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Feature

End of the Flat Earth: a new era at GSWA

Ruth Murdie
Geological Survey of Western Australia
ruth.murdie@dmp.wa.gov.au

The Geological Survey of Western Australia (GSWA) has entered the 3D era with the release, in December 2015, of the first three dimensional (3D) digital geological models in a new line of digital products called '3D Geomodel Series'. In such a large state as Western Australia these two models are just a taste of what is to come. The actual 3D models are part of a complete package replete with a full suite of GIS data, such as is included on other two-dimensional GSWA digital packages. The new addition is a 3D geological model, which can be viewed in the included free visualisation software, Geoscience Analyst, provided by Mira Geoscience. Alternatively, the models are also provided in widely used file formats for import into the users' own 3D modelling software.

The aim of the publication of 3D geological models is to better represent the growing amount of structural information at depth, which has been derived from recent seismic and magnetotelluric surveys and modelled from potential field data at increasing resolution. By releasing models that include structure at depth GSWA hopes to promote a better understanding of the Earth's structure, and to develop an improved knowledge base to underpin exploration for mineral and energy resources in Western Australia.

Faults, fracture zones and shear zones can be pathways for fluids and melts within the solid Earth. The Earth's 3D structure, therefore, not only reflects the distribution of physical properties of the rock mass in bedrock, sedimentary basins and regolith cover, but often relates very closely to the spatial distribution of the mineral deposits and energy resources that formed as a consequence of fluid flow in Earth's crust. 3D structural modelling and numerical simulation of geological processes are emerging techniques that can be used to extend knowledge from exposed and well-understood areas to inaccessible or data-poor parts of the Earth's crust and lithosphere, and to test the validity of conceptual models and interpretations.

The construction of the 3D models utilized the full spectrum of the extensive geological mapping and geophysical (magnetic, gravity, deep seismic reflection) data acquired by GSWA as part of the Exploration Incentive Scheme (EIS), a State Government initiative that aims to encourage exploration in Western Australia for the long-term sustainability for the State's resource sector.

Since its inception in 2008, EIS funding has enabled GSWA to undertake state-wide high resolution regional aerial magnetic surveys at 400 m standard line spacing. This data, together with open source data of higher resolution, means that the state magnetic image is now gridded at 80 m spacing. Gravity surveying has progressed at 2.5 km spacing across as much of the State as has been made accessible, with additional high resolution gravity and magnetotelluric surveys in areas of special interest. This include transects sampled by deep reflection seismic surveys which, as part of the EIS scheme, have been targeting areas where the deep structural architecture is of particular interest.

The stimulus for both of the recently released models was the acquisition of the deep crustal reflection Youanmi seismic lines (Wyche et al., 2014) across the northern Yilgarn Craton. The interpretation of those lines provided the first insight into the structural architecture at depth in this area and showed the two-layer nature of the Yilgarn Craton. The Archean greenstones and igneous complexes sit in granite surrounds. The shape of each layer is determined by a network of trans-crustal faults, some of which define domain boundaries. The faults are also potential pathways for ore-bearing fluids.

The areas covered by the two models are within the Windimurra Igneous Complex and the Sandstone greenstone belt (Figure 1). These regions, which are located in the northern Yilgarn Craton, host deposits of gold and vanadium. The models support exploration and enhance the possibility that more gold, platinum group elements, nickel, and copper will be discovered.

Windimurra model

The Windimurra model is located where the three Youanmi seismic lines intersect. The region hosts the largest relatively

