Passive seismic studies show configuration of Paleoproterozoic subduction zones and their role in craton assembly in Western Australia

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SUMMARY

The Capricorn Orogen Passive source Array (COPA) is the passive source seismic component of a major Science and Industry Endowment Fund (SIEF) project, "The distal footprints of giant ore systems: Capricorn case study". COPA focuses on the deep crustal and shallow lithospheric structure in the Capricorn Orogen with the aim to better understand the tectonic amalgamation of the Western Australian Craton. The objective of COPA is to produce 3D multiple scale seismic images across the orogeny, that together with other geological and geophysical datasets help constrain the timing and kinematic evolution of Capricorn Orogen's fault zones, and their role in the metallogenic history.

Key words: Capricorn Orogen, passive seismic monitoring, receiver function, ambient noise, common conversion point

INTRODUCTION

The Paleoproterozoic era witnessed the assembly of the world's major continents by amalgamation of numerous Archean nuclei, through widespread subduction and continental collision. In Western Australia, the Capricorn Orogen records two collisional orogenic events, the 2215–2145 Ma Ophthalmian and 2005–1950 Ma Glenburgh Orogenies that amalgamated the Pilbara and Yilgarn Cratons to form the West Australian Craton. An Archean to Paleoproterozoic crustal element, the Glenburgh Terrane forms an exotic microcontinent between these two Archean units. These three crustal blocks were assembled along two major crustal suture zones. The lithospheric architecture across these sutures is of particular interest in studying not only their spatial connection to world-class mineral deposits, but also the characteristics of early Wilson cycles in the Paleoproterozoic.

The location of major crustal structures and broad architecture of the Capricorn Orogen are poorly constrained, as it has undergone a protracted period of reworking and large areas are covered by regolith. To improve the exploration potential of the region, a better understanding of the crustal architecture of the orogen is critical, including the identification of any island arcs or exotic accreted crustal material.

Results from previous studies including active source deep seismic profiling, receiver functions and MT studies, show a much reworked orogenic crust that is distinct from the simple Archean crust in the neighbouring cratons, suggesting progressive collisional processes during the final amalgamation of the Western Australian Craton. For example the deep seismic profile 10GA survey through the orogen (Johnson et al. 2013) reveals three deep penetrating faults that separate four seismically distinct tectonics blocks, suggesting that progressive and punctuated collisions of continental blocks played an important role in the craton building process. Receiver functions (Reading et al. 2012) characterize a distinct orogenic crust which has patterns of upper crustal discontinuities, thickened crust and low impedance contrast across the Moho, favouring a weakened orogenic crust that has accommodated most of the horizontal deformation during the craton formation and reworking processes. Along the craton margins, both active source profiling and MT studies (Johnson et al., 2012; Selway et al. 2009) show that the suture zones that separate the cratons from the Capricorn Orogen dip towards the craton side, suggesting a preferred subduction direction during the last stage of convergence (e.g. Tyson et al., 2002; van der Velden and Cook, 2005).

Previous seismic studies were all based on line deployment or single station analyses; therefore it is essential to develop 3D seismic images to test whether these observations hold consistently throughout the Capricorn Orogen. The specific aims of the passive seismic monitoring were to test if (1) distinct crustal blocks are present within the orogen, (2) distinct lithological differences are present in the upper crust and upper mantle, and if (3) crustal and lithospheric deformation along the craton margins, in general, follow the wedge tectonic model, with the subduction of juvenile blocks under the lithospheric mantle, and associated craton-ward dipping sutures (Snyder 2002).

METHOD AND RESULTS

An array of 36 broadband seismometers were deployed across the Capricorn Orogen and adjoining Yilgarn and Pilbara Cratons, covering an area of 500 km by 500 km with roughly 40 km spacing (including stations from previous deployments). Each station was deployed for approximately one year (Figure 1). The aim was to collect sufficient data for 3D structural imaging using body wave tomography, ambient noise surface wave tomography, and P- and S-wave receiver function Common Conversion Point (CCP) stacking techniques. We aimed for a 40 km lateral resolution at the surface which will degrade to about a 100 km resolution at the base of the cratonic lithosphere (200–250km depth) due to the low frequency of the earthquake waves.

A second high-resolution array of 24 seismometers spaced ~ 2 to 8 km apart was deployed in the central portion of the array and left to record for ~ 1 year. This array lies along the profile of the deep crustal seismic reflection line 10GA–CP2. Data from this survey was integrated with that from the high resolution array, and also processed for Common Conversion Point stacking.

