

Basin Architecture from Gravity Gradiometer and Seismic data, South-Western Margin of the Fitzroy Trough and Gregory Sub-basin, Canning Basin Western Australia*

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Abstract

The Canning Basin is an under-explored frontier basin. Most of the available information about the subsurface structure is from ‘vintage’ 2D seismic lines and approximately 250 exploration wells. Buru Energy has acquired a FALCON[®] Airborne Gravity Gradiometer (AGG) survey (38,800 km²) over the SW margin of the Fitzroy Trough and Gregory Sub-basin, also covering parts of the Jurgarra and Barbwire terraces, and the Broome and Crossland platforms.

A new workflow was used to reinterpret ‘vintage’ seismic data with the aid of the AGG data to produce a geological model. An initial seismic interpretation was performed by Buru Energy. The following integrated interpretation of the AGG, seismic, magnetic, well, and other available data allowed for an improved understanding of sub-surface structures and stratigraphy. A basement structure map, two intra-sedimentary structure maps and a distribution map of interpreted gravity sources, many of which are carbonate reservoirs, were produced. The interpretation of 16 seismic traverses with the assistance of AGG data and validation through 2.5D gravity modelling is a key component to this interpretation workflow.

The results, integrated in a 3D geological model, produced with SKUA-GOCAD[™] and validated by forward modelling and heterogeneous property inversion in VPmg, show that overlying the basement is a sequence of Ordovician carbonate and shale bearing formations of relatively constant thickness and clear definition in the AGG data. The internal structure of the platforms and terraces is well defined due to low vertical gravity gradient (G_{DD}) values in the fault heave area of these formations. In the northern part of the survey, thickness variations in the Ordovician-Silurian Carribuddy Group are linked to large listric growth faults, which form the WNW Fitzroy Trough trend. These faults, less important in the south, predate the Devonian to Carboniferous faults of the NW Gregory Sub-basin trend.

Devonian carbonates have a pronounced appearance in the AGG data. Formed during the Devonian Pillara Extension they define the Gregory Sub-basin. The Pillara Extension was near parallel to the Ordovician-Silurian listric faults, which reactivated as transfer faults. Deposition of

the Devonian-Carboniferous Fairfield Group was followed by the Meda Transpression. After deposition of Permian sequences in the Gregory Sub-basin and Fitzroy Trough, the Triassic Fitzroy Transpression inverted particularly the WNW trending growth faults in the north as well as the major faults between platforms terraces and troughs.

Introduction

Most of the available information about the subsurface of the Canning Basin, an underexplored frontier basin, is from 'vintage' 2D seismic lines and approximately 250 exploration wells. In 2013 Buru Energy acquired a large Airborne Gravity Gradiometer (AGG) survey (38,800 km²), and magnetic data, over the southwestern margin of the Fitzroy Trough and Gregory Sub-basin, also covering parts of the Broome and Crossland platforms and the Jurgarra and Barbwire terraces (Figure 1). The lithostratigraphy of this part of the Canning Basin is shown in Figure 2.

An integrated geologic interpretation of the basement architecture and the basin infill of parts of the Fitzroy-Gregory Trough in the Canning Basin in Western Australia, has resulted in an improved 3D understanding of the geological evolution of this underexplored frontier basin. Available 2D seismic data was interpreted simultaneously with AGG and airborne magnetic data, well data, Landsat Geocover and Shuttle Radar Topography Mission (SRTM) data, along with published geological maps and literature. The study demonstrates that potential field data, particularly AGG data, can be used in combination with 2D seismic data to assist the seismic interpretation.

The key to this integrated approach is the interpretation of seismic traverses with the assistance of AGG data, and particularly the validation of the interpreted seismic traverses by 2.5D gravity modelling. The workflow presented here produced a geological model and an overall better understanding of the 3D distribution of lithological units, the fault structure and the geological evolution. In particular, the understanding of the deep structure and its tectonic inversion has been improved. Gravity modelled traverses and the interpretation maps were used for further planning of seismic acquisition and input for 3D modelling. A 3D model was produced in SKUA-GOCADTM.

Method

The workflow of the integrated interpretation and modelling method involves the following stages:

- (1) Structural interpretation maps of the intra-sedimentary fault structure (Figure 3) and basement fault structure were produced by integration of AGG and seismic data with all available datasets. Intra-sedimentary features, including faults, were mapped at intermediate and shallow levels, and the distribution of the various gravity sources was mapped at an intermediate structural level (Figure 4). AGG data was used to map structure between the seismic lines and in areas where seismic data was of low quality.
- (2) Werner (Werner, 1953) and Euler (Reid et al., 1990) methods in line magnetic data were used to produce a depth to magnetic basement map, using magnetic line data.

- (3) Before the potential field data interpretation project started, a seismic interpretation was performed by Buru Energy. [Figure 5](#) illustrates limitations of some of the ‘vintage’ seismic data along one of the modelled traverses. It shows that the interpretation of some of the seismic lines is limited by data quality and further interpretation was only possible through integration of other data.
- (4) Seismic traverses crosscutting the AGG survey were reinterpreted using the integrated structural interpretation as a constraint ([Figure 6](#)). All selected traverses are NE-SW ([Figure 1](#)), each of them consisting of up to three seismic lines, occasionally with gaps in between ([Figure 6](#)). Images of the AGG data, AGG profile data (vertical gravity gradient component, G_{DD} , and gravity, g_D) and the structure maps were used together with the seismic data to constrain fault locations and depths as well as thickness distributions of geological units. Gradually an improved understanding of the tectono-sedimentary evolution of the basin was obtained, allowing for a better understanding of the deep structure.
- (5) Time-to-depth conversion of the interpreted traverses was completed using CGG’s proprietary software LCT. Using velocity data from scattered wells in the area, the digitized interpreted seismic traverses were converted from the time domain to the depth domain.
- (6) The interpretation of the seismic traverses was then validated by 2.5D gravity modelling. To account for excess or absent mass, modifications were made to the interpretation. In some cases, multiple models were tested to assess the plausibility of alternative geological assumptions. [Figure 7](#) shows the final model for the seismic traverse.
- (7) Knowledge gained from the 2.5D gravity modelling was fed back into the structural interpretation maps to update the conceptual model. Using this workflow, significantly improved interpretation of ‘vintage’ seismic data was achieved. A comparison of the initial seismic interpretation ([Figure 4](#)) to the final validated interpretation ([Figure 6](#)) clearly shows the value of integrating AGG and other datasets to produce an integrated interpretation that honours all data. [Figure 8](#) shows the result of six modelled sections in the northern part of the survey in 3D view. This is the area selected for 3D modelling which outline is shown in [Figure 1](#).
- (8) 3D geological modelling was performed in SKUA[®] GOCAD[®] after the completion of the 2.5D gravity modelling ([Figure 9](#)). The completed 2.5D modelled traverses ([Figure 8](#) and [Figure 9](#)) were used as input. The model was validated by forward modelling and inversion, using VPmg. [Figure 9](#) shows the fault network and the horizons and [Figure 10](#) shows the final result; a 3D voxel model.