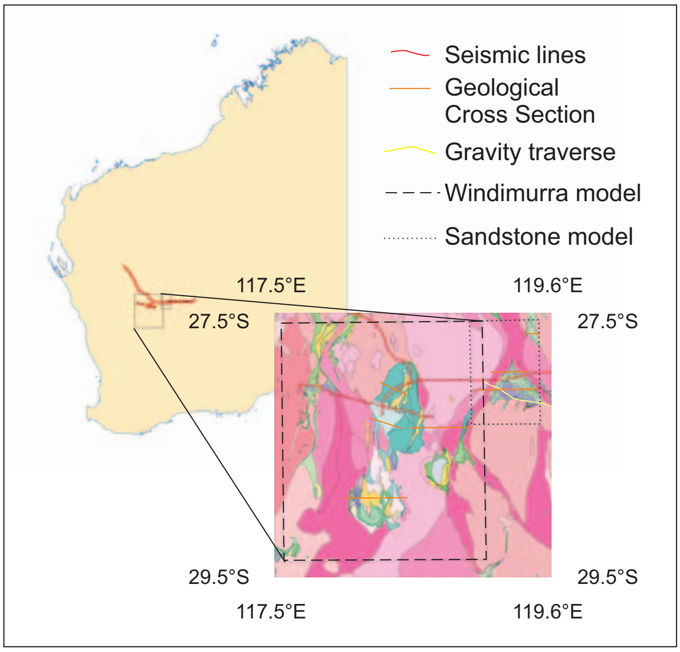

Figure 1. *Location of the 3D model areas and the deep reflection seismic lines on which the models are based.*

intact and exposed mafic and ultramafic intrusive complex in Australia; the Windimurra Igneous Complex. The Complex has a surface expression of about 2500 m^2; approximately 85 km north-south and 37 km east-west. It is widely believed that the intrusions are the result of a mantle plume affecting a significant area of the Yilgarn Craton (Ivanic et al., 2010; Wyche et al., 2012; Wyman and Kerrich, 2012; Van Kranendonk et al., 2013). The intrusions host significant V–Ti mineralization in the Fe-rich upper zones. The exposed Complex has an overall felsic composition compared to other layered gabbro intrusions worldwide, and has been described as a having an anorthositic affinity (Ahmat and De Laeter, 1982) and a high Ca-Fe tholeiitic composition (Ahmat, 1986). However, it is possible that its composition is more typically tholeiitic (c.f. Nebel et al., 2013) if it can be shown that a large volume of ultramafic zone material exists at depth.

The seismic images show that the Windimurra Igneous Complex is a shallow, funnel shaped cone with a lower zone of strongly layered reflectors. The upper and middle zones are less reflective, but still layered, and all follow the overall form of the Complex. The lower zone is about 6.9 km thick and the upper zones are about 3 km thick, giving a total thickness of about 10 km (Figure 2).

