

Preliminary interpretation of deep seismic reflection line 10GA–CP1: crustal architecture of the northern Capricorn Orogen

by

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Introduction and aims of the seismic survey

Seismic reflection line 10GA–CP1 is oriented approximately north-northeast–south-southwest, broadly normal to the strike of the major geological structures in the northern Capricorn Orogen (Frontispieces 1–3; Plate 1; Thorne et al., 2011). It traverses rocks of the Fortescue and Hamersley Groups in the Turner and Hardey Synclines, and granite–greenstones of the Pilbara Craton in the Rocklea Dome, before crossing the Nanjilgardy Fault system into the Ashburton Basin to the south. Based on the known stratigraphy, stacking all the Archean and Paleoproterozoic supracrustal units present in the northern Capricorn Orogen gives a maximum cumulative thickness of ~26 km. The total thickness of the stratigraphy along 10GA–CP1 is probably less than 20 km, as the transect only passes through a small part of the Capricorn Group, and as the 4 km maximum thickness for the Turee Creek Group is only preserved locally in the Hardey Syncline.

The principal objectives of seismic reflection line 10GA–CP1 were to determine:

- the nature of reactivated growth faults that formed during deposition of the Fortescue Group in the southern Pilbara region

- the character of major faults, e.g. the Nanjilgardy Fault, that mark the boundary between the Pilbara Craton and the Ashburton Basin
- the crustal architecture of the Ashburton Basin — is it consistent with current tectonic models for the orogen?
- the deep crustal structure and nature of the Mohorovičić discontinuity (‘the Moho’) beneath the northern Capricorn Orogen (discussed by Kennett, 2011).

The preliminary interpretation of seismic transect 10GA–CP1 is presented in two sections. In the first section, an interpretation is presented based upon the nature of the seismic reflection data, and constrained by outcrop geology along the section line, as well as the gravity and magnetic data for the region. In the second section, the first interpretation is re-assessed in the light of additional regional aeromagnetic, gravity, and magnetotelluric datasets, and the results of regional geological mapping elsewhere in the northern Capricorn Orogen.

10GA–CP1: preliminary seismic interpretation

Turner Syncline to Baring Downs Fault

Northeast of the Baring Downs Fault, the Moho is weakly defined and has a gentle, undulating character, at a variable depth of 11.5 – 12.3 s two-way travel time (TWT) or 34–37 km (Fig. 1). The crust is thinnest beneath the Turner Syncline and Rocklea Dome, and thickest between the Nanjilgardy and Baring Downs Faults. Beneath the Archean to Paleoproterozoic supracrustal rocks, the crust shows a broad two-fold subdivision into a generally weakly reflective upper crust, corresponding to the exposed granite–greenstones of the Pilbara Craton, and a moderately reflective lower crust referred to as the Carluhunda Seismic Province (Korsch et al., 2011). The boundary between these crustal divisions is undulating and offset by the major faults, but generally occurs at a depth of 4–7 s TWT (12–21 km).

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In addition to the Baring Downs Fault, three other major crustal structures — the Nanjilgardy Fault, Soda Fault, and Moona Fault — are imaged in the seismic data (Fig. 1). With the possible exception of the Moona Fault, these structures are interpreted to extend through the crust to the Moho. The Baring Downs Fault is imaged as a moderately steep, broadly northeasterly dipping structure in upper crustal levels, but becomes asymptotically northeasterly dipping towards the Moho. The Nanjilgardy Fault is a single, steep, north- to northeast-dipping structure in the middle- to lower-crustal levels, but splays upwards into a complex, transpressive flower structure defined by steep to flat-lying, northeast- or southwest-dipping, minor faults. Both the Moona and Soda Well Faults are steep to vertical close to the surface, but flatten out to form irregular, northeasterly dipping listric structures in the middle to lower crust.

At the northeastern end of 10GA–CP1 (Fig. 2), the Fortescue Group dips gently to the southwest, and is imaged in the north as a series of weak to strong, layered reflections. Here, three units can be recognized within the Fortescue Group, based on their seismic reflectivity: a lower layer of weak reflections 0.25 s TWT (~0.8 km) thick; a middle layer of strong reflections 0.7 s TWT (~2.2 km) thick; and an upper layer of weak reflections 0.5 s TWT (~1.4 km) thick. The lower seismic layer cannot be tied to the outcrop geology, but possibly corresponds to sedimentary rocks of the Hardey Formation. The middle layer equates to the mostly basaltic rocks of the Boongal, Pyradie, and lower Bunjinah Formations, whereas the upper layer includes the upper Bunjinah Formation and Jeerinah Formation. Although the seismic reflections lose some of their definition beneath the Turner Syncline, they suggest a southwesterly thickening of the Fortescue Group from about 1.5 s TWT (~4.5 km) to about 2 TWT (~6 km) approaching the Moona Fault. Some loss of seismic definition also occurs on the southwestern limb of the Turner Syncline, where the Fortescue Group appears to have a maximum thickness of about 1.7 s TWT (~5 km).

