Salt Resources in the Netherlands as Surveyed Mainly by AKZO

H.M. Harsveldt

Geological Survey of the Netherlands, Spaarne 17, Haarlem, The Netherlands

ABSTRACT

In this paper a short outline is given on the geological situation within the concession-areas and drilling-permits of AKZO Zout Chemie Nederland B.V. in the Netherlands. New information about the extension of the salt boundary coming from so far not released well data will be given. Successive will be dealt with geological gravimetrical and seismic data about the saltdomes of Pieterburen, Zuidwending, Winschoten, Weerselo and the saltcushions in the Eastern part of the Netherlands. Also new information will be released about the geological findings in the Twenthe-Rijn concession, regarding Röt and Zechstein salt.

INTRODUCTION

Since the activities of several oil companies in the Netherlands and the Netherlands part of the Continental shelf started in 1963, the knowledge of the subsurface of these areas has increased considerably. From gravimetrical measurements, confirmed for the greater part by subsequent seismic investigations the distribution of important salt basins in the North Sea area has been inferred.

The Mid North Sea High and the Ring Köbing Fynn High separated a Northern and Southern North Sea basin. Both basins were interconnected by a North-South running segment of the Central Graben. The Southern Northsea basin is the continuation of the Northwest German Zechstein basin. Except for saltpillows and salt diapirs, many saltwalls with a NS to NNE–SSW strike dominate in the German and Netherlands part of this basin. In the W part of the Netherlands salt basin just as in the British part salt pillows with a NW–SE strike are predominant. (Fig. 1).

Detailed information on the salt occurrences is not known as all data about the subsurface of the North Sea shelf are confidential. More data are available about the salt occurrences on the mainland because many wells have been drilled in the exploration for oil and gas resulting in the discovery of rock salt deposits of Zechstein age to a maximum thickness of 200 m in the subsurface of the central part of North Holland, the Markerwaard, S. Flevoland and the NW part of the Veluwe. Already known were the Zechstein diapirs in the NE and E of the Netherlands namely the Winschoten diapir, the Schoonlo diapir and the Weerselo diapir (Fig. 2). The knowledge of these salt diapirs has increased due to subsequent research, whereas new ones have been discovered amongst others the salt diapirs of Zuidwending and Pieterburen.

Also information is presented on the exploration activities in the Gelria concession during the period 1924–1927 and subsequent seismic work, resulting in the detection of saltpillows. In this contribution the salt diapirs, pillows and layers will be discussed successively.

ROCKSALT EXPLORATION IN THE NETHERLANDS

Since oil and gas exploration in the Netherlands commenced in 1961 many wells drilled in the gas containing reservoir rocks of the Rotliegendes and Carboniferous passed the Zechstein Formation and proved the presence of rock salt in areas where they were thought to be absent. It has appeared that outside the known Zechstein salt basin in the eastern and north eastern Netherlands Zechstein rock salt also occurs in the subsurface extending from central Middle North Holland through the Markerwaard and S. Flevoland to the NW part of the Veluwe. Based on data's of several wells it is possible to indicate the configuration of the salt boundary (Fig. 3).

It has appeared that in this area a WNW–ESE running inlet to the Zechstein salt basin existed and salt has been deposited there. In contrast to the concept of Ziegler who designates a Tessel-IJsselmeer High as an island in the Zechstein sea, preference is given here to the presence of an

Figure 1. Extension of Zechstein basin in the Netherlands and the Netherlands part of the Continental shelf (P. Heybroek, U. Haanstra, D. A. Erdman with additional data by H. M. Harsveldt).

inlet toward the Zechstein salt basin. The Southern Zechstein salt boundary is interrupted by more of these inlets (viz. Meiningen, Fulda, Wesel). Ziegler arrives at his representation by tracing the salt boundary from well Almelo 3 to the west, leaving the Texel-IJsselmeer High as an area without salt sedimentation during the Zechstein.

Within this bight of the salt basin salt thickness of up to 200 m occur at two places. These thick layers, representing deeper parts of the former basin, are respectively in the subsurface of the Markerwaard and directly East of the Veluwemeer. Based on stratigraphic interpretation all four salt cycles may be recognized within this newly discovered Central Netherlands salt basin, although the salts of the Aller Series occur locally and in thin deposits. The other three cycles are represented in the entire basin.

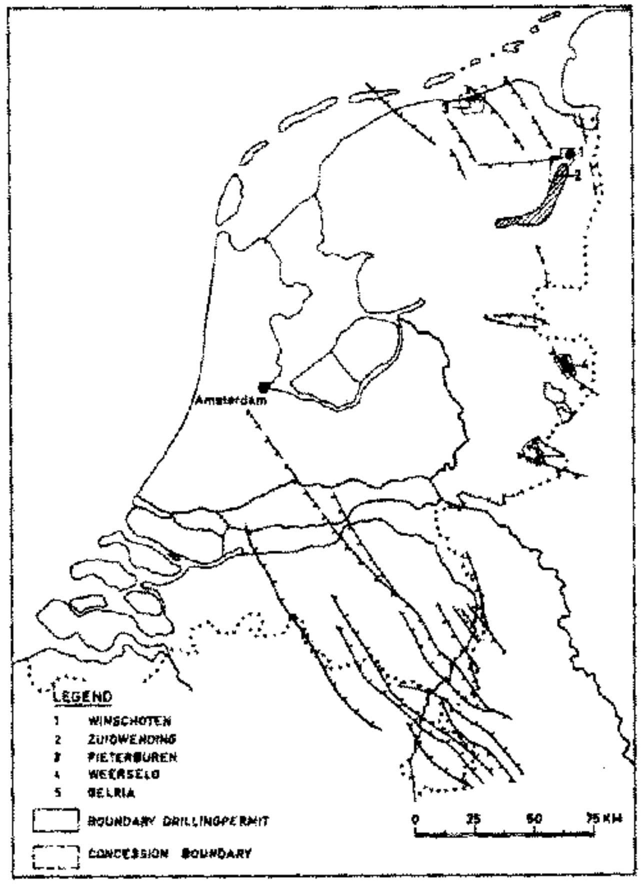

Figure 2. Outline map of salt occurrences as surveyed by AKZO and Mij. M.W.

The Werra salt, with thicknesses varying between 40 and 125 m is best developed, second best is the development of the Leine salt (20–60 m) whereas the Stassfurt salt attains thicknesses between 5 and 25 meters. There are no indications of halokinesis in this subbasin. The depths at which the rock salt occurs varies, due to the presence of fault patterns and is between 1,500 and 2,200 m. Potash sedimentation is also absent. Royal Dutch saltworks also made further progress after the publication by Cox (1965) with regard to exploration and exploitation. New salt concessions and drilling permits have been applied for since that time. At present the salt industry is active in the Twenthe-Rijn concession, obtained in 1933 and the Adolf van Nassau concession, obtained in 1954 and extended in 1967 with an area around Veendam.

Within the Twenthe-Rijn concession primarily rock salt of the Triassic series is exploited although possibilities for the exploitation of the Zechsteinsalt at greater depths also exists. Zechstein salt in this area has proved to be present at 1042.50 m by the deep well Hengelo Z1. Within the Adolf van Nassau concession Zechstein rock salt from the diapirs of Winschoten and Zuidwending is exploited. The drilling permit for the Pieterburen area obtained in 1969, was

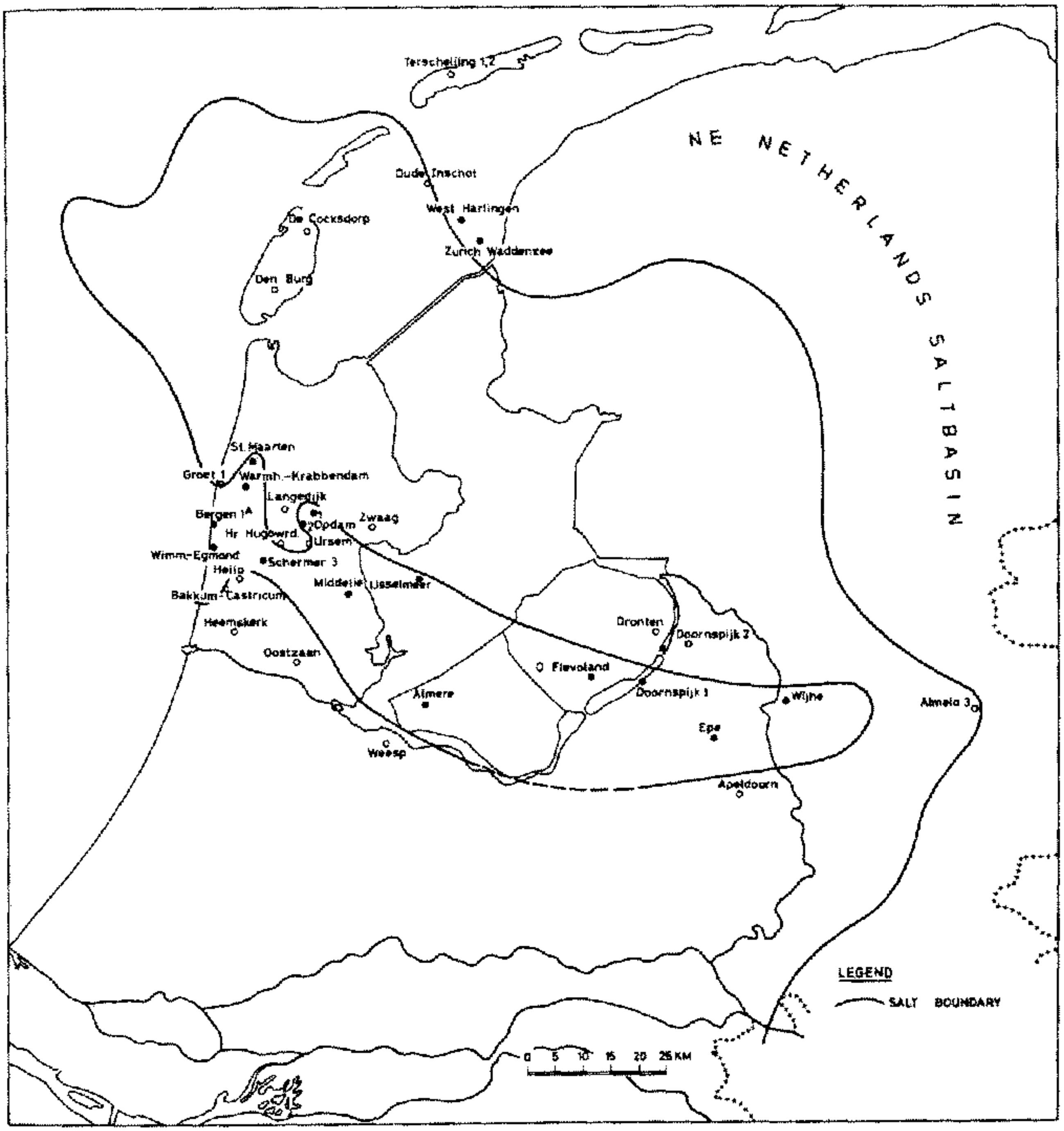

Figure 3. Central Netherlands Salt basin. Open circle = borehole without salt. Closed circle = borehole with salt.

explored with one boring, and afterwards temporarily abandoned in 1972.

