Climate vs. tectonic induced variations in Cenozoic sediment supply from western Scandinavia

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Introduction

The scope of this work is the causality of sediment flux variations from western Scandinavia during the Cenozoic. Over the decades of exploration in the North Sea and in the Norwegian shelf most of these variations were given tectonic causes. During the final period of North Atlantic break-up (Paleocene-Early Eocene) this link is quite striking, especially in the northern British Isles and in the Faeroe-Shetland Platform where sediment production pulses can be correlated with well documented periods of tectonic activity (e.g. magmatism). However, during the subsequent Cenozoic epochs this link is much less constrained. For this period we therefore search for an alternative explanation in terms of climate and climate change [1-3]

Methods

The extensive seismic and well data set allow investigation of inland erosion rates via the offshore distribution of sediments. However, varying marine conditions (semi-enclosed basin of the North Sea and continental margin of the Norwegian shelf) and non-uniform stratigraphic control from wells (large hiatuses in the Norwegian shelf – [4]) can be a reason for pitfalls in seismic correlation between corresponding units. Therefore, a rather semi-quantitative approach is applied in this study.

Tectonism and climate in the Cenozoic era

A number of Cenozoic tectonic episodes have been constrained by the offshore sedimentary record: 1) structures related to the opening of the North Atlantic [5], 2) changes in plate motions [6], 3) inversion movements in the Norwegian shelf [7] and in the North Sea [8-10] and 4) basin subsidence following the Paleozoic and Mesozoic extension episodes [11]. Episodic surface uplift of unknown tectonic cause has been invoked to explain low-relief, high elevation landscapes and variations of the sediment flux [12]. This is based on a particular rudimentary understanding of the Davisian cyclic landscape evolution model, which does not consider the occurrence of flexural isostasy or glacial buzzsaw processes. Observations of small scale sedimentary structures of ambiguous origin and activity of salt-related structures is not evidence for this hypothesised large-scale uplift [13]. Furthermore, there is little if any evidence for onshore Cenozoic tectonic activity, which is also not constrained by fission track dating [2, 14-20].

Climate variations during Cenozoic times are constrained by oxygen isotope values in benthic foraminifera [21-22] and floral assemblages [23]. The Paleocene and Eocene epochs were times of warm climates, peaking in the Late Paleocene Thermal Maximum [21]. A rapid cooling on the

Eocene-Oligocene transition changed the global conditions from 'greenhouse' to 'icehouse', resulting in glaciers reaching sea level in East Greenland [24] as well as in increased seasonality through colder winters [25]. After a subsequent warming in late Oligocene and Early Miocene the climate started to deteriorate after the Mid-Miocene Climatic Optimum towards the Pliocene when the North Hemisphere Glaciation begun and the frequency and intensity of climate variations boosted significantly [26].

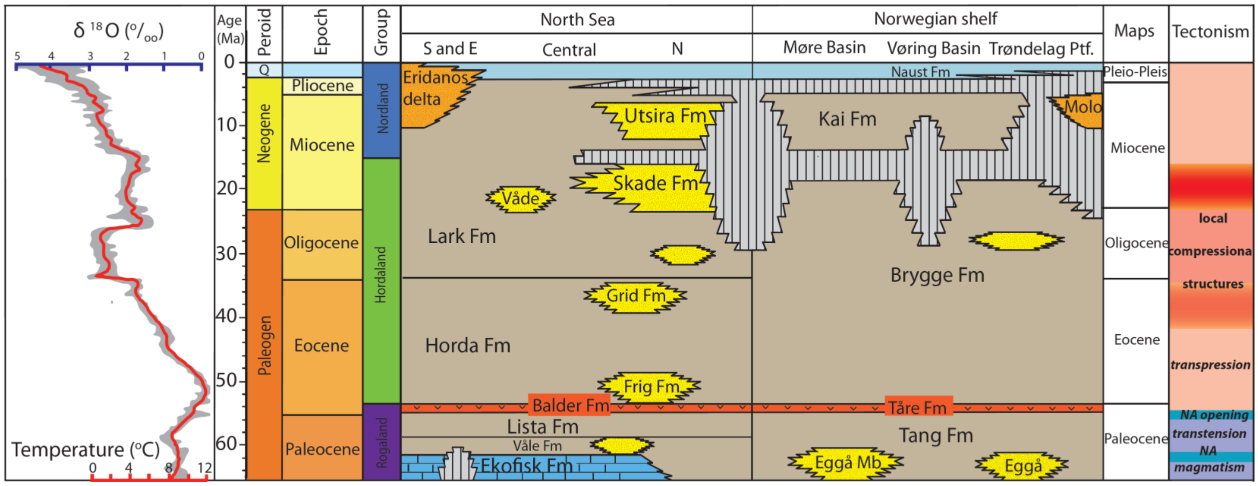

Figure 1 Lithostratigraphic scheme in the study area (modified from Rasmussen et al., 2004) with oxygene isotope curve (Zachos et al., 2001) and tectonic episodes (Dore et al., 2008, Nielsen et al., 2007) of Cenozoic era

