Conductivity-depth imaging in the Ord Basin, Western Australia

Yijie Zhan
Geological Survey of Western Australia
alex.zhan@dmirs.wa.gov.au

Arthur J. Mory
Geological Survey of Western Australia
arthur.mory@dmirs.wa.gov.au

Peter W. Haines
Geological Survey of Western Australia
peter.haines@dmirs.wa.gov.au

SUMMARY

The Ord Basin contains three asymmetrical synclines encompassing Cambrian and Devonian strata overlying the Kalkarindji Large Igneous Province, which extends across the Western Australian – Northern Territory border in northern Australia. Previous understanding of the basin was based mostly on surface mapping and a few mineral and petroleum drillholes. No seismic data are available in western part of the basin, and the airborne electromagnetic (AEM; AusAEM 02 in 2019–2020) survey becomes the first geophysical method to profile the basin down to a depth of 600 m.

A large portion of the basin, including the Hardman Syncline and southern part of the Kalkarindji Large Igneous Province is covered by 10 west–east AEM flight lines, in which contrasts of conductivity are highly consistent with outcrop geology and the Cambrian section in Okes-Durack 1 drilled in 1923–24. The survey shows Devonian sandstone and conglomerate are more resistive than underlying Cambrian siltstone in the western part of the syncline. The mid-Cambrian section especially is dominated by shale and siltstone of the Panton Formation and Nelson Shale, and shows a higher conductivity than younger coarser grained units. Intermediate and high conductive sections associated with Cambrian outcrops appear to shallow and thicken towards the east, indicating a Cambrian depocentre at least 50 km east of the Devonian outcrops. The AEM data, in conjunction with aeromagnetic data, also indicates that most outcrops mapped as Windoo Sandstone in the south of the basin underlie the lower Cambrian Antrim Plateau Volcanics, rather than overlie as previously interpreted. These outcrops are most likely associated with the Neoproterozoic Timperley Shale of the Wolfe Basin, but may locally include other Precambrian units.

Key words: Ord Basin, AEM, Hardman Syncline, Antrim Plateau Volcanics

INTRODUCTION

The Ord Basin straddles the Western Australian – Northern Territory border in the east Kimberley region of northern Australia and covers 40 000 km^2, of which 16 000 km^2 lies in Western Australia. The basin contains up to 2.5 km of Cambrian and Devonian strata, with the post-volcanic succession preserved in the Hardman, Rosewood and Argyle Synclines to the east of the Halls Creek Fault (Mory and Beere, 1988; Cutovinos et al., 2002a,b). The three synclines are surrounded by the Kalkarindji Large Igneous Province, which in this area is composed of the basaltic Antrim Plateau Volcanics that are broadly coeval with the first significant Phanerozoic extinction event (Jourdan et al., 2014). The Ord Basin has no seismic reflection data in either WA or the NT, but the basin is covered by the 1992 Geoscience Australia and 1997 NTGS aeromagnetic surveys, and the 2019-2020 WA–NT airborne electromagnetic (AusAEM 02) survey (Fig. 1). The latter resolves the basin to a depth of ~600 m in a manner comparable to seismic reflection surveys.

GEOMETRY OF HARDMAN SYNCLINE ON AEM DATA

The Hardman Syncline in the central part of the Ord Basin contains the most complete, and therefore thickest, sedimentary section of the basin, and occupies an angular area formed by the Halls Creek, Osmond and White Mountain Fault Zones (Dow and Gemuts, 1969; Windrim and Barnes, 2002). The White Mountain Fault extends to the southeast in the Northern Territory, where it is referred to as the Negri Fault, and displaces the lower Paleozoic sections in the Hardman Syncline (Cutovinos et al., 2002a,b). The syncline has been lightly explored for mineral (Windrim and Barnes, 2002; Wood et al., 2002) and petroleum (Okes-Durack 1, which was drilled after the discovery of an oil seep near the junction of the Ord and Negri Rivers in 1919; Purcell, 1984) resources.

