GEOLOGICAL HISTORY OF THE SOUTHERN HORN GRABEN[1]

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ABSTRACT

Best, G., F. Kockel & H. Schöneich 1983 Geological history of the southern Horn Graben. 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: 025-033.

The structural history of the southern Horn Graben is analysed based on the data of the released German offshore wells Q-1, R-1 and S-1 and two E-W directed seismic lines. Rifting presumably already started during the Late Carboniferous. The main phase of taphrogenesis took place during the deposition of the Lower and Middle Buntsandstein (Bacton interval) and an asymmetric graben with a more pronounced western flank was formed. During Röt and Muschelkalk sedimentation, Permian salts mobilized at the boundary faults and in the graben center, forming salt pillows. These salt structures entered the diapiric stage mainly during Keuper deposition while subsidence continued. At the beginning of the latest Jurassic and during the Early Cretaceous general subsidence and tilting towards the west took place, following a Middle-Late Jurassic period of uplift and erosion of the Graben and its surroundings. The negative movements have continued at increasing rates till present times. Weak diapiric movements in the salt structures persisted until the Late Miocene.

INTRODUCTION

The general structural pattern of the eastern part of the German North Sea shelf area is relatively simple. The main feature in the north is the WNW-ESE striking Ringkøbing-Fyn High, a positive element active from at least the Dinantian till the beginning of the Middle Oligocene. During the Late Palaeozoic it formed an obvious part of the northern margin of the NW German-SE North Sea Carboniferous, Rotliegend and Zechstein basins. South of it, the West Schleswig Block forms the southern slope of the Ringkøbing-Fyn High and the adjacent platform. This element is defined as a relatively stable area with a basinal sedimentary sequence during Upper Rotliegend, Zechstein and Triassic deposition but without significant halokinetic mobilization of Permian. Towards the west and bordering the Ringkøbing-Fyn High and the West Schleswig Block is the Horn Graben, a NNE to NE-striking rift zone with diapiric salt structures astride the border faults which were tectonically active in Late Palaeozoic and Triassic times. West of the Horn Graben, the East North Sea Block acted during the Permian and Triassic rather like a marginal part of the Ringkøbing-Fyn High and can be regarded as its western prolongation. The Central Graben, west of this positive element, is not treated in this paper (Fig. 1 and ZIEGLER, 1982).

The following study of the Horn Graben development is based on the three boreholes Nordsee Q-1, R-1 and S-1, released for this paper by the German North Sea Consortium, as well as on 2 E-W seismic lines shot in 1980 by Placid Germany Ltd.

STRATIGRAPHY AND FACIES DEVELOPMENT

The crystalline basement of the eastern North Sea High was reached in well Q-1. Here, the muscovite-biotite augen gneiss is albitic and shows a metamorphism in the greenschist facies. K-Ar dating by Mobil Research Lab. provided an age of 415 ± 8 Ma (recalculated with new standard) (FROST ET AL., 1981), a clear indication of a Caledonian age of the youngest metamorphism. Nevertheless, it cannot be excluded that the albitic augen gneiss is a diaphtorite and represents a much

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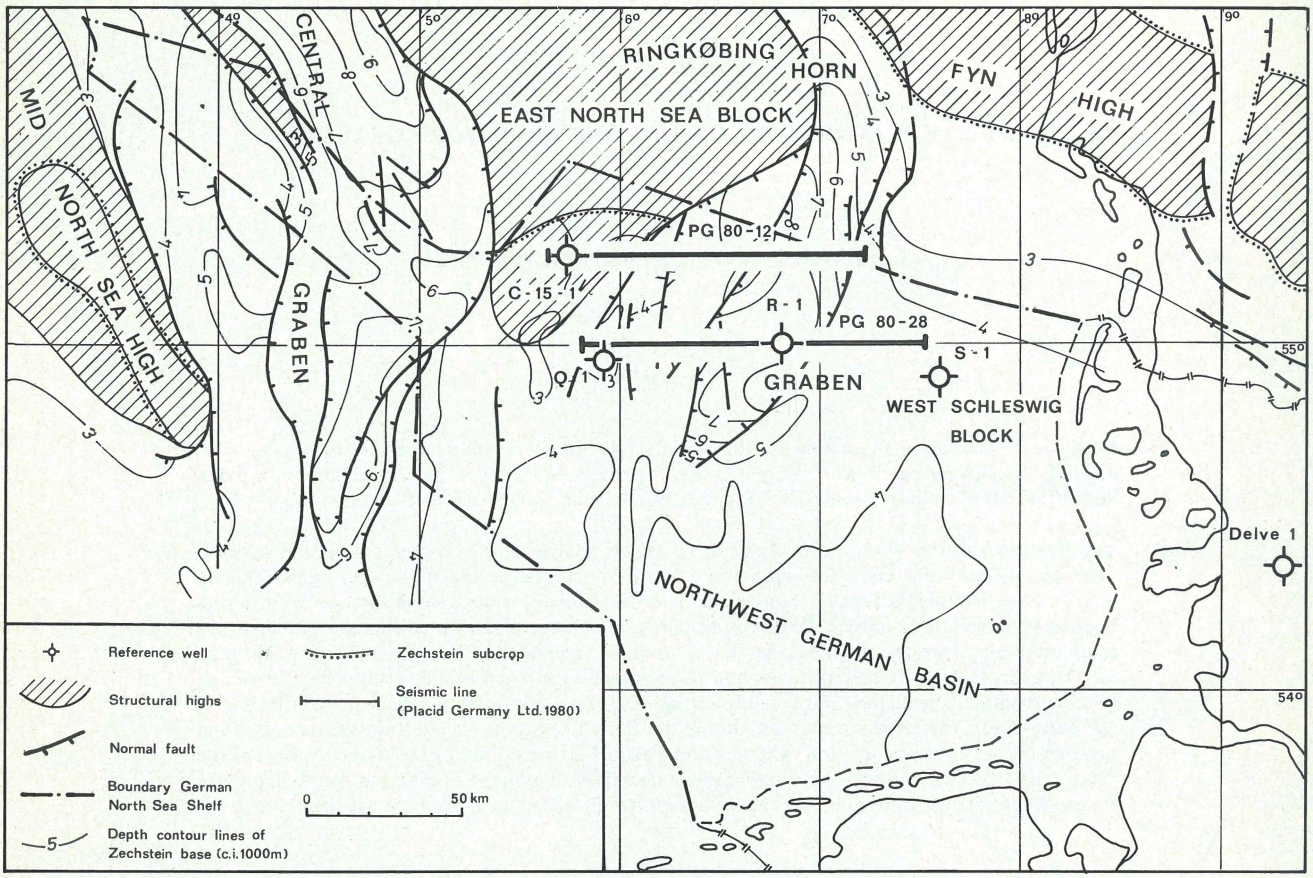


