Nøvling: An unusual salt structure on the southern margin of the Danish Zechstein Basin

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The Nøvling salt structure is located on the southern margin of the Danish Zechstein Basin. The present study of this structure is based on a detailed gravity survey, reflection and refraction seismic data, and well information. Apart from the exploratory well Nøvling-1, and a shallower well Herning-1, a number of wells, mainly 20–30 m deep, were drilled in this general area (by the Geological Survey of Denmark). Through this combined study using geological and geophysical methods it is possible to distinguish several stages in the development of the Nøvling structure. It is shown that these stages are closely related to fault-ing at the base Zechstein level. The faulting, which apparently started as normal faulting in the Triassic, triggered the first salt movements from the deeper parts of the basin to this peripheral area. The faulting was reactivated during the late Jurassic, resulting in the formation of a salt pillow. The tectonic regime changed in the post-Paleocene tertiary when transpressional movements along a promi-nent basement wrench fault became dominant. This ultimately resulted in the formation of a positive flower structure and the uplifting of the Saale Quaternary surface. At shallow depths the salt became dissolved creating a topographic de-pression above the flower structure. The present depression was formed at the beginning of the last late glacial time. Quaternary landforms in the Nøvling area are therefore greatly influenced by recent tectonic events.

Key words: Nøvling, Zechstein salt, Danish Basin, transpression, geophysics, neotectonics.

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The Nøvling salt structure is located in west central Jutland within a NW-SE trending zone of intense basement faulting. This zone, which separates the Ringkøbing-Fyn High from the Danish Basin to the north, corresponds to a regional negative aeromagnetic lineament named the Vinding Line by Dikkers (1977) and the Vinding Fracture Zone by Cartwright (1990). The present study area within this fracture zone is shown in Figure 1.

Earlier studies of the Nøvling salt structure were based on a detailed gravity survey of the area, log information from the wells Nøvling-1 and Herning-1, and surface mapping of the Quaternary deposits and landforms (Madirazza 1977). It was stressed that this structure, in contrast to all the other known salt structures in the Danish Basin, is characterized by a distinct Bouguer gravity high, the residual gravity anomaly amounting to about +3.0 mgal (Fig. 2). No seismic sections from the central parts of this gravity anomaly were available at that time. However, on the basis of the collected data it was concluded that the Nøvling structure was a very shallow salt diapir with a thick residual caprock which, in part, intruded the Quaternary deposits. Subsequently several reflection seismic sections from this marginal part of the basin became available. The sections DNJ-15 (and the partly overlapping DNJ-100) and ADK-85-143 cross the gravity anomaly in a SW-NE direction, i.e. perpendicularly to the regional structural trend. Another seismic section, ADK-85-145, subparallel to these, crosses the study area some 4–5 km SE of the Nøvling structure (for location of these seismic lines see Fig. 2). Britze & Japsen (1991) inferred that Nøvling is a deep-seated salt pillow with the Zechstein in contact with the base Triassic at a depth of about 2000 m. However, Jacobsen & Munkholm (1993) concluded, on the

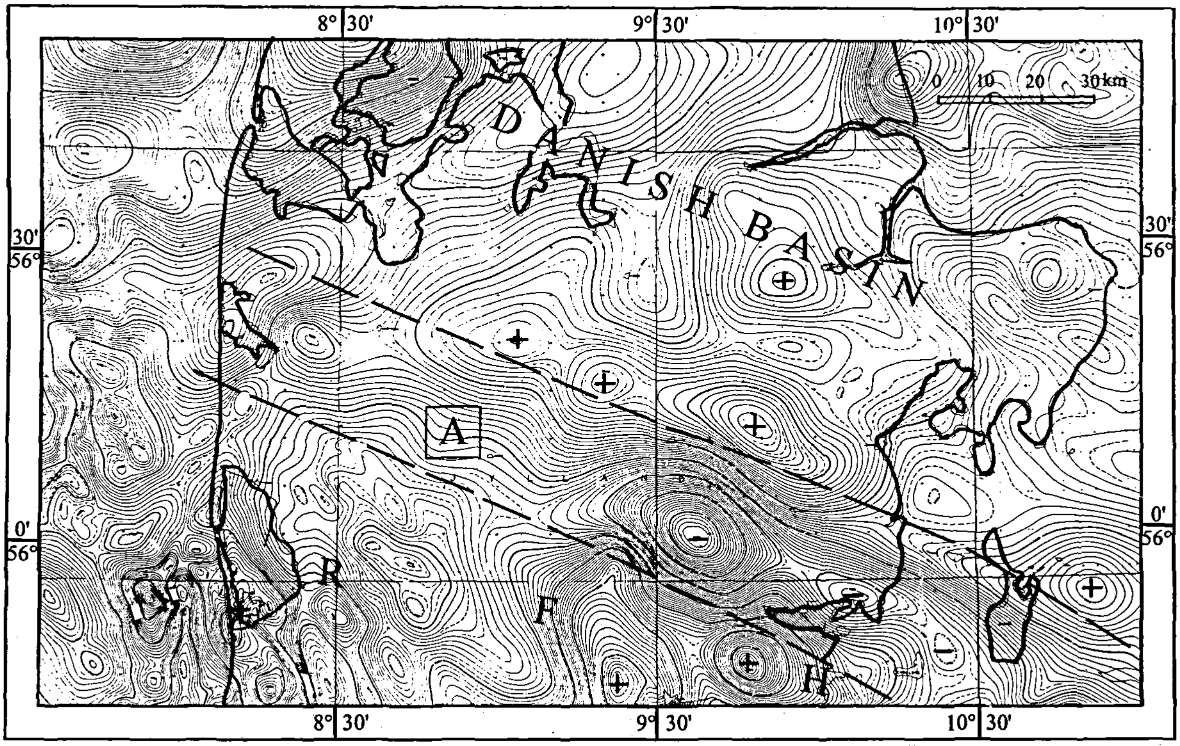


Fig. 1. Aeromagnetic total field anomaly in central Jutland (flight height 800 m). The study area (rectangle marked A) is located within the negative magnetic anomaly (limited by dashed lines). This regional magnetic lineament, named Vinding Line by Dikkers (1977), separates the Ringkøbing-Fyn High (RFH) from the Danish Basin.

basis of an integrated gravimetric and refraction seismic study, that Nøvling is a shallow salt diapir in accordance with the interpretation of Madirazza (1977). A study of a larger area SE of the Nøvling structure, and bordering onto it, was published recently by Lykke-Andersen, Madirazza & Sandersen (1996). In that work it was shown that particularly wrench faulting, often with a lateral convergent slip (transpression), was an important factor in the formation, and the deformation, of the Quaternary deposits and landforms.

