

3D gravity and magnetic modelling of the Irish Continental Shelf

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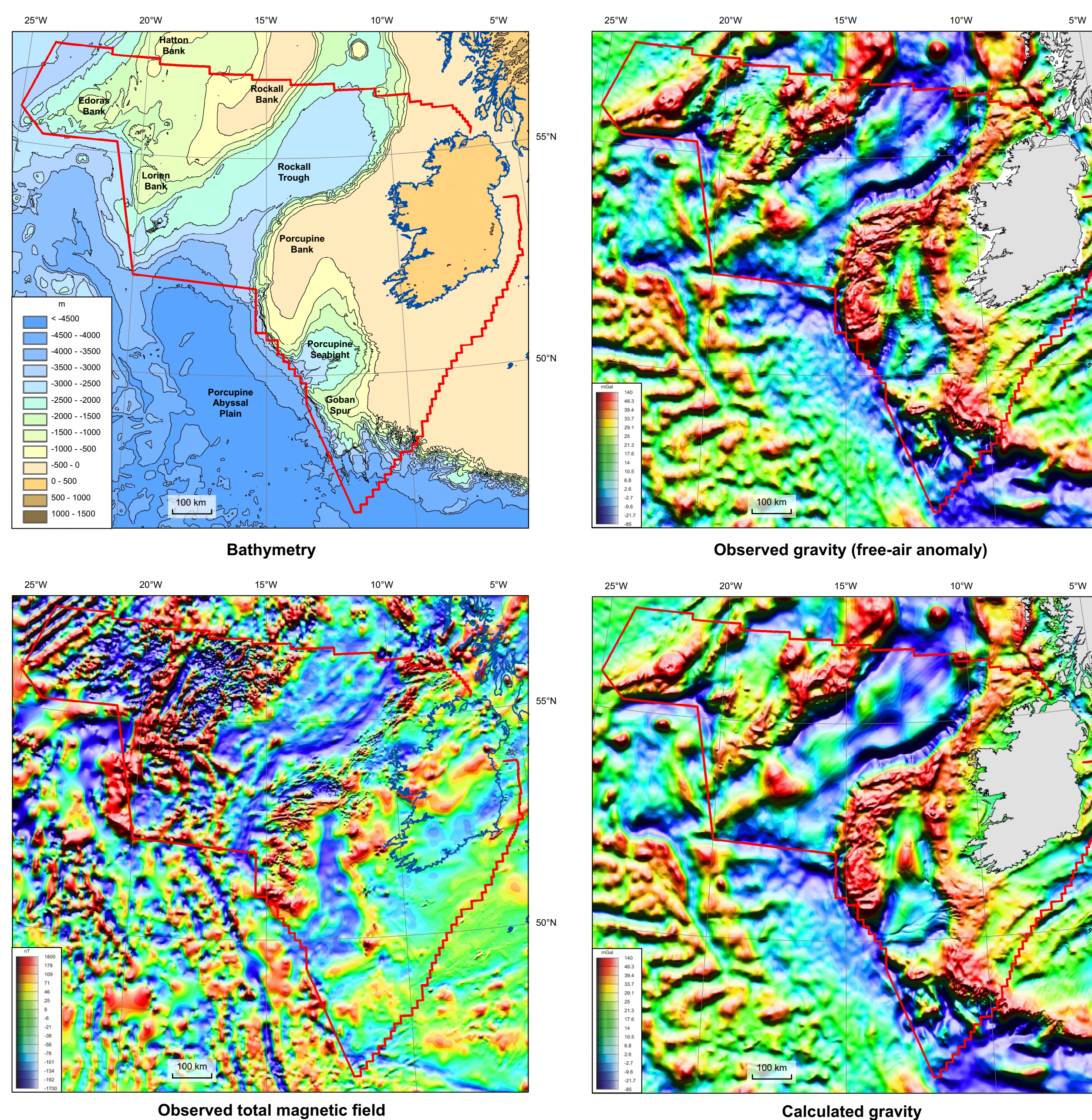


