimentation rates probably started to exceed subsidence rates.

The Late Tertiary sedimentary sequence shows uniform progradation from the east. The fairly monotonous and uniform Tertiary evolution is interrupted only locally by continued salt diapirism.

The thickness of the Quaternary cover is up to 600 m in the Central Graben area.

3.0 Description of the formations

All formations recorded by drilling in the Danish Central Graben area are listed and described in the present chapter. The descriptions are based on a compilation of information available in the DGU files. This basic material is of a heterogeneous character as it comprises analyses and reports worked out by various companies and by DGU. The descriptions given below are, therefore, to be regarded as preliminary, and further investigations must be carried out to elucidate certain stratigraphic and depositional aspects. Thus, the majority of the lithostratigraphic units are treated and named here informally. Only for the Triassic, Lower Jurassic, and Lower Cretaceous units sufficient knowledge has been established to refer these to formal lithostratigraphic units. All lithostratigraphic units are defined on wire-line log characteristics.

A review of the present standard stratigraphic subdivision is given in fig. 2. The bio- and chronostratigraphic correlation is generally at the same level of documentation. This stratigraphic concept will probably be revised through supplementary biostratigraphic studies.

As a rule, the lithology of each unit or formation is described, as interpreted from various sample descriptions and from wire line logs. The diagnostic log motifs and formation boundaries are treated. Furthermore, the thickness, distribution, geological age, depositional environment, source rock potential, reservoir potential, and sealing potential are described. The evaluation of thickness and distribution is partly based on seismic data. The formation descriptions are accompanied by palinspastic profiles and generalised formation maps comprising thickness and distribution. Tables on such primary data as depth, thickness, porosities etc. are presented in chapters 8 and 9.

Well locations are given on a map (fig. 1). Legends for signature on maps, palinspastic profiles, and well sections are given in fig. 3.

3.1 Pre-Permian

By Jørgen Gutzon Larsen & Olaf Michelsen

Data on Pre-Permian rocks are reported only from the P-1 well, which was bottomed in Caledonian basement. The geology of this formation in the western part of the Danish sector is, therefore, poorly known. According to the age determinations performed and reviewed by Frost et al. (1981), the North German-Polish Caledonides extend under most of the North Sea and join the Scottish-Norwegian Caledonides, whereas most of the Ringkøbing-Fyn High is underlain by Precambrian basement.

Caledonian basement

The P-1 well, situated on the western extension of the Dogger High, was bottomed in a sequence of greenschists, believed to be meta-tuffs between 11259-11464' b.KB. In some of these beds, phenocrystal relics of clinopyroxene, titanite and apatite may be abundant, whereas green biotite (?primary), zircon and brown amphibole are scarce. The amphibole is surrounded by a clinopyroxene reaction zone - a relation, which is believed to be of igneous origin, e.g. caused by resorption of amphibole phenocrysts or xenocrysts by lowering of the water pressure or increase in temperature in a crystallizing magma. Light grey to reddish, thin beds are intercalated with the meta-tuff. They are rich in albite-oligoclase, forming fragmental to more or less rounded relics, together with scattered grains of the