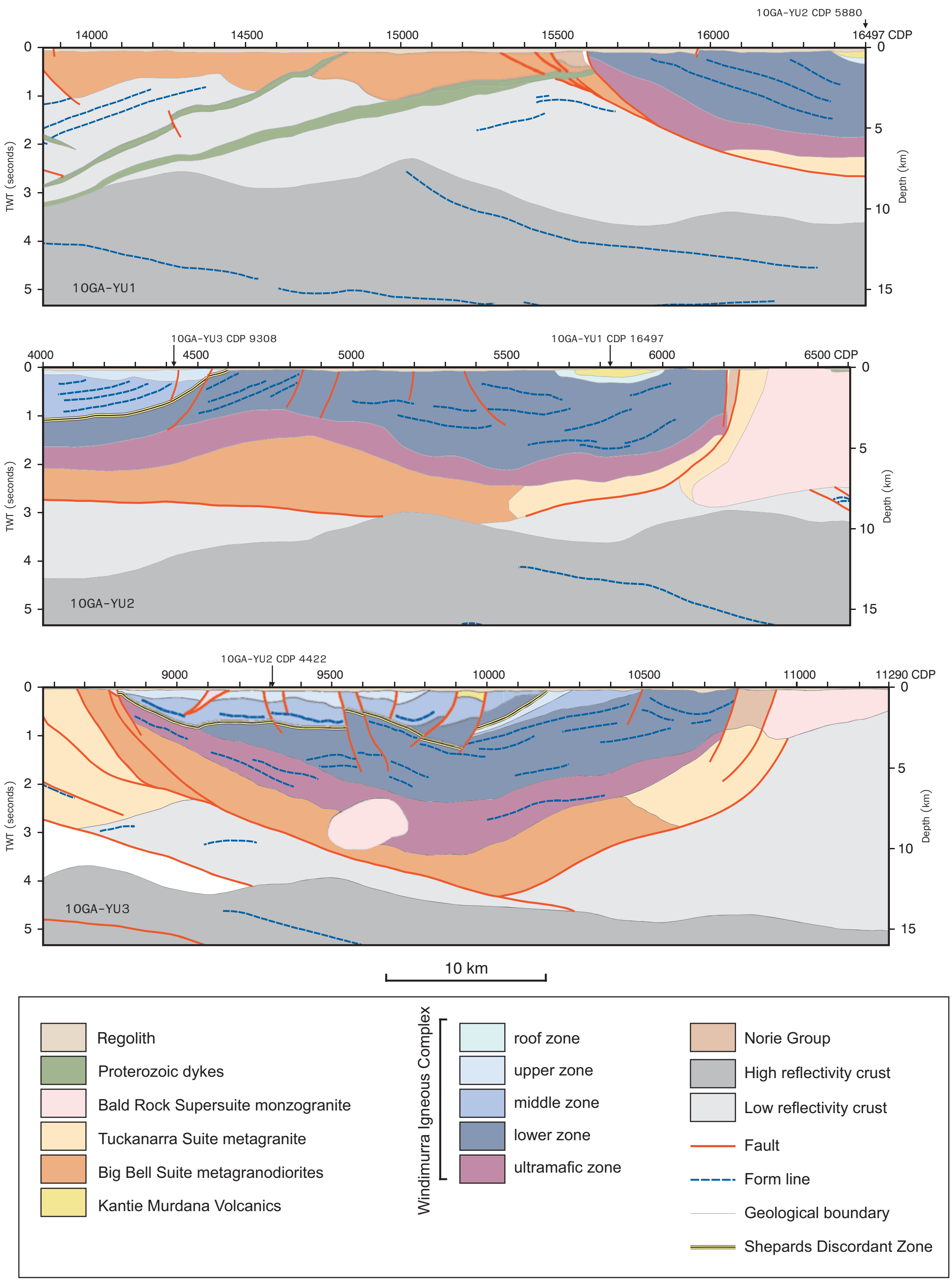

Figure 2. *Seismic interpretations from the Youanmi seismic lines, which were the framework for starting the Windimurra model (Ivanic et al., 2015).*

Using the seismic interpretations a 3D volume of the area was generated (Ivanic and Brett, 2015) and then populated by generic densities for the given rock types. Early models, before the bounding faults were added, showed that the original complex was potentially twice the present size. Forward models were run and the geometries of the layers away from the seismic lines were adjusted to give a better fit to the observed gravity data. This resulted in simple geometries with curvatures across the body that fitted the seismic images. Inversions were then run using this starting model. This showed that lower density rocks were required below the complex, rather than thick ultramafic rocks. This was reconciled with the seismic interpretation in that granitic sills parallel to the layering would also produce the layered seismic character of this area (Ivanic and Brett, 2015). Other results from the inversions showed that the densities or volumes of the upper and middle zones should be reduced, but since the initial densities were only estimates they could easily have been overestimated. For example, as the ultramafic zone has not been directly sampled it may contain significant proportions of pyroxenite or gabbroic rocks thereby reducing the average density. Likewise the density of the upper zone was estimated from drillhole data that sampled mainly the magnetite-rich part of the zone.

Overall, the model (Figure 3) and structural reconstructions established that the igneous complex is at least 10.5 km thick, making it one of the largest known on Earth. The model also revealed that a 3 km thick ultramafic unit underlies the whole complex making the overall composition closer to the usual tholeiitic/komatiitic basalt composition and thus a potential target for Ni–Cr–PGE mineralisation.

Sandstone model

The Sandstone model focuses on the Sandstone greenstone belt, which hosts a number of gold deposits and is being explored for nickel deposits. The model building started as a training exercise but became the blue-print for the production of small, localised models and the development of a full package for production purposes (Murdie et al., 2015).