Seismic data suggests that a section of the Hamersley Group about 1 s TWT (~3 km) thick is preserved in the Turner Syncline. The reflections corresponding to this unit are poorly defined on the northeastern limb, but are stronger near the syncline axis and the southwestern limb.

Pilbara Craton granite–greenstones in the Rocklea Dome are generally weakly reflective, although a number of prominent southwest-dipping to flat-lying reflections are recorded at depth, unconformably underlying the Fortescue Group. These reflections are interpreted as discontinuous greenstone sheets within the granitic crust. A prominent, steeply north-dipping mylonite zone, the Mithgoondy Shear (Frontispiece 1), is exposed in surface outcrops of the Rocklea Dome, but is not observed in the seismic profile.

A thick, almost complete, succession of the Fortescue Group outcrops on the southwestern limb of the Rocklea Dome, and is cut by the Karra Well and Soda Faults. Despite this, the succession is poorly imaged in the seismic profile, probably as a result of complex near-

surface conditions. Further west, between the Soda and Nanjilgardy Faults, a succession of weakly to strongly reflective lower and middle Fortescue Group rocks 1.7 s TWT (~5 km) thick is interpreted to overlie the weakly reflective granite–greenstone rocks. Here, the strongest reflections are from the lower 1.3 s TWT (~4 km) of the stratigraphy, whereas the subhorizontal dip of the reflections is caused by the trace of 10GA–CP1 being parallel to the local geological strike.

The stratigraphic succession between the Nanjilgardy and Baring Downs Faults (Fig. 3) has been difficult to interpret from the seismic reflection data. Surface outcrops consist of a fold- and fault-repeated succession of rocks of the upper Wyloo Group, consisting of the Mount McGrath Formation, Duck Creek Dolomite, and Ashburton Formation, whereas a thick succession of lower Wyloo Group rocks occurs along-strike to the northwest. In the seismic profile, the overall structural elements are delineated; however, the stratigraphy below the Duck Creek Dolomite is often poorly defined, with significant lateral variation in reflective character. Preliminary interpretation of these data suggest a marked thickening of the lower Wyloo Group (from 0.3 – 1.3 s TWT, or 1–4 km) and upper Wyloo Group (from 0.3 – 1.3 s TWT, or 1–4 km) towards the Baring Downs Fault. In this area, the lower Wyloo Group can be interpreted to directly overlie granite–greenstone basement rocks. The nature of the stratigraphy below the Mount McGrath Formation, in the flower structure of the Nanjilgardy Fault, has not been determined due to the weak reflections in this area.

Baring Downs Fault to the southern limit of 10GA–CP1

Within this part of the transect (Fig. 3), the depth to Moho shows little variation, ranging from about 12.3 s TWT (~37 km) at the Baring Downs Fault, to about 13 s TWT (~39 km) near the southern end of 10GA–CP1 (Frontispiece 1). Beneath the supracrustal succession, mid- to lower-crustal levels can be subdivided into a generally strongly reflective upper crust, and a weakly reflective lower crust. The boundary between these divisions is undulating, and generally occurs at a depth of 8.3 – 9.5 s TWT (25 – 27.5 km). This seismic structure contrasts markedly with that present northeast of the Baring Downs Fault, and has accordingly been interpreted as a separate seismic entity, the Bandee Seismic Province (Korsch et al., 2011). The nature of this crust is unknown, as the Bandee Seismic Province is not exposed in the Capricorn Orogen.

Several major faults were identified in the upper crust and supracrustal succession, although none of these structures could be traced below a depth of about 4.5 s TWT (~13.5 km). Most faults are moderately to steeply southward-dipping in the upper parts of the profile, although the Blair and Beasley Faults become flatter, but still southward-dipping, at depth. Major faults preserve either an extensional or thrust sense of movement.

