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COMPILATION AND GEOLOGICAL IMPLICATIONS OF THE MAJOR CRUSTAL BOUNDARIES MAP AND 3D MODEL OF WESTERN AUSTRALIA

DMcB Martin, R Murdie, DE Kelsey, R Quentin de Gromard, CM Thomas, HN Cutten, Y Zhan, Y Lu, PW Haines and J Brett

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Cover image: Journey to the centre of the Kimberley (© 2010 PL Schubert)

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Compilation and geological implications of the major crustal boundaries map and 3D model of Western Australia

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Abstract

Major crustal boundaries that penetrate the lithosphere to the Moho define the tectonic blocks involved in the assembly of the Australian continent, and are consequently considered important for understanding its geological evolution and the localization of mineral and petroleum systems. Systematic 2D mapping of these first-order structures has previously only been conducted on a continental scale within Australia, and has typically not considered regional details of geological evolution or their implications in 3D. This Record describes the geological evolution of Western Australia from the perspective of a statewide compilation of major crustal boundaries and volumes interpreted primarily from seismic and potential field data, although also taking into account regional geological understanding. This is the first study of its kind to fully integrate 2D and 3D compilations to ensure a realistic structural architecture.

KEYWORDS: basement, basin, craton, crust, geophysics, lithosphere, orogen, Phanerozoic, Precambrian, seismic, structure, tectonics

Introduction

The crustal architecture of the Australian continent consists of a series of well-defined upper crustal elements that were originally interpreted from surface geology and potential field data (e.g. Shaw et al., 1995) and forms the basis of many tectonic interpretations of the continent. This crustal architecture was primarily assembled in the Proterozoic during the amalgamation and dispersal of Columbia/Nuna and Rodinia, and was subjected to Phanerozoic reactivation during the assembly and breakup of Gondwana. However, the precise locations of the deep major crustal structures that bound these elements are poorly defined in both space and time, and are commonly only illustrated on highly stylized time-slice cartoons (e.g. Tyler, 2005; Cawood and Korsch, 2008; Betts et al., 2015). Given the significance of these structures to understanding the details of the tectonic evolution of Australia, and their importance in many mineral and petroleum systems, it is somewhat surprising that they have not yet been mapped in more detail than the national compilation of Korsch and Doublier (2015).

Prior to the relatively recent acquisition and collation of a national network of seismic reflection profiles (Kennett et al., 2016) and potential field datasets (Kennett et al., 2018), national maps of crustal boundaries were mainly based on high-level interpretations of gravity and magnetic data and small-scale geological maps. Consequently, the resulting schematic tectonic maps are simplistic and commonly do not correlate well with established local and regional geology, with major boundaries crosscutting the regional structural grain in some areas. However, recent improvements in the amount and quality of seismic, potential field, isotopic and geochronological data in Western Australia, combined with detailed local knowledge of the tectonic evolution of the State, has enabled the compilation of a statewide map and 3D model of major crustal boundaries in unprecedented detail. Although these products are confined to Western Australia, they also incorporate recent advances in tectonic understanding of relevant areas that adjoin the State, and could be used as a starting point for a more detailed national model. This new map and 3D model of major crustal boundaries and associated volumes, are products of the Accelerated Geoscience Program, and form the basis of a discussion of the 4D tectonic assembly of Western Australia presented in this Record. The digital data for the map are available on GSWA's **GeoVIEW.WA** interactive geological map, and from the **Data and Software Centre** where the 3D model is also available for download.

Previous work

Numerous studies of the tectonic evolution of Australia have presented schematic maps of major crustal elements at the continental scale (e.g. Plumb, 1979; Shaw et al., 1995; Myers et al., 1996; Betts et al., 2002; Tyler, 2005; Cawood and Korsch, 2008; Betts et al., 2015; Aitken et al., 2016), culminating in the compilation of a national GIS dataset of major crustal boundaries at a scale of 1:2 500 000 (Korsch and Doublier, 2015, 2016). These maps are commonly based primarily on the 2D interpretation of potential field data with limited detailed integration with local or regional geology, although many boundaries are now also constrained in the third dimension via deep reflection seismic surveys. Shaw et al. (1996) recognized the importance of acquiring more data, the necessity of 'more precise and meaningful integration with the geology' and the creation of a solid geology map that integrates geochronological and geophysical data. Despite the wide availability of datasets that constrain both 2D and 3D crustal architecture, no coherent synthesis of all the major crustal boundaries of Western Australia has yet been attempted, with the majority of studies having focused only on the 2D assembly of the West Australian Craton (e.g. Horwitz and Smith, 1978; Gee, 1979; Myers, 1990, 1993; Tyler and Thorne, 1990; Cawood and Tyler, 2004; Johnson et al., 2013). The Proterozoic assembly of Western Australia has recently been summarized by Johnson (2013) although this study did not map out the major crustal boundaries, and also did not cover the Archean and Phanerozoic evolution of the State.

The earliest interpretations of the crustal architecture of Western Australia are those of Horwitz and Smith (1978) and Gee (1979), which both focused primarily on the assembly of the Pilbara and Yilgarn Cratons along the Capricorn Orogen to form the West Australian Craton (WAC), and later deformation around its margins. These studies pre-dated the application of plate tectonic theory in this area, and interpreted the geological history in terms of 'fixist' cratons surrounded by younger mobile belts, although nonetheless identified the major crustal elements that are still recognized today. Starting in the 1990s, plate tectonic theory was increasingly applied to interpretations of the assembly of the WAC (Myers, 1990, 1993; Tyler and Thorne, 1990; Myers et al., 1996; Cawood and Tyler, 2004; Johnson et al., 2013). Similar interpretations on a broader scale have led to the recognition that Proterozoic Australia was assembled via the amalgamation of three cratons, namely the West Australian (WAC), North Australian (NAC) and South Australian (SAC) Cratons along their intervening orogens. Together these form a triple-junction geometry (Fig. 1) that is mostly obscured beneath the Canning Basin and Centralian Superbasin and their eastward extensions into South Australia. This triple-junction geometry has since become an enduring feature of the majority of State and national structural and tectonic interpretations (e.g. Gee, 1979; Myers, 1990, 1993; Shaw et al., 1996; Betts et al., 2002, 2015; Tyler, 2005; Cawood and Korsch, 2008; Korsch and Doublier, 2016; Johnson, 2021), although the detailed architecture, timing and geodynamics of its formation remain controversial (cf. Betts et al., 2002; Smits et al., 2014; Howard et al., 2015; Kirkland et al., 2017).

Methodology

Compilation of the major crustal boundaries map of Western Australia has broadly followed the methodology of Korsch and Doublier (2016) in which the location and character of major crustal boundaries were first identified in deep crustal reflection seismic profiles, then extrapolated along strike using other data sources such as potential field data and regional geological maps. Korsch and Doublier (2016) did not provide a definition of a major crustal boundary, although they did define the hierarchy of subdivision of crustal blocks in Australia. For the purposes of this Record, we define a major crustal boundary as 'a lithospheric-scale structure that is interpreted to transect the crust to the Moho, or a structure within the crust that forms the boundary between interpreted tectonic units at the terrane or province scale'. The second part of this definition acknowledges that most major crustal boundaries are listric and, in some cases, may not transect the full thickness of the crust, or else sole into other structures that do. The definition also ensures that the boundaries of significant tectonic units recognized at the terrane or province scale are captured by the dataset.

A significant simplification and source of uncertainty in the compilation of major crustal boundaries is that lithospheric-scale dipping structures are represented as a single line feature on a projected 2D surface. This is further complicated for structures under cover that are interpreted from potential field data. In areas of outcrop, crustal boundaries have been co-located with the major mapped faults that are interpreted to be the surface expression of the boundary. However, in areas under cover, the methodology of Korsch and Doublier (2016) has been applied on seismic sections where there is no surface expression of the boundary. In cases similar to that illustrated for the Baring Downs Fault in figure 4 of Korsch and Doublier (2016), we have chosen to extrapolate the boundary to coincide with the surface fault expression. Regardless of what method is used to show the subsurface extent of structures in 2D plan-view, their lateral positioning orthogonal to strike has low accuracy, particularly when interpreted from potential field data in which the depth and orientation of the feature is poorly constrained in areas away from seismic sections. The large uncertainties in the accuracy of the boundary location in such cases is reflected in large values (in km) for the precision attribute of these boundary segments. Extrapolation of boundaries along strike beyond their point of definition on seismic sections involved the integration of all available datasets to provide the most geologically plausible interpretation. Priority was given to datasets that tend to image mid- to lower crustal levels, such as gravity, active and passive seismic and magnetotelluric (MT) data over more traditional datasets such as aeromagnetic data that primarily image the upper crust. However, all boundaries have been geologically reconciled with these upper crustal datasets. The various segments of each boundary were then assigned a comprehensive set of attributes that are summarized in Table 1 and described in detail in the data dictionary that accompanies the digital layer.

Following 2D compilation and attribution, the boundaries were modelled in 3D to validate geometric relationships and make full use of the depth component of the 3D data sources, mainly the seismic reflection data, although also passive seismic and MT models (Murdie, 2021). Any changes in interpreted geometry necessitated by the 3D model were then fed back into the 2D map compilation. The resulting 3D model captures the complexities of the geometries produced by intersecting dipping structures, particularly where a structure bounds several tectonic units or changes dip or dip-azimuth along strike. The 3D model also accounts for crustal blocks that are not exposed at the surface. The presence of these blocks is mainly determined by their distinctive seismic characteristics, and consequently the term 'seismic province' is used to refer to a discrete volume of middle to lower crust that cannot be traced to the surface, and whose crustal reflectivity is different from that of laterally or vertically adjoining provinces (Korsch et al., 2010). In other cases, MT methods have been used to define lower crustal layers based on their relative conductivity.

Principal data sources

Major crustal boundaries were interpreted from a variety of data sources that have been integrated to provide the most geologically plausible interpretation for each boundary. Each data source is discussed in detail below in order of importance to the overall interpretation, along with the advantages and disadvantages of each.

Figure 1. Major crustal elements of Australia (modified after Tyler, 2005; Cawood and Korsch, 2008). Light dashed lines are older cratons that pre-date those in heavier dashed outlines. The heavier dashed outlines correspond to West Australian Craton, North Australian Craton and South Australian Craton. Abbreviations: WAC, West Australian Craton; NAC, North Australian Craton; SAC, South Australian Craton. The Diamantina Craton comprised the NAC and SAC crustal elements, and extensions into Antarctica (Cawood and Korsch, 2008) in a configuration that pre-dated the one shown here

Table 1. Attributes of the 1:2 500 000 major crustal boundaries of Western Australia feature class. Abbreviations: T, text; I, integer; D, date

Item name	*Optional*	*Type*	*Width*	*Description*
FEATURE	false	T	150	General crustal boundary category (e.g. Fault or shear zone, Geological boundary)
TYPE_	false	T	20	Dominant specific boundary type, as identified in or inferred from the source datasets (e.g. normal, reverse or thrust, strike-slip, isotopic)
NAME	false	T	50	Generic name that enables selection of common boundaries; primarily based on tectonic unit that it bounds
DESCRIPTN	false	T	254	Broad defining characteristics (e.g. boundary between A and B) and reference if appropriate (author and abbreviated journal info)
FEAT_CONF	false	T	10	Overall confidence of interpretation (e.g. very low, low, moderate, high)
SEIS_LINE	true	T	254	Name of source/defining seismic line and link to associated data via Geoscience Australia persistent identifier (PID)
FEAT_SCALE	false	T	20	Vertical extent of feature (e.g. crustal, lithospheric)
SOURCETYP1	false	T	20	Principal data source for feature interpretation (e.g. outcrop, gravity, aeromagnetics)
SOURCETYP2	false	T	20	Secondary data source for feature interpretation (e.g. outcrop, gravity, aeromagnetics)
SOURCETYP3	false	T	20	Tertiary data source for feature interpretation (e.g. gravity, aeromagnetics)
DIP_EST	false	T	30	Estimated average dip in the upper crust (e.g. gentle, moderate, steep, subvertical)
DIP_DIR	false	T	35	Approximate dip direction
MAX_AGE	false	T	20	Maximum age of boundary at Eon level or lower
MIN_AGE	false	T	20	Minimum age of boundary at Eon level or lower
COMMENT_	true	T	254	General comments (e.g. surface fault name). Components listed in chronological order separated by semicolons
EVENT_1	true	T	80	Interpreted initiating tectonic event. Event names to match Explanatory Notes Database
EV_CONF_1	true	T	10	Confidence on initiating tectonic event constraints (e.g. low, moderate, high)
EVENT_2	true	T	80	Interpreted first reactivating tectonic event. Event names to match Explanatory Notes Database
EV_CONF_2	true	T	10	Confidence on first reactivating tectonic event constraints (e.g. low, moderate, high)
EVENT_3	true	T	80	Interpreted second reactivating tectonic event. Event names to match Explanatory Notes Database
EV_CONF_3	true	T	10	Confidence on second reactivating tectonic event constraints (e.g. low, moderate, high)
EVENT_4	true	T	80	Interpreted third reactivating tectonic event. Event names to match Explanatory Notes Database
EV_CONF_4	true	T	10	Confidence on third reactivating tectonic event constraints (e.g. moderate, high)
EVENT_5	true	T	80	Interpreted fourth reactivating tectonic event. Event names to match Explanatory Notes Database
EV_CONF_5	true	T	10	Confidence on fourth reactivating tectonic event constraints (e.g. moderate, high)
CAP_SCALE	false	T	10	Scale used to digitize the feature, or scale of dataset from which feature was imported (e.g. 1:2500000)
PRECISN_KM	false	I		Across-strike XY uncertainty in kilometres at relative level (RL) of interpretation
BASINCOVER	true	T	254	Where concealed, list of overlying basins in chronological order separated by commas
EXTRACT_DA	false	D		Date the layer was created
SYMBOL	false	T	254	Combination of FEATURE and TYPE_ for plot purposes

Seismic reflection

Deep seismic reflection profiles are the most detailed source of interpretive material when constraining the crustal scale of major structures or boundaries. The majority of the interpreted major crustal boundaries in Western Australia are transected by at least one deep seismic reflection profile at some point along their strike (Fig. 2), either in Western Australia or in adjoining states or territories. However, these profiles commonly do not have a unique interpretation, due to factors such as antiquity, data quality and processing techniques, orientation of the lines with respect to the imaged structures, and influence of prevalent geological paradigms at the time of their original interpretation. For this reason, there has been no systematic re-interpretation of the seismic data as part of this compilation, although in each case, the most current seismic interpretation has been honored. Crustal lines that have not been processed for deep imaging, such as BMR88-01 to 03 in the northern Canning Basin, were not used.

The seismic reflection data provides the starting point for identifying the crustal scale of a boundary, and its apparent dip. These attributes were then applied to the full strike extent of the boundary, unless other data, such as additional seismic profiles, suggest otherwise. Boundaries that coincide with outcropping faults have been approximately located at the relevant common depth point (CDP) on the profile or snapped to the relevant fault, although concealed boundaries with no surface expression are projected to surface using the same methodology as that described by Korsch and Doublier (2016).

In the 3D model, the seismic interpretation raster images were draped onto a vertical profile that represents the 'curtain' of CDPs (Fig. 3). The interpretive cartoon images were used rather than the SEGY data to avoid re-interpreting the data. The cartoons were drawn to scale retaining as accurately as possible the CDP locations. However, due to the curvature of some of the profiles, the draping onto the curtain may not image the boundaries in their precise location and, in some instances, there is a slight mismatch between the image and the interpreted boundary. In some cases, such as MT data, the sections are planar vertical surfaces as presented in the original data sources.

Geological mapping

The second most important dataset for identifying major crustal boundaries is geological mapping, especially the 1:500 000 State Linear Structures (GSWA, 2020a; Fig. 4a) and the 1:500 000 Tectonic Units layers (GSWA, 2017; Fig. 4b), and local geological knowledge. These data layers, and their underlying links to GSWA's Explanatory Notes System (ENS), capture essential information regarding the location of major faults and the timing and setting of tectonic units and events in the State. All the interpreted boundaries in this compilation honor these data sources, particularly where major crustal boundaries are interpreted to coincide with outcropping major faults. However, in areas with significant cover where current basement interpretations are considered out of date, for example under the Canning and Carnarvon Basins, crustal boundaries may not match existing interpreted major structures.

Gravity potential field

The isostatic residual of the State Bouguer gravity anomaly map (GSWA, 2020b) is the best potential field dataset for interpreting crustal-scale structures because it mostly emphasizes large density contrasts within the mid- to lower crust (Fig. 5a). A limitation of this dataset is that 2D images do not directly convey the depth of the anomalies. No specific forward modelling or inversion of the data to determine depth were carried out as part of this study, although gravity forward modelling accompanied many original interpretations of seismic reflection lines. Profile modelling and 3D inversion across the State would be a worthwhile exercise in the future, particularly in areas that are not well constrained by seismic reflection data. However, to partly overcome the limitations of 2D potential field data, multiscale edges (worms, Fig. 5b) were used to evaluate the dip of the major gravity gradients (Brett, 2020c).

Multiscale edges provide a way of extracting structural information from potential field data over a range of depth scales. They are generated by finding maximum and minimum inflection points in the calculated total horizontal derivative of the potential field data. This is done for many upward continuation heights, with greater height corresponding to progressively deeper features (hence *multi*scale). Adjacent points are then joined to create polylines (worms) that define isocontours of features for each continuation layer. Note that the relationship between height continuation level and depth is not well defined; for example, a continuation height of 92 km does not imply a depth to source of 92 km.

Aeromagnetic potential field

Regional structural analyses commonly rely heavily on interpretation of aeromagnetic data, such as reduced to pole (RTP) images of total magnetic intensity. This data mostly emphasizes near-surface structure that is not the primary focus of this study; for this reason, aeromagnetic datasets were not a significant input into this interpretation. However, upward continued magnetic data that emphasizes deeper anomalies was used to confirm boundaries interpreted from other datasets. In particular, 10 km upward continued RTP data (Fig. 6a) is complementary to the isostatic residual gravity data, in conjunction with RTP multiscale edges (worms, Fig. 6b).

Passive seismic models

Passive seismic techniques use natural earthquakes to investigate the depth and velocity structure of the crust. Data from permanent and temporary stations across the State (Fig. 2) were used to inform the construction of the 3D model using two techniques: receiver function analysis and ambient noise tomography. Receiver function analysis uses the direct and reflected waves generated from incoming P-wave arrivals from teleseismic earthquakes to image the layering of the crust. In particular, receiver function analysis was used to define the depth to the Moho in this model. Ambient noise tomography uses the fundamental vibrational frequencies of the Earth to determine areas of different shear-wave velocity, which is used to infer the composition (mafic or felsic) of different crustal units, and aids in the differentiation of seismic provinces.

