Boundaries: The lower boundary is primarily marked by the sonic velocity which is high and uniform in the underlying metamorphic greenstone, and relatively lower and nervous in the present series. The upper boundary is between the present mainly greyish series and the overlying reddish series of assumed Rotliegendes age. The log motifs are not significant, but the change from high gamma ray readings above to relatively lower below is used for location of the boundary.

Distribution: The Early Carboniferous deposits are probably present in major parts of the Danish Central Graben, but due to lack of data (seismic mapping is critical), a delineation of the extension is not possible.

Geological age: Based on studies of the miospores, part of the series is dated to Early Carboniferous, Late Visean or Early Namurian (Bertelsen 1978). - The lower part of the series has not been dated, thus it may be of Carboniferous or Devonian age.

Depositional environment: It is a marginal fluvially dominated environment with minor coal swamps. The occurrence of thin limestone beds with foraminifera, ostracods, and crinoid fragments shows that short marine transgressions periodically flooded the area.

Source rock potential: Probably poor for oil since the Rotliegendes volcanism and/or depth of burial-temperature increase may have led to overcooking. No studies have been carried out in the Danish region.

Reservoir potential: Limited reservoirs in form of porous sandstones may be expected.

Sealing potential: The series is probably not sealed, being overlain by the Rotliegendes. The Carboniferous shale beds will possibly be able to act as seals.

3.2 Permian

By Fritz Lyngsie Jacobsen & Jørgen Gutzon Larsen

In North-West Europe two mega-basins began their development during Late Carboniferous to Early Permian: The South Permian Basin stretching from eastern England into Poland , and the North Permian Basin reaching from Scotland into Denmark. These two basins were separated by the Mid North Sea High and the Ringkøbing-Fyn High which came into existance early in Permian. The initial phase of subsidence was accompanied by extensive subaerial volcanism. This was followed by a period of oxidation and erosion under desert conditions and deposition of redbeds and sabkha sediments in the two Permian basins (fig. 19). These rocks are included in the Rotliegendes Group as originally established by Werner (1786). Continuous subsidence and transgression of the sea, but with a restricted connection to the ocean, lead to the formation of the evaporites of the Zechstein Group.

Rotliegendes Group

Autunian

Type section: For the present being the P-1 well, 10541-10865' b.KB may suffice as a reference for the Rotliegendes volcanics and underlying sediments belonging to the Autunian stage. However, it should be noted that this correlation is based purely on lithostratigraphical evidence.

Thickness: The volcanic rocks and interbedded sediments form a 99 m thick pile in the P-1 well, but in all other wells of the Danish off shore sector, the base of the volcanic rocks has not been penetrated. Therefore only minimum thicknesses of 44 m in B-1, 148 m in W-1, 71 m in Q-1 can be given. The underlying sediments in P-1 well comprises 33 m of redbrown sandstone, siltstone, claystone, and marlstone (Bertelsen 1978).

Lithology: The lithology is summarized in fig. 18. The volcanic sequences are classified as lava flows with interbedded agglomerates, tuffs and detrital sediments. The lava flows are generally a few metres in thickness or less, may be of the pahoehoe type, but flows up to 7 m in thickness occur. Presumably some of the 'agglomerates' noted in the mudlog may originate from scoriaceous or vesicular top zones. The cores and cuttings indicate, together with the log data, especially gamma ray, the predominance of basalts; but more differentiated rocks occur in the P-1 and W-1 wells. From the latter well these rocks are described as andesites and rhyolites (mudlog). They may occur as lava flows and pyroclastic beds. Most of the rocks look rather oxidized and they are often cut by secondary veins. The interbedded sediments are mostly (silty) claystone but a 28 m thick metamorphosed limestone occurs in W-1.