Fig. 1
Structural map of the German North Sea sector with depth of Zechstein base (contour interval 1000 m)

older, Precambrian fragment of the Fenno-Scandian shield, remetamorphosed in Caledonian times.

Devonian, in Old Red facies, overlies the crystalline basement in the Q-1 well at 3804 m, with a total thickness of 738 m. It consists of siltstones alternating with fine- to coarse-grained sandstones and some conglomerate beds, all predominantly red. Between 3616 and 3777 m numerous marine fossils were encountered, such as Chitinozoa, Hystrichosphaeridea, scolecodonts as well as remnants of tabulate corals (determined by Birenheide as: *Thamnopora* ex gr. *cervicornis*), indicative for an Early to Middle Devonian age. This shows clearly that during this period marine influences extended far northward into the Old Red facies realm.

Dinantian, Namurian and Westfalian are absent on the western shoulder of the Graben and have not been reached by R-1 and S-1. Therefore, the distribution of the Carboniferous below the Lower Permian on the flank of the Ringkøbing-Fyn High cannot be determined with certainty. Nevertheless, HEDEMANN's (1980) subcrop map appears acceptable, as it assumes that due to pre-Permian Graben movements, Carboniferous strata in the Graben center extend further northward than on its western shoulder.

The Lower Rotliegend in S-1 consists of an alternation of basic lavas, volcanic breccias, tuffites, claystones and sandstones, in total more than 80 m thick. In contrast to all analysed Rotliegend volcanites of the German mainland, which are subalkaline basalts, dacites, rhyodacites and rhyolites, the basalts in S-1 have the chemical characteristics of alkaline basalts, such as those of oceanic sea-mounts (ECKHARDT, 1979). In this context, it is of interest that in well C-15-1, west of the Graben, true tholeiitic ocean floor basalts have been encountered (ECKHARDT, pers. comm.). From these data it can be concluded that during Lower Rotliegend deposition, rifting in the Horn Graben area reached an advanced stage.

The Upper Rotliegend starts in the Q-1 borehole with 6 m of fanglomeratic conglomerates with pebbles of quartz, siliceous shales, greywackes and volcanite. In S-1 a basal sandstone of 8 m is present. The development of the Upper Rotliegend differs considerably west and east of the Graben, respectively. On the western shoulder it measures only 161 m and consists of claystones, siltstones and marly siltstones with only 9 m of sandstone. In the east the Upper Rotliegend is 1134 m thick. Correlation with the Lower Ems region could be established for both the lower, sandy-clayey part and for the saliferous higher portion and the Upper Rotliegend Claystone.

The Zechstein development in Q-1 and S-1 shows a basinal, near-shelf margin facies with, in its lower two cycles, 14-20 m

of Zechsteinkalk, 35 m of Werra Anhydrite, 14-23 m of Stassfurt Carbonate in a stinkkalkfacies, followed by Stassfurt Halite, which has a primary, unmobilized thickness in the order of 550-600 m. The higher Zechstein cycles are only complete in S-1, whereas in Q-1 they are reduced by leaching and erosion below the Berriasian transgressive beds. The total thickness of the Zechstein is 1132 m in S-1 and probably did not exceed 1200 m in the central part of the Horn Graben.

