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3D Geological Modelling Applied to Geothermal Exploration in South Australia

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SUMMARY

This paper describes 2D/3D Geological/Geophysical Modelling undertaken by the author for Torrens Energy in 2009, for the purpose of establishing 3D Geological Models of the upper crust within their Torrens Hinge Zone tenements in South Australia. Geological Models are a requirement for any Geothermal Energy explorer searching for Hot Dry Rock or Hot Sedimentary Aquifer targets. These Geological Models are assigned thermal parameters determined by field and laboratory measurements based on the lithologies included in the model. Heat resources may then be computed for the given volume based on the geological model and thermal rock properties. Whilst the studies were carried out for the purpose of creating temperature models and geothermal resource estimates, this document will discuss the geological models, geophysical investigations and tectonic implications generated by the study. Examples of Geological Models are shown from the Torrens Energy Port Augusta, Yadlamalka and Parachilna Geothermal Prospects.

Introduction and Geological Setting

The principle behind this 3D Geological Modelling study is to integrate existing geological and drilling information with geophysical data such as seismic, gravity and magnetics, in a 3D environment which will simulate the 3D geology of the region of interest by creating a 3D geological model which can then be used as an input for thermal modelling.

Central South Australian Geology is dominated by these main structural elements. To the west lies the Archean-Mesoproterozoic Gawler Craton. This is overlain in areas by undeformed Adelaidean to Cambrian basin sediments of the Stuart Shelf. In the east is a complexly folded region of Adelaidean to Cambrian sedimentary and volcanic rocks known as the Adelaide Geosyncline. The Torrens Hinge Zone (THZ) of South Australia is a long but narrow (up to 40 km wide) geological transition zone between the Stuart Shelf and the folded Adelaide Geosyncline rocks (Drexel et al, 1993), as seen in Figure 1.

In the study areas of the THZ, the Adelaidean and Cambrian sedimentary sequences are underlain at depths between 2,000 and 7,000m by the Gawler Craton Olympic Domain rocks (Matthews and Godsmark, 2009). Two study areas have been selected near Port Augusta and Parachilna to the immediate west of the Flinders Ranges, some 350 – 500 km north of Adelaide respectively. Heat flow values of over 90 mW/m^2 have been recorded in several wells drilled in the THZ. With several kilometres thickness of moderate conductivity sediments overlying the crystalline basement in this region, predicted temperatures at 5000 m are up to 300°C in some areas (Matthews and Godsmark, 2009).

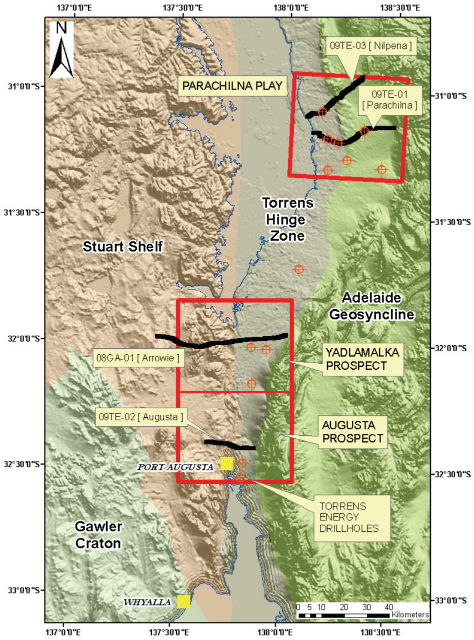

Figure 1 *Location Map of Central South Australia showing tectonic elements, study areas, seismic lines and drillholes.*

Data and Methodology

Available geological data included historic and Torrens Energy drillholes and South Australian (SA) geological mapping. Geophysical data comprised SA magnetic and Bouguer Gravity data along with recently acquired Torrens Energy and Geoscience Australia 2D depth-converted Seismic. Rock thermal properties were derived from laboratory measurements performed by Torrens Energy and top and downhole temperatures measured from drilling.

The Intrepid 3D Geomodeller suite was used to build the 3D Geological Model. The 3D Geomodeller software interpolates between geological boundaries, orientation data and drillholes to generate a 3D geological model that is flexible and readily adaptable with additional geological information. Geomodeller also supports faults and fold information into its interpolation. The final output can be discretised into a 3D "voxel" model of desired resolution to use in 3D Geothermal Modelling.