The Hardman Syncline is crossed by six east–west AEM lines, of which CDI 5003002 and 5003003 (Figs. 1 and 2) image the broad geometry through contrasting conductivities. The contrasts are highly consistent with the surface geology (as mapped by Dow and Gemuts, 1969, and Mory and Beere, 1988) and the mostly mudstone section above the Antrim Plateau Volcanics in Okes-Durack 1, which allows conductivity variations to be confidently correlated with lithologies at depth. The surface geology mapped by Mory and Beere (1988) can be correlated with the AEM profiles, showing that the syncline is filled with sandstone and conglomerate of the Devonian Mahony Group, and a combination of Cambrian sandstone, limestone, shale and volcanics (Fig. 3). Sandstone and conglomerate of the Devonian Mahony Group in the western part of the syncline is more resistive than the underlying Cambrian Goose Hole Group, which shows intermediate and high conductivities on the AEM profiles due to the dominance of siltstone and shale within the Panton Formation and Nelson Shale. Both the intermediate and high conductive sections appear to shallow but thicken towards the east, indicating that the Cambrian depositional axis was at least 50 km to the east of the Devonian deposits. This points to significant erosion near the original Cambrian depocentre prior to deposition of the Devonian succession based on the thickening eastward trend. The eroded section is estimated at about 600 m for the upper Cambrian and 300 m for the middle Cambrian near drillhole RC01NC003. The remnant of the Middle Cambrian, most likely the Nelson Shale, is about 220 to 300 m thick at this location, with 40 to 120 m of undrilled section overlying the resistive volcanics.

The mid-Cambrian Antrim Plateau Volcanics and Nelson Shale in the west of the Hardman Syncline lie next to a fault, and have a apparent dip of ~20° (Fig. 3) to the east. This dip and distances between formation boundaries (2.3 km between A and B; 1.1 km between B and C) indicates thicknesses of about 780 m for the Antrim Plateau Volcanics and 370 m for the Nelson Shale at this location. However, the thicknesses of these units may have been much greater due to the apparent dip and faults cutting this area. The steepness of the Cambrian strata near the Osmond Fault indicates a compressional or transpressional movement after deposition. If this event pre-dated deposition of the Devonian succession it could explain the westward shift in the depocentre from the Cambrian to Devonian (Zhan, 2023). Given the almost 100 Ma break between the Devonian and Cambrian sections there is a case to place the respective successions in separate basins.

AEM CORRELATION OF 'WINDOO SANDSTONE'

South of the Hardman Syncline the Antrim Plateau Volcanics surrounds patchy sandstone outcrops (Figs. 1 and 4) with much concealed by colluvial deposits in the Kalkarindji Large Igneous Province. Originally mapped by Gemuts and Smith (1968) as the 'Gardiner Beds' these outcrops are of uncertain age and stratigraphic position (Casey and wells, 1960; Dow and Gemuts, 1967 & 1969). Blake and Warren (1996) later assigned these to the Windoo Sandstone (and specified a Cambrian–Ordovician age because the unit was inferred to overlie the volcanics. However, in many areas, including the type section, there is uniformly bland magnetic signature over the supposed 'Windoo Sandstone' compared to the surrounding Antrim Plateau Volcanics (Fig. 4). This bland response is also at odds with the transition evident along the southeastern margin of the Hardman Syncline, where the volcanics dip towards the axis of the syncline below the Nelson Shale (Fig. 4). The contrasting of magnetic signature between the two areas shows that the bulk of the 'Windoo Sandstone' underlies the Antrim Plateau Volcanics, although some outcrops mapped as that unit seemingly overlie the basalts.

AEM line 5008001–002 (Fig. 5) crosses the Antrim Plateau Volcanics and 'Windoo Sandstone' as mapped by Blake and Warren (1996). The basalts form an extensive and thick resistive layer within the syncline (Fig. 5). The sandstone outcrops correspond to scattered and thin, near-surface resistive bodies, but the majority of the interpreted sandstones are shown as highly conductive layer (Fig. 5). The conductive layer is better interpreted as a lithology with a high content of clay rather than sandstone that only lies at the core of a broad anticline (see annotations in Fig. 5a). The conductive layer can be traced westwards beneath the basalts in the syncline, with a possible displacement across the Addie Creek Fault Zone (Fig. 5). On the western side of that syncline the Antrim Plateau Volcanics are underlain by Neoproterozoic outcrops of the Wolfe Basin including the Timperley Shale (Gemuts and Smith, 1968).