For a better understanding of the Triassic stratigraphy and facies development the British nomenclature of RHYS (1975) is cited as well (between brackets). The Lower and Middle Buntsandstein (Bacton Group) reaches an average thickness of 780 m on the eastern shoulder of the Graben. All formations and members known from the German mainland can be recognized in the sequence of the S-1 well. In the Graben center the thickness of the Group increases to a maximum of 4200 m. The Röt, Muschelkalk and Keuper (Haisborough Group) are nowhere complete below the Berriasian transgressive beds. In R-1, within the Graben, at least the Rhaetic Sandstone Member and the Upper Rhaetic (Winterton Formation) are lacking. In S-1 even more erosion took place, also removing the Keuper Halite Member. The Röt Halite Member is well developed as a rock salt interval, whereas the Muschelkalk Halite Member is dolomitic-anhydritic with very little salt. Apart from this, the Middle Triassic (Dowsing Dolomitic Formation) as a whole closely resembles the German Muschelkalk. Halite members within the Keuper are known on the mainland in the Lower Gips Keuper (= km 1) and in the Rote Wand Member (= km 3). In the Horn Graben region only the upper halite member is developed with 35 m thickness. This indicates a marginal position of the Horn Graben region during Middle and Late Triassic or it suggests

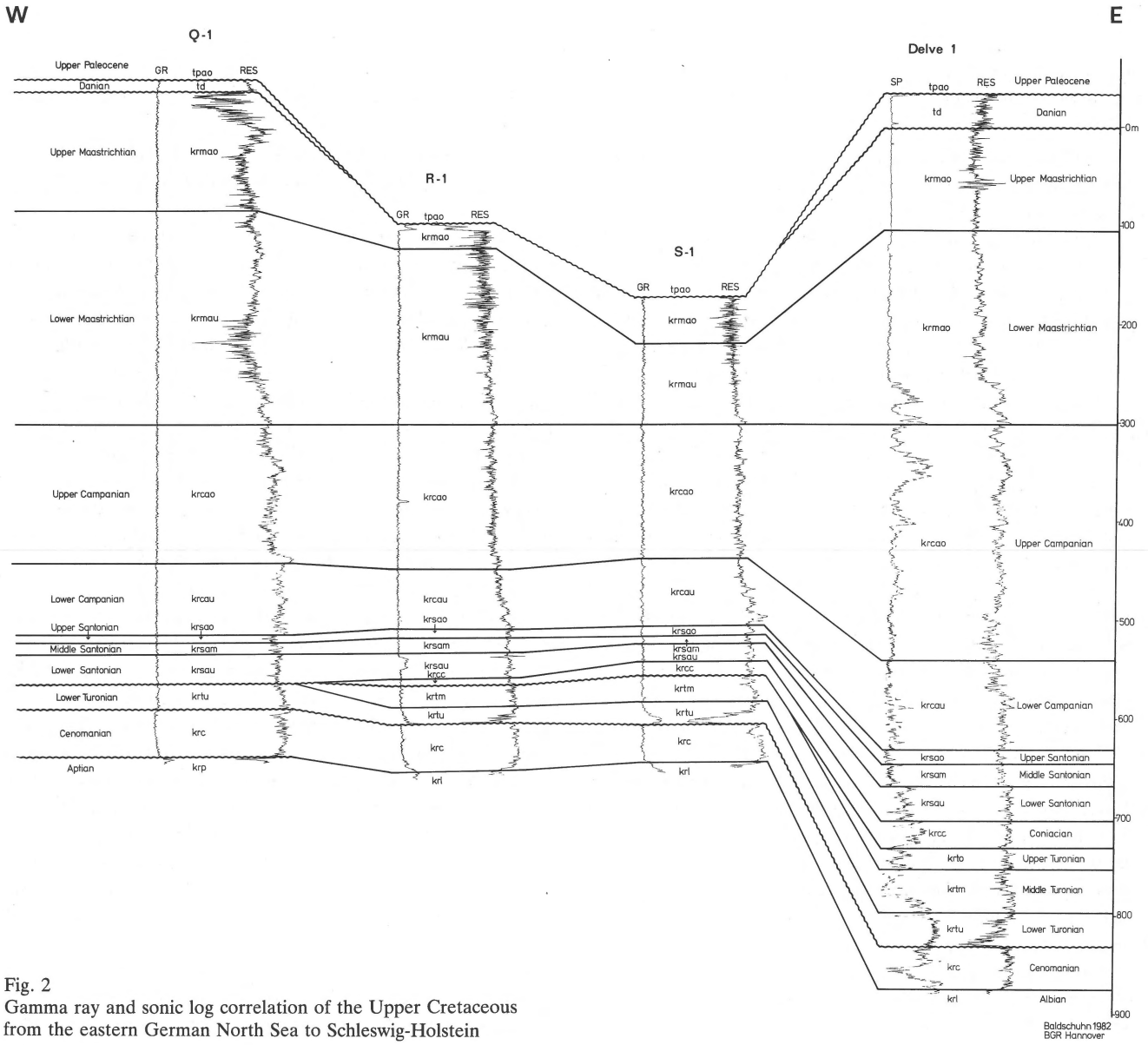


Fig. 2
Gamma ray and sonic log correlation of the Upper Cretaceous from the eastern German North Sea to Schleswig-Holstein