The surface geology of the Bandee Seismic Province comprises polyphase-deformed Ashburton Formation, although this structural complexity is not imaged in the

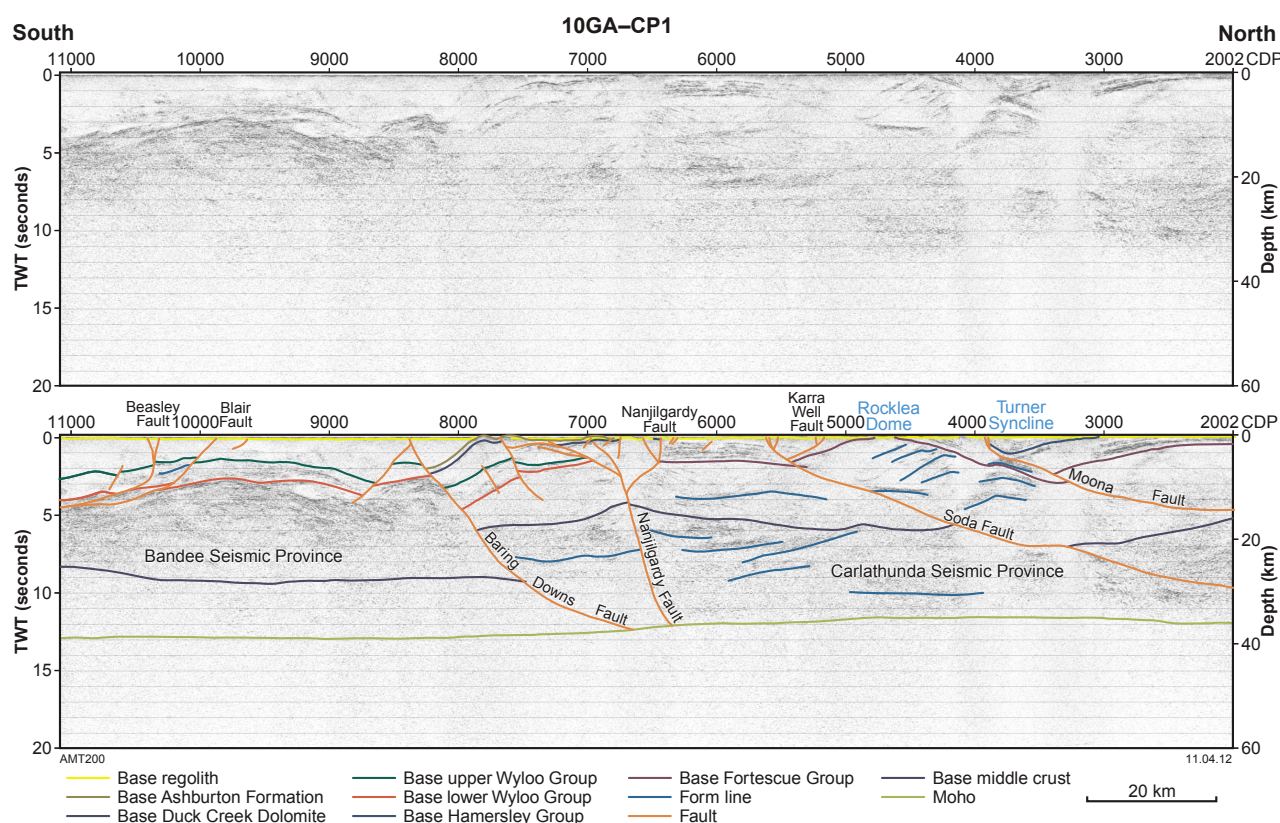


Figure 1. Migrated seismic section for line 10GA-CP1 across the northern Capricorn Orogen. Display shows vertical scale equal to the horizontal scale, assuming a crustal velocity of 6000 m/s. Common Depth Point (CDP) locations are shown in Frontispiece 1 (100 CDP = 2 km).

subsurface, probably because of a lack of continuous reflective markers within the stratigraphy (Fig. 2). The generally poor reflective response in this part of the section has also made it difficult to subdivide the upper Wyloo Group south of the Baring Downs Fault.

