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Discussion

Comment on: "Cenozoic evolution of the eastern Danish North Sea" by M. Huuse, H. Lykke-Andersen and O. Michelsen, [Marine Geology 177, 243–269]

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Neogene uplift and erosion of the southern part of the Scandinavian Shield and adjoining areas have been revealed by several studies during the last 10 yr. The amount of late Cenozoic erosion induced by the Neogene uplift and subsequent glacial processes that has been estimated in some of these studies has, however, been questioned in a recent paper by Huuse et al. (2001). Huuse et al. (2001) estimated late Cenozoic erosion from stratal geometries along a N–S oriented seismic section west of Jylland, Denmark (Figs. 1 and 2). These authors found erosion to be several hundred metres less than estimated in studies of maximum burial based on vitrinite reflectance and sonic data (Jensen and Schmidt, 1993; Japsen, 1998). We find, however, that the preserved late Cenozoic record in the eastern North Sea is in good agreement with the section removed by the late erosional event as estimated by basin modelling and sonic data (Japsen and Bidstrup, 1999). According to our interpretation, a section of ca. 400 m westward dipping, upper Miocene sediments is erosionally truncated along an E–W oriented seismic dip-line that intersects the strike-line published by Huuse et al. (2001) (Fig. 3). Eastwards extrapolation of this upper Miocene unit fits with the estimates of the section removed by erosion based on data in wells where mid-Miocene sediments are preserved. Consequently, ca. 400 m of upper Miocene sediments appear to have been deposited in the easternmost North Sea Basin and then removed by erosion, e.g. during the Plio–Pleistocene. Closer to the Scandinavian Shield, where the base-Quaternary unconformity cuts into Paleogene and older strata, an earlier phase of Neogene uplift and erosion also appears to have taken place, e.g. during the mid-Miocene (Japsen et al., in press).

Japsen and Bidstrup (1999) studied maximum burial of the drilled section in 68 Danish wells in order to estimate the amount of section missing due to late Cenozoic erosion. This they found to be smaller than that estimated in previous studies. The study was based on basin modelling constrained by e.g. vitrinite reflectance data and by sonic data from different stratigraphic units. These authors found the thickness of the missing section to increase towards the coasts of Norway and Sweden from zero in the North Sea to ca. 500 m in most of the Danish Basin, but over a narrow zone it was found to reach ca. 1000 m on the Skagerrak–Kattegat Platform. The increasing amount of erosion matches the increase in the hiatus at the base of the Quaternary where Neogene and older strata are truncated, and the Mesozoic succession is thus found to have been more deeply buried by ca. 500 Paleocene–Miocene sediments in large parts of the area. On the basis of

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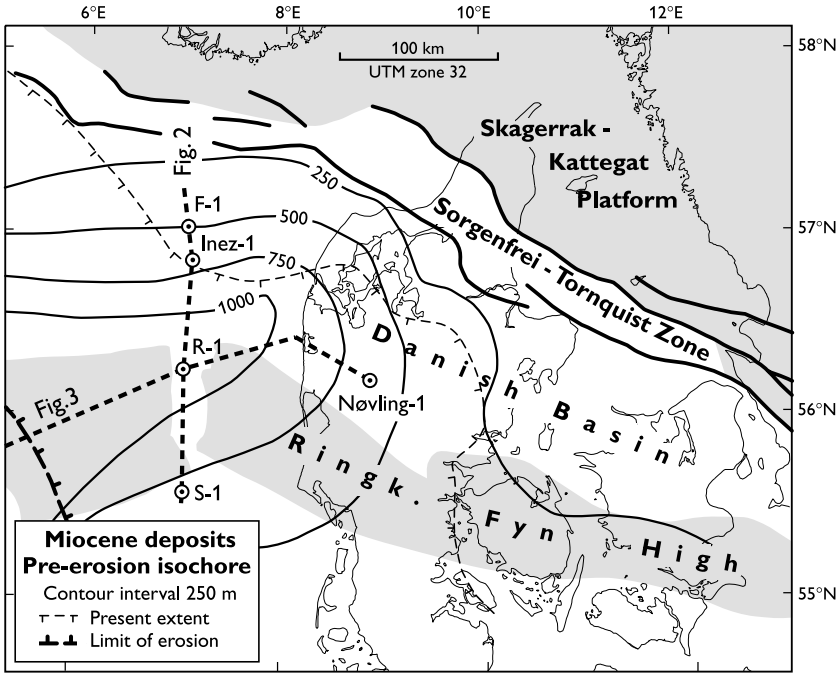