To date rock salt has not been exploited in the Weerselo concession, obtained in 1967. In this concession where some borings had been made previously, the Fleringen 1 well was drilled in 1965 and rock salt of the Zechstein was encountered at a depth of 1,125 m.

TWENTHE-RIJN CONCESSION

The number of exploitation wells present here has been increased from 75 in 1965 to more than 260 to date. In all the wells, rock salt of the Upper Bunter, the so-called Röt-salt, has been found.

The upper surface of the rock salt formation occurs between 300 and 500 m below ground (Fig. 4). The salt layer

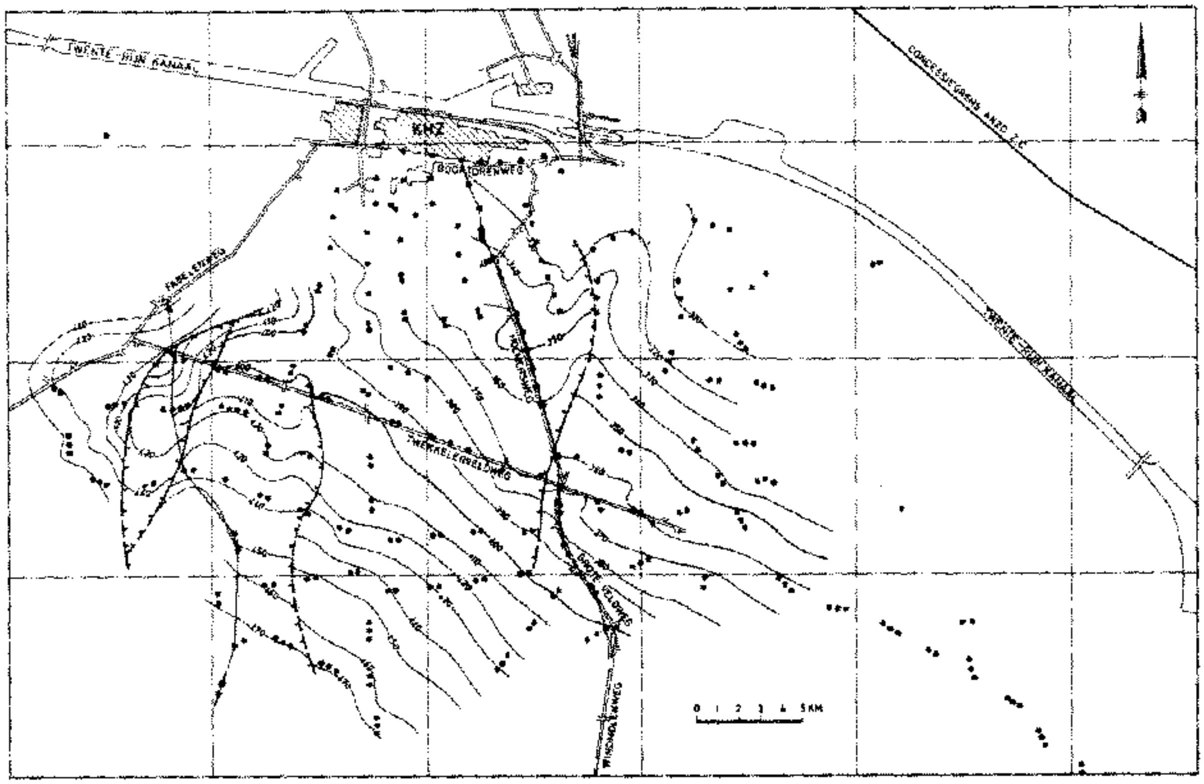

Figure 4. Contour map on top of Upper Bunter salt (in meters below ground) contour interval 10 m. Twenthe-Rijn concession.

dips toward SSW and attains thicknesses varying from 10 to 70 m. Locally a thickness of 100 m occurs. The salt layer does not increase gradually in thickness, but consists of interconnected thicker and thinner salt lenses, which are shown distinctly on the isochore map (Fig. 5). These thicker and thinner saltridges are WSW–ENE oriented. The irregular distribution of thickness is caused by the relief of the upper surface of the Middle Bunter (Fig. 6).

The irregular surface has been inundated by the transgressing Röt sea, resulting in the development of a landscape with lagoons where under the prevailing climate (desert), evaporites have been deposited.

In the deeper parts of the lagoon purer salt deposits have precipitated than in the stilzones. In Figures 7 and 8 two N–S running profiles over the salt field are drawn. They show a distinct relation between relief of the bottom and thickness of the salt. The salt lens with a thickness of 100 m found in boring 156 is related to considerable subsidence of the upper surface of the Middle Bunter, whereas the occurrence of a thin salt deposit in boring 150 may be ascribed to the presence of a sill in the Middle Bunter surface. In the profile on Figure 8 the same trend is visible.

A closer study on the Rötsalt layer reveals that due to the presence of intercalated clastic rockbeds-layer can be subdivided into four separate salt layers that have been designated from oldest to youngest with the letters A to D.

Salt A is the thickest salt layer. The salt is colorless to brown-gray at some places milky white, opaque, middle to coarse grained, with stringers and lenses of anhydrite and clay as impurities.

Salt B is thinner than Salt A, also middle to coarse grained with more impurities of anhydrite and clay.

Salt C is thicker than Salt B but not as thick as Salt A. It is gray-white to milky white to colorless middle to coarse grained salt with impurities of anhydrite and clay. About halfway the section downwards various shades of red occur. The reddish colors are characteristic for this layer.

Salt D is the thinnest salt. It is characterized by orange to yellowish orange colors and also anhydritic and clayey. This type of salt has not been encountered in all borings. The subdivision of the Rötsalt layer is shown in Figure 9. Concerning the interbedded rock layers in the salt, the separating bed between the Salts B, C and D consists of a sandy clay layer with lenses and nodules of anhydrite. Crevices and cavities in the layer have been filled up with rock salt. The separating rock layer between Salt A and Salt B consists of a clayey anhydrite-dolomite layer that locally becomes practically completely dolomite. Directly underlying Salt A is a massive anhydrite layer, the base of which overlies the sandy developed Middle Bunter.

A study of the lithology of the salt shows that upwards in the salt section the salt becomes increasingly impure. This indicates a steady warping of the lagoon during the sedimentation of the evaporites.

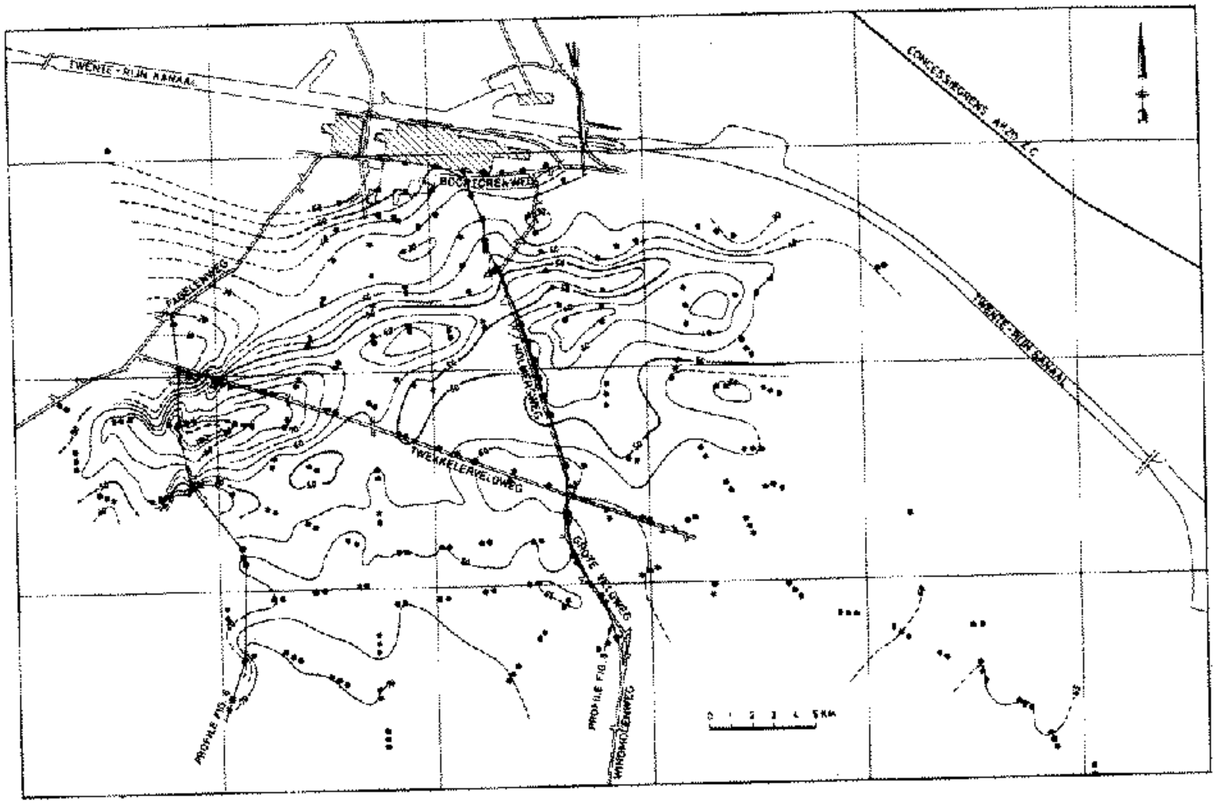

Figure 5. Isochore map of Upper Bunter salt, Twenthe-Rijn concession contour interval 5 m).

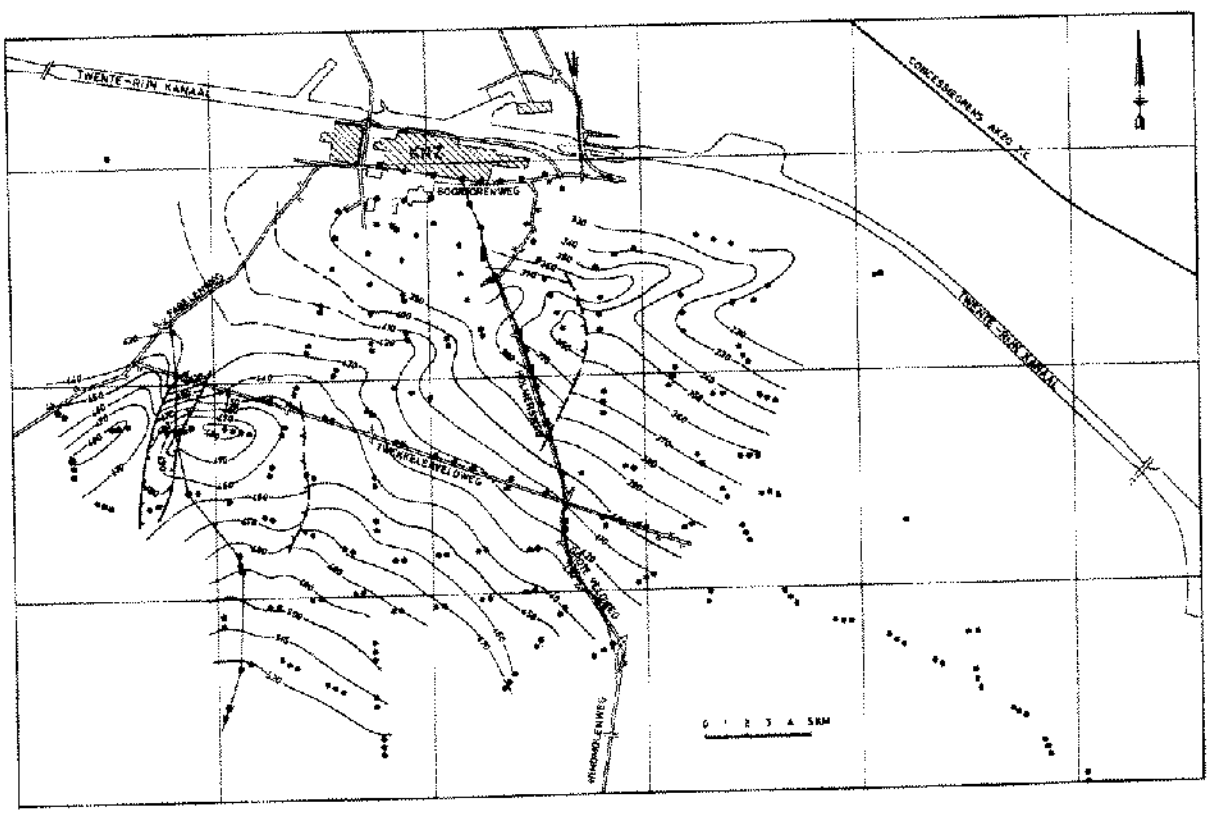

Figure 6. Contour map on top of Middle Bunter in meters below sea level, contour interval 10 m, Twenthe-Rijn concession.