Development of the Nøvling salt diapir

Pre-tertiary history

Figure 3a shows the interpreted seismic section DNJ-15. In Figure 3b this section and the relevant part of the section DNJ-100 are depth-converted. The depth conversion is based on information from the exploratory well Nøvling-1, shown in Figure 4 (Rasmussen 1973). In this well (TD 3762 m) the base Zechstein was encountered at a depth of 3535 m. The Zechstein sequence was 111 m thick, of which only the upper 62 m consisted of salt, the lower part being anhydrites and dolomites (Jacobsen 1973). The seismic velocity recorded for the salt interval was about 4350 m/s and for the anhydrite/dolomite interval about 5860 m/s. For the part of this section on the NE side of the salt structure, where the salt is very thick, we have used a seismic velocity of 4600 m/s.

In the section SW of the Nøvling structure the base Zechstein is dissected by several very steep faults which show only minor or no vertical displacement, and where the entire post-Zechstein sequence is essentially horizontal. Some faults appear to extend to the surface. These characteristics suggest wrench faults trending parallel to the edge of the basin. In this part of the section the Zechstein is either absent or very thin. Between about SP 40 and SP 70 (a distance of some 3 km) the seismic response is poor and the reflections are hardly recognizable. In section ADK-85-143, however, the seismic picture within this corresponding area is relatively clear, especially at shallow levels (Fig. 5a). This depth-converted section is shown in Figure 5b. We see a complexly faulted area consisting of two to three upwards diverging faults which appear to merge downwards into one subvertical Zechstein basement fault, thereby forming a positive flower structure (Harland 1971, Harding 1985, Jenyon 1986). Apart from this structure a number of very steep or vertical faults at shallow levels (from about SP 1200

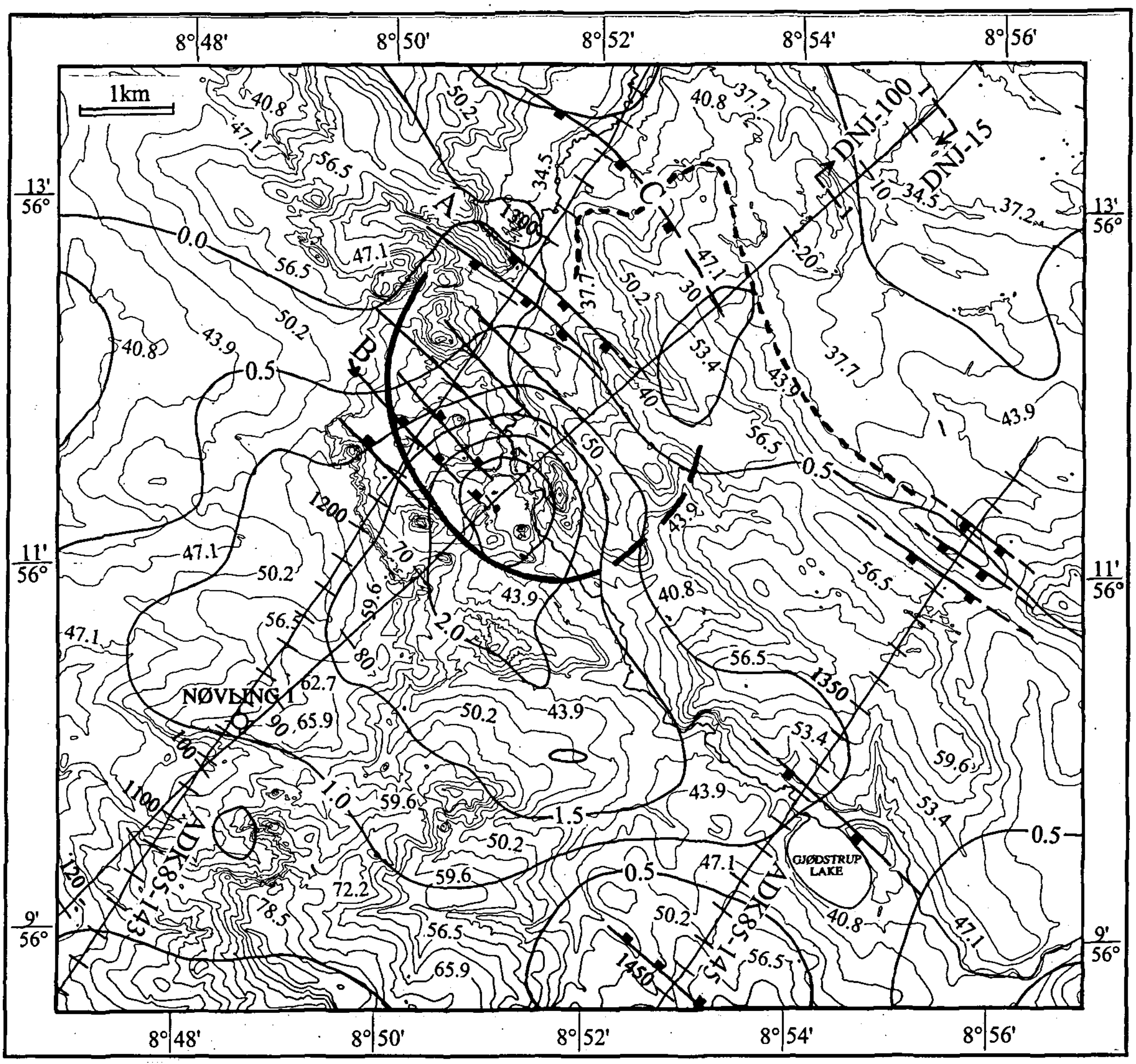


Fig. 2. Topographic map of the study area with the residual Bouguer gravity anomaly (mgal), the location of the reflection seismic sections DNJ-15 (with the partly overlapping DNJ-100), ADK-85-143, ADK-85-145, the well Nøvling-1, the main basement fault A, and the faults B and C. The approximate limit of the flower structure (heavy oval line) with several parallel faults in front of the fault A are also shown. Dashed line in the NE part of the map marks the border between the hill island and the glacial outwash plain. The original topography is on the scale 1:20,000 with a contour interval of 5 feet. The shown contours are in metres, equidistance 3.1 m or 3.2 m. For location of the well Herning-1 see Fig. 6.

to SP 1290) are present in front of the basement fault. We shall return to this faulted area in the discussion on the Tertiary and the Quaternary history.

