Multi-data source approach for estimating depth to basement, Curnamona Province, South Australia

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Introduction

The Curnamona Province is an oval-shaped inlier of late Palaeoproterozoic to Mesoproterozoic metasedimentary and meta-igneous rocks in northeastern South Australia and western New South Wales. The province is host to the world-class Broken Hill Ag–Pb–Zn deposit and is prospective for iron oxide–copper–gold (FeO–Cu–Au) deposits (Burtt et al., 2004; Fig. 1). Crystalline rocks of the region, like many other parts of South Australia, are extensively covered by younger sedimentary sequences.

Depth to basement data sets were identified as one of the key information gaps in an audit and gap analysis for the province undertaken by McConachy et al. (2003). This article is a summary of the data sources and methods used to obtain a depth to basement estimate for the covered portions of the Curnamona Province. The data set will aid mineral exploration and reduce exploration risk for this highly prospective region of the state.

Definition of basement

For the purposes of the Curnamona Province, depth to basement data set basement is taken to be the shallowest 'crystalline' rocks affected by a pervasive orogenic event and are Palaeo- to Mesoproterozoic in age (Cowley and Reed, 2004). The main orogenic event that affected the province is the Olarian Orogeny (~1600 Ma; Conor, 2004), with subsequent deformation and metamorphism during the Delamerian Orogeny (~500 Ma) which mainly affected the southern and far northern portions of the province.

For this reason, Palaeo- and Mesoproterozoic rocks are defined as basement within the province whereas, outside the province boundary, Neoproterozoic and Cambro-Ordovician rocks are defined as basement. Boundaries of these areas are shown on Figure 1. This approach mostly accords with the differences in magnetic signatures of the Neoproterozoic and Cambrian cover, which is generally non-magnetic where unmetamorphosed and little deformed, but highly variable in magnetic character where strongly affected by the Delamerian Orogeny, due to the growth of metamorphic magnetite and intrusion of magnetite-bearing igneous rocks. These different definitions of basement also reflect the general perception of the metallic mineral prospectivity, although undeformed cover may still be prospective for certain types of deposits (e.g. Mississippi Valley-type Pb–Zn in the Cambrian, or heavy mineral sands and roll-front uranium deposits in Tertiary palaeochannels).

In the southern Curnamona Province, the extent of Palaeo- to Mesoproterozic rocks is defined by outcrop and unconformable relationships with overlying, younger stratigraphy, whereas in the covered northern portions it is defined by airborne geophysics. Outcropping Palaeo- to Mesoproterozoic rocks of the Mount Painter and Mount Babbage Inliers are included as part of the Curnamona Province, as is the covered region to the east of the ranges (Fig. 1).

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Drillholes

In the southern Curnamona Province, including the southern Benagerie Ridge, numerous mineral exploration drillholes provide the basis for the depth to basement data set using the definitions above (Fig. 1). However, the northern part of the province has sparse drilling and only a few drillholes that intersect crystalline basement (Fig. 1), so alternative sources of data, such as seismic and airborne magnetics, were required to estimate depth to basement.

Drilling in many areas did not penetrate fresh rock, so depth to basement was taken as the top of recognisable Palaeo- to Mesoproterozoic lithologies. This varies from saprock in areas close to outcrop, to saprolite in the more deeply covered areas. In the Mulyungarie, Mingary and Benagerie Ridge region, the depth of weathering of Willyama Supergroup rocks varies from 1 m to >80 m. Weathered basement is generally represented as saprolite, but may include thick kaolinite-rich zones containing iron mottling. Factors affecting the thickness of weathered basement include the degree of ?Mesozoic–Cainozoic erosion, in some instances by Tertiary palaeochannels and, locally, by the mineralogy of the pre-existing basement e.g. sulphide and calcsilicate-rich zones show more intense weathering.

Seismic line interpretation

In areas of few or no drillholes intersecting crystalline basement, other methods of depth estimation were required. Sediments in the Moorowie and Yalkalpo Sub-basins, part of the Cambrian Arrowie Basin, unconformably overlie Neoproterozoic stratigraphy, which in turn overlies Palaeo- to Mesoproterozoic rocks with generally angular unconformity. Potential for oil and gas in Cambrian sediments encouraged seismic surveys to be conducted in this region.

These seismic lines delineate seismic reflectors correlative to specific sedimentary sequences intersected in Moorowie 1, a deep drillhole in the Moorowie Sub-basin. Disrupted, incoherent and seismically amorphous zones below the seismically reflective layered sequences of the Moorowie and Yalkalpo Sub-basins have been interpreted as crystalline Palaeo- to Mesoproterozoic basement (Fig. 2).