Log charactetistic: The volcanic rocks are characterized by cyclic variations in the sonic velocity, and

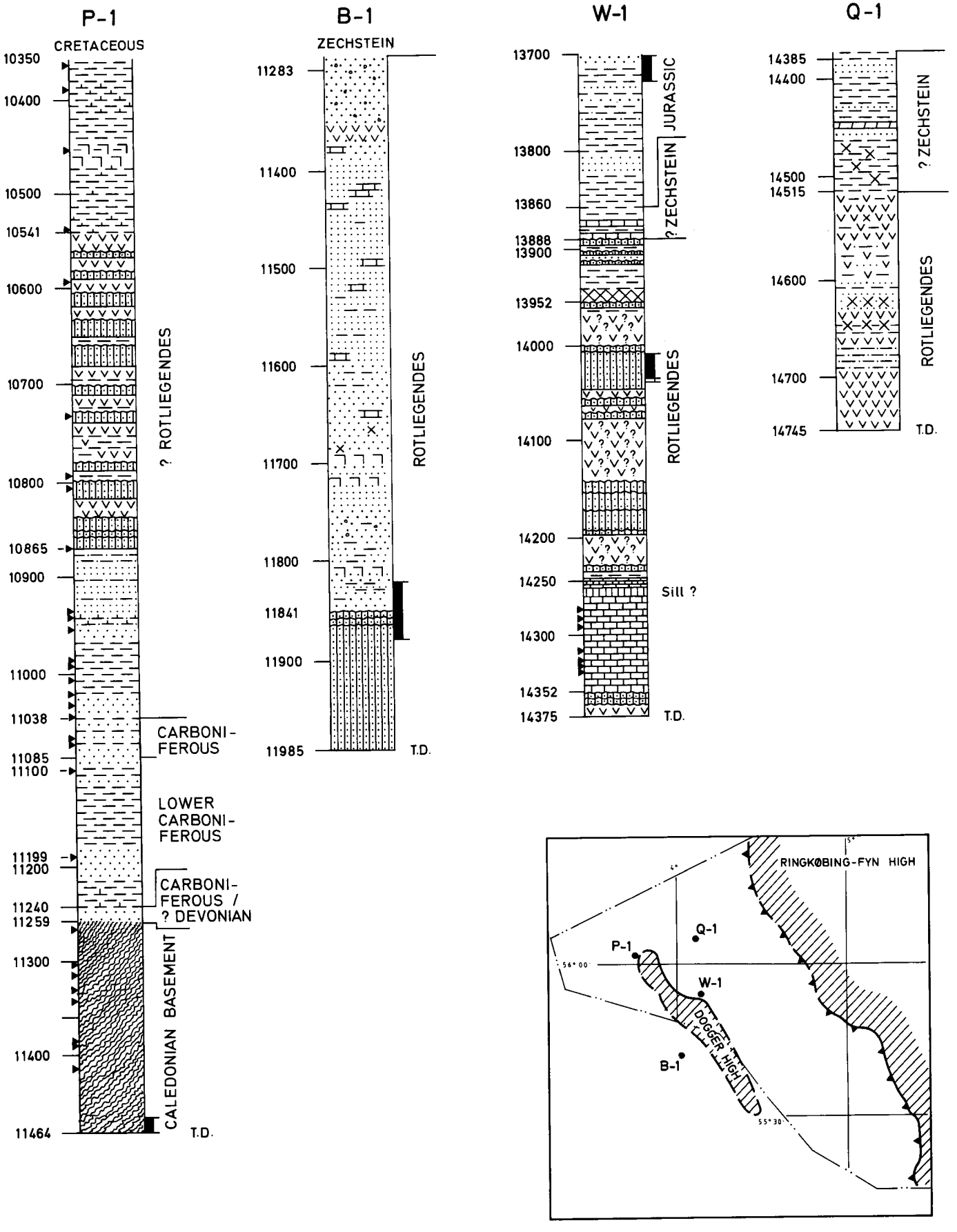

Fig. 18: Lithological profiles of the Rotliegendes deposits. For legend, see fig. 3.

