Passive Margins Modelling Project

Helping industry to understand the structure of the Atlantic Margin

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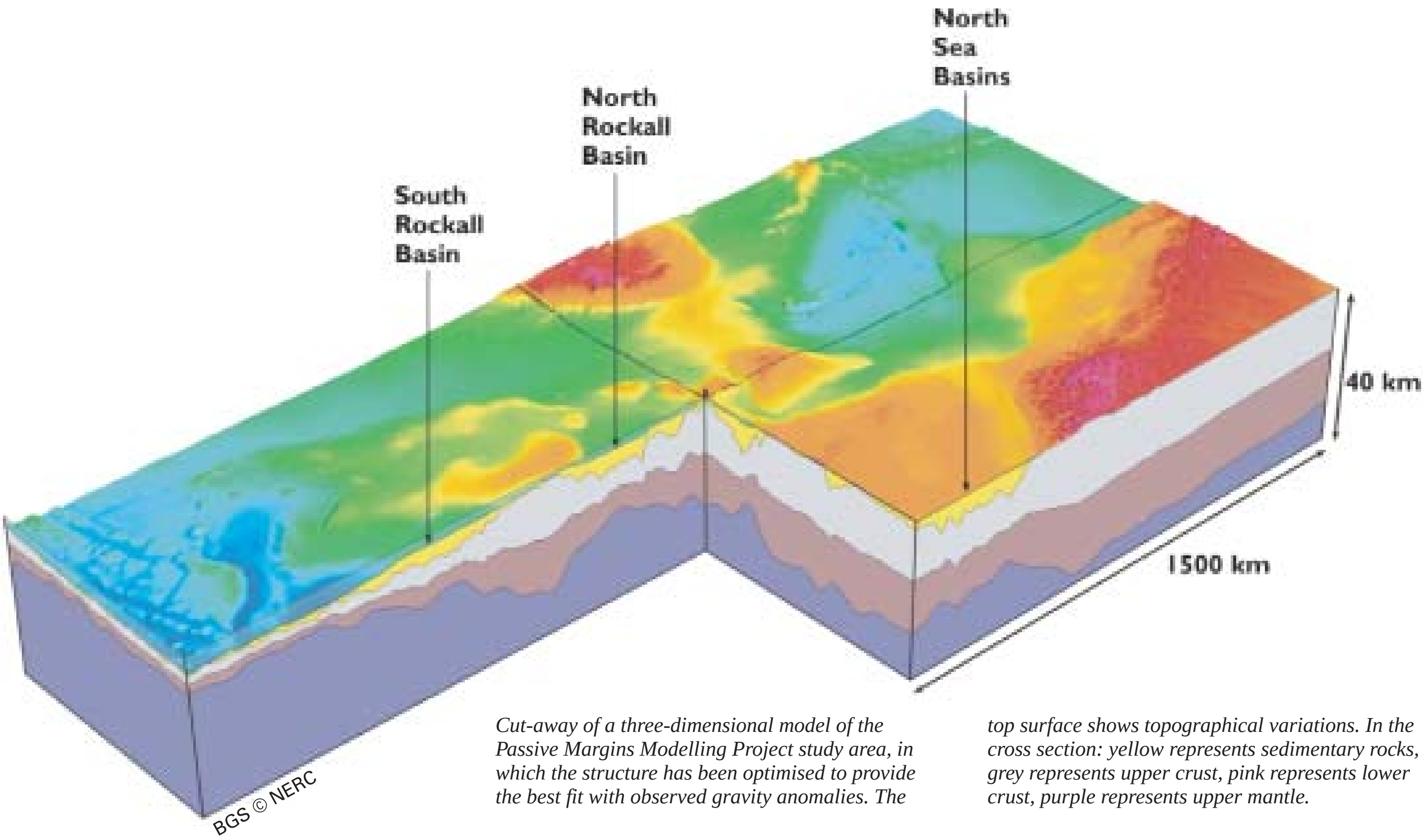
To the west of Britain, Ireland and Norway, and east of the relatively young oceanic crust of the north Atlantic, lies a region between 100 and 1000 kilometres wide which is underlain by older, continental, crust. The potential for hydrocarbons in the sedimentary basins of this region has led to it becoming a focus for commercial exploration in recent years, and this has coincided with a growing scientific interest in the nature of continental margins. In this climate, the BGS teamed together with a group of oil company sponsors to undertake the 'Passive Margins Modelling Project' which has been investigating the three-dimensional structure of the north-east Atlantic margin.