Tectonism and climate as factors controlling sediment production

Tectonic surface uplift would increase river power, cause river incision and increase hillslope gradients above the threshold for occurrence of landslides. In that case tectonic uplift controls the long term frequency of landslides and hence the rate of erosion [3]. However, less dramatic tectonic disturbances are likely able to explain the Paleocene sedimentary response. For example, earthquakes and fault movements can increase the occurrence of landslides and mobilise sediment accumulations on the coast proximal shelf and onshore [27]. On the other hand, in a tectonically stable environment fluvial erosion is a poor candidate for creating variations in erosion rates regardless the amount of precipitation [28]. In the presence of subtropical climates the erosion is further inhibited by extensive vegetation cover as little bedrock is exposed and soils are well-developed. In case of climate cooling the tree limit lowers, exposing more bedrock for erosion. Furthermore, the erosional regime changes dramatically in the presence of alpine glaciers and cirques and when periglacial processes are in play. The occurrence of glaciers is controlled by the Equilibrium Line Altitude (ELA) which depends on the temperature and the amount of precipitation. Erosion in glaciated areas is proven to be much higher than in the fluvial regimes [29] and is further boosted when climate conditions change the altitude of the ELA frequently.

Model of the sediment fluxes in the light of tectonism and climate change

During Paleocene and Early Eocene large volumes of submarine fans were deposited in the North Sea and were sourced from The East Shetland Platform and Scottish highlands. [30]. These erosive events are well correlated with tectonic deformation and magmatism [10, 31]. Much smaller sand systems of this kind originated from the Norwegian mainland (e.g. the Siri channel) [30]. The submarine fans in the Norwegian shelf comprise the Eggå Member, deposited in the vicinity of the Jan Mayen Fracture Zone which, most probably, was the structure controlling feeding and distribution of this sand system [32]. Large thicknesses of the Paleocene deposits along the Norwegian coast have been commonly assigned to the uplift of the hinterland [33]. However, the increased sediment output could also be a result of seismicity related to the North Atlantic opening which is indicated by large thicknesses of Paleocene deposits in the vicinity of the Møre Trøndelag Fault Zone. In the North Sea Eocene depositional rates were lower than during any other Cenozoic epoch. Sand-prone deposits originated solely from the westerly source and sediment input from Scandinavia was minor. This can be explained by a relative tectonic stability after opening of the North Atlantic at ~56Ma and a very warm, humid climate with subtropical fauna and flora [23]. These conditions abruptly terminated on the Eocene – Oligocene boundary when climate has cooled and the floral assemblages changed in the North Atlantic realm [25]. This change correlated well with the increase of sediment yield of the Scandinavian shield which resulted in deposition of over 1000 m thick prograding wedge in the Eastern North Sea. A very close correlation between fluctuations of oxygen isotope data close to the Eocene – Oligocene boundary and lithology variations has been well documented in this area [2]. In the Northern North Sea the clastic deposits became coarser and clay mineralogy changed [34]. We suggest that the Oi-1 cooling and increased seasonality increased importance of glacial and periglacial processes at high altitudes with larger seasonality in river runoff. During the colder climate in Late Miocene the Molo Formation was deposited in the Norwegian shelf. In the Southern North Sea the deposition of the Eridanos deltaic system started in the Late Miocene. These depositional systems have been commonly explained as result of tectonic uplift, but, again, we propose the climate-driven explanation as the rejuvenation of topography in Scandinavia by available stresses is not physically possible. Similarly, invoking a causative uplift of Scandianvia before the deposition of Naust Formation and lithologicaly similar deposits in the Norh Sea is unnecessary, given the onset of North Hemisphere Glaciation at around 2.8Ma [26].

Summary

Our model of the Cenozoic evolution gives more importance to the climate-related control on variations of the sediment input rates after the opening of the North Atlantic. Many tectonic episodes of ambiguous origin can be discarded. The low-relief highlands of Scandinavia (‘peneplains’) have alternative explanations [2].

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