Numerous seismic lines were interpreted with two-way times picked for the sediment–basement contact. Seismic velocity surveys conducted in

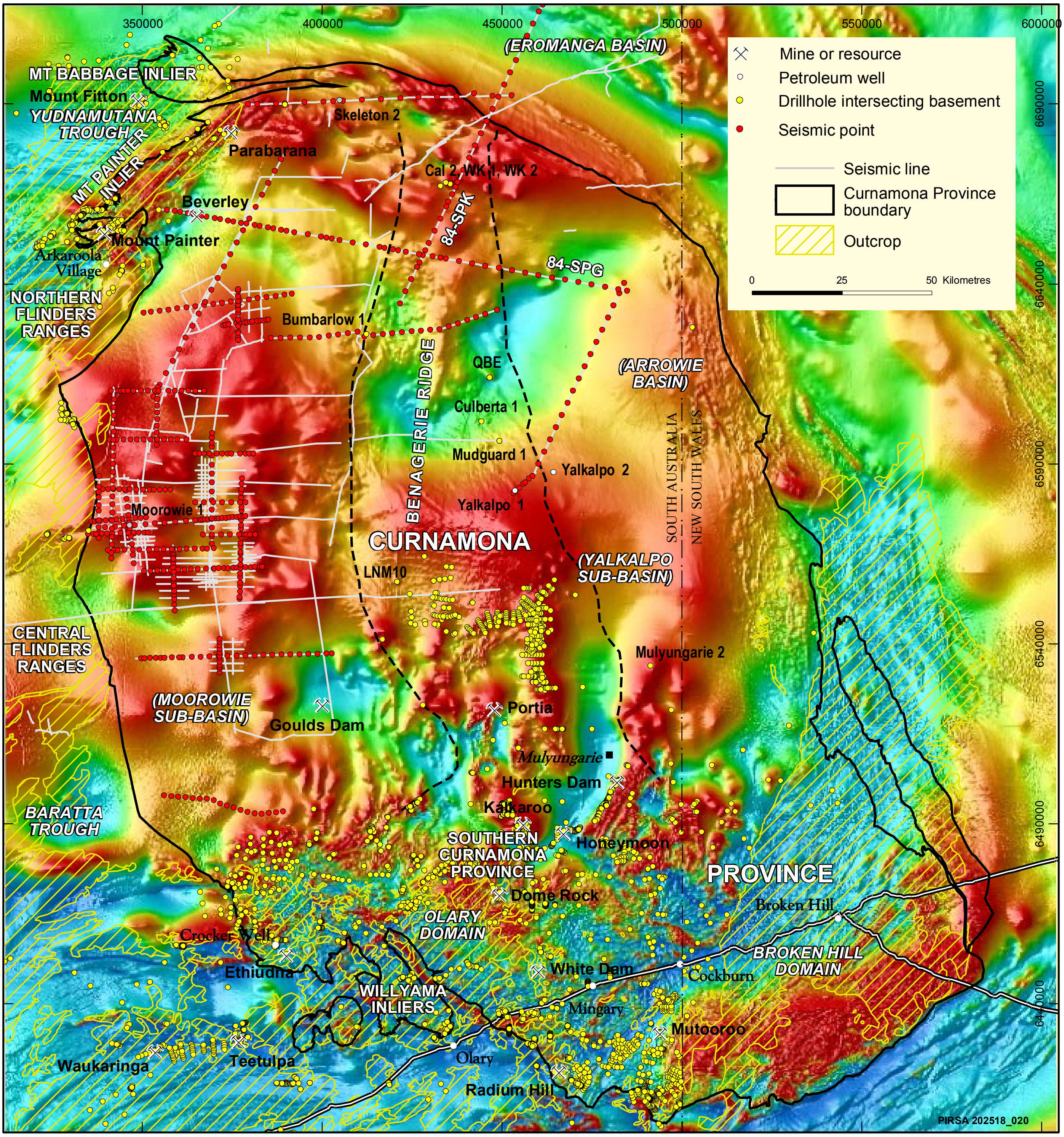


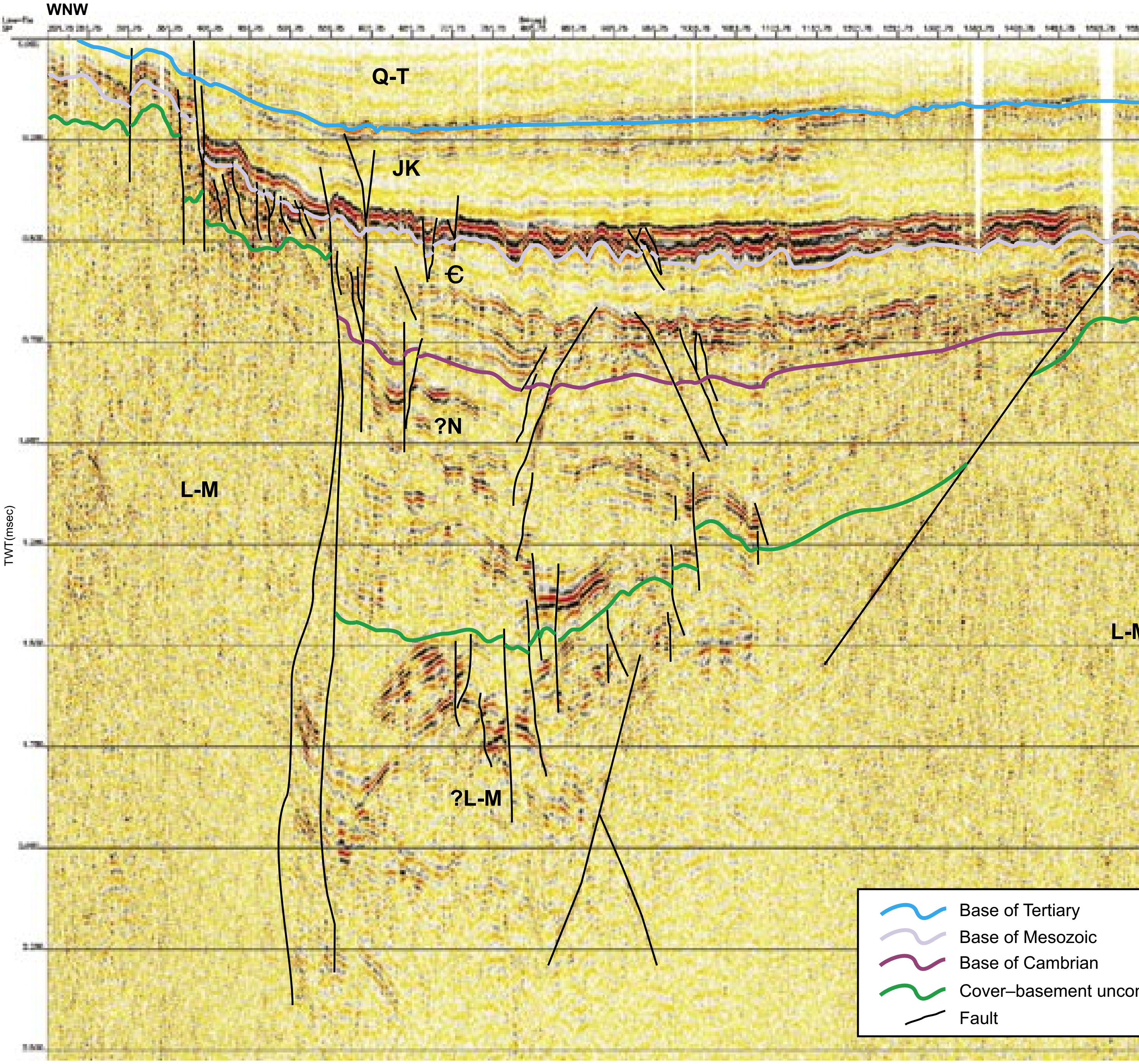
Fig. 1 *Total magnetic intensity image showing the Curnamona Province boundary, outcrop boundaries, basement-intersecting drillholes, and seismic lines used in depth to basement estimation.*

drillholes Moorowie 1 and Skeleton 2 were used to determine the correlation between intersected stratigraphy and seismic reflectors. A mathematical program (Statistica) was used to plot velocity versus depth for the Moorowie 1 velocity survey (Elliot, 1984). A second-order polynomial was fitted to the resultant time–depth curve. A formula developed from curve matching was used to convert the interpreted sediment–basement two-way time to depth in areas where Cambrian and Neoproterozoic successions overlie Palaeo- to Mesoproterozoic basement.

A similar seismic velocity survey and two-way time–depth conversion was conducted for Skeleton 2 in the northern Curnamona Province. This hole intersected Cainozoic and Mesozoic sediments unconformably overlying Mesoproterozoic granitoid at 564 m (Callen et al., 1990). No Neoproterozoic or Cambrian sediments were intersected, indicating erosion or non-deposition of these sediments before deposition of the younger sequences. Callen et al. (1990) were able to determine a formula that accurately converted two-