Geological Results

The result of this interpretation and modelling is an improved understanding of the 3D structure, stratigraphy and tectono-sedimentary evolution of the basin. A sequence of Ordovician carbonate and shale bearing formations of relatively constant thickness overlying the metamorphic basement is clearly defined as g_D and G_{DD} highs in the AGG data. The fault structure of the platforms and terraces is well defined by low GDD values in the fault heave areas of these formations ([Figure 3](#) and [Figure 4](#)). Particularly in the northern part of the survey, thickness variations in the Ordovician-Silurian Carribuddy Group are related to the activity of large listric growth faults ([Figure 11](#)). Integrated interpretation of the seismic traverses, the magnetic and AGG data and 3D modelling revealed that these growth faults are WNW trending fault. The WNW trending listric faults of the Fitzroy Trough trend that control the thickness distribution of the Carribuddy Group are interpreted to

be rooted in the same extensional detachment fault. Related extension is mostly concentrated in the Fitzroy Trough, and less evident toward the south.

The distribution of Devonian carbonates formed during the Pillara Extension, defines the NW trending Gregory Sub-basin. The Ordovician-Silurian listric faults were reactivated as transfer faults during the Pillara Extension. Spoon-shaped extensional faults with approximately northeast trends ([Figure 12](#)) developed in between the transfer faults. Deposition of the Devonian-Carboniferous Fairfield Group was followed by the Carboniferous Meda Compression, causing local inversion and regional uplift during a major glaciation.

After deposition of Permian sequences in the Gregory Sub-basin and Fitzroy Trough, the Triassic Fitzroy Transpression inverted the NNW trending growth faults in the Fitzroy Trough and the major faults between platforms, terraces and troughs. Anticlinal structures, potentially prospective, formed by inversion of the Ordovician-Silurian growth faults. There is a direct relationship between the magnitude of Ordovician-Silurian growth faulting and the size of the anticlinal structures formed above by tectonic inversion. Larger anticlines are found in the north of the survey area, in the Fitzroy Trough systems ([Figure 12](#)).

Conclusions

In underexplored frontier basins like the Canning Basin, integrated interpretation of 2D ‘vintage’ quality seismic data in conjunction with AGG data and the value of 2.5D gravity modelling of geological cross sections along seismic lines has proven to be valuable. The seismic data that was used to constrain the modelling could be interpreted with increased confidence to deeper levels, as the cross sections were validated by 2.5D gravity modelling. The detail of the interpretation, construction and modelling allowed the identification of potentially prospective stratigraphic units, structural trends, and prospective structures. An improved understanding of the tectono-sedimentary evolution was also achieved. This workflow improved the understanding in particular of the deep structure and related inversion. It also revealed the differences of the Palaeozoic evolution between the Fitzroy Trough and the Gregory Sub-basin. The Palaeozoic evolution of the Fitzroy Trough is defined by WNW trending Ordovician-Silurian listric faults, rooted in a major detachment fault and in the northeast of the survey overprinted by the NW trending extensional faults formed during the Devonian Pillara Extension. These Devonian faults define the Gregory Sub-basin and its terraces (Jurgarra Terrace and Barbwire Terrace).

Regional uplift and local inversion is related to the Carboniferous Meda Compression. The Triassic Fitzroy Transpression inverted the NNW trending growth faults in the Fitzroy Trough, forming prospective anticlinal structures. The guided interpretation of the vintage seismic data provides key geological insights to constrain the final inversions of the gravity data. By gravity modelling multiple seismic traverses, the 3D understanding of the structure, stratigraphy and tectono-sedimentary evolution of the basin is better understood. This ultimately leads to improved exploration decisions, such as targeted seismic surveys and drilling locations. Because of better 3D basin definition with AGG data, Buru Energy now actively uses these data to assist in seismic interpretation and in planning future exploration activities.

References Cited

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Werner, S., 1953, Interpretation of magnetic anomalies of sheet-like bodies: *S.G.U. ARSBOK*, v. 43, p. 1-130.

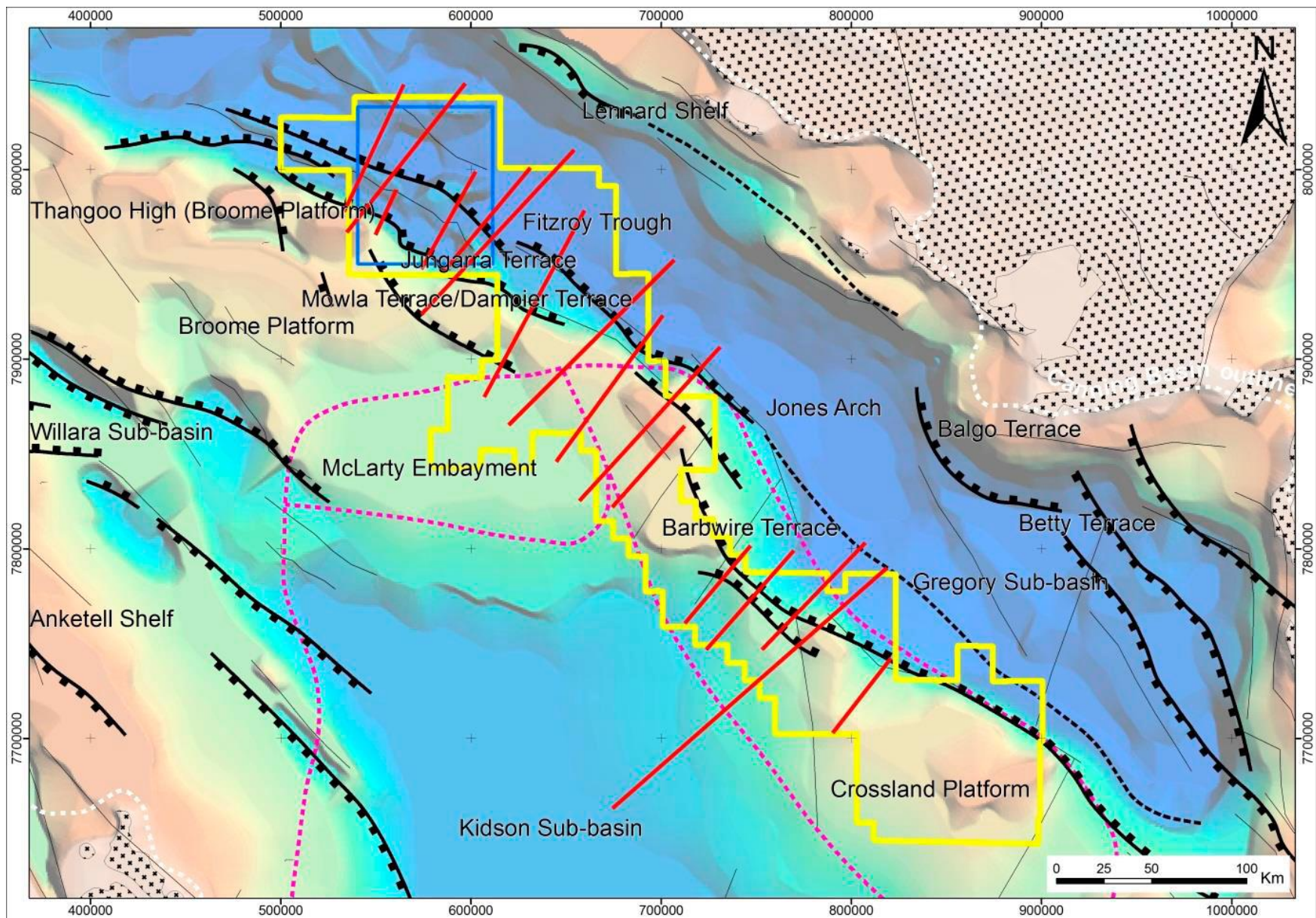


Figure 1. Location of the Airborne Gravity Gradiometer (AGG) survey (boundary shown in yellow) at the southwestern margin of the Fitzroy Trough and Gregory Sub-basin. The location of the modelled seismic traverses is shown in red and the outline of the 3D model is shown in blue.

