AAPG Annual Meeting
March 10-13, 2002
Houston, Texas

Unmasking Triassic Structural and Depositional Patterns in the Northern North Sea: A New Vision for the Evolution of the Triassic System

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Introduction

The continental Triassic reservoirs of the North Viking Graben have long been known to contain hydrocarbons following discoveries in Dunbar and Snorre Fields. Our knowledge of the structural and sedimentological development of the Northern North Sea Triassic system is, however, limited at best. This is due in part to the low numbers of Triassic well penetrations, poor resolution of older 3D seismic surveys, and the extensive tectonic overprinting of deeper stratigraphic levels that took place during Late Jurassic rifting.

The majority of published models for the formation of the Triassic basins in the western portion of the North Viking Graben indicate a typical half-graben system controlled by eastward-dipping major border faults, which have then been reactivated during the later Jurassic rift episode (e.g. Clemmensen et al., 1980; Badley et al., 1988; Yielding et al., 1991; Steel, 1993; Færseth, 1996). This implies a thickening of syn-rift sedimentation to the west. One paper, by Dahl and Solli (1993), briefly discusses the Triassic basins being controlled by *westerly* dipping border faults, with associated syn-rift thickening to the east. The dating of this Triassic rift period also varies. Badley et al. (1988) deduced that there were two episodes of rifting, with Late Permian-Early Triassic rifting along a N-S axis, and later Bathonian-Albian rifting along a NE-SW axis. Steel (1993) discusses an evolution from Early Triassic rift basins to an open basin in the mid-Triassic to Late Jurassic post-rift interval. Færseth (1996) described a Late Permian-Early Triassic period of rifting, with later Triassic sediments forming part of the post-rift section; this view ties in with a late Permian volcanic intrusive event (Fossen and Dunlap, 1999).

This paper will present evidence that the rifting was initiated between the latest Permian and Middle Triassic, on dominantly westward-dipping normal faults – a fault trend opposite in polarity to that formed by subsequent Late Jurassic extension.

Stratigraphy

The Triassic of the Northern North Sea is divided into several formations (Fig. 1; Lervik et al., 1989). There are different stratigraphic nomenclatures between the UK and Norwegian sectors; to increase interpretive resolution, we use the more detailed Norwegian terminology here. The Triassic is composed of the Hegre Group. This is broken down into the Teist, Lomvi, and Lunde Formations (Fig. 1). The Lunde Formation has Lower, Middle, and Upper Members, with the Upper Member being broken down into several separate reservoir units (Nystuen et al., 1989).

Data and Techniques

A regional database of 2D and 3D seismic coverage (Fig. 2), well logs and core, covering the Northern North Sea, has been utilized for an analysis and restoration of the pre-Jurassic structural and depositional regimes in an area between the Dunbar and Snorre Fields. Seismic interpretation of selected horizons has been coupled with well data in an attempt to identify significant depositional patterns throughout the area. Structural interpretation has been carried out to identify tectonic sequences through the Triassic and into the Jurassic; the gross sedimentology of these sequences has been determined using analysis of mud-logging data and core.

Field analogues have been used in an attempt to build a comparative spatial and temporal model for the structural and sedimentological evolution of Triassic-aged continental half-grabens. These analogues include the Newark Supergroup of the Newark Basin, eastern USA; Permo-Triassic basins of the Western Isles, Scotland; the Morrison Formation of southeastern Utah; and the Cuyo Basin of Argentina. They have provided a detailed knowledge of both localized and large-scale tectono-sedimentary interactions.

Results

A new structural model for the Triassic of the Northern North Sea is based on detailed seismic interpretation of the large 3D data coverage available to the University of Edinburgh (see Fig. 2). This can be summarized as follows:

(1) Initial rifting is recorded in the earliest Triassic (Fig. 3), following possible late Permian activity. This rifting is ~20 Ma older than similar rifting of the Central Atlantic Margin basins associated with the breakup of Pangea (Olsen, 1997). Several small sub-basins have been identified within the Teist Formation; these are half-graben in form, and are controlled by north-south striking, *westward*-dipping planar normal faults. Sediment thickens into the extensional faults here, in an easterly direction.