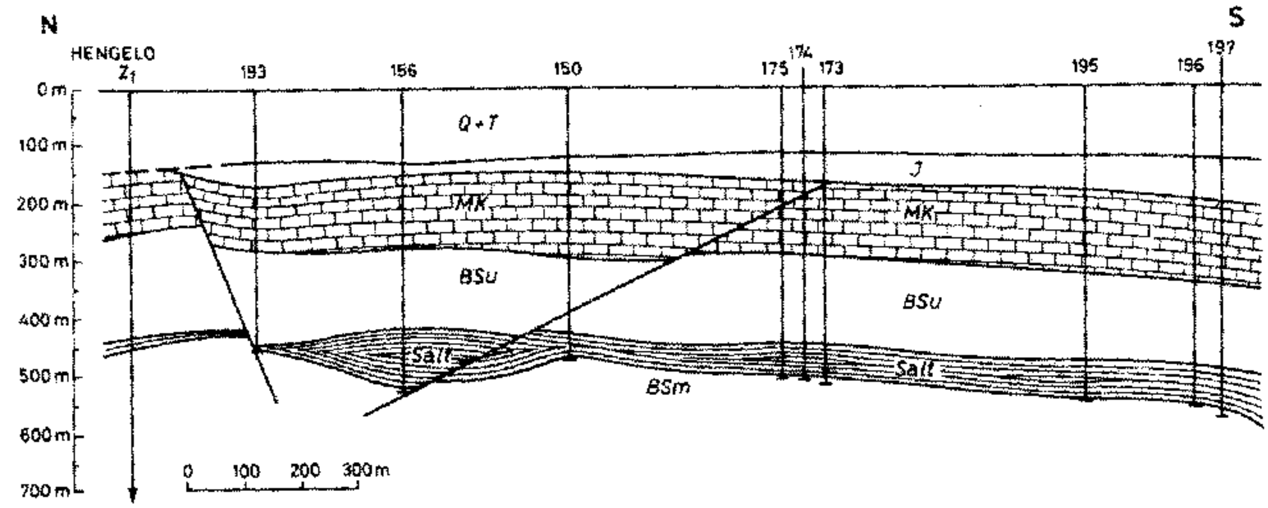

Figure 7. Hengelo Z1 profile, Twenthe-Rijn concession.

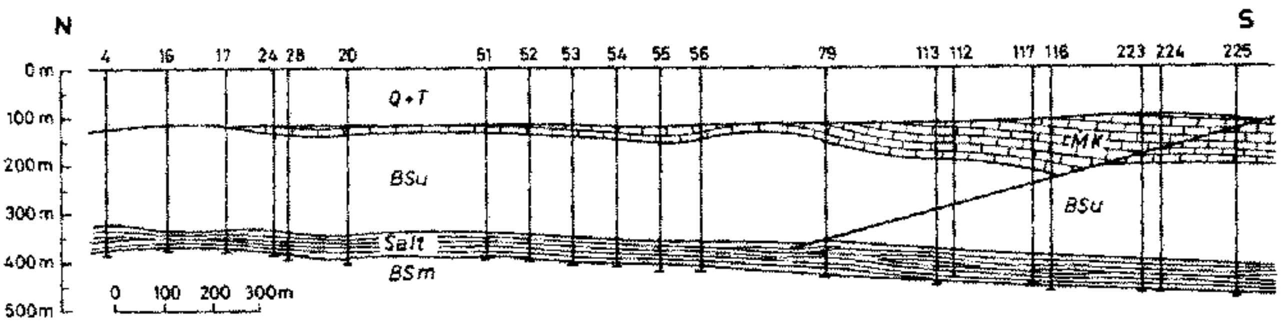

Figure 8. Profile along Holmersweg-Grote Veldweg, Twenthe-Rijn concession.

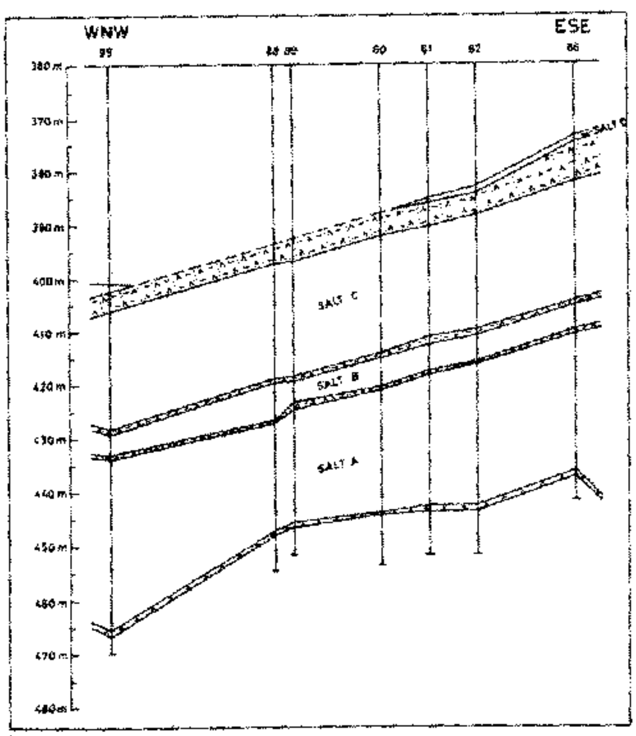

Figure 9. Subdivision of the Röt salt layer in Twenthe-Rijn concession.

To date four N–S to NNE–SSW running faults of minor importance have been recognized within the salt field (Fig. 4). They are indicated with the letters A–D. The displacement along the faults is little (30 m at the most). In 1965 an exploration was carried out for the rock salt layers of the Zechstein in a part of the concession between the boreholes Oele and Beckum within an area of about 7 km². Within this area 5 seismic sections have been shot by SEISMOS, showing after interpretation that the top of the Zechstein in this area could be expected between 950–1250 m below sea level. The area examined is cut by faults, the largest of which has locally a stratigraphic throw of about 150 m.

Furthermore it was found that salt thicknesses in between 175 m and 300 m could be expected in the Zechstein. The thicker deposits occur in the S part of the examined area (Fig. 10). In borehole Hengelo Z1, at shotpoint 6 of seismic section 4, the top of the Zechstein was expected at about 1050 m. Hengelo Z1 found the rock salt of the Röt between 438 and 454 m and entered at 1,042 m the rock salt of the Leine series. Drilling of the well continued until the top of the Carboniferous was reached at approximately 1,496 m. The perforated Zechstein section amounts to 454 m. This section includes 26 m Leine rock salt, 18 m Stassfurt rock salt and more than 100 m Werra rock salt. In

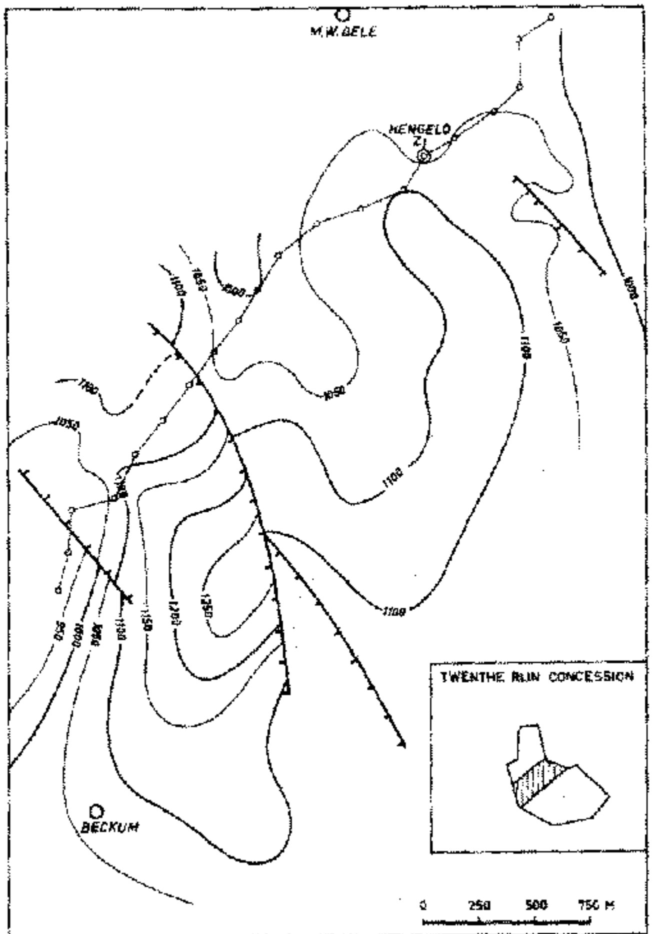

Figure 10. Top of Zechstein between borings Oele and Beckum in meters below sea level, contour interval 50 m, Twenthe-Rijn concession.

Figures 11 and 12 the seismic and geological situation of Hengelo Z1 is presented.

It appears that the reflection within the Zechstein represents the top of the Werra anhydrite, as found in Hengelo Z1. The reflection is distinct over the entire examined area. It represents the basis of the rock salt section of the first cycle which is also the lowest exploitation boundary.

BUURSE CONCESSION

In 1918 this concession was granted to the State, which recommended the exploitation to the N.V. Nederlandse Zoutindustrie. The concession has been exploited until 1952. In the period 1918–1932, eight production wells have been drilled. All the wells reached the Rötsalt of the Upper Bunter formation at depths varying between 270 and 300 m below ground surface. The Rötsalt layer dips westerly. The strike of the layer is about N–S. The thickness of the salt layer lies in between 68 and 93 meters. Also in this area the salt layer is subdivided by shale and anhydrite layers in four smaller salt layers of about the same composition as the salt layers in the Twenthe-Rijn concession.