Geological Inputs for Modelling

3D Geological modeling methodologies rely heavily on interpretation and integration of many data types, as well as some creative thinking and intuition. Geomodeller 3D geological models require a defined 3D volume of interest, which encompasses target area, heat source, basin thickness and topography. For both Parachilna and Port Augusta, a depth below Mean Sea Level of 7km and a maximum of 1.5km above MSL to clear the range topography was deemed sufficient, giving an 8.5km thick model. The area covered in the Parachilna model was 50x45km, and 50x80km over Port Augusta/Yadlamalka (Figure 1). A surface topography grid is also required for the model to compute the intersections of the geological interfaces at surface, Topography was imported into the models from SRTM DEM grids at 90m resolution clipped to the surface Area Of Interest (AOI).

Further requirements in Geomodeller are the defined geology in the form of lithological interfaces and associated structural orientations, and a stratigraphic pile which defines the relationships between the lithologies. Sequences of conformable geological units such as found in sedimentary basins may be grouped in onlapping series interfaces, whereas intrusives are defined as erosional interfaces and appear where required in the stratigraphic pile to best satisfy contact relationships. Unconformable sequences also form erosional interfaces. In strongly deformed regions, structural requirements may imply that lithologies must obey onlapping rather than erosional rules. A simplification of the stratigraphy was also created for ease of modelling (Figure 2a), which essentially has grouped the Cambrian and Neoproterozoic Adelaidean sequences into their major tectono-stratigraphic units.

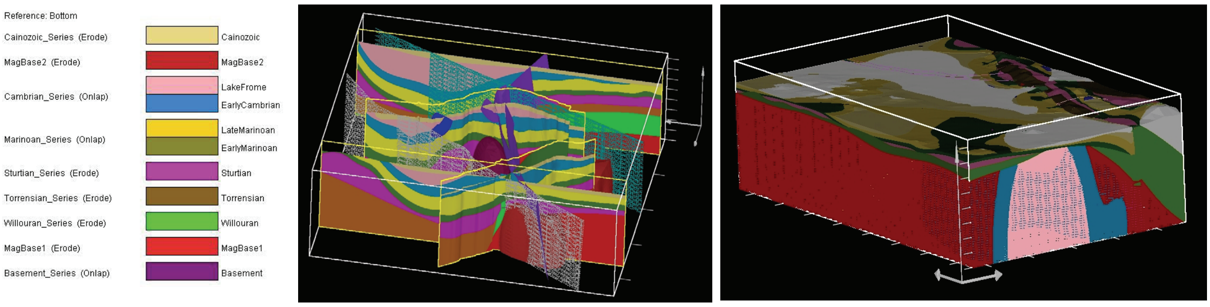

Figure 2. *(Left to Right)* ***a).*** *Simplified Geomodeller Stratigraphy.* ***b).*** *3D Geomodeller Section view of Parachilna Model.* ***c).*** *Solid 3D Model of Port Augusta/Yadlamalka.*

Geological information at surface may be defined importing simplified or grouped GIS shapefiles derived from public domain geology polygons, and assigning these to the simplified stratigraphic formations. Likewise geological orientation data, where known from mapping, have been supplied where possible and assigned to specific formations. Torrens Energy and historic diamond drillhole data have provided constraint in the 3rd dimension. Once again the geological logs of these drillholes were simplified to the stratigraphy and the drillholes imported using the import tools in Geomodeller.

Supplementing Geology with Geophysical data

To supplement the existing geological information, interpretation of four 2D depth-converted seismic lines, (two from the Parachilna area and two from the Port Augusta/Yadlamalka area), was performed.

These were constrained wherever possible by drilling and outcrop information. Seismic sections were imported into Geomodeller as image backdrops along vertical sections through the model and the interpretation transformed into interfaces within these vertical sections.

The interpretation along these sections was augmented further in the Parachlina AOI by 2D modelling of state magnetic data along profile lines adjacent to the 09TE-01 seismic line. In the Port Augusta region, 2D magnetic modelling was also performed in order to obtain estimates of basement depth and magnetic body shapes and locations. In each case images or actual 3D data points from the results were imported back into Geomodeller. Euler Deconvolution of magnetic data was also used in this area to provide spot estimates of depth to shallow-dipping volcanic units, implying local estimates to the top of Willouran-age Beda Volcanics. Finally, structural interpretation of both gravity and magnetic data was used to define fault traces in Geomodeller.

3D Geological Models

Computation time of the two 3D Geological models is dependent on the amount of data supplied. Results which are strongly biased to orientation data were treated with caution. Some additional inference of contacts and orientations was required to ensure geological consistency, especially near faults. Additional sections linking drillholes provided stronger cross-correlation of geological interfaces, especially in the Port Augusta/Yadlamalka area where data was widely spaced. Although in some cases actual outcrop geology was further from the area of interest than required, it was included to provide geological reality and well-defined constraints on modelling. As faults also require orientation information to be computed in the modelling, their direction, dip and apparent movement were estimated either from seismic images or geological and geophysical images. Examples of images from the 3D modeling are shown in Figures 2b and 2c.