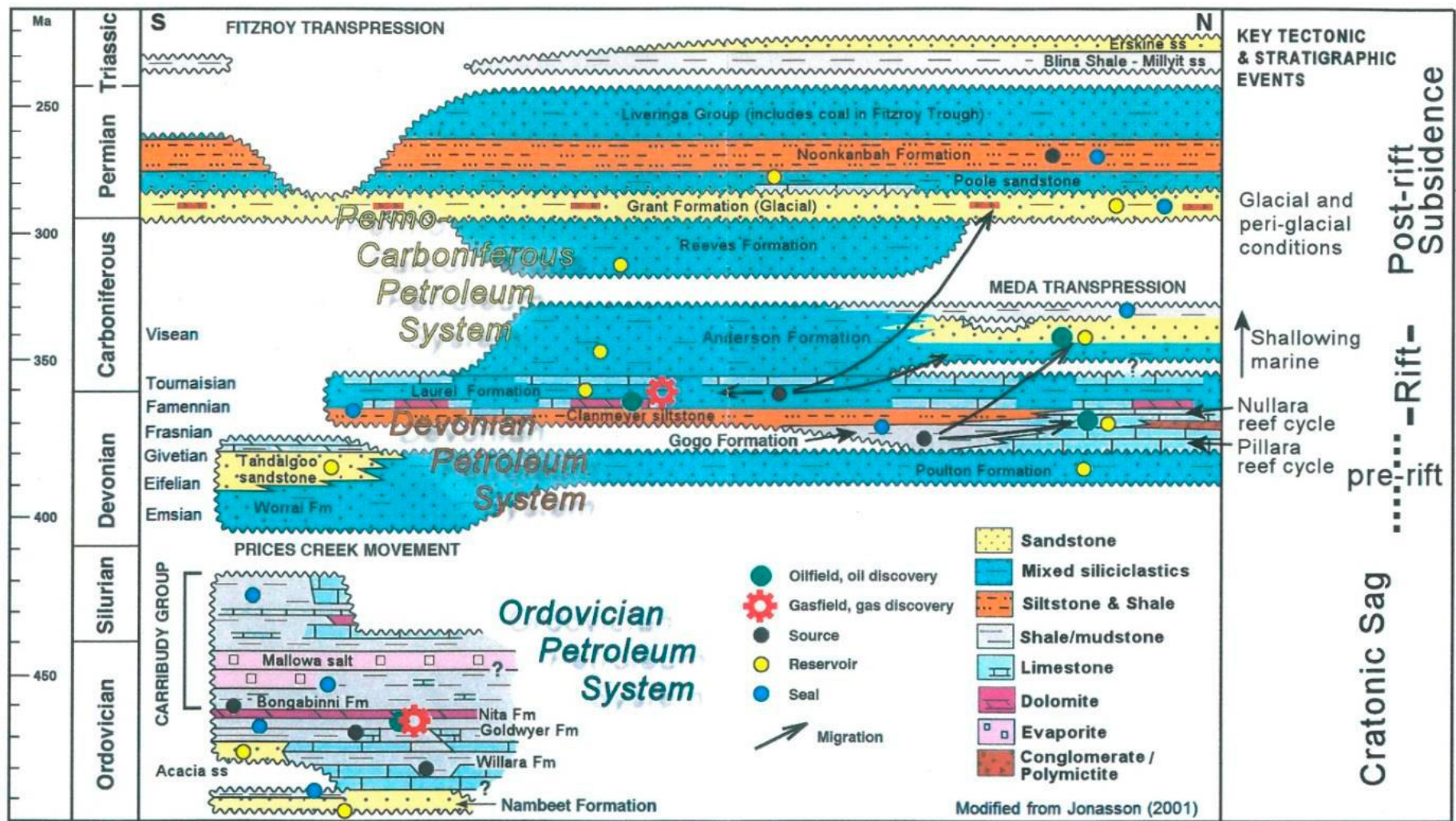


Figure 2. Schematic lithostratigraphy of the Canning Basin, with key tectonic and stratigraphic events and petroleum systems.

