Integrated Interpretation of Geophysical Data Over the NW Shelf, Australia (Westralia ACCESS project)*

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Abstract

The North West Shelf of Australia is a world-class gas province, consisting of several major sedimentary basins (Carnarvon, Roebuck, offshore Canning, Browse and Bonaparte) that cumulatively make up the Westralian Superbasin. Filled with thick Late Palaeozoic, Mesozoic and Cainozoic sedimentary succession related principally to the fragmentation of Gondwana, it is estimated to contain 92% of Australia's remaining conventional gas reserves (144 Tcf, Geoscience Australia/BREE report, 2012). Two extensive multi-client marine surveys, which acquired gravity, magnetic and 2D seismic data across the NW Shelf, have been reprocessed and interpreted to provide a regional update to the structural and tectonic configuration of the continental margin. Integration of these datasets with public domain potential field data has enabled a new qualitative interpretation that includes the COB, major and minor faults, depocentres and structural trends. These data layers were subsequently used within selected 2D models, with physical properties based on the analysis of key well logs, to validate the seismic interpretation and refine the basement surface and composition in areas where it was poorly imaged. The basement horizon was extrapolated between the seismic control using 3D gravity modelling. A 10-layer earth model of dimensions 2400km by 700km was constructed, and using merged survey and public domain gravity data, initial constrained gravity inversions were followed by manual editing of the basement surface (for instance, using grid-editing tools to replicate extensional fault geometries as defined from the qualitative interpreted work) to derive an updated basement surface. The resulting model should provide a significant uplift in the understanding of the highly prospective Westralian basins.

Introduction

The scope of the study was to use potential field's data to help improve seismic imaging and provide a more robust methodology of interpolation of geological surfaces and structure between 2D seismic lines. Furthermore, a QC documentation process has been designed and applied to highlight the degree of influence implemented by the potential field's data when building the final subsurface model (with respect to the initial seismic derived model). The acquired 2D gravity and magnetic data would initially be subject to a qualitative interpretation that would incorporate any additional public domain data over an expanded area to determine a regional setting. The available seismic data was also be used to classify anomalies. 2D modelling followed on from the qualitative interpretation to establish balanced seismic/potential field cross sections. Finally, a 3D Earth model was produced to derive an updated top basement depth surface across the study area. This process would involve both an automated gravity inversion and a manual surface editor. The full workflow would include:

- Qualitative interpretation
    - Qualitative Interpretation of tectonic fabric using available gravity and magnetic data
    - Extension (and interpretation) of area of interest using public domain data to integrate qualitative interpretation with regional fabric
    - Improve geological map for use in quantitative modelling
    - Produce a compilation map of structural fabric derived from the above items

- Cross correlation of gravity and magnetic data with seismic data
    - Lineation correlation observed in qualitative interpretation with existing seismic data
    - 2.5D gravity and / or magnetic modelling along selected seismic lines (5 lines)

- 3D inversion and forward modelling over area of interest
    - Build starting model using information derived from the qualitative and 2D modelling
    - Integrate third party data into the model (e.g. well/seismic/horizons)
    - Perform a 3D forward computation to assess accuracy of starting model
    - Modify 3D model using forward and inverse 3D modelling
    - A number of logging tools will be implemented to track changes to the 3D model which will allow the results to be evaluated

Datasets Utilized

The following public domain and proprietary datasets were utilized for the study (see Figure 1):

- Seismic PSDM – 28 lines/11,776 kms ACCESS MC2D
- Shipborne Magnetics and Gravity Data:
    - Arafura Sea – 7,040 km of marine grav/mag (2009)
- New Dawn marine grav/mag merged from NWS07 & ISM07 surveys
- Interpretation Depth Horizons:
    - Seabed, base Miocene, base Tertiary
    - Aptian unconformity, top Jurassic, top Triassic
    - Top Permian, Basement
- Well logs:
    - 13 wells from Browse Basin
    - 4 wells from Bonaparte Basin
    - 3 wells from Northern Carnarvon Basin

- Public Domain datasets
  - World Gravity Model 2012 (2 arc-min) from bgi.omp.obs-mip.fr
  - Earth Magnetic Anomaly Grid/EMAG2 v2 (2 arc-min) from www.geomag.org
  - GEBCO Global Bathymetry 2014 (30 arc-second) from www.gebco.net
  - SRTM World Topography (3 arc-sec) from www2.jpl.nasa.gov/srtm
  - CRUST 1.0 – depth to Moho grid (1 deg)
  - Oceanic crust age grid (6 arc-min) from www.earthbyte.org
  - Australian coastline: Australian Standard Geographical Classification (ASGC) Digital Boundaries (July 2011) from www.abs.gov.au
  - Maritime borders and EEZ limits from www.marineregions.org
  - Regional data from Geophysical Archive Data Delivery System (GADDS) and other Geoscience Australia portals (e.g. Petroleum wells and stratigraphic units databases)
  - Government of Western Australia (DMP) data from GeoVIEW