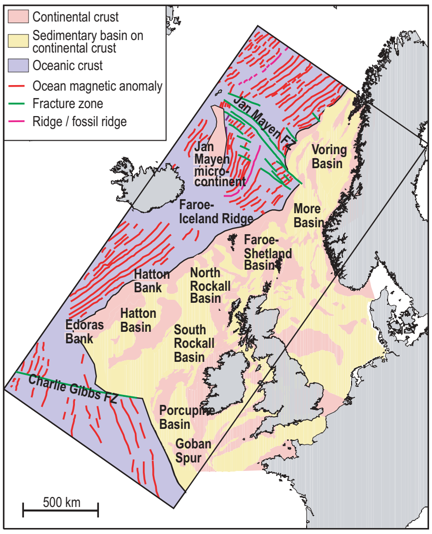
Despite the recent interest, the margin is still poorly understood. It covers a huge area, seismic surveys are relatively sparse over much of it, and large parts have not been tested by drilling. In addition, serious exploration difficulties have arisen because of widespread volcanic lavas and sills. Seismic energy is scattered by these rocks, making it very difficult to interpret the underlying strata using conventional seismic reflection technology.

There are, however, other resources we can use. The Earth's gravity and magnetic fields can be mapped over the whole study area and variations in these can be used in the interpretation of geological structure. In mapping these fields, we combined data acquired by the BGS with other regional data-sets. The gravity coverage derived from satellite altimetry over oceanic areas was of particular value. Our knowledge of topographical variations and of the physical properties of the rocks are also important resources. As part of the project, rock densities were analysed using geophysical logs gathered during previous drilling operations. This enabled us to estimate how compaction influences the density of the sedimentary rocks and predict densities in areas not sampled by drilling.

We gathered our information sources together in a Geographical Information



Cut-away of a three-dimensional model of the Passive Margins Modelling Project study area, in which the structure has been optimised to provide the best fit with observed gravity anomalies. The top surface shows topographical variations. In the cross section: yellow represents sedimentary rocks, grey represents upper crust, pink represents lower crust, purple represents upper mantle.



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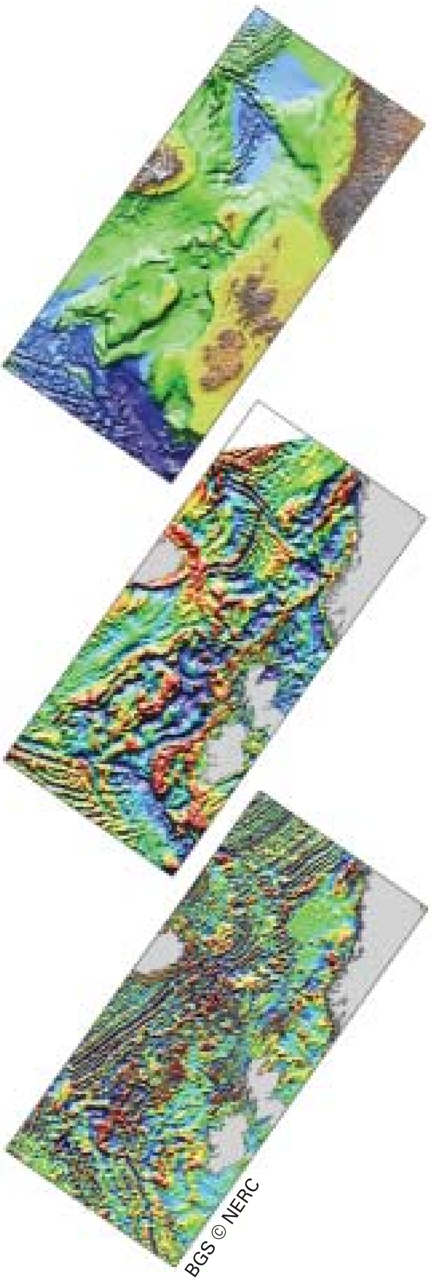

