Gondwana Research 28 (2015) 1212–1227

Contents lists available at ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Linking mainland Australia and Tasmania using ambient seismic noise tomography: Implications for the tectonic evolution of the east Gondwana margin

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ARTICLE INFO

Article history:
Received 6 March 2014
Received in revised form 17 September 2014
Accepted 23 September 2014
Available online 22 October 2014

Handling Editor: A.R.A. Aitken

Keywords:
Ambient noise tomography
Bass Strait
Bayesian inversion
East Gondwana
Selwyn Block
Tasmania

ABSTRACT

For nearly half a century, a number of conflicting tectonic models have been postulated to explain the enigmatic geological relationship between Tasmania and Victoria, with a view to unifying our understanding of the evolution of the eastern margin of Gondwana in Australia. In this study, ambient noise data from an array of 24 broadband seismometers is used to produce a high-resolution 3-D crustal shear wave velocity model of Bass Strait, the key to understanding the missing link. We apply a novel transdimensional and hierarchical Bayesian inversion approach to construct group velocity maps in the period range of 2–30 s, and subsequently invert group velocity dispersion for 3-D shear wave velocity structure. This allows us to image, for the first time, the entire crust beneath Bass Strait in high detail and elucidate the geometry and position of key crustal features with corroboration from complementary datasets. The three sedimentary basins related to the failed rifting event associated with the Australia–Antarctica breakup, in particular Bass Basin, clearly emerge from the tomographic solution model. A key feature of the 3-D shear wavespeed model is a distinct mid-lower crustal NW–SE high velocity zone which extends from northwestern Tasmania to south-central Victoria, confirming a Proterozoic geological connection. We also image three north–south high velocity belts that appear to span Bass Strait, with some interruption from velocity variations possibly related to more recent tectonic events. These belts are consistent with recent gravity and magnetic maps, and may indicate the presence of an exotic Precambrian terrane (the Selwyn Block). The model also images the crustal velocity structure of the southern Stawell and Bendigo Zones, and their internal large-scale multi-layer characters, a legacy of their Early Paleozoic intra-oceanic origins. Another high velocity anomaly imaged in the mid-lower crust is an east–west lineament beneath the northern part of Bass Strait, which may be an intrusive feature associated with the failed rift.

1. Introduction

The crustal structure beneath Bass Strait is key to understanding the tectonic relationship between Tasmania and mainland Australia, and more broadly, the late Proterozoic to early Palaeozoic evolution of the east Gondwana margin. During the last few decades a large number of studies have attempted to correlate and reassemble the continental blocks of mainland southeastern Australia, Tasmania and Antarctica (Sproll and Dietz, 1969; Baillie, 1985; Li et al., 1997; Boger and Miller, 2004; Cawood, 2005; Cayley, 2011; Gibson et al., 2011; White et al., 2013); however, the position of Tasmania in Cambrian reconstructions remains controversial. A diverse range of techniques have so far been exploited to infer information on crustal structure and composition beneath Bass Strait, mainly in studies focusing on similarities recognised in the geology (Crawford and Berry, 1992; Powell and Baillie, 1992; Reed, 2001; Cayley, 2011) and in geophysical, geochemical and other types of data in Tasmania and/or mainland Australia. Geophysical methods include potential field imaging and modelling (e.g., Leaman et al., 1994; Gunn et al., 1997a, 1997b; Morse et al., 2009; McLean et al., 2010), seismic reflection profiling (Drummond et al., 2000; Cayley et al., 2011) and seismic tomography (Rawlinson and Kennett, 2008). Palaeomagnetic evidence in the form of magnetic remanence (Li et al., 1997) has also been used. Geochemical investigations include apatite fission track (O'Sullivan et al., 2000) and detrital zircon age analysis (Berry et al., 2001), U–Th–Pb monazite dating (Berry et al., 2005, 2007, 2008) and a variety of other geochemical measurements (Reed et al., 2002; Clemens and Benn, 2010). Only a few interpretations rely on an integrated approach whereby

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http://dx.doi.org/10.1016/j.gr.2014.09.014
1342-937X/

multiple datasets are used to provide a tighter set of constraints (Cayley et al., 2002; Direen and Crawford, 2003; Teasdale et al., 2003).