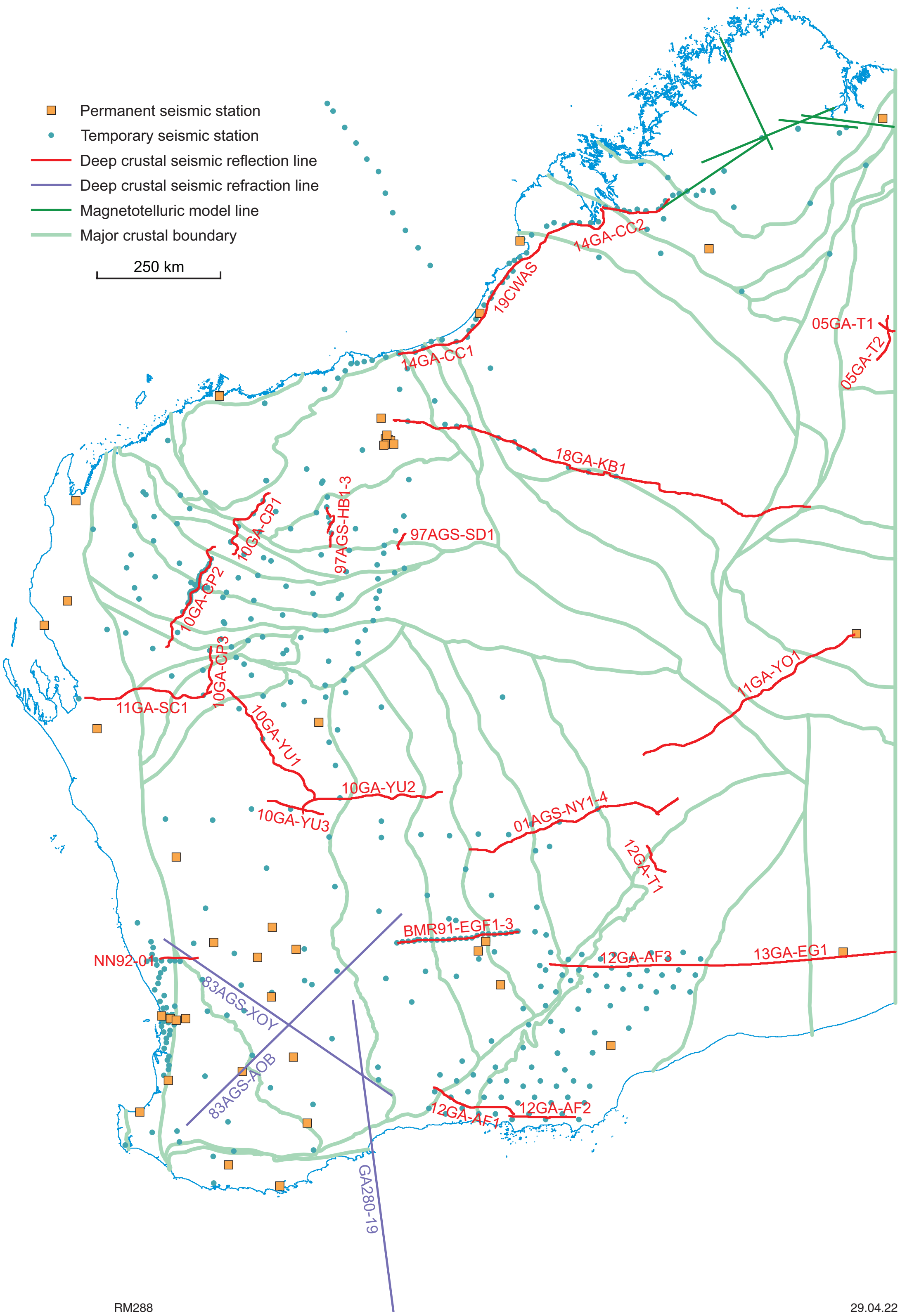

Figure 2. Map of Western Australian major crustal boundaries, deep crustal seismic lines, MT lines and passive seismic stations used in this study

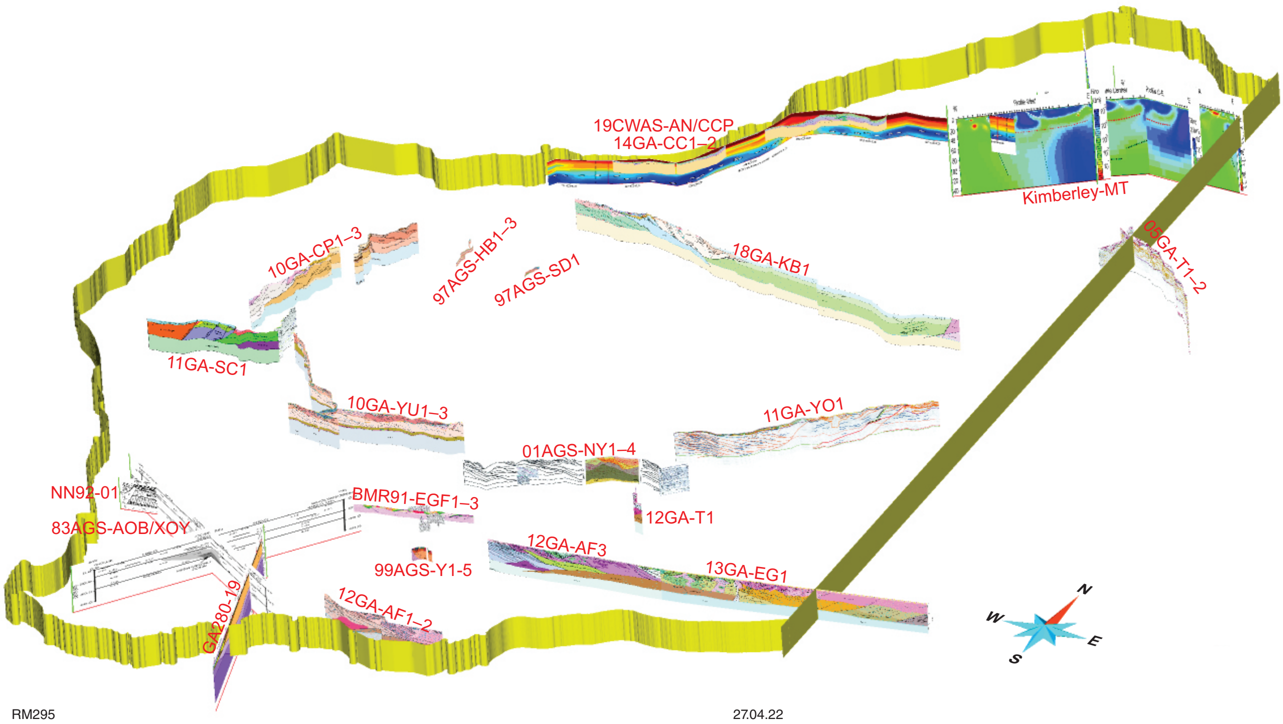

Figure 3. Images of seismic and MT interpretations georeferenced in 3D space

Point data from the receiver function analysis from recent local seismic deployments have been integrated with interpolated data from the 2012 AuSREM model (Kennett and Salmon, 2012) and recent deep crustal seismic reflection lines to give an updated interpretation of Moho depth for Western Australia (Fig. 7).

Seismic refraction

Seismic refraction surveys provided crustal structure information in areas where seismic reflection images were not available. These surveys tend to pre-date the reflection lines. The resolution is not as detailed as reflection images, although they provide data on boundaries that show a significant change in seismic velocity. This data was primarily used to constrain the depth to major crustal layers in the southwest Yilgarn Craton (Figs 2, 3).

Magnetotelluric models

Magnetotelluric (MT) models image changes in electrical conductivity of the crust and are useful for 3D interpretations. Since changes in seismic and electrical properties do not necessarily correspond to the same boundaries, seismic data has been preferentially used to ensure consistency across the model. However, in areas such as the Kimberley where there is no seismic data, the MT models were used as an indicator of the larger and deeper crustal structure (Figs 2, 3).

Sm–Nd and Lu–Hf isotope maps

Isotope maps are increasingly being used to characterize lithospheric architecture and crustal evolution through time. In particular, a recent compilation of statewide whole-rock samarium–neodymium and zircon lutetium–hafnium isotope data was produced as part of the Accelerated Geoscience Program (Lu et al., 2021a) and was used to inform and validate some of the major crustal boundaries. The complete Sm–Nd and Lu–Hf isotope compilation includes data from felsic and mafic igneous rocks, as well as sedimentary rocks. However, felsic igneous rocks provide an important window into the age and evolution of the middle and lower crust, and maps of the contoured isotope data characterize major crustal provinces. Significant gradients on Sm–Nd and Lu–Hf isotope maps of two-stage depleted mantle model age (T_{DM}^2) and crustal residence time (the difference between T_{DM}^2 and crystallization age) are typically associated with major crustal structures (Lu et al., 2021a). The resolution of these maps is currently very coarse in places, and in regions with large data gaps, the results of the Natural Neighbor interpolation tool used to generate them in ArcGIS Spatial Analyst might be skewed, although the point data clearly highlights major crustal provinces based on their isotopic character (Fig. 8). For these reasons, the interpolated maps were used in conjunction with the point data when validating crustal boundaries.

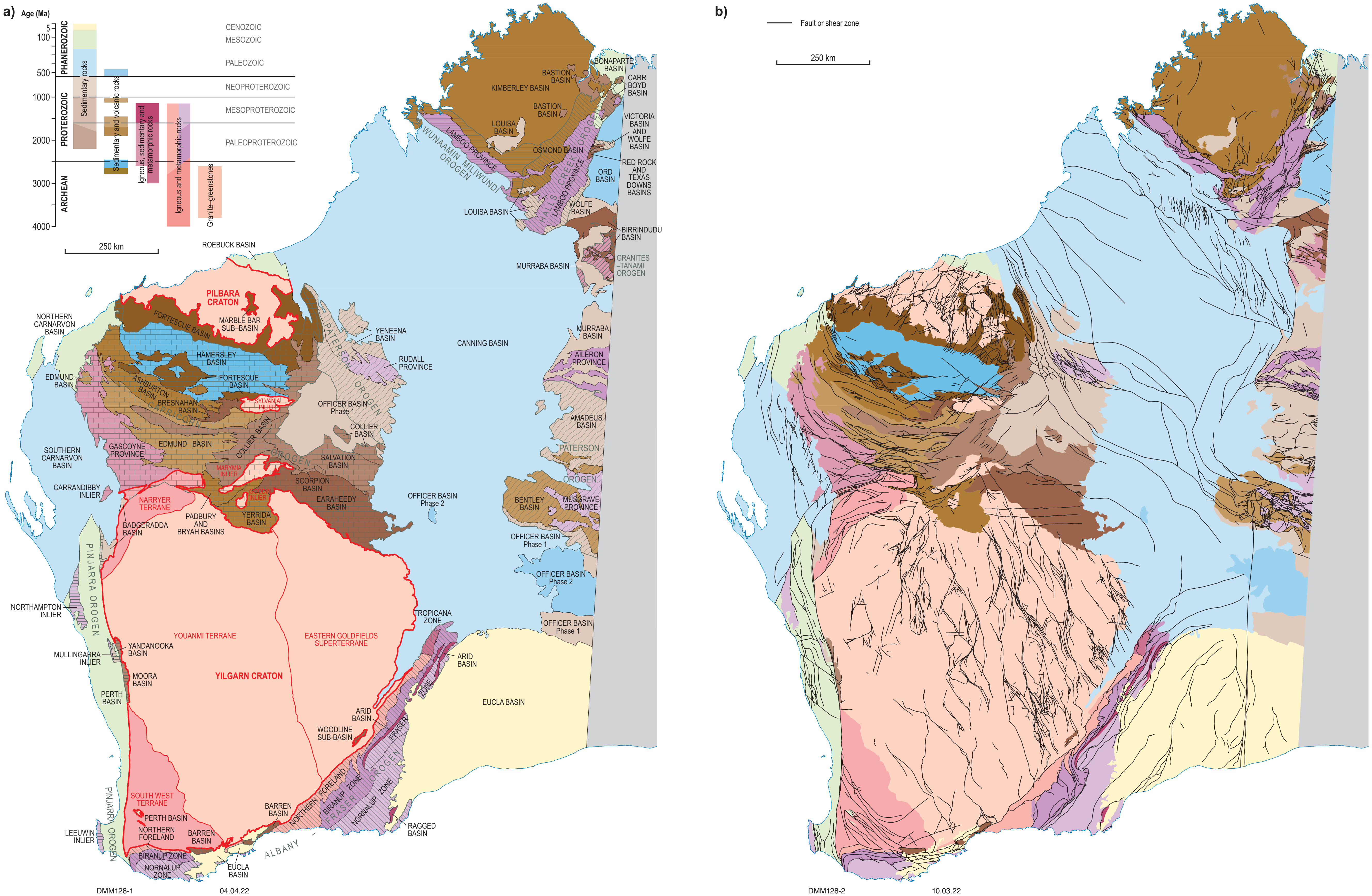

Figure 4. Geological framework of Western Australia: a) tectonic units and events (GSWA, 2021), b) faults and shear zones overlain on tectonic units

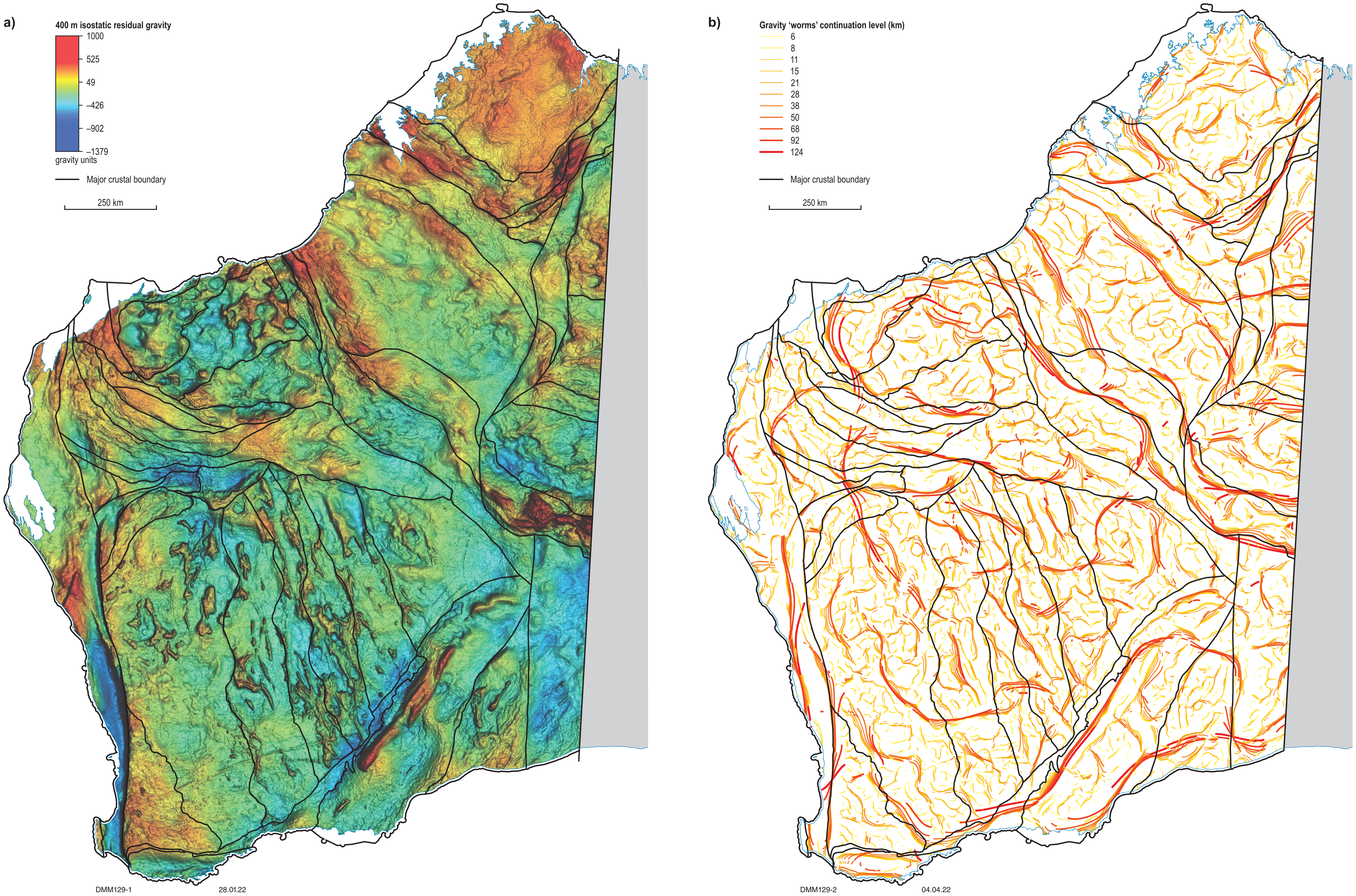

Figure 5. Major crustal boundaries as reflected in gravity data: a) isostatic residual gravity (Brett, 2020b); b) multiscale edges (worms) after Brett (2020c). Note, the relationship between continuation height and depth to source is not simple, although greater values do imply deeper sources (see Brett, 2021 for details)

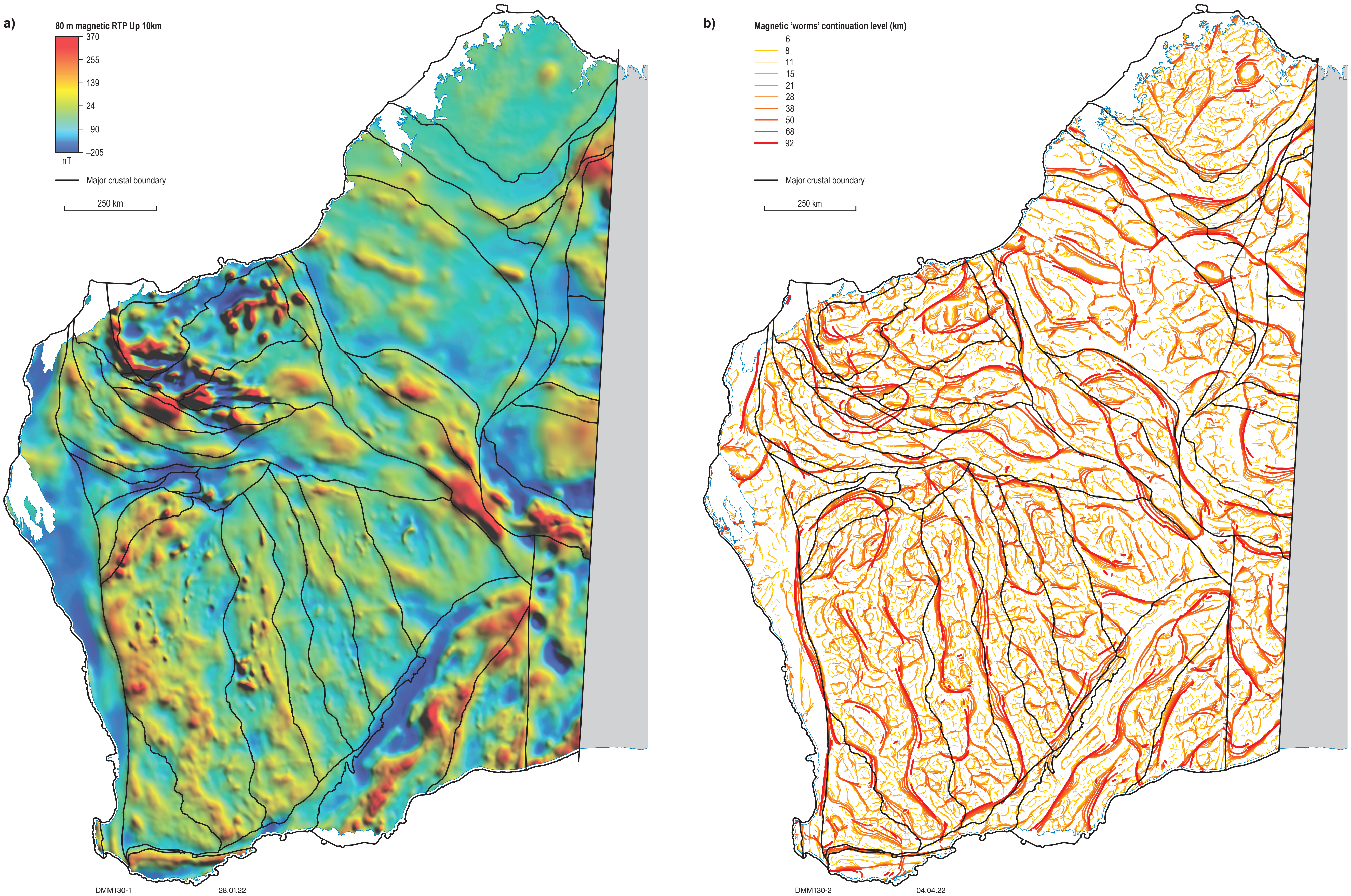

Figure 6. Major crustal boundaries as reflected in magnetic data: a) 10 km upward continued (based on Brett, 2020a), reduced to pole; b) multiscale edges (worms) after Brett (2020c). Note, the relationship between continuation height and depth to source is not simple, although greater values do imply deeper sources (see Brett, 2021 for details)

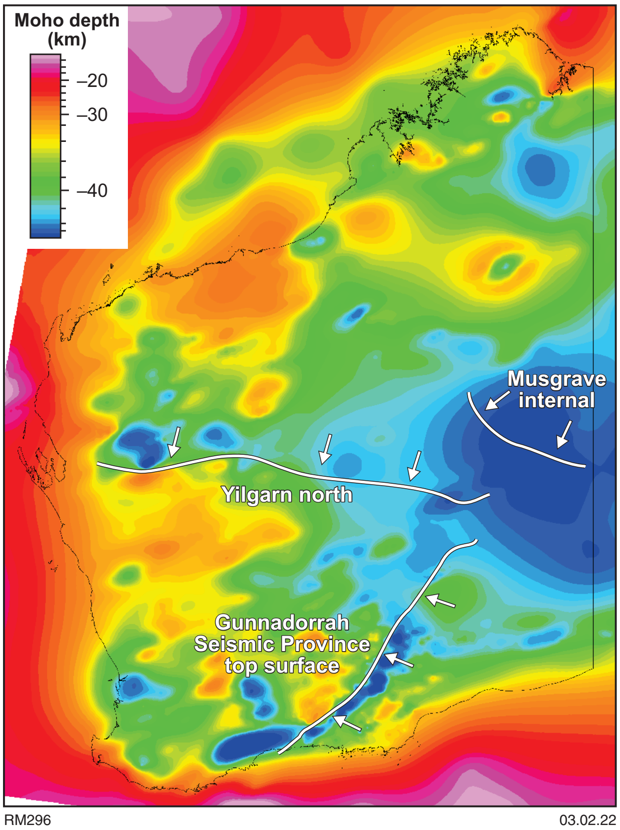

Figure 7. Moho depth below sea level. Annotated lines show where major crustal boundaries coincide with a significant offset or repetition of the Moho discontinuity. Arrows show the dip direction of the boundary/top surface of the Moho along these offsets. After Murdie and Yuan (2021)

2D data structure

Each crustal boundary in the 2D dataset consists of one or more segments determined by a detailed set of attributes (Table 1) that significantly expands on those used by Korsch and Doublier (2015) for the national dataset. These attributes aim to capture the key features of each boundary, specifically the name and source of the boundary, its geological characteristics, and measures of confidence in its interpretation. At the highest level, each boundary has a unique name that is based on the formal name of the crustal block or seismic province that it bounds; although not all blocks have formal names, in which case logical names have been applied. Fault names are only used for structures that are within a crustal block, such as the Chalba Shear Zone and Baring Downs Fault. This name field allows all segments of a common boundary to be selected when querying or displaying the data, and is not intended to be used for formal naming of the boundary. For the purposes of description and discussion in this Record, these informal boundary names are used in inverted commas. Specific fault names that comprise each segment of a named boundary are also captured in a comments field where appropriate, and a more detailed description of the boundary, and some source references, is given in a description field. The attribute table also captures a hyperlink, where relevant, to the persistent identifiers of the raw and processed seismic data that are held by Geoscience Australia. Some elements of the attribute table are also reflected in the description of the components of the 3D model (Appendix 1).