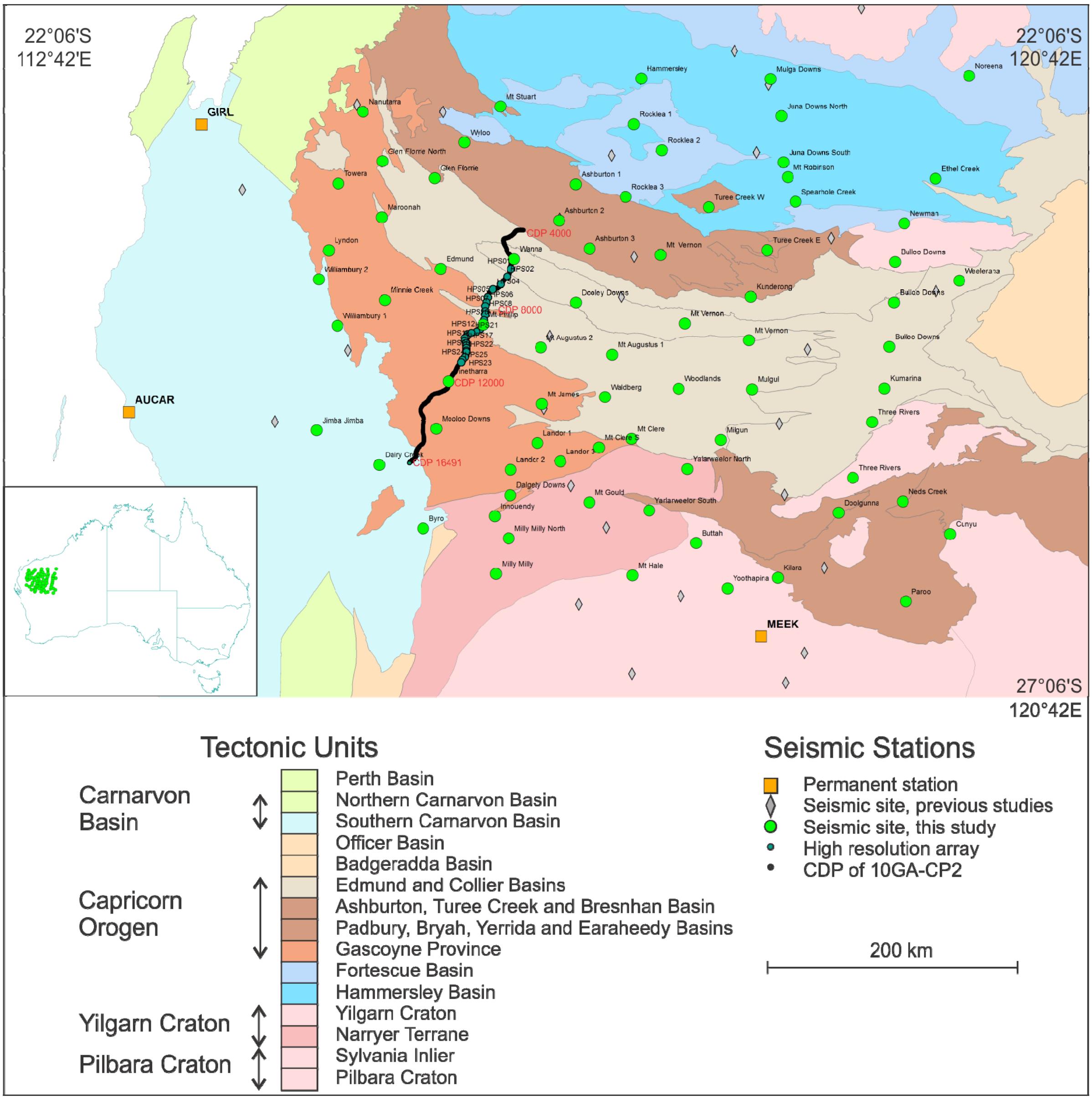

Figure 1. Tectonic unit map of the Capricorn Orogen, showing the location of the Capricorn Orogen Passive Seismic Array (COPA), the high resolution array, and stations from previous campaigns

Receiver Functions

Preliminary results of the crustal structure in the orogen are obtained from seismic receiver functions (Figure 2). A simple H-k stacking technique (Yuan, 2015) stacks available receiver functions for an optimum pair of bulk crustal thickness (H) and Vp/Vs ratio. The maps show bulk crustal thickness, Vp/Vs ratio (a proxy for composition) and crustal density anomalies from gravity inversions (Aitken et al, 2013). A thicker and denser crust with faster velocities is observed in the Capricorn Orogen compared to the cratons on either side. Compositionally the orogen is complex which may indicate different terranes/deformation process during its evolution in the Proterozoic. The northern margin of the Yilgarn Craton has anomalously thicker, denser and higher velocity crust at the same location as an abrupt change in crustal conductivities are observed in the MT study (Dentith et al., 2014).