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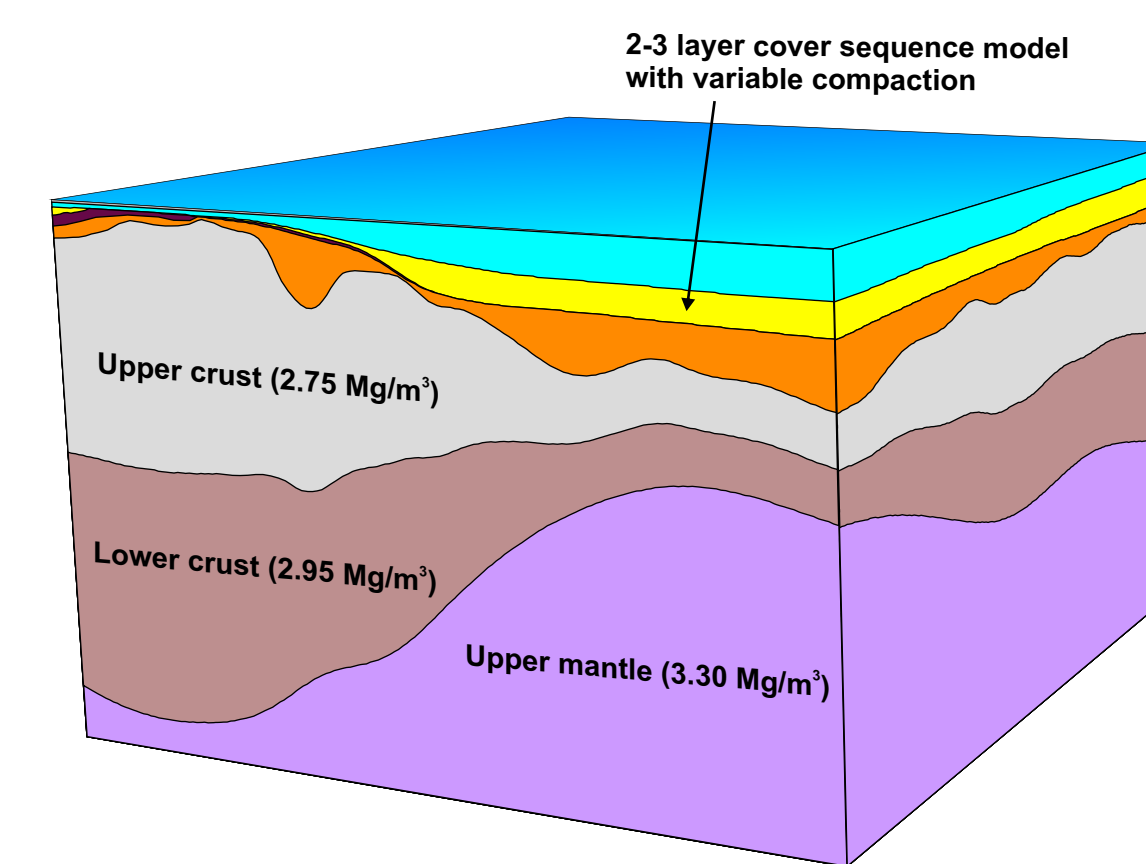
Methods for gravity modelling of three-dimensional lithospheric structure (Kimbell et al., 2004) have been refined and applied to the investigation of the Irish Continental Shelf. The key improvements were in the resolution of the observed anomalies and in the detail with which the starting model for cover sequence structure was defined. The former was made possible by access to results from the Irish National Seabed Survey (see images to the right). The latter involved building a multi-layer cover sequence model from a range of sources and assigning densities to this in a way that accounted for the laterally varying overcompaction associated with the Cenozoic denudation of the shelf areas. After model optimisation based on gravity inversion, regional crustal thickness variations were defined which are in reasonable agreement with the results of wide-angle seismic experiments. High crustal extension factors ($\beta > 5$) characterise the deeper parts of the Rockall and Porcupine basins and in places the models indicate extreme stretching ($\beta > 10$) beneath these basins. This could be because of instability in the inversion, although other recent investigations have independently suggested similarly high extension factors. In contrast, the Hatton Basin is characterised by an extension factor of about 2. Magnetic modelling indicates that the variations in the thickness of the crystalline crust predicted by the gravity models can explain the regional magnetic anomaly patterns over the Rockall and Porcupine basins, but that significant additional magnetic material (probably a combination of magnetic basement and Cretaceous and Cenozoic igneous rocks) is required to explain the anomalies in the Hatton Basin region. The magnetic signature of the Rockall Basin is distinctly different to that over the basement (of similar apparent thickness) formed during mid Cretaceous (C34n) opening of the ocean basin to the south. This is an impediment to hypotheses that invoke mid Cretaceous sea-floor spreading rather than intracontinental rifting to explain the development of the basin. The exception is in the extreme south of the basin where the volcanism associated with the Barra Volcanic Ridges combined with indications of relatively strong lithosphere could be evidence of incipient ocean opening. The modelling resolves a pattern of NE- to NNE-trending local Mesozoic basins on the margins of the Rockall Trough, helping to delineate structures that were previously only sparsely sampled by seismic surveys. It appears possible that rifts with similar trends underlie the volcanic rocks which obscure the deeper parts of the Hatton Basin. The linear trends of the basins to the south and south-east of Ireland are interpreted to have been inherited from a basement fabric that was initially established during the late Precambrian assembly of this basement and subsequently subjected to Caledonian and Variscan reactivation.

Reference:
Kimbell, G. S., Gatliff, R. W., Ritchie, J. D., Walker, A. S. D., and Williamson, J. P. 2004. Regional three-dimensional gravity modelling of the NE Atlantic margin. *Basin Research*, Vol. 16, 259-278.



Methodology

An initial model for the structure of the cover sequence was constructed from a range of sources prior to gravity modelling. The model comprised the water column, Cenozoic (post-basalt) sediments, a basalt layer (where present), older sedimentary cover, crystalline crust and upper mantle. The density of the upper sedimentary layer was modelled assuming a normal compaction trend whereas laterally varying overcompaction was simulated in the deeper sedimentary layer to allow for the effects of Cenozoic denudation of the shelf areas. The crystalline crust was split into upper and lower parts of equal thickness and an initial estimate of the depth to Moho was based on the assumption of local isostasy. The density model for the underlying mantle included the effects of thermal contrasts across the continent-ocean boundary.