Qualitative Interpretation

The mapping of potential field anomalies, recognising trends and offsets and relating them to geological structures, indicative of the area, is an important process in integrating complimentary geophysical datasets. This approach works well in most geological settings, where density and susceptibility variations can be related to structure and rock properties. An automated interpretation is completed to establish the main trends; followed by a manual interpretation using the available datasets. The interpretation is also compared to existing interpretation projects for correlation and updating. The above information is used to produce a structural map. Where possible, additional data, especially seismic, are used as a constraint to assist the quantitative interpretation and to help quantify the potential field anomalies. Bouguer gravity data is very effective in defining the sublinear edges of the Argo and Cuvier oceanic crust; the curved COB delimiting the Gascoyne oceanic crust is less clearly defined. Analysis of gravity anomaly orientations shows a predominant NE-SW trend for the Browse, Roebuck and North Carnarvon Basins, a continuation of the onshore WNW-ESE trends for the offshore Canning Basin, and several superimposed trends for the Bonaparte Basin (see Figure 2). The fault interpretation picked from the gravity data clearly maps both basement structure (e.g. Malita graben) and lithological changes (e.g. North Carnarvon Basin linear high coincident with the 100m bathymetry contour).

Public domain magnetic data allows oceanic crust to be interpreted from magnetic striping and lends support to the gravity-derived COB interpretation (see Figure 3). Magnetic gradients effectively delimit the offshore boundaries of the Kimberley and Pilbara blocks, and highlight volcanic intrusives; these are especially prominent adjacent to the Argo oceanic crust and within the offshore Canning Basin. Analysis of magnetic anomaly orientations for the offshore Canning, Roebuck and North Carnarvon show dominant trend orientations similar (but rotated towards the north) compared to the gravity trends (Figure 4). Gravity and magnetic trend orientations within the Browse Basin are the most dissimilar.

Two-Dimensional Gravity Modelling

It is standard practice in potential field interpretation to undertake 2D modelling of gravity and magnetic data along seismic sections (Figure 5). The complementary nature of seismic and potential field data, suggests a balanced model satisfying both geophysical datasets can be delivered. The horizontal imaging strengths of seismic data and vertical imaging strengths of potential field data assist one another and allow model scenario testing prior to delivering the preferred balanced model. Forward modelling does require the interpreter to make assumptions on the densities, velocities and susceptibilities of the lithologies being modelled. For this study, a set of density and velocity values were determined from well information provided by PGS. The objective of modelling the gravity and magnetic field data in conjunction with the seismic is to yield a balanced model, which satisfies all datasets; helps quantify the gravity and magnetic anomalies and allow extrapolation to areas with no seismic data. The Arafura Sea 2D models required some changes at basement and Moho levels to fit the long wavelength gravity field but no changes to the shallow parts of the sections. None of the 2D models through the Browse and North Carnarvon basins required changes to the seismic basement interpretation, but higher density blocks (interpreted as carbonates and prograding sediments) were required within the shallowest Neogene layer. One of the Browse 2D models requires a low-density body within the recent sediments; seismic data suggests a salt body is plausible.

Three Dimensional Gravity Modelling and Structural Inversion

An initial 3D earth model is constructed from the available data and seismic interpretation (Figure 6). The gravity field is computed for this model. Comparison of the calculated gravity components with the measured values provides a direct measure of the accuracy of the input Earth model. Residual errors greater than the noise level indicate areas where the Earth model is inaccurate and needs to be refined. Using gravity inversion techniques, the Earth model can then be modified to reduce errors by (1) optimising horizon surfaces and/or (2) optimising layer densities between horizons. The interpreter has full control over the anomaly wavelengths that are being optimised at each stage of the inversion process and in this way can selectively target specific geologic features. By analysing longer wavelength residual errors, the interpreter can determine the modifications required in the deeper part of the Earth model (i.e. Moho and basement layers) and conversely shorter wavelengths contain information about shallower geologic features. This procedure is continued until the residual errors are reduced to a threshold specified by the user that represents the noise level of the data. The resulting Earth model is one that honours all available data including wells.

A 3D model extending along the NW Shelf and using seven interpreted seismic horizons was constructed and the basement surface carefully inverted to fit gravity survey data merged into a global gravity compilation (Figure 7). The resulting basement surface is conformable with the qualitative interpretation. Some misfit can be attributed to changes in shallow lithology as identified within the 2D models. The inverted basement horizon has additionally undergone a “sharpening” phase whereby interpreted faults have been used to deform the basement horizon assuming on a conventional fault growth model and the parameters manually adjusted to minimise the gravity misfit.