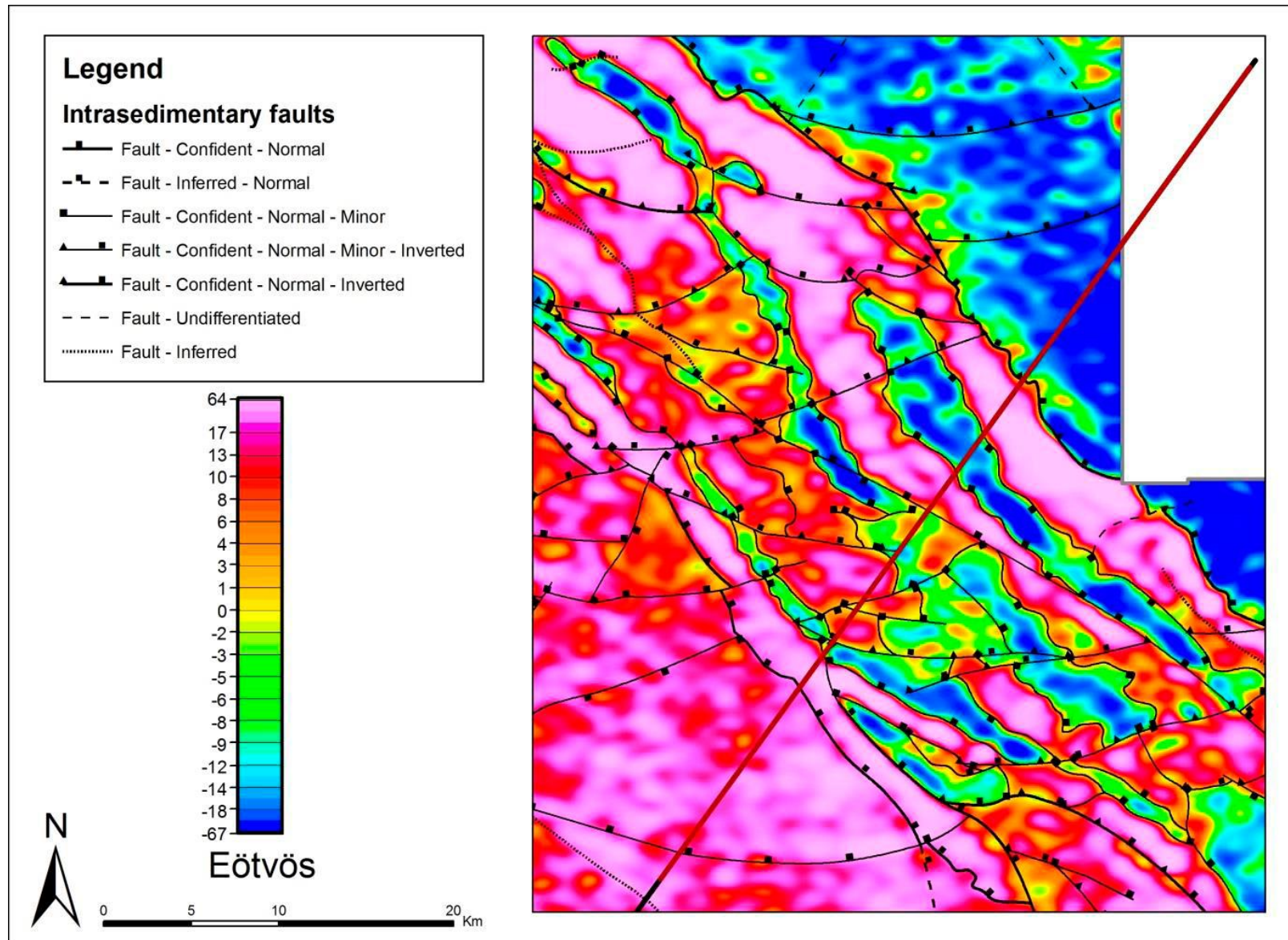


Figure 3. Integrated structural interpretation of the AGG data near the traverse (red line) shown in Figure 4, Figure 5, and Figure 6. The mapped faults are overlain on the image of G_{DD} . The extent of the traverse shown in Figure 5 and Figure 6 is shown in red. The underlying black line shows the further extension of the traverse to the SW. At the northeast extension of the seismic traverse, outside the survey area, there is no AGG data available for 2D modelling.

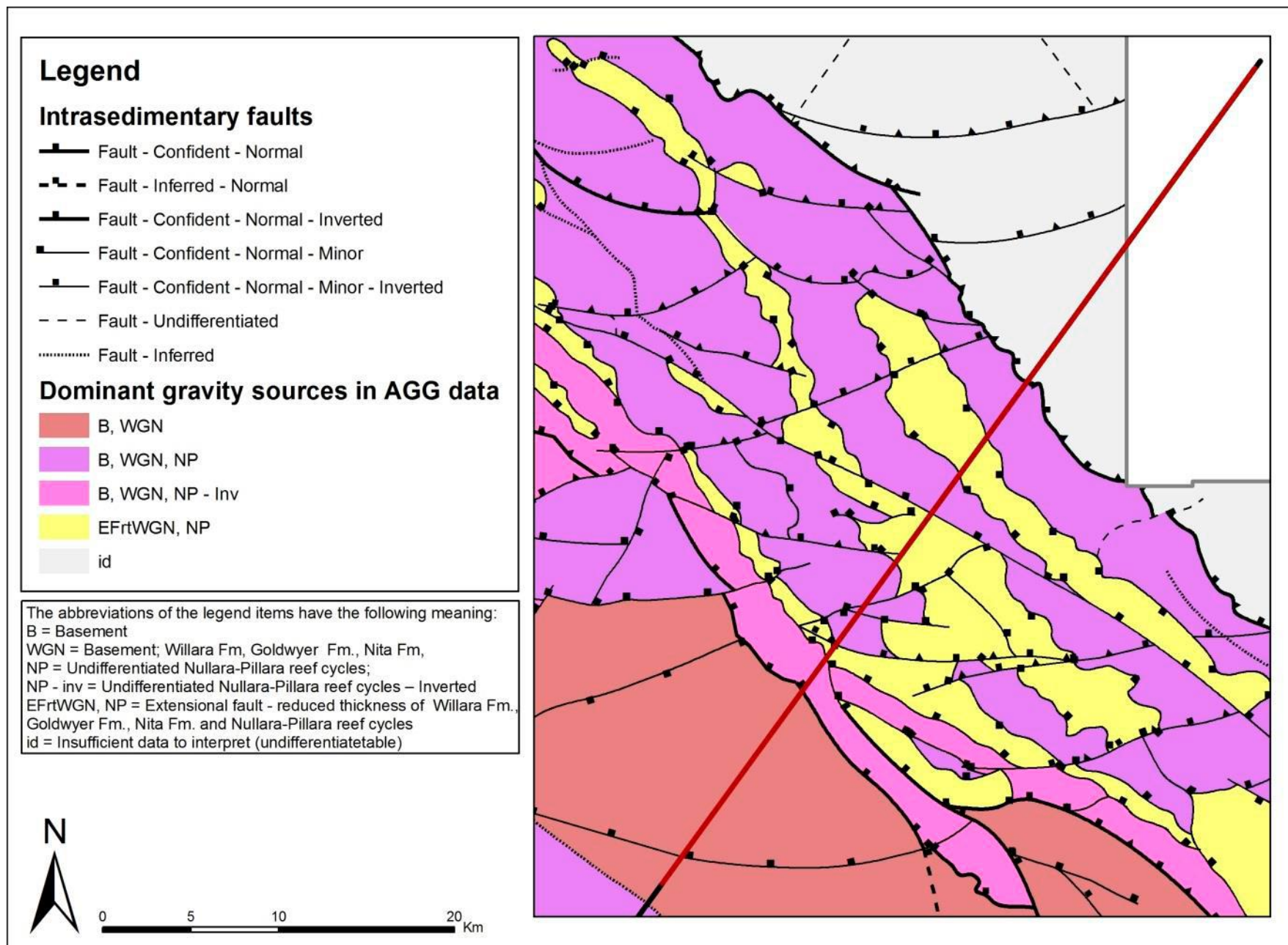


Figure 4. Interpretation of the distribution of gravity sources identified by the integration of seismic and AGG data.