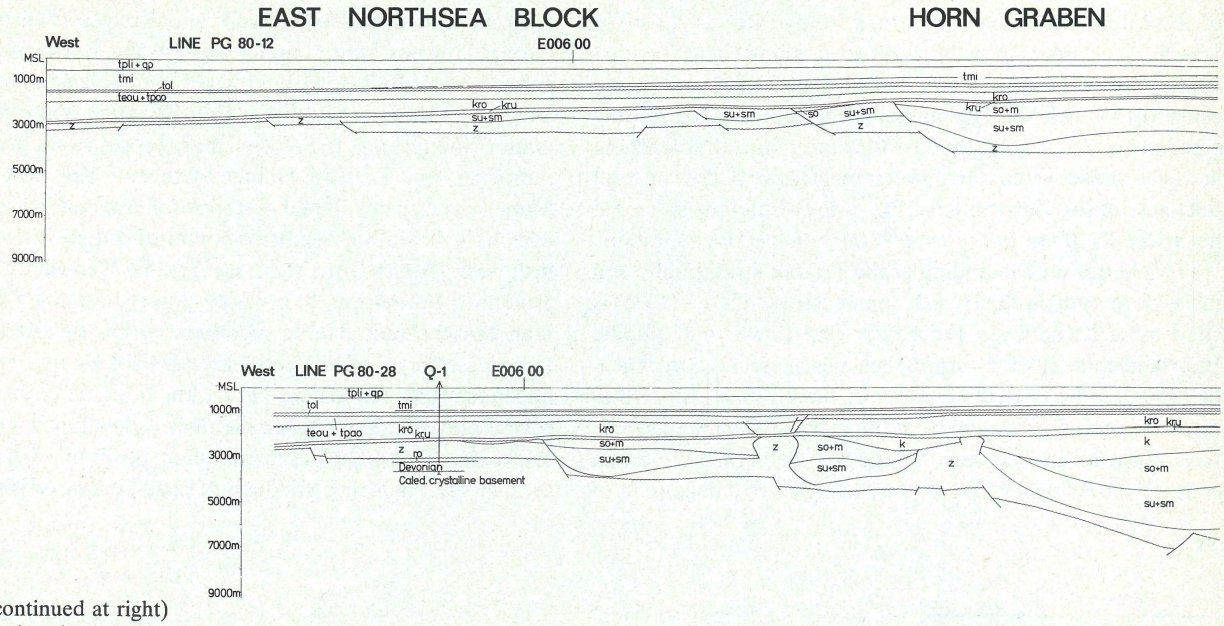


Fig. 3 (continued at right)
Cross section through the eastern part of the German North Sea (Southern Horn Graben) based on two seismic lines by courtesy of Placid Germany Ltd.

that not too much of Zechstein salt was extruded and redeposited during the diapiric stage of the salt structures in Late Triassic times.

The Lower and Middle Jurassic have not been recognized in the wells or on the seismic profiles.

Upper Jurassic (Kimmeridgian), known from areas further to the west, has not been encountered in the three boreholes, but it might be present as a thin cover in other parts of the Graben area or in rim sinks persisting at the flanks of the central and outer salt structures.

The Early Cretaceous transgression started during the Berriasian. Non-sequencies in the very thin Lower Cretaceous have been observed at the base of the Hauterivian, in the Aptian and at the base of the Cenomanian. The thickness of the Lower Cretaceous varies from 75 m in the east to 110 m in the west.

The Upper Cretaceous of the three wells is well correlatable with the development on the German mainland (Fig. 2). Sedimentation rates remained rather low during the Cenomanian to Santonian (total thickness ca. 130 m). During the Early Campanian subsidence increased markedly, and nearly 50% of the Upper Cretaceous consists of Maastrichtian.

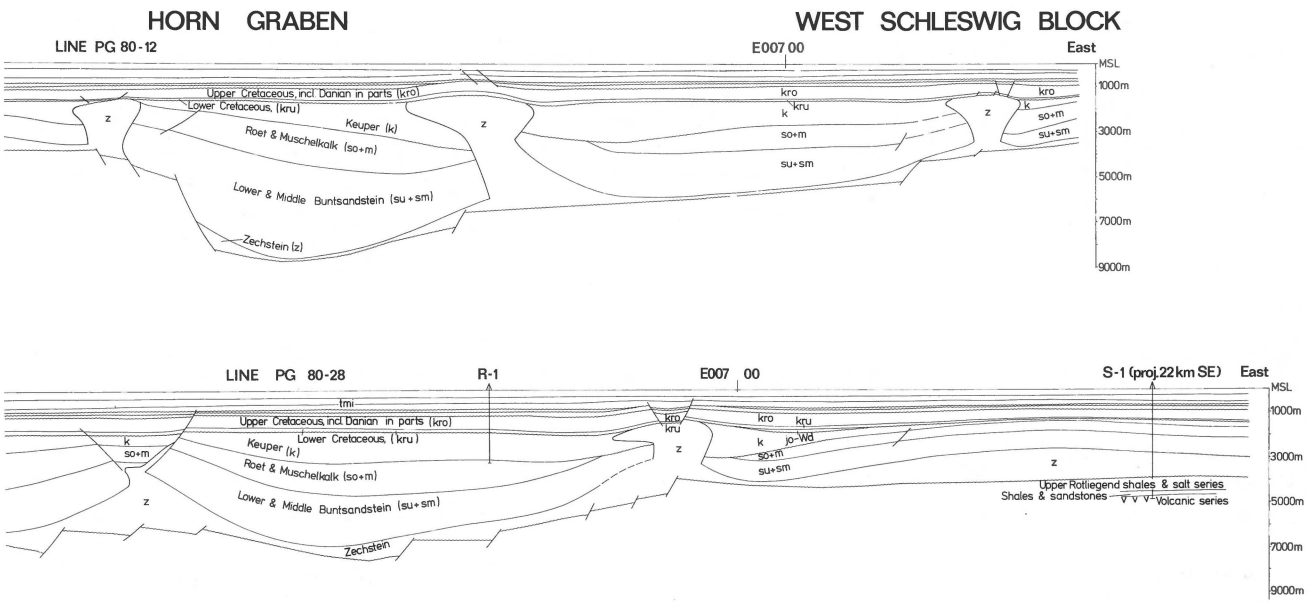
Danian and Upper Paleocene sediments are only known from Q-1, whereas further to the east, Tertiary sedimentation started with the Early Eocene Balder Ash Formation. Middle Eocene, Upper Eocene and Lower Oligocene are absent below the Middle Oligocene transgressive beds. The Middle and Upper Oligocene are characterized by pelagic, highly calcareous sediments. Lower and Middle Miocene marine deposits remain rather thin, even in the western part of the region-under-discussion. During the Late Miocene and Pliocene huge lense-shaped prograding sediment bodies were deposited, thickness maxima migrating westward in time.