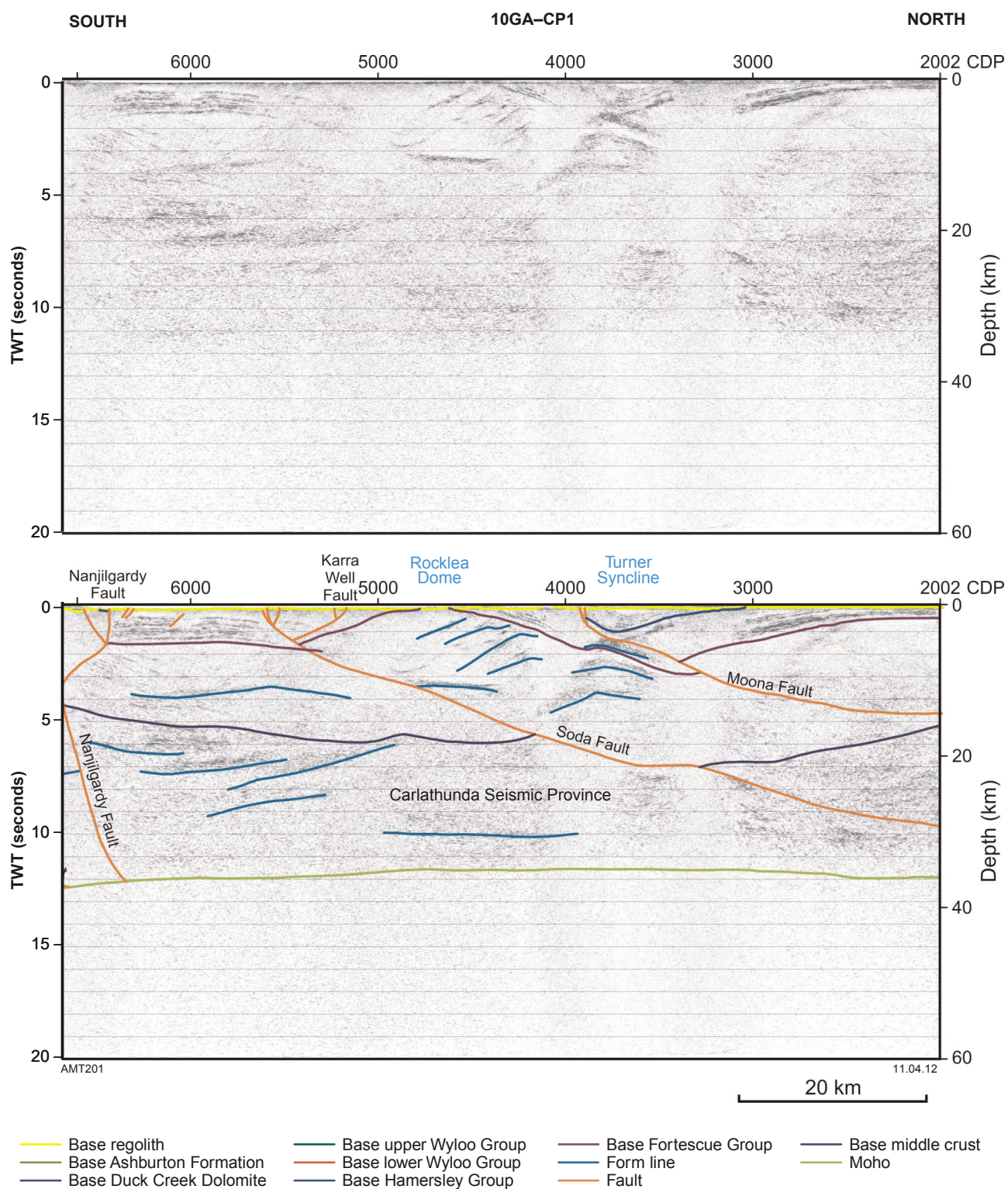
The reflective response is stronger below the interpreted base of the upper Wyloo Group, and the crustal architecture is imaged as a broad, faulted, upright anticline, whose axis lies immediately north of the Blair Fault. The thick (1 – 1.3 s TWT, or 3–4 km), weakly to strongly reflective layer that immediately underlies the Ashburton Formation is interpreted to be the lower Wyloo Group, with the high reflectivity of this layer caused by the Cheela Springs Basalt. Reflective layers beneath the interpreted lower Wyloo Group also show a broad anticlinal structure. Although these reflections could be due to an underlying succession of Hamersley and Fortescue Group rocks, the presence of numerous internal angular relationships is a feature not seen in this part of the stratigraphy elsewhere in the seismic profile.