In addition, the outcropping Timperley Shale and associated units along the western margin of the syncline shows a smooth magnetic response with a sharp contact against that of the Antrim Plateau Volcanics to the east (Fig. 4). The sharp contact is probably due to the overlying volcanics having been eroded, rather than being a fault. The magnetic response and the sharp contact are in stark contrast with the southeastern margin of the Hardman Syncline described above, but mirror those over most of the interpreted 'Windoo Sandstone' in the east where the Antrim Plateau Volcanics are not present (Fig. 4). Therefore, the area of the previously interpreted Windoo Sandstone (Fig. 4a) covered by colluvial sediments is tentatively interpreted as having bedrock older than the mid-Cambrian Antrim Plateau Volcanics and is likely to include the Neoproterozoic Timperley Shale (Zhan, 2023). The patchy outcrops referred to the 'Windoo Sandstone' are possibly equivalent to the thin Neoproterozoic Nyuless Sandstone that locally sits between the Timperley Shale and Antrim Plateau Volcanics to the west of the Kalkarindji Large Igneous Province (Gemuts and Smith, 1968).

CONCLUSIONS

Ten westerly trending AEM survey lines across the Ord Basin help resolve its structural geometry. The conductivity profiles confirm that the Hardman Syncline is displaced by the White Mountain Fault and is bounded by the Osmond Fault to the north. Steeply dipping Cambrian strata near the Osmond Fault, shallow and thicken towards the east. In comparison, Devonian deposition seems restricted to the footwall block of the western boundary fault. This geometry implies that the Cambrian and Devonian successions were possibly controlled by different tectonic regimes, with a post-Cambrian compressional or transpressional movement along the western boundary and deep erosion near the Cambrian depocentre. In the southern Ord Basin, an area enclosed by the Cambrian Antrim Plateau Volcanics and covered by colluvial sediments is interpreted as Precambrian bedrock, perhaps equivalent to the Neoproterozoic Timperley Shale and associated units, below the volcanics, rather than the volcanics lying below the supposed Cambrian–Ordovician 'Windoo Sandstone' strata.