ADOLF VAN NASSAU CONCESSION

Within this concession are situated the diapirs of Winschoten and Zuidwending. Both diapirs were discovered in the period 1935–1945 during a gravity survey of the N.V. Bataafsche Petroleum Maatschappij. By order of the Royal Dutch Saltworks, the Winschoten diapir was further examined by the N.V. Nederlandse Aardolie Maatschappij (1951) with refraction seismics after which three discovery wells each to a depth of 1,000 m were drilled.

Since the concession was granted (1954) nine production wells have been drilled and additional seismic investigations were carried out by SEISMOS. An interpretation of the seismic and well data resulted in a geologic picture of an oblong shaped diapir with a NW–SE strike and a steep east flank, disturbed by a fault with a throw of about 300 m (Fig. 13). The top of the rock salt is at about 400 m, the basis at 2,500–3,000 m. Close to the 1,000 m contour the rock salt dips very steeply. The NE flank of the salt diapir is less known because seismic investigations were prohibited close to the town of Winschoten. Directly overlying the rock salt is a caprock of varying thickness (6–40 m) composed of very pure white to light gray icy anhydrite.

The rock salt present is clear to dull translucent and contains very large rock salt crystals (up to 15 cm length). The salt is coarse grained with few impurities of gypsum or anhydrite. A fresh breach in the salt smells of sulphuretted hydrogen. As no continuous clay anhydrite or dolomite layers have been found it is difficult to determine exactly the cycle to which the salt belongs. Based on lithologic evidence the rock salt may be assumed to be equivalent to the Stassfurt cycle. The potash content in the rock salt is negligible and lies in between 1 and 2%.

The Zuidwending diapir has been subsequently explored in 1967 by means of seismic investigations and drilled holes. The salt body appears to be sickle-shaped in outline within the 1,000 m contour. Two culminations occur, namely a southern culmination with a SW–NE strike and a northern culmination with a more or less E–W direction of strike. Both culminations are surrounded by the 300 m contour top salt (Fig. 13).

The first continuous contour line over the salt body is the 350 m contour. The several seismic sections show that the Zechstein salt has moved upwards from depths between 2,500 and 3,000 m along a comparatively narrow stem situated between 2,000 and 1,000 m. During its movement to the surface the overlying Mesozoic and Cenozoic layers were penetrated and pushed aside which has caused a slight overturn of the flanks of the salt diapir. The southern culmination has not yet been explored by wells. In the northern culmination there are seven production wells with total depths between 1,400 and 1,600 m. In all these wells the uppermost surface of the rock salt was found above 200 m. The rock salt is coarse grained, very pure, clear to dull translucent, colorless to gray, and with very scanty impurities in the form of anhydrite strings.

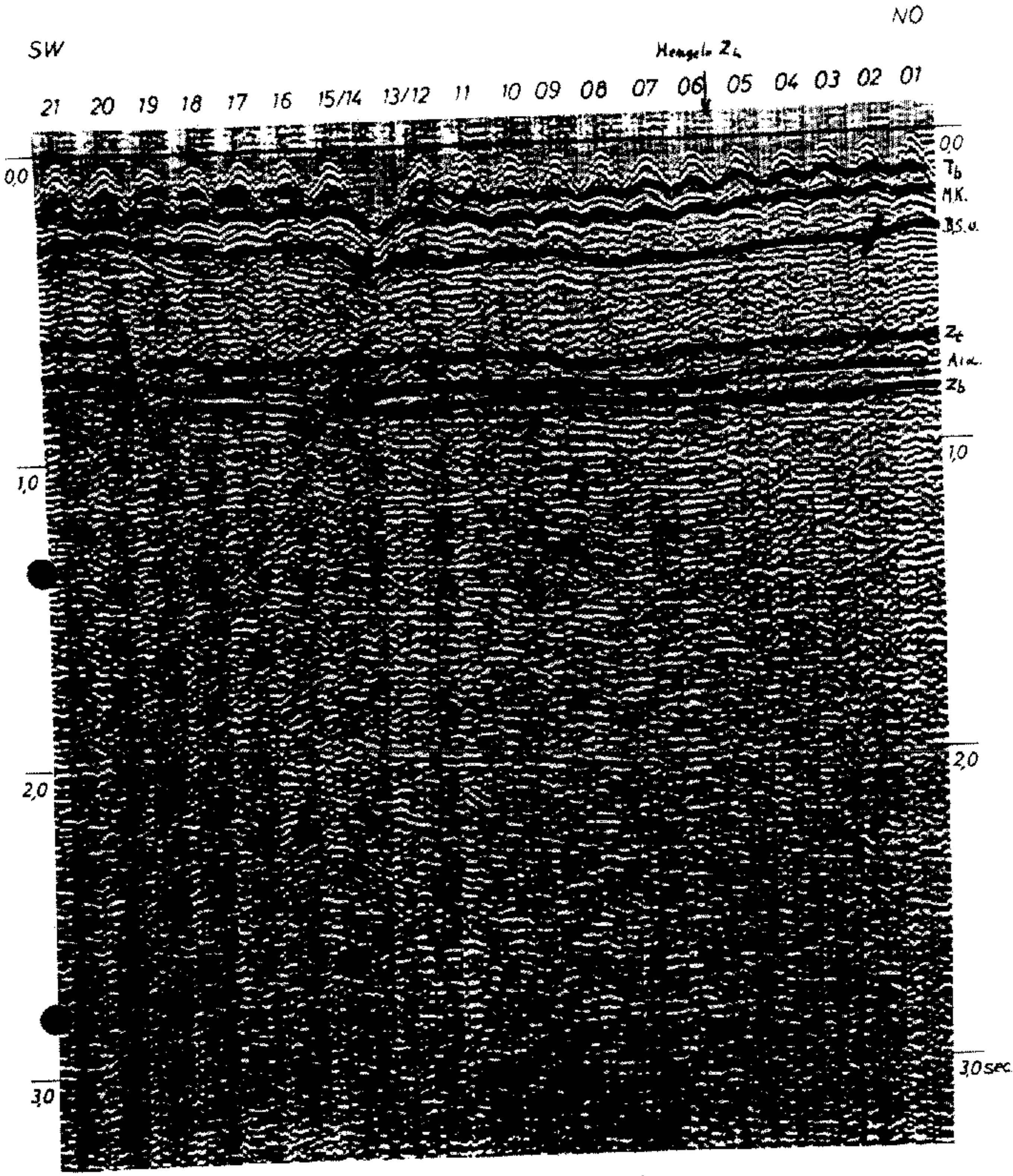

Figure 11. Hengelo Z1, seismic section.

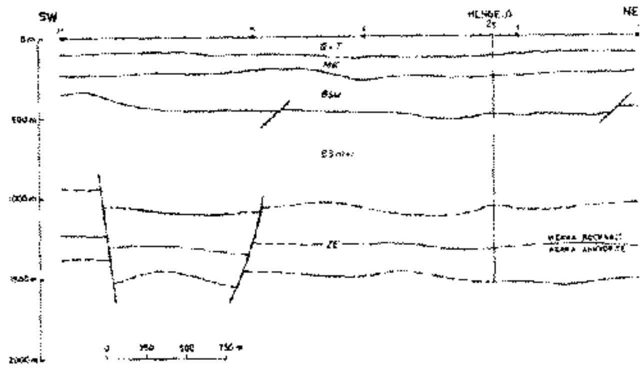

Figure 12. Hengelo Z1, Zechstein salt profile, Twenthe-Rijn concession.

An exact age determination of the salt has not been possible due to the absence of continuous limestone or anhydrite layers. Also the density logs taken do not reveal the presence of these layers in the salt section. Locally in well 3 and 4 some pink salt was found. All salt encountered smells of sulphuretted hydrogen. Based on the lithology, it is assumed that the salt is correlative with the Stassfurt Series. The Potassium content is between 0.01 and 1.2%, and the magnesium content is between 0.01 and 0.05%. Directly above the rock salt a caprock occurs with a thickness of 40 to 49 m. The upper part of the caprock consists predominantly of gypsum, at the base rather pure anhydrite occurs.

The beginning of diapirism cannot be inferred from the profile (Fig. 14). In Zuidwending the thinning of the

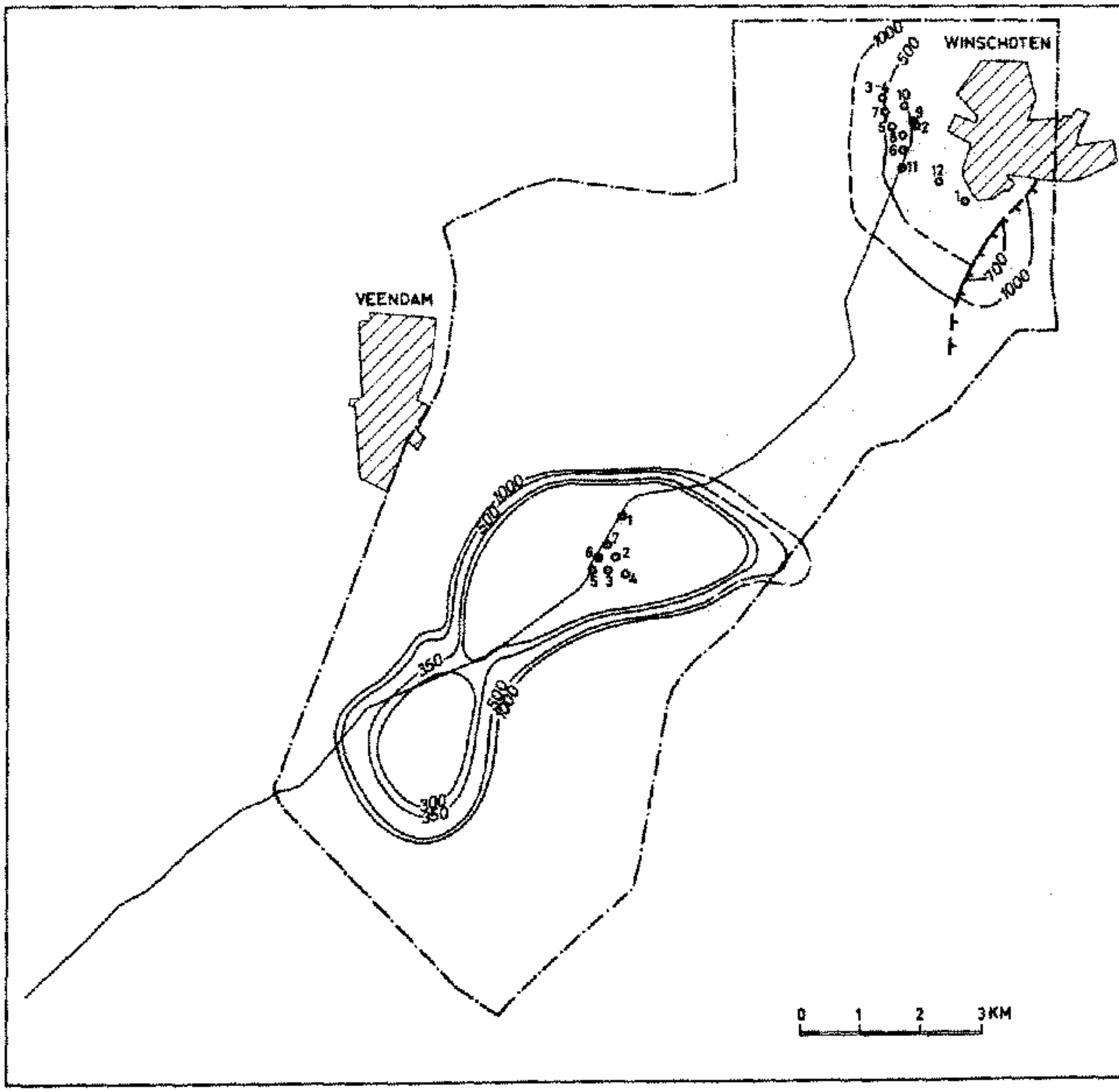

Figure 13. Contour map, Top of Zechstein Winschoten and Zuidwending salt diapirs, Adolf van Nassau concession.