THE STRUCTURAL DEVELOPMENT OF THE SOUTHERN HORN GRABEN

Up till now, the Late Palaeozoic history of the southern Horn Graben was not well understood, but the data now available allow a reasonable interpretation. There are indications of a rather thick Upper Rotliegend salt sequence in the German Graben sector, indicative for a basin development within the proto-Horn Graben during the Permian, perpendicular to the axis of the main basin further south. The chemistry of the Rotliegend basalts on the Graben shoulders suggests an early rifting phase (see above). Thus, it may be concluded that rifting already started during the Late Palaeozoic, in pre-Rotliegend or Rotliegend times. The halokinetically disturbed Zechstein salt sequence does not permit a good analysis of the taphrogenetic history in Late Permian times.

Synsedimentary faulting is clearly observable in the Lower Triassic (Fig. 3, line 12). The main western border fault of the Graben opened during Lower and Middle Buntsandstein sedimentation (Bacton interval), parallel to the rejuvenated NNE-striking Rotliegend depression. A half-graben formed with its depocentre near the western border fault. The subsidence maximum lies ca. 10 km south of the Danish-German border. The stratigraphic throw at this main fault decreases from here towards NNE and SSW. The western margin of the Graben shows repeated step faulting. The thickness of the Lower and Middle Buntsandstein within the rift can exceed more than four times that on the shoulders. Early Triassic rifting clearly took place without substantial mobilization of Zechstein salt.

Epeirogenic subsidence continued on a minor scale during Röt and Muschelkalk deposition. During this period Zechstein salt started to flow, forming salt pillows over the border



faults and over the central horst. The westernmost salt structure on profile 28 as well as the westernmost and easternmost salt structures on profile 12 already entered their diapiric stages in Muschelkalk times, as indicated clearly by the formation of secondary rim sinks on the flanks of the diapirs. During Keuper times, downwarping of the Graben floor may have continued, at least in the central part. The main cause of subsidence was, nevertheless, the halokinetic migration of the Zechstein salt into the salt structures. Now nearly all salt structures entered their diapiric phase. Secondary rim sinks formed in which the Keuper transgressively overlies Lower Triassic sediments at the former pillow flanks. It is assumed that the upward movements of the diapirs and the downwarping of the secondary rim sinks continued during the Early Jurassic. During the Middle Jurassic and the Oxfordian a general uplift of the Graben area as well as its western and eastern surroundings occurred, together with positive movements of the Ringkøbing-Fyn High and the West Schleswig Block. The total uplift in the area-under-discussion is estimated to have reached more than 1000 m at the Q-1 site. The Kimmeridgian transgression may have reached the Graben zone and corresponding sediment remnants are assumed to have been preserved in the easternmost rim sink in profile 28. The available data permit to conclude that the taphrogenetic movements had stopped completely before the Kimmeridgian transgression, only minor halokinetic movements of the salt structures persisting.

The main Cretaceous transgression took place in the Berriasian, probably eroding off the thin Upper Jurassic cover. At this time the rift was already dead. No thickness variations in the Lower Cretaceous nor in the lower part of the Upper Cretaceous indicate downfault movements along the marginal faults of the Graben or downwarping of the Graben zone. It is only in the Campanian and Maastrichtian that the rate of subsidence of the whole area, together with a tilting towards the west, increased markedly. This subsidence triggered weak halokinetic movements of the buried diapiric structures.

The geological history during the Paleocene is not well documented. Danian and Late Paleocene marine sedimentation is assumed, but such deposits have been removed by the Early Eocene transgression except on the western Graben shoulder. Small extension grabens formed over the culmination of the still rising post-diapiric structures during the Palaeogene, but these are covered by the Lower Miocene. From the Late Miocene onwards even the salt structures remained inactive. The North Sea basin was filled with prograding sediment bodies coming from the east.