As both these reflection seismic sections show, the structural picture on the NE side of this area is quite different. On that side there is no faulting of the base Zechstein horizon which is inclined appreciably bas-inwards. And, in a marked contrast to the SW side, the Zechstein attains great thicknesses (reaching 1300 m in the vicinity of the structure). On both sides of the faulted area there is a primary peripheral sink of a salt pillow formed during the Jurassic. An unconformity between the Jurassic and the Lower Cretaceous is present on both sides of this area. On the NE side of the structure this unconformity is very prominent, and a large part of the Jurassic (and even a part of the Triassic) was eroded prior to deposition of the Lower Cretaceous. This implies that the salt pillow was somewhat asymmetric towards the close of the Jurassic, its northern limb having been supported by thicker salt

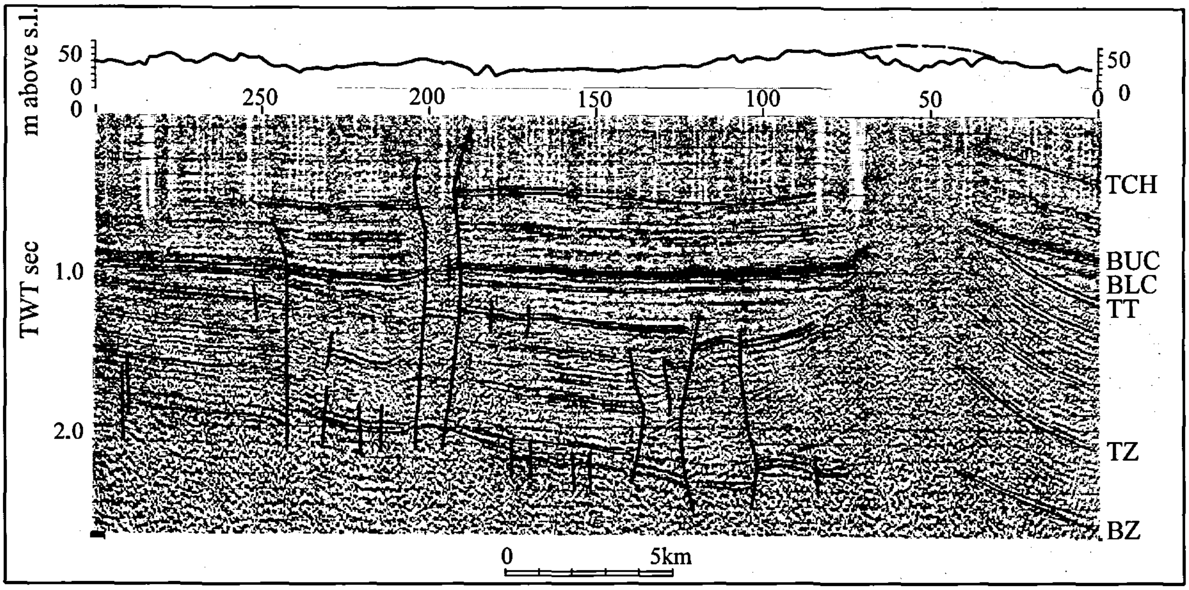


Fig. 3a. Interpreted reflection seismic section DNJ-15. BZ = Base Zechstein, TZ = Top Zechstein, TT = Top Triassic, BLC = Base Lower Cretaceous, BUC = Base Upper Cretaceous (Base "chalk sequence"), TCH = Top Danian (Top "chalk sequence"). Topographic profile above this section is also shown. The estimated pre-collapse surface is dashed.

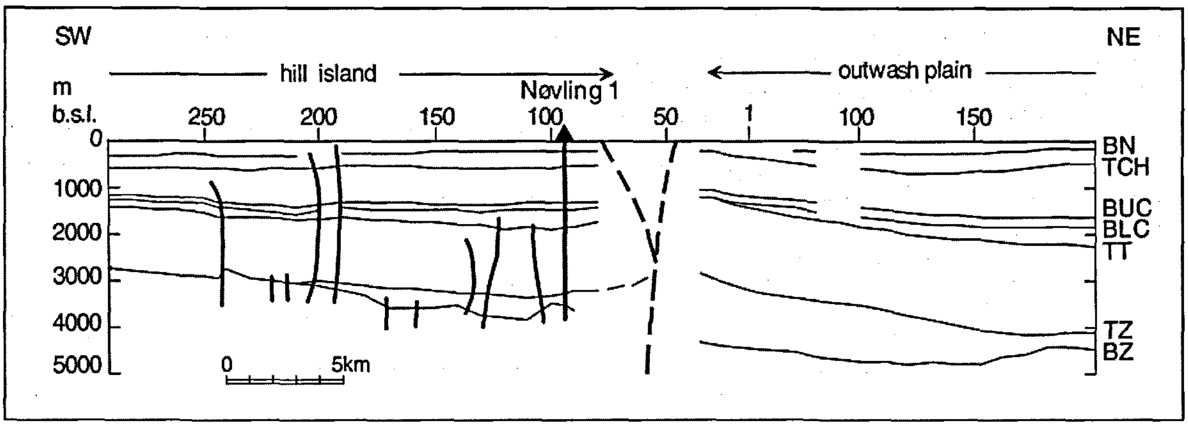


Fig. 3b. Depth conversion of the interpreted reflectors from seismic section DNJ-15 and part of DNJ-100. Legend as in Fig. 3a. BN = Base Neogene (Base Miocene).

than the southern limb. We assume that below the pillow an older Triassic basement fault, downthrown to the north, i.e. towards the deeper parts of the basin, was reactivated during the Late Jurassic, or at the Jurassic-Lower Cretaceous boundary (Late Cimmerian time), and that additional salt from the basin therefore flowed into the pillow. This elevated its northern limb somewhat so that it became more exposed to erosion (and possibly also non-deposition) of the Jurassic sediments than the southern limb. It is relevant to mention here that according to e.g. Geil (1991), as well as the experimental studies by Koyi & Petersen (1993), the formation of most of the salt structures in the shallower southern part of the Danish Basin is probably due to flow of salt from the deeper northern part of the basin. Jenyon (1985) describes also some salt movements from the deeper parts of the southern Zechstein basin towards the shallow upthrown "platform" which seem to be comparable to the structural configuration in this southern part of the Danish Basin.