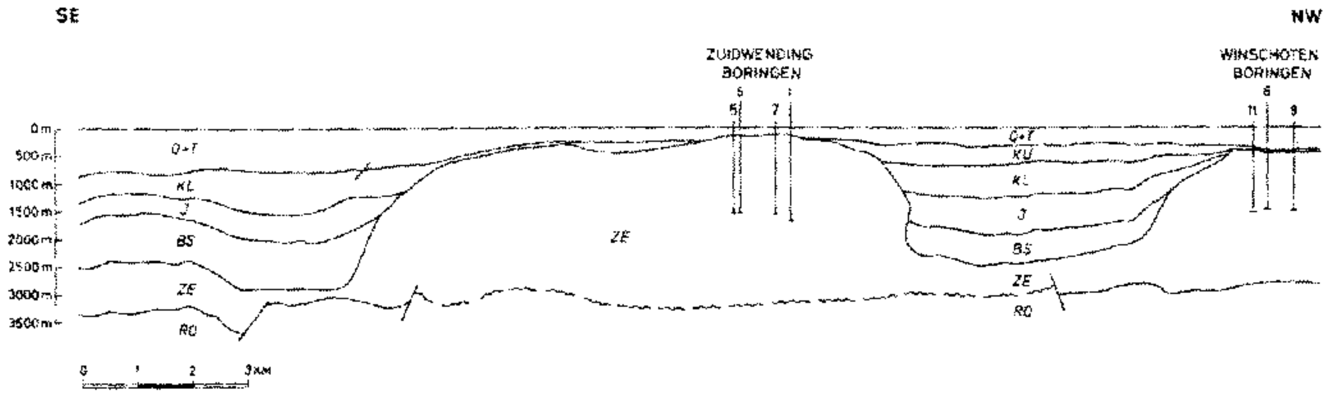

Figure 14. SE–NW profile over Zuidwending and Winschoten salt diapirs, Adolf van Nassau concession.

overlying Tertiary sediments within the rim syncline towards the salt structure show that halokinetic movements have decreased during Tertiary. The caprock of the diapir of Winschoten is directly overlain by Upper Cretaceous sediments also of smaller thickness than directly around the diapir, which means that here the salt movements have decreased in Upper Cretaceous times.

WEERSELO CONCESSION

Within this concession is the salt diapir of Weerselo. The first surmise concerning the possible occurrence of rock salt in this area was expressed by van Waterschoot van der Gracht in the annual report of the Government Institute for the geological exploration of the Netherlands of 1910. He mentioned the abnormal strong salinity of the groundwater around Weerselo, that is reflected in the saliferous vegetation particularly the presence of the plant *Glaux maritima*. In a well drilled in this area salt water was found at a depth between 159 and 166 m below ground in a sandstone of lower Cretaceous age. No salt beds were encountered. It was until 1942 before the next well in this area was drilled. This was the Weerselo 1 drilled by the combine B.P.M.–Elwerath. This well drilled through the Quaternary, Tertiary and Upper Cretaceous formations and found a caprock of anhydrite at 448 m below the surface.

Below the caprock, at a depth of 476 m, rock salt of the Zechstein formation was observed to the total depth of the boring at 889.50 m. At that depth the base of the salt was not yet reached. In the period 1942–1943, the same combine successively drilled four wells namely Deurningen 1, Deurningen 3, Tubbergen 1 and Tubbergen 2. Only Deurningen 3 found the upper side of the salt at a depth of 280 m after drilling through Quaternary, Tertiary and Liassic sedimentary rocks. The top of the rock salt was found at 319 m below the surface. A caprock consisting of anhydrite was found between 280 and 319 m below the surface. The well reached a total depth of 393 m in rock salt without having reached the base of the salt.

The wells Tubbergen 1 and Tubbergen 2 reached total depths of 667.50 and 589 m respectively in the Muschelkalk. Deurningen 1 was terminated at 259.20 m in the Upper Bunter. The last three wells are outside the area of the salt piercement.

In the fifties, a seismic investigation of the salt structure near Weerselo was executed by the N.V. Nederlandse Aardolie Maatschappij. In 1965 after taking over the finder-rights of the salt by the N.V. Koninklijke Nederlandse Zoutindustrie from the Nederlandse Aardolie Maatschappij b.v., the area was further investigated seismically by SEISMOS. This investigation was followed by drilling the Fleringen 1 well in which rock salt of the Werra and Stassfurt series were found.

The complicated setting is distinctly visible in the profile over the Fleringen 1 well (Fig. 15) and from the stratigraphic sequence in the well. Due to the presence of the Gronauer thrust fault the Stassfurt salt at 1,159 m is underlain by deposits of the Lower Bunter, whereas at 1266 m strata of the Lower Bunter overlie the Stassfurt salt. The profile over the southern part of the salt piercement and over the Deurningen 3 well (Fig. 16) shows a more quiet tectonic picture.

The stratigraphic subdivision of the Zechstein below the upthrust plane is as follows: Stassfurt rock salt (Na2) from 1262–1363 m. Below here from 1363–1396 is the Basal Anhydrite (A2), a dark gray to brown-gray, locally white anhydrite with thin intercalations of dolomite. Crevices and cracks in the Basal Anhydrite have been filled with salt. From 1396–1590 m is the Maindolomite (Ca2). It is subdivided into an upper dolomitic part (1396–1450 m), a middle anhydrite part (1450–1485 m) and a lower dolomite (1485–1590 m). Between 1590 and 1658 m, the Upper Werraanhydrite (A1β) is present. It has thin intercalations of light brown colored dolomite. The Werra rock salt (Na1) occurs from 1658–1709 m.

From 1709–1753 m is the Lower Werraanhydrite (A1α). The Zechstein section terminates with Zechstein limestone (Ca1) from 1753–1758 and the Coppershale from 1758–

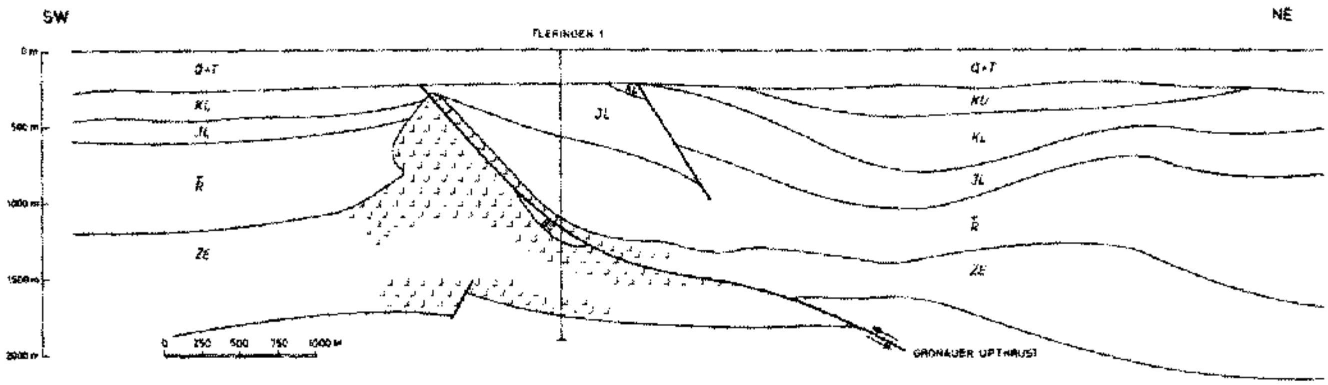

Figure 15. Profile N part Weerselo salt diapir over Fleringen 1, Weerselo concession.

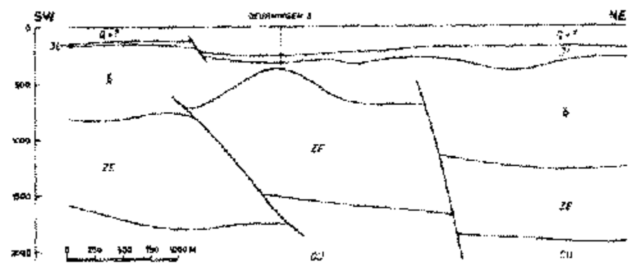

Figure 16. Profile S part Weerselo salt diapir over Deurningen 3, Weerselo concession.

1759 m. The rock salt encountered is rather pure locally, as clear as glass. The scarce impurities consist of thin anhydrite and clay intercalations occurring as lenses and laminae. The compilation of the geologic and seismic data resulted in a contour map (Fig. 17) showing a rather complicated NW–SE strike and in the northern part bifurcated intensely faulted salt piercement, pressed up high against the eastern face of the Gronauer upthrust.

The Gronauer upthrust originated as a consequence of the Laramic phase of the alpine orogenesis after the deposition of the Upper Cretaceous and before the sedimentation of the Tertiary, that lie discordant over the folded older subsurface. Under the influence of this orogenic movement, the Zechstein salt and part of the Bunter were dragged along the upthrust face. As a consequence, the west flank of the salt piercement became overturned. It can be inferred from the profiles Figures 15 and 16 that before the Laramic phase the Zechstein salt very probably was present as a pillow covered by Triassic, Liassic, and locally, Cretaceous sediments. This pillow developed during the Triassic as a result of a beginning halokinesis. Only during the Laramic phase was the halokinese triggered that led to the development of the Weerselo salt diapir.

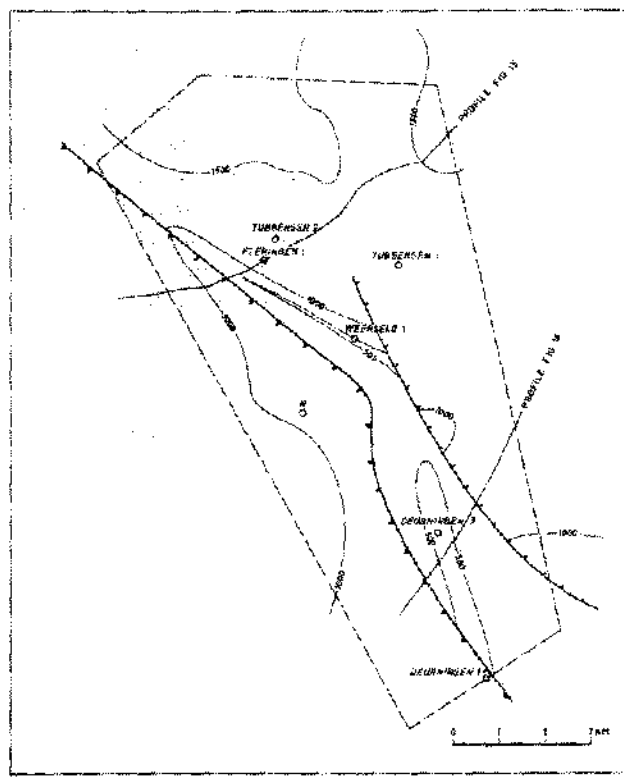

Figure 17. Top Zechstein in meters below sea level, contour interval 500 meters, Weerselo concession.