ACKNOWLEDGMENT

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Figures

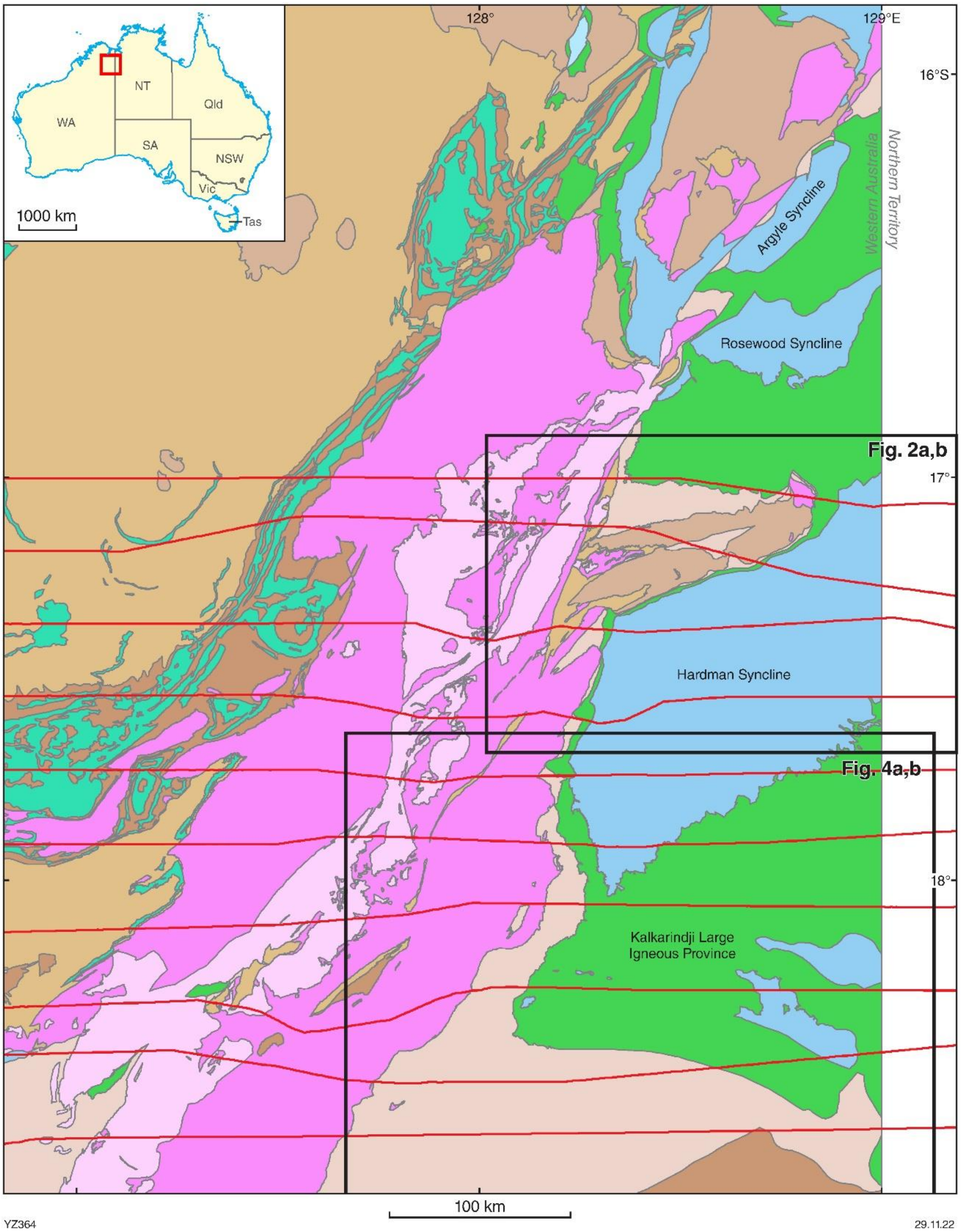

Figure 1. Location of the Hardman Syncline and Kalkarindji Large Igneous Province of the Ord Basin