It seems that the Nøvling pillow remained stationary during the Early Cretaceous, but that renewed flow of salt took place during a part of the Late Cretaceous and the Early Paleocene (Danian), since the entire "chalk sequence" (Upper Cretaceous and Danian) thins considerably over the salt structure (from about 750 m to 400 m); this could, in part, be due to compaction (Petersen 1983, Sørensen 1986). As inferred from the two sections ADK-85-143 and DNJ-15 (Figs 3a, 3b, 5a, 5b), at the close of the Late Paleocene the entire post-Jurassic sedimentary column, on both sides of the salt structure, was still lying horizontally, and at the same depth, as there are no appreciable differences in thicknesses of the individual sedimentary units on either side of the faulted area, nor are there any intra-Cretaceous unconformities visible (except close to the salt structure itself). And the Upper Paleocene, although somewhat deformed due to later faulting, retains the same thickness over the structure as away from it, showing that the salt pillow was inactive during that time.

Tertiary history

The entire post-Zechstein sedimentary column now lies considerably higher on the NE than on the SW side of the basement fault (Figs 3b, 5b). Furthermore, the post-Zechstein strata, including the Upper Paleocene, dip appreciably towards the NE. The Eocene and the remaining Tertiary onlap the Upper Paleocene north of the structure, whereas on the SW side the Tertiary units retain their conformable relationship. After deposition of the Upper Paleocene, the basement fault (the old Triassic fault?) was rejuvenated, which resulted in further downfaulting and possibly also a certain steepening of the basin floor on the NE side. Thus the increased differential loading triggered new salt movements from the basin, considerably increasing the salt thickness on that side. In this way the entire post-Zechstein sedimentary column on the NE side was uplifted along the nearly vertical basement fault extending to the surface. The uplift across the fault is now on the order of 250 m at the top Danian level (Fig. 5b). This event is marked by the Paleocene/Eocene unconformity which, we consider, also dates the beginning of the Tertiary transpressional regime and the development of the present flower structure. Clausen, Korstgård & Egebjerg (1996) described some, apparently comparable, transpressional structures from the Danish Central Graben where, during the Late Cretaceous and the Paleogene, the Zechstein salt intruded along the fault planes formed during an earlier extensional faulting phase.

As seen in Figures 5a & 5b, there are three major faults, marked A, B, C, which converge at depth to form what we refer to as the main Zechstein basement fault A. Fault B marks the boundary of the flower structure on the SW side, whereas the fault C is a subsidiary to the main basement fault A. In the section shown in Figure 5b the "chalk sequence" has collapsed over the highest part of the salt body and the base Upper Cretaceous is encountered at a (maximum) depth of about 800 m. We do not think that dissolution of salt at such

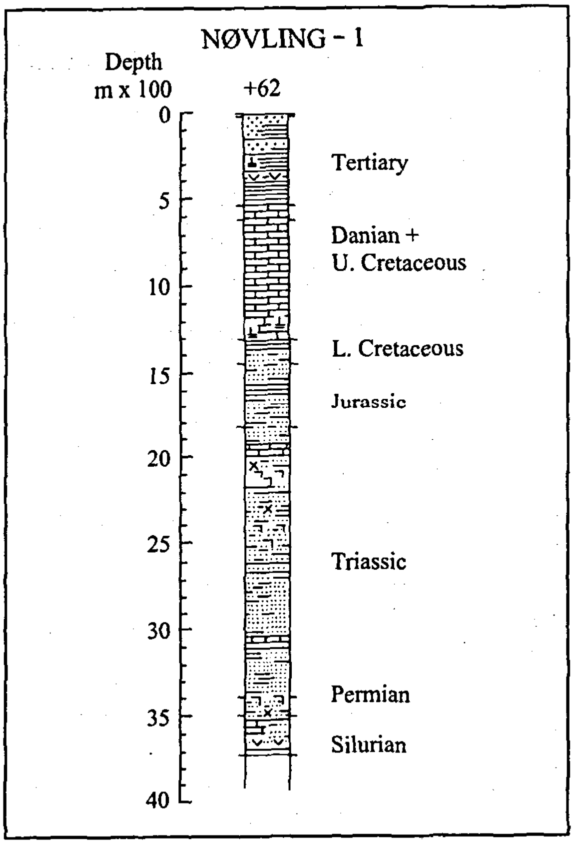


Fig. 4. Nøvling-1 well (from Rasmussen 1973). For location see Figs 2, 7.

great depths can satisfactorily explain this collapse. However, there is a clear relationship between the collapsed base and top of the "chalk sequence", and also of the Quaternary depression (compare with Figs 3a, 5a). It is also certain that the collapse took place after deposition of the Upper Paleocene which retains its thickness over this area and is conformable with the Top Danian.

On the other hand, the salt pillow and the overlying rocks in front of the main basement fault probably became exposed to a great lateral stress component which resulted in the uplift of, primarily, the shallower and loosely consolidated Tertiary sediments. In this way an ellipsoidal anticlinal structure supported by diapiric salt developed. The axial plane of this structure was essentially parallel to the NW-SE strike of the main basement fault. However, at shallower depths, where the compressional load was gradually released, conjugate tensional joints/faults above the diapir formed parallel to the axial plane of the compressional fold (compare Figs 2 and 5b). We expect that these joints, or minor faults, served as "feeders" for the salt as it was squeezed from the salt diapir to the surface due to the lateral stress component at deeper levels.