GELRIA CONCESSION

The Gelria concession was granted to the "Nederlandse Maatschappij tot het verrichten van mijnbouwkundige Werken N.V." for the exploitation of rock salt and coal. Previous to acquiring the grant, this company had drilled five deep wells and six test wells in the years 1924–1927. In the deep wells the presence of Zechstein rock salt and coal was proven.

Because it was stipulated in the concession-conditions that in contradiction to exploitation elsewhere in the Netherlands, the mining was allowed only by means of the room and pillar method, the salt-exploitation never started. More clarity about the distribution of the rock salt in the subsurface was obtained after a seismic investigation by the Nederlandse Aardolie Maatschappij b.v. in the period 1950–1952. Seven seismic profiles were shot, four in N–S and three in an E–W direction. The seismic program was concluded with the drilling of the Lichtenvoorde 2 to test the Zechstein possibilities for mineral resources.

An interpretation of the seismic and well data concluded upon the presence of salt pillows in the subsurface between 750 and 450 m below sea level (Figs. 18, 19). Due to the wide meshes of the seismic net an exact delineation of the salt pillows is impossible. A salt pillow measuring 2½ × 2½ km lies just west of the town of Groenlo and is demonstrated in the Gelria 4 well (salt thickness over 350 m). A smaller one, proven in Gelria 1 well is situated about 5 km west of Winterswijk (salt thickness over 200 m).

Based on seismic evidence it may be concluded that two more small salt pillows occur. One is just west of Corle (salt thickness over 300 m) and the other is just west of Lichtenvoorde (salt thickness over 250 m) (Fig. 20). The rock salt present belongs to the Werra cycle. It is gray to brownish gray, locally reddish, clear, with few anhydrite impurities. The Stassfurt and Leine cycles in this area are only developed in the dolomite-anhydrite facies. Some rock salt is from the Stassfurt cycle (Gelria 1: 15 m; Gelria 5: 3 m) and the Leine cycle (Gelria 5: 9 m) occurs sporadically. Over the entire area the salt is sealed off from the Mesozoic layers by the Plattendolomite and the Mainanhydrite.

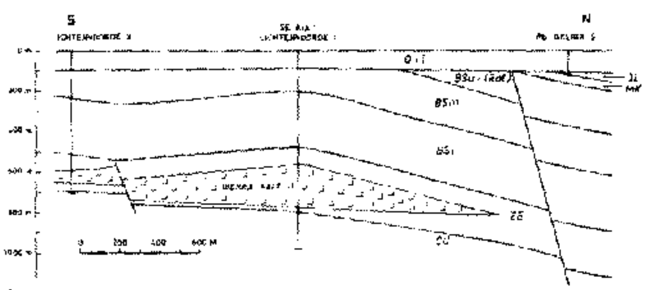

Figure 18. Gelria salt pillow.

DRILLING PERMIT GRONINGEN–WADDENZEE

The drilling permit was applied for in 1968 by N.V. Koninklijke Nederlandse Zoutindustrie. Apart from a gravimetrical investigation carried out before 1968 that showed the presence of a deficiency of mass (−18 m gal) probably caused by the presence of salt in the subsurface, a seismic survey was conducted to evaluate the rock salt prospects. Eight seismic sections were shot over the area. Four of these sections traversed in WSW–ENE direction, four in NW to SE direction. With this, the area was sufficiently covered to get an insight in the configuration of the upper side of the salt formation and the outline of the salt diapir.

The geological picture resulting from the interpretation of the seismic sections shows a diapir with a WSW–ENE strike faulted in the central and northern part. Based on these data a drilling permit was granted in 1969. Drilling of the Pieterburen 1 well started in 1971. It is located directly south of the village of Pieterburen, and south of the WSW–ENE running fault directly north of the village, between the shotpoints 650–649 of seismic section 2187 (Fig. 21).

The top of the Zechstein was found at 219 m below the surface. From the surface to 219 m the well penetrated the Quaternary (to 40 m), Tertiary (to 160 m) and Upper Cretaceous (to 219 m). A caprock with a thickness of 93.50 m consisting entirely of gypsum was found above the rock salt. The rock salt was found at a depth of 313.5 m. In alternating succession the Liniensalz ($Na_3\beta$) and Orangesalz ($Na_3\gamma$) occur, indicating rumbling of the salt layers and lower down, from 746.60–774.80 the Banksalz ($Na_3\delta$) was found. In the latter interval, from 752.40–754.20 potash-magnesium salts of the Ronnenberg seam (K_3Ro) were encountered.

The Mainanhydrite (A3) with a thickness of about 30 m occurs from 774.80–805.44 m and dips about 50 degrees. The following lithological subdivision has been made:

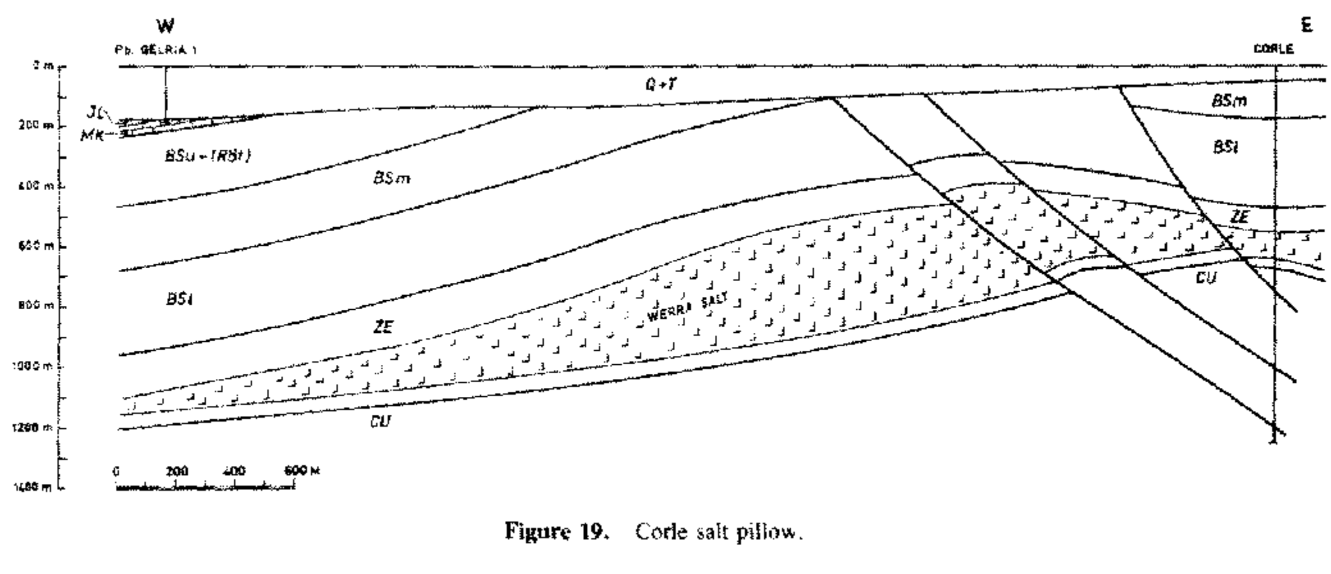

Figure 19. Corle salt pillow.

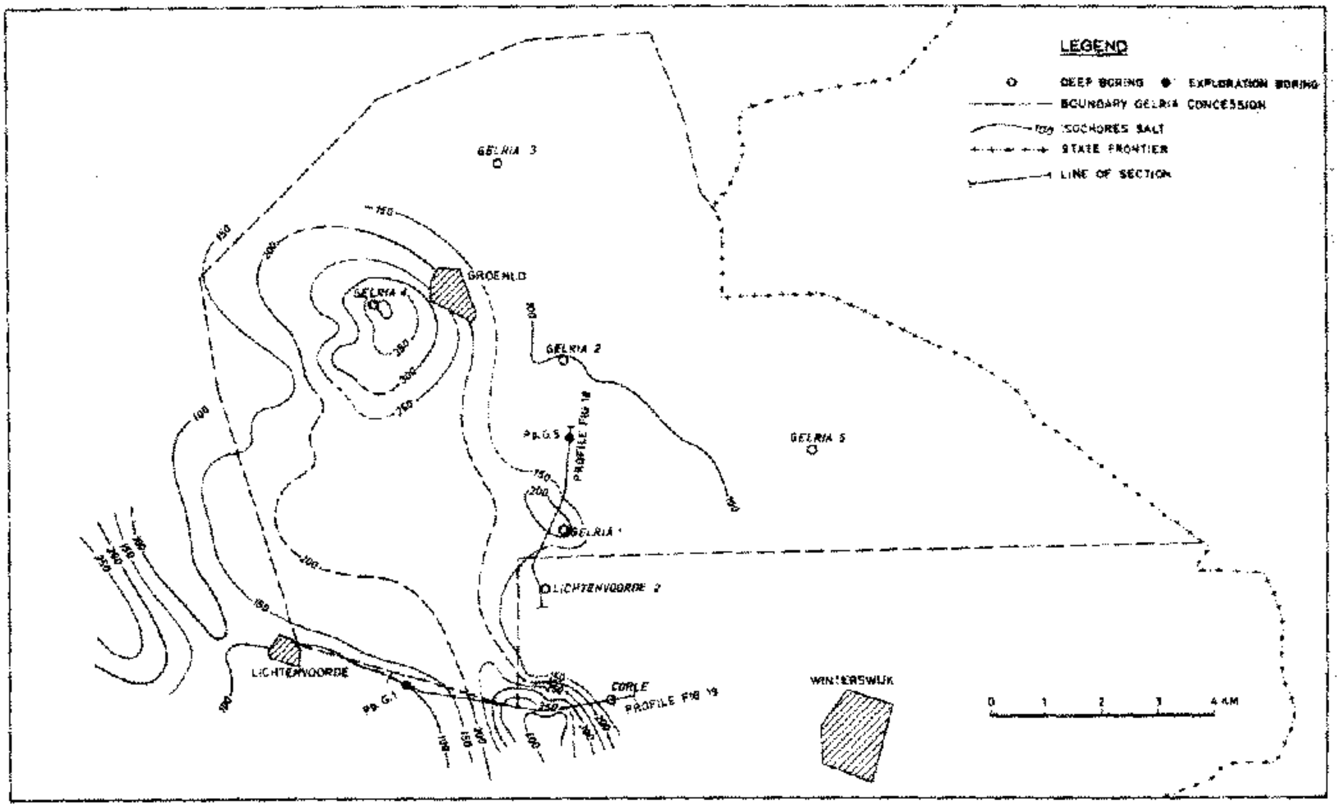

Figure 20. Salt pillows Eastern Gelderland-Gelria concession.