The detailed attributes in Table 1, which are also described in the data dictionary that accompanies the dataset, capture the geological characteristics of each boundary. Firstly, each boundary is assigned a feature and type, both of which have been generalized due to the uncertainties in their tectonic origin and their repeated reactivations. The majority of features are interpreted to be faults or shear zones, although a few more enigmatic boundaries are classified merely as 'geological boundary', especially those that are unconstrained by (or not well-defined in) seismic reflection data, or are primarily interpreted from potential field data or Sm–Nd isotope maps. The type refers to the dominant structural style or the style interpreted to have been predominant at initiation of the boundary. Estimates of dip and dip direction, mainly derived from reflection seismic profiles, are provided for all boundaries except those that are interpreted to be vertical or subvertical. Since the majority of major crustal boundaries are listric at the lithospheric scale, as imaged and interpreted in seismic reflection profiles, quoted dips are estimates for the upper-crustal portion of the boundary. Each boundary is also classified as either lithospheric or crustal, depending on whether it transects all or part of the crustal lithosphere, respectively; these definitions are consistently applied throughout this Record. Maximum and minimum ages reflect the interpreted maximum initiation age and youngest age of reactivation of each boundary, and are assigned at the level of era or period. Assigned events are those for which evidence can be reasonably inferred, and at least one initiating event is assigned for each boundary. However, in some cases, the specific event is unknown or undefined, in which case the parent event as defined in ENS is assigned as the initiating event (e.g. Yilgarn Craton Events). Details of all assigned events can be found by querying the ENS database, accessible via GSWA's **GeoVIEW.WA** interactive geological map. Qualitative estimates of confidence are applied to the validity of each feature, and to each tectonic event assigned to a feature, based on the quantity and quality of the supporting data and current geological understanding.

One of the largest uncertainties in the dataset relates to the depiction of dipping lithospheric-scale structures in 2D that are largely interpreted from potential field data in which the relative level, or depth, of the interpreted feature is unconstrained. This uncertainty is addressed through the capture of two important attributes of the major crustal boundaries map, namely the capture scale and precision. The capture scale is the same as the nominal viewing scale of the dataset and gives a qualitative estimate of the level of detail involved in digitizing the feature, whereas the precision is an estimate of the half-width, in kilometres orthogonal to strike, of a horizontal envelope at the inferred relative level of the interpretation. Consequently, boundaries that are under significant cover, or are interpreted primarily from potential field datasets with little or no seismic constraints, have lower estimates of precision (high values in km). Some of the uncertainty inherent in 2D depiction of lithospheric structures that are mostly listric is addressed in the associated 3D model (Murdie, 2021), which honors the seismic sections or other available 3D data. However, due to the scale of the structures and small sampling area of the source datasets, the spatial accuracy of these structures remains relatively low and becomes lower with depth.

3D model structure

The framework of the 3D model is the Major crustal boundaries map of Western Australia (Martin et al., 2021), combined with the interpretations of the various seismic reflection profiles, passive seismic models or MT models. Seismic profiles only constrain the dip of a structure at a specific location and depth; in the majority of cases, this dip was extrapolated away from the seismic line, which may or may not be a correct assumption, and was only changed where there was a geological reason to do so.

The top and bottom bounds of the model are the surface topography and bathymetry as defined by the Shuttle Radar Topography Mission digital elevation model, smoothed to a 10 km grid size, and the Moho as derived from seismic and MT data (Murdie and Yuan, 2021; Fig. 7). The outer surrounds of the model consist of a vertical boundary that corresponds to the three nautical mile offshore limit. No attempt was made to image the offshore continental basins and deeper crustal structure. All surfaces close in a 'watertight' manner (Fig. 9a), thus dividing the model into discrete blocks (Fig. 9b). These blocks are assigned a terrane or province name and a crustal block name in which terranes or provinces are grouped together into a cratonic/orogenic entity. Wherever possible, these names follow accepted formal conventions.

Many parts of the State are covered by deep basins that range in age from Archean and Proterozoic to Phanerozoic. Some of these basins have been imaged to crystalline basement in the deep crustal seismic lines, although many have not. Commercial shallow seismic reflection lines detail areas of basins that are considered prospective for hydrocarbon exploration. However, these do not typically image deeper than 'basement', which may or may not be crystalline basement or metamorphosed sediments of older basins. Also, due to the scope of this project and the potential complexity of the model, the Proterozoic and younger basins are modelled as a single volume. The depth of these basins is captured within the OZ SEEBASE 2020 model (Geognostics Australia Pty Ltd, 2020; Fig. 10), which uses potential field data in conjunction with mapped geology and seismic and MT profiles to constrain basin volumes. The Neoarchaen–Paleoproterozoic Fortescue–Hamersley Basin was modelled separately based on intersections on seismic lines 97AGS-HB1-3, 97AGS-SD1, 10GA-CP1-3 and 18GA-KB1.

All boundaries, surfaces and crustal blocks included in the model are listed in Appendix 1 with details of the rationale behind their definition and construction. The model was built in the Geoscience Australia Lambert projection to facilitate a square grid and identical vertical and horizontal units.

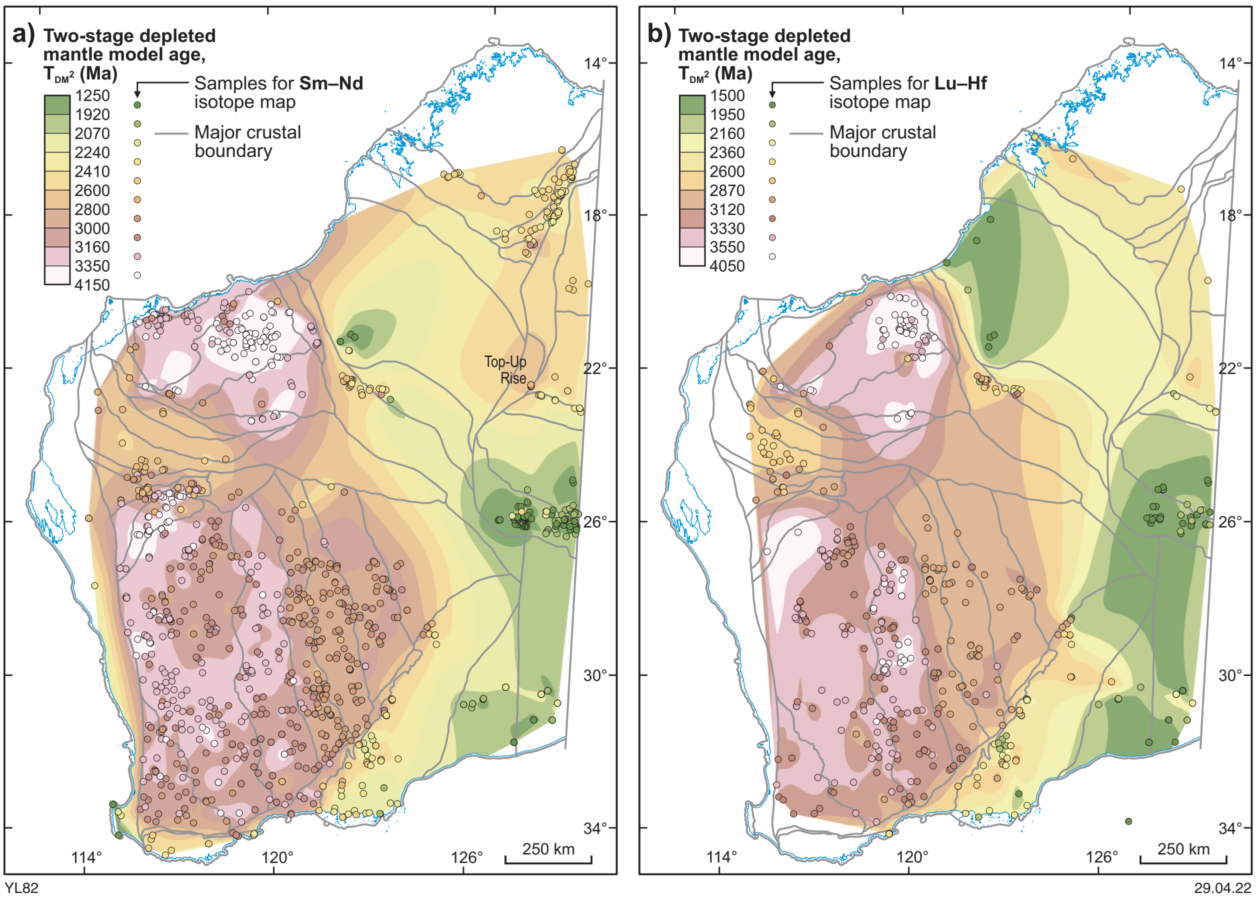

Figure 8. Major crustal boundaries as reflected in isotope maps: a) two-stage depleted mantle model age (T_{DM}^2) based on whole-rock Sm–Nd isotopes. The location of the Top-up Rise drillholes is indicated by the red arrow; b) T_{DM}^2 based on zircon Lu–Hf isotopes. After Lu et al. (2021b,c)

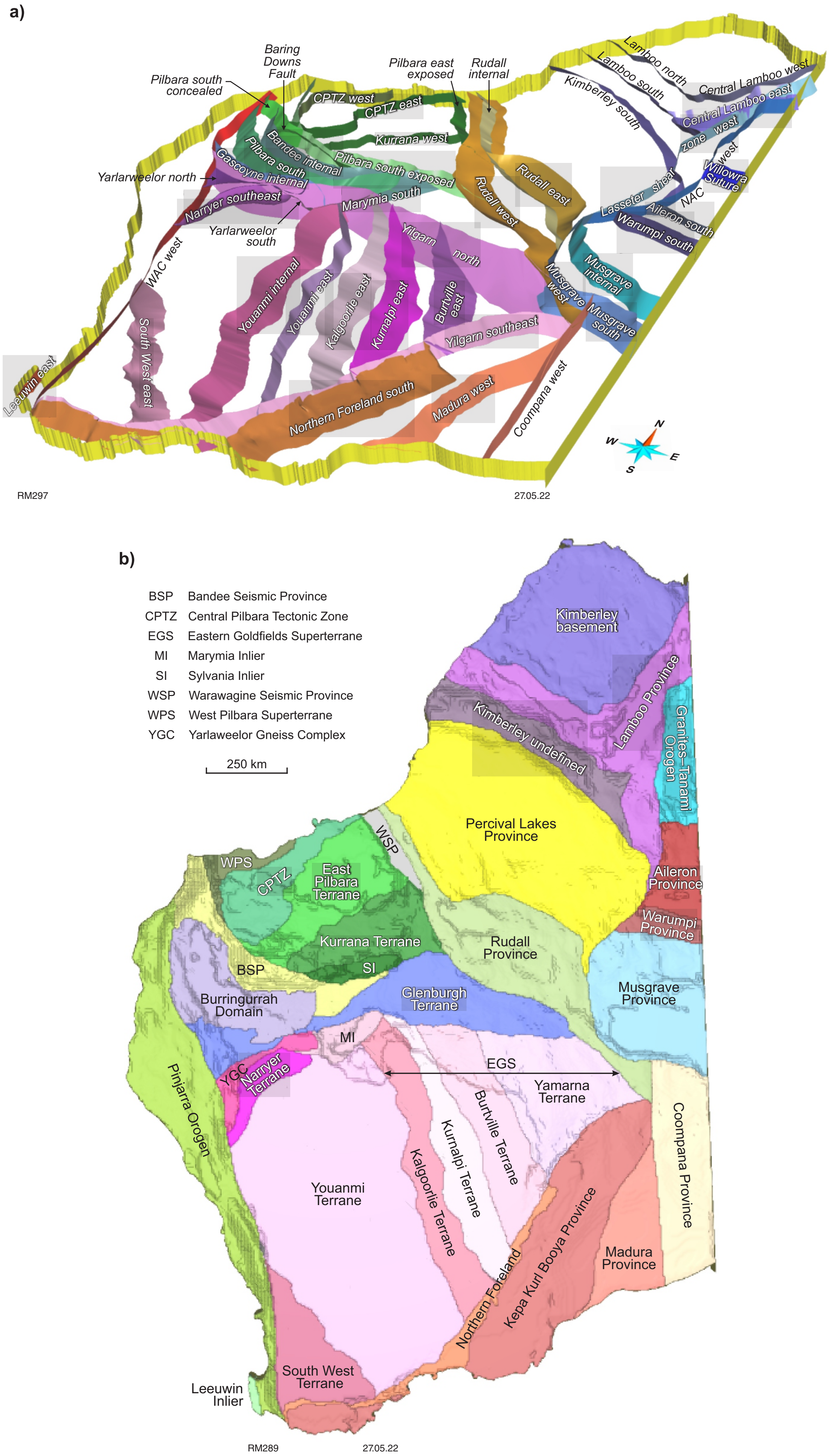

Figure 9. Major crustal boundaries and blocks in 3D: a) boundaries showing the dip and dip direction, and the spatial relationship between them; b) crustal blocks as delineated by the major crustal boundaries

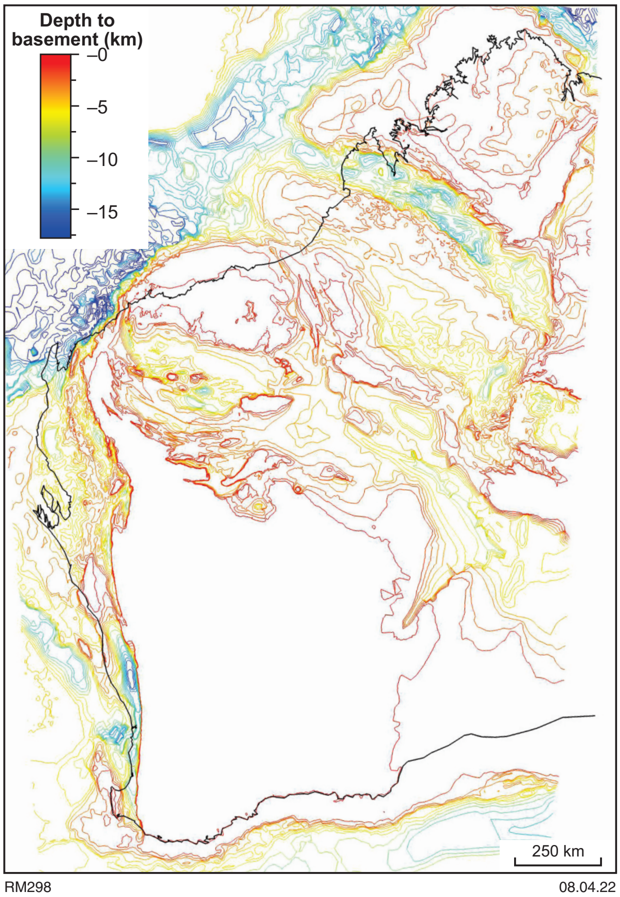

Figure 10. SEEBASE contours expressed as depth to basement in kilometres reproduced from Geognostics Australia Pty Ltd (2020)

Origin and tectonic significance of major crustal boundaries and volumes

The assembly of crustal elements along the major crustal boundaries of Western Australia is best described in the context of the tectonic evolution of the State. This evolution begins with the Archean assembly of the Pilbara and Yilgarn Cratons, followed by their Paleoproterozoic collision to form the WAC. Later assembly of the North Australian Craton (NAC) was coeval with intracratonic events within the Paleoproterozoic WAC, although the timing and geodynamics of collision between the WAC and NAC is controversial with four potential timelines considered viable by various authors. The boundaries most affected by this controversy are those that form the eastern margin of the WAC and western margin of the NAC (Figs 11a, 12). The major crustal architecture of Western Australia (Fig. 11) was largely established by the end of the Proterozoic following amalgamation of the WAC and NAC, and collision of these combined blocks with the South Australian Craton (SAC), although some structures were reactivated during the development of overlying Phanerozoic sedimentary basins.

Pilbara Craton assembly

The Pilbara Craton is the oldest crustal block in Western Australia and preserves the earliest evidence of structures and rock associations interpreted to have formed by processes similar to those that operate at modern plate boundaries (Trendall, 1990b; Van Kranendonk et al., 2002, 2004; Hickman, 2012; Cawood et al., 2018). Although it does not contain the oldest rocks in Western Australia (Froude et al., 1983; Kinny et al., 1988; Kinny and Nutman, 1996), there is evidence from gneissic enclaves, isotopic data, and inherited and detrital zircons to suggest that evolved felsic crust existed in the East Pilbara Terrane (EPT) of the Pilbara Craton by 3.8 – 3.6 Ga (Van Kranendonk et al., 2007; Tessalina et al., 2010; Petersson et al., 2019; Hickman, 2021). Also, c. 3.6 Ga crust has recently been identified in the Sylvania Inlier (Wingate et al., 2019d,e). The basement to the Kurrana Terrane (KT) and West Pilbara Superterrane (WPS) may be of similar age, and these tectonic units are all separated by significantly younger major crustal boundaries. Consequently, their relative spatial location in the Paleoarchean is not known.

The oldest major crustal boundaries in the State were likely initiated during 3280–3165 Ma rifting of Eoarchean to Paleoarchean crust that is interpreted to constitute the basement beneath much of the exposed Pilbara Craton (Fig. 13a). This event is known as the East Pilbara Terrane Rifting Event (EPTRE), and is interpreted to have resulted in the formation of several microcontinental plates of which the Karratha Terrane, EPT and KT are representatives within the present-day Pilbara Craton (Hickman, 2021). The EPTRE is likely to have initiated all three of the major crustal boundaries within the exposed Pilbara Craton (Fig. 12), which comprise the western and eastern margins of the Central Pilbara Tectonic Zone (CPTZ) and the western margin of the KT, although they have all been significantly reactivated during younger events (Fig. 13b). The CPTZ is interpreted to be underlain by thinned EPT crust, bound to the east by the ‘CPTZ east’ boundary that is defined by the Tabba Tabba Shear Zone. The western margin of the KT is defined by the Kuranna Shear Zone, which also forms the southern margin to the Mosquito Creek Basin (MCB) that is interpreted here to overlie the southern margin of the EPT. However, previous studies have interpreted the MCB as a separate terrane (Bagas et al., 2008a; Hickman and Van Kranendonk, 2012). Due to the lack of seismic constraints on these boundaries, their style and orientation is largely inferred from related outcropping faults and shear zones. Similarly, the 3D architecture of concealed crustal blocks is inferred from the two seismic lines that extend into the southern and eastern margins of the exposed Pilbara Craton (Figs 2, 3), which both sample the crust beneath the EPT. Due to the potentially similar age and composition of the lower crust of the various terranes of the Pilbara, no attempt has been made to divide the lower crust into separate seismic provinces along the terrane boundaries. However, the Carlathunda–Ripon Hills Seismic Province beneath the EPT is named separately (Fig. 12), based on precedent. From passive seismic measurements, the Moho across the Pilbara is 26–35 km thick and the average bulk composition shows a felsic signature (Yuan, 2015) that is typical for early Archean crust that has undergone delamination of a mafic root (Abbott et al., 2013).