Parachilna

In the Parachilna area we interpret from seismic data and modelling that the Early Cambrian to Adelaidean rocks transit from relatively flat-lying in the west to moderately east-dipping at a fault contact known as the Ediacara Fault. Our modelling shows The Ediacara Fault to be a steeply west-dipping feature, upthrown on the eastern side, which evolves in the south from a relatively simple antiform, to a complex horst structure involving several faults and possibly basement or diapiric material from the centre of the Parachilna AOI to its northern edge. Basement depths in the far west are predicted to range from 2km depth in the north to 5km in the south. In the faulted horst blocks of the Ediacara Fault region basement or diapiric material may reach depths of 2km. East of the Ediacara Fault is a moderately folded deep synclinal basin, perhaps over 7km in thickness, adjacent to the range front fault. Early to Middle Cambrian units of the Lake Frome and Hawker Groups to the west have been confirmed by deep drilling, whilst Adelaidean rocks of Marinoan to Sturtian ages are expected to lie beneath these based on their presence in the Ediacara Hills to the north in the fault zone and outcrops of these units to the west on the Stuart Shelf. Inference of Torrensian to Willouran rocks is based on the apparent presence of diapirs to the south and east, although these rocks are expected to thin out somewhere in this region. Torrensian rocks in particular may not appear anywhere west of the Ediacara Fault system. Basement has been largely undifferentiated in the Parachilna 3D model with the exception of what are inferred to be two large magnetic intrusives in the central parts and northwest.

Port Augusta/Yadlamalka

In the Port Augusta/Yadlamalka region there is geological complexity and uncertainty, but more drilling data and more diverse magnetic signatures and seismic imagery. The interpretation on the seismic lines 09TE-02 (Augusta) and 08GA-01 (Arrowie) has been performed in a manner similar to those at Parachilna, relying on nearby drillholes and regional lithological relationships to provide the means of interpreting seismic events. In general the stratigraphy is identical to that used at Parachilna, with the addition of several intrusive basement units of varying magnetic signature and a subdivision of Willouran units. Modelled trends show an eastward – thickening wedge of sediments toward the range front, with possible down-thrown rift basins evolving closer to the range. To the northeast near Yadlamalka, northwesterly-directed thrust faults occur before the range front, possibly facilitated by Willouran evaporitic units and/or diapirism. To the east of these thrusts, sediments begin to dip more strongly or are deformed. Deformation peters out in the thrust footwall as sediments become more flat-lying toward the Stuart Shelf.

In the vicinity of Port Augusta, the model predicts gently dipping sediments of 800 – 1200m thickness, overlying granitic or metamorphic basement, crossing a significant north-northeast trending basin-defining fault coincident with the onset of a significant gravity low and a step in the magnetics and seismic images. North of this fault, basin thickness increases, from 800m in the west to 4500m at the base of the range fault. Deeper reflectors in the Augusta seismic section are enigmatic but their pattern is suggestive of rifting. Modelling results also demonstrate localised basins containing Cambrian sediments. The northern parts of the model, near Yadlamalka show similar gently dipping Adelaidean stratigraphy ranging from 600m thickness in the far west to 2300m before encountering a the thrusts which displace Willouran volcanics close to surface, as evidenced by the Arrowie seismic section, drilling and magnetics. A very marked angular unconformity exists between the sedimentary/volcanic pile and the basement, which comprises a series of west-dipping reflectors. Roughly midway across the model Torrensian lithologies are inferred to appear. Magnetic modelling has suggested that a number of magnetic intrusives are present, along with slices of Willouran age volcanics. These have been emplaced into the model where most likely.

Conclusions

Two large 3D Geological models have been made of sections of the Torrens Hinge Zone in South Australia. The northern model near Parachilna shows moderately dipping Cambrian to Adelaidean sediments of thicknesses between 2000 and 4000m overlying unknown basement in the west. A modern active fault system, the Ediacara Fault, has uplifted basement locally and forms the boundary of a deep, moderately deformed north-south basin adjacent to the Flinders Range front.

The southern model between Lake Torrens and Port Augusta shows transitions between gently dipping Adelaidean sequences of up to 2300m thickness with thrusted, deformed basins to the north and deeper rifted basins to the south. Evidence from seismic and magnetics suggests the presence of substantial sedimentary or volcanic sequences lying beneath Willouran Beda Volcanics and overlying deformed metamorphic or granitic basement with sharp unconformity.

Each model has been converted to 3D voxels using Geomodeller export tools and used in proprietary Geothermal heat resource modelling software to generate heat resources models.

References

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