Conclusions

The workflow used to obtain a gravity-derived basement horizon permits new and interesting insights of the Westralia Superbasin. The qualitative work, based on survey data, produced an interpretation of the main tectonic fabric. Many of the features identified could be confirmed from previous work, adding confidence to the results. Additional information, particularly located between the existing seismic data, in terms of fault mapping and possible basinal areas, was gleaned from the survey. 2D gravity modelling was conducted along five seismic sections. Through a number of iterations, an integrated set of models was produced satisfying both the seismic and gravity datasets. In particular, the 2D modelling helped with the interpretation of the top basement, in areas where the seismic information may be lacking. The 3D depth surfaces correlated well with existing data and added further information in areas without constraint. Furthermore, manual “sharpening” has resulted in a more geological basement surface.

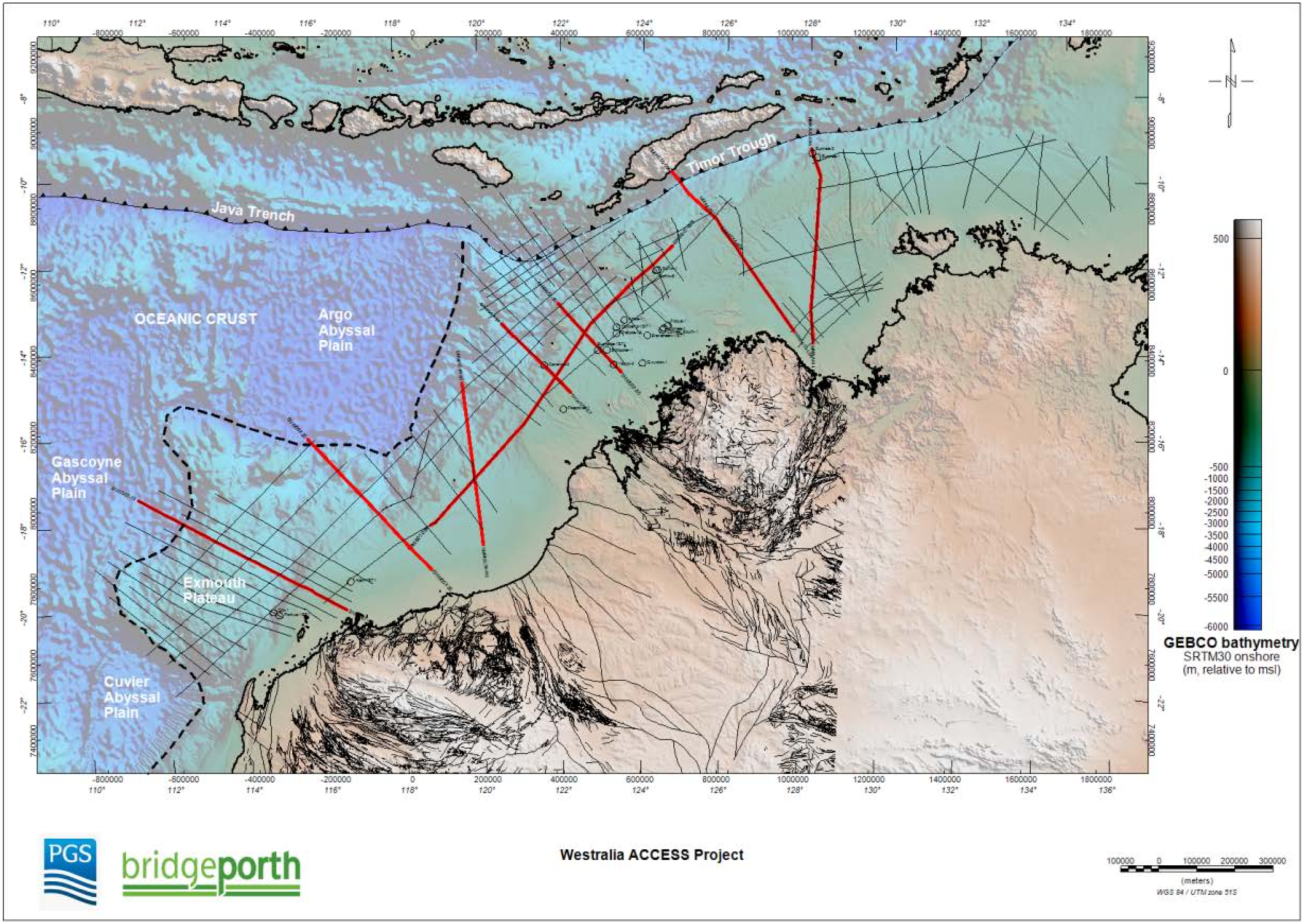

Figure 1. Seismic and well data overlying GEBCO bathymetry/topography surface.