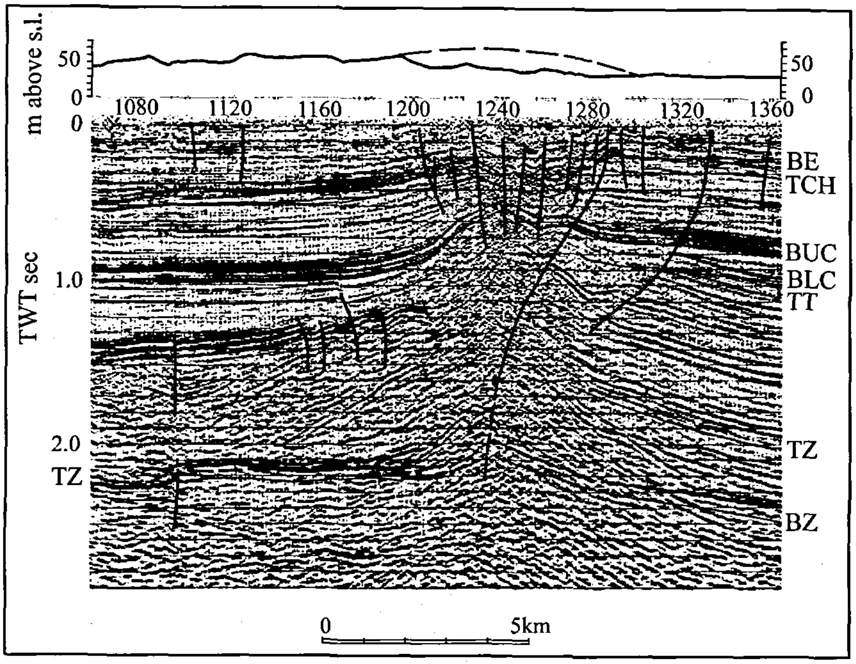


Fig. 5a. Interpreted reflection seismic section ADK-85-143. BZ = Base Zechstein, TZ = Top Zechstein, TT = Top Triassic, BLC = Base Lower Cretaceous, BUC = Base Upper Cretaceous (Base "chalk sequence"), TCH = Top Danian (Top "chalk sequence"), BE = Base Eocene. Topographic profile above this section is also shown. The estimated pre-collapse surface is dashed.

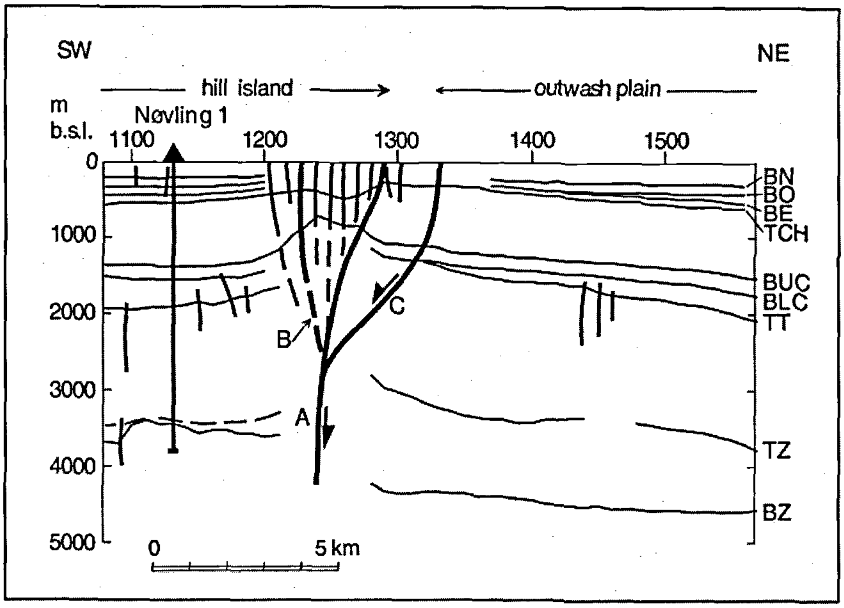


Fig. 5b. Depth conversion of the interpreted reflectors from seismic section ADK-85-143. Legend as in Fig. 5a. BO = Base Oligocene, BN = Base Neogene (Base Miocene).

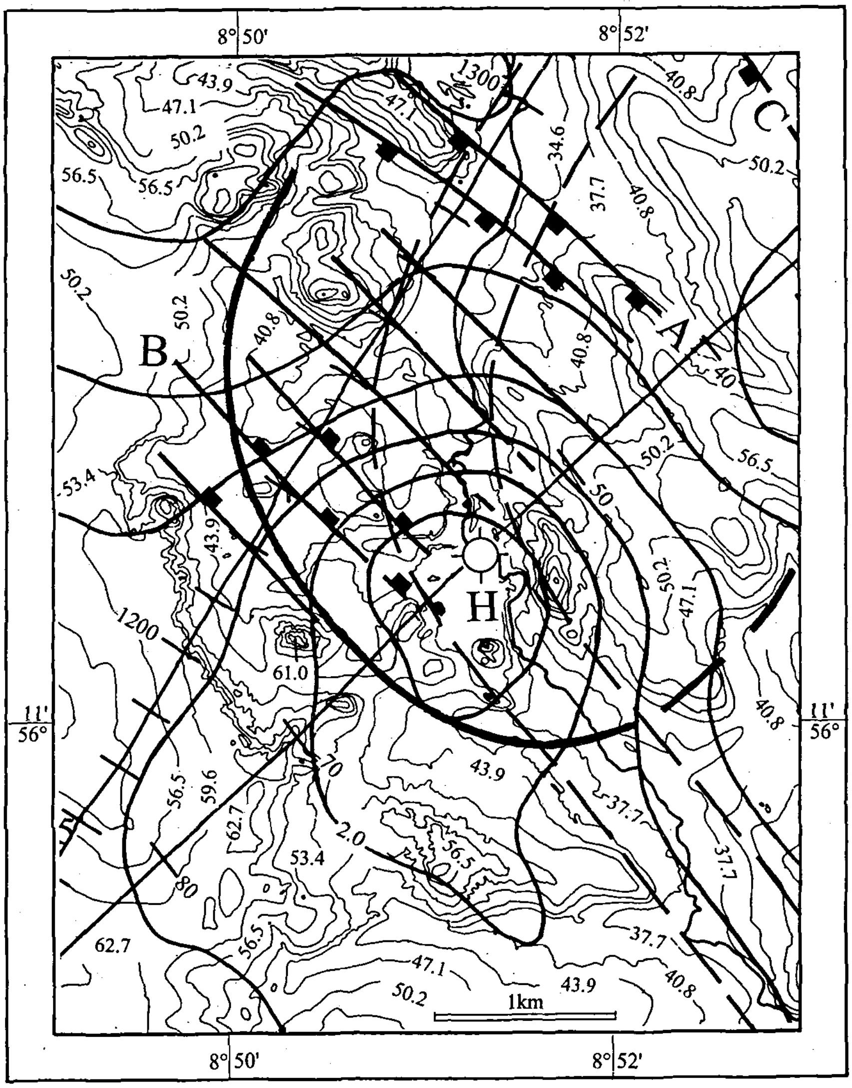
This model appears to afford the most plausible explanation for the apparent absence of salt above the Upper Cretaceous along this section, as well as for the formation of the tensional joints/faults which reach the surface.