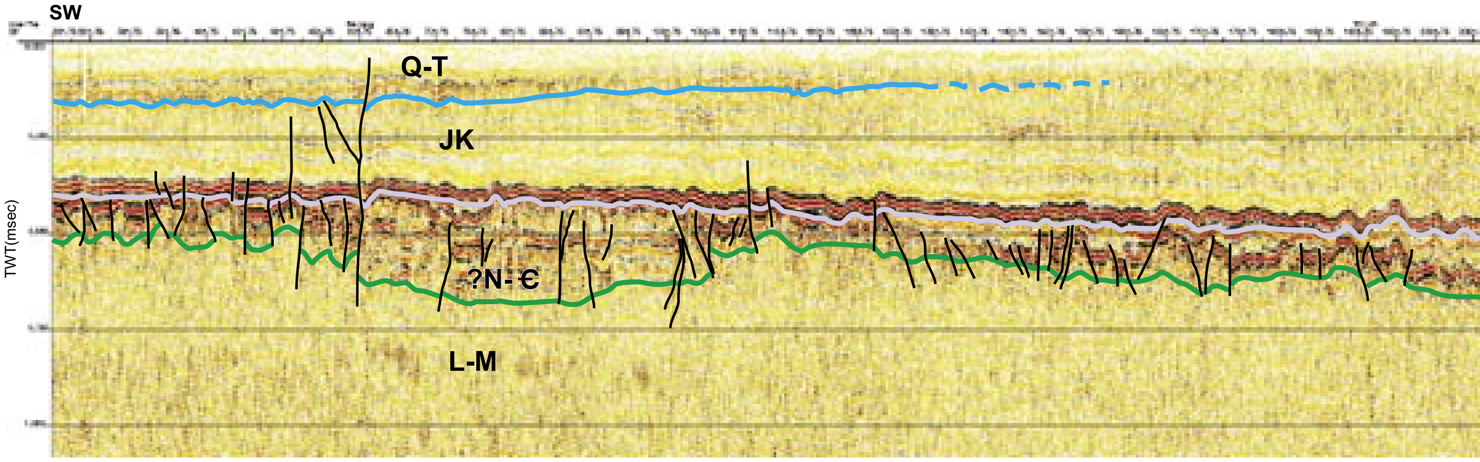
84-SPG

WNW



84-SPK

SW



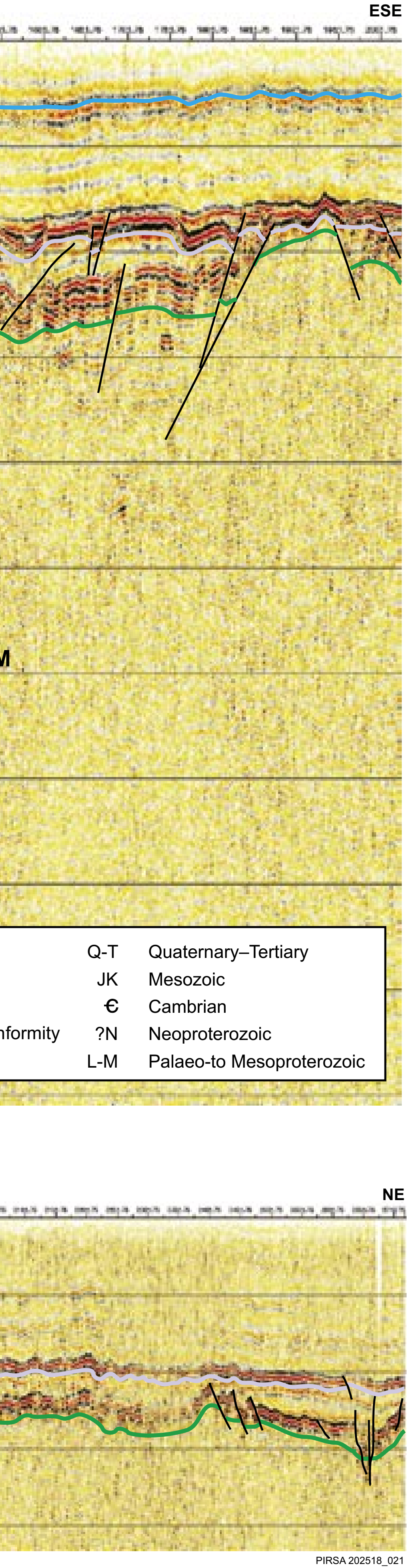


***Fig. 2** Stratigraphic interpretation of seismic lines 84-SPG **(a)** and 84-SPK **(b)**.*

way time to depth from this drillhole. This formula was used to convert two-way time to depth in areas where there were no interpreted Neoproterozoic and/or Cambrian sequences overlying Proterozoic basement.

The Moorowie 1 velocity formula was not used in areas without Neoproterozoic–Cambrian sediments as it was found to overestimate depth to basement when compared to basement depths intersected in drillholes.

Drillhole data and seismic interpretation depth points were gridded to produce an estimated depth to basement grid for the Curnamona Province (Fig. 3).

Euler automatic depth to magnetic source solutions

The Euler deconvolution method of automating depth to source from potential field data was employed to gain depth information from regions with poor drillhole and seismic data.

Thompson (1982) and Reid et al. (1990) developed the Euler deconvolution method for gridded magnetic and gravity data. During 2003, Des Fitzgerald and Associates, in association with Geoscience Australia, PIRSA and Reid Geophysics, have further extended and unified the method.

The two-equation solver in the Euler Deconvolution tool was used to calculate the depths to magnetic bodies within the area of interest. The resulting solutions were sorted using the default sorting criteria of the software and then clustered. The resulting sorted depth solutions were then gridded using the nearest neighbour technique (Fig. 4).

The observed drillhole depths and basement picks were then used to test how the Euler depth estimates performed in areas where this information was available. Several profiles were extracted across both the resulting Euler Depth grid and a second grid incorporating only drillhole and seismic depths to examine the validity of the method (Fig. 5). Results indicated very good agreement between both data sets; differences in depths between the two along the profiles are due primarily to differing magnetic characteristics of the basement. Given this encouraging result, the Extended Euler method can be expected to produce similar quality estimates where there is little or no other information.

The two data sets consisting of Euler Depths and drillhole–seismic depths were incorporated into the one grid using the new multiple data set gridding tool available within Intrepid software. An option for weighting the interpolation scheme towards observed depth data as opposed to the calculated Euler depths was used.

Incorporation of the two data sets produced a significantly improved basement depth estimate of the area of interest. This represents a breakthrough in the use of an automatic geophysical method to produce a reliable depth to basement map.