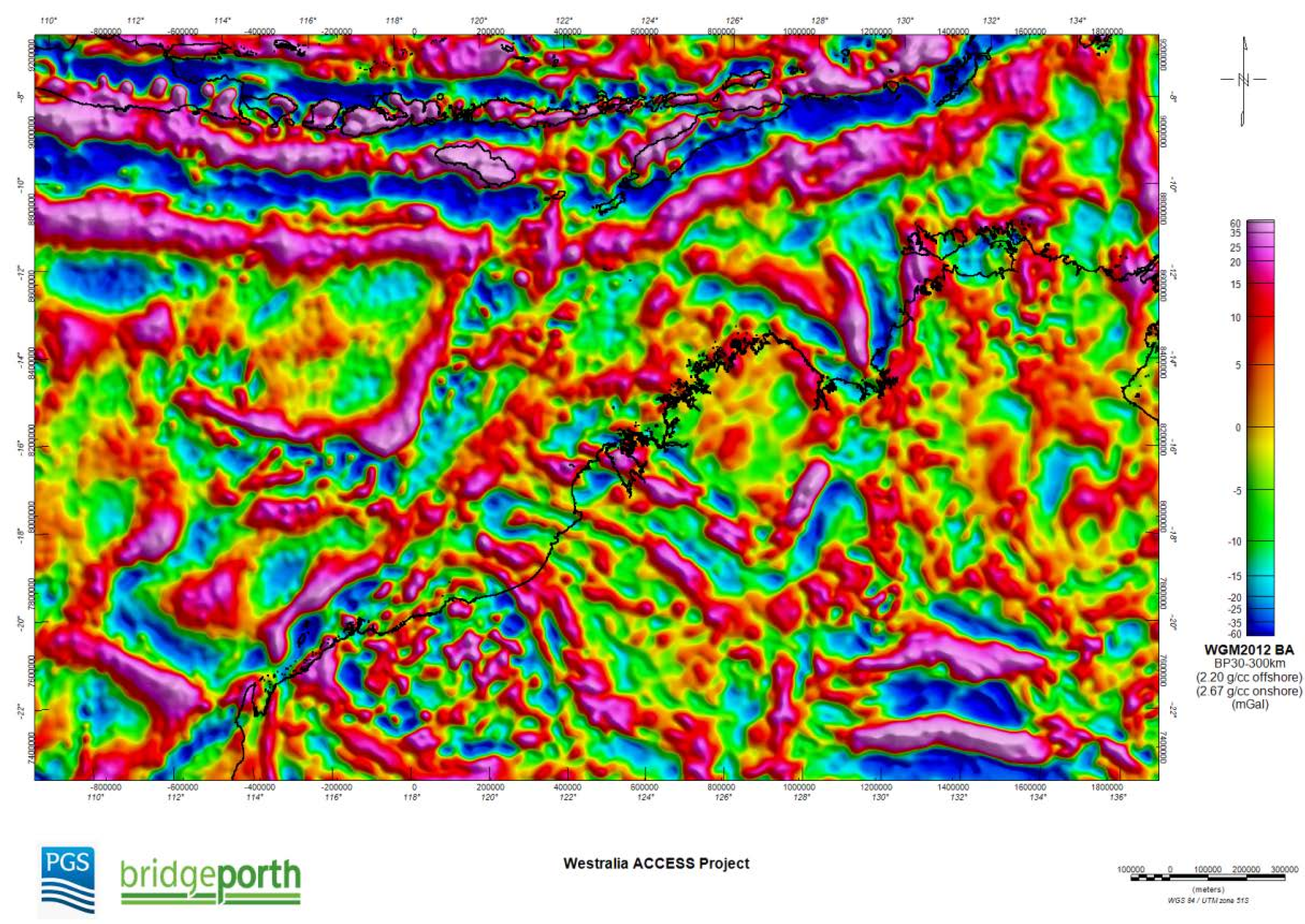

Figure 2. WGM2012 Bouguer gravity anomaly, with a 30-150km band-pass filter applied.