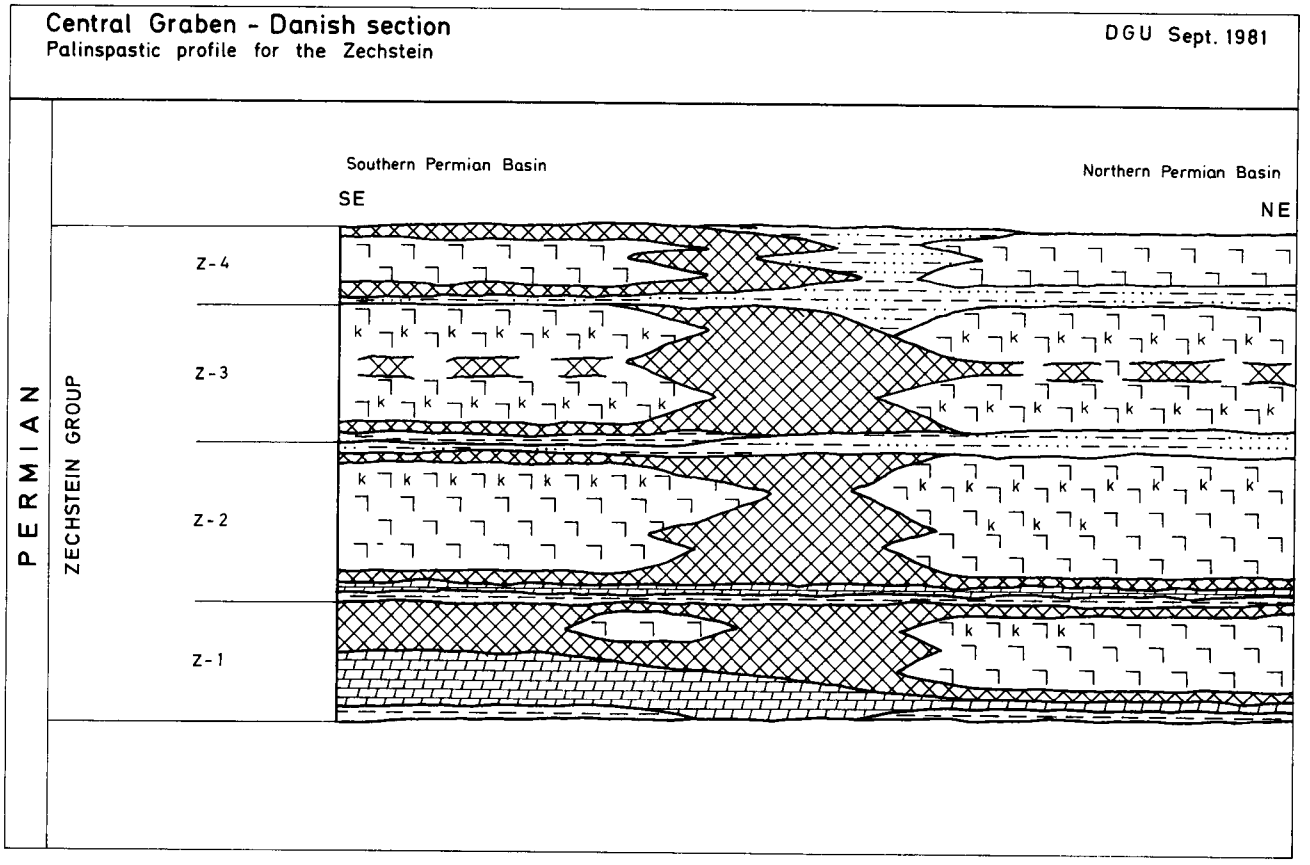

Fig. 19: Palinspastic profile of the Zechstein deposits. For legend, see fig. 3.

by formation density logs with high values in the massive besaltic lava flows, and lower values in the interbedded deposits or porous top zones. The gamma ray intensity is variable but generally relatively low especially in the massive basalt lava flow. Massive lava flows with high gamma ray intensities and lower densities may be rhyolites. The lithologies of the B-1, W-1, Q-1, and P-1 wells based on the geophysical logs and the mudlog are shown in fig. 18. The differentiated rock types are not indicated as they await more detailed examination. They form a smaller portion of the massive flows, but could be more frequent among the intrabasaltic deposits.