Discussion of seismic interpretation

Seismic reflection data indicate a crustal thickness of about 11.7 – 12 s TWT (34–36 km) for the exposed southern part of the Pilbara Craton (Fig. 3, top). This is close to the values of 30 km \pm 2km and 34 km obtained by the passive seismic studies of Reading and Kennett (2003),

and Reading et al. (2012) for locations in the general vicinity, and also within the 28–37 km range reported for the southern Pilbara from the seismic reflection and refraction study of Drummond (1983).

Our deep seismic study has highlighted major differences between mid- to lower-crustal levels of the Pilbara Craton along 10GA-CP1. Upper-crustal granite–greenstone rocks, which occur northeast of the Baring Downs Fault, do not appear to be present south of this structure. Similarly, the middle- to deep-crustal levels, corresponding to the Carlathunda and Bandee Seismic Provinces, are quite different in their reflective character. These differences suggest that the combined granite–greenstone and underlying Carlathunda Seismic Province were once separate from the Bandee Seismic Province, but became juxtaposed along the line of the Baring Downs Fault. The timing of this amalgamation is uncertain, but must have pre-dated deposition of the lower Wyloo Group. This event may have occurred in the early stages of the 2215–2145 Ma Ophthalmian Orogeny, although the level of Ophthalmian deformation on the exposed Pilbara margin is not consistent with the presence of a major crustal suture along the line of the Baring Downs Fault. A more likely interpretation is that this suture pre-dates the Fortescue Group, and represents a southern terrane boundary analogous to those described from the northern Pilbara Craton (Hickman and Van Kranendonk, 2008; Hickman et al., 2010).