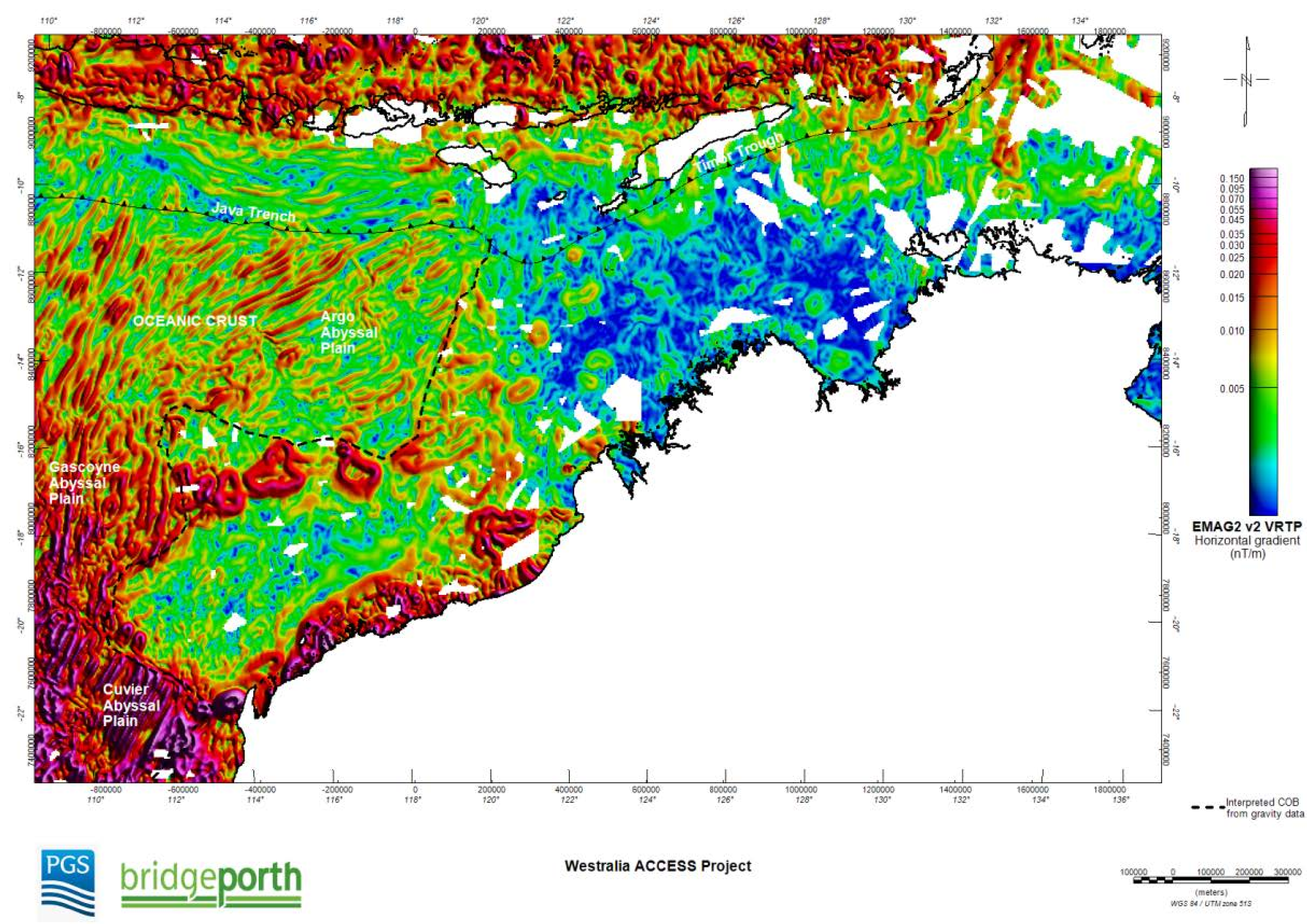

Figure 3. EMAG2 V2 Magnetic anomaly reduced-to-pole.