The Sandstone greenstone belt is a refolded syncline located east of the Windimurra Igneous Complex. The belt was also sampled by the 10GA-YU2 seismic line and had been mapped at 1:100 000 scale in 2003 (Chen, 2003; Chen and Painter, 2005). The margin of the greenstone belt was defined by two major faults; the Youanmi Shear Zone on the west, dipping to the east, and the Edale Shear Zone on the east, dipping to the west. The Youanmi Shear Zone is the boundary between the Murchison and Southern Cross Domains of the Youanmi Terrane of the Yilgarn Craton. In the seismic data it is apparent that the Youanmi Shear Zone is the more recent fault, truncating the Edale Shear Zone and continuing to the Moho.

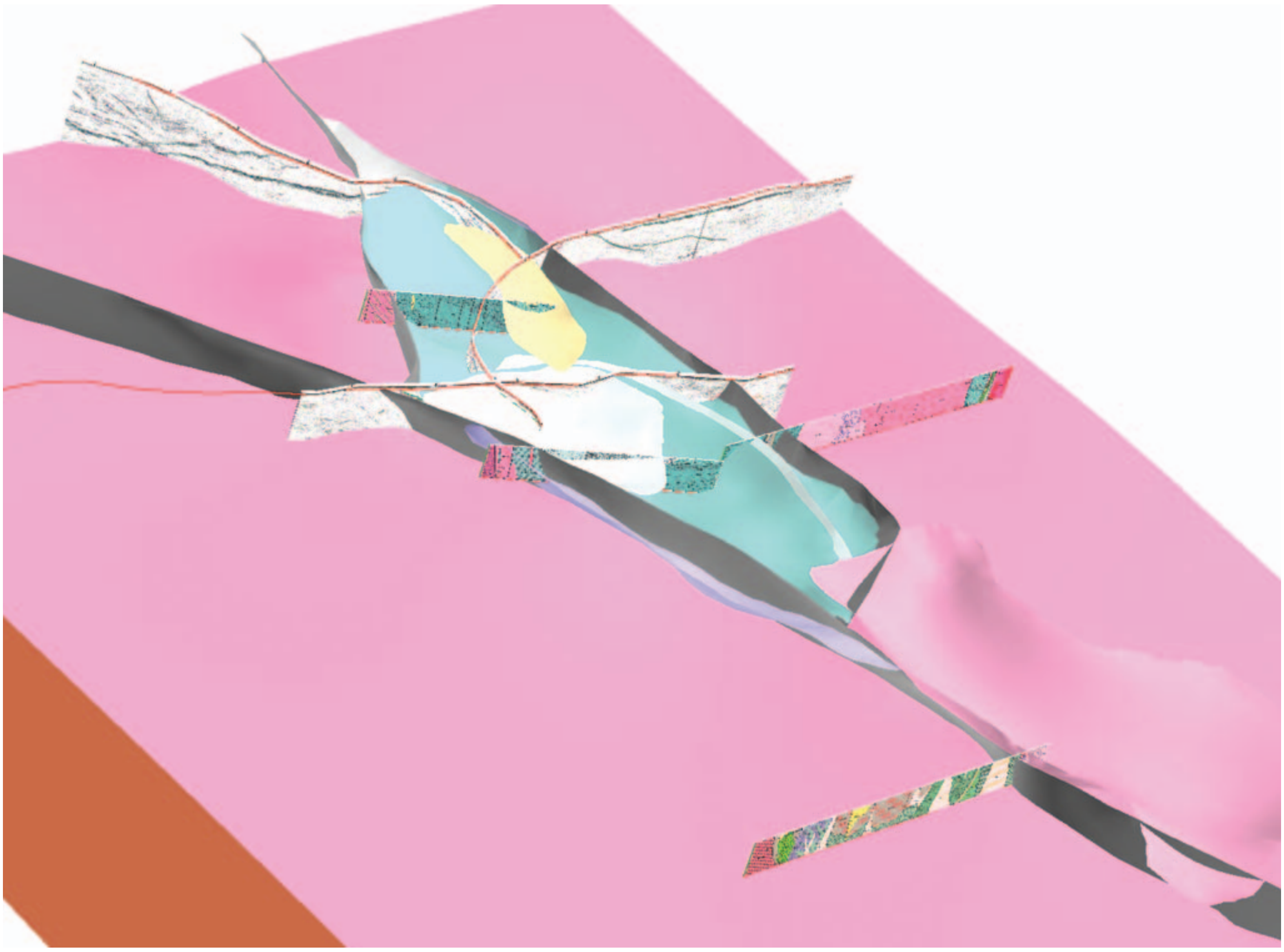

Figure 3. *A screen shot of model surfaces from the Windmurra model. These are shown in the same colour as would be found on the State geological map sheets. Grey surfaces show the geological faults in the model. Also shown are the geological sections from the 1:100 000 map series and the seismic interpretations, all correctly located.*

The first aim of the model was to establish the thickness of the greenstone belt. A 1 km spaced gravity traverse had been made over the western limb and the southern extent of the belt and it was estimated that the greenstone was about 4 km thick (Figure 4a) (Chen, 2005). The interpreted cross section provided with the 1:100 000 Atley map indicated that the author felt that the bottom of the greenstone belt was relatively flat, with an undulating surface generated by an intrusive/faulted contact with the underlying granite (Figure 4b).

The seismic interpretation, however, had indicated that the greenstone belt had a 'V' shape with a typical keel (Figure 4c) (Zibra et al., 2014). Forward models could replicate both theories, depending on the parameters used. A basin inversion