Studies that attempt to link Victoria and Tasmania have been wide ranging and have undergone considerable changes through time, leading to a great variety of plausible, although often incompatible and conflicting, tectonic models. For instance, many interpretations conclude by requiring that Tasmania shifts some hundreds of km along an east–west, either sinistral or dextral Palaeozoic strike-slip fault in Bass Strait (Harrington et al., 1973; Baillie, 1985; Stump et al., 1986; Elliott and Gray, 1992; Betts et al., 2002), often referred to as the Colac–Rosedale Fault. However, there is a lack of evidence for the existence of this fault from available data (e.g., modern magnetic and gravity datasets do not show evidence for any lateral offset between Tasmania and Victoria), including no persuasive along-strike correlation in terms of stratigraphy and metamorphic history. Other studies claim an extension of the western Victoria terranes, controlled by an elongated Avoca–Sorell Fault system, off the western margin of the pre-Ordovician Tasmanian crust (Gibson et al., 2011). Another idea that has recently been considered is that of an exotic Proterozoic microcontinent that comprises west Tasmania, the Selwyn Block (the northward extension of west Tasmania that spans Bass Strait and penetrates beneath central Victoria) and submerged continental crust adjacent to Tasmania, which collided with the eastern margin of Gondwana during the Delamerian Orogeny (Cayley et al., 2002; Cayley, 2011).

One of the main difficulties in reconciling the connection between mainland Australian and Tasmanian tectonics is the lack of proven Precambrian exposure in the Lachlan Orogen, other than Proterozoic ages obtained from felsic and mafic enclaves entrained in Newer Volcanics above the Selwyn Block (Allchurch et al., 2008). This is in stark contrast to the Western Tasmania Terrane that exhibits numerous outcrops of Proterozoic rocks, apparently excluding any tectonic affinity between them (Moore et al., 2013). This apparently excludes any simple pre-Cambrian tectonic link, although correlation of structures imaged by aeromagnetic data across Bass Strait strongly implies a Proterozoic basement connection between western Tasmania and central Victoria (Cayley et al., 2002). A Cambrian affinity between western Tasmania and central Victoria is demonstrated by Late Cambrian (Tyennan) unconformities in both regions, and by common post-Late Cambrian stratigraphy. Like much of Victoria, the Eastern Tasmania Terrane differs significantly from the Western Tasmania Terrane. The Eastern Tasmania Terrane does not contain any evidence of Precambrian rocks and no evidence of a Proterozoic continental basement has been reported, either in outcrop nor inferred from geophysical surveys. Most significantly, the presence of Bass Strait and the thick Mesozoic and Cainozoic sedimentary and volcanic sequences that mask the older terranes, makes the link between Tasmania and Victoria even harder to decipher. This has significantly impeded the ability of conventional surface mapping in evolving a definitive narrative of Australia's geotectonic history, which remains one of the great challenges of Australian Earth sciences.

In this study, a 3-D shear wave velocity model from a new ambient seismic noise dataset is produced to unravel the long standing controversies surrounding Bass Strait's deep geology, tectonic evolution and the relationship between Tasmania and Victoria. Since it was first demonstrated that Rayleigh wave energy emerges from the long-term cross-correlation of background seismicity recorded by station pairs (Shapiro and Campillo, 2004), a cascade of remarkably detailed images of the crust have been obtained by exploiting this class of data (Yang et al., 2007; Bensen et al., 2009; Saygin and Kennett, 2012; Young et al., 2013a, 2013b). Recent developments have allowed large scale features to be imaged at greater depth (Poli et al., 2012; Shen et al., 2013), and small scale features to be imaged near the surface (de Ridder and Biondi, 2013; Draganov et al., 2013).

