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Regional geological and tectonic structures of the North Sea area from potential field modelling

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Abstract

The spatial distribution of large-scale crustal domains and their boundaries are investigated in the North Sea area by combining gravity, magnetic and seismic data. The North Sea is situated on the plates of three continents, Avalonia, Laurentia and Baltica, which collided during the Caledonian orogeny in the middle Palaeozoic. The location and continuation of the collisional sutures are debated. We apply filters and transformations to potential field data to focus on the crystalline crust and uppermost mantle on a regional scale in order to extract new information on continental sutures. The transformations reveal intrinsic features of crustal transitions between the Caledonian plates and their relation to later extensional structures. The transformations include the Hough Transform applied to the gravity field, calculation of fractional derivatives and integrals of the gravity and magnetic fields, the pseudogravity field and the horizontal gradient field as well as upward continuation. The results indicate a fundamental difference between the lithosphere of Avalonia, Laurentia and Baltica. The location of the Mesozoic rift system (the Central Graben and Viking Graben), may have been partly determined by the presence of the sutures between these three plate, indicative of extensional reactivation of compressional structures. A significant lineament across the entire North Sea between Scotland and North Germany indicates that the lower crust of Baltica provenance may extend as far south-westward as to this lineament. Comparison of the power spectra of the gravity field in five selected areas shows significant differences in the long wavelength components between the areas north and south of the lineament corresponding to differences in crustal properties. This lineament could represent the suture between lithosphere of Caledonian origin (Avalonia) versus lithosphere of Precambrian origin (Baltica) in the lower crust and upper mantle. If this is the case, the lineament is the missing link in the reconstruction of the triple plate collision.

Keywords: North Sea; Gravity data; Magnetic data; Potential field modelling; Crustal structure; Lineaments

1. Introduction

Potential field data are a primary source of information on subsurface geology and tectonic features. Gravity and magnetic data may reveal both large and small scale features, including differences in basement type, magmatic intrusions, volcanic rocks, basement surface and fault structures. As such, this type of data provides an invaluable source of information, which is complementary to seismic data.

The North Sea region has been the subject of intense geophysical exploration since the discovery of major hydrocarbon resources. Numerous seismic results have been published on the post-Zechstein deposits, but only

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few publications have targeted the pre-Zechstein deposits beneath the base of the Mesozoic sequences. As such, there are uncertainties as to the existence and thicknesses of Palaeozoic deposits, possible intrusions, differences in crustal domains and location of the continental suture zones.

Until the MONA LISA project in 1993–95 (MONA LISA Working Group, 1997a) there was almost no knowledge about the crustal structure and the configuration of the plates that collided during the early to mid-Palaeozoic amalgamation of the lithosphere in the area. The MONA LISA data identified, along four seismic profiles (Fig. 1 Table 1) (Abramovitz and Thybo, 1999, 2000; MONA LISA Working Group, 1997a), the location of the main sutures in the area, but the main triple junction between the colliding plates could not be identified. In particular, the west and southward extent of Baltica has remained unknown (Thybo et al., 1999, 2002). The relation of the bounding sutures to other plates may be of utmost importance for understanding of the process of subsequent rifting and basin formation. We apply different transformation techniques to potential field data from the area and identify lineaments that may reveal the hidden sutures and thereby provide significant new evidence to the Caledonian and earlier formation of the lithosphere in the area. We further address the importance of early collisional structures in the crust and uppermost mantle for the subsequent tectonic evolution. Identification of main sutures and other structures may hold the key to unravelling later processes of rifting and basin formation, in particular the location and fault structures of rift grabens.

2. Geological setting

The North Sea area was the site of a triple plate collision zone during the Caledonian orogeny (Fig. 2). Four major tectonic events influenced the area since the Cambrian: (i) the Caledonian collision during Late Ordovician to Early Silurian, (ii) subsequent rifting and basin formation mainly identified in the Carboniferous to Permian, (iii) Mesozoic rifting and graben formation and (iv) inversion during Late Cretaceous to Early Tertiary (Ziegler, 1990).

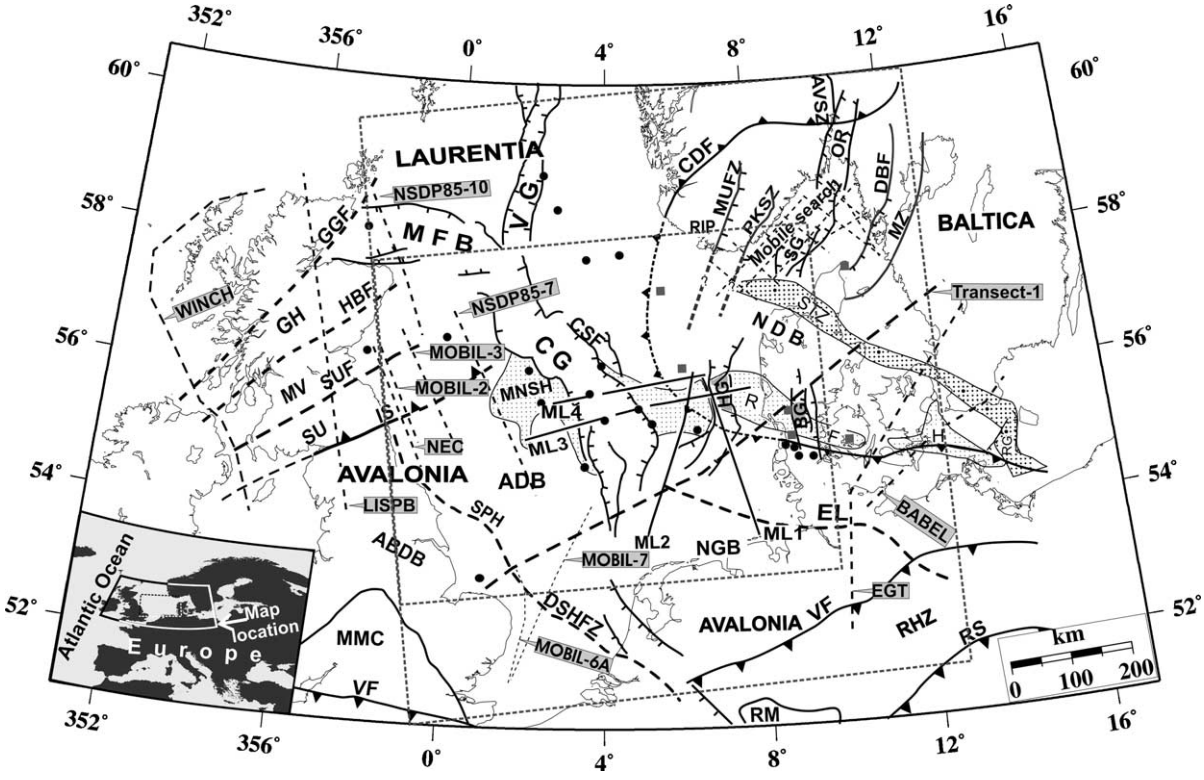

Fig. 1. Main tectonic features and deep seismic lines in the North Sea area. Squares indicate boreholes with Precambrian basement (>825 Ma), circles indicate boreholes with possible Caledonian basement (450–415 Ma). As the authors did not have access to the full gravity and magnetic datasets at the beginning of this study, some of the transformations will show a smaller areal coverage than others. The different areas are outlined by dashed squares. The inner dashed square shows the area used in calculation of the Hough Transform, while the outer dashed square shows the area used in calculation of the pseudogravity transform and the amplitude of the horizontal gradient. Abbreviations as in Table 1.