Fig. 1. Location map with indication of structural elements and the Miocene isochore prior to late Cenozoic erosion (compare Japsen et al., in press). The isochore is reconstructed from the known stratigraphy in the area and estimates of the total missing section in wells (Japsen and Bidstrup, 1999). It is assumed that the missing section of ca. 1000 m on and along the Skagerrak–Kattegat Platform was composed of 500–250 m Paleocene–Miocene sediments and 500–750 m Chalk, respectively thinning and thickening towards north-east. The present extent of the Miocene deposits is indicated as well as the limit of the area where the Miocene deposits have been eroded. Seismic sections along the indicated profiles are shown in Figs. 2 and 3 (bold, dashed lines). Major faults indicated by bold lines, shallow basement indicated by grey tone (< ca. 3 km).

these observations Japsen and Bidstrup (1999) suggested that the onset of erosion occurred during the Neogene, and that the Skagerrak–Kattegat Platform was affected by tectonic movements prior to glacial erosion.

The interpretation of Huuse et al. (2001) concerning the southern S-1 well on the profile shown in Fig. 2 is in agreement with the study of Japsen and Bidstrup (1999). According to the latter study, the drilled section in the S-1 well is at maximum burial today, an interpretation which is supported by vitrinite data and by Chalk sonic data relative to a revised normal velocity–depth trend for the North Sea Chalk (Japsen, 2000). However, a section ca. 200 m thick may nevertheless have been removed, as estimated from the erosional unconformity below the Quaternary deposits seen on seismic sections.

Note that post-exhumational burial will reduce the burial anomaly (or 'net uplift and erosion', Jensen and Schmidt, 1993) estimated from studies of maximum burial, e.g. a Quaternary reburial of 500 m will mask the effect of a pre-Quaternary erosion of 500 m. The total section removed by erosion is thus found by adding the magnitude of the burial anomaly to the amount of subsequent reburial. Consequently, in Fig. 2 we have indicated the estimated missing section for the S-1 well relative to the base-Quaternary unconformity, whereas Huuse et al. (2001) have indicated the burial anomaly of 150 m for this well found by Japsen (1998) and mislabelled it 'missing overburden': given that the Quaternary cover in this well is ca. 300 m, a burial anomaly with a magnitude of 150 m would result in a missing section of 450 m. According to the interpretation of Japsen and Bidstrup (1999), the drilled section in the S-1 well is at maximum burial today, and the missing sec-

