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The nature of the Moho in Australia from reflection profiling: A review

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ABSTRACT

The transition between the crust and mantle across the Australian continent shows considerable variations in both depth and sharpness. Recent extensive seismic reflection profiling provides a comprehensive data set to investigate the nature of the Moho in a wide range of geological environments. In reflection seismology the crust is normally characterized by distinct reflectivity whose base is taken as the location of the reflection Moho. This attribution to the base of the crust ties well to refraction and receiver function studies that make a more direct estimate of the depth to the base of the crust. The character of the reflection Moho varies widely across the Precambrian areas of Australia with no consistent link to the surface geology or the estimated age of the crust. In a number of places a double Moho is preserved with underthrusting, suggesting that the reflection Moho is a very ancient feature (at least 1400 Ma in the Capricorn Orogen). Elsewhere, the current Moho reflects multiple generations of crustal reworking.

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1. Introduction

Extensive use of seismological methods has been made in Australia in the study of the crust and upper mantle using both man-made and natural sources. In particular there has been a sustained program of using seismic reflection profiling to characterise the whole crust. Reflection studies of the whole crust have grown from short experimental spreads in the 1960s to large-scale transects (see, e.g., [1]). A nearly 2000 km long reflection transect, using explosive sources, with 20 s recording was built up across southern Queensland in the 1980's. Explosive sources in drill holes continued to be used until 1997, when they were replaced with arrays of powerful vibrator sources. From 1999 to 2007 reflection acquisition was carried out using vibrators and recording equipment from the ANSIR Major National Research Facility. Since 2007 commercial contractors have been used, with the same style of acquisition parameters.

Since 2004 there has been a major national investment in seismic reflection work funded through investment from Geoscience Australia, State and Territory Geological Surveys and, since 2007, the AuScope infrastructure initiative. Over 14,000 km of full crustal reflection profiles have been acquired with recording to 20 s or more. Surveys in 2013–2014 have added more than 2000 km of full-crustal profiling and provide reflection results in a number of areas with little outcrop, which had not been previously studied.

This large and sustained effort has provided new insights into crustal structure, architecture and evolution across much of the Australian continent (Fig. 1). The dense sampling provided by the reflection transects has been of considerable value in mapping the character and geometry of the Moho on the continental scale [2,3].

Across Canada, Cook et al. [4] have presented a synthesis of results from the Lithoprobe program (1984–2003) on the character of the crust–mantle transition. Lithoprobe provided extensive reflection profiling in transects across major features of Canadian geology, including work in Archean and Proterozoic domains that may well have been linked to Australia in past supercontinent cycles. A feature of the Lithoprobe work was extensive use of seismic refraction so that many areas have good seismic wavespeed control for the deep crust and uppermost mantle. Across the Fennoscandian Shield, marine reflection profiles in the Gulf of Bothnia are complemented by 2000 km of land acquisition in the FIRE experiment [6] that provides good coverage of the major Archean and Proterozoic units, including the region of rather thick crust in southern Finland. Reflection work in Australia's Gondwana neighbour India [7] has concentrated on Proterozoic suture zones. Fine examples of reflection results from a wide range of geologic environments are provided by Carbonnell et al. [8], who also discuss the way in which refraction and receiver function analysis can be used to build up a more coherent picture of the many different styles of transition between crust and mantle in the continents.

Unlike the Canadian program of focussed transects in Lithoprobe, the extensive reflection coverage in Australia has been built up by investment from Geoscience Australia in partnership with State and Territory Geological Surveys directed mainly at economic targets. Since 2007 the AuScope infrastructure project has provided support directed at major scientific questions. The result is a mixture of long line-profiles and areas with stronger 3-D control on structure.

1.1. Major patterns of Moho variation across Australia

The Moho in seismic reflection records is identified as the base of crustal reflectivity, since the upper mantle shows few distinct reflections – probably because the horizontal scale length of structures is rather longer than in the crust. Other major sources of information on Moho depth across Australia come from early seismic refraction work, and from receiver function studies that exploit the conversions and reflections in the crust, which follow the major seismic phases from distant earthquakes recorded at permanent and portable seismic stations.

Kennett et al. [2] have assembled a wide range of information on Moho depth across Australia, and have demonstrated the strong consistency between the estimates obtained using different techniques. Seismic reflection profiling provides much of the detailed control on the depth to Moho in Australia, supplementing more localised information from refraction and receiver function studies. Recent experiments have added much information in areas that hitherto had very limited sampling, particularly in Western Australia. The compilation in Fig. 1 extends the results of Kennett et al. [2], and Salmon et al. [3], and includes Moho depth estimates from the extensive campaign of reflection profiles in 2013–2014 in regions of cover, notably across the Eucla basin to the Gawler craton, to the east of the Mt. Isa block, and in the Canning basin.

Fig. 1 shows the full current suite of information on Moho depth across Australia from both active and passive seismology, including the most recent reflection profiles, superimposed on a simplified tectonic representation. The individual points are colour coded by the depth to Moho with a symbol shape showing the nature of the technique employed. One of the striking features in the pattern of crustal thickness is the trend for the major tectonic blocks to be outlined by a narrow belt of somewhat thickened crust. This is particularly noticeable for the Yilgarn craton in Western Australia and for the Gawler craton in South Australia.

In this paper we present a number of examples of the nature of the reflection Moho, working geographically from west to east across the Australian continent, and approximately ordered in age from the Archean to the Proterozoic–Phanerozoic transition in the east. We look at way in which the reflectivity at the base of crust relates to the rest of the crust and the implications this has for crustal evolution, with comparisons to similar configurations in Canada [4], Fennoscandia [5,6], India [7], and elsewhere.

1.2. Reflection profiling and the character of the Moho

The reflection seismic method relies on the return of seismic energy to the surface from physical contrasts in the subsurface, associated with local changes in seismic wavespeed and/or density. In sedimentary basins, reflectors tend to be distinct and continuous, so that individual horizons can be tracked over considerable distances. In contrast, in the crystalline crust individual reflection segments tend to be short, and many crustal features become apparent from a change in the character of the reflection sequence in horizontal position or time. Full-crustal reflection surveys are carried out along nearly linear profiles, frequently exploiting access along public roads, though logistic considerations may require bends in the line. Only in a few cases is full 3-D control available from intersecting lines. Recording and processing are car-