CONCLUSIONS

The southern Horn Graben and its development in space and time stands paradigmatically for a number of similar structural elements in NW Europe, such as the Glückstadt Graben in Central Schleswig Holstein (Fig. 4). In the Horn Graben, however, the mass of secondarily mobilized Upper Permian salt is limited and thus does not over-mask the block-faulting of the pre-salt basement important for the origin of the grabens. In the Horn Graben, as well as in the Glückstadt Graben, the following stages of development can be observed:

1) Initial formation of a NNE-SSW depression as early as Late Palaeozoic times,
2) Main taphrogenetic phase during the Early Triassic leading to the activity of the synsedimentary border faults being much more prominent in the west than in the east

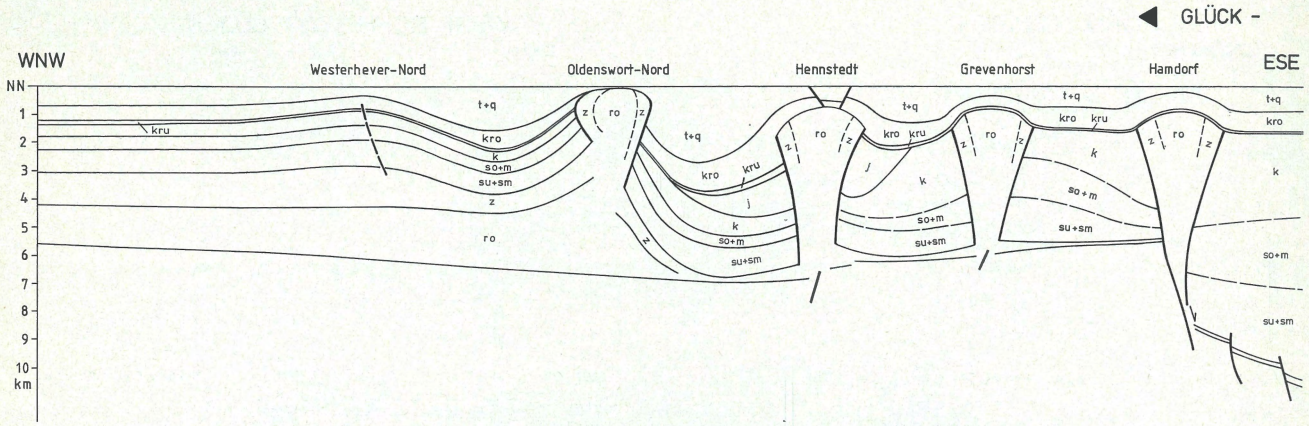


Fig. 4 (continued at right)
Cross section through Schleswig-Holstein (NW-Germany) vertical scale exaggerated twice.

(formation of half graben structures),

3) Halokinetic mobilization of Permian salts in Röt times (in the Glückstadt Graben: Upper Rotliegend and Zechstein salts; in the Horn Graben: only Zechstein salts), triggered by taphrogenetic faulting,
4) Further subsidence of the Graben zone in Middle and Late Triassic,
5) Beginning of the diapiric stage of the first salt structures during Muschelkalk deposition, culmination during Keuper,
6) General elevation of the Graben region and its surroundings in Middle and Late Jurassic. Marked decrease of halokinetic activity,
7) Transgression during the Early Cretaceous and increasing subsidence during the Late Cretaceous,
8) During the Palaeogene reactivation of halokinetic movements causing uplift of the buried diapirs.

There is, however, also a main difference between the Horn Graben and the Glückstadt Graben. Due to the presence of great masses of mobilizable Permian salt in the Glückstadt Graben, the initial salt structures Hamdorf and Eisendorf, astride the main border faults, and originally triggered by the initial rifting, initiated the formation of subsidiary salt structures which become gradually younger towards the Graben margins. This occurrence of non-tectonically triggered salt structures (called salt dome families by SANNEMANN, 1963) is lacking in the Horn Graben area.

ACKNOWLEDGEMENTS

We are grateful to the German North Sea Consortium for their willingness to release the well data of Nordsee Q-1, R-1 and S-1 and to Placid Germany Ltd. for their permission to publish the interpretation of their seismic sections.

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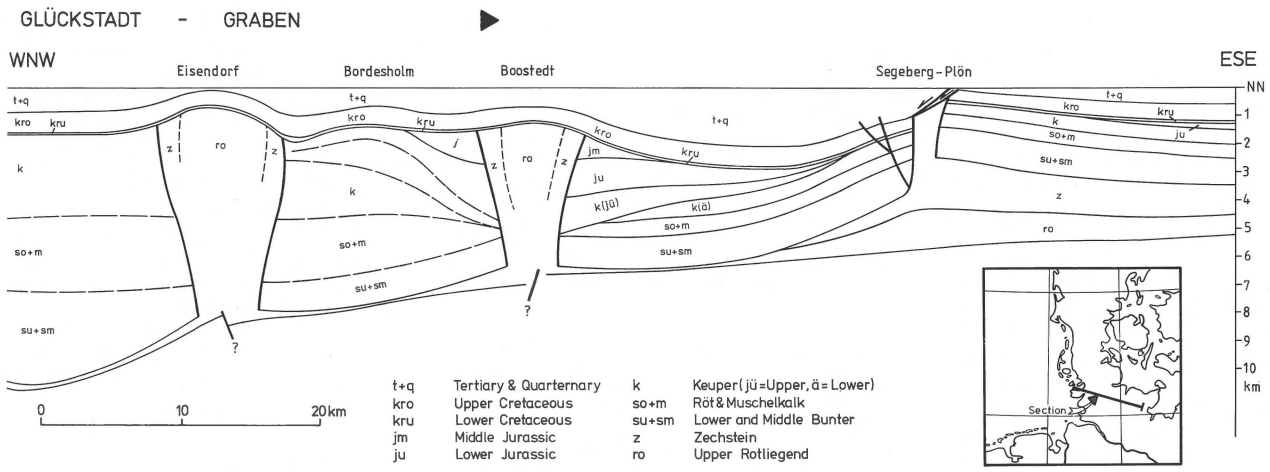

APPENDIX

Stratigraphic subdivision of wells Q-1, R-1 *and* S-1

Nordsee Q-1:

5° 56′ 06″ E; 54° 57′ 14″ N; Water depth ca. 38 m; Ref. level: sea bottom.