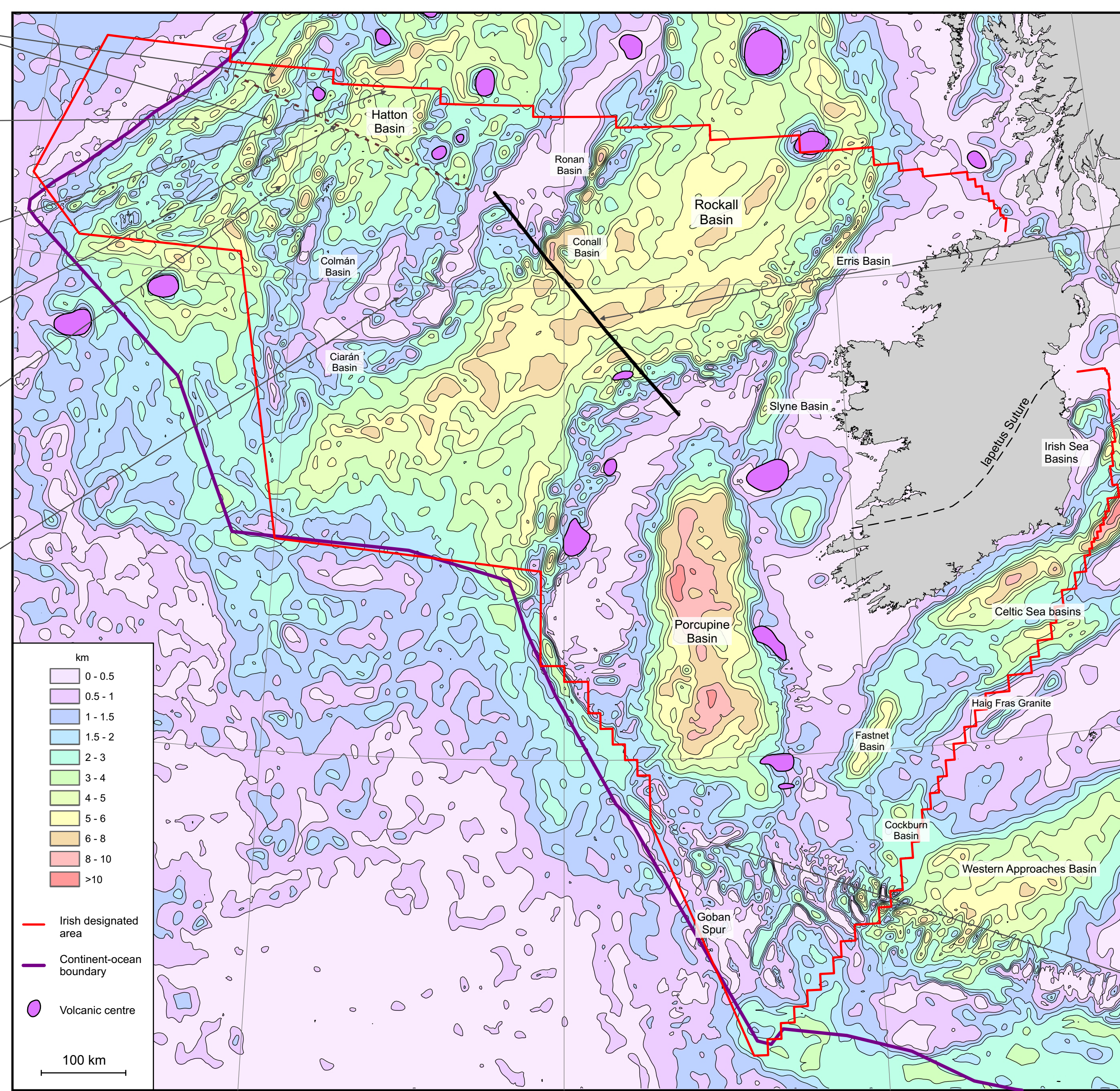


Mismatches between observed and calculated gravity anomalies were reduced by inversion methods, accommodating longer wavelength residual anomalies by modifying the Moho and the shorter wavelength residuals by modifications to the top basement surface. Flexural modelling was undertaken to see to what extent departures from local isostasy can be explained by the strength of the lithosphere during sediment loading. Comparisons with the results of wide-angle experiments were used to assess the accuracy of the modelling.