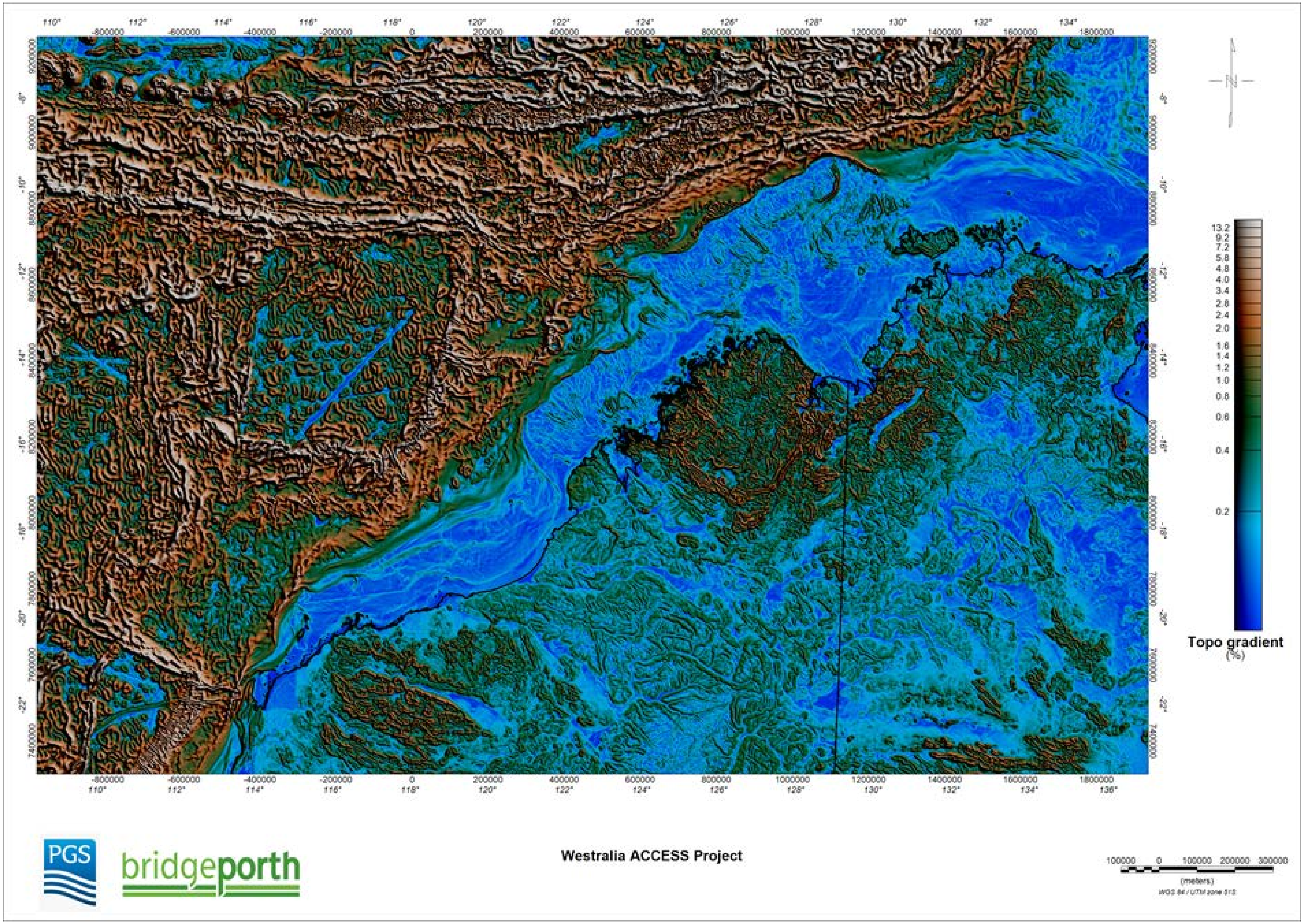

Figure 4. Total Horizontal gradient of the GEBCO bathymetry/topography surface.