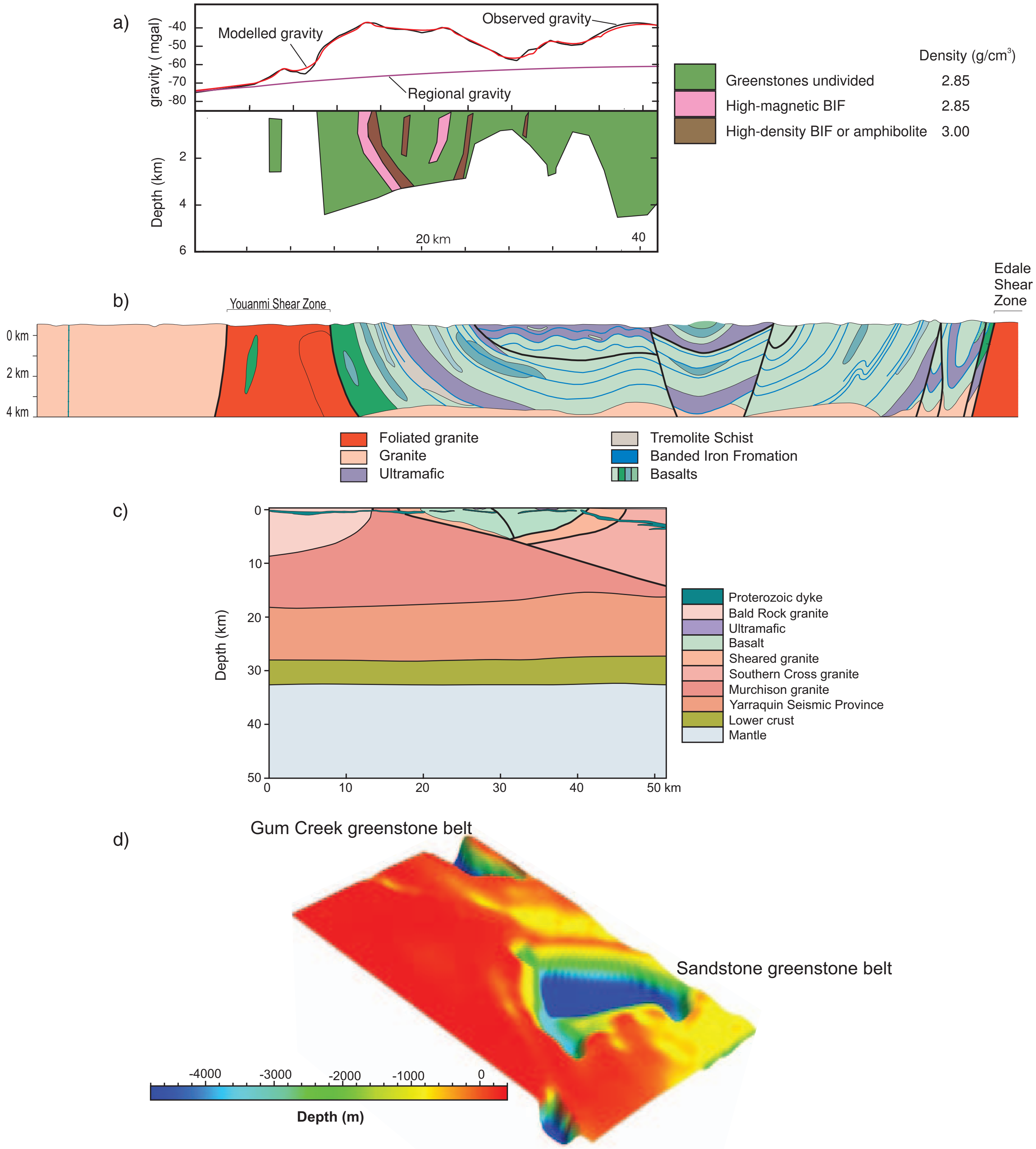

Figure 4. *Estimated depth of the Sandstone greenstone belt. (a) gravity model of Shevchenko from Chen (2005), (b) cross section of the 1:100 000 Atley map by Chen (2003). This section lies along the widest part of the greenstone, (c) interpretation from the seismic reflection survey (Zibra et al., 2014), (d) basement inversion of the whole greenstone belt (Murdie et al., 2015).*

routine was used in the reverse sense i.e. a dense body in a less dense surround, to find the depth of the dense body (Figure 4d). This gave a thickness to the western limb of 3.8 km and a maximum thickness to the eastern limb of 6.5 km.

The 3D modelling showed that the greenstone belt was more likely to be irregularly shaped; influenced by the refolding of the syncline and intrusion by the younger granite (Figure 5). The seismic section was probably showing the whole package of greenstones and associated bounding shear zones in a wedge between the Youanmi and Edale Shear Zones.

As the gravity spacing was not close enough to resolve the individual units within the greenstone, and the units themselves not of sufficient density contrast, modelling of the internal structure was based on the magnetic data. The greenstone contains several units that include coherent layers of banded iron-formations, which have a very strong magnetic signal and trace the folding in the greenstone. Inversions of a basic initial model showed the structure associated with the highly magnetic zones. A continuous band around the north was delineated and this band was repeated on the southern edge, supporting the interpretation of the initial structure as a syncline that had been subsequently been deformed by north-south folding. Scattered areas in the centre showed less coherent banded iron- formations in the upper layers.

Accessing the models

The 3D modelling of both the Windimurra Igneous Complex and the Sandstone greenstone belt was carried out using Geomodeller software as the implicit code was easy to use and the models could be rebuilt as ideas were being generated.