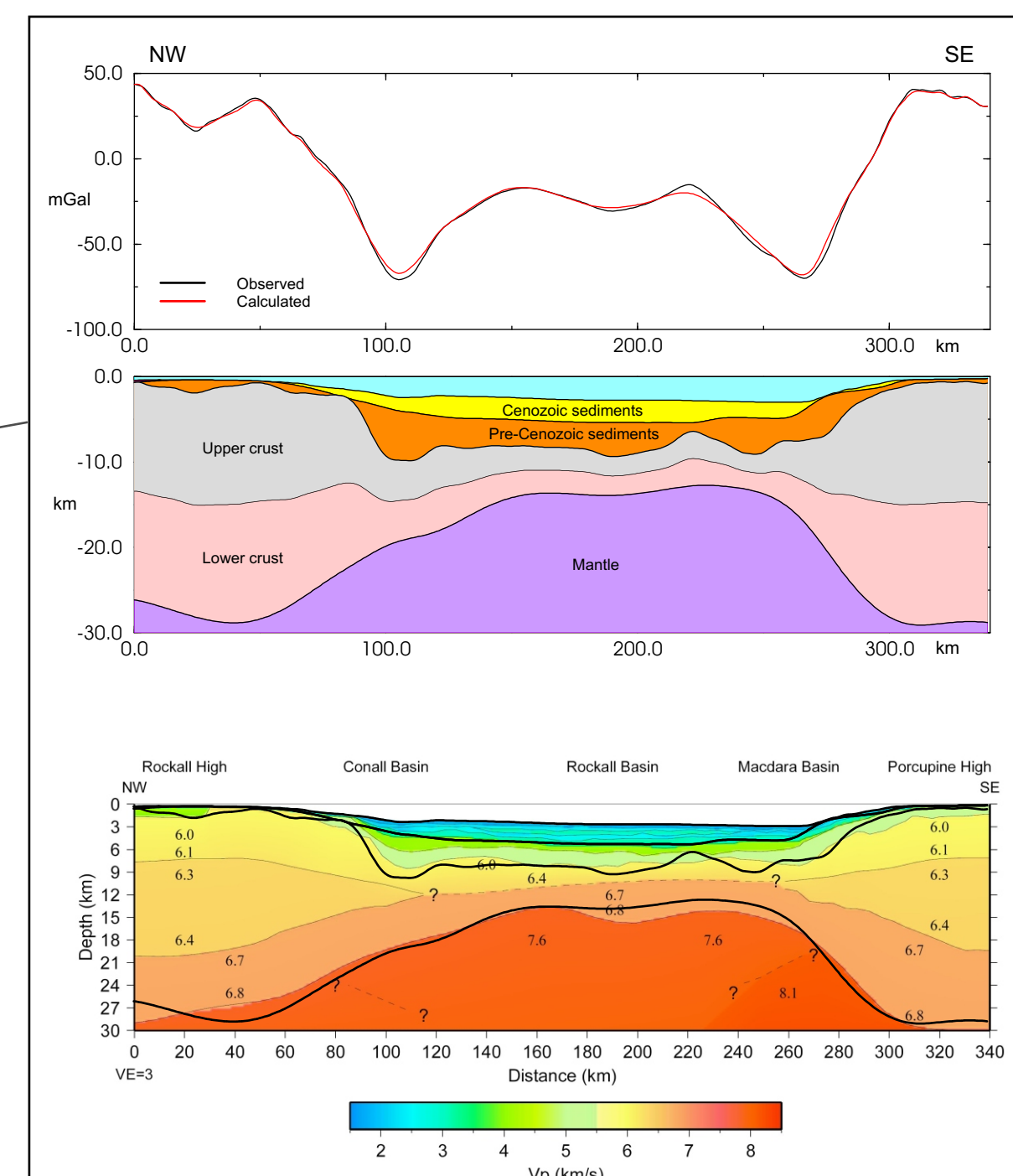
Magnetic anomalies were calculated over both the initial (isostatic) model and the optimised model, employing simple assumptions about the magnetisation of the crystalline basement and Cenozoic basalts. These provided insights into the extent to which the overall crustal geometries can explain the observed magnetic anomaly pattern and the degree to which the optimisation process improves this match (see further discussion in the bottom panel).

The main panel below illustrates the resolution provided by the optimised cover sequence model and identifies some of the features this has revealed.

- Hatton Ridge basins**
These narrow, linear basins are offset by the SE-trending South Hatton Lineament (see below)
- Seaward-dipping reflectors**
These are the main cause of the thickening of the cover sequence here, but are not well constrained by the modelling
- Northern Hatton Basin**
The cover sequence has a modelled thickness of 3-6 km in the northern part of the Hatton Basin, although this includes Palaeogene volcanic rocks. Shallow drilling has proven Mesozoic (mid-Cretaceous) sedimentary rocks to the NW on the Hatton High and such rocks may underlie the volcanic sequence within the basin. The tendency for higher magnetic field values to occur over the deeper parts of the basin may indicate a thinning of the volcanic sequence (assuming it is reversely magnetised).
- South Hatton Lineament (brown dashed line)**
This possible transfer fault marks offsets in the structure of both the Hatton Ridge basins and the main Hatton Basin, and can also be seen as a distinct change in magnetic character
- Southern Hatton Basin**
The modelling suggests that variations in the thickness of the pre-lava sedimentary rocks in the southern part of the Hatton Basin are organised in a series of NNE-trending zones, which could be Mesozoic rifts. There is a clear correspondence with the magnetic anomaly pattern which, unlike in the northern Hatton Basin, correlates positively with structural features. In addition to magnetic basement and Palaeogene igneous rocks, this area may also have been influenced by Cretaceous magmatism (as observed in the Barra Volcanic Ridges).
- Basins on the Rockall High**
The Colmán and Clarán basins were identified by Naylor et al. (1999) from their expression on seismic line W1-32. The 3D model provides more information about the forms of these basins, indicating that the former is a linear NE-trending feature whereas the latter appears to be bounded by an E-W structure on its N side. There was little previous evidence of the two additional basins revealed by the modelling along the axis of the high further east (but see the correlation with RAPIDS-33). New information is also provided about the basins and buried Mesozoic fault blocks along the eastern edge of the Rockall High. For example, the western margin of the Connall Basin appears more arcuate than in previous interpretations.
- Gravity and magnetic correlations in the southern Rockall and Porcupine basins**
Magnetic, volcanic ridges of presumed Cretaceous age in the southern Rockall and Porcupine basins can be correlated with features revealed by gravity data. The Barra Volcanic Ridges in the Rockall Basin bracket an area that has an anomalously high gravity field, despite the presence of a thick, low-density sedimentary succession. This suggests that the crust here is held out of isostatic equilibrium, perhaps because of anomalously strong (proto-oceanic?) basement. Magnetic data help to trace the Porcupine Volcanic Ridge System southwards across that basin and indicate a close correlation between one of the ridges and an axis across which there is a distinct change in modelled sediment thickness.
- Magnetic anomalies over Barra Volcanic Ridges in the southern Rockall Basin**
Distinct isostatic gravity anomaly high coincides with the area between the two main ridges