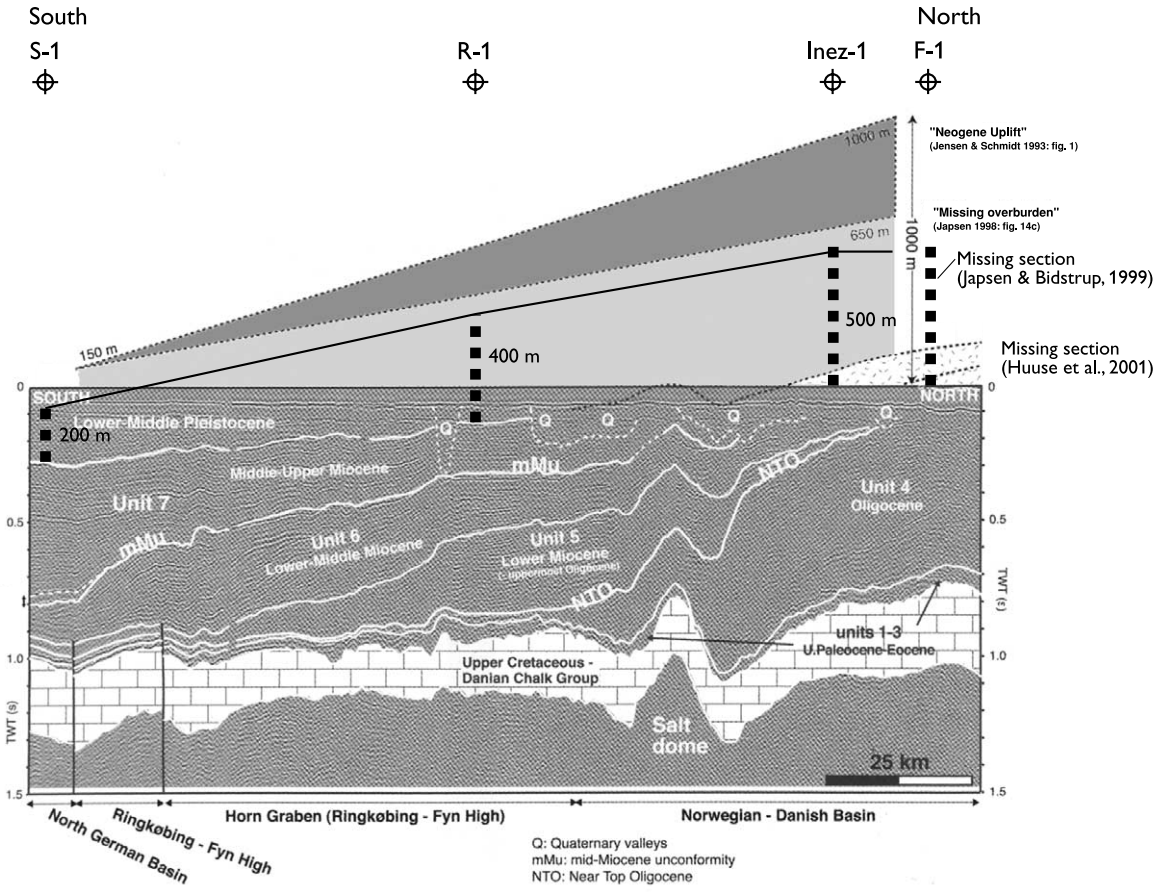

Fig. 2. N–S oriented seismic section interpreted by Huuse et al. (2001) with indication of different estimates of section missing due to late Cenozoic erosion in the eastern North Sea (their fig. 11). The section removed prior to Quaternary reburial as estimated from basin modelling and sonic data by Japsen and Bidstrup (1999) is added to the original figure of Huuse et al. (2001). To the south, the drilled section in the S-1 well is found to be at maximum burial by both studies. To the north, Huuse et al. estimated a missing section of only a few hundred metres from the stratal geometries along the section, whereas Japsen and Bidstrup estimated ca. 500 m to be missing. It should be noted that no Miocene deposits are present along the northern end of this strike-line and that the dip-line shown in Fig. 3 reveals a section of ca. 400 m of westward dipping, upper Miocene sediments that are erosional truncated just west of the R-1 well. Location on Fig. 1.

tion can thus only be assessed from seismic sections.

Around the northern F-1 and Inez-1 wells, where no Miocene sediments are present today, we find, however, that a missing section of ca. 500 mainly Miocene sediments is compatible with the present stratigraphy. To underline this, we present an E–W oriented seismic section where the Neogene stratigraphy is tied to wells with a subdivision based on ongoing studies of dinoflagellates (Fig. 3). This interpretation reveals a section of ca. 400 m westward dipping, upper Miocene sediments that is erosionally truncated in the eastern North Sea along the strike-line published by Huuse et al. (2001). Eastwards extrapolation of this upper Miocene unit fits with the estimated missing section of 300–400 m in the R-1 and Nøvling-1 wells where mid-Miocene sediments are preserved, and thus represents an independent control on these estimates that were based on geophysical well data (Japsen and Bidstrup, 1999). Consequently, ca. 400 m of upper Miocene sedi-