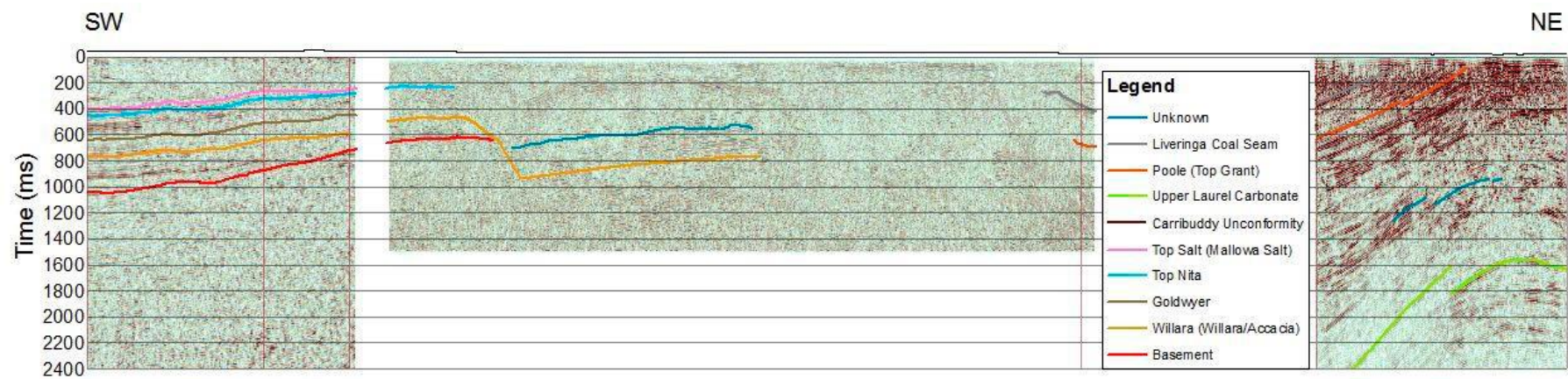


Figure 5. Seismic data along the modelled traverse, shown in [Figure 4](#). Note the variable quality of the each of the seismic lines along this part of the traverse. The original seismic interpretation of these ‘vintage’ seismic data is also shown.

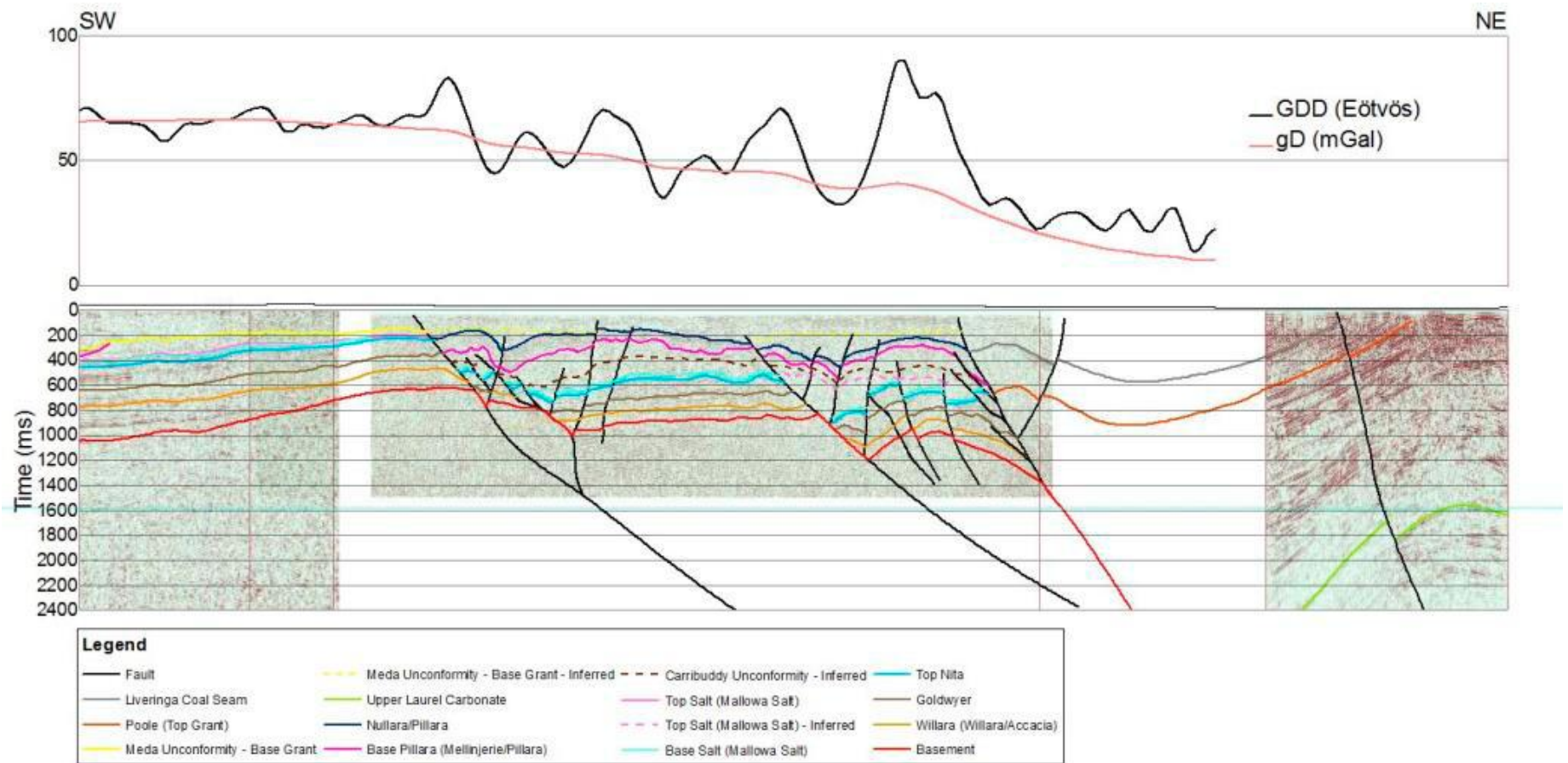


Figure 6. Final interpretation of the seismic traverse, shown in Figure 4. This interpretation was produced using the conceptual geological model developed by the interpretation of the AGG data with the other available datasets. Profiles of the G_{DD} and g_D , used to construct the position of faults and gravitational features on this traverse, are shown above. Both G_{DD} and g_D are plotted with the same vertical scale (top panel).