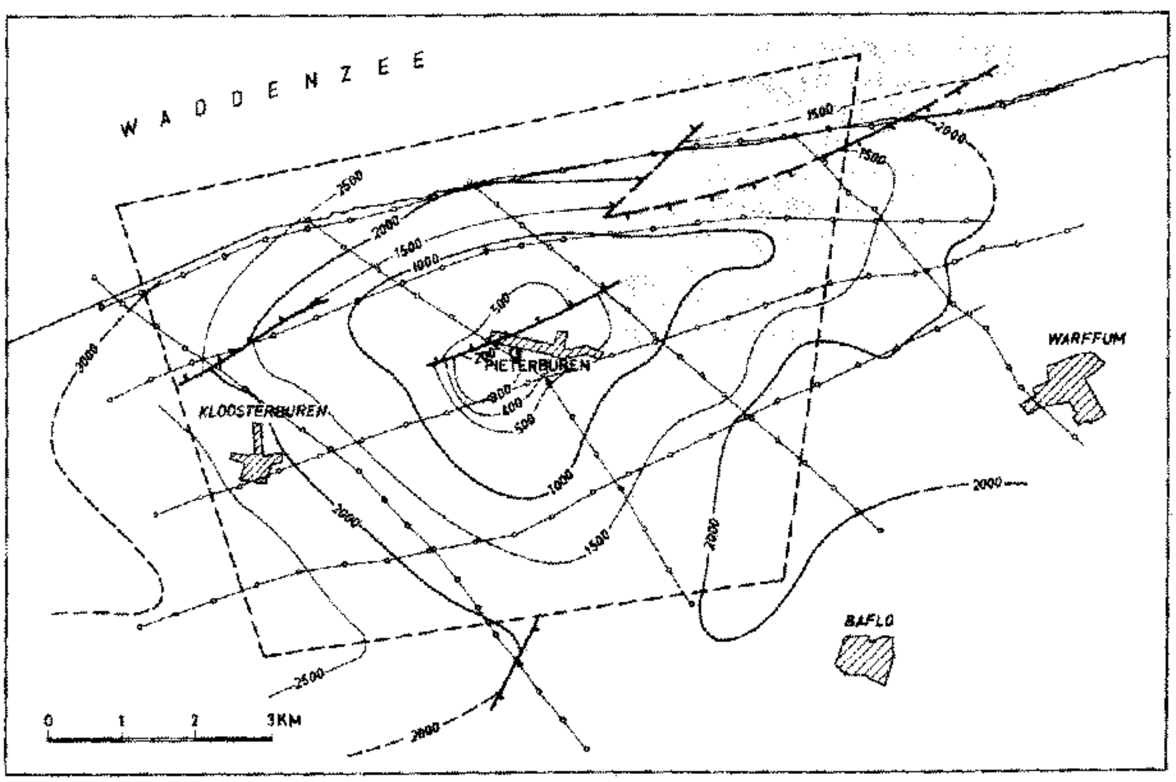

Figure 21. Contour map Top Zechstein in meters below sea level.

774.80–777.10: stratified blue-gray anhydrite. The stratification is caused by intercalations of black shale films to thin shale layers. Directly underlying is a compact massive blue-gray to brown-gray anhydrite with oil traces to 781.45 m. Further down to a depth of 784.20 m, stratification occurs again, caused by flaser development of the layers that constitute the anhydrite. Also traces of oil occur in this rock unit. From 784.20 m to 792.98 m dolomite and shale layers of varying thickness (some mm to local 1 dm) are present in the anhydrite. The dolomite content increases strongly between 792.98–795 m and due to the presence of alternating thin dolomite, shale and anhydrite lamina, the Mainanhydrite obtains a shaly character. The rock in this point of the section has a strong bituminous smell. Between 795–797.50, the lithology is not known due to loss of core. From the gammaray and density log the presence of intercalated potash-magnesium salt may be inferred.

From 797.50–798.80, the Mainanhydrite consists again mainly of anhydrite. Downward to a depth of 800.16 m the rock has the same composition as that between 792.98–795 m. Below the latter depth down to 805.29 m the Mainanhydrite is composed of massive marble-like anhydrite with scarce thin intercalations of dolomitic anhydrite and salt. At 805.29 m a black to locally gray to brown-gray clay has been found. This clay is tectonically compressed and disturbed and occurs down to 805.44.

This clay very likely represents the "schwarze Tonlage." Directly below this clay, rock salt (Basissalz: $Na3_{\alpha}$) follows until the total depth of the well at 903.20 m. The salt is of rather pure composition, locally brownish-yellow but for the greater part dull white translucent, middle coarse to coarse grained and containing two very thin anhydrite laminae. Summarizing, it may be stated that in the Pieterburen 1, after drilling through the overburden, steeply inclined and folded evaporites of the Leine series were reached. Strong folding may be inferred from the alternating occurrence of Liniensalz and Orangesalz.

It is also evident that from the succession of the various salts (Liniensalz, Orangesalz, Liniensalz, Orangesalz, Liniensalz, Orangesalz, Banksalz) that a reversal of the normal stratigraphic sequence may be observed.

Contrary to all expectations younger salts have been found instead of older salts. In Pieterburen the Mainanhydrite was encountered below the Banksalz. The transition of Banksalz into Mainanhydrite is abnormal. According to the section encountered, below the Banksalz the younger salts of the Leine serie would have been expected. To explain the abnormal contact between Banksalz and Mainanhydrite a thrustfault is assumed to be present at the contact of both rock formations at 774.80 below the surface. If this fault must bring about the contact as it has been found in Pieterburen, the displacement caused by it must be equal to the thickness of the salt section between Mainanhydrite and a part of the Banksalz. In order to achieve this, the thickness of the Basissalz, the Liniensalz, the Orangesalz and part of the Banksalz until the assumed fault, must be known. In Figure 22, the real thicknesses of the salts have been constructed, taking into account the observed dips. Doing this for the Basissalz a thickness of at least 70 m is found, for the Liniensalz at least 60 m, for the Orangesalz 15 m and for that part of the Banksalz up to the fault about 20 m. This means that in total at least 165 m of salt have been displaced along the fault (Fig. 23).

Besides this another reason for assumption of a fault at 774.80 are two other indications. The first indication is noticeable on the temperature log (Fig. 24). This log was run from total depth to surface, the temperature curve shows a gradual temperature drop upwards from 105°F at 903 m to 79°F at the top of the rock salt. In the interval 805 to 775 m the regular course of the temperature curve is disturbed. From 805–795 m the temperature drops suddenly from 97°F to 94.5°F, from 795–775 m the temperature rises from 94.5°F to 96°F. The sudden temperature drop between 805 and 775 may be explained by accelerated cooling along a fault plane.

A third indication for assuming a fault in the Pieterburen salt section is found in the seismic interpretation of VAR section 2187 (Fig. 25). Beneath the shotpoints 651–650, a thrust fault is present at the base Zechstein reflection.

The displacement along this fault amounts to 150 m. This thrust fault may be extended without difficulty into Pieterburen at 774.80 m without disarranging the construction, for which reason it may be assumed that this basal Zechstein thrust fault is the same as the thrust fault present in the Pieterburen section. The dip of the fault plane may be about 70°.

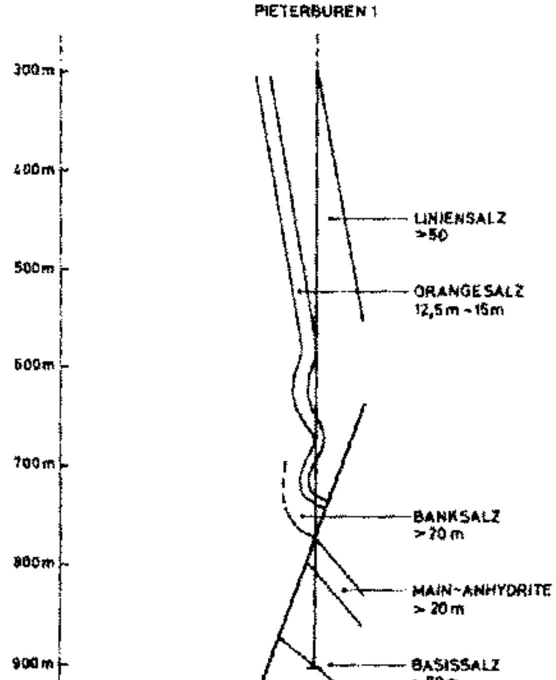

Figure 22. Thickness determination, salt layers.

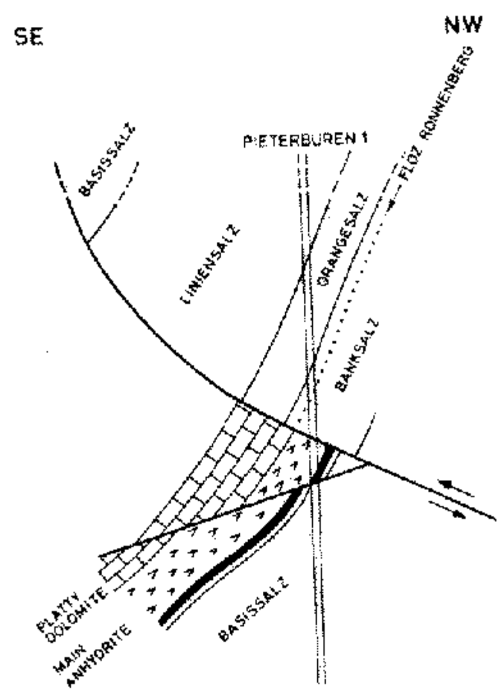

Figure 23. Detailed structural situation of Mainanhydrite.

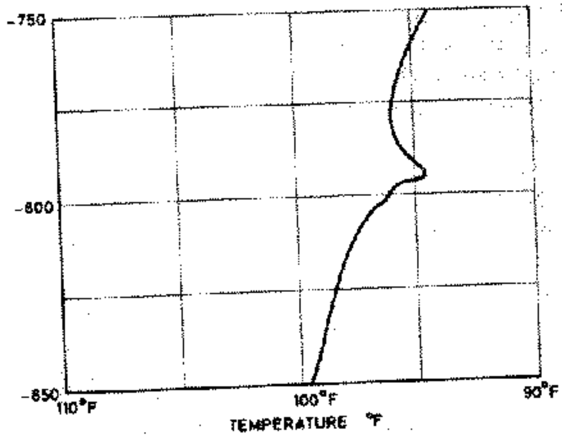

Figure 24. Temperature log Pieterburen 1 between 850–750 meters.

A closer examination of the lithologic sequence found in the Mainanhydrite reveals that here also the sequence is reversed because the "schwarze Tonlage" normally occurring as a thin layer at the top of the Mainanhydrite has been found at the base.