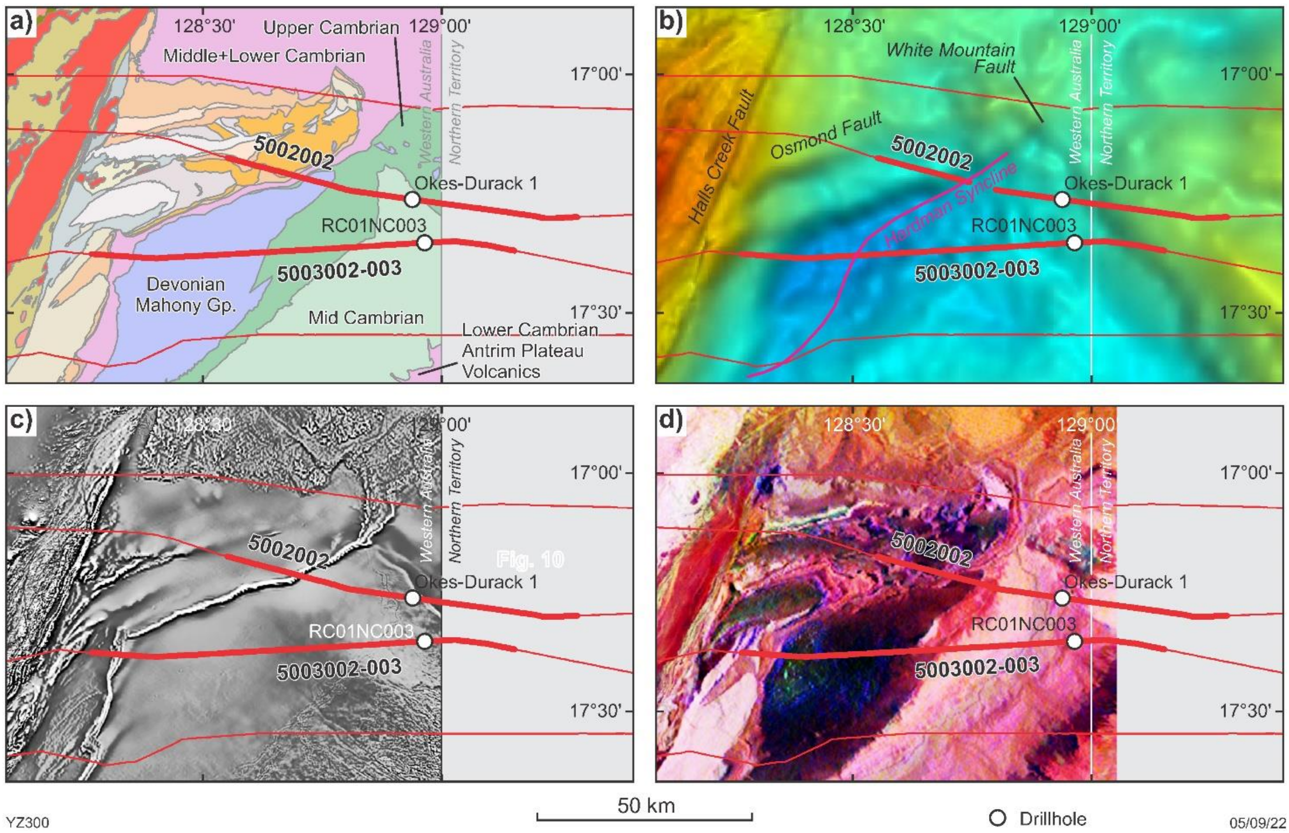

Figure 2. Maps of the Hardman Syncline and AEM lines: a) interpreted bedrock geology (modified after Mory and Beere, 1988 and GSWA2020a); b) Bouguer gravity (GSWA, 2020b); c) 1vd magnetic (GSWA, 2020c); d) radiometrics KTU (GSWA, 2020d)