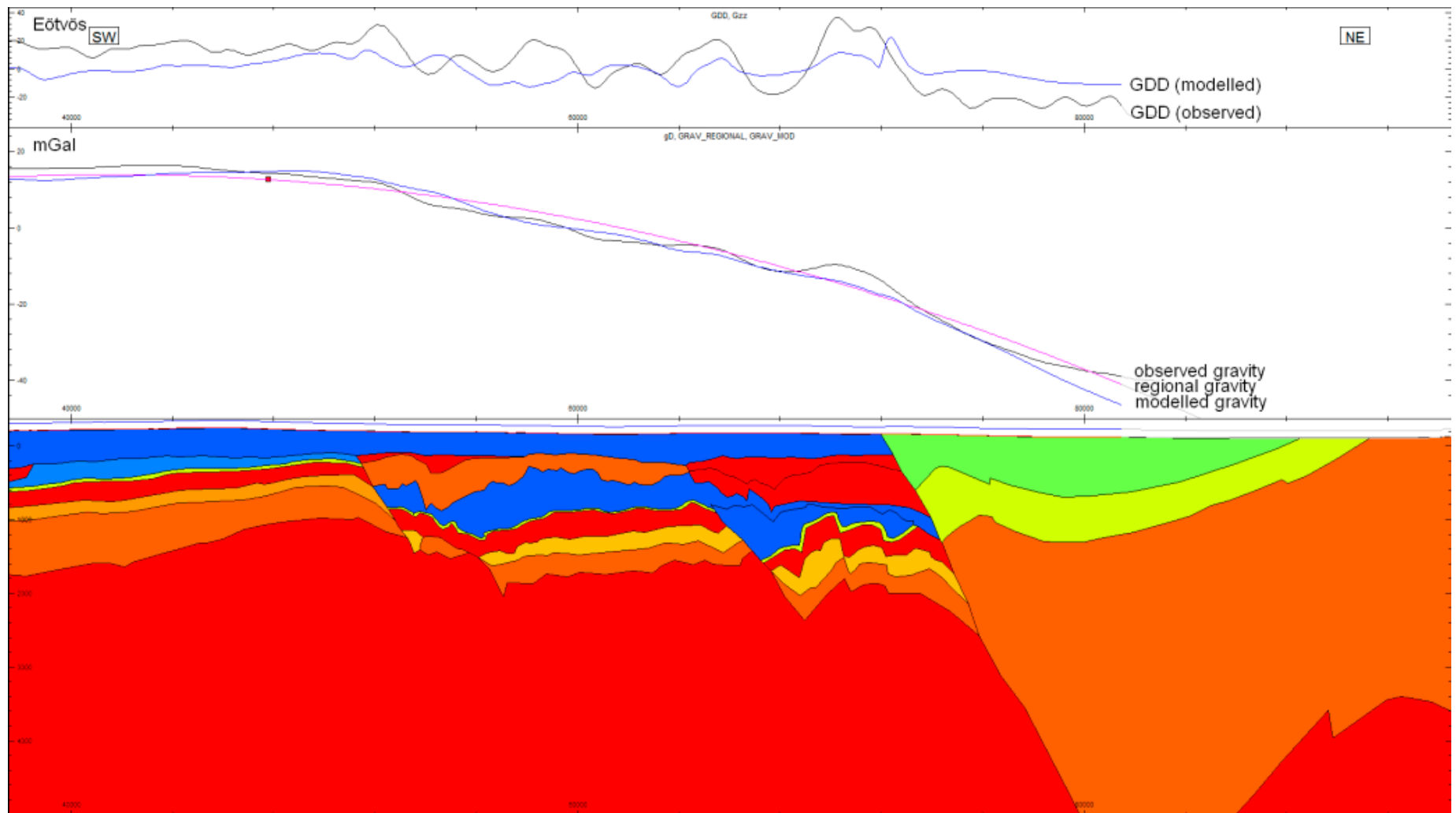


Figure 7. Final result of gravity modelling of the traverse shown in the [Figure 3](#), [Figure 4](#), and [Figure 5](#). The vertical and horizontal scales of the section are in meters. Each colour shown in the modelled section represents a different density applied in the final model (in order of decreasing densities: red = 2.7 g/cm^3 , orange = 2.65 g/cm^3 , light orange = 2.6 g/cm^3 , greenish yellow = 2.55 g/cm^3 , light green = 2.52 g/cm^3 ; light blue = 2.37 g/cm^3 and dark blue (top layer) = 2.35 g/cm^3).

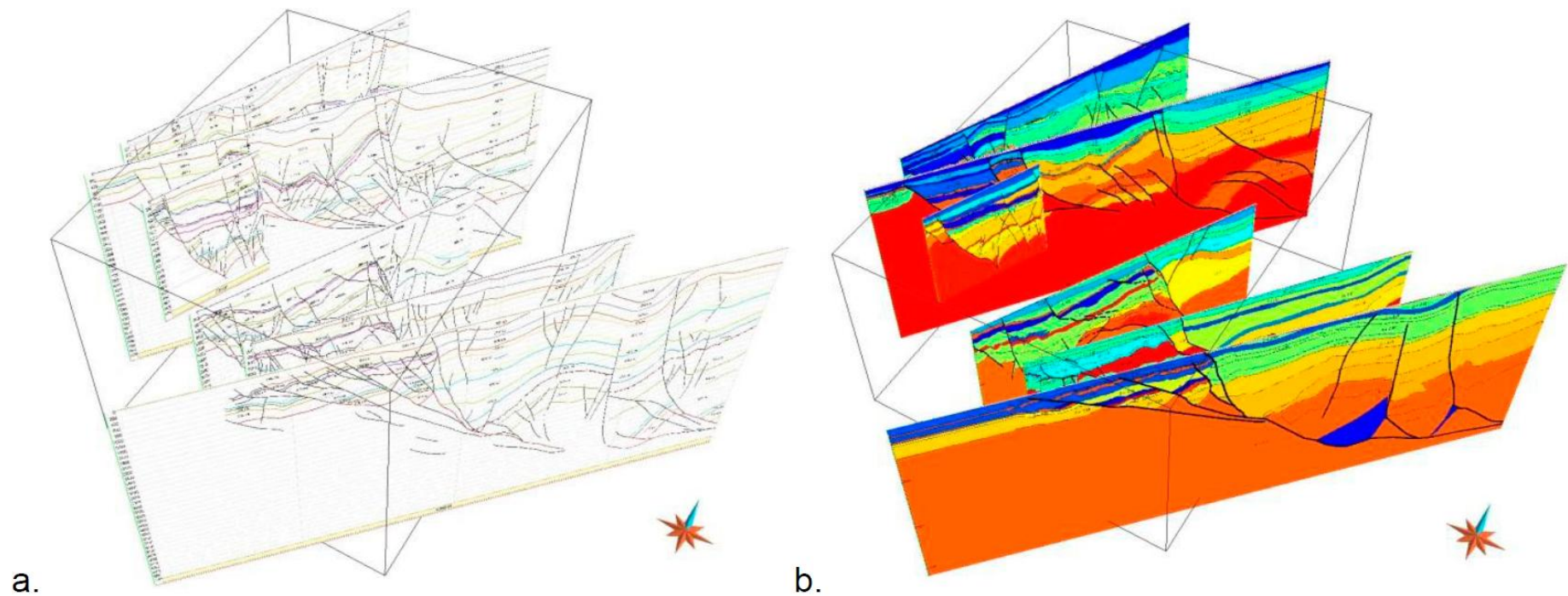


Figure 8. Final result of gravity modelling of the six traverses in the northern part of the survey are, shown in a 3D view. The left image (a) shows the validated cross sections in time. These sections show all interpreted horizons and faults. The image on the right (b) shows the same sections in depth (vertical exaggeration 6x). The colours on these sections represent different densities; however, the colours do not match between the cross sections. View from the southeast.