Korstgård, Lerche, Mogensen & Thomsen (1993) discuss some structural settings in the Danish Central Graben which resemble the development of the Nøvling structure, especially during the transpressional phase. These authors emphasize the influence of the Zechstein salt on the overburden, its relationship to faulting and the halokinesis which there continued into the Late Miocene.

Quaternary development

The salt that intruded the shallow post-Danian sediments (and possibly also extruded at the surface) was necessarily flowing southwest and south in the direc-

Fig. 6. Enlarged part of Fig. 2. The two dashed parallel lines mark the limits of the oldest terrace of the present stream (compare with Fig. 2).



tion of "least resistance", i.e. away from the uplifting Tertiary sediments on the upthrown side of the main basement fault. As seen in Figures 2, 6 and 9b, the positive gravity effect falls sharply to about zero on the NE side of this fault which delimits the occurrence of the shallow vertical joints/faults, and also of the area where the "chalk sequence" has collapsed (Figs 5a, 5b). The salt intrusion first elevated the surface, but it was also relatively quickly dissolved under the humid, warm climatic conditions, leaving behind a topographic depression and caprock minerals.

This process of uplift and collapse of the surface could have taken place repeatedly during the post-Paleocene Tertiary and, especially, Pleistocene times, depending on the tectonic activity along the main basement fault and the prevailing climatic conditions. According to e.g. Gripp (1952) and Picard (1969), the surface uplift caused by the rising salt would preferably occur under cold Pleistocene climatic conditions when deep permafrost prevented the salt from being dissolved at shallow depths, whereas conditions for dissolution of salt and the consequent collapse of the surface would be most favourable during a warmer climate. However, at Nøvling the amount of salt rising towards the surface was probably never very large at any one time. To judge from the topographic picture above the seismic sections (Figs 3a, 5a) during the last such episode, a minor hill, rising some 30 m above the surrounding area, existed before the collapse of the Quaternary surface. The estimated pre-collapse surface above the flower structure is dashed. The residual gravity along section ADK-85-143 (Fig. 2) attains the highest values of about +1.5 mgal which could indicate that the amount of salt dissolved in this northwestern part of the depression was relatively small.

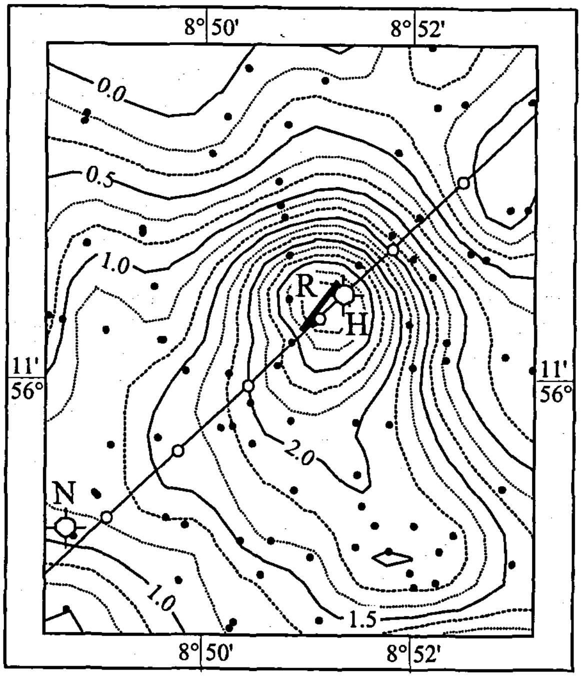


Fig. 7. The residual Bouguer gravity anomaly, contoured with interval 1/6 mgal, in the central part of the salt diapir area (compare with Fig. 2). The dots mark the gravity stations. Open circles indicate the line of the gravity profiles (Figs 9a, 9b) along the reflection seismic line DNJ-15. R = line of the refraction seismic profile shown in Fig. 8. N = Nøvling-1 well, H = Herning-1 well.

The situation along section DNJ-15 is different. This section crosses the central part of the residual gravity anomaly having values as high as +3.0 mgal (Figs 2, 6, 9b). As mentioned earlier, between about SP 40 and SP 70 (Fig. 3a) the seismic response is poor and no correlation with, particularly, the structural features at shallower levels identified in section ADK-85-143, can be established. However, the topographic profile of the Quaternary surface above this DNJ-15 section also shows a depression above the corresponding faulted area.

A wide stream valley crosses the area of the depression above the flower structure. The valley of the present stream (Herningsholm Å, Å=stream in Danish) closely follows the NW-SE trending Quaternary landforms in this general area until it reaches the depression, where it turns sharply northeast (Fig. 6). As reported earlier (Madirazza 1977), within this southeastern part of the depression, where the highest positive gravity values were recorded, the older stream terraces are strongly upward bent and the present undersized stream has cut a very narrow trench (a "canyon") through the older uplifted terrace, where additional terraces also appear. The well Herning-1 was drilled (in 1947) on the lowest terrace of the present stream (at about SP 57) to a depth of 126 m (for location see Figs 6, 7). In that well gypsum crystals began to appear at very shallow depths within the Quaternary deposits and the limit between the Quaternary and the caprock was arbitrarily placed at a depth of 58 m (by Aksel Nørvang, Danmarks Geologiske Undersøgelse, archive No. 84778).

A refraction seismic profile was recently acquired near the Herning-1 well and along the reflection seismic line DNJ-15 (Fig. 7). These data (Fig. 8) showed a change of seismic velocity from 1.600 m/s near the surface to about 5.000 m/s at a depth of 100 m (Jacobsen & Munkholm 1993). It is difficult to explain these data without the presence of a considerable amount of compact caprock minerals at very shallow depth. This conforms with the above description of the Herning-1 well. A caprock material consisting of gypsum, admixed with anhydrite, and possibly also carbonates (the Nøvling area is at the margin of the Zechstein basin), could have such a high seismic velocity.