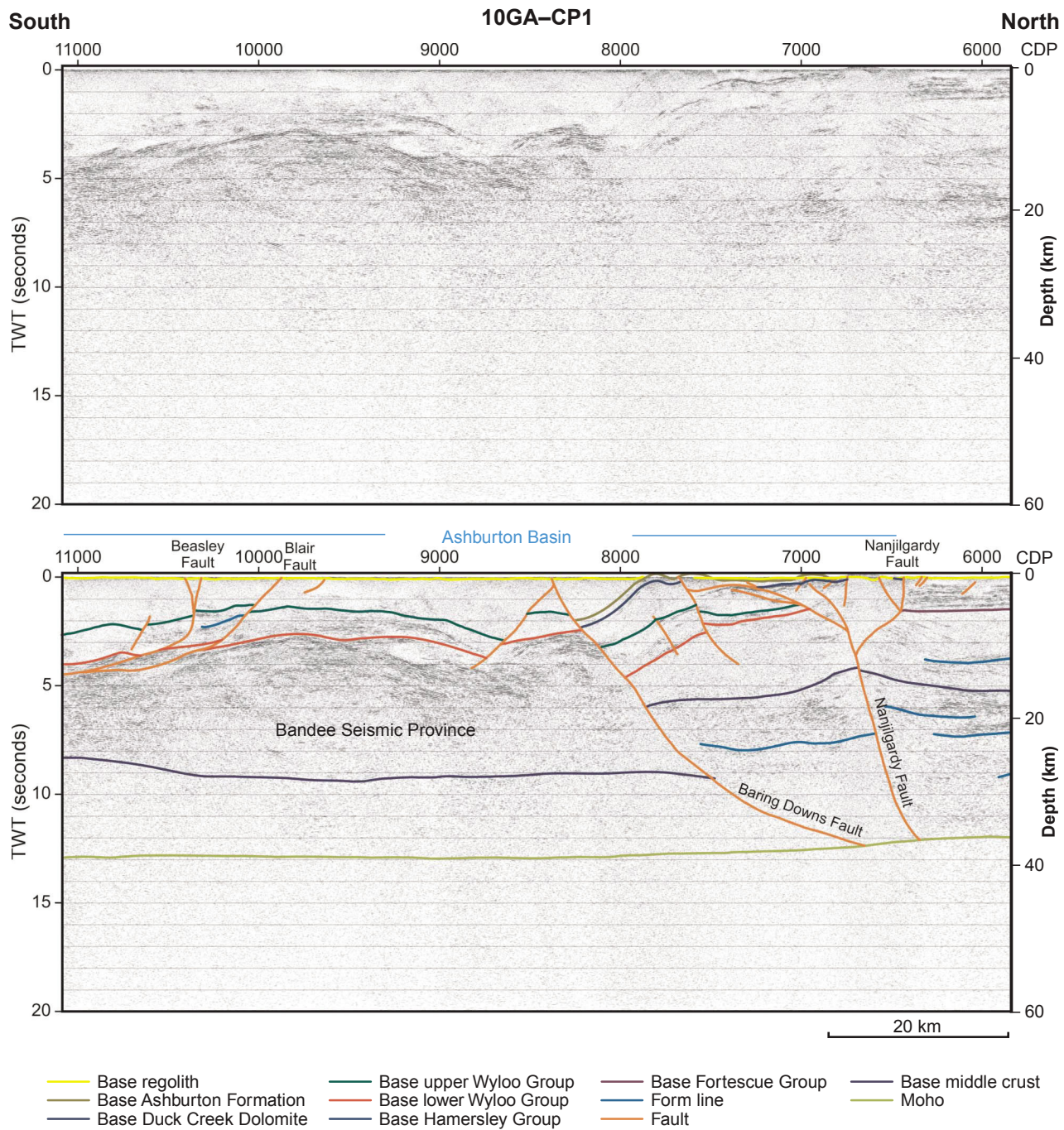


Figure 3. Clip of line 10GA-CP1, showing the crustal architecture between the Nanjilgardy Fault and the central Ashburton Basin. Display shows vertical scale equal to the horizontal scale, assuming a crustal velocity of 6000 m/s. Common Depth Point (CDP) locations are shown in Frontispiece 1 (100 CDP = 2 km).

Seismic profile 10GA–CP1 has delineated the northward-dipping attitude of the Baring Downs, Nanjilgardy, Soda, and Moona Faults. This is in contrast to previous interpretations that suggested that the major faults in the south central Pilbara Craton are steeply south-dipping (Thorne and Seymour, 1991). Syn- Fortescue Group growth faults in the southern Pilbara have also been postulated as south-dipping (Thorne and Trendall, 2001), a view not supported by the seismic data, which instead indicates that the Fortescue Group thickens from about 1.5 s TWT to roughly 2 s TWT (4.5 – 6 km) when traced in a southwesterly direction from the northeastern limb of the Turner Syncline towards the Moona Fault. The presence of north-dipping faults in the south central Pilbara has to be reconciled with the south-dipping, northward verging, structural fabric present in the southeastern Hamersley Basin (Tyler and Thorne, 1990; Tyler, 1991). This switch in fault orientation may take place across the eastern margin of the Turee Creek Syncline, where a marked change in the style of Ophthalmian deformation occurs, and which may mark the location of a related, buried, fossil transfer structure (Tyler, 1991; Plate 2).

Seismic profile 10GA–CP1 also represents a major advance in our understanding of the deep crustal structure beneath the Ashburton Basin. This area is now seen to mark the change from the north-dipping structural style of the south central Pilbara, to the south-dipping geometries characteristic of the southern Capricorn Orogen. The Ophthalmian suture between the Pilbara Craton (including the Bandee Seismic Province) and the Glenburgh Terrane is not observed on 10GA–CP1, being located south of the exposed Ashburton Basin, at the Lyons River Fault (Johnson et al., 2011; Korsch et al., 2011). Extensional and thrust faults, which cut both the lower and upper Wyloo Groups, may represent Ophthalmian structures that were subsequently reactivated during the 1820–1770 Ma Capricorn Orogeny. The strong Ashburton Fold Belt (Capricorn Orogeny) deformation recorded in surface outcrops of the Ashburton Formation does not appear to be present in the underlying lower Wyloo Group, which is imaged as a relatively continuous, although faulted, layer. This relationship suggests the possibility that the contact between the lower Wyloo Group and the Ashburton Formation is a significant structural decollement.

10GA–CP1 preliminary interpretation: additional geological and geophysical constraints

The previously discussed seismic interpretation of 10GA–CP1 (Fig. 4a) represents a major advance in the understanding of the crustal architecture of the northern Capricorn Orogen. However, there are aspects of the seismic interpretation south of the Nanjilgardy Fault, particularly whether or not the Hamersley and Fortescue Groups are present south of the Nanjilgardy Fault, that are at odds with other lines of evidence. These additional lines of evidence are summarized below.

