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4D Regional Tectonic Modeling: Plate Reconstructions Using a GIS

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4D plate-tectonic modeling proved invaluable in unraveling the structure and paleogaeography of the conjugate Norwegian and Greenland plate margins, particularly prior to the Early Eocene opening of the North Atlantic. Here, "4D" means the true 3D evolution of the basin geometry through geologic time. We present a case study describing the reconstruction of these margins. In this example, the plate reconstruction software operates within an ArcView desktop geographic information system (GIS), thus facilitating the rapid integration and analysis of a diverse suite of geological and geophysical datasets. The results have important implications for the hydrocarbon prospectivity of the region. This paper describes the methodology, uses and implications of these techniques in hydrocarbon exploration.

In this case study, the plate reconstruction software was used to instruct the GIS to reposition various geometric shapes, structural and stratigraphic elements to their positions at earlier stages in geological time. The use of GIS technology allowed the user to interactively query and carry out spatial analysis on the data at any time step. Techniques such as draping palaeogeography maps over palaeobathymetric surfaces, and major lineaments and fault patterns over structural surfaces were also made possible. The workflow diagram (Fig. 1) illustrates this integration, showing the novel combination of software and datasets, including the use of custom solutions for 3D visualization of the reconstructed structure and stratigraphy.

The use of GIS technology provides an accurate method of repositioning shapes on the surface of the Earth, but the accuracy of the plate reconstructions is primarily dependent on the quality and interpretation of the underlying data. The underlying plate model was based on the latest available published information and provided the possibility to improve on previous attempts to model and visualize the tectonic history of the North Atlantic. The reconstructions were tied to the fixed global hotspot reference frame of Müller *et al.* (1993), with the Late Cretaceous to Cenozoic time scale of Cande & Kent (1995) and the Mesozoic time scale of Gradstein *et al.* (1994). The principal source of data for the relative motion of the Greenland and Eurasian plates during the opening of the North Atlantic, and for the relative movement of the Jan Mayen microcontinent following its separation from Greenland at magnetic anomaly 5, were taken from Skogseid (1994). Movements prior to the break-up of the North Atlantic at magnetic anomaly 24B were based on Roest & Srivastava (1989).

One of the current limitations of many reconstruction packages is the inability to reconstruct raster data. The North Atlantic margin model integrated geological and geophysical data with a variety of different formats, thus a custom module was developed by GeoArctic to enable the import and reconstruction of both raster and vector data. The types of data used in the modeling ranged from seismic and potential field interpretations to field mapping. Detailed coastal outlines, concession boundaries and other present-day data were also reconstructed in order to identify the relative position of the structural features.

In addition to the plate reconstruction software, the project also used 3D visualization tools developed by GeoArctic to generate fence diagrams and display them with structural