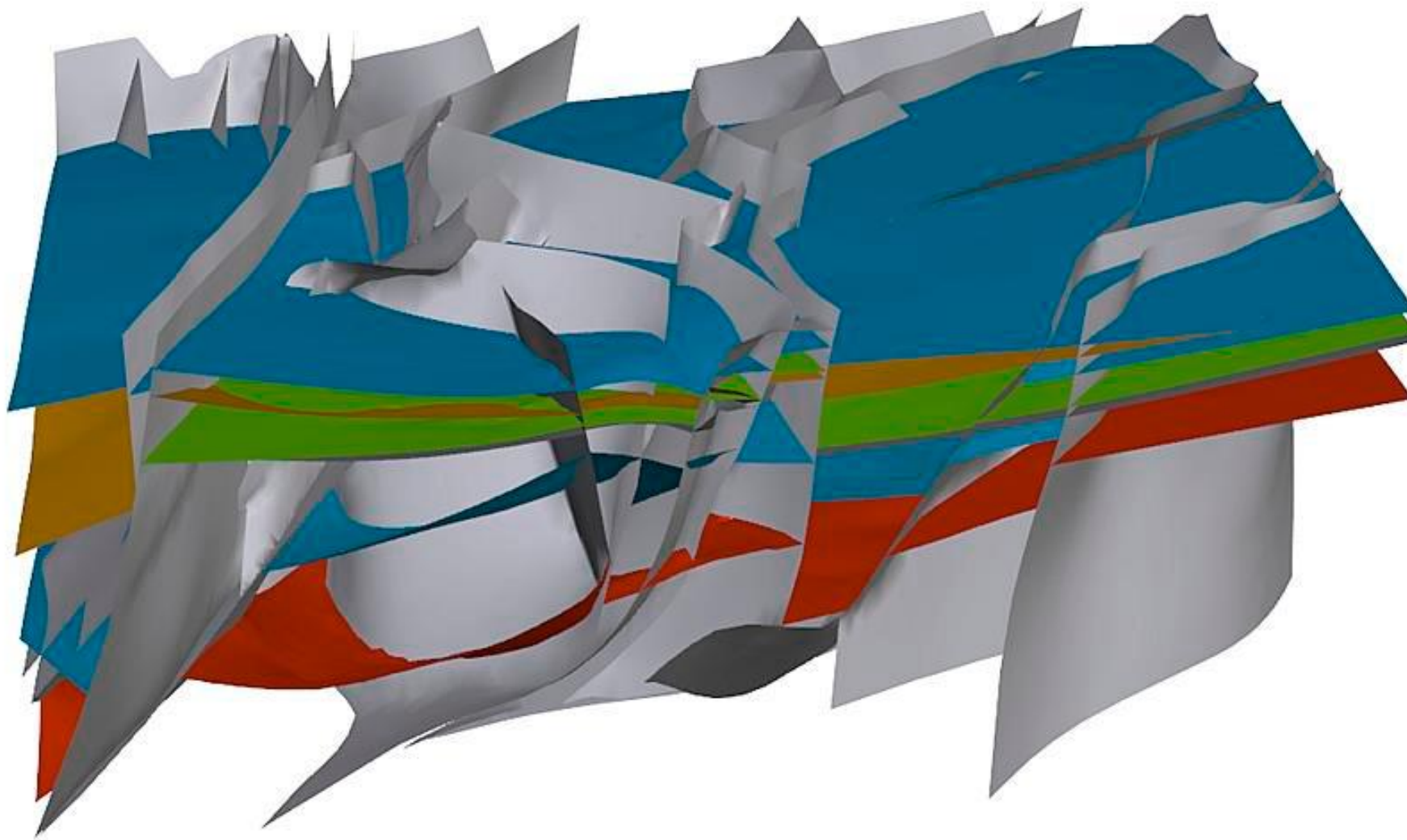


Figure 9. 3D Fault network (in grey) and horizons, produced in SKUA[®] GOCAD[®] for part of the survey area. The following horizons are shown: Top metamorphic basement (red), top Nita Formation (blue), base Nullara-Pillara carbonates (dark grey), top carbonates of the Nullara and Pillara Formations. (light green), top Laurel Formation (brown) and Poole Formation/top Grant Formation (light blue). View is toward the east. The model shows an area of 83 km (N-S) x 71 km (E-W) and reaches a depth of 6.5 km. The outline of the 3D model is shown in [Figure 1](#).

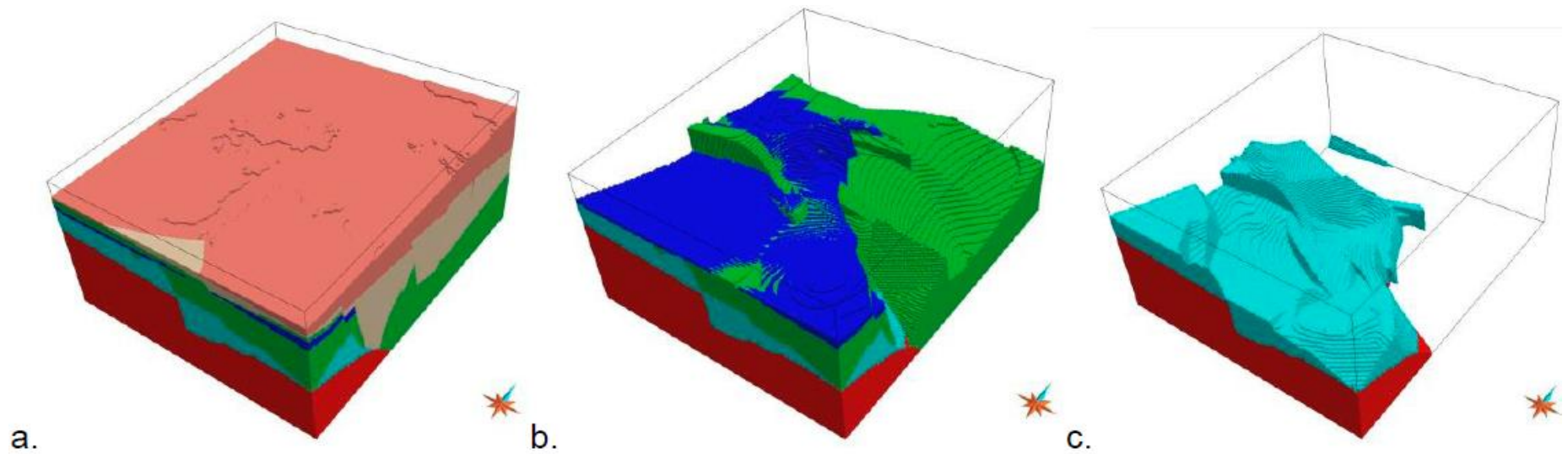


Figure 10. a. 3D voxel model of part of the survey area. Vertical exaggeration 5x. The geological intervals shown are metamorphic basement (red), top Nita Formation to top metamorphic basement (light blue), top Laurel Formation to top Nita Formation (green), Nullara and Pillara Formations. (dark blue), Poole Fm./top Grant Formations to top Laurel Formation (beige) and surface to Poole Formation / top Grant Formation (pink). b. The same model showing the distribution of the carbonates of the Nullara and Pillara Formations (dark blue). c. A view of the structure at the stratigraphic level of the top Nita Formation.