- Both the surface geology and the regional gravity data suggest that the section between the Nanjilgardy and Baring Downs Faults is a down-faulted, westward continuation of the Bellary Dome. Since a complete Fortescue and Hamersley Group stratigraphy is exposed in the Bellary Dome (Thorne et al., 1991a), these rocks should also be present in the equivalent part of the 10GA–CP1 profile.
- The upper Hamersley Group is exposed immediately south of the Nanjilgardy Fault at Mount Maquire, southeast of Paraburdoo (Thorne and Tyler, 1993). A complete succession of Hamersley and Fortescue Group rocks is also preserved further east, on the southern flank of the Sylvania Inlier (Tyler et al., 1990).
- A broad aeromagnetic anomaly is present within the central Ashburton Basin, which coincides with the anticlinal crest indicated on the 10GA–CP1 seismic profile. The broad scale, uniform nature of this anomaly suggests it has a deep-seated source, below the strongly deformed and stratigraphically dismembered Ashburton Formation, which extends down to a minimum depth of 1.5 s TWT (~4.5 km). Geophysical modelling carried out as part of this study suggests that the aeromagnetic anomaly could be caused by a very strongly magnetic unit, such as the Hamersley Group, occurring at a depth of 9.5 – 10 km. This modelled depth is similar to the 8–11 km depth expected for the Hamersley Group based on the position of the basal contact of the lower Wyloo Group on the seismic profile.
- The results of a recent magnetotelluric study (Heinsen et al., 2011) indicate the presence a conductive layer at depth beneath the Ashburton Basin.
- There are no features of the Fortescue and Hamersley Group stratigraphy that suggest proximity to a southern basin margin at the Nanjilgardy Fault (Seymour et al., 1988; Thorne et al., 1991b; Thorne and Trendall, 2001). This stratigraphy, totalling almost 10 km in thickness, would have to have been stripped from the area south of the Nanjilgardy Fault prior to the deposition of the lower Wyloo Group.
- Paleocurrent and provenance data suggest that during deposition of the middle to upper Turee Creek Group, the Hamersley Group was distally exposed to the south of the present-day Pilbara margin (Thorne and Seymour, 1991; Martin et al., 2000).

In addition to the arguments listed above, other lines of evidence relate to the interpretation of the lower and upper Wyloo Group in the 10GA–CP1 seismic profile.

- Terminating the 1 km thick Duck Creek Dolomite at the Baring Downs Fault does not agree with the presence of mapped exposures of Duck Creek Dolomite in the central Ashburton Basin on eastern TUREE CREEK map sheet (Thorne et al., 1991a).
- The seismic interpretation of 10GA–CP1 shows the lower Wyloo Group varying in thickness from about 0.3 – 1.3 s TWT (1–4 km) between the Nanjilgardy and Baring Downs Faults. A similar thickness variation is interpreted for the Mount McGrath Formation (upper Wyloo Group). Although these thickness changes