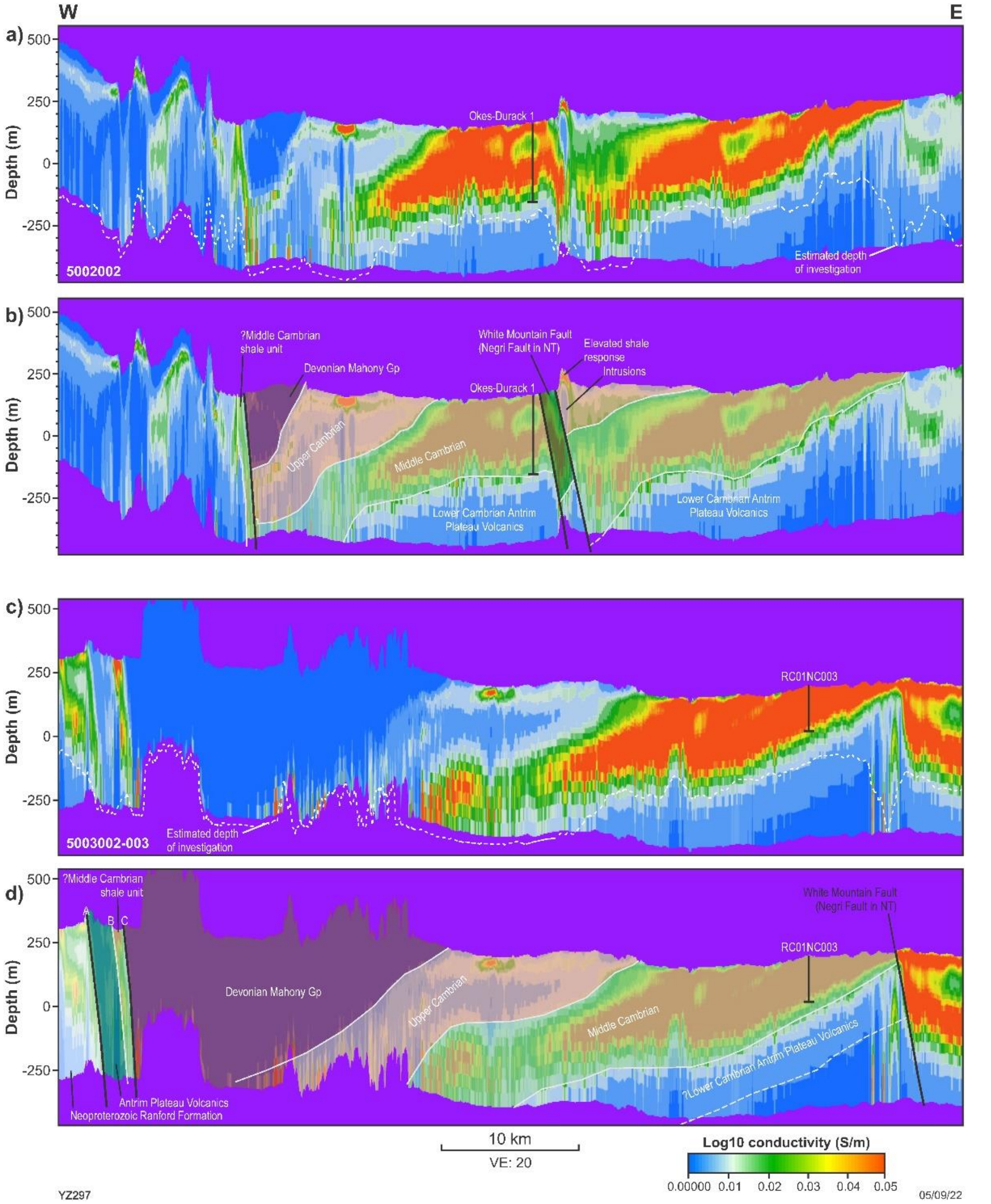

Figure 3. AEM profiles across the Hardman Syncline: a) uninterpreted CDI 5002002; b) interpreted CDI 5002002; c) uninterpreted CDI 5003002–003; d) interpreted CDI 5003002–003. See Figure 2 for profile locations