Discussion

The Curnamona Province depth to basement data set has helped define specific structural elements such as the Benagerie Ridge, a new Neoproterozoic graben, and the western, northern and northeastern province boundaries.

Curnamona Province boundaries

A significant structural feature highlighted by the depth to basement data set is the western margin of the Curnamona Province, from Mount Painter in the northwest to the western Crocker Well area in the southwest. Along this margin, the province is bounded by a crustal-scale fault that separates deformed and metamorphosed Palaeo- to Mesoproterozoic metasediments and meta-igneous rocks that are overlain by relatively undeformed and gently dipping Neoproterozoic, Palaeozoic, Mesozoic and Cainozoic sediments from more highly deformed and metamorphosed Neoproterozoic to Cambrian sedimentary and igneous rocks of the Flinders Ranges. In the southern region, the vertical movement on this fault is up to 6900 m. Depth to basement shallows to the north in the Mount Painter region where an east–west-trending belt of Palaeo- to

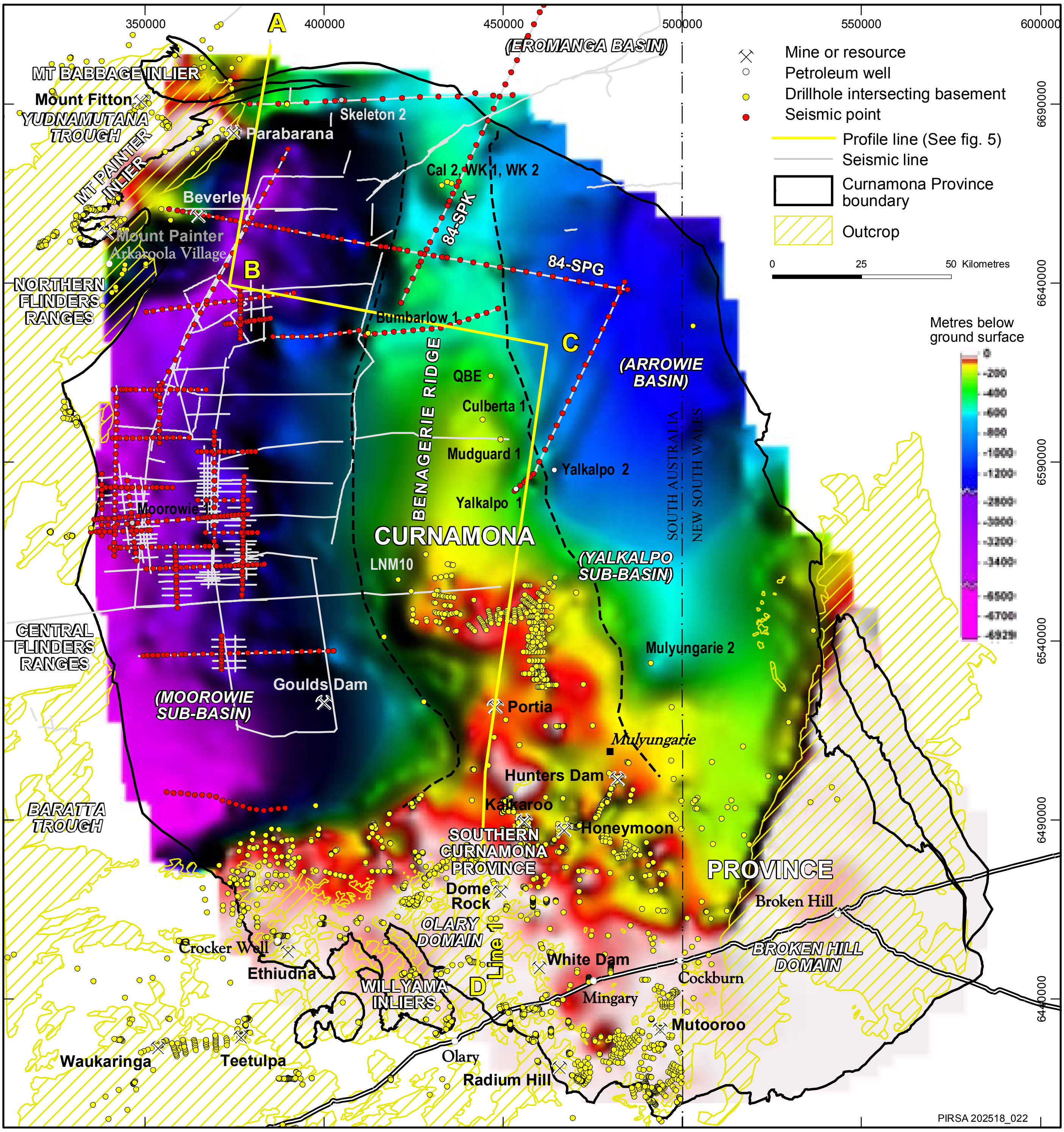


Fig. 3 Drillhole depths and seismic interpretation depths gridded to produce a pseudocolour image of depth to basement for the Curnamona Province.