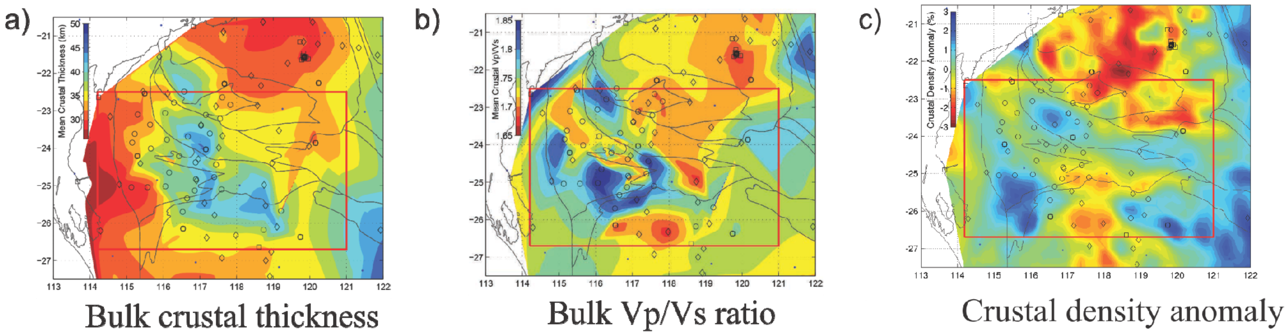

Figure 2. Results of the receiver function analysis showing bulk crustal thickness, bulk Vp/Vs ratio and crustal density anomaly from Aitken et al. (2013)

Ambient Noise Tomography

From ambient noise tomography we obtain shear wave velocities in a 3D volume for the orogenic crust (Figure 3). Waveforms for the same time period at station pairs are cross-correlated for all station pair combinations and then stacked to obtain the empirical surface wave travelling between them. Phase and group velocities are calculated for each station pair. Significant structural differences are evident in the shallow- and mid-crust. The high velocity northern margin of the Yilgarn Craton is prominent as previously observed in the receiver function and MT images.

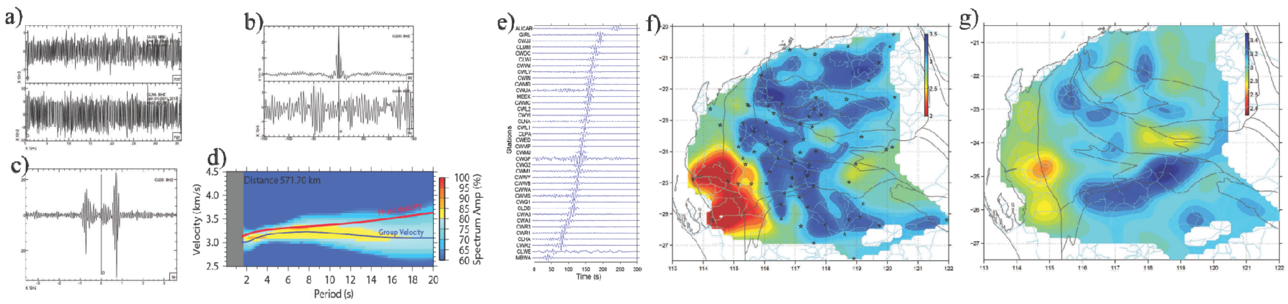

Figure 3. Ambient Noise Processing
a) 10 min vertical component recordings at stations CLNA and CLDD
b) auto- and cross- correlation of a)
c) stack of over 6 months of cross-correlated waveforms
d) dispersion measurements of a station pair
e) stacked correlations for all Capricorn stations pairs sorted by inter-station distance
f) group velocity topographic results for the period 2.5 s (~3 km depth)
g) group velocity topographic results for the period 15 s (mid crust)

Common Conversion Point Stacking (CCP)

A receiver function CCP stack was applied to the high-resolution array and COPA stations on the same profile to reveal crustal discontinuities (Figure 4c). The results correlate well with the deep seismic reflection profile (10GA–CP2) shot along the same line, as well as the coincident magnetotelluric data. The north dipping Moho and south dipping crustal structures (seen as truncated crustal regions) are observed in the data. A slow velocity mid- to lower-crust is inferred from the negative velocity gradients in the centre of the array, which are consistent with the ambient noise observations and highly conductive mid crust imaged in the MT survey.

Ambient noise tomography was inverted over the same profile as the CCP. The tomography is able to show the absolute velocities: under the Edmund basin the mid-to-lower crust has fast group velocities, while the shallow crust has slower group velocities (Figure 4d). The Gascoyne Province in contrast has faster group velocities in the shallow crust in the vicinity of the Minnie Creek Batholith and slower velocities in the mid-lower crust.