Geological age: At present radiometric age determinations have been performed on the B-1 well, giving 212 +/- 14 Ma (K/Ar by Larsen 1972) and on the W-1 well, where a large spread is observed, 89-230 Ma (Geological Dating Services). This age is regarded as updated, due to metamorphism, and the volcanics are overlain by Upper Permian sediments. Permian volcanic rocks also occur in the North Permian Basin, i.e. in the D-1 well, dated to 237 +/- 16 Ma; the C-1 well, 281 +/- 8 Ma (Larsen 1972, Rasmussen 1974); the L-1 well overlain by marginal Zechstein deposits; and the 2/7-2 well of the Norwegian sector (Dixon et al. 1981). Unfortunately the ages of the volcanic rocks recorded within the Central Graben (P-1, Q-1, W-1) are uncertain as they are not overlain by dated, typical Zechstein sediments (see fig. 18). In this connection it should be mentioned that Triassic(?) and Jurassic volcanics are known from the triple junction between the Viking Graben and the Moray Firth Basin (Woodhall & Knox 1979).

Petrography: So far only a few petrographic descriptions are available. Dixon et al. (1981) recorded plagioclase and scattered clinopyroxene and altered olivine phenocrysts in the B-1 basalts, which are similar to those of the C-1 and D-1 well of the North Permian Basin. Altered plagioclase phenocrysts occur in the cored basalt of W-1. Rhyolites have only been described from the R-1, associated with the Horn Graben. The secondary minerals of the basalts include among others: calcite, anhydrite, epidote, chlorite, serpentine, haematite, goethite, and quartz, possibly originating from the thermal rise associated with the volcanism.

Chemical analyses of the basalts of B-1 show that they can be classified as transitional olivine tholeiites

grading into hawaiites, typical for the Permian volcanism north of the variscian fold belt. In contrast the younger volcanic rocks in the region appear to be more alkaline: the ?Middle Triassic - Middle Jurassic, alkaline basalts of the east Moray Firth Basin (Woodhall & Knox 1979); the Permian - Middle Jurassic alkaline dykes of Sunnhordland, West Norway (Faerseth et al. 1976); the nephelinitic lavas of the Egersund Basin east of the Viking Graben (Dixon et al. 1981); and the Lower Cretaceous phonolites, leucite bearing lavas and trachytes of Zuidwal-1 in North-West Holland (Cottencon et al. 1975). Alkaline basalts are, however, also known from the initial Permian volcanism in the Oslo Graben.

Extension: The extension and thickness of the (?)Rotliegendes volcanics within the Danish Central Graben have not been mapped due to scarcity of data. A palinspastic profile for the Rotliegendes Group is given in fig. 17. Volcanic rocks presumably cover the floor of the Central Graben and the Horns Graben, as shown by the deepest wells (B-1, P-1, Q-1, W-1, and R-1). Volcanic rocks have been reached north and south of the Ringkøbing-Fyn High (C-1, D-1, L-1, and in Rødby-2 and Rødekro-1 respectively), but neither on the high itself nor in the Danish Subbasin east of the C-1 well. In the deepest parts of the subbasin, however, no well has penetrated the Zechstein salt. Restricted areas with Permian volcanic rocks occur in the British, Norwegian, and German sectors adjacent to the westernmost Danish sector. The present distribution presumably represents down faulted remnants of a much larger cover, which was eroded away before the Zechstein submergence. It is likely that volcanic rocks have been preserved in the Graben zones and in the basins which were associated with the volcanism, i.e. the Oslo-Bamble-Horn Graben system and/or the North and South Permian Basins. It is unknown whether the initial formation of the Central Graben was associated with volcanism.

Saxonian

Type section: The B-1 well at 11283-11841' b.KB is chosen as reference well for the Rotliegendes sediments; however, it should be noted that these sediments may be contemporaneous with the volcanism in other areas.