(2) At the boundary between the Teist and Lomvi Formations (~238 Ma), fault-linkage caused extension to become focused on a few through-going normal faults, with cessation of movement on others. This period is still reflected by eastward-thickening sedimentation into the border faults. The locus of extension for the entire Triassic rifting is thought to be further to the east than previously identified, in the region of the Øygarden and Horda fault-zones. This may help explain the Permo-Triassic dyke swarms that are present in southwestern Norway (Fossen and Dunlap, 1999) but are absent in the Northern North Sea.

(3) Continued pulsed movement throughout the Lunde Formation, controlled by several major border faults, led to a series of internal unconformities within the basin fill (Fig. 4).

Conclusions

Rifting of Triassic age in the Northern North Sea is interpreted to be controlled by a series of north-south striking, westward-dipping border faults. Through time, these become progressively linked or abandoned. This rifting, with the earliest phase occurring in the latest Permian or earliest Triassic, accumulated sediments in half-grabens with thickening to the east. The main locus of Triassic extension is much further to the east than previously thought. The determination of the sedimentology of these continental half-grabens, from well information and use of field analogues, has led to the identification of several tectonostratigraphic sequences (see Fig. 1) that are typical of Central Atlantic Margin basins (Olsen, 1997), characterized by syn-rift fluvio-lacustrine development.

Acknowledgements

We thank TotalFinaElf Exploration UK PLC for funding this research, providing data, and giving permission to publish this information. Various other members of TFE are thanked for useful discussion on this subject, particularly Roger Kimber and Martin Kubala. We must also thank Roy Schlische, Martha Withjack, Dennis Kent and Delores Dailey (Rutgers University), and Peter LeTourneau (Lamont-Doherty Earth Observatory), for giving help and useful discussion during fieldwork in the Newark Basin.

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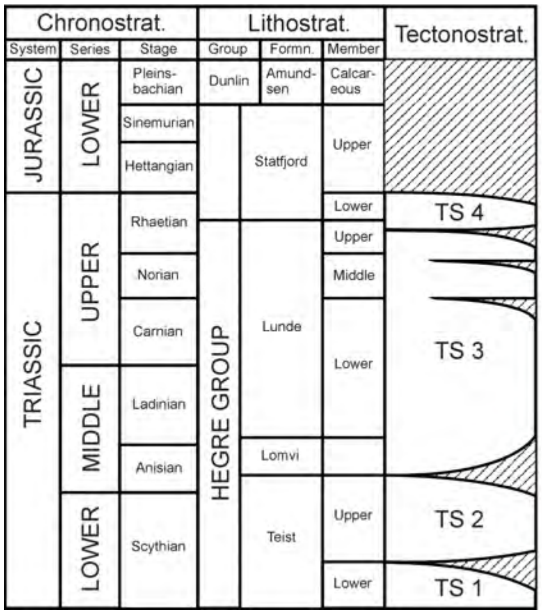

Figure 1. Overview of the chrono-, litho- and Tectono-stratigraphy of the Triassic of the Northern North Sea, compiled from Nystuen et al. (1989) and Olsen (1997).