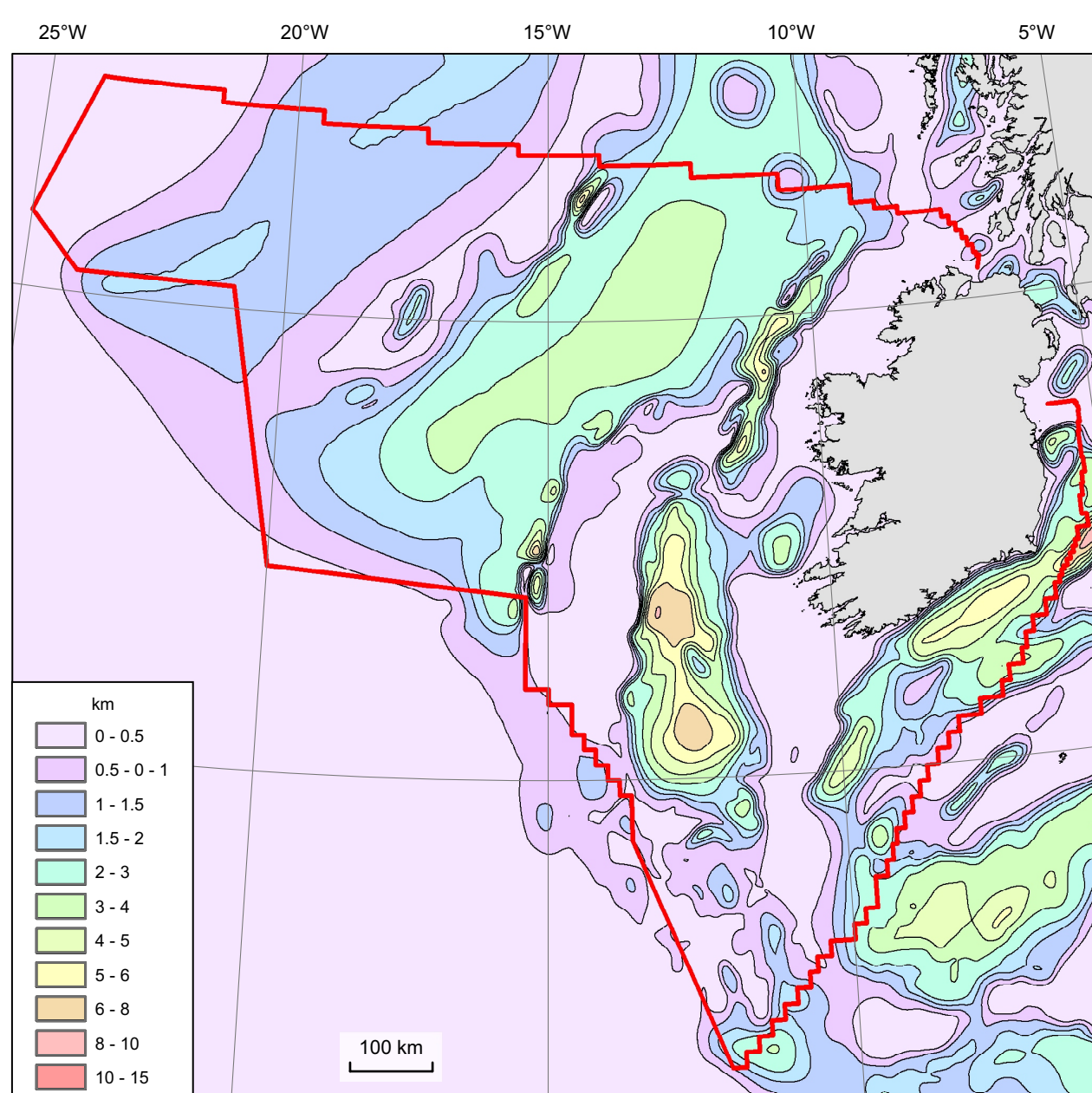
Modelled cover sequence thickness



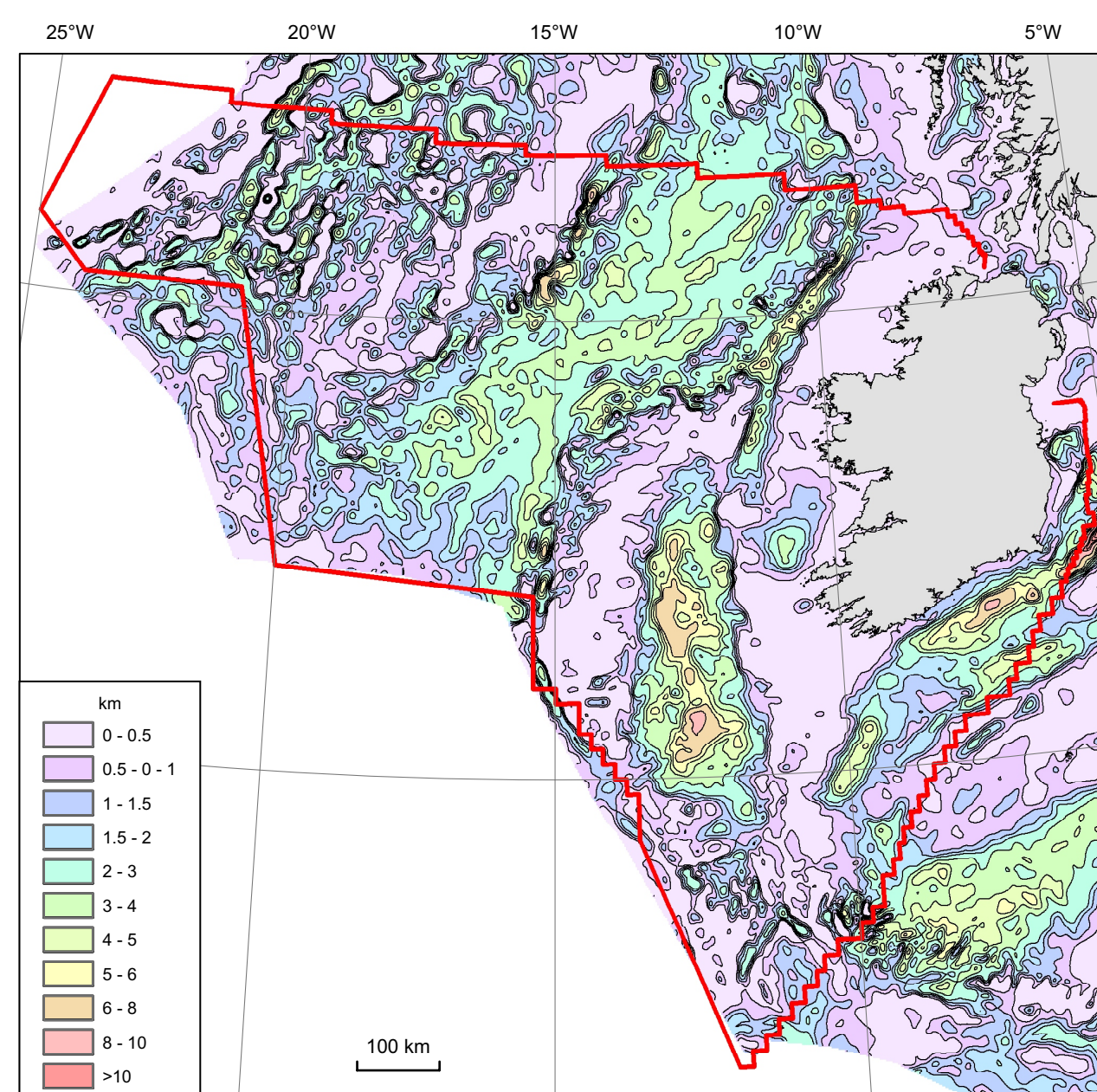
Comparison of 3D modelling results with a wide-angle seismic model for the RAPIDS-33 profile (Mackenzie et al 2002). Interfaces from the gravity model (top panel) are superimposed as heavy black lines on the velocity model in the bottom panel. Note the agreement on the asymmetry of the main basin and the presence of a (previously unmapped) basin on the Rockall High at the NW end of the profile.

Region south and south-east of Ireland
The model emphasises NNE-trending (Fastnet Basin, Irish Sea Basins) and ENE-trending (Celtic Sea Basins, Haig Fras Granite) structural control in this region. The change in trend between the Celtic and Irish Seas could reflect the greater influence of Variscan structures in the former area, but it is interesting to note a similar change in the trend of Caledonian features including the Iapetus Suture, which swings from an ENE trend across the west of Ireland to a more northerly trend across the east of Ireland and back to an ENE trend beneath mainland Britain. Older (Avalonian?) antecedents for these trends can be recognised in Britain, for example in the ENE-trending structures of the Lake District and NNE-trending structures of the Welsh borderlands. It is possible that these trends defined the original structural fabric of the Avalonian basement to the south and south-east of Ireland which influenced Caledonian and Variscan deformation in this region and, in turn, established the structural controls over subsequent basin evolution.