Ødum (1926, p. 140) described some samples of Danian limestone from a minor near-surface pit (now covered and inaccessible) located a few hundred metres south of the well Herning-1. According to that author, the limestone and the flint concretions were strongly brecciated and marked by slickensides. The fracturing of the breccia showed subsequent healing. The limestone was (at least) 6 m thick. Ødum did not exclude the possibility that the limestone was "in situ", although it was known that, in this part of Jutland, the post-Danian tertiary cover had a considerable thickness. The presence of salt structures in the Danish Basin was still unknown at that time.

The Bouguer gravity along the seismic section DNJ-15 is shown in Figure 9a and the corresponding residual gravity profile in Figure 9b (for location see Fig. 7). The residual maximum is separated into a

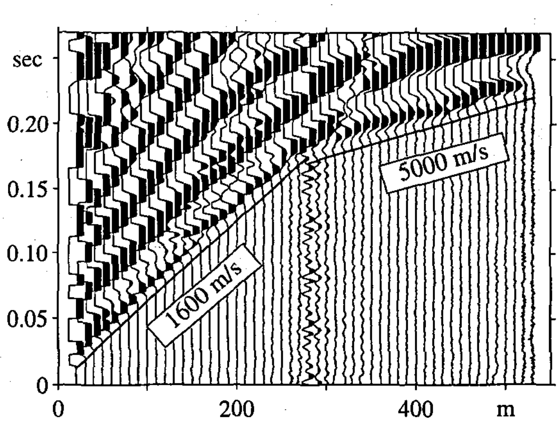


Fig. 8. Refraction seismic profile (marked R in Fig. 7) acquired in the area of the Bouguer gravity maximum. The very high velocity, which occurs at a depth of about 100 m, indicates very shallow caprock (see text). A reverse shot (not shown) confirms these data.

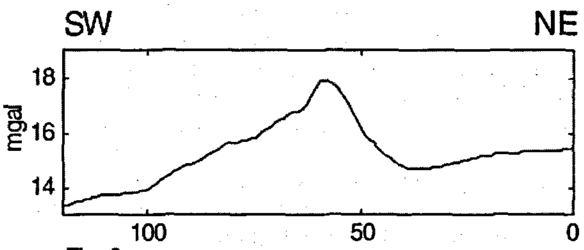


Fig. 9a

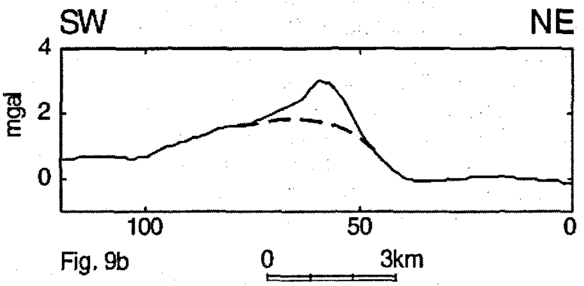


Fig. 9b

Fig. 9a. Bouguer gravity profile along seismic line DNJ-15 (SP indicated). The regional increase towards NE is due to the influence of the Silkeborg gravity maximum anomaly (e.g. Abrahamsen & Madirazza 1986).

Fig. 9b. Residual gravity, reflecting the shallow structure along the seismic line DNJ-15, computed as the difference between upward continuations to heights of 0.2 km and 3 km (see Jacobsen 1987). The residual maximum is separated into a broader maximum (dashed) and a narrow higher maximum interpreted as caused by very shallow caprock (see text).

broader maximum (dashed), which reaches + 2.0 mgal, and a very steep and narrow minor part above it with a peak reaching +3.0 mgal. A caprock, in combination with a positive gravity effect from a shallow salt intrusion within the post-Danian tertiary sediments, could account for the broad and less positive part of the gravity anomaly. The minor part above it covers a much smaller area and coincides with the section of the stream valley where above discussed deformation of the terraces, and the surrounding ground, has taken place.

The fact that here the caprock is encountered at very shallow depths does not necessarily mean that in this area new caprock was added from below, thus increasing the volume of a pre-existing caprock. We believe that a more likely explanation is that older caprock was being forced upwards by the salt due to the latest transpressional episode along the main basement fault. This would also favour the transformation of anhydrite into gypsum within a zone of the circulating ground water, which, in turn, would greatly increase the volume of the caprock (in the case of anhydrite by about 60%).

Thus in this southern part of the depression, crossed by the seismic section DNJ-15, the collapse was followed by a partial uplift. It is possible that the conjugate joints/faults which cross section ADK-85-143 also extended into this area, but that they were obliterated in the course of this last deformational episode.

The Nøvling diapir is located in the northeastern part of the large Skovbjerg hill island (in Danish: bakkeø) considered to be of a Saale age (e.g. Madsen 1921, Hansen 1965) and on the border between these older Pleistocene deposits and the last late glacial outwash sediments originating from the melting of the Weichsel ice sheet in Jutland (Figs 3b, 5b). These late glacial sediments onlap the older glacial terrain of the hill island along its northeast side where the Nøvling structure is located (see Fig. 2). We therefore suggest that along this side, which parallels the regional NW-SE trend, the border between the older glacial terrain of the hill island and the late glacial outwash plain is conditioned by the same type of tectonic activity that was taking place during the post-Paleocene tertiary. Generally, deeper structural features, especially those within the tertiary and the Upper Cretaceous, are often "reflected" in the Quaternary topography (see Figs 3a, 5a). Gjødstrup Lake, SE of the Nøvling structure, occupies a depression in the Quaternary surface which occurs above a low in the base tertiary.

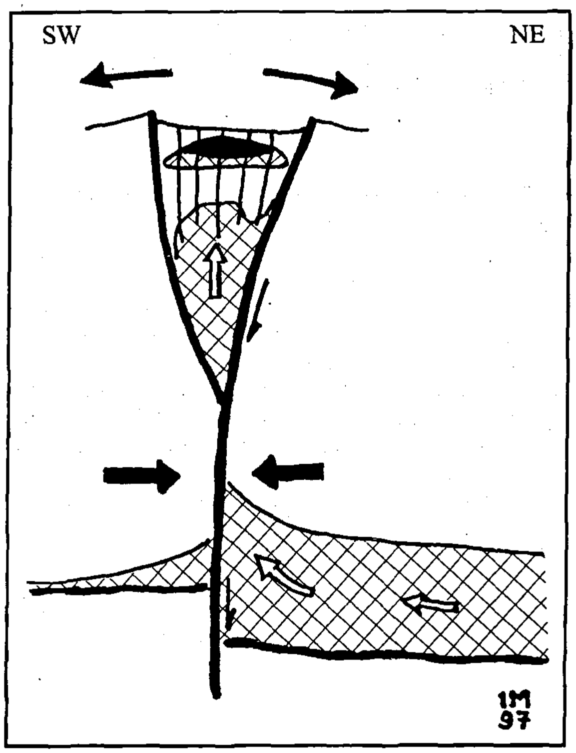


Fig. 10 Schematic illustration of the Nøvling salt diapir in front (SW) of the main Zechstein basement fault (see also Fig. 2). Squares = salt, black = caprock. Not to scale (see text).