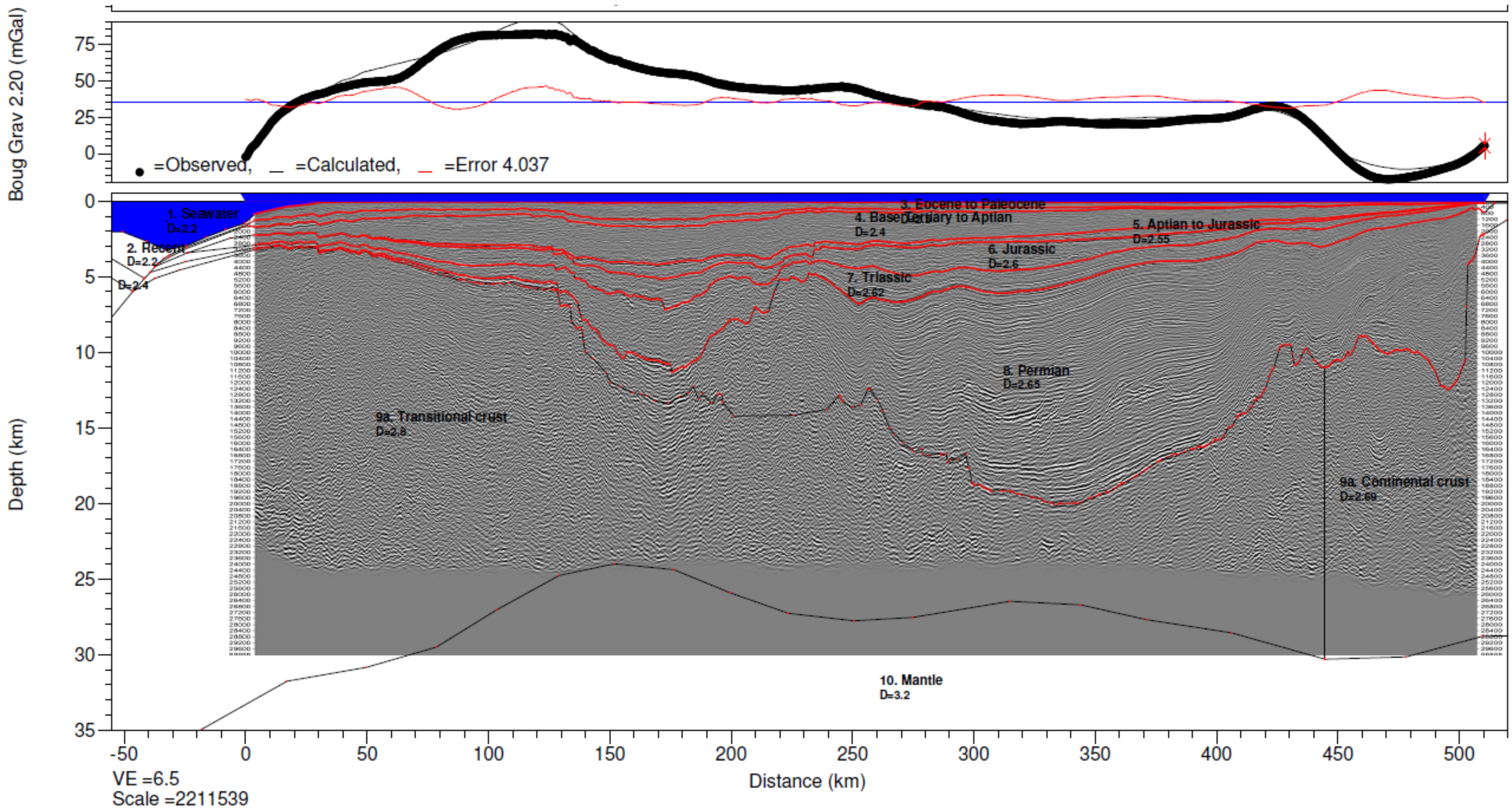

Figure 5. 2D depth section showing integrated seismic and gravity interpretation.