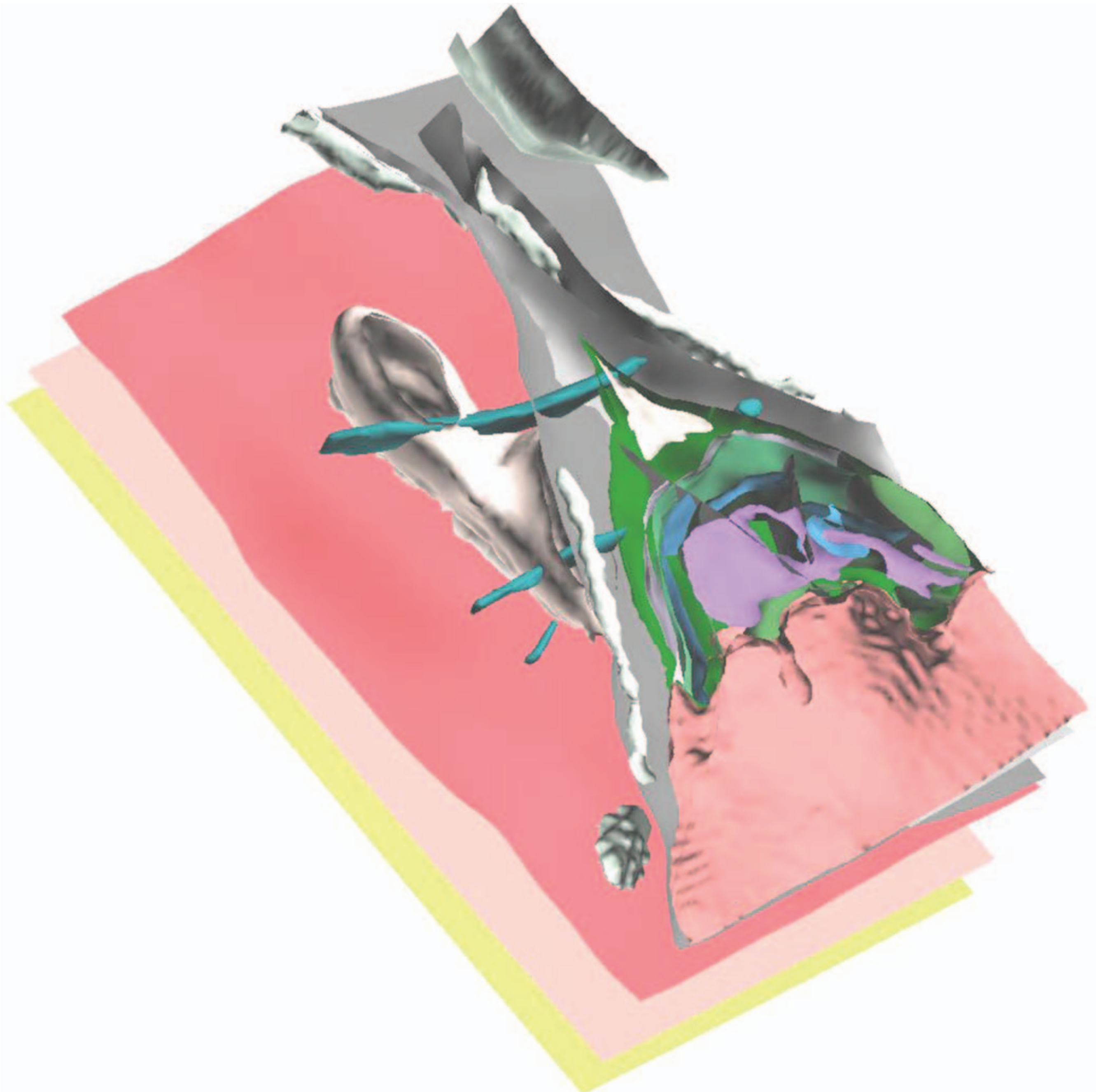

Figure 5. *A screen shot of the Sandstone Greenstone Belt model surfaces within Geoscience Analyst.*