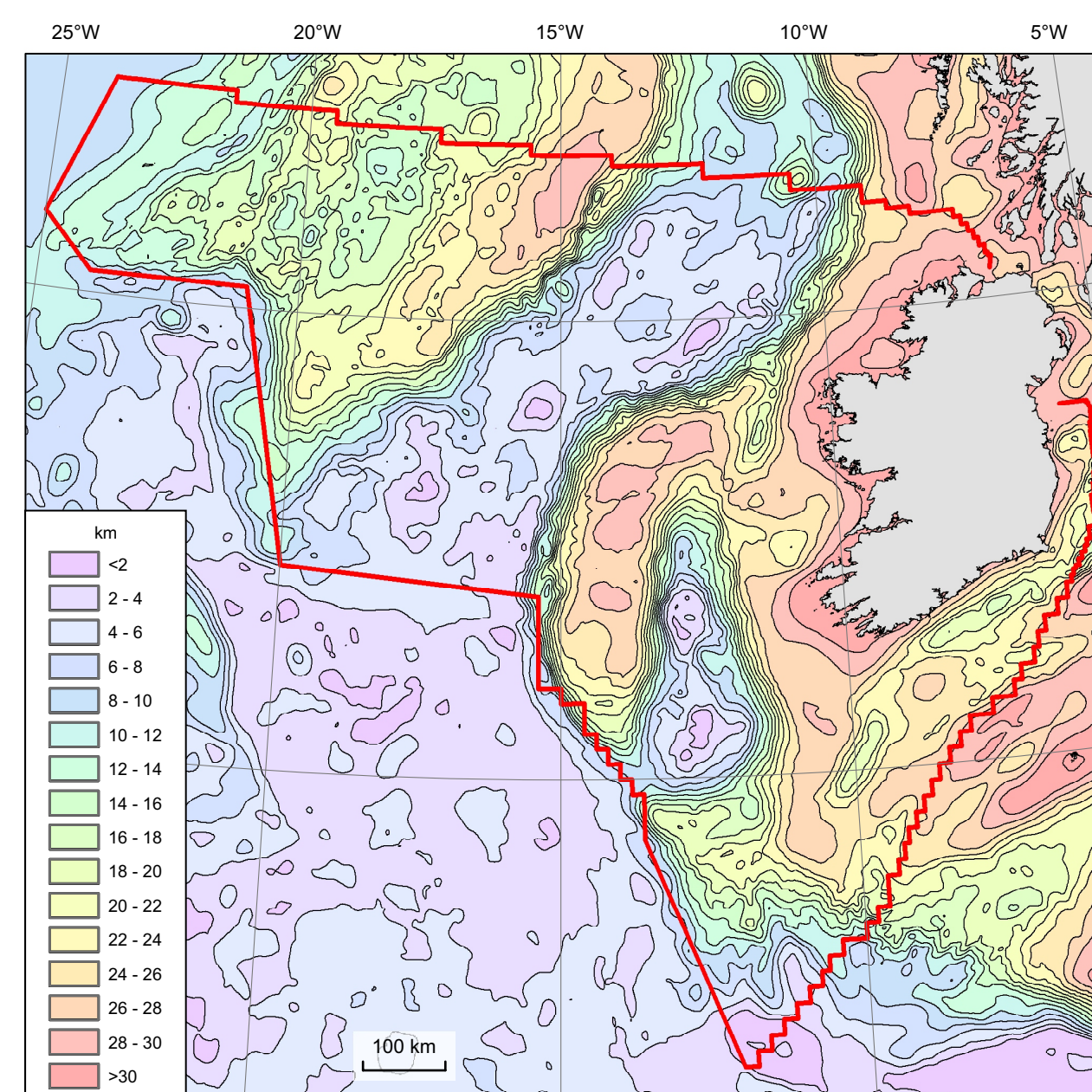
Goban Spur area
The model suggests a strong lineament with an ENE trend parallel to the Goban Graben, which lies about 30 km to the NE. The lineament appears to be implicated in the northward truncation of structures such as the Shackleton and Merlin basins.