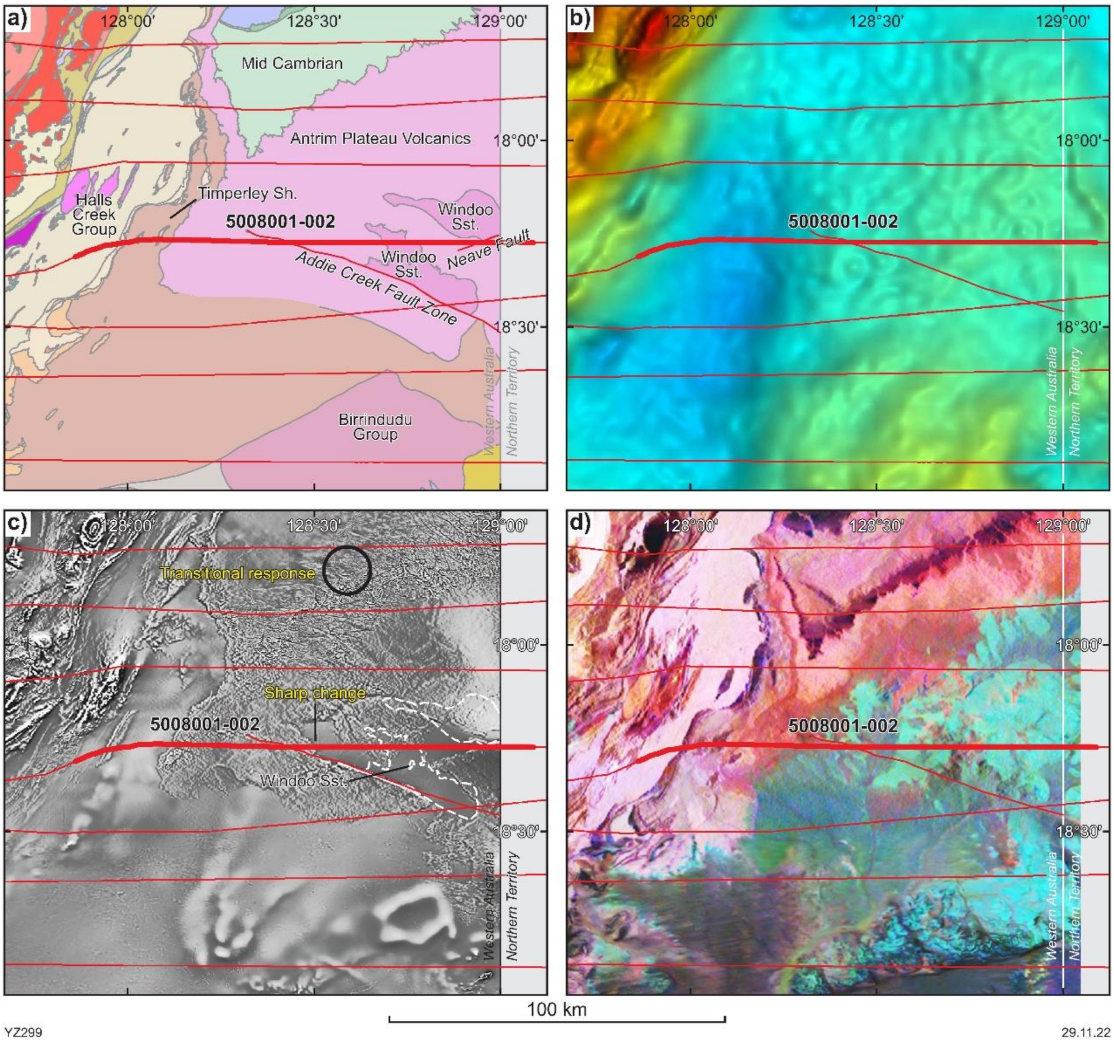

Figure 4. Maps in the Kalkarindji Large Igneous Province showing the Antrim Plateau Volcanics and nearby sedimentary rocks: a) interpreted bedrock geology (GSWA, 2020a); b) Bouguer gravity (GSWA, 2020b); c) 1VD magnetic (GSWA, 2020c); d) radiometrics KTU (GSWA, 2020d)

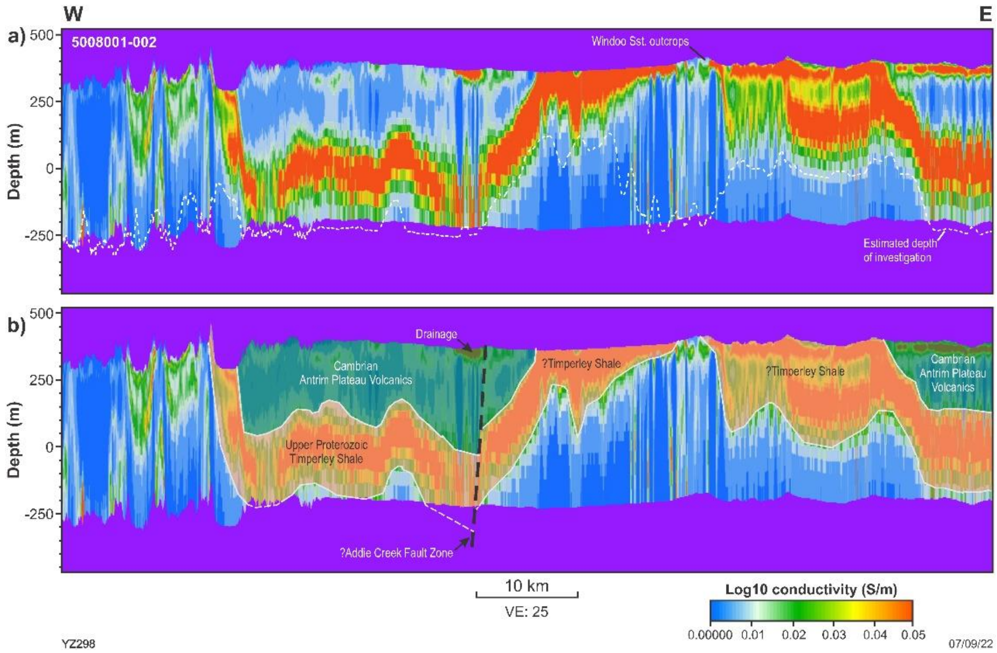

Figure 5. AEM profiles across the Kalkarindji Large Igneous Province. The Windoo Sandstone underlies the Antrim Plateau Volcanics and is probably correlated to the Nyuless Sandstone above the well-defined Neoproterozoic

Timperley Shale in the west: a) uninterpreted CDI 5008001–002; b) interpreted CDI 5008001–002. See Figure 4 for profile locations

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