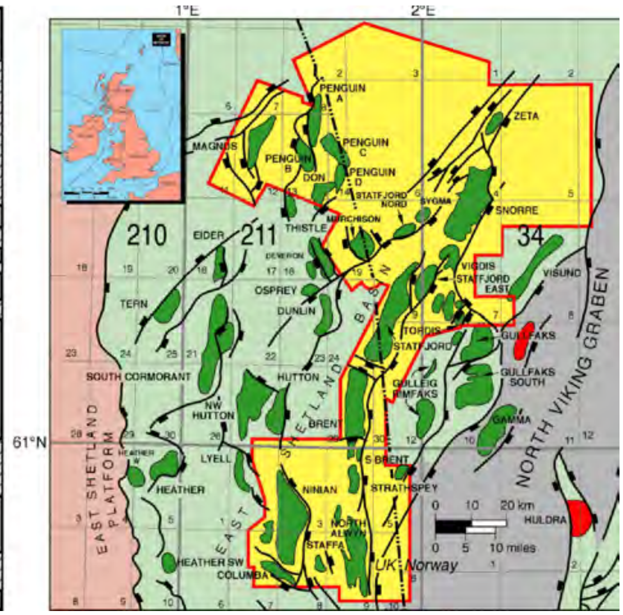

Figure 2. Map of 3-D seismic coverage held at the University of Edinburgh, highlighted in yellow. Oilfields are marked in green, gasfields in red.

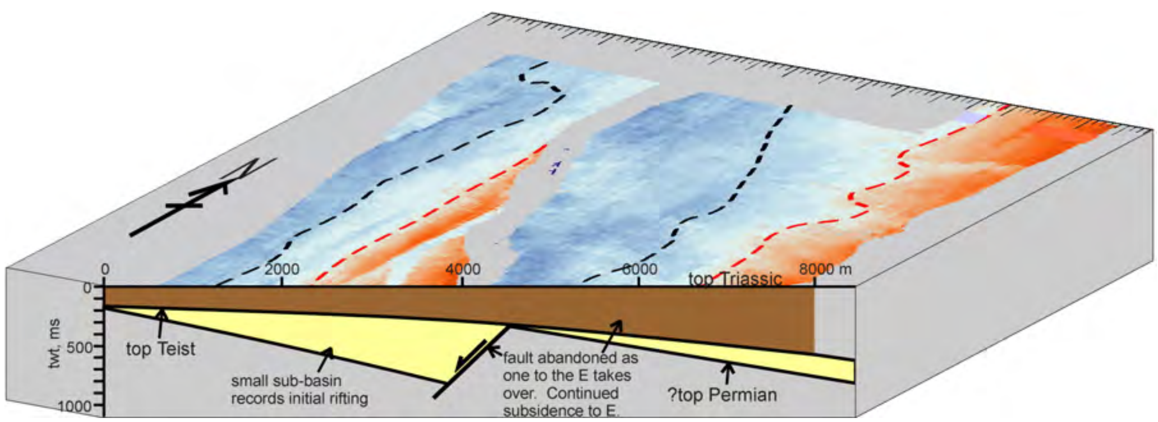

Figure 3. Surface slice at top Triassic time, with SW-NE vertical interpretation from seismic (*c.f.* Fig. 4). From interpretation of seismic horizons at several levels, the tectonic evolution of the area can be determined. This example shows sub-basins of the initial Permo-Teist rifting (in yellow), overlain by a syn-rift middle and upper Triassic package (brown) controlled by a major border fault to the east.

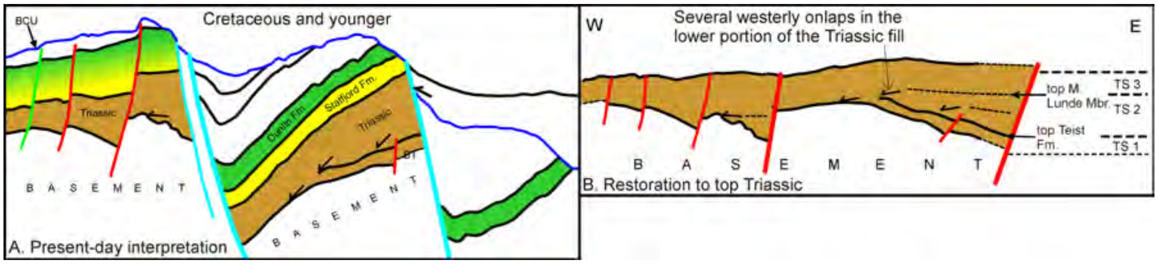

Figure 4. A. E-W seismic line interpretation, showing present day structure controlled by a southeastward-dipping Late Jurassic master fault system. B. Restoration to top Triassic time, showing thickening of Triassic to the east, into a westerly-dipping border fault system.