German North Sea Consortium: Amoco Hanseatic, Elf Aquitaine, C. Deilmann Bergbau GmbH, Deutsche Texaco AG, Deutsche Schachtbau, Veba Oel AG, Gewerkschaft Brigitta, Gewerkschaft Elwerath, Preussag AG, Wintershall AG.

Contractor: Transocean Drilling Co. Date: 1-5-1966 - 23-8-1966.

Lithology, stratigraphy: RITTER, KIND; special investigations: ELSTNER, FÜCHTBAUER, DRONG, v.d. BRELIE, BIRENHEIDE, HINSCH.
Revisions: KOCKEL (Tertiary), BALDSCHUHN (Upper Cretaceous).

- ca. 220 m Quaternary
- 1425 m Tertiary
  - ca. 752 m Pliocene
  - 908 m Upper Miocene (Morsum, Sylt and Gram formations)
  - 980 m Reinbek and Langenfelde formations
  - 1090 m Middle (and Lower?) Miocene
  - 1191 m Upper and Middle Oligocene

----------transgression----------

  - 1344 m Lower Eocene 3 + 2
  - 1355 m Lower Eocene 1 (Balder Formation)
  - 1415 m Upper Paleocene

----------transgression----------

  - 1425 m Danian

----------hiatus----------

- 2099 m Upper Cretaceous
  - 1437 m Upper Maastrichtian 2
  - 1545 m Upper Maastrichtian 1
  - 1654 m Lower Maastrichtian 2
  - 1762 m Lower Maastrichtian 1
  - 1831 m Upper Campanian 2
  - 1902 m Upper Campanian 1
  - 1943 m Lower Campanian 2
  - 1975 m Lower Campanian 1
  - 1984 m Upper Santonian
  - 1996 m Middle Santonian
  - 2025 m Lower Santonian

----------transgression----------

  - 2028 m Middle Turonian
  - 2050 m Lower Turonian

----------hiatus----------

  - 2099 m Cenomanian

----------transgression----------

- 2209 m Lower Cretaceous
  - 2111 m Upper Aptian

----------hiatus----------

  - 2141 m Middle and Lower Barremian
  - 2160 m Hauterivian

----------hiatus?----------

  - 2176 m Valanginian
  - 2209 m Lowermost Valanginian and Berriasian

----------transgression----------

-	2905 m	Zechstein	
	- 2226 m	Z 4 group?	
	- 2267 m	Z 3 group	
		- 2262 m Hauptanhydrit	
		- 2265 m Plattendolomit	
		- 2267 m Grauer Salzton	
	- 2856 m	Z 2 group	
		- 2274 m Deckanhydrit	
		- 2828 m Stassfurt Halite	
		- 2833 m Basalanhydrit	
		- 2856 m Stinkkalk	
	- 2905 m	Z 1 group	
		- 2890 m Werra Anhydrite	
		- 2904 m Zechsteinkalk	
		- 2905 m Kupferschiefer	

----------transgression----------

-	3067 m	Rotliegendes	
			3037 - 3047 m sandstone, 3060 - 3067 m basal conglomerate

----------transgression----------

-	3804 m	Devonian	Old Red sandstone

----------transgression----------

-	3835 m	Crystalline basement	
total depth			

Nordsee R-1:

6° 49° 15″ E, 55° 00′ 00″ N; Water depth ca 35 m; Ref. level: sea bottom.

German North Sea Consortium: Amoco Hanseatic, Elf Aquitaine, C. Deilmann Bergbau GmbH, Deutsche Texaco AG, Deutsche Schachtbau, Veba Oel AG, Gewerkschaft Brigitta, Gewerkschaft Elwerath, Preussag AG, Wintershall AG.

Contractor: Transocean Drilling Co. Date: 18-9-66 - 19-10-66.

Lithology, stratigraphy: KIND, RITTER, WECHSLER. Special investigations: ELSTNER, v.d. BRELIE, MÄDLER, FÜCHTBAUER. Revisions: KOCKEL (Tertiary), BALDSCHUHN (Upper Cretaceous).

-	1062 m	Quaternary + Tertiary	
	- ca. 446 m	Quaternary + Pliocene	
	- 682 m	Upper Miocene (Morsum, Sylt and Gram formations)	
	- 820 m	Reinbek and Langenfelde formations	
	- 870 m	Middle (and Lower?) Miocene	
	- 930 m	Upper Oligocene	
	- 962 m	Middle Oligocene	

----------transgression----------

	- 1062 m	Lower Eocene 3-1	

----------transgression----------

-	1608 m	Upper Cretaceous	
	- 1082 m	Upper Maastrichtian?	
	- 1176 m	Lower Maastrichtian 2	
	- 1259 m	Lower Maastrichtian 1	
	- 1406 m	Upper Campanian	
	- 1443 m	Lower Campanian 2	
	- 1467 m	Lower Campanian 1	
	- 1475 m	Upper Santonian	
	- 1491 m	Middle Santonian	
	- 1516 m	Lower Santonian	
	- 1524 m	Upper Coniacian	