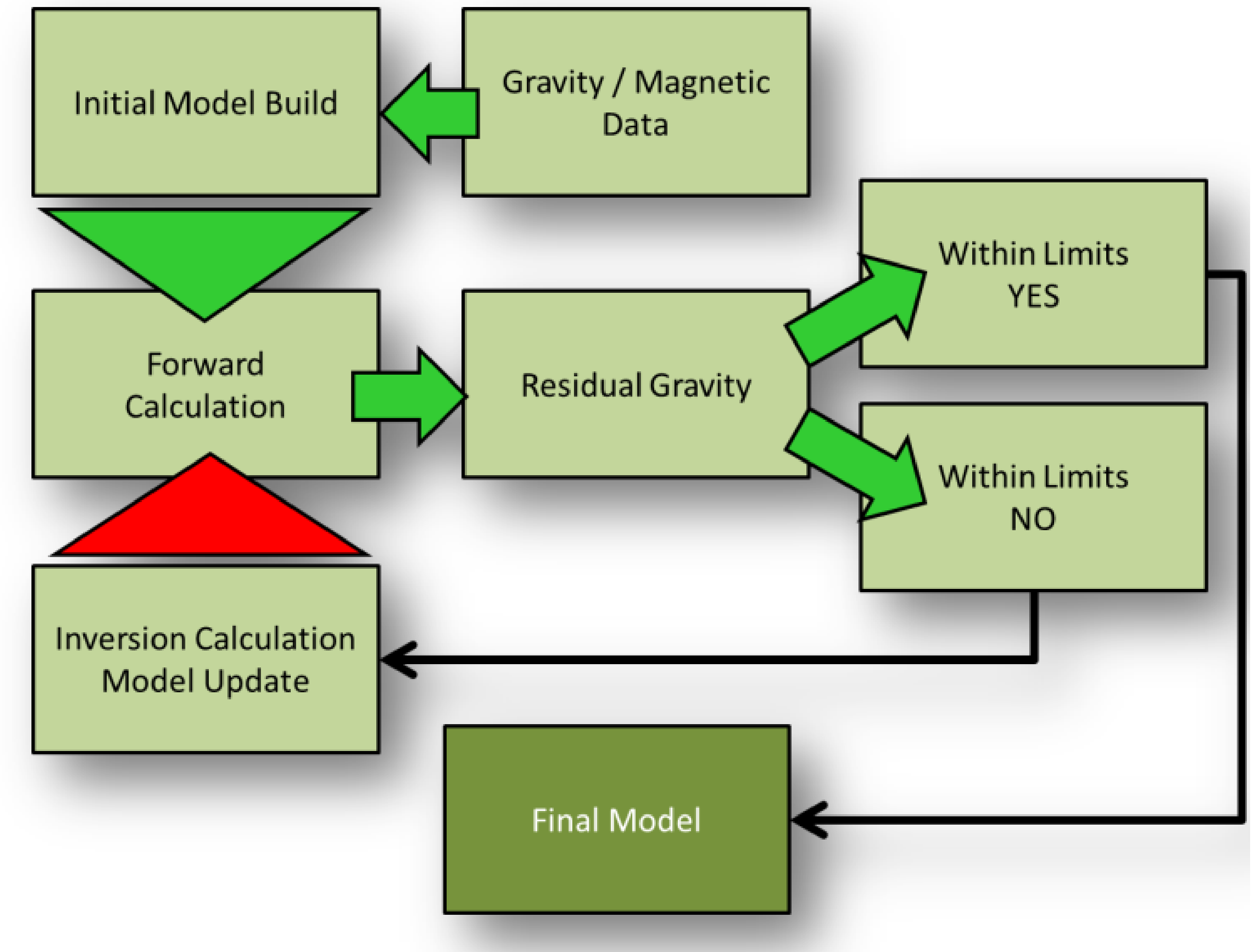

Figure 6. 3D gravity modelling workflow.

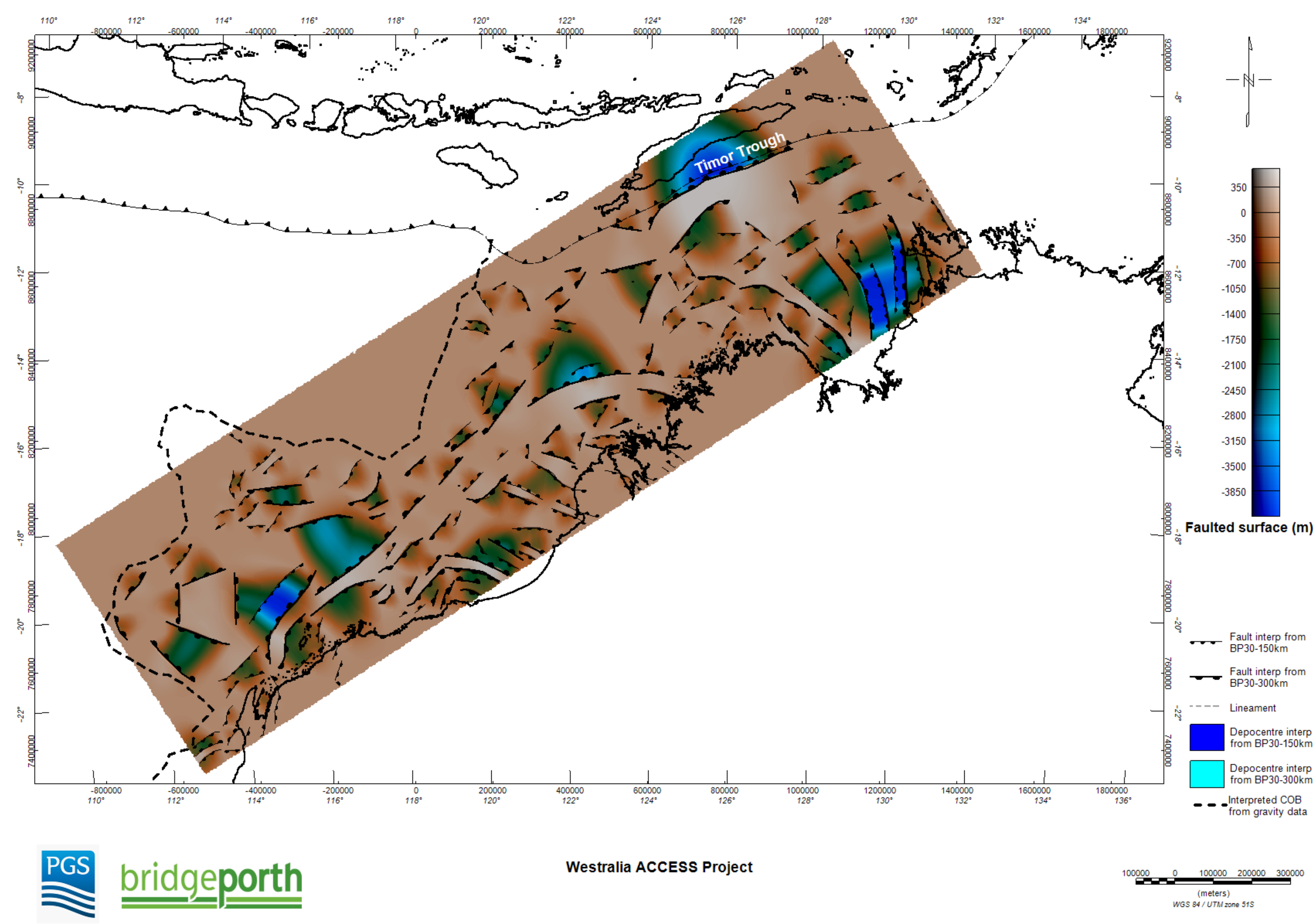

Figure 7. Example of faulted surface (constrained with seismic and gravity/magnetic data) to be applied to 3D inversion depth surface.