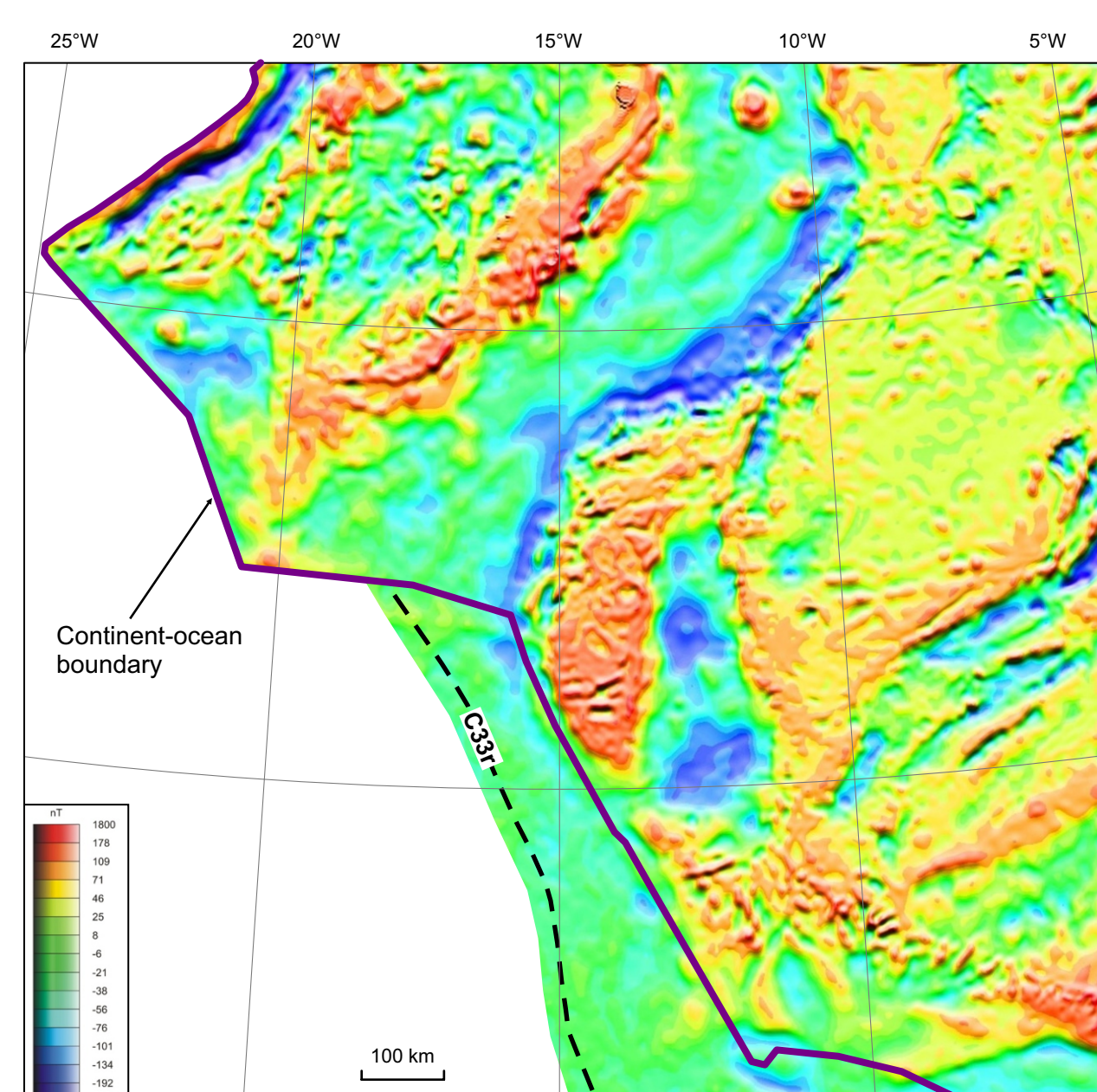
Initial model of pre-Cenozoic sediment thickness



Pre-Cenozoic sediment thickness after optimisation



Modelled thickness of crystalline crust



Computed magnetic anomaly

The maps above illustrate the changes in the modelled thickness of the pre-Cenozoic sedimentary rocks brought about by inversion of residual gravity anomalies. The process accentuates the sharpness and linearity of some basin margins, strongly implying fault control. In some cases this is confirmed by seismic data (e.g. from the Slyne, Erris and Porcupine basins). The most prominent changes occur beneath the Hatton Basin, where pre-existing information about the pre-lava sedimentary sequence was very sparse and only a very simple initial model employed. A strong NNE-trending grain appears in the optimised model. Shallower interfaces (e.g. top basalt) were relatively poorly constrained in this area, raising the possibility that at least some of the modelled sub-basalt structure is an artefact due to inaccuracies in the shallower parts of the model. There is, however, limited seismic evidence for rapid variations in depth to basement beneath the basin, and the apparent structural grain does parallel that of known Mesozoic basins further east, so this does suggest an area worthy of further investigation.

A forward magnetic model, based on the assumption of normally magnetised crystalline crust and reversely magnetised Cenozoic lavas, differs from the observed field (see top panel) quite considerably, indicating the influence of local magnetisation variations within the basement and several phases of Cretaceous and Palaeogene igneous activity. The regional magnetic anomaly patterns over the Rockall and Porcupine basins do, however, match the observations reasonably well and there is a surprisingly good correspondence in the subtle magnetic variations over the central part of the Rockall Basin north of around 55°N. It was not generally appropriate to include oceanic crust in the magnetic model because magnetic reversals are not simulated, but it is relevant to assess the signatures associated with the boundary between normally magnetised ('Cretaceous Quiet Zone') oceanic crust and continental crust in the Porcupine-Goban region. Whereas the anomaly over the Rockall Basin can be simulated by thinning the crust without changing its average magnetic properties, an oceanward increase in magnetisation is required to generate the patterns across the Porcupine-Goban continent-ocean boundary, where a similar change in crustal thickness occurs. This suggests that it is unlikely that the Rockall Basin is floored by mid Cretaceous oceanic crust of the type present further south.