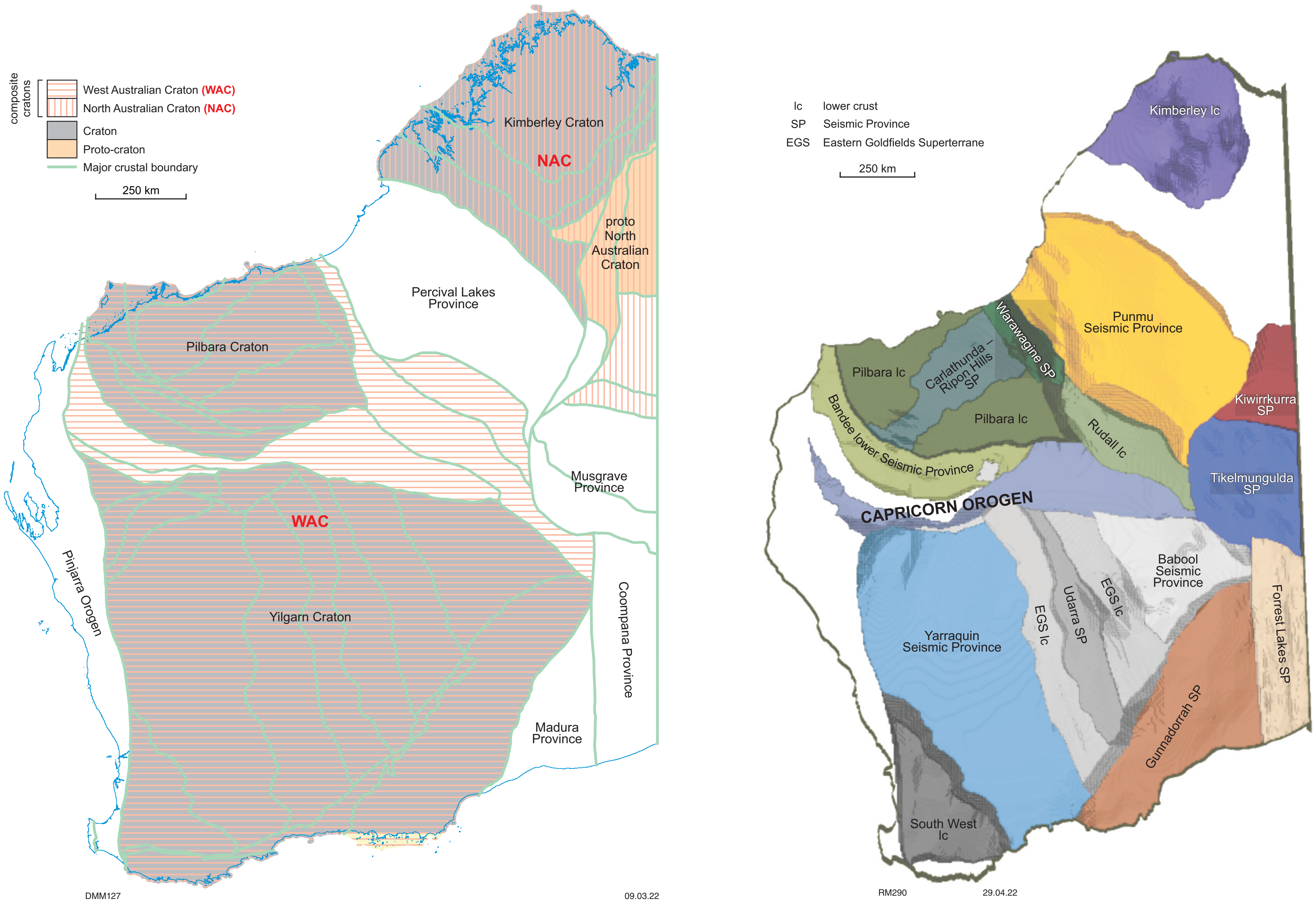

Figure 11. Cratons and major crustal boundaries of Western Australia as defined by this study: a) Surface projection of major crustal elements. The extent of the interpreted Mirning Ocean coincides with four juvenile crustal blocks: the Percival Lakes, Musgrave, Madura and Coompana Provinces. b) Major lower crustal elements including Seismic Provinces (where they have been imaged) and lower crustal components where the crust is inferred to have a lower layer, although has not been imaged

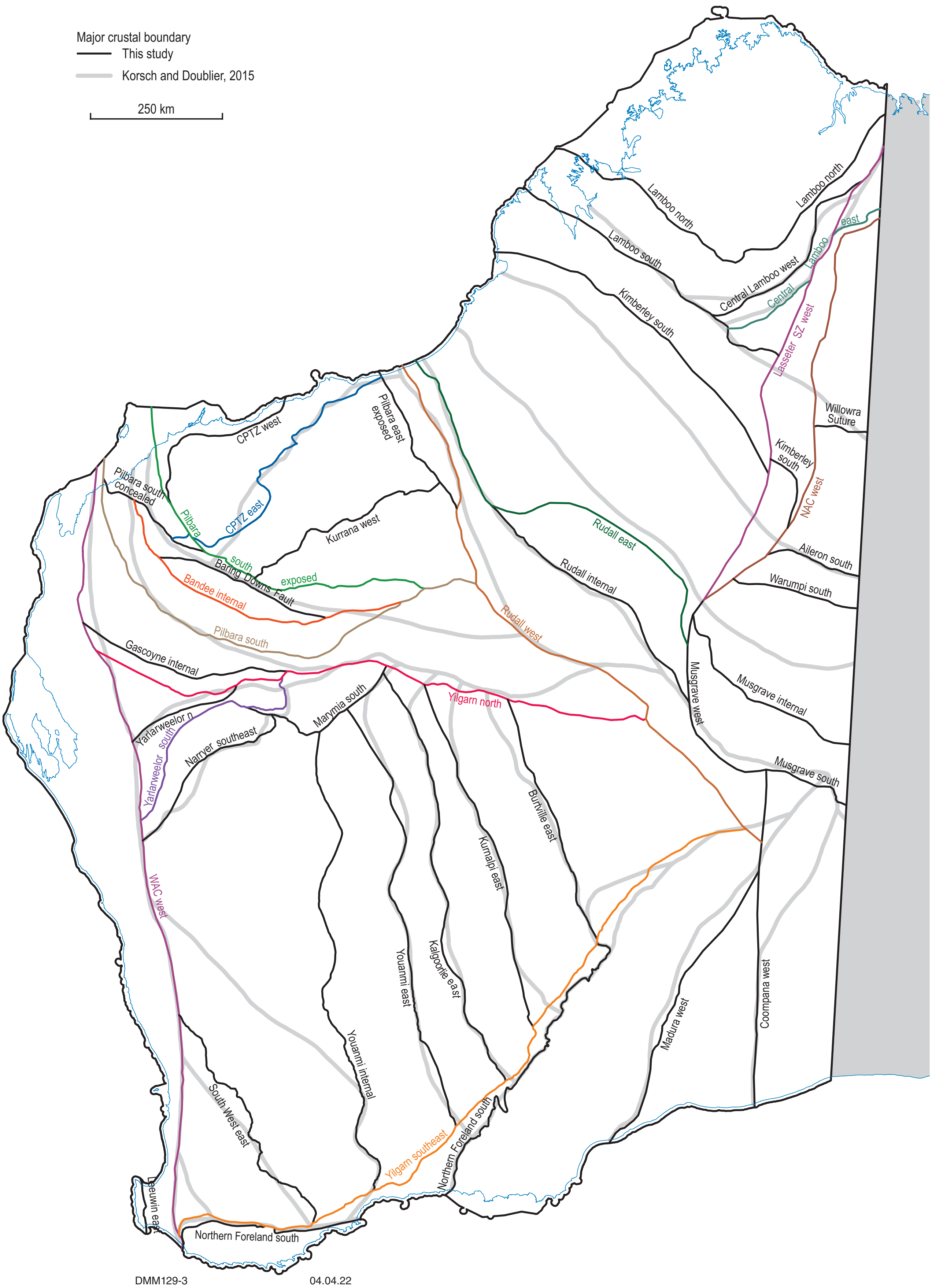

Figure 12. Comparison between named major crustal boundaries of this study (labelled) and Korsch and Doublier (2015).

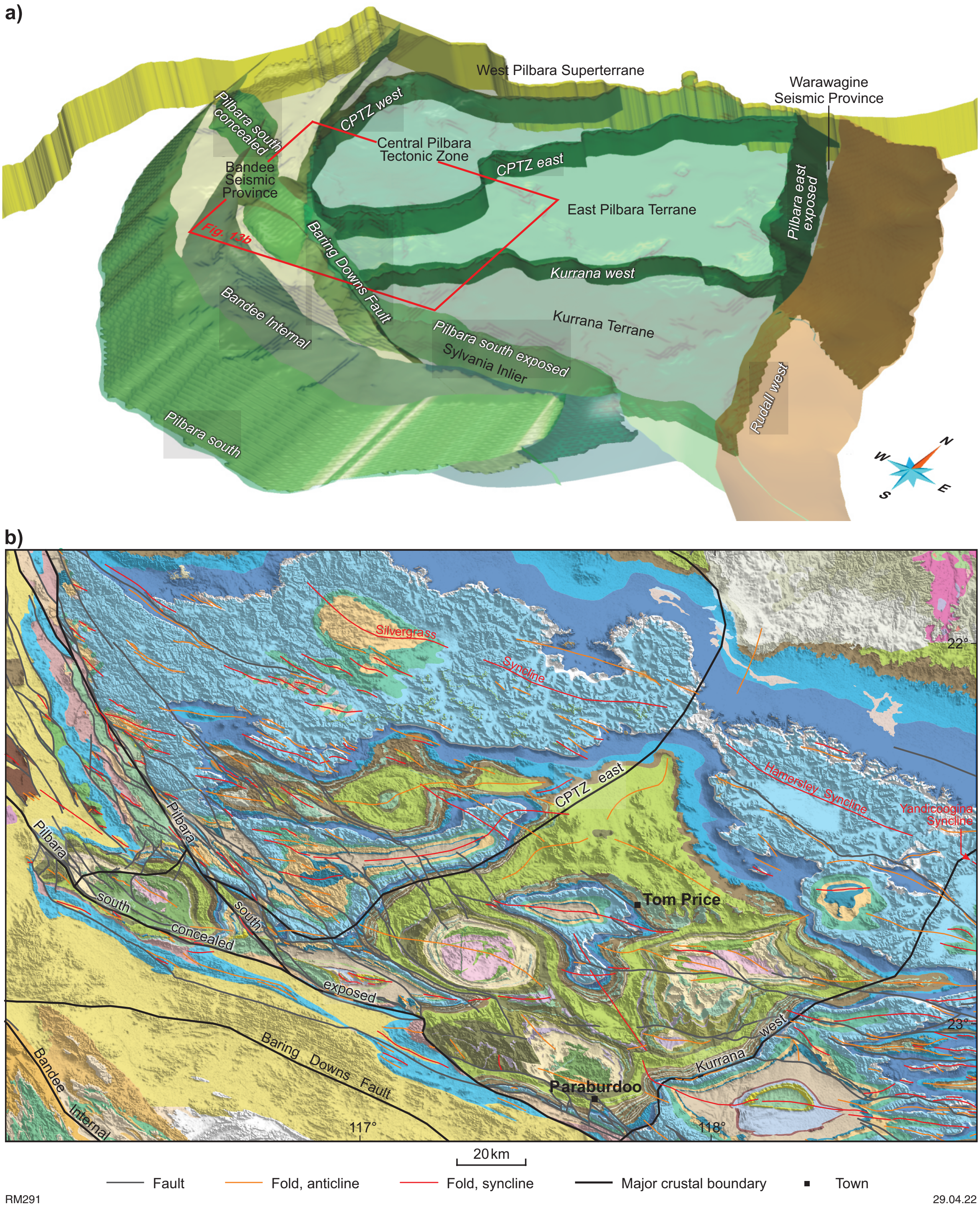

Figure 13. Pilbara Craton detail: a) showing the relationships of the crustal boundaries to the intervening crustal blocks. Subvertical boundaries are interpreted based on outcrop data and predominantly strike-slip kinematics; b) geology superimposed on topography of the Tom Price area, showing the domed region between the 'CPTZ east' and 'Kurrana west' boundaries, that is here named the Jarndunmunah uplift after the local Aboriginal name for Mount Nameless. Note refolding of the Hamersley–Silvergrass Syncline and a northeast-trending anticline within the Fortescue Group to the east of the 'CPTZ east' boundary within this area that may reflect reactivation of this boundary. Abbreviation: CPTZ, Central Pilbara Tectonic Zone

The oldest major crustal boundaries identified in this study form the margins of the CPTZ and EPT (cf. Champion and Huston, 2016), and are interpreted to have been initiated as extensional structures during the EPTRE. The northwestern margin of the CPTZ is defined by the Scholl Shear Zone and referred to in this dataset as 'CPTZ west', although it was not recognized by Korsch and Doublier (2015, 2016; Fig. 12). This boundary is interpreted to be a predominantly subvertical shear zone that was initiated by strike-slip reactivation of an earlier structure, formed during the EPTRE and possibly reactivated during the Prinsep Orogeny, in response to accretion of the WPS to the EPT during the North Pilbara Orogeny at 2955–2919 Ma (Hickman, 2021). The WPS is the product of the accretion of the Karratha, Regal and Sholl Terranes during the Prinsep Orogeny and its collision with the CPTZ along the 'CPTZ west' boundary (Van Kranendonk, 2007; Hickman and Van Kranendonk, 2012).

A similar structural history is interpreted for the Tabba Tabba Shear Zone, which forms the subvertical 'CPTZ east' boundary, and the portion concealed beneath the Fortescue and Hamersley Basins is similar to that interpreted by Bagas et al. (2008a). However, the combination of outcrop, gravity and isotopic data suggests that the far southwestern extent of the 'CPTZ east' boundary is also present within the Wyloo Inlier where it is dextrally offset along the younger 'Pilbara south exposed' boundary (Fig. 12). The Kuranna Shear Zone is interpreted as a northwest-dipping terrane boundary, referred to in this dataset as 'Kurrana west', along which the MCB was thrust over the KT (Tyler et al., 1992; Bagas et al., 2008a; Hickman, 2021). The presence of granitic rocks of the same age as the Cleland Supersuite to the south of this boundary suggest that it too may have been initiated during the EPTRE (Hickman, 2021), although there is no evidence from potential field, structural or isotope data to suggest that the MCB occupies a separate terrane (cf. Bagas et al., 2008a; Hickman and Van Kranendonk, 2012).

All three of these boundaries are well exposed, and well represented in gravity and isotopic datasets that have been used to extrapolate them southwestwards beneath the Fortescue and Hamersley Basins. In the upper crust, these boundaries separate the WPS, CPTZ, EPT and KT, whereas the lower crust is designated as generic 'Pilbara lower crust' due to a lack of seismic data. The exception is beneath the EPT where the lower crust has been imaged on seismic line 10GA-CP1 and is termed the Carlathunda Seismic Province and on seismic line 18GA-KB1 where it is termed the Ripon Hills Seismic Province even though there is no major crustal boundary traversing the intervening crust. Hence, this crustal block is called the Carlathunda–Ripon Hills Seismic Province in this dataset (Fig. 11b).

Following the North Pilbara and Mosquito Creek Orogenies, the Pilbara Craton was relatively stable until the onset of the Fortescue Rifting Event (FRE) at c. 2.78 Ga (Hickman and Van Kranendonk, 2012; Hickman, 2021). This rifting event is commonly interpreted to have resulted in the fragmentation of a larger crustal block known as Vaalbara that likely included the Kaapvaal Craton of southern Africa (e.g. Cheney, 1996; Martin et al., 1998; Wingate, 1998; Zegers et al., 1998; de Kock et al., 2009; Smirnov et al., 2013). Rifting was responsible for the creation of two major crustal boundaries that define the concealed southern margin of the craton, namely 'Pilbara south exposed' and 'Pilbara south' (Fig. 12), and possibly also part of the eastern boundary with the Paterson Orogen. The 'Pilbara south' boundary is largely concealed although was reactivated during younger events within the Capricorn Orogen to create the Lyons River Fault, which is the boundary between the southernmost component of the Pilbara Craton and the Glenburgh Terrane. These events also led to the creation of other younger crustal boundaries that may be reactivations of older Neoarchean features. These include the 'Bandee internal' boundary (Fig. 12), which equates to the Talga Fault, and the Baring Downs Fault that have both been interpreted as major crustal boundaries in previous seismic interpretations, although these are poorly constrained (Johnson et al., 2011b, 2013). The Sylvania Inlier, although interpreted as part of the Kurrana Terrane (Tyler et al., 1992), is bounded by the younger 'Pilbara south exposed' boundary to the north and the Baring Downs Fault and 'Bandee internal' boundary to the south (Fig. 13a).

The 'Pilbara south' boundary defines the maximum extent of the rifted southern margin of the Pilbara Craton (Fig. 11a) that is concealed beneath younger Proterozoic basin cover. In the 3D model, this concealed crustal block is called the Bandee Seismic Province (Korsch et al., 2011) and is divided into upper and lower volumes based on differing seismic characteristics. The Baring Downs Fault is the surface expression of an internal boundary within the Pilbara Craton that separates the Carlathunda Seismic Province from the Bandee Seismic Province at depth on seismic line 10GA-CP1. The Bandee Seismic Province also contains an internal crustal boundary ('Bandee internal', Fig. 12) that corresponds to the Talga Fault and its strike extensions.

To the east, isotopic data suggests that the Pilbara Craton extends beneath the Rudall Province and southern part of the Yeneena Basin (Kirkland et al., 2013a,b), where it is called the Warrawagine Seismic Province (Fig. 12), although the location of the eastward extension of the 'Pilbara south' boundary in this region is uncertain. This boundary has been modelled by following the regional surface structural grain, which takes it northwards where it joins with the 'Bandee internal' boundary to merge into the 'Pilbara south concealed' boundary (Fig. 12).

The size of the area inferred to be underlain by the Pilbara Craton (Fig. 11a), based on the boundaries identified in this study, is slightly larger than previously recognized (cf. Trendall, 1990a; Hickman and Van Kranendonk, 2012), especially with respect to its southern and western margin, and more closely approximates that proposed by Myers (1990). These previous interpretations extended the southern margin to roughly the location of the Baring Downs Fault. Following rifting during the FRE, and the breakup of Vaalbara, the older Paleo- and Mesoarchean crustal boundaries within the Pilbara Craton do not appear to have been reactivated during later orogenesis (e.g. Ophthalmia and Capricorn Orogenies), although were possibly active during deposition of the Fortescue and Hamersley Groups (Powell and Horwitz, 1994). These boundaries also appear to have a strong spatial correlation with contrasting styles of Ophthalmian folding between the east and west Hamersley province, and delineate the east and west margins of an inlier of predominantly Fortescue Group rocks centered on Tom Price (Fig. 13b). This lack of obvious reactivation is intriguing given the evidence of extensive Ophthalmian orogenic fluid flow across the craton (Rasmussen et al., 2005), and could be partly due to the existence of a proposed décollement separating the crystalline basement from the overlying Fortescue and Hamersley Groups (Cunneen, 1997; Cawood and Hollingsworth, 2002). However, a northeast trending anticline within the Fortescue Group to the east of the southwestern extrapolation of the 'CPTZ east' boundary, and orthogonal refolding of the northwestern end of the Hamersley Syncline near Hamersley Gorge (Fig. 13b), may reflect younger reactivation along this boundary.

Yilgarn Craton assembly

The Yilgarn Craton contains the oldest known component of the Australian crust, the Meeberrie Gneiss of the Narryer Terrane (Froude et al., 1983; Kinny et al., 1988; Nutman et al., 1991), and is perhaps the best studied craton in terms of identifying the major crustal boundaries along which it was assembled (Gee et al., 1981; Myers, 1990; Tyler and Hocking, 2002; Cassidy et al., 2006). However, very few tectonic events have been identified and named that allow for as detailed a description of the tectonic history as for the Pilbara Craton. Exceptions are the recently proposed c. 2730 Ma Yilgarn Orogeny (Zibra et al., 2017) and the 2665–2655 Ma Wangkathaa Orogeny (Blewett et al., 2004), neither of which are currently recognized in GSWA's ENS database. Consequently, no specific tectonic events are assigned to any of the recognized major crustal boundaries within the Yilgarn Craton in this dataset.