----------hiatus----------

	- 1545 m	Middle Turonian	
	- 1562 m	Lower Turonian	

----------hiatus----------

	- 1608 m	Cenomanian	
-	1770 m	Lower Cretaceous	
	- 1653 m	Albian	

----------hiatus----------

	- 1770 m	Aptian - Berriasian	

----------transgression----------

-	2906 m	Middle and Lower Keuper	
	- ca. 2390 m	Triton anhydrite Formation	
			ca. 1880 - 2010 m Keuper Anhydrite Member
	-ca. 2495 m	Keuper Halite Member	
	- ca. 2905 m	Dudgeon Saliferous Formation	
-	3001 m	Upper and Middle Muschelkalk	
	- 3001 m	Dowsing Dolomite Formation (upper part)	
			2940 - 3001 m Muschelkalk Halite Member
Total depth			

Nordsee S-1:

7° 35′ 38″ E, 54° 53′ 52″ N; Water depth ca. 21 m; Ref. level: sea bottom.

German North Sea Consortium: Amoco Hanseatic, Elf Aquitaine, California Asiatic Oil Corp., C. Deilmann Bergbau GmbH, Deutsche Texaco AG, Deutsche Schachtbau, Veba Oel AG, Gewerkschaft Brigitta, Gewerkschaft Elwerath, Preussag AG, Wintershall AG.

Contractor: Transocean Drilling Co. Date: 31-10-66 - 11-5-67.

Lithology, stratigraphy: KIND, RITTER; special investigations: ELSTNER, v.d. BRELIE, HINSCH, FÜCHTBAUER, DRONG, GOLDSCHMIDT, ZIMDARS; Revisions: KOCKEL (Tertiary), BALDSCHUHN (Up. Cretaceous).

- ca.	50 m	Quaternary	
-	768 m	Tertiary	
	- ca. 208 m	Pliocene	

- 335 m Upper Miocene (Morsum, Sylt and Gram formations)
- 450 m Reinbek and Langenfelde formations
- 575 m Middle (and Lower?) Miocene
- 623 m Upper Oligocene (Chatt Formation)
- 630 m Middle Oligocene (Rupel Formation)

----------transgression----------

- 666 m Lower Eocene 3
- 752 m Lower Eocene 2
- 763 m Lower Eocene 1 (ash marker)
- 768 m Upper Paleocene

----------transgression----------

- 1238 m Upper Cretaceous
  - 816 m Upper Maastrichtian 1
  - 863 m Lower Maastrichtian 2
  - 897 m Lower Maastrichtian 1
  - 944 m Upper Campanian 2
  - 1033 m Upper Campanian 1
  - 1067 m Lower Campanian 2
  - 1102 m Lower Campanian 1
  - 1111 m Upper Santonian
  - 1119 m Middle Santonian
  - 1138 m Lower Santonian
  - 1147 m Upper Coniacian
  - 1153 m Lower Coniacian

----------hiatus----------

  - 1177 m Middle Turonian
  - 1201 m Lower Turonian

----------hiatus----------

  - 1224 m Upper Cenomanian
  - 1235 m Middle Cenomanian
  - 1238 m Lower Cenomanian
- 1313 m Lower Cretaceous
  - 1249 m Upper + Middle Albian

----------hiatus----------

  - 1260 m Upper Aptian

----------non-sequency----------

  - 1274 m Barremian
  - 1284 m Hauterivian
  - 1313 m Lowermost Cretaceous

----------transgression----------

- 1526 m Middle and Lower Keuper
  - 1526 m Dudgeon Saliferous Formation (lower part)
- 1725 m Muschelkalk
  - 1565 m Dowsing Dolomite Formation (upper part)
  - 1640 m Muschelkalk Halite Member
  - 1725 m Dowsing Dolomite Formation (middle part)
- 2750 m Buntsandstein
  - 1875 m Dowsing Dolomite Formation (lower part)
  - 1967 m Röt Halite
  - 2406 m Bunter Sandstone Formation
    - 2055 m Solling Member
    - 2134 m Hardegsen Member
    - 2213 m Dethfurt Member
    - 2406 m Volpriehausen Member
  - 2750 m Bunter Shale Formation
    - 2420 m Rogenstein Member
    - 2750 m Bunter Shale Member and Bröckelschiefer Member
- 3882 m Zechstein
  - 2884 m Z 4 group
    - 2842 m Aller Halite
    - 2843 m Pegmatitanhydrit
    - 2844 m Roter Salzton
  - 3195 m Z 3 group
    - 3167 m Leine Halite
    - 3189 m Hauptanhydrit
    - 3194 m Plattendolomit
    - 3195 m Grauer Salzton
  - 3826 m Z 2 group
    - 3808 m Stassfurt Halite
    - 3812 m Basalanhydrit
    - 3826 m Hauptdolomit
  - 3882 m Z 1 group
    - 3861 m Werraanhydrit
    - 3881 m Zechsteinkalk
    - 3882 m Kupferschiefer

----------transgression----------

- 4842 m Rotliegendes

3964-4385 m Rotliegend Halite
4739-4747 m Rotliegend 'Basal Sandstone'
4747-4842 m Volcanic series

Total depth