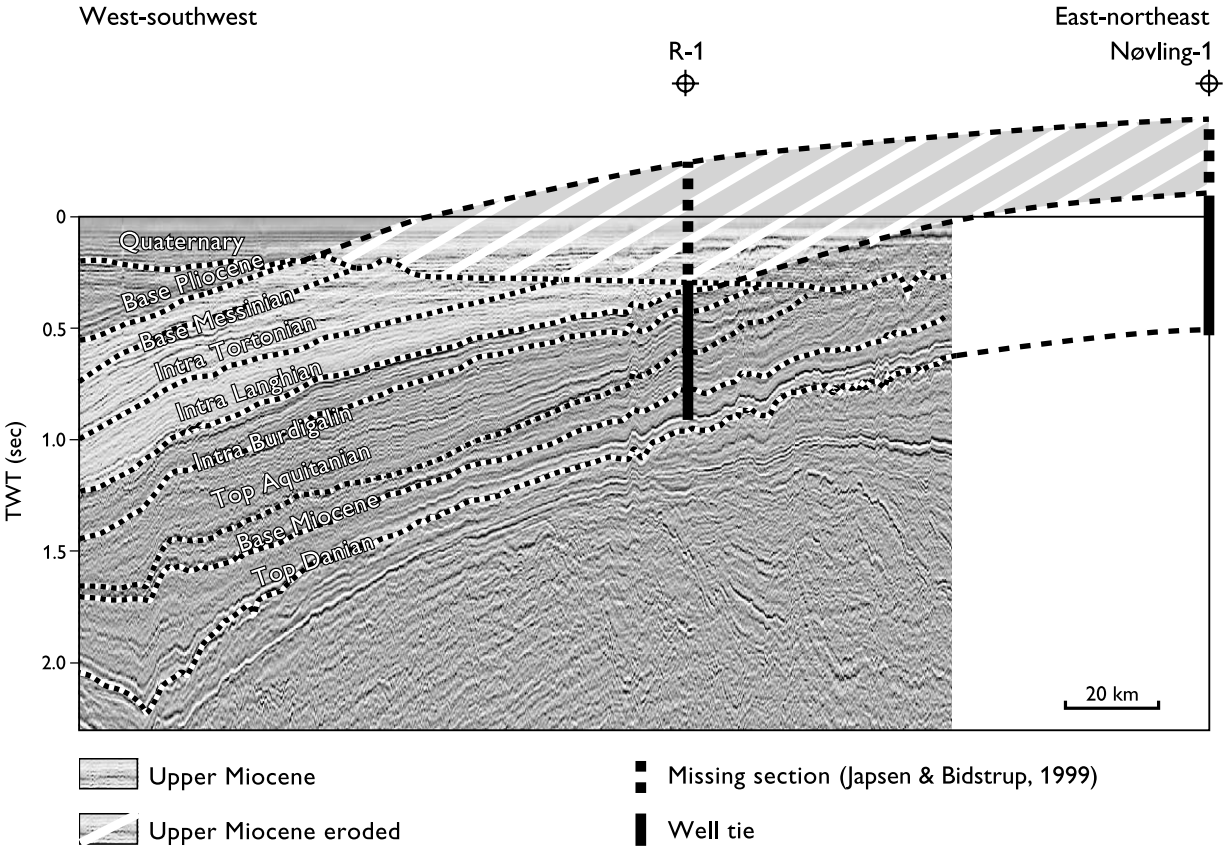

Fig. 3. E–W oriented seismic section showing a westward dipping section of ca. 400 m upper Miocene sediments that are erosionally truncated in the eastern North Sea. Extrapolation of this unit fits with the estimated missing section of 300–400 m in the R-1 and Nøvling-1 wells where mid-Miocene sediments are preserved. Consequently, ca. 400 m of upper Miocene sediments appear to have been deposited in the easternmost North Sea and then removed by erosion, e.g. during the Plio–Pleistocene. Location on Fig. 1.

ments appear to have been deposited along the eastern part of this section and subsequently removed by erosion, e.g. during the Plio–Pleistocene.

In summary, we have found agreement between estimates of the missing upper Miocene section removed by late Cenozoic erosion obtained by structural extrapolation and by studies of maximum burial (Japsen and Bidstrup, 1999). However, the structural estimate must be based on extrapolation of the preserved strata along an east–west oriented dip-line reaching from the late Cenozoic depocentre in the central North Sea to the exhumed margin of the North Sea Basin. Extrapolation along the north–south oriented strike-line presented by Huuse et al. (2001) will inevitably lead to erroneous results.

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