Rotliegendes sediments: Most data on the Rotliegendes sediments originate from southern North Sea and the North German Basin (Ziegler 1981 and Marie 1976). They consist of desert sand and sabkha-to playa-type deposits. Degradation of the Variscian foldbelt to the south caused influx of fanglomerates and braided stream (wadi) deposits along the southern margin of the basin. The desert sand dune deposits in the southern part of the basin are the main reservoirs of the Rotliegendes gas play. In the centre of the basin, sabkha shales and evaporites were deposited in thicknesses above 1000 m (North Germany) to 300 m (eastern part of the British sector). Along the northern boundary of the basin, a basal conglomerate, overlain by red shales, siltstone and thin sandstones, forms a marginal facies derived from the Ringkøbing-Fyn High.

Rotliegendes sediments reach about 100-200 m in the Norwegian-Danish Basin. The sediments show a general coarsening towards the north and northeast, in agreement with data from the British sector, pointing towards a northern source area.

In the Danish wells of the Central Graben Rotliegendes sediments are only identified with certainty in the B-1 well (Rasmussen 1974), where silty sandstone with thin beds of evaporites are underlain by dated Permian volcanics and overlain by Zechstein evaporites.

In the W-1, Q-1, and P-1 wells, the typical basinal Zechstein Group is missing (fig. 18), and it is not certain whether the shaly facies with dolomite, anhydrite and rock salt belongs to Rotliegendes or to a Zechstein (or younger, ?Triassic) marginal facies shown in fig. 18. Intercalations of volcanic material near the top of the Rotliegendes sediments (B-1) indicate that the volcanism was active until the end of Rotliegendes time.

Zechstein Group

The Zechstein Group, as originally established by Werner (1786) for the South Permian Basin, has been subdivided into four cyclic series (Richter-Bernburg 1955). This division can also be applied to the North Permian Basin in the Danish North Sea sector (fig. 19). At present, however, it is not possible to make a certain stratigraphical correlation to the Central Graben area.

Type section: No type well can be given for the Danish Central Graben area due to the fact that drilling here penetrates only few metres into cap rock, or just into the rock salt below. The nearby B-1 well, with a marginal facies relation to the South Permian Basin, and the D-1 well, representing a basinal facies of the North Permian Basin, are used as reference sections for the structural high and deeper sections of the Central Graben respectively.

Thickness: The thickness of the Zechstein Group within the Central Graben is poorly known, due to halokinesis, to the scarcity of deep wells, and to uncertain stratigraphy above the ?Rotliegendes volcanics in wells P-1, Q-1, and W-1 (see the interpretation in fig. 19). Furthermore, seismic evidence to characterize the Zechstein deposits has not yet been evaluated. For these reasons, thicknesses of zero to several km (in the salt diapirs) are expected.

Lithology and distribution: The lithology of the Zechstein Group varies in accordance with distance to land: the Ringkøbing-Fyn High, Dogger High and Mid North Sea High are fringed by sabkha sediments and lagoonal evaporites dominated by limestone, dolomite, and anhydrite, as in B-1 and L-1 outside the Graben. These marginal deposits grade into the thick basinal facies dominated by rock salt with the basal kupferschiefer, and interbedded with salt, clay, dolomite, anhydrite, and K-Mg salt forming up to four evaporite cycles. Zechstein deposits have not yet been identified with certainty by the wells on the structural highs in the central part of the Danish Central Graben nor by seismic methods in the deeper parts here. Rocks of the marginal facies presumably frame the salt deposits in the northern and southern part of the Graben where the thick salt deposits have formed salt domes and diapirs.

In the idealized profile of the evaporites (fig. 19) in the eastern part of the North Sea, a tentative lithostratigraphic correlation is given. To the south, there is a well established succession controlled by data from several wells. To the northeast, the profile is based on the Danish D-1 well and the Norwegian 17/4-1 well. The differing evolution of the four cycles of evaporites in the two mega-basins is shown: in the South Permian Basin, Z-2 is the major cycle, and in the North Permian Basin, both Z-1 and Z-2 and partly Z-3 are major cycles and Z-4 subordinate.