A fourfold subdivision of the Yilgarn Craton was first proposed by Gee et al. (1981), who recognized the Eastern Goldfields, Southern Cross and Murchison 'Provinces' and the 'Western Gneiss Terrain'. Myers (1990) later recognized six differently named fault-bounded terranes, including the informal Narryer terrane, some of which were wholly or partly equivalent to the subdivisions of Gee et al. (1981). This new crustal architecture was then revised by Tyler and Hocking (2002) who formalized the hierarchical nomenclature that has become the basis of wider subdivision of the tectonic units of Western Australia, although this nomenclature has itself been revised in recent times. Under the scheme of Tyler and Hocking (2002), the Yilgarn Craton was subdivided into the Narryer, Murchison Granite–Greenstone, South West, Southern Cross Granite–Greenstone and Eastern Goldfields Granite–Greenstone Terranes. Building on previous studies (e.g. Swager et al., 1992; Swager, 1995, 1997; Barley et al., 2002, 2003), Cassidy et al. (2006) revised and added further detail to the framework by subdividing some terranes into contiguous tectonostratigraphic domains, and renaming and elevating the Eastern Goldfields 'Granite–Greenstone Terrane' to Eastern Goldfields Superterrane (EGS). This superterrane was further subdivided into the Kalgoorlie, Kurnalpi and Burtville Terranes that were themselves subdivided into domains. They also downgraded the Murchison and Southern Cross 'Granite–Greenstone Terranes' to domains within a newly named Youanmi Terrane and renamed them as the Murchison and Southern Cross Domains. Their complete terrane nomenclature consisted of the Narryer, Youanmi, South West, Kalgoorlie, Kurnalpi and Burtville Terranes. These names have persisted, with the exception that their 'Burtville Terrane' of the EGS is subdivided by GSWA into the Burtville and Yamarna Terranes that are separated by the Yamarna Shear Zone (Pawley et al., 2009; Fig. 13).

In each of the schemes described above, the boundaries that separated the domains, terranes or provinces were commonly poorly defined or imprecise, and these remain controversial. However, an extensive network of deep crustal seismic lines, combined with more detailed geological mapping and geophysical data, now permits these boundaries to be more precisely defined (Kennett et al., 2016, 2018; Korsch and Doublier, 2016). Conversely, detailed geochemical and isotopic data are beginning to question the contiguity of the terranes themselves with the only two undisputedly distinct terranes being the Youanmi Terrane and the EGS that are separated by a significant structural and Sm–Nd and Lu–Hf isotopic boundary (Fig. 8; Cassidy et al., 2006; Smithies et al., 2018; Lu et al., 2021b). This boundary, typically called the Ida Fault in the majority of previous work but 'Youanmi east' in this dataset (Fig. 12), coincides with the Ida Fault in the south, the Ballard Fault and Kunanalling Shear Zone in the centre, and the Waroonga-Emu Shear Zone in the north, and consequently does not match previous interpretations of the boundary perfectly (cf. Cassidy et al., 2006; Korsch and Doublier, 2015) (Fig. 12). This is primarily because interpreted boundaries were not always accurately tied to mapped structures, and seismic data combined with new mapping and structural interpretation have necessitated a rethink of the location and significance of some structures (e.g. the Ida Fault). Also, some structures, such as the Plumridge Detachment in the southeast Yilgarn Craton (Korsch and Doublier, 2015), lack seismic or surface structural evidence, and consequently are not included in this dataset (Fig. 12).

The oldest component of the Yilgarn Craton is separated from the Youanmi Terrane by the 'Narryer southeast' boundary (Figs 12, 14), expressed at surface by the Balbalinga and Yalgar Faults, that was imaged in seismic line 10GA-YU1 as a steep north-northwest–dipping structure, in the 10GA-CP3 line as an almost horizontal boundary and in 11GA-SC1 as a gentle west-dipping boundary. The boundary between the South West Terrane and the Youanmi Terrane, called the 'South West east' boundary in this dataset (Fig. 12), has been shifted significantly farther southwestwards (cf. Cassidy et al., 2002, 2006) as the result of recent mapping (Quentin de Gromard et al., 2021) and Sm–Nd isotopic studies (Lu et al., 2021b). Restricted seismic data along line NN92-01, combined with new mapping, suggest that this boundary dips moderately to the northeast (Fig. 14) and also forms the southwestern boundary of a newly recognized Corrigin Tectonic Zone (Quentin de Gromard et al., 2021) that separates it from the remainder of the Youanmi Terrane. Recent mapping, geochronology, geochemistry and isotopic studies of the Youanmi Terrane (Cassidy et al., 2002, 2006; Ivanic et al., 2012; Van Kranendonk et al., 2013; Wyche et al., 2014; Lu et al., 2021b) have indicated that the Murchison and Southern Cross Domains do not represent discrete allochthonous terranes brought together during an accretionary event (cf. Myers, 1995). However, seismic imaging along line 10GA-YU2 supports the existence of a major crustal boundary between them (referred to here as 'Youanmi internal') that corresponds at surface to the Kawana Fault in the south, Clampton Fault in central parts, and the Youanmi Shear Zone in the north, and was not recognized by Korsch and Doublier (2015; Fig. 12).

The Youamni Terrane was imaged to the Moho in the 10GA-YU lines where it comprises a non-reflective upper crust, a highly reflective middle crust (the Yarraquin Seismic Province, Fig. 14) and a horizontally layered lower crust with a consistently flat and sharp Moho interface at the relatively shallow depth of 32–36 km. This layering and thickness appears typical of Archean crust (Yuan, 2015). The strong horizontal fabric in the lower crust has been used to infer that the lower crust provided a first-order decoupling horizon between the stronger lithospheric mantle and the middle and upper crust (Zibra et al., 2014). The 'Youanmi internal' boundary appears to cut across the upper and middle crustal layers although not the lower crust. The 'Youanmi East' boundary (Fig. 12) is interpreted to cut the lower crust. It is implied from 10GA-YU2 that this lower crust also exists under the EGS. However, on line 01AGS-NY1, the published interpretation has a basal crustal layer, although it has not been explicitly defined as a different unit from the middle crust. The depth of the Moho is slightly deeper and the bulk density slightly more intermediate than the Pilbara Craton, indicating the slightly younger age and interpreted trend towards the modern plate tectonic regime rather than vertical Archean tectonics (Yuan, 2015).

The 'Youanmi east' boundary is the principal isotopic and structural boundary between the Youanmi Terrane and EGS, and there is little evidence for discrete allochthonous terranes within the latter which probably developed due to plume-related rifting of older Youanmi-style crust (Ivanic et al., 2013; Smithies et al., 2017, 2018). However, the mapped structures that separate the currently named terranes of the EGS have been imaged on many deep crustal seismic lines, and are consequently still recognized as major crustal boundaries in this dataset (Fig. 12). The boundary named 'Kalgoorlie east' in this dataset separates the Kalgoorlie and Kurnalpi Terranes, and has previously been called the Ockerburry Fault System (Cassidy et al., 2006; Korsch and Doublier, 2015). This name is derived from the exposed fault system at the southern end, although in the central parts, it corresponds to the Perseverance Fault, and in the northern part to the Celia Fault System and Lockeridge Fault. The gentle east-northeast–dipping 'Kalgoorlie east' boundary is primarily constrained by seismic line BMR91-EGF01 and to a lesser extent line 01AGS-NY1. The Kurnalpi and Burtville Terranes are separated by the gently east-northeast–dipping 'Kurnalpi east' boundary that is constrained on the 01AGS-NY1 seismic line. This boundary is also known as the Hootanui Fault System (Cassidy et al., 2006; Korsch and Doublier, 2015) and at surface comprises various strands of this fault. The 'Burtville east' boundary (Fig. 12) separates the Burtville and Yamarna Terranes, although was not recognized as a terrane boundary by Cassidy et al. (2006). It was imaged on seismic line 01AGS-NY1 as a major crustal boundary and called the Yamarna Fault System by Korsch and Doublier (2015). The northern extent of all the major crustal boundaries within the EGS differs significantly from previous work (Fig. 12), especially where they are covered by the Earaheedy and Yerrida Basins (cf. Cassidy et al., 2006; Korsch and Doublier, 2015). These differences relate mainly to changes in the mapped location of faults at surface, and alternative interpretations of the potential field geophysical datasets and additional passive seismic data (Dentith et al., 2018), especially in areas under cover.

The boundaries that divide the upper crust into terranes all traverse the whole crust, thus dividing the lower crust into similarly shaped segments. The steep dip of the boundaries at the surface becomes shallower with depth until they sole into the Moho. Some lower crustal blocks, such as the Udarra Seismic Province under the Kurnalpi Terrane and the Babool Seismic Province under the Yamarna Terrane (Figs 11b, 14), have been imaged on seismic lines.

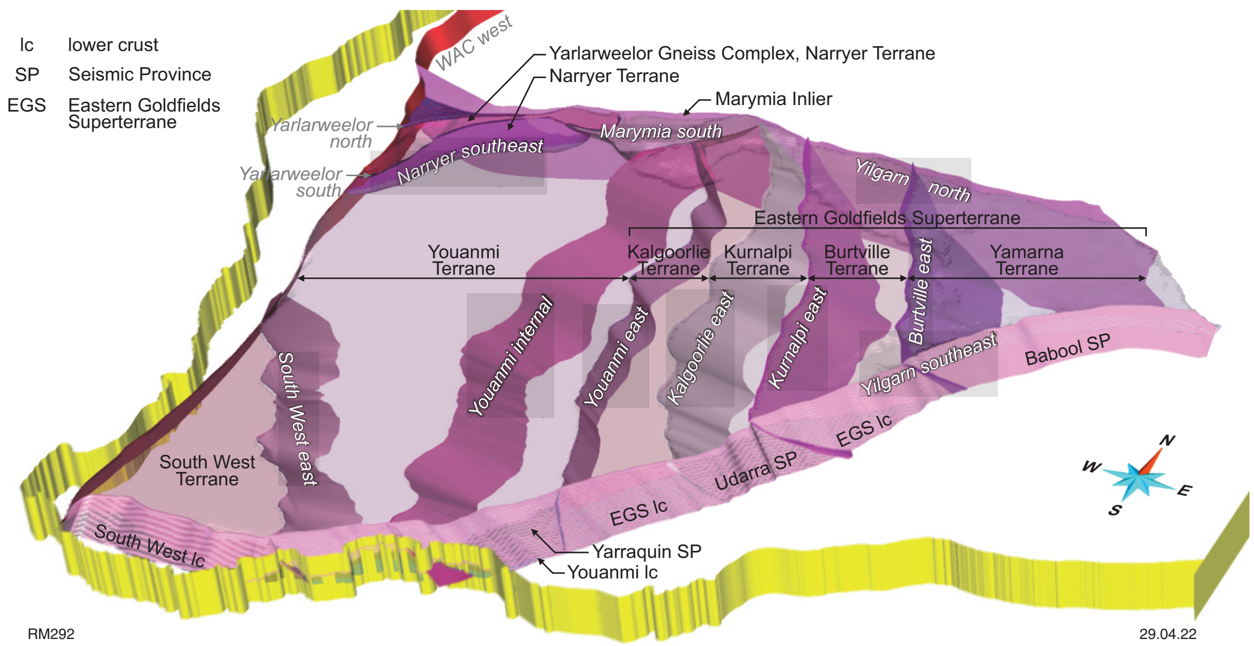

Figure 14. Subdivisions of the Yilgarn Craton and Marymia Inlier showing upper and lower crustal blocks including area where the lower crust comprises two layers

The lower crust under the Kalgoorlie and Burtville Terranes has not been imaged, although it is anticipated that it will have similar characteristics to the Udarra and Babool Seismic Provinces. Hence, it is called the 'EGS lower crust' in this dataset (Fig. 14). The Moho under the EGS is slightly deeper (35–39 km) and the overall composition of the crust slightly more intermediate than the Youanmi Terrane (Yuan, 2015).

The Marymia Inlier is a poorly studied allochthonous fragment of the Yilgarn Craton that is separated from the remainder of the craton by the 'Marymia south' boundary (Fig. 12), which has no seismic constraints and has not been recognized by previous work (cf. Cassidy et al., 2006; Champion and Cassidy, 2007; Korsch and Doublier, 2015; Champion and Huston, 2016). However, new Sm–Nd isotope data (Lu et al., 2021b) shows that the southwestern end of the inlier has closer affinity with the EGS than the Youanmi Terrane, and is isotopically distinct from the Goodin Inlier, which has close affinity with the Youanmi Terrane. This boundary has consequently been interpreted to coincide with the Jenkin and Goodin Faults in the east, and with the Murchison Fault in the west. These faults are likely to have been initiated during Yerrida and Bryah Basin rifting (Sheppard et al., 2016a; Occhipinti et al., 2017), and inverted during collision of the Yilgarn Craton with the combined Pilbara Craton and Glenburgh Terrane during the 2002–1947 Ma Glenburgh Orogeny and later by the 1817–1772 Ma Capricorn Orogeny (Johnson, 2013). Potential field data does not support extrapolation of the northern extents of the 'Youanmi internal', 'Youanmi east' and 'Kalgoorlie east' boundaries into the Marymia Inlier (Figs 6, 8).

The lower crust of the South West Terrane has only been investigated by seismic refraction lines, which showed that the crust is divided into sections with lower and higher velocities. However, when these lines were shot, the term 'seismic province' was not in use and consequently no formal subdivision or naming has been attempted in this area.

West Australian Craton assembly

Prolonged collision between the Pilbara and Yilgarn Cratons to form the Capricorn Orogen ultimately produced the WAC (Fig. 1; Myers et al., 1996), and marks the onset of assembly of the Australian component of the Columbia supercontinent, as defined by Meert (2012). This assembly began with the 2215–2145 Ma Ophthalmia Orogeny during which the Glenburgh Terrane, an exotic microcontinent, was accreted to the southern margin of the Pilbara Craton (Blake and Barley, 1992; Powell and Horwitz, 1994; Martin et al., 2000; Occhipinti et al., 2004; Rasmussen et al., 2005; Martin and Morris, 2010; Johnson et al., 2011a; Martin, 2020). Although the tectonomagmatic history of the Glenburgh Terrane is distinctly different from both the Pilbara and Yilgarn Cratons (Johnson et al., 2017), the main magmatic episodes in the Halfway Gneiss have been dated at between c. 2600 and 2430 Ma (Johnson et al., 2011a, 2017), and are broadly coeval with air-fall tuffs in the Hamersley Group (Trendall et al., 2004). Also, no magmatic arc associated with the Ophthalmia Orogeny has yet been identified, and the proposed direction of subduction could have been either northward beneath the Pilbara Craton (Blake and Barley, 1992; Martin and Morris, 2010) or southwards beneath the Glenburgh Terrane (Johnson et al., 2011a,b, 2017).

The principal crustal structures that were active during this orogeny are the 'Pilbara south exposed' and 'Pilbara south' boundaries, although the Baring Downs Fault and 'Bandee internal' boundaries may also have been active at this time (Fig. 12). These boundaries were likely initiated as extensional structures during the FRE. They were then reactivated during the Ophthalmia Orogeny as either thrust or strike-slip boundaries. Andean-type subduction-related intrusions of the 2002–1974 Ma Dalgaringa Supersuite within the Halfway Gneiss suggest the existence of a continental-margin arc related to the Glenburgh Orogeny along which subduction was to the north along the southern margin of the Glenburgh Terrane (Sheppard et al., 2004; Johnson et al., 2011a; Johnson, 2013). The moderately south-dipping Cardilya Fault that comprises the eastern part of the 'Yilgarn north' boundary (Figs 12, 13) on seismic lines 10GA-CP2 and 10GA-CP3, is interpreted as the collisional suture between the Yilgarn Craton and the combined Glenburgh Terrane – Pilbara Craton (Sheppard et al., 2004; Johnson et al., 2010, 2011b; Martin and Morris, 2010; Calvert et al., 2021). This implies closure of an intervening ocean and a subduction reversal as a consequence of collision during the Glenburgh Orogeny to produce the south-dipping 'Pilbara south' boundary (Johnson et al., 2011b). From passive seismic imaging, the deepening of the Moho to the south along the strike of the Cardilya Fault and eastwards implies that the Glenburgh Terrane was subducted beneath the northern margin of the Yilgarn Craton (cf. Hackney, 2004), at least as far east as the 'Rudall west' boundary. All subsequent tectonic activity in the Capricorn Orogen was intracratonic within the WAC, and did not generate any new major crustal boundaries although existing boundaries were commonly reactivated. This intracratonic tectonic activity was accompanied by the emplacement of large batholiths (Sheppard et al., 2010; Uren et al., 2022) that, along with other components of the orogen that are younger than the Glenburgh Terrane and older than the Edmund Basin, are interpreted in the 3D model as the newly named Burringurrah Domain (Fig. 9b).

Although the crustal architecture of the Capricorn Orogen is relatively well constrained by the Capricorn seismic lines in its central part, the extents under cover to the east and west are relatively unknown. The eastern extents beneath the Salvation, Savory and northwest Officer Basins are the least understood. There are no seismic constraints in this area, and the thick basin cover significantly impedes the interpretation of potential field data. The eastern extent of the 'Pilbara south' boundary has been interpreted to follow the structural grain represented by the Nuninga Spring and Kimberley Well Faults, roughly correlating with the Tangadee Lineament of Muhling and Brakel (1985), whereas the eastern extent of the 'Yilgarn north' boundary follows the northern margin of what used to be known as the "Stanley Fold Belt". The crustal scale and attitude of these boundaries has been extrapolated eastward from the Capricorn seismic lines, and implies a large area of Glenburgh Terrane beneath the Mesoproterozoic basins of the eastern Capricorn Orogen. The far eastern margin of the Glenburgh Terrane is defined by the 'Rudall west' boundary that is locally represented by the Marloo Fault, although it is likely that it may extend farther east as basement to the central Rudall Province beneath the Canning and Officer Basins and pre-date Mesoproterozoic initiation of that boundary. Due to the uncertainty of the nature of the basement under the Rudall Province, the volume bounded by the 'Rudall west' and

'Rudall internal' boundaries is called the 'Rudall lower crust', even though it may represent the rifted eastern margin of the Glenburgh Terrane (Fig. 15; Kirkland et al., 2013b). The MacAdam Seismic Province, which was imaged beneath the Glenburgh Terrane on seismic line 10GA-CP2, is also extended as far east as the 'Rudall west' boundary, which is consistent with other Archean terranes that have a two-layered crust.

Sm–Nd and Lu–Hf isotopic data (Lu et al., 2021b,c) suggest that the central and southeastern parts of the Anketell Regional Gravity Ridge (Fraser, 1976) is composed of crust with strong WAC affinities, whereas the northeastern end is more juvenile. This interpretation extends the WAC to the 'Rudall east' boundary in this dataset (Figs 11a, 12), although the precise location of this boundary is uncertain and alternative interpretations are possible. This boundary is primarily constrained by interpretation of the northeastern margin of the gravity ridge and a significant break in the continuity of the ridge where the northwestern end of 'Rudall internal' intersects 'Rudall east' (Fig. 5). The interpretation of crustal boundaries in this area is complicated by the 18GA-KB1 seismic line being at a low angle to the structural grain (Fig. 2). This complicates interpretation of the geometry of the Parallel Range and Triwhite Hills Faults, which are both alternative candidates for this boundary (see Discussion).

The western extension of the Glenburgh Terrane beneath the Southern Carnarvon and Northern Perth Basins is also not well constrained, despite the existence of one deep crustal seismic line and numerous shallow seismic lines. Complex boundary geometries along this margin are due largely to complexity related to a Paleozoic accommodation zone incorporating the Carrandibby Inlier that separates the Northern Perth and Southern Carnarvon Basins, and has possibly reactivated older structures in the Capricorn Orogen. This accommodation zone was imaged on seismic line 11GA-SC1 where it crosses the Byro and Merlinleigh Sub-basins of the Southern Carnarvon Basin, although the details are not resolvable at the scale of this dataset, and are obscured by the thick basin cover. Exposed boundaries to the east have merely been extrapolated along strike to the west where they are truncated by the 'WAC west' boundary (Fig. 12). The southwestern extrapolation of the Errabiddy Shear Zone is interpreted with a normal offset because of later reactivation of this segment during formation of the younger accommodation structure. The Ballythanna Fault may also be a lithospheric structure that splays from the Errabiddy Shear Zone to the east where it forms the southern boundary of the Yarlarweelor Gneiss Complex, although more seismic data would be required to resolve the complexities of this area. Consequently, the 'WAC west' boundary has been considerably simplified in this area where it changes dip direction along the northern continuation of the west-dipping Darling Fault, which forms the southern part of the boundary, becoming an east dipping structure that follows the Kennedy Range and Wandagee Faults on the western side of the Merlinleigh Sub-basin (Figs 9a, 12). The complexity of the 'WAC west' boundary in this area is a function of reactivation of basement structures during Early Permian rifting along this margin. In particular, the Errabiddy Shear Zone appears to have localized extension at a high angle to the margin during opening of the Byro Sub-basin along the Madeline and Ballythanna Faults.