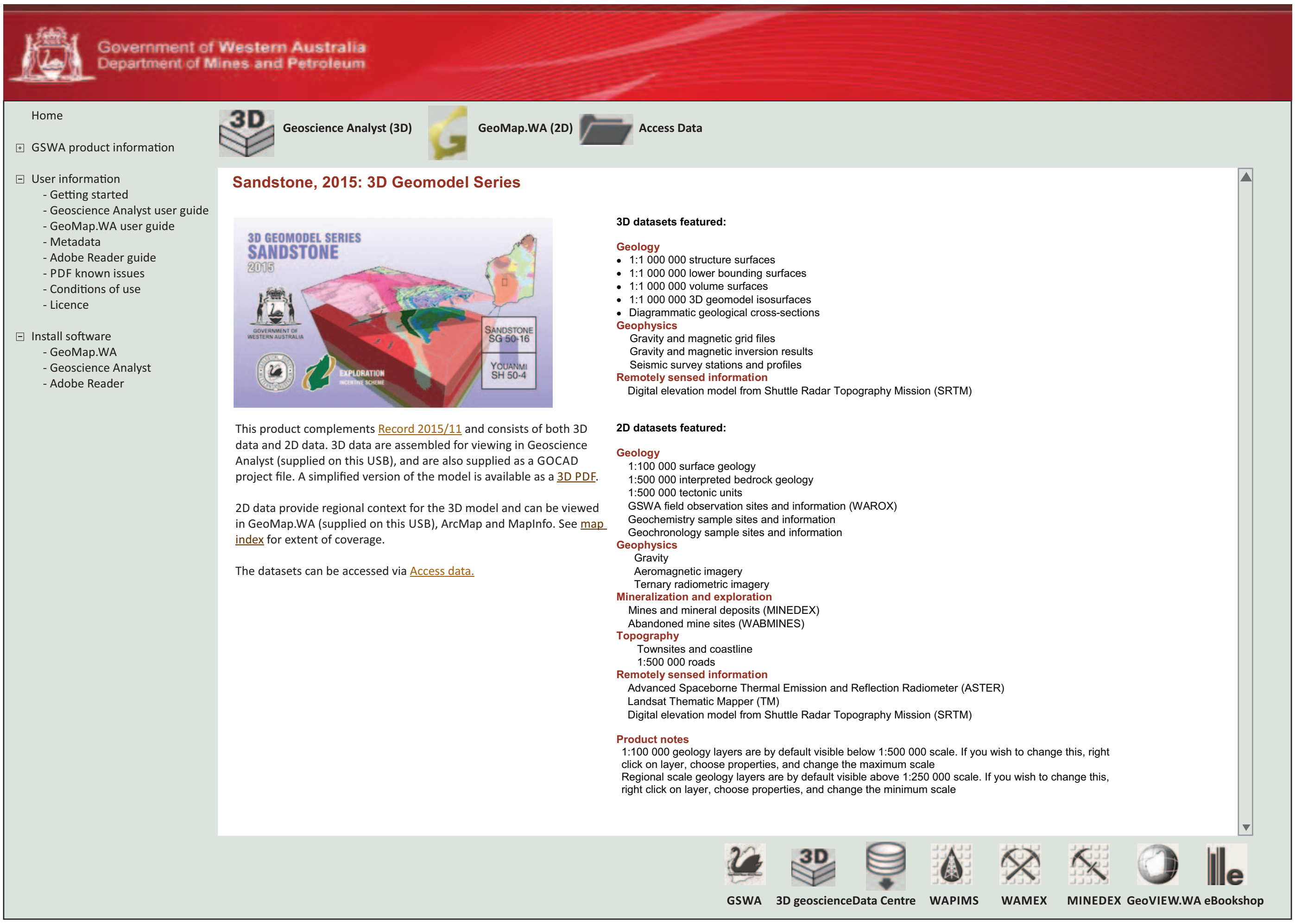

Figure 6. *The html start page of the Sandstone 3D Geomodel package with all the links to all the data and software clearly visible.*

Some inversions were run within Geomodeller and others were run using VPmg code once the model had been taken into GOCAD.

The final models were produced in GOCAD and exported to Mira Geoscience's free visualisation software, Geoscience Analyst. Geoscience Analyst is an easy to use package that reads in almost all the components of a GOCAD project with no loss of quality in the objects, as is the case with other visualisation options such as 3D PDF. Geoscience Analyst also allows the user to import, visualise, annotate, save and distribute the various objects within a model, and has the capacity to include links to external documents. There is quick interrogation of data values, attributes and histograms via dynamic links between 3D views and data tables. The software is able to import ASCII, ESRI, Geo-referenced images, Geosoft and GOCAD Mining Suite files/objects.

For some years, GSWA has been producing 2D digital packages that provide a whole suite of information on a particular area including geology, geophysical data, remote sensing, tenement and title information. The 3D product was simply linked into this platform. All data is supplied on a USB stick. A html start page (Figure 6) has all the links to the 2D and 3D packages as well as links to download the software. All reference material and any help documents are also included.

Future projects include a 3D fault model of the northern Yilgarn Craton and a 3D model of the Capricorn Orogen. The ultimate goal is a state-wide 3D model portfolio.

Acknowledgements

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