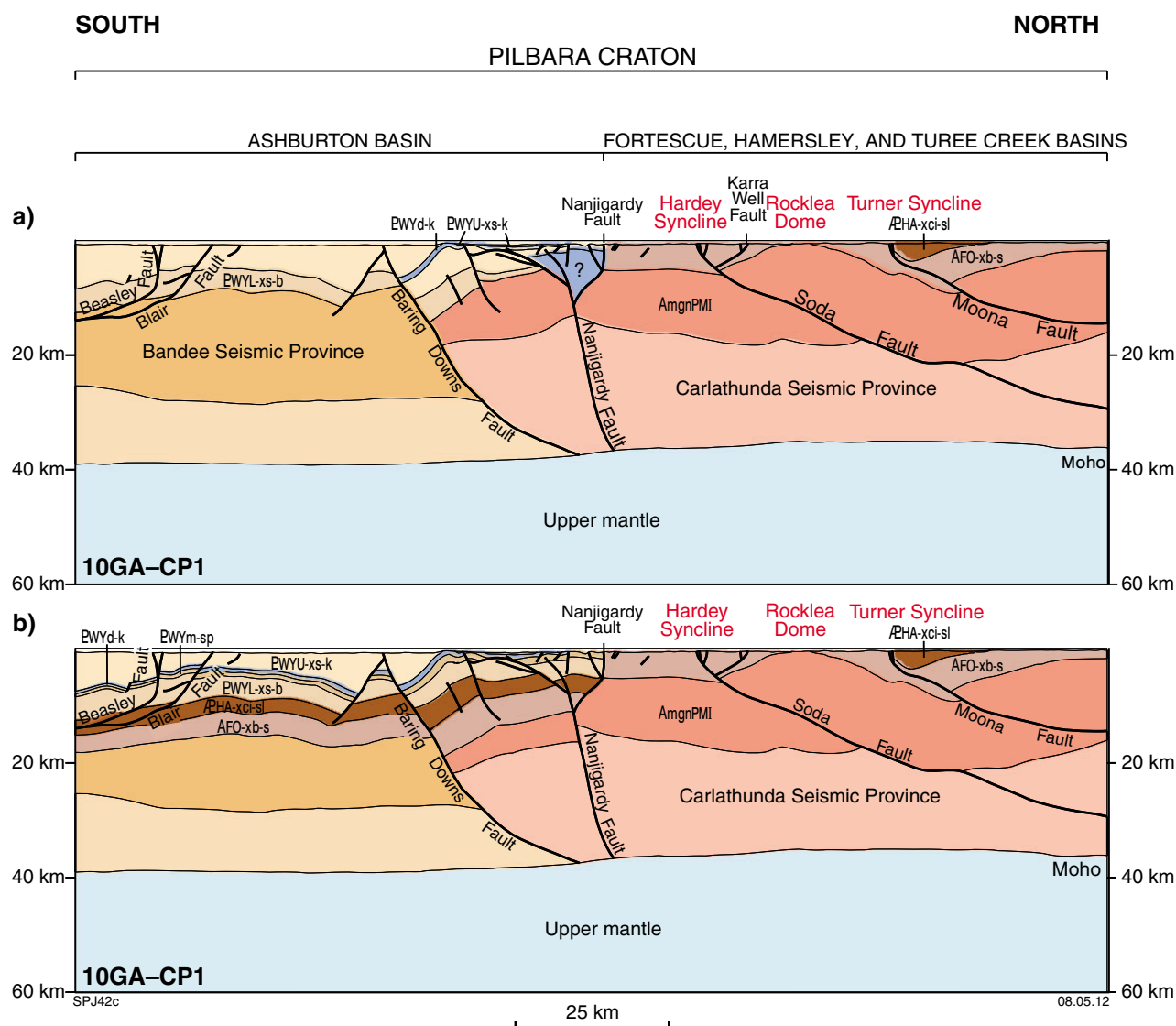


Figure 4. Preliminary interpretations of seismic line 10GA-CP1: a) preliminary seismic interpretation; b) alternative preliminary geological interpretation. This interpretation is based on that shown in Figure 2, but uses additional geological and geophysical evidence to show the likely distribution of the Fortescue, Hamersley, and upper Wyloo Groups south of the Nanjilgardy Fault. Abbreviations: AmgnPMI — Pilbara Craton, AFO-xb-s — Fortescue Group, AHA-xci-sl — Hamersley Group, PWYL-xs-b — lower Wyloo Group, PWYU-xs-k — upper Wyloo Group, PWYm-sp — Mount McGrath Formation, EWYd-k — Duck Creek Dolomite.

cannot be ruled out entirely, they do not match with observations from adjacent surface outcrops, which indicate relatively consistent thicknesses of ~3 km and ~1.2 km for the lower Wyloo Group and Mount McGrath Formation, respectively (Thorne and Seymour, 1991).

10GA-CP1: alternative preliminary interpretation

Figure 4b is an alternative cross-section for 10GA-CP1, which is based on the seismic data, but also tries to address the problems with the preliminary seismic interpretation

south of the Nanjilgardy Fault, cited above. Geological evidence suggests that the Duck Creek Dolomite, and possibly the Mount McGrath Formation, underlie the Ashburton Formation south of the Baring Downs Fault; however, these units cannot be distinguished on the basis of their seismic reflectance. Similarly, there is geological and geophysical evidence to suggest that the Hamersley and Fortescue Groups underlie the lower Wyloo Group between the Nanjilgardy Fault and the southern end of 10GA-CP1. Based on their known thicknesses, the positions of the Hamersley and Fortescue Groups on the seismic profile appear to coincide with a complexly structured, moderately reflective layer below the lower Wyloo Group. Although this layer does not have the

same reflective signature as the exposed Hamersley and Fortescue Group rocks seen at the northern end of 10GA–CP1, this may be due to an increased structural complexity and, in particular, the presence of numerous low-angle faults, beneath the Ashburton Basin. A similar explanation may also account for the difficulties in interpreting the seismic signature of supracrustal rocks between the Nanjilgardy and Baring Downs Faults.

The revised interpretation shows the Hamersley and Fortescue Groups extending from the exposed Pilbara Craton, across the Baring Downs Fault, to the southern Ashburton Basin. This succession overlies, and must therefore post-date, the boundary between the Bandee Seismic Province and the combined Pilbara granite–greenstone – Carlathunda Seismic Province, providing further support that this contact represents an Archean crustal suture within the Pilbara Craton.

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