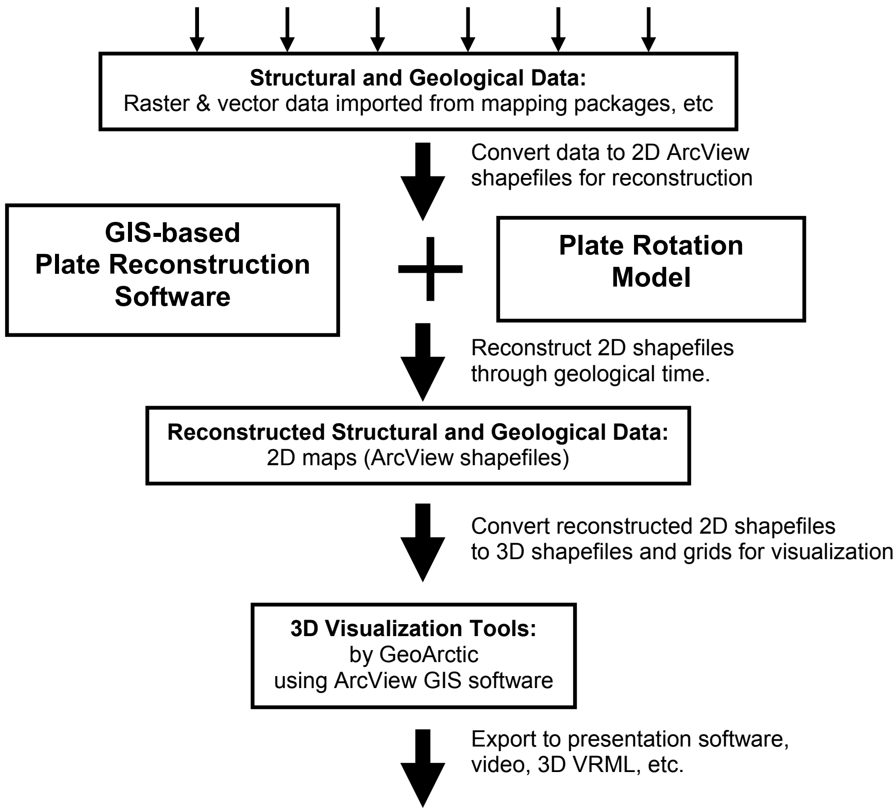
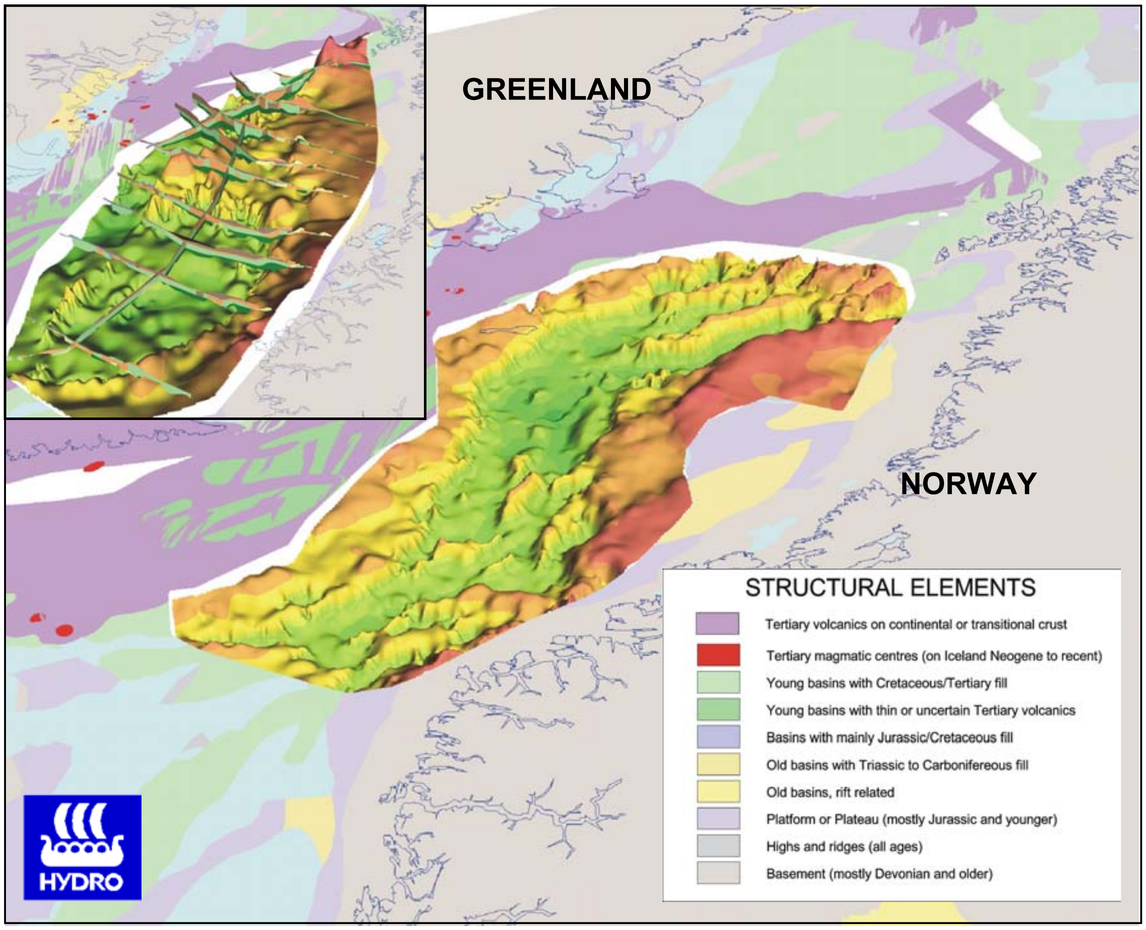


Figure 1: Plate reconstruction work flow.

surfaces, faults and other spatial data within the ArcView GIS (Fig. 2). Fence diagrams and cross-sections were automatically generated along user-defined lines of section using the reconstructed structural data. Geoseismic and geological cross-sections, structural modeling profiles, potential field maps and Ocean Bottom Seismic (OBS) profiles generated in other software packages were also moved into their reconstructed positions and displayed in the 3D views.

The accurate correlation of structural lineaments between East Greenland and the Norwegian shelf using the plate tectonic reconstruction methods developed for this study have important implications for the hydrocarbon prospectivity of the area. The underlying structural architecture of the North Atlantic region and the basement grain imposed during the Caledonian orogeny are known to have had a fundamental influence on the subsequent structural and depositional evolution of the region (Doré, 1991). Major structural lineaments were compiled and additional observations incorporated into the structural database from regional seismic and potential field data, and from field work in East Greenland. The plate reconstruction model allowed detailed structural maps, interpreted from seismic reflection data in Mid-Norway and Greenland, to be integrated with the reconstructed tectonic elements from both sides of the Atlantic margin (Fig. 2).

Plate reconstructions were also used to compare the deep crustal structure and to map the distribution of Tertiary volcanics along the North Atlantic margin. A lower crustal high velocity body is interpreted above the mantle on OBS data from both the Mid-Norway (Mjelde *et al.*, 1997; Van Schaack *et al.*, 1998, in-house data) and East Greenland margins (Schlindwein, 1998; Mandler & Jokat, 1998). 3D visualization helped to establish the close relationship



between the position of this deep structure and the distribution of the overlying Tertiary

Figure 2: Reconstruction of Greenland and Norway before breakup. The 3D image is a geological horizon mapped from seismic data, and is overlain on a 2D structural-element basemap. Inset: Fence diagram generated from the reconstructed structural surfaces.

volcanics. Unraveling the structural architecture of these features and the relative timing of volcanic and structural events had an important effect on the heat flow model of the margin. This in turn has implications for hydrocarbon maturity and migration in the region.

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