In the Nøvling area the surface tertiary sediments consist of Middle Miocene quartz sand and gravel, interbedded with micaceous clay and fine sand. Within the depression these sediments are covered by several metres of poorly sorted water-laid sand and gravel which probably consist mainly of redeposited Tertiary sediments which became exposed after the formation of the depression, especially in its steep western wall. Their thickness would depend on the relief of the pre-collapse Quaternary surface. Several minor isolated hills, lower lying than the surrounding ground, but topped by the same type of morainal material that forms the highest surface Pleistocene deposits in this general area, can be seen within the northern and western parts of the depression where they are partly buried by the redeposited sediments.

We assume that the uplift of the old glacial terrain above the Nøvling salt structure took place under cold climatic conditions, probably towards the close of the Weichsel glaciation. The dissolution of the salt, and the following collapse of the ground above the structure, indicates a warmer climate and disappearance of the permafrost at the beginning of late glacial time. As reported earlier (Madirazza 1977), a layer of peat, at a maximum depth of two metres, is encountered in the western and northern parts of the depression. This peat has a C^{14} age of 11.690 ± 160 years (before 1950), i.e. it dates from the early Allerød, a warm late glacial time. The peat is covered by beds of fine grained sand which, according to the pollen studies by Kolstrup (see Madirazza 1977), also are of Allerød age. This means that lacustrine conditions prevailed within the depression during the post-peat Allerød time.

Draining of the lake in a northerly direction was most likely related to movement along an underlying NW-SE trending fault. Subsequently, the wide Herningsholm stream valley was formed (Fig. 6). This was followed by renewed tectonic activity in the southern part of the depression. As suggested above, part of the caprock was probably pressed up to higher levels, elevating the older stream terraces and the surrounding ground. The present stream bed in the area of the highest positive gravity anomaly, where the greatest upward bending of the stream terraces also occurs, lies 6–7 m below the Allerød peat layer. This strong erosion to the present stream level was probably initiated towards the close of late glacial time (Yngre Dryas), but it continued throughout the Holocene.

Conclusions

It is demonstrated that Nøvling is a very shallow salt diapir which developed from a Jurassic salt pillow on the southern margin of the Danish Zechstein Basin. Due to extensional faulting in the Triassic and the Jurassic, large amounts of salt moved from the deeper parts of the basin to this peripheral part. At the close of the Late Paleocene, increased differential loading on the NE side of the salt structure triggered additional salt movements which elevated the entire post-Zechstein sedimentary column on that side along a nearly vertical basement fault extending to the surface. This event is marked by the Paleocene/Eocene unconformity NE of the salt structure. Thus the Eocene and remaining tertiary units (as well as the late glacial outwash plain) onlap the Paleocene beds. After the Paleocene the style of faulting has changed to, dominantly, transpressional wrench faulting, as evidenced by the positive flower structure recognized on the reflection seismic sections. From then on the basement fault plane became the main route by which the salt rose to the surface, depending on the pressure exerted by the lateral convergent component (transpression) along this fault. At shallower tertiary levels, however, tensional stresses prevailed, which resulted in the formation of a series of parallel conjugate tensional faults/joints which served (and, we presume, still serve) as the transport routes for the salt being supplied by the transpressional stresses from below. At times, however, the shallow salt body could possibly have become completely detached, or nearly so, from the deeply buried Zechstein salt layer. This situation is schematically illustrated in Figure 10.

At shallow levels, within the zone of circulating ground water, salt was dissolved creating a topographic depression above the flower structure. We consider that the present depression in the Saale glacial terrain formed at the beginning of the Weichsel late glacial time. The terraces of the stream valley which crosses this depression were deformed by the caprock being pressed up to, practically, the ground surface. The transformation of anhydrite into gypsum at shallow depth has most likely also played an important part in the increase of the caprock volume and thus the surface deformation in this area.

Dansk sammendrag

På baggrund af kombinerede geologiske og geofysiske data kan man inddele Nøvling saltdiapirens udvikling i flere faser. I Trias- og Juratiden dominerede ekstensions-forkastninger, og saltet fra Zechsteinbassinet blev tilført dette periferområde. Ved slutningen af Jura dannedes en saltpude, antageligt over en normalforkastning i bassinets bund. Før aflejring af Nedre Kridt blev pudens randsænke udsat for en erosion, som især var kraftig på NØ-siden (Jura/Nedre Kridt diskordans). Puden voksede i Øvre Kridt og Danien. Efter aflejring af Øvre Paleocæn hæves hele post-Zechstein sedimentsøjlen på NØ-siden af puden på grund af salttilførsel fra bassinet (Paleocæn/Eocæn "onlap" diskordans på denne side). Dermed dannedes en forkastning op til den eksisterende overflade. På den tid begyndte også udviklingen af en positiv "flower"-struktur, og det tertiære transpressionsregime indledtes. Saltet fra bunden af bassinet presses op til overfladen langs forkastningsplanet. En topografisk hævning dannedes over "flower"-strukturen, og salt opløses nær overfladen. Denne proces gentog sig sandsynligvis flere gange i løbet af tertiær- og kvartærtid. Den sidste sådanne deformation (den nuværende depression i Saaleoverfladen) skete i præ-Allerød senglacial tid. Herningsholm Å dal, som krydser saltdiapirens område, bliver hævet på grund af tilførsel/vækst af caprock'en i sen- til postglacial tid i den syd-østlige del af "flower"-strukturen. De laveste nuværende terrasser befinder sig 6–7 meter under Allerød tørv. I Nøvling området "afspejles" dybere geologiske strukturer, især inden for tertiæret og Øvre Kridt, ofte i den kvartære topografi. Således er f.eks. Gjødstrup Sø opstået i en lavning i den kvartære overflade. Denne lavning modsvares af en depression ved basis tertiær.

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