Mesoproterozoic Mount Painter Inlier rocks form a basement high. Tectonic activity in the Early Cambrian caused uplift of the Palaeo- to Mesoproterozoic rocks in this region and in the Benagerie Ridge, severing the connection between the Arrowie and Warburton Basins (Gravestock and Hibburt, 1991; Zang, 2003).

The eastern and northern to northeastern margins of the Curnamona Province are poorly defined due to lack of drilling and seismic coverage. The lower metamorphic grade of Proterozoic rocks in these regions renders them difficult to distinguish from overlying younger sequences due to poor magnetic contrast. Seismic line 84-SPK, which crosses the northeastern margin of the province, indicates that Proterozoic rocks progressively deepen below interpreted Mesozoic rocks without a major bounding fault as seen along the western margin. This seismic line suggests that Palaeo- to Mesoproterozoic rocks continue northwards and may form an eastern extension of the Muloorina Ridge (Fig. 2b).

Benagerie Ridge

The Benagerie Ridge is a palaeo-topographic high constrained by bounding

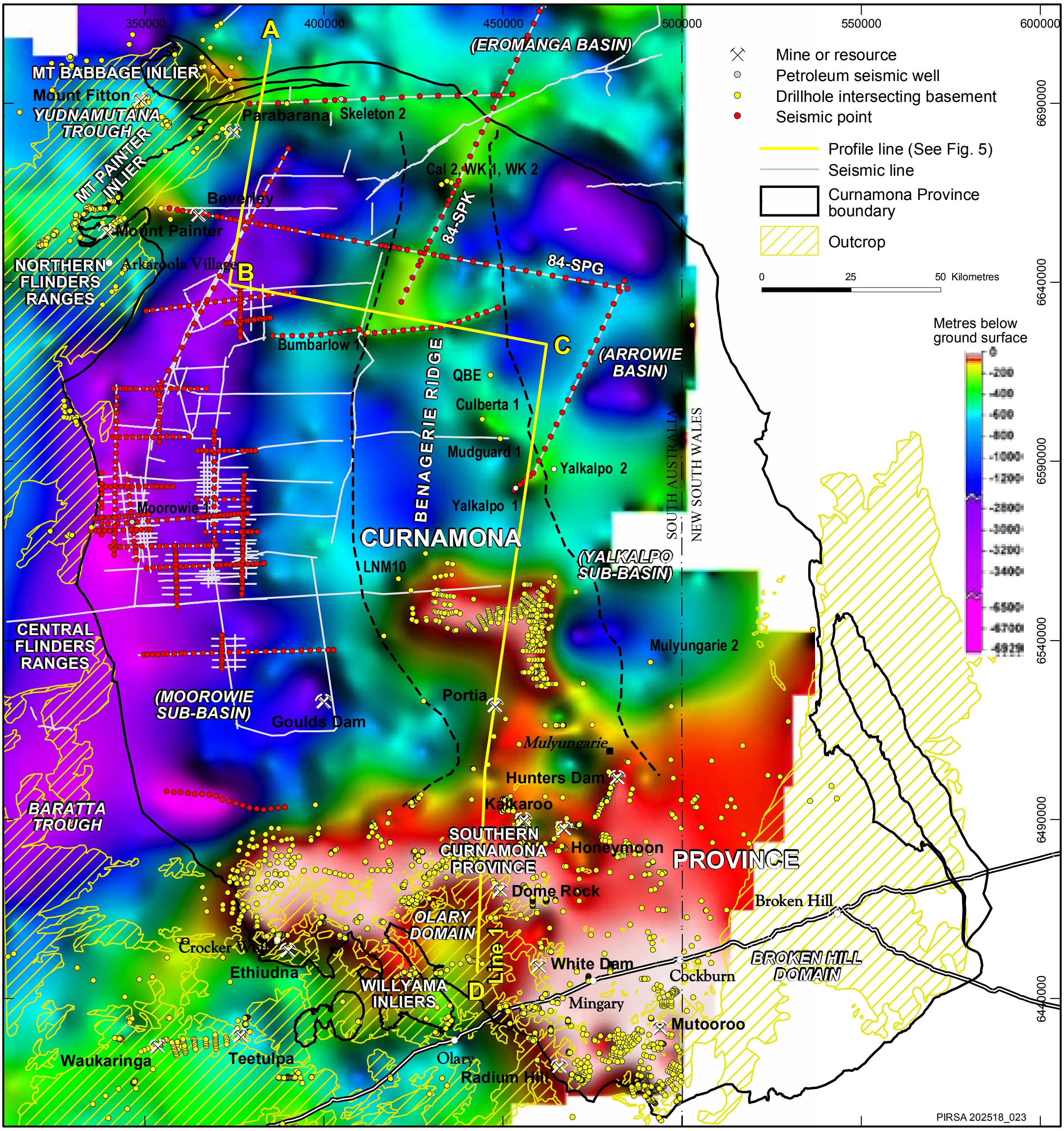


Fig. 4 *Drillhole, seismic interpretation depths and Euler solution grid of depth to basement.*

faults. This horst-like structural element consists of relatively low metamorphic grade Palaeoproterozoic Willyama Supergroup metasediments overlain by interlayered Mesoproterozoic basalt and sandstone (Bumbarlow 1; Youngs, 1978), basalt to andesite breccia (Lake Namba 1; Curtis and Moore, 1982) and felsic volcanics.