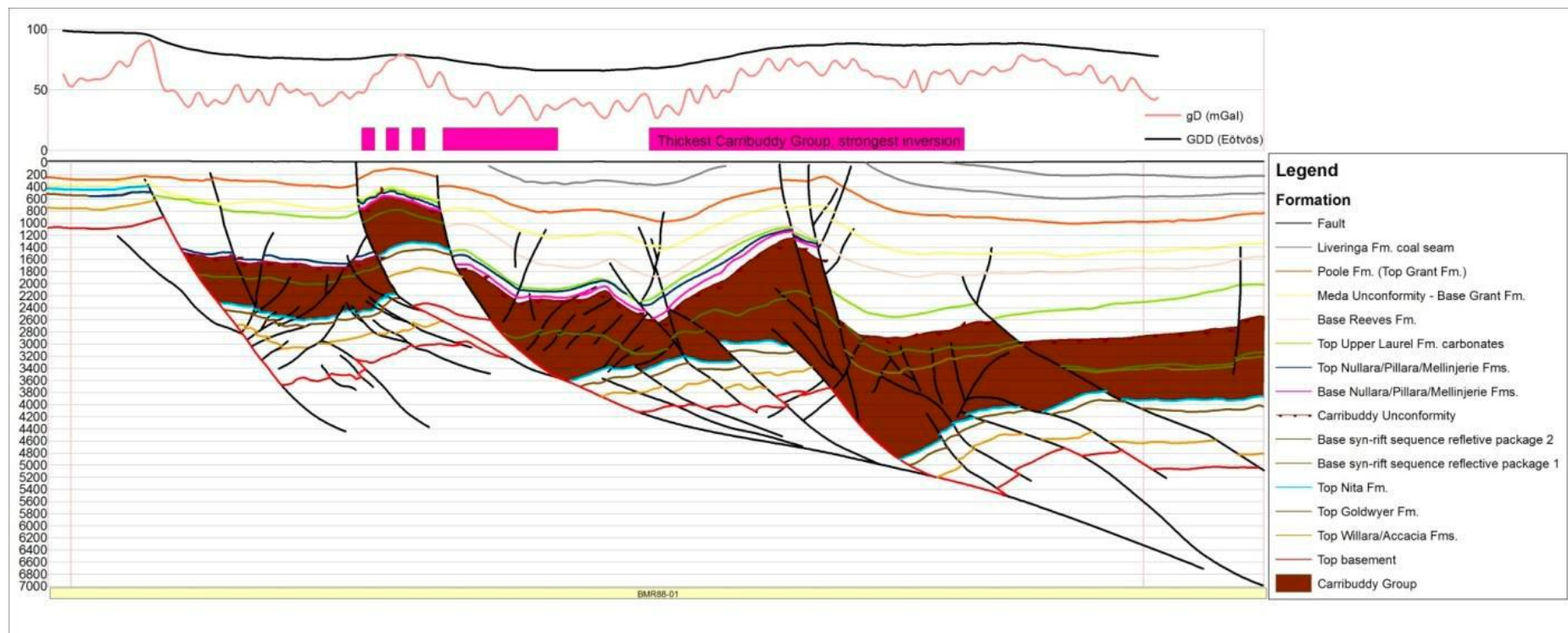


Figure 11. Final result of gravity modelling of one of the seismic traverses (location shown as blue line in [Figure 12](#)). The Carribuddy Group is shown in brown and areas of strong inversion are indicated with the pink bars above the section.

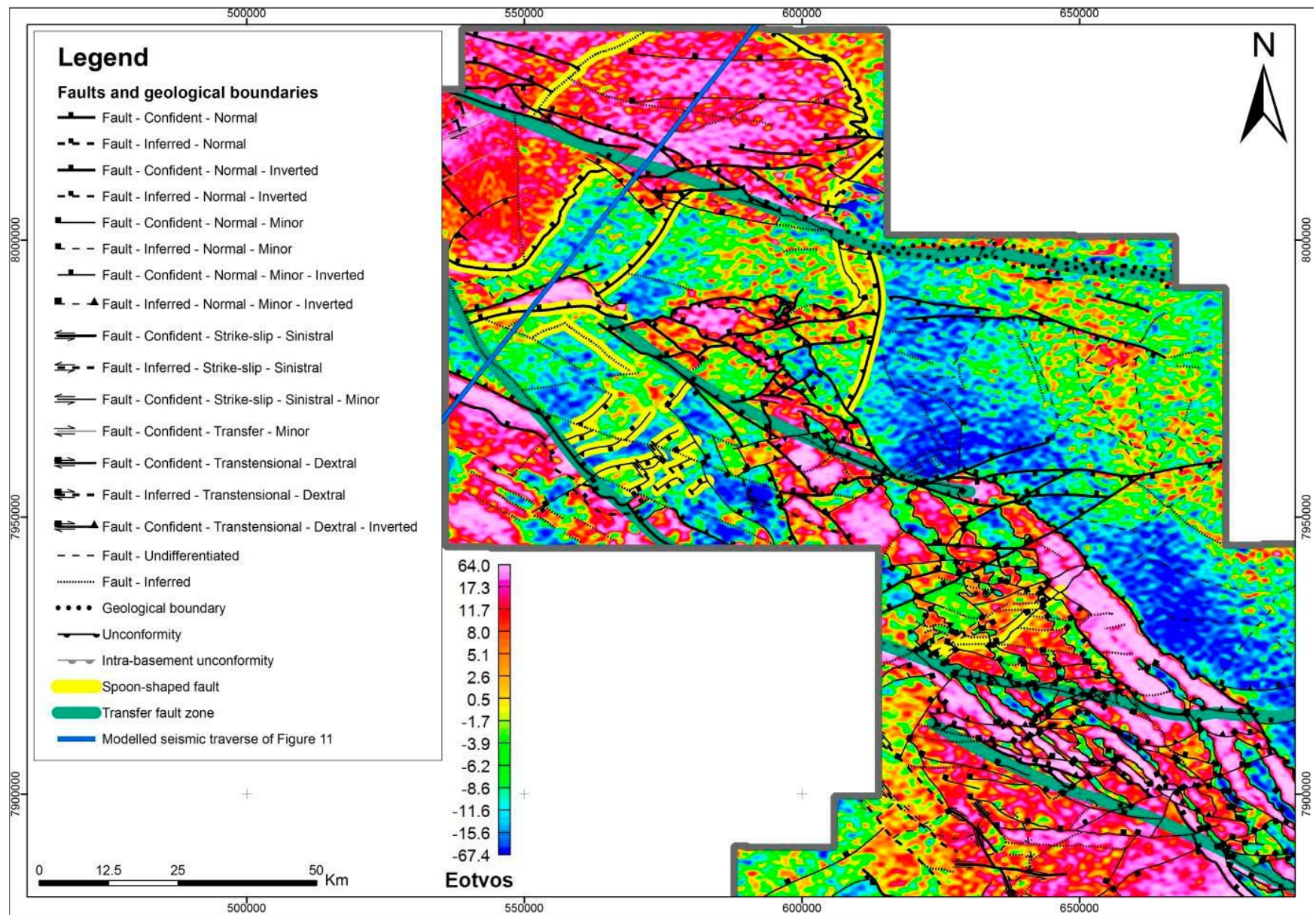


Figure 12. Fault interpretation of the northern part of the survey area overlain on the GDD. The main listric faults of the Fitzroy Trough trend are highlighted in green. Faults highlighted in yellow are normal faults activated during the Pillara extension, during which the WNW trending faults of the Fitzroy Trough trend were reactivated as transfer faults.