3.3 Triassic

By Finn Jacobsen

Deposition during the Triassic continued in the basinal areas developed during the Permian, but in Early Triassic the highs were also gradually covered by sediments. The pattern of sedimentation in the two mega-basins is analogous to that of the Rotliegendes,

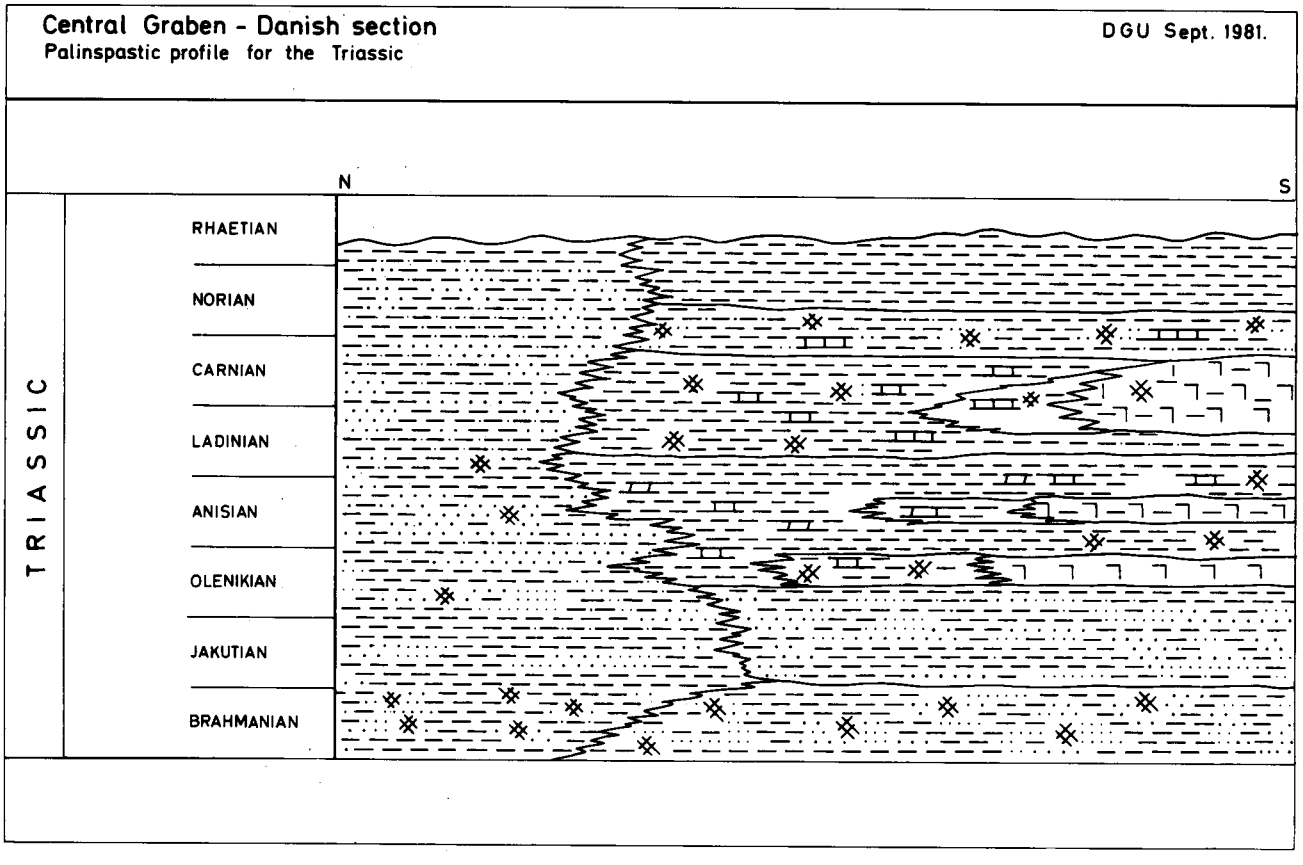

Fig. 20: Palinspastic profile of the Triassic deposits. For legend, see fig. 3.