The eastern and western margins of the ridge are onlapped by Neoproterozoic, Cambrian, Mesozoic and Cainozoic sediments. The axis, however, is covered only by Mesozoic and Cainozoic sediments, indicating either non-deposition or uplift and erosion of Neoproterozoic and Cambrian sediments before deposition of the younger sequences. Basement depths range from ~40–50 m in the southern part of the ridge to >500 m in the northern region. The range of depths to basement in this region make it accessible for mineral exploration whereas, on the flanks of the horst, Palaeo- to Mesoproterozoic basement is covered by up to 6900 m of combined Neoproterozoic, Palaeozoic, Mesozoic and Cainozoic sediments.

Figure 6 highlights the various structural elements of the covered portions of the Curnamona Province,

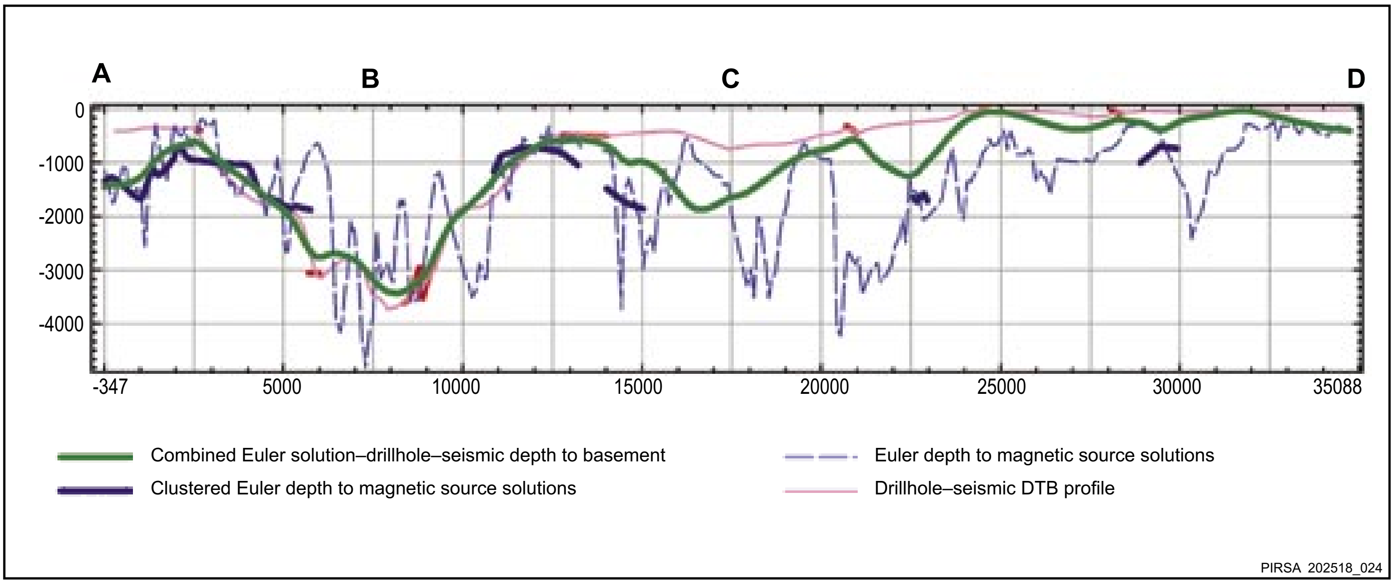


***Fig. 5** Profile comparison of Euler depth to magnetic source solutions with combined Euler solution–drillhole–seismic depth grid and drillhole–seismic depth to basement grid. The profile is located on Fig. 4.*

including the Benagerie Ridge and Moorowie and Yalkalpo Sub-basins.

A new Neoproterozoic graben

Historical seismic data reveal that the Cambrian successions of the Moorowie Sub-basin unconformably overlie a fault-bounded graben filled with Neoproterozoic sediments (Fig. 2a). This graben widens to the south towards the thick Sturtian glacial successions preserved in the corridors between the Willyama Inliers (Preiss and Conor, 2001), but is separated from these by an east–west structural culmination, probably of Delamerian age. Because of the definition of basement used in this paper, the Sturtian rocks of the corridors are included in 'basement' as shown on Figures 3 and 4. The corridors have been interpreted as a Delamerian modification of a Sturtian extensional graben system forming part of the Baratta Trough (Preiss, 1987).

At the northern end of the graben, the Neoproterozoic fill is juxtaposed against Palaeo- to Mesoproterozoic basement by a ?Delamerian fault, but a thick Sturtian glacial succession reappears at the western margin of the Mount Painter Inlier in the east-southeast-trending Yudnamutana Trough (Preiss, 1987). It is suggested that the newly defined graben is also of Sturtian age, originally linking the Yudnamutana Trough in the north with the Baratta Trough in the south, where a great thickness of Sturtian sediments is preserved in the eastern part of the central Flinders Ranges. The Sturtian rifting that provided the accommodation space for these sediments was the last major extensional event immediately pre-dating the interpreted break-up of Rodinia (Preiss, 2000).