Here, we extract structural information from the data using a novel Bayesian transdimensional tomography technique that describes the solution in terms of a posterior probability distribution of data fitting models from which summary information (e.g. average model, standard deviation of the ensemble) can be extracted. This approach has been shown to be far more robust than conventional tomography methods (Young et al., 2013a, 2013b). Results are interpreted in conjunction with information provided by potential field data, exploration wells, seismic reflection lines, geochemical analysis and field mapping.

2. Geology and tectonic setting

The basement structure of Bass Strait has proven difficult to study since direct terrane observations are very limited by the submergence of most of the geological outcrop. Although potential field data provide insight into the geophysical response of the basement, the presence of several thick, failed-rift basins, namely Otway, Bass and Gippsland Basins (see Fig. 1), remain obstacles for the completion of a model of the basement at constant high resolution. Therefore, the geological knowledge of submerged Bass Strait has largely been inferred from direct observations in both Tasmania and Victoria.

The island of Tasmania can be divided into two distinct geological domains: the Western Tasmania Terrane (WTT) and the Eastern Tasmania Terrane (ETT) (Fig. 1). The WTT exhibits widespread outcrop of Neoproterozoic sedimentary and volcanic rocks, although the majority were metamorphosed during the Cambrian (Berry et al., 2007). In contrast, the oldest rocks in the ETT are early Ordovician or younger (Powell et al., 1993), suggesting that these two disparate geologies on either side of the Tamar River could potentially be separated by a crustal-scale discontinuity, the so called Tamar Fracture System (Williams, 1978).

The oldest outcropping rocks in western Tasmania are predominantly metaquartzites and siltstones of the Rocky Cape Group in the Rocky Cape Block (ranging from ~1000 Ma to a maximum of 1430 Ma) (Black et al., 2004). The Rocky Cape Group is unconformably overlain by the Late Neoproterozoic to Cambrian Togari Group, which has been dated by Calver (1998) at ca 750 Ma. Emplacement of high-K calcalkaline andesitic to felsic Mount Read Volcanics (Perkins and Walshe, 1993) and syn-orogenic sedimentary deposition were mainly produced by a Middle Cambrian extensional event in northwestern Tasmania (Stacey and Berry, 2004).

The turbidites of the Stony Head Sandstone are the oldest rocks of eastern Tasmania, deposited during the Early Ordovician(?) (Powell and Baillie, 1992; Powell et al., 1993; Seymour, 2011). These rocks are part of a larger succession of turbiditic sandstones and mudstones, the Mathinna Supergroup, which forms the pre-Carboniferous basement of the ETT from the Furneaux Islands to Eaglehawk Neck in southeastern Tasmania (Powell et al., 1993). During the Devonian, prior to and following the Tabberabberan Orogeny, large areas of NE Tasmania were subjected to granitoid intrusions (Black et al., 2005). Another major feature of Tasmanian geology is the large volume of Jurassic tholeiitic dolerite intrusions. In Tasmania, this event has principally injected sills into the Tasmania Basin cover sequence.

Further north across Bass Strait, Victoria is part of a major accretionary orogen called the Tasmanides that formed along the Pacific margin of Gondwana from the late Proterozoic to ca 100 Ma (see Glen, 2013, for a recent overview). Although the westernmost part of Victoria is part of the Delamerian Orogen, we will focus only on the central provinces of the Lachlan Orogen (except for the Grampians–Stavely Zone). The subdivision of the Lachlan Orogen has been established relative to several deformation and lithology patterns, which allow identification of a number of distinct zones. The Stawell, Bendigo, Melbourne and Tabberabbera zones will be briefly described below (Fig. 1). These areas of the crust were extensively deformed by several cycles of intermittent orogenesis, namely the Delamerian (~520–490 Ma), Benambran (~455–440 Ma), Bindian (~420 Ma) and ultimately Tabberabberan (~390 Ma). The following description of the abovementioned zones is largely based on VandenBerg et al. (2000) and Cayley et al. (2011).

The Grampians–Stavely Zone lies in the easternmost part of the Delamerian Orogen and contains Middle–Late Cambrian calcalkaline volcanic rocks of the Mount Stavely Volcanic Complex and overlying marine