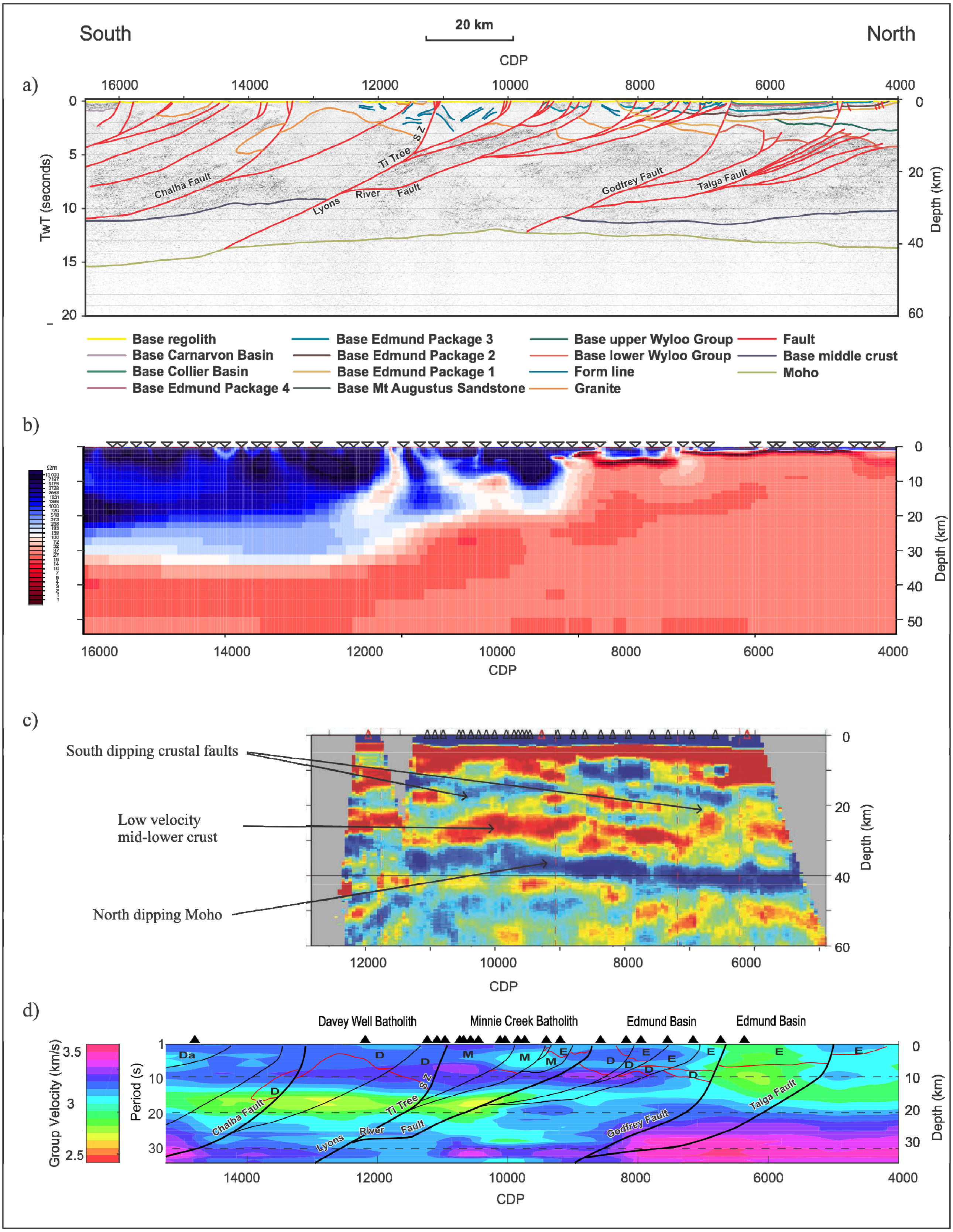

Figure 4. a) Deep crustal reflection interpretation from 10GA–CP2 (Johnson et al, 2011)
b) The MT inversion profile from Heinson et al. (2011)
c) The CCP stack results from the high resolution and COPA array
d) Ambient noise tomography from the high resolution and COPA arrays. D = Durlacher Supersuite, M= Minnie Creek Batholith, E = Edmund Group, Da = Dalgaringa Supersuite

CONCLUSIONS

Based on receiver function and ambient noise techniques, the Proterozoic Capricorn Orogen has a thicker crust and a higher Vp/Vs ratio than the adjacent Archean Yilgarn and Pilbara Cratons. These patterns are replicated in the density anomaly of Aitken et al (2013). The tomographic structures are still being compiled as the array moves eastwards, but already the edge of the Yilgarn Craton is shows the presence of deeper layers. The high resolution array replicated features observed in the deep crustal reflection and magnetotelluric line. This method shows that a much cheaper field campaign can lead to almost as high resolution data.

Initial results are enabling us to define a distinct velocity structure that eventually might be assigned to different crustal domains. As more data is received from the network, the resolution across the orogen will increase, highlighting both the crustal-scale architecture and differences in tectonic evolution between the Archean cratons and Proterozoic orogenic crust.

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