Conclusions

Drillhole depth to basement data integrated with interpretations from seismic and magnetic data form the basis of the Curnamona Province depth to basement data set. Drillhole information constrains depth estimates derived from other data sources, allowing confidence in basement depth estimates in areas where there are few drillholes. The Curnamona Province depth to basement data set reduces exploration risk and promotes mineral exploration in poorly explored regions of the province. The Benagerie Ridge and covered basement region east of Mount Painter are two poorly explored areas highlighted by this data set as being within exploration depth. The data set also elucidates important Neoproterozoic and Cambrian tectonic and basin development features.

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For further information on the Curnamona Depth to Basement Data Set contact Andrew Burtt (ph. 08 8463 3072). The data set is also available by download from SARIG (www.minerals.pir.sa.gov.au).

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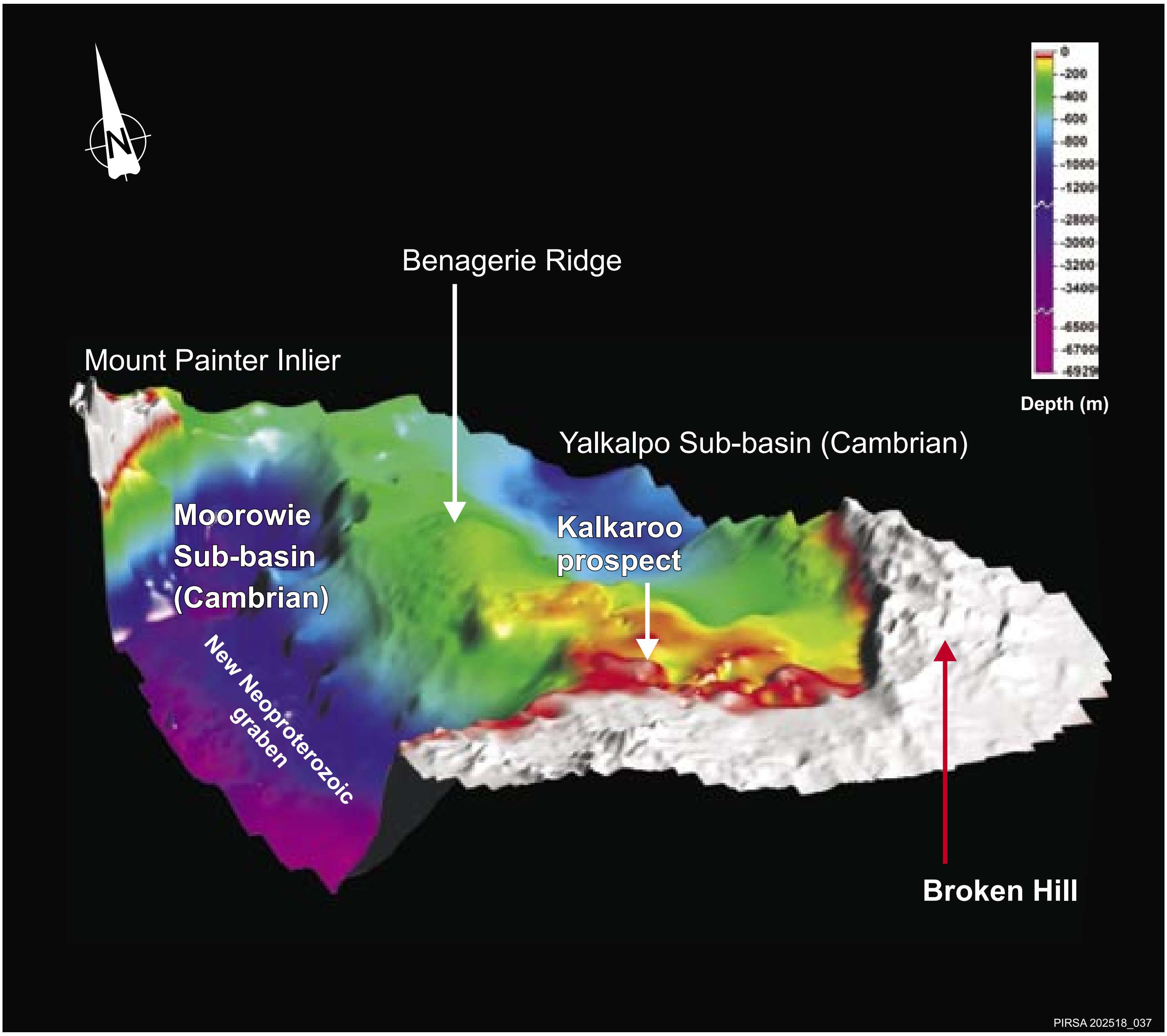

***Fig. 6** 3D representation of Curnamona Province depth to Palaeo–Mesoproterozoic basement.*

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