The thrust fault also explains the absence of the Platten-

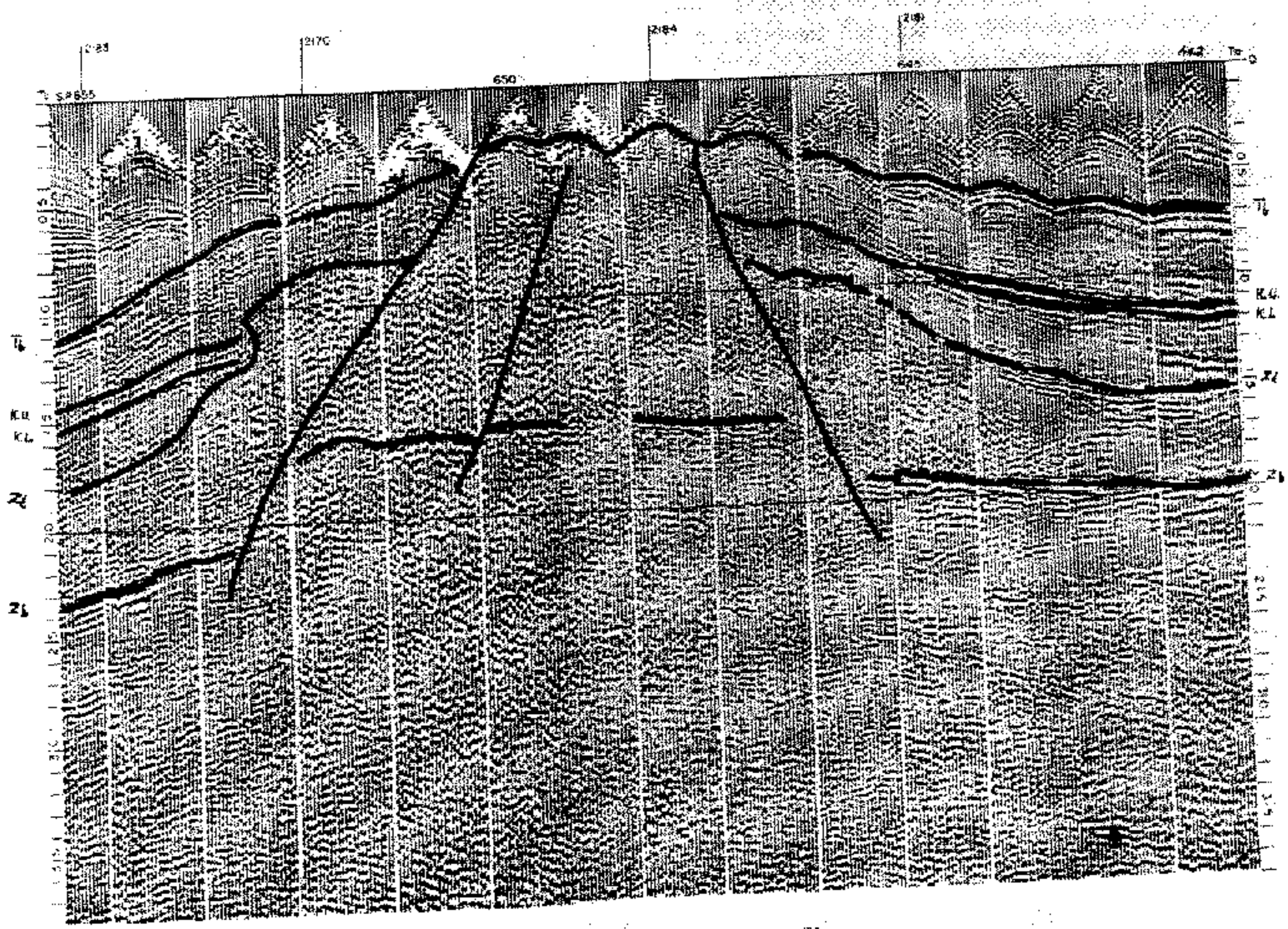

Figure 25. Siesmic reflection profile.

dolomite in the Pieterburen section. Finally, lithologic evidence may also lead to the assumption of an extra fault because the "Anhydritschale," normally occurring above the "schwarze Tonlage" should be present here below the "schwarze Tonlage" but is absent. Directly below the "schwarze Tonlage" the Basissalz was found. This fault may be assumed to have cut the Pieterburen section directly below the "schwarze Tonlage," at 805.44 m below the surface.

Only a minor displacement along this fault is needed (Fig. 23) to explain the absence of the "Anhydritschale" in Pieterburen. The dip of the fault plane is opposite to the dip of the large thrust fault found at 774.80 m in the well. Directly below the fault, the Basissalz is found until total depth at 903.20 m in the Pieterburen section.

An attempt has been made to give a geological interpretation of seismic section 2187 by means of all data available (Fig. 26). Three faults can be traced distinctly in the salt; the central one is the thrust fault found in the Pieterburen borehole section. Relying on the succession of the salt layers, it may be assumed that directly SE of Pieterburen, the Stassfurt salt will be present and directly NW of Pieterburen will be the Leine salt. As the Stassfurt salt is the most mobile of all the salts in the Zechstein it has very probably been the impetus for the contortion of the salt layers within the diapir. The assumption as sketched shows intruded Stassfurt salt in the central part of the diapir.

The mechanics of salt dome formation are shown in Figure 27. Since the sedimentation of the Zechstein salt layers the following movements of the salt may be assumed to have taken place. In view of the thinning of the Bunter towards the salt body, it is concluded that during the Bunter a salt pillow developed from the Zechstein salt layer (27B). The absence of Jurassic deposits above the salt is caused either by non-deposition or by erosion during a younger period. At that time the salt deposits may have been close to the surface and may have been partly subjected to erosion before the sediments of the Cretaceous were deposited (27C). After sedimentation of the Cretaceous (27D), the pillow stage developed into the diapiric stage (27E). This diapiric stage very probably has been introduced by the alpine orogenesis at the end of the Upper Cretaceous (Laramic phase). Triggered by orogenesis the salt moved halokinetically upwards along the originated faults and locally broke through the Cretaceous layers to the Tertiary surface.

The possibility should not be excluded that during this time the salt diapir was subjected to solution by groundwater. The fact that the Pieterburen caprock consists mainly of gypsum points to this assumption. It is at present known that the salt during its passage through the overburden has pierced the Bunter, the Lower Cretaceous and locally the

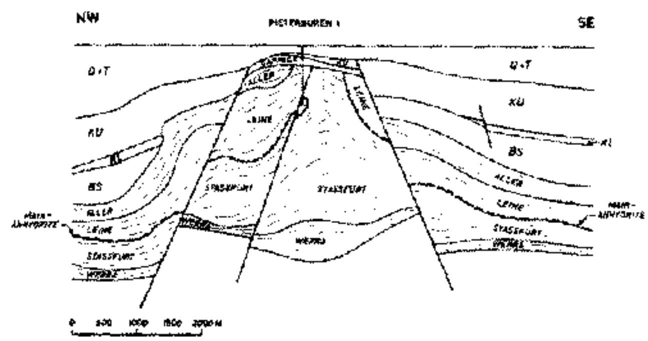

Figure 26. Geological interpretation of seismic reflection profile.

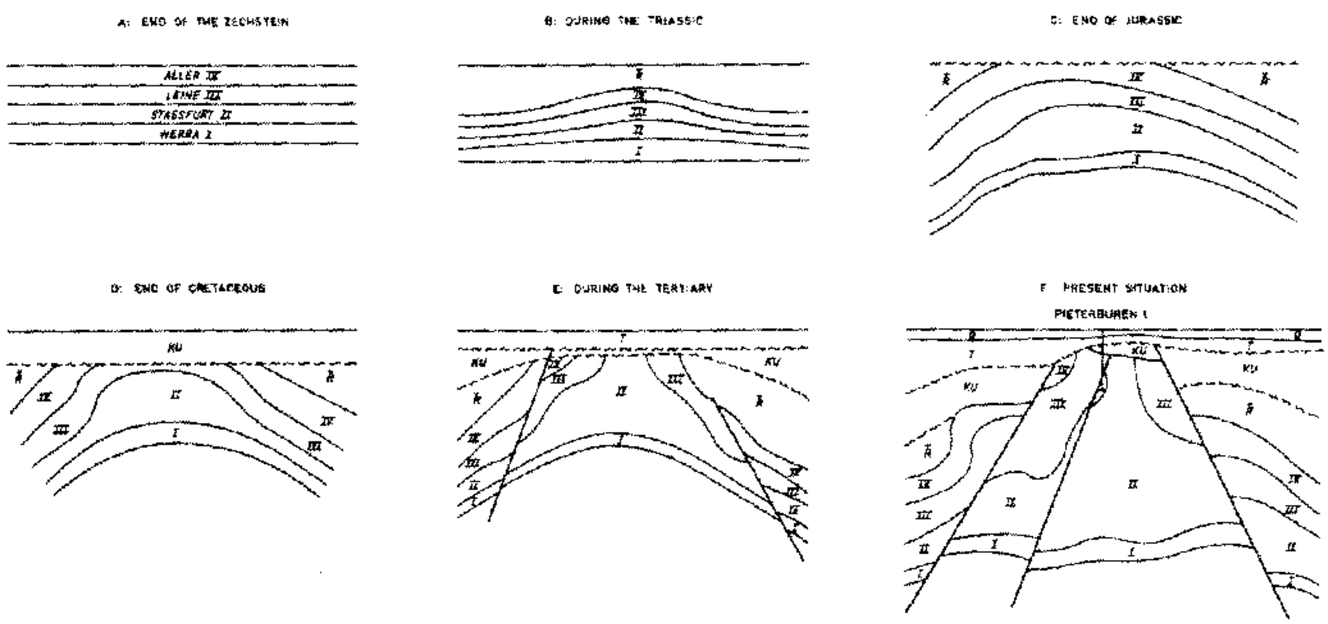

Figure 27. Sketch of possible progressive development of Pieterburen salt diapir.

Upper Cretaceous (Fig. 27F). The minor thickness of the Tertiary and Quaternary sediments above the salt diapir indicates that the salt movements have continued up to the Quaternary.

This means that the salt diapir of Pieterburen should be classified as a young salt dome. Influenced by the latest movements a slight overhang to the NW was formed. The presence of an overhang may also be concluded from comparing the gravimetrical map with the top of rock salt contour map. The gravimetrical map shows a mass deficiency about 4 km south of the village of Pieterburen, indicating the largest rock salt volume to be south of the village. According to the top rock salt contour map, the highest point of the Pieterburen diapir is just below the village. It is apparent that the movement to the NW initiated under influence of tectonics and halokinese resulted in an NW overhang of the salt body.

DISCUSSION

D.H. Kupfer:

Question. You show the Pieterburen fault as reverse or thrust, implying compression. Is reverse (compressive) faulting commonplace in Northern Netherlands or unusual?

Answer. There are many normal faults in the Northern Netherlands area above and below the salt. Within the salt the effects of faulting are less easy discernable however in the case of Pieterburen the evidence for compression and contortion is clear seen the reversed succession of the separate salt layers. The phenomenon thrustfaulting is not commonplace in the Northern Netherlands.

G. Richter-Bernburg

Question. Did you have enough cores from the bore holes for identifying the stratigraphic position of the perforated salts?

Answer. Yes, the full salt section was cored. The recovery amounted to 97%, which made identification possible.

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The petroleum companies supplying data were the Superior Oil (U.K.) Limited, Continental Netherlands Oil Company, Chevron Oil Company of the Netherlands, Placid International Oil Ltd., Mobil Producing Netherlands Inc., Philips Petroleum Company Netherlands, Amoco Netherlands Petroleum Company, Petroland b.v., Nederlandse Aardolie Maatschappij b.v.

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