a

b

c

The Passive Margins Modelling Project study area and images of its surface topography (a) and observed gravity (b) and magnetic (c) fields.

System (GIS). This included geophysical grids and images, the modelling results, and mapped geological and tectonic elements. The GIS became a central feature of the project. Not only was it a very powerful tool for data compilation and analysis, but it also provided a means of delivering digital project outputs to the sponsors in a form they could interact with and integrate readily with their own data.

The modelling phase of the project commenced with the investigation of the structure of the Earth's crust along a series of transects across the margin. Initial models were constructed using the results of previous seismic surveys and these were then tested and developed using the gravity and magnetic methods. This provided valuable insights, but we still faced a major challenge in extending our models into three dimensions. There were insufficient seismic data to construct a satisfactory initial three-dimensional regional model, and it was not possible to do this directly from the gravity and magnetic data because of the non-uniqueness of their interpretation (a given field is amenable to a range of interpretations). We needed other, independent ways of constructing models of the Earth's structure.

One of the key principles we employed was isostasy. This had been recognised as early as the 18th century, when surveyors noticed that the deflection of a plumb-line due to the horizontal gravitational attraction of a mountain range was much smaller than predicted. The conclusion was that the mountains were supported by buoyancy generated at depth, for example by the thickening of the Earth's crust above denser mantle. This has since been found to be a general phenomenon, with mountains usually underlain by thick crust and deep oceans by thin crust. In effect, Archimedes' principle can be applied to the Earth, with an outer layer of crust and upper mantle (lithosphere) 'floating' on the underlying, more plastic asthenosphere. With local isostatic compensation every part of the lithosphere is considered to float independently. If the lithosphere has strength, it behaves in a flexural fashion, with some of the variations in load supported by this strength rather than compensated isostatically.

Starting with the observed topographical variations and an initial estimate of variations in the thickness and density of the upper, sedimentary layer, it was possible to predict variations in the thickness of the crust using isostatic principles. Allowance had to be made for the effect of temperature on the density of the Earth's upper mantle in these calculations (temperature increases towards the mid-Atlantic ridge, where new ocean crust is being formed). One model was constructed on the basis of local isostasy, and further alternatives were generated by assuming different strengths for the lithosphere during the deposition of the sedimentary rocks. The resulting range of models were compared with each other and with the results of seismic surveys. The gravity and (to a lesser extent) magnetic fields predicted by each were compared with the observed fields. In this way it was possible to discriminate between the different models and identify which assumptions were most appropriate in which areas. Components of the models (for instance, the basin geometries) were then modified to improve the fit between observed and calculated gravity anomalies.

The results of the modelling provide, for the first time, a regional three-dimensional view of the crust and upper mantle across the whole north-east Atlantic margin. They represent a resource that can be called on in future investigations at a variety of scales and provide insights not only into present-day structure but also into the way the margin has evolved. The key to making the most of the modelling results is to integrate them with independent interpretations of lithospheric structure (primarily seismic interpretations). In addition to identifying the most appropriate modelling assumptions for a particular area, this can aid in the recognition of anomalous features. These might include zones where the crust has been thickened by the introduction of igneous material at its base (underplating) or where the upper mantle density is anomalous.

The project outputs have now been delivered to the sponsors and we are looking for opportunities to develop the regional three-dimensional modelling approach further. There is considerable potential for applying it to other continental margins worldwide.