North Australian Craton assembly

The NAC was assembled between c. 1910 and 1805 Ma during collision of the putative Kimberley Craton with a block that is commonly called the proto-NAC (pNAC; Fig. 11), along the Halls Creek Orogen (HCO) on the eastern margin of the craton (Tyler and Griffin, 1990; Betts and Giles, 2006; Cawood and Korsch, 2008; Tyler et al., 2012; Hollis et al., 2013; Betts et al., 2015; Maidment et al., 2020). The Kimberley Craton is entirely concealed beneath the Kimberley Basin, and is mainly inferred from geophysical datasets (Shaw et al., 1995). Apart from the Tanami lines (10GA-T1–5), which were mainly based in the Northern Territory, there are no deep seismic lines in this region of Western Australia and all interpretations are extrapolated from the Northern Territory data. MT data from the western part of the Kimberley Craton shows a distinct change in electrical properties from horizontal structures in the upper crust to steeply dipping structures under the eastern Kimberley (Spratt et al., 2014).

The HCO extends westwards into the Wunaamin Miliwundi Orogen (formerly King Leopold Orogen), which together constitute the Lamboo Province (Fig. 16). The Lamboo Province, which is divided into western, central and eastern zones by a series of mapped major fault systems, is commonly interpreted to comprise allochthonous oceanic- or back-arc terranes that were accreted onto the margins of the Kimberley Craton during the 1870–1850 Ma Hooper Orogeny (Tyler et al., 1995; Johnson, 2013). The 1837–1808 Ma Halls Creek Orogeny records the accretion of the Kimberley Craton with the pNAC (Tyler et al., 1998). Further growth of the NAC after c. 1800 Ma continued with magmatic and metamorphic events associated with the Tanami, Stafford, Yambah, Strangways and Argilke Events and the Liebig Orogeny (Cawood and Korsch, 2008; Hollis et al., 2013; Johnson, 2013, 2021; Iaccheri, 2019). The protracted assembly of the NAC between c. 1850 and 1630 Ma was broadly coeval with intracratonic reactivation of the Capricorn Orogen within the WAC (Cawood and Tyler, 2004), following the Glenburgh Orogeny.

There are very few constraints on the scale and geometry of interpreted crustal boundaries within the NAC in Western Australia, with the majority having been determined in the Northern Territory (e.g. Selway et al., 2011; Korsch and Doublier, 2016; Kennett et al., 2018) and extrapolated for the purposes of this study (Fig. 12). The southern limits of the Kimberley Craton and the Lamboo Province are poorly constrained on the Canning Coastal reflection seismic profiles (Maidment and Zhan, 2016; Zhan, 2017; Haines et al., 2018) because the reflection lines fail to show structures within the basement. All other boundaries in this area are constrained by geological mapping and interpretation of potential field data (Lindsay et al., 2015). However, more recent passive seismic imaging clearly shows the different structural elements (Zhao et al., 2022). The interpreted southern margin of the Kimberley Craton is defined in the major crustal boundaries dataset by the 'Kimberley south' boundary, which is interpreted in the common conversion point (CCP) image of the Canning Coast 19CWAS passive seismic profile, dips moderately northeast, and is entirely concealed beneath the Canning Basin (Figs 12, 16). However, the Fenton Fault System may be a surface expression of

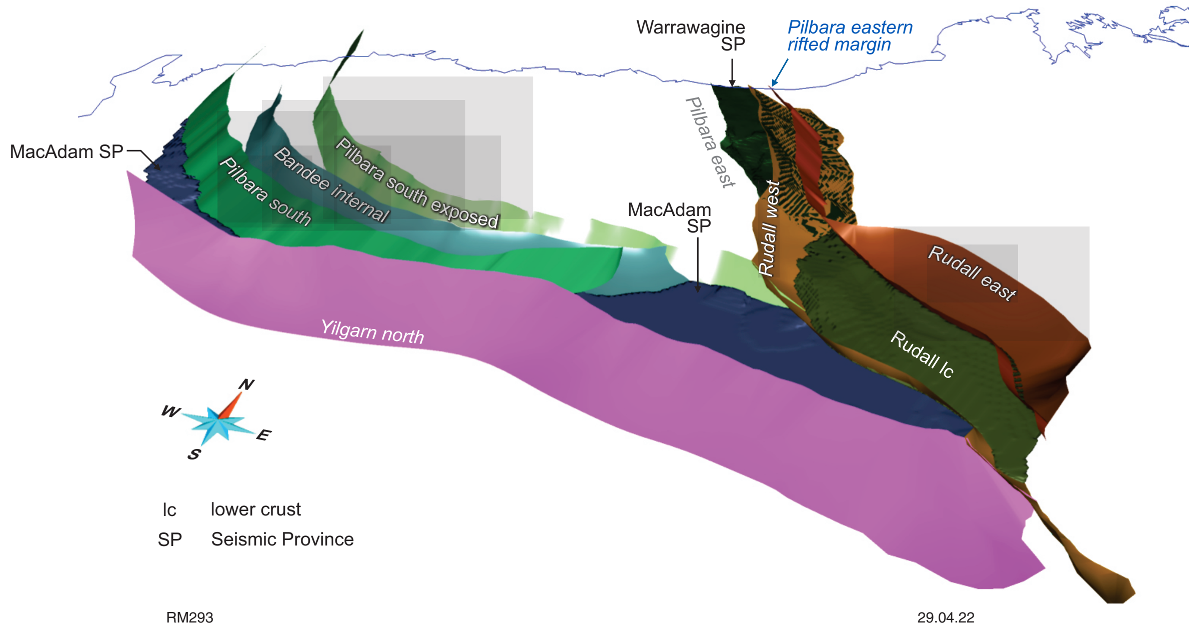

Figure 15. Subdivisions of the Rudall and Gascoyne Provinces showing the possible extents of the rifted margins of the Pilbara Craton. The MacAdam Seismic Province is the lower crustal part of the Gascoyne Province and, in this interpretation, wraps around the northern margin of the Yilgarn Craton and southern rifted margin of the Pilbara Craton

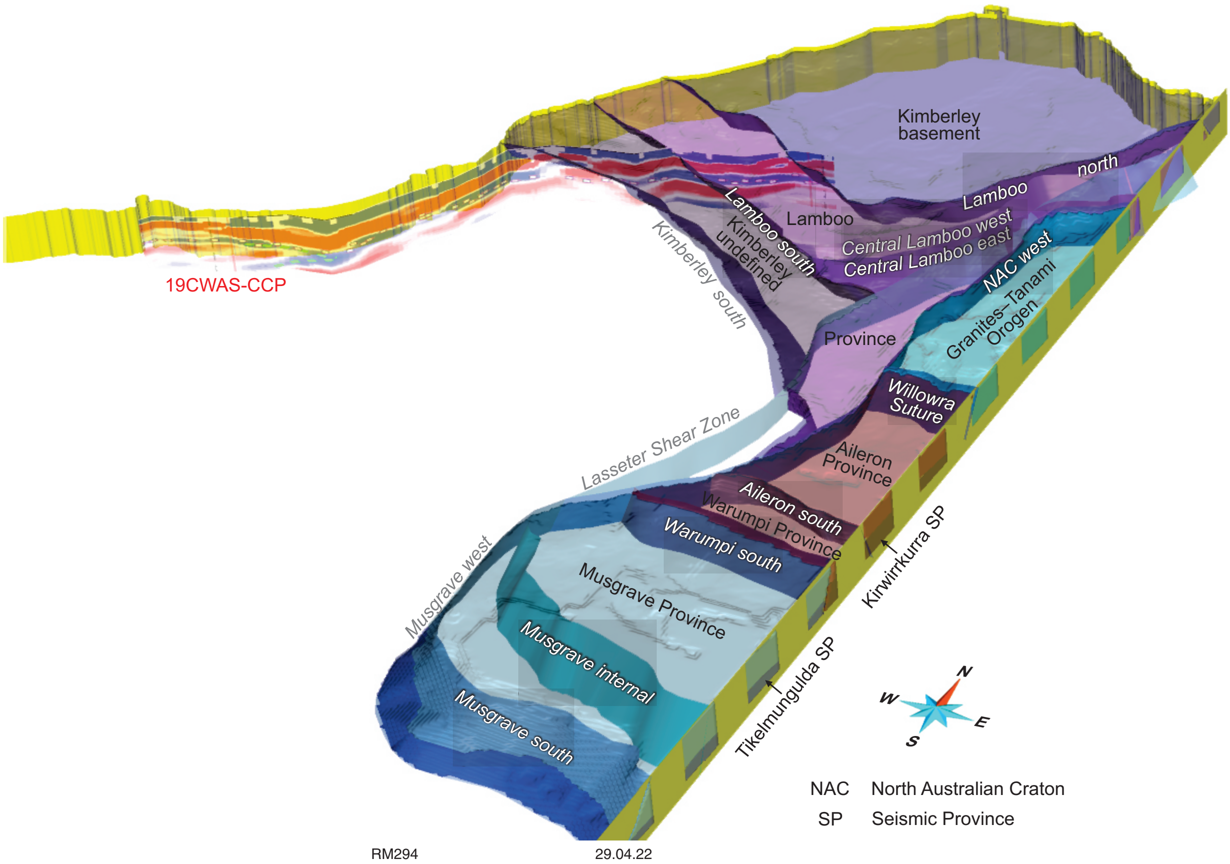

Figure 16. Detail of the Kimberley Craton and associated crustal blocks that make up the eastern part of WA, including the lower crustal blocks. The image of the 19CWAS-CCP line illustrates the reasoning behind the interpreted location and dip of the 'Kimberley south' boundary, which is not well constrained

later reactivation along this boundary. Both boundaries of the Lamboo Province in the Wunaamin Miliwundi Orogen are also interpreted to dip moderately northeast. The ‘Lamboo south’ boundary is intersected by seismic line 14GA-CC2, although it was not imaged on this line, and may be related to the Pinnacle Fault at the southwestern end. This boundary is interpreted to be predominantly a normal fault due to significant reactivation during Canning Basin extension, although was probably initiated as a reverse or thrust fault. The ‘Lamboo north’ boundary on the other hand is constrained mainly by mapping of the moderately northeast-dipping Inglis Fault System (Tyler and Griffin, 1990; Lindsay et al., 2015) that is dominated by southwest-verging thrust faults. There are no seismic constraints on crustal boundaries within the Lamboo Province in the HCO, with all geometries based on geological mapping and inversion of potential field data along a single profile (Betts et al., 2015). In this region, the major crustal boundaries are mostly moderately to steeply southeast-dipping and have large sinistral strike-slip displacements related to the Halls Creek Orogeny (Tyler et al., 1995, 2012; Thorne and Tyler, 1997). The ‘Central Lamboo east’ boundary, that is partly equivalent to the ‘Halls Creek Suture’ of Betts et al. (2015), mostly comprises the Halls Creek, Angelo and Syenite Camp Faults, and was interpreted by these authors as the suture between the Tickalara Metamorphics and the p-NAC (Fig. 11). Current GSWA interpretations also include the Osmond Fault as part of this boundary because it separates elements of the Central and Eastern Zones of the Lamboo Province to the east of the Halls Creek Fault. The crust beneath the Fitzroy Trough of the Canning Basin, between the ‘Lamboo south’ and ‘Kimberley south’ boundaries, has been assigned to the Kimberley Craton for the purposes of this compilation (Fig. 16) because it lies to the northeast of what is commonly interpreted as the WAC–NAC suture (e.g. Tyler, 2005), although the seismic properties are different from those of the Kimberley Craton.

To the south of the Kimberley Craton, the p-NAC was interpreted to have accreted to the HCO at c. 1850 Ma via the subduction of an oceanic basin (Bagas et al., 2008b, 2010). The so-called ‘Willowra Suture’ separates the Granites–Tanami Orogen and Aileron Province (Fig. 16). However, this structure is unlikely to be a suture because the isotopic signature of magmatic rocks from the Granites–Tanami Orogen and Aileron Provinces overlap (Lu et al., 2021a), implying there is no obvious change in crust across the ‘Willowra Suture’. Moreover, initiation of the ‘Willowra Suture’ must pre-date deposition of the widespread 1865–1835 Ma (meta)sedimentary package (Bagas et al., 2010) that covers much of the NAC, including the Granites–Tanami Orogen and Aileron Province (‘Detrital P’ package of Maidment et al., 2020). The Warumpi Province was accreted to (Scrimgeour et al., 2005) or re-attached to (Hollis et al., 2013) the southern margin of the Aileron Province during the 1640–1630 Ma Liebig Orogeny along a series of east–west faults collectively known as the Central Australian Suture (Hollis et al., 2013), and referred to in this dataset as the ‘Aileron south’ boundary (Figs 12, 16).

Assembly of Proterozoic Western Australia

The precise timing of the assembly of the WAC and NAC within proto-Australia and the final assembly of Proterozoic Western Australia is controversial. Proto-Australia consisted of the combined WAC and Diamantina Cratons, with the WAC adjacent to the NAC in their present-day relative positions (Fig. 1; Cawood and Korsch, 2008). The WAC and NAC were amalgamated before intrusion of the c. 1070 Ma Warakurna Large Igneous Province, which is present on both cratons (Wingate et al., 2004). Previous plate tectonic models of the assembly of Proterozoic Western Australia via collision of the WAC and NAC have relied primarily on interpretation of the tectonomagmatic history of the Paterson Orogen. Early interpretations considered the orogen to be allochthonous with respect to the WAC (Myers, 1990, 1993; Smithies and Bagas, 1997), although it is now recognized as a reworked component of the eastern WAC margin (Kirkland et al., 2013b; Gardiner et al., 2018; Tucker et al., 2018). Collision of the WAC and NAC is commonly linked to the poorly understood 1830–1765 Ma Yapungku Orogeny (Bagas, 2004; Cawood and Korsch, 2008), although recent work has identified the younger and also poorly understood 1377–1275 Ma Parnngurr Orogeny as a more likely candidate (Maidment, 2017; Gardiner et al., 2018; Payne et al., 2021). The Parnngurr Orogeny is roughly coeval with the initial transpressive phase of the 1321–1171 Ma Mutherbukin Tectonic Event in the Capricorn Orogen (Korhonen et al., 2015, 2017) and Stage I of the Albany–Fraser Orogeny (AFO) (Spaggiari et al., 2011, 2015).

The protracted assembly of the NAC between c. 1850 and 1630 Ma was broadly coeval with intracratonic reactivation of the Capricorn Orogen within the WAC (Cawood and Tyler, 2004), following the Glenburgh Orogeny. Basins in the Rudall Province were active at the same time as the Ashburton and Blair Basins of the Capricorn Orogen, indicating that they were linked and wrapped around the southern and eastern margins of the Pilbara Craton (Johnson, 2013).

Assembly of the WAC and NAC must also have post-dated 1950–1900 Ma, the age of a cryptic juvenile crustal growth event determined from Sm–Nd and Lu–Hf isotopes that occurred in the Coompana, Madura and Musgrave Provinces, and part of the basement concealed beneath the Canning Basin (Kirkland et al., 2015, 2017). These juvenile crustal ages have been interpreted as reflecting the presence of a Paleoproterozoic Mirning Ocean to the east and southeast of the WAC (Kirkland et al., 2017). Three possible timelines for closure of the hypothetical Mirning Ocean, and subsequent WAC–NAC collision, have been proposed and are vigorously debated; these are c. 1.8 Ga (Smithies and Bagas, 1997; Cawood and Korsch, 2008; Johnson, 2013), c. 1.7 Ga (Maidment, 2017; Gardiner et al., 2018) and c. 1.3 Ga (Myers et al., 1996; Maidment, 2017; Gardiner et al., 2018). In addition, a new c. 1.5 Ga timeline has recently been proposed by Payne et al. (2021), although they support final amalgamation according to the c. 1.3 Ga timeline.

It is also questionable whether the two cratons actually collided, because new passive seismic imaging along the Canning Coast on lines 19CWAS-AN and 19CWAS-CCP (Zhao et al., 2022), and new zircon Lu–Hf isotope data (Lu et al., 2021c), suggest they are distinct and separated by a large area underlain by juvenile crust (Kirkland et al., 2013a,b). This area of juvenile crust beneath the Canning Basin was previously called either the Kidson Craton (Frogtech Geoscience, 2019) or Punmu Seismic Province (Doublier et al., 2020) if referring to the lower crust, although has since been renamed the Percival Lakes Province (Zhao et al., 2022), which refers to the entire crustal block. This region equates to the northwestern part of the Mirning Ocean and the name refers to the crustal block bound by the 'Rudall east', Kimberley south' and 'NAC west' boundaries (Figs 11a, 12).

Proterozoic Western Australia is interpreted to have been assembled from proto-Australia through partial closure of the hypothetical Mirning Ocean from c. 1500 Ma, and through the injection of voluminous felsic magmas during the 1225–1125 Ma Maralinga Event, which resulted in cratonization of the Proterozoic crust between the SAC (as part of the Mawson Craton) and the WAC (Kirkland et al., 2017; Spaggiari et al., 2020). This assembly involved rotation and lateral translation following rifting of the Diamantina Craton and separation of the SAC from the NAC (Cawood and Korsch, 2008). However, the SAC crustal element is not present in Western Australia. Partial closure of the Mirning Ocean and amalgamation of the WAC, NAC and SAC to form Proterozoic Australia is commonly interpreted to have produced a triple-junction geometry (Fig. 1) between the three cratonic blocks (Myers et al., 1996; Tyler, 2005; Cawood and Korsch, 2008; Howard et al., 2015; Smithies et al., 2015; Korsch and Doublier, 2016; Johnson, 2021). However, there is also evidence for truncation of crustal boundaries and elements along a north-northeasterly trending structure (Figs 2, 11a, 12) that has been termed the 'Lasseter Shear Zone' (LSZ) (Braun et al., 1991; Aitken et al., 2016). Intracratonic reactivation of this structure during younger orogenic events has produced an obvious geophysical lineament (Figs 5, 6) that has significantly influenced the location and style of overlying Phanerozoic basins, and is a prominent feature of the eastern part of the bedrock geological map of Western Australia (Myers and Hocking, 1998; Martin et al., 2015).

Extent and significance of the Mirning Ocean

The Mirning Ocean was initially proposed to refer to the 1950–1900 Ma juvenile basement beneath the Musgrave, Madura and Coompana Provinces based on zircon Lu–Hf isotope data (Kirkland et al., 2015, 2017; Spaggiari et al., 2020). Recent zircon Lu–Hf isotopic data from basement rocks in the Percival Lakes Province adjacent to the northeastern margin of the WAC (Fig. 11a) indicated that this area is also underlain by 1950–1900 Ma juvenile crust (Lu et al., 2021c). The 654–505 Ma granites that include the O'Callaghans Supersuite and felsic components of the Kalkarindji Suite, intrude the northwestern part of the Percival Lakes Province and contain very few xenocrysts of which none are older than c. 2305 Ma (Fig. 17), providing further evidence of the young age of the crust in this area compared with the adjacent cratons. The zircon Lu–Hf isotope map shows that Proterozoic crust extends from the Percival Lakes Province to the Musgrave, Madura and Coompana Provinces, all of which share the juvenile basement signature associated with the Mirning Ocean adjacent to the eastern margin of the WAC (Lu et al., 2021c). However, it is not clear precisely when the hypothetical Mirning Ocean formed or whether the NAC occupied the opposing margin at that time. The preservation of this young, juvenile crustal signature between the WAC and the NAC suggests that either the two cratons never collided, because the intervening crust was not fully consumed in the process, or the proposed 1950–1900 Ma Mirning Ocean post-dates collision. Current understanding of the tectonic evolution of the Paterson Orogen (Anderson, 2015; Maidment, 2017; Gardiner et al., 2018; Payne et al., 2021), and the adjacent margins of the WAC and NAC (Jones et al., 2013; Lindsay et al., 2015; Zhao et al., 2022), do not support the latter interpretation. The crustal block that contains the preserved remnants of the hypothetical Mirning Ocean is bound on the western side by the 'Rudall east', part of 'Musgrave west', 'Musgrave south', part of 'Coompana west' and the 'Madura west' boundaries, and on the eastern side by the 'Warumpi south' and 'Kimberley south' boundaries (Figs 11a, 12).

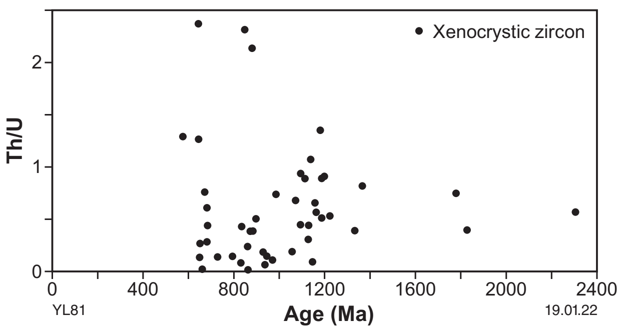

Figure 17. Compilation of all zircon data from granite samples in the Percival Lakes Province (probability density plot) showing xenocryst ages <2305 Ma that confirm the juvenile nature of this crustal block interpreted from Sm–Nd and Lu–Hf isotopic data. Granites range in age from 654 Ma to 505 Ma and belong to the O'Callaghans Supersuite and a felsic component of the Kalkarindji Suite

Proterozoic tectonics and basin evolution of the eastern WAC

The eastern margin of the WAC is concealed beneath a thick succession consisting of several stacked basins ranging in age from late Paleoproterozoic to Cenozoic (Fig. 18). The western boundary of the Paterson Orogen is called 'Rudall west' in this dataset (Figs 12, 15), and is very similar to the eastern margin of the WAC as defined by Myers (Myers, 1990); it is reflected at the surface by the Vines and Marloo Faults and their interpreted southeastward extension under cover. A small amount of late-stage reworking of the northern part of the eastern WAC margin is localized between the 'Rudall east' and 'Pilbara east exposed' boundary (Figs 12, 15), most likely during the 840–654 Ma Miles and 654–509 Ma Paterson Orogenies (revised ages after: Dunphy and McNaughton, 1998; Cross et al., 2011; Jourdan et al., 2014) that also reworked elements of the intracratonic Centralian Superbasin.

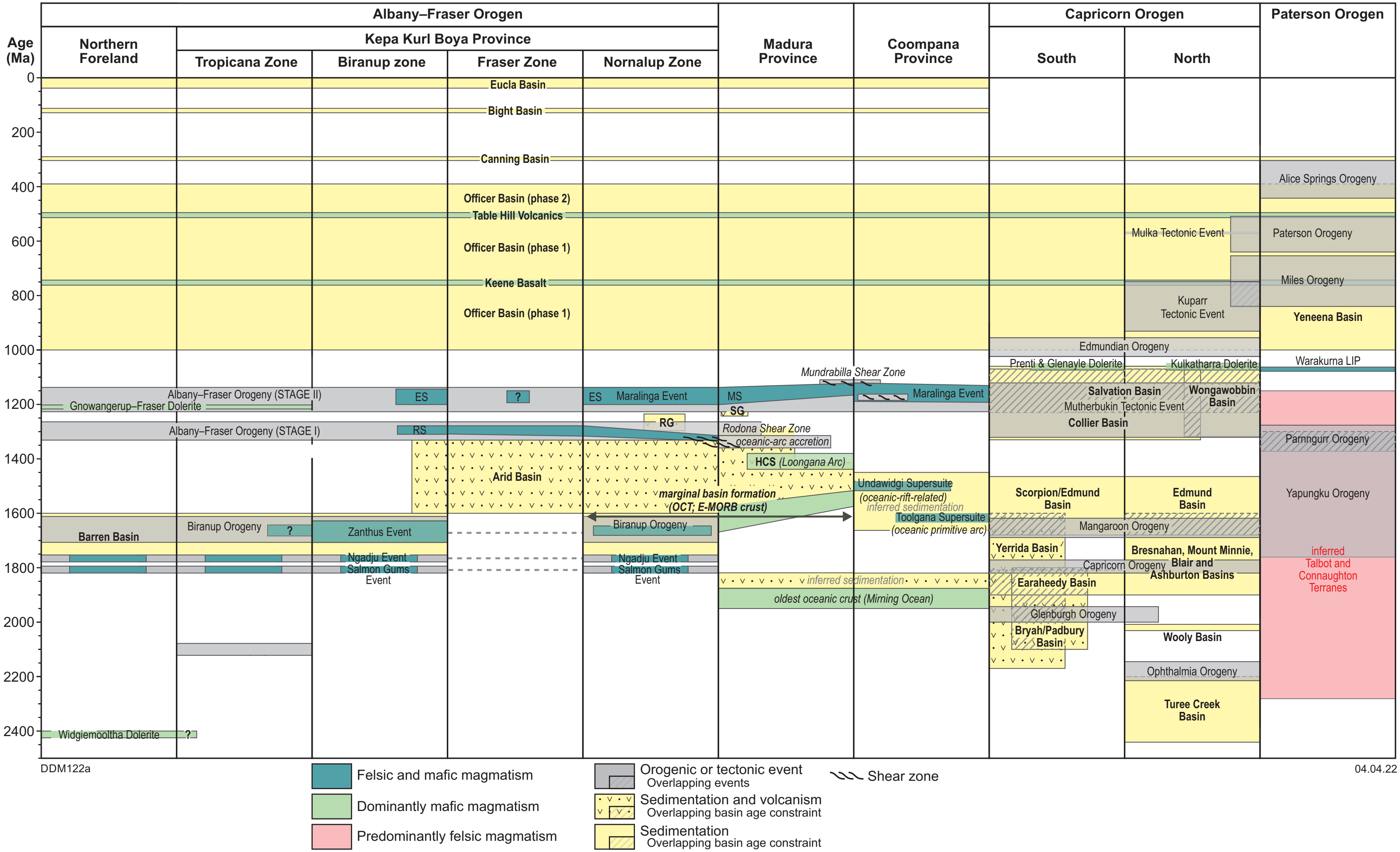

Figure 18. Time-space plot for the eastern WAC margin from the Paleoproterozoic to Cenozoic. Abbreviations: E-MORB, enriched mid-ocean ridge basalt; ES, Esperance Supersuite; LIP, Large Igneous Province; MS, Moodini Supersuite; OCT, ocean-continent transition; RG, Ragged Basin; RS, Recherche Supersuite; SG, Salisbury Gneiss; HCS, Haig Cave Supersuite

Some of the older basins appear roughly coeval according to current age constraints, although their tectonic settings and the stratigraphic correlations between them are poorly understood. Of the basins with an architecture that can reasonably be related to this margin, the 1.8–1.6 Ga Bresnahan Basin, in the eastern Capricorn Orogen (Thorne and Seymour, 1991), is the oldest and is broadly coeval with the Barren Basin (Fig. 18) in the Albany–Fraser Orogen (Spaggiari et al., 2015) and with sedimentation in the Rudall Province (Maidment, 2017). However, predominantly westerly paleocurrents in the older Ashburton Basin suggest that sedimentation could have been controlled by earlier uplift along the entire eastern margin of the WAC. The Bresnahan Basin consists of a series of north-northeast trending half-grabens that have down-to-the-east normal faulting (Thorne and Seymour, 1991). Although the Barren Basin was extensively inverted during evolution of the Albany–Fraser Orogen, it is interpreted to have been initiated as an extensional basin with similar structural style and orientation (Spaggiari et al., 2011, 2015). Facies associations in the Bresnahan Basin suggest a terrestrial setting, whereas the Barren Basin is interpreted as a continental rift or back-arc basin along the southeastern margin of the WAC. Further extension of the Barren Basin resulted in the formation of a passive margin and oceanic basin that characterizes the early stages of the 1.6–1.3 Ga Arid Basin and is roughly coeval with intracratonic extension in the Capricorn Orogen that initiated the 1.6–1.4 Ga Edmund Basin. The uppermost Arid Basin has a change in tectonic regime at c. 1410 Ma associated with the initiation of eastward subduction and the creation of an oceanic arc outboard of the WAC, known as the Loongana Arc (Fig. 18) and preserved in the adjoining Madura Province (Spaggiari et al., 2015, 2020). The southeastern margin of the WAC is called the 'Madura west' boundary in this dataset (Fig. 12), and comprises the east-dipping East Rodona Shear Zone and its northeastward extension. Spaggiari et al. (2015) initially proposed that the consequence of accretion of the Loongana Arc onto the eastern margin of the WAC was the conversion of the upper Arid Basin into a foreland basin, and a reversal in subduction direction beneath the accreted portion of the arc during Stage I of the AFO at c. 1330 Ma. The current understanding for Stage I of the AFO does not involve subduction reversal but rather delamination of the lower crust following eastward subduction beneath the Loongana Arc. This triggered partial melting of the lithospheric mantle and emplacement of the mafic-dominated Fraser Zone in an overall convergent tectonic setting (Spaggiari et al., 2018, 2020).

The timing of the onset of subduction during Stage I of the AFO (Spaggiari et al., 2014) roughly coincides with sedimentation and minor volcanism along the entire eastern margin of the WAC as recorded in the Ragged, Collier and Wongawobbin Basins (Fig. 18). The Ragged Basin on the southeastern WAC margin is the most closely associated with the onset of subduction, and has been interpreted by Waddell et al. (2015) as an upward-coarsening shallow fluvial succession deposited initially in an extensional intracratonic basin. Although no paleocurrent data were presented, the source of detritus in the Ragged Basin is inferred to be the Yilgarn Craton and adjacent Albany–Fraser Orogen. Deposition and thrust emplacement of the Mount Ragged Formation is constrained between c. 1314 and 1175 Ma. The age of the Collier Basin to the north is typically considered to be between c. 1171 and 1070 Ma (Martin, 2003; Martin and Thorne, 2004; Cutten et al., 2016), although recent dating of clastic sedimentary rocks in the Ilgarari Formation (Wingate et al., 2019a,b,c) suggest that it may be closer to 1300 Ma. The tectonic setting of the Collier Basin is less constrained, although facies variations, paleocurrents and thickness trends suggest a source area and depocentre beneath younger cover on the eastern margin of the WAC (Martin and Thorne, 2004; Martin et al., 2008; Cutten et al., 2016). The c. 1320 Ma Wongawobbin Basin (Sheppard et al., 2016b) on the northeastern WAC margin (Fig. 18) has been interpreted as an extensional intracontinental basin, that is inferred to be a far-field response to deformation in the Albany–Fraser and Musgrave Orogens. Geochronological data and stratigraphic correlation suggest that it is slightly older than the Collier Basin, and sparse paleocurrent data suggest a northwesterly paleoslope. In addition to these exposed basins, the concealed Manunda Basin has been imaged on 11GA-YO1 beneath the Officer Basin and is interpreted to be of similar age (Korsch et al., 2013). Detrital zircon analysis of end-of-hole lithologies beneath the Officer Basin in Lancer 1, Empress 1A and NJD 1, that all have maximum depositional ages of roughly 1300 Ma (P Haines, 2021, written comm.), supports this interpretation. Although the Manunda and Wongawobbin Basins are relatively recent discoveries, the potential genetic link between the AFO and Mesoproterozoic basins along the eastern margin of the WAC was recognized some time ago (Myers, 1990).

This link is characterized by the conversion of the rifted eastern margin of the WAC into an active margin. This involved inversion of the AFO and Mesoproterozoic extensional structures, accretion of the Loongana Arc, obduction of the Arubiddy Ophiolite Complex, partial closure of the Mirning Ocean and underthrusting of the Gunnadorrah Seismic Province under a region of thickened crust and beneath the Yilgarn Craton (Spaggiari et al., 2014, 2020; Kirkland et al., 2015, 2017). The crustal architecture of the Gunnadorrah Seismic Province has been imaged on the 12GA-AF1–3 (Spaggiari and Tyler, 2015) and 13GA-EG1 (Holzschuh, 2019) active seismic lines and in passive seismic and MT data (Sippl et al., 2018). The Gunnadorrah Seismic Province is characterized by gently west-dipping reflectors that appear to truncate east-dipping structures of the overlying Kepa Kurl Booya Province. It is only present at depth in Western Australia and underlies both the AFO and the Madura Province and may represent lower crustal material related to the emplacement of the 1190–1140 Ma Moodini Supersuite or older, extension-related crust or both (Spaggiari et al., 2015, 2020). The early stages of subduction involved accretion of the Madura Province to the eastern margin of the WAC along an east-dipping subduction zone, represented by the 'Madura west' boundary (East Rodona Shear Zone, Fig. 12), during Stage I of the AFO (Spaggiari et al., 2015). Ongoing convergence during Stage I of the AFO resulted in crustal thickening, lower crustal delamination, emplacement and exhumation of the Fraser Zone. The underthrusting of the Gunnadorrah Seismic Province was probably during Stage II of the AFO. The Coompana and Madura Provinces have similar Sm–Nd isotopic signatures, although are separated by the Mundrabilla Shear Zone that comprises the 'Coompana west' boundary in this dataset (Fig. 12). To the east of the Mundrabilla Shear Zone, the Coompana Province is underlain by the Forrest Lakes Seismic Province (Fig. 11b).

Significance of the Lasseter Shear Zone

The Lasseter Shear Zone (LSZ) was first proposed by Braun et al. (1991) to explain basin evolution and deformation in central and western Australia during the middle Paleozoic, related to the Alice Springs Orogeny. Their kinematic modelling suggested that north–south shortening in central Australia was contemporaneous with north–south and northeast–southwest-directed extension in Western Australia during the Late Devonian to early Carboniferous, and the LSZ was proposed to accommodate these contrasting kinematic styles. This structure can be recognized as a prominent curvilinear structural zone linking the HCO to the Musgrave Province on the surface geological map of Western Australia (Myers and Hocking, 1998; Martin et al., 2015) and in potential field geophysical datasets (Brett, 2020a,b). This structure was extended southwards to link to the 'Coompana west' boundary (Fig. 9a), in a Gondwana configuration of Australia and Antarctica, and named the Mundrabilla–Frost Shear Zone by Aitken et al. (2016), although the current interpretation is significantly different from both theirs and that of Korsch and Doublier (2015; Fig. 12). Both the LSZ and more extensive Mundrabilla–Frost Shear Zone truncate Mesoproterozoic provinces and structural trends, suggesting hundreds of kilometres of offset during the Mesoproterozoic to Neoproterozoic, possibly related to the assembly of Rodinia (Aitken et al., 2016). However, detailed interpretation that integrates high-resolution geophysical data with surface mapping suggests that the LSZ is not a simple through-going curvilinear structure as proposed by previous work. In particular, the Mundrabilla Shear Zone, which equates to the 'Coompana west' boundary, is not readily traceable northwards through the Musgrave Province (Fig. 12).

The LSZ as defined in this study was not recognized by Korsch and Doublier (2015) and consists of two boundaries that are informally called 'Lasseter SZ west' and 'NAC west' (Figs 12, 16). The 'Lasseter SZ west' boundary corresponds most closely with what has been interpreted as the LSZ in the past, and consists of the sinistral strike-slip Halls Creek Fault and its southerly extension under younger cover where it also displaces the 'Kimberley south' boundary. The majority of the sinistral displacement is interpreted to be late Paleozoic, although many authors have suggested that the LSZ was likely initiated in the early Paleozoic or Mesoproterozoic (Dow and Gemuts, 1969; Braun et al., 1991; Thorne and Tyler, 1997; Aitken et al., 2016), possibly via reactivation of a much older structure. The southern end of 'Lasseter SZ west' joins the 'NAC west' to become the 'Musgrave west' boundary, which in turn wraps around the Musgrave Province as the 'Musgrave south' boundary (Fig. 16) in a geometry that resembles a frontal- to lateral-ramp transition or oblique ramp (Butler, 1982). This interpretation is speculative and suggests that the Anketell Regional Gravity Ridge (Fraser, 1976) is not a continuous coherent geological feature, although it appears to be borne out by both high-resolution potential field data (Brett, 2020a,b) and available whole-rock Sm–Nd isotope data (Lu et al., 2021b). Together these datasets imply that the portion of the gravity ridge between the 'Rudall east' and 'Rudall internal' boundaries is part of the WAC (Figs 5a, 12), whereas the remainder of the ridge to the north of the intersection of these boundaries has strong affinities with the Mirning Ocean (Fig. 8).

The 'NAC west' boundary roughly coincides with the Balgo Fault in outcrop, which separates the eastern Canning Basin from the Granites–Tanami Orogen and Aileron Province, and has also been called the East Canning Fault (Perincek, 1996). The northern extent of this boundary is concealed beneath Phanerozoic basins, and in the south, it merges under cover with the 'Lasseter SZ west' boundary (Fig. 12) where both boundaries have been imaged on 18GA-KB1. The character and affinity of the crust between these two strands of the LSZ is speculative, and the 'Kimberley south' boundary is interpreted in the southern part of this region based exclusively on gravity data. However, Sm–Nd isotope data from the Top-up Rise drillholes, which were drilled within the 10 km precision envelope of 'NAC west' (Fig. 8), indicate that bedrock in this area has strong affinities with the NAC as opposed to areas west of 'Lasseter SZ west', which have affinities with the Percival Lakes Province (Lu et al., 2021b).

An enigmatic feature of the LSZ is that the dominant Paleozoic sinistral strike-slip kinematics that were originally used to define the structure (Braun et al., 1991), and that are well documented in the HCO (Dow and Gemuts, 1969; Thorne and Tyler, 1997), are at odds with some apparent offsets of the southern margin of the NAC (Figs 11, 16). The block bounded by the 'Lasseter SZ west', 'NAC west' and 'Kimberley south' boundaries may be part of the Mirning Ocean, although given the uncertainties in the location of the Top-up Rise drillholes with respect to the 'NAC west' boundary, it could also be part of the NAC. The former interpretation implies a relative dextral strike-slip offset along 'NAC west' whereas the latter interpretation would be consistent with previous interpretations of sinistral strike-slip displacement along the LSZ. However, it is likely that the LSZ represents a wide, long-lived deformation zone that records varied kinematics (Shaw et al., 1996). One such interpretation that fits the arrangement of boundaries presented here, is that the eastern end of the Fitzroy Trough is a Paleozoic to Mesozoic transtensional basin (Braun et al., 1991) whose opening may be related to sinistral strike-slip along the LSZ that inverted a previous dextral shear zone. In this scenario, the earlier (i.e. Late Mesoproterozoic or Neoproterozoic) dextral strike-slip could be related to the assembly of Proterozoic Australia within Rodinia, or to the intracratonic Paterson and Petermann Orogenies. Sinistral shearing along the Halls Creek Fault Zone during intrusion of the c. 1860 Ma Paperbark Supersuite (Bow River Granite of Dow and Gemuts, 1969; Thorne and Tyler, 1997), coincident with the Halls Creek Orogeny, establishes the antiquity and varied kinematics of the LSZ.

Proterozoic tectonics of the western WAC

The western margin of the WAC, called 'WAC west' in this dataset (Fig. 12), is the most prominent major crustal boundary in the State that coincides over much of its length with the 1000 km long Darling Fault and has a long and complex tectonic history (Wilde, 1999; Fitzsimons, 2003; Cawood and Korsch, 2008). This boundary is imaged on 11GA-SC1 and separates the majority of the Pinjarra Orogen from the WAC, although this interpretation differs from that of Mory et al. (2003) who found that the majority of the Merlinleigh and Byro Sub-basins may be underlain by the Pinjarra Orogen on the basis that their orientation does not match the exposed structural grain of the Gascoyne Province or Carrandibby Inlier. The northern part of the 'WAC west' boundary is concealed beneath the Southern Carnarvon Basin where it coincides in part with the Kennedy Range, Wandagee and Yanrey Faults within the basin.

At the scale of this dataset, significant simplification of the geometry of the boundary was necessary across a complex accommodation zone or relay ramp between the northern Perth and Southern Carnarvon Basins centred on the Carrandibby Inlier east of Shark Bay (Figs 4, 9a, 12). South of the Byro Sub-basin, the boundary is well constrained as a steep west-dipping fault at all crustal levels, although to the north of the accommodation zone, it is only constrained by shallow seismic, which indicates a steep easterly dip within the Southern Carnarvon Basin (Iasky et al., 1998). The limited deep seismic data available from the Pinjarra Orogen shows that it forms an inconsistently layered basement beneath the Southern Carnarvon Basin.

The surface expression of the Darling Fault appears to be strongly controlled by a proto-Darling Fault zone that was initiated at c. 2570 Ma (Wilde, 1999), although the majority of the tectonic activity along this margin reflects events associated with accretion, rifting and breakup of Rodinia and Gondwana (Wilde, 1999; Janssen et al., 2003). The 'WAC west' boundary truncates at a high angle several older major crustal boundaries within the Capricorn Orogen and Yilgarn Craton that range in age from Neoarchean to Orosirian, and also post-date Mesoproterozoic sedimentary basins and dykes of the 1218–1202 Ma Marnda Moorn Large Igneous Province (Wang et al., 2014), suggesting that the present geometry was initiated at least by the late Mesoproterozoic (Cawood and Korsch, 2008; Johnson, 2013). The majority of the Pinjarra Orogen to the west of the boundary is concealed beneath Paleozoic to Mesozoic strata (Hall et al., 2012), with exposure confined to the Northampton, Mullingarra and Leeuwin Inliers, and consequently its tectonic setting and structural evolution are not well constrained. Nonetheless, available data suggest deformation of c. 1300 Ma basement metagranitic rocks during the 1205–1150 Ma Darling Orogeny, followed by later sedimentation, granulite facies metamorphism and deformation during the 1095–990 Ma Pinjarra Orogeny (Fitzsimons, 2003; Johnson, 2013) and accretion of the Leeuwin Inlier during the 780–515 Ma Leeuwin Orogeny (Collins, 2003). Detrital zircon age modes within the granulite facies paragneisses do not support the Yilgarn Craton as a source area, suggesting significant late Mesoproterozoic to Neoproterozoic transcurrent movement along this boundary (Bruguier et al., 1999; Fitzsimons, 2003).

The oldest components of the Pinjarra Orogen were emplaced adjacent to the WAC by c. 755 Ma, when the northeast trending Mundine Well Dolerite (Wingate and Giddings, 2000) was intruded on both sides of the 'WAC west' boundary, and prior to deposition of the largely unmetamorphosed 1600–1000 Ma Yandanooka Group. These dykes have been dextrally offset as a consequence of later oblique collision of the Australo–Antarctic and Indo–Antarctic components of Gondwana along the Pinjarra Orogen at 550–500 Ma (Bruguier et al., 1999; Collins, 2003; Fitzsimons, 2003; Janssen et al., 2003). The Leeuwin Inlier at the southern end of the Pinjarra Orogen is the youngest metagranitic component (Wilde, 1999; Collins, 2003) that is separated from the remainder of the orogen by the steep east-dipping Dunsborough Fault, which comprises the 'Leeuwin east' boundary (Figs 9a, 12). Hence, it is modelled as a separate block. The dominant transcurrent kinematics on the 'WAC west' boundary during the late Proterozoic suggest that it was predominantly a steep structure at this time.

Phanerozoic boundaries and reactivations

Although the majority of major crustal boundaries initiated during the Phanerozoic are offshore and relate to the rifting and final breakup of Gondwana, many structures of this age within onshore basins are the product of reactivation of Precambrian boundaries in the lead up to this event. One of the earliest Phanerozoic reactivations of Precambrian major crustal boundaries is identified along the Parallel Range Fault, related to the 'Rudall east' boundary (Fig. 12), leading to deposition of the Yapukarninjarra Formation in the Barnicarndy Graben (Normore et al., 2021), and then the widespread Nambeet Formation in the southern Canning Basin during the early Ordovician. Subsequent reactivation of Precambrian boundaries is related to the long-lived Alice Springs Orogeny and related subsidence between the WAC and NAC during the Late Ordovician to mid-Carboniferous (Dunlap et al., 1995; Haines et al., 2001). These reactivations are largely responsible for the surface expression of the LSZ and reactivation of older major crustal boundaries around the margins of the Canning Basin (cf. Braun et al., 1991). In particular, the location of the Devonian–Carboniferous Fitzroy Trough on the northern margin of the basin appears to be controlled by the 'Kimberley south' and 'Lamboo south' boundaries, whereas the western margin of the Barnicarndy and Samphire Grabens coincides with the 'Rudall east' crustal boundary (Fig. 12). Similarly, the 'WAC west' boundary exerted a strong control on Carboniferous–Permian rifting along this margin that resulted in opening of the Southern Carnarvon and Perth Basins. During breakup, the separation of Australia from its neighbours in Gondwana was first initiated along the Northwest Shelf and propagated anticlockwise and southwards along the western margin of the Perth and Carnarvon Basins, and finally to the Bight and Eucla Basins on the southern margin (Cockbain, 2014). The effects of Phanerozoic reactivations of major crustal boundaries are not evident in the 3D model, primarily due to the small scale of the model and because all basins are modelled as a single object, with the exception of the Fortescue–Hamersley Basin.

Discussion

Although the map and 3D model of the crustal architecture of Western Australia presented in this Record are the most detailed of their kind currently publicly available, their accuracy and usefulness are limited by the data on which they are based, and by the current understanding of the geological evolution of the State. Some of the limitations of the source data have been discussed as part of the description of these sources in the methodology section. The most significant limitations of the dataset relate to alternative interpretations of both the location and significance of some boundaries, the most significant of which are discussed below. Perhaps the most useful outcome of this compilation has been the identification of knowledge and data gaps that need to be filled to obtain a more robust understanding of the crustal architecture and geological evolution of the State.

Alternative interpretations

This interpretation of the major crustal boundaries of Western Australia is based on current GSWA understanding of the geological evolution of the State. However, alternative interpretations of this evolution could significantly influence the interpreted location of some boundaries, and vice versa. Consequently, this section explores some of these uncertainties and alternative interpretations, the majority of which relate to boundaries in areas of sparse seismic data or under deep cover, such as beneath the Canning Basin. Perhaps the most significant uncertainties relate to initial assembly of the NAC and the timing and geodynamics of its amalgamation with the WAC to form Proterozoic Western Australia. By contrast, assembly of the WAC is well constrained with numerous seismic lines in the Yilgarn Craton and Capricorn Orogen, although boundaries in some older and geologically significant areas such as the Pilbara Craton are less well constrained.

In the Pilbara Craton, for example, the interpreted western extent of the 'CPTZ west' boundary differs from that of Bagas et al. (2008a) who interpreted a concealed boundary with the WPS beneath the Fortescue and Hamersley Basins. Potential field and Sm–Nd isotopic data (Fig. 8; Lu et al., 2021b) from the CPTZ do not suggest a major crustal boundary between the Sholl Terrane and basement to the Mallina Basin (cf. Hickman et al., 2010), although more isotopic data are required to confirm this interpretation. Smithies and Farrell (2000) identified a major structural corridor, named the Chichester Tectonic Zone, in the southern part of the exposed Pilbara Craton. Hickman (2021) has extended the Chichester Tectonic Zone beneath the Fortescue and Hamersley Basins, and interpreted it as an east-southeast trending terrane boundary that involved northerly subduction beneath the EPT to produce the Sisters Supersuite. However, this structure does not display the characteristics of other major crustal boundaries within current potential field (Figs 5a, 6a) or isotopic data (Fig. 8), and is consequently not included in this dataset. There is a subtle difference in the interpretation of 'CPTZ east' compared with Korsch and Doublier (2015), although these authors did not recognize 'CPTZ west', 'Kurrana west', 'Pilbara east exposed' and the 'Pilbara south exposed' boundaries (Fig. 12). These discrepancies are mainly due to the recent acquisition of new seismic and isotopic data from the Pilbara Craton.

There are significant differences in the interpretation of some boundaries in the Yilgarn Craton (Fig. 12) compared with those of Korsch and Doublier (2015) that are in turn based on Cassidy et al. (2006). These include a significantly revised interpretation of the boundary between the Youanmi and South West Terranes as a consequence of new mapping in the southwest Yilgarn Craton (Quentin de Gromard et al., 2021). The Youanmi Shear Zone was omitted from the national compilation by Korsch and Doublier (2015), and no reasons were given, although it is included as the 'Youanmi internal' boundary in this dataset mainly because it is a major crustal feature on the 10GA-YU2 seismic line. More isotopic data are required from the Marymia Inlier to better constrain specific affinities with the bulk of the Yilgarn Craton to the south. The available isotopic data suggest a closer affinity with the EGS than with the Youanmi Terrane (cf. Cassidy et al., 2006). Steep gradients in potential field data (Figs 5a, 6a) also suggest that there may be an additional boundary farther north, roughly equating to the Peak Hill Schist and its eastward extension into the Jenkin Fault, which may represent the true southern limit of the Marymia Inlier. It is also likely that the Yilgarn Craton extends eastwards beyond the significantly younger 'Rudall west' boundary (Fig. 12), although the location of the 'Yilgarn north' boundary beneath the Canning and Officer Basins in this area cannot be interpreted from available data.

Korsch and Doublier (2015) proposed an alternative interpretation for the crustal architecture of the Capricorn Orogen that links the Lyons River Fault ('Pilbara south' boundary) into the northern boundary of the Yilgarn Craton southeast of the Coobara Dome, such that the Pilbara and Yilgarn Cratons are in direct contact to the east of this area (Fig. 12). This interpretation is more closely aligned with the interpretation of Myers (1990), and would imply a significant southward extension of the Pilbara Craton, although it is not supported by the presence of a well-developed structural fabric comprising the northeast-trending Tangadee Lineament (Muhling and Brakel, 1985) that crosscuts the marked gravity gradient that characterizes this boundary (Fig. 5a). Korsch and Doublier (2015) also extended the Baring Downs Fault across this lineament (Fig. 12), an interpretation that is not followed in this study, although both interpretations are unconstrained by seismic data.

The lithospheric architecture of the NAC is the most poorly constrained in 3D, and is mainly based on plate tectonic interpretations of surface geology, supported by forward-modelling of gravity data and seismic sections outside of Western Australia, that invoke accretion of allochthonous blocks to the Kimberley Craton (e.g. Betts et al., 2015). However, a recent detrital zircon study has suggested that the zones of the Lamboo Province may not be allochthonous (Maidment et al., 2020), and also that the Kimberley Basin is underlain in part by the Paperbark Supersuite, as indicated by the age and composition of porphyroclasts in the Aries kimberlite pipe (Downes et al., 2007). These relationships have been used to suggest a coherent regional sequence by c. 1885 Ma that was deposited in a backarc setting behind a margin to the north of the NAC (e.g. Hollis et al., 2015), rather than a series of discrete allochthonous terranes related to accretion along the southern margin of the concealed Kimberley Craton (Kohanpour et al., 2017; Maidment et al., 2020). This autochthonous interpretation of the Lamboo Province and its affinity to the Kimberley Craton differs from that of Betts et al. (2015) whose 'Halls Creek Suture' was interpreted to form an oroclinal bend around the Kimberley Craton, implying that this crustal block is either part of the p-NAC or a different allochthonous block. However, the major crustal boundaries interpreted in this study are compatible with either of these interpretations.

The interpreted boundaries between the WAC and NAC that are concealed beneath the Canning Basin are similarly very poorly constrained. Although they are transected by four deep seismic reflection lines, three of these were not optimized to image deep structures. The interpretation in this Record of the location of these structures, and their strike continuity, differs markedly from that of Korsch and Doublier (2015). These differences are mainly due to the availability of new active and passive seismic data and their influence on interpretation of the potential field data, and that Korsch and Doublier (2015) did not recognize the LSZ (Fig. 12).

There is little difference between the ‘Rudall internal’ boundary and its northwestward extension, and the Camel–Tabletop Fault Zone of Korsch and Doublier (2015). However, the ‘Rudall east’ boundary (Fig. 12) is significantly different between our interpretation and that of Korsch and Doublier (2015). There is also an additional possibility to our interpretation of the ‘Rudall east’ boundary. The known southernmost limit of 654–505 Ma granites in the Paterson Orogen, consisting of the O’Callaghans Supersuite and felsic components of the Kalkarindji Suite, is the Parallel Range Fault (Fig. 19) that may define the boundary between the WAC and the Percival Lakes Province. Therefore, an alternative for the ‘Rudall east’ boundary would be that instead of crossing the northern end of the Rudall Province to merge with the ‘Rudall internal’ boundary, the more eastern Triwhite Hills Fault segment of ‘Rudall east’ instead continues northwestward as the Parallel Range Fault (Fig. 19). This alternative interpretation would create a sliver of interpreted WAC crust beneath the Barnicarndy Graben between the ‘Rudall internal’ (Barnicarndy – Camel–Tabletop Faults) and the ‘Rudall east’ (Parallel Range – Triwhite Hills Faults) boundaries. However, this remains to be determined as existing drillcores in this region do not intersect crystalline basement. This alternative placement of the boundary would also follow the mapped distribution of the Neoproterozoic Throssell Range Group and the Lamil Group more closely, which is strongly controlled by the Parallel Range Fault. Correct placement of the ‘Rudall east’ boundary has important economic implications because the interpretation presented in this dataset implies that the sliver between it and the Parallel Range Fault may be intruded by the 654–603 Ma O’Callaghans Supersuite and would therefore be prospective for Telfer-style Au deposits. Conversely, if the boundary is placed along the Parallel Range Fault, this same area would be underlain by WAC crust and instead be prospective for Nifty-style Cu mineralization.

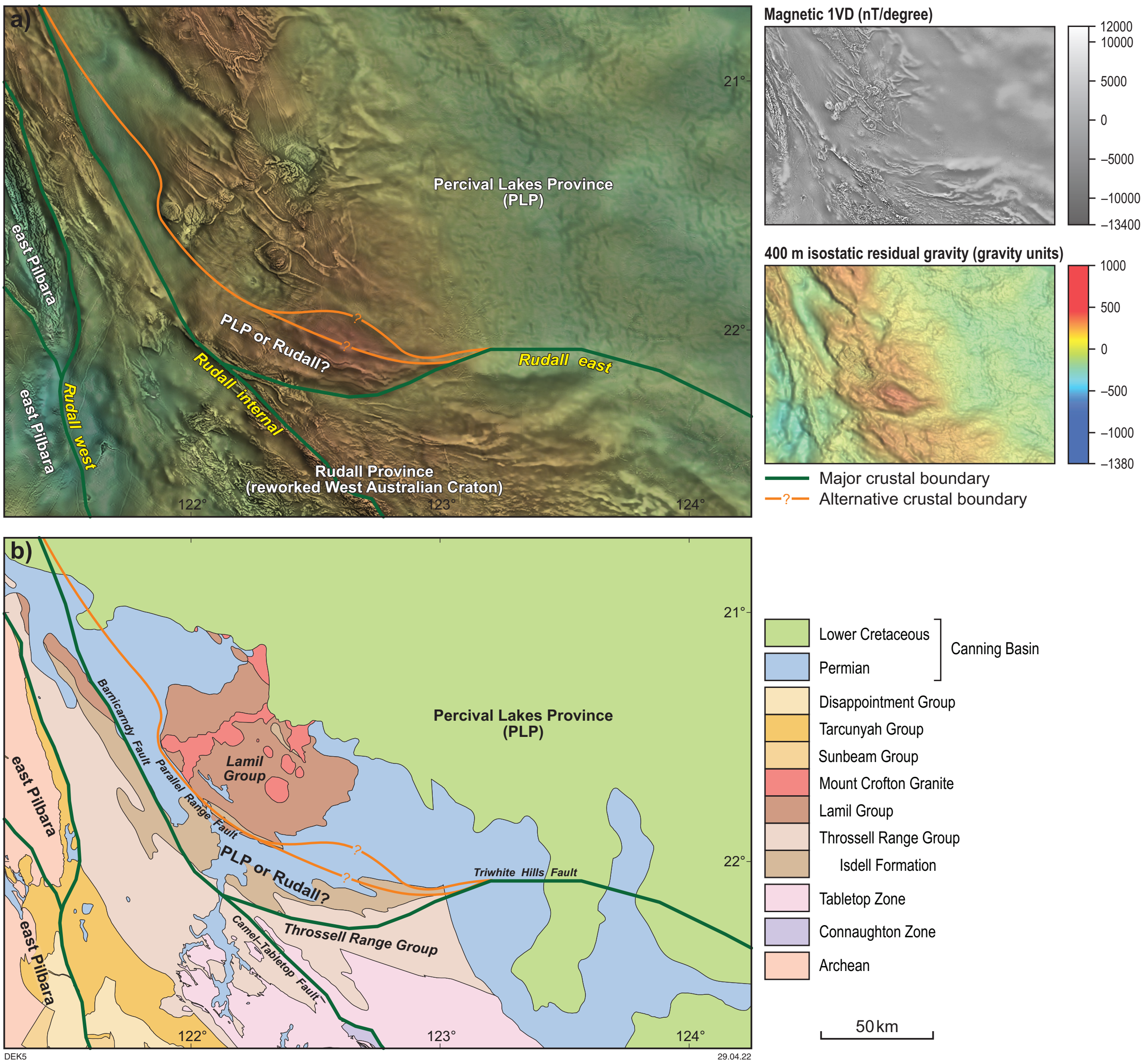

Figure 19. Alternative interpretation of major crustal boundaries in the Rudall Province, especially of the ‘Rudall east’ boundary, taking into account the significant differences in surface geology; a) compared to composite potential field data; b) compared to interpreted bedrock geology. Note there are no whole-rock isotopic constraints on the affinity of the deep crust between the ‘Rudall east’ boundary and the Parallel Range Fault

Korsch and Doublier (2015) placed the northern margin of the newly named Percival Lakes Province on the southern side of a prominent residual gravity high, coincident with the Dampier Fault and its extension into the Desert Bore Shear Zone, which is a considerably different location from our interpretation (Fig. 12). Active and passive seismic data suggests this boundary is more closely associated with the Fenton Fault System on the northeastern side of the high (Zhan, 2017; Zhao et al., 2022). There is little evidence from seismic or potential field data for the existence of a major crustal boundary within the Percival Lakes Province corresponding to the Admiral Bay Fault Zone of Korsch and Doublier (2015), which they correlate across the LSZ to the Bloods Backthrust Zone to the north of our 'Musgrave internal' boundary (Fig. 12).

Recognition of the LSZ in this dataset is a significant point of difference with the interpretation of Korsch and Doublier (2015), who extend three major crustal boundaries across this feature (Fig. 12) that has been imaged at the eastern end of 18GA-KB1. However, with the exception of the 'Aileron south' boundary, none of the boundaries within the southern NAC, or within the LSZ as defined by 'Lasseter SZ west' and 'NAC west' boundaries, are well-defined in Western Australia since they are mostly interpreted beneath thick Neoproterozoic and Phanerozoic basin cover. In particular, the Western Australian component of the 'Willowra Suture' could be farther south, on the northern edge of a prominent residual gravity high (Fig. 5a). Furthermore, Sm–Nd isotopic data from the Top-up Rise drillholes within the LSZ (Fig. 8) suggest that the 'Kimberley south' boundary mapped 140 km to the north could be a dextrally offset extension of the 'Willowra Suture'. Constraints on the location of the 'Warumpi south' boundary (Fig. 12) are very poor. This boundary could conceivably be either farther south or north of the current location, under the Amadeus Basin. If farther south, the Warumpi Province could continue all the way to the northern boundary of the fold and thrust belt along the northernmost Musgrave Province (Bloods Backthrust Zone of the 'Petermann Nappe Complex'), meaning 'Warumpi south' would be approximately where Korsch and Doublier (2015) place their boundary (Fig. 12). If farther north, 'Warumpi south' could be directly south of the southern limit of outcropping Warumpi Province. Ultimately, more isotopic and seismic data are required to precisely constrain the major crustal boundaries in this region. A recent reinterpretation of the 11GA-YO1 line (Quentin de Gromard et al., 2017) has resulted in the recognition of the 'Musgrave internal' boundary, which was not recognized by Korsch and Doublier (2015) who placed a major boundary to the north along their interpreted Bloods Backthrust Zone. These authors interpreted the Bloods Backthrust Zone as the strike extension of the Woodroffe Thrust in the Northern Territory, whereas this thrust is interpreted farther south in Western Australia where it is truncated in the lower crust by the lithospheric scale 'Musgrave internal' boundary (Quentin de Gromard et al., 2017).

There are some subtle differences in interpretation of boundaries within the Albany–Fraser Orogen and beneath the Eucla Basin, compared with Korsch and Doublier (2015). The majority relate to differences in interpretation of the location and significance of lithospheric structures under cover, with the most significant being the northern extent of the Mundrabilla Shear Zone. Korsch and Doublier (2015) interpret this structure as deviating into a northwesterly trend (Fig. 12), whereas the majority of other authors consider it to be a north-south trending structure that extends from the Eucla coast to the Musgrave Province (e.g. Martin et al., 2015; Spaggiari and Tyler, 2015; Aitken et al., 2016).

Future directions

More data are required to resolve these differences in interpretation, particularly in areas under deep cover and for structures that are unconstrained by deep reflection seismic lines. Reflection seismic constraints are required for large parts of the NAC, the Pilbara Craton and southwest Yilgarn Craton where very few lines currently exist (Fig. 2). Filling known data gaps in the isotopic data through targeted sampling will also help to constrain boundaries in some areas, particularly on the NAC where data are sparse (Fig. 8). Many of the boundaries that are less constrained are also under deep cover, such as the Canning Basin, beneath which basement characterization via geochronological and isotopic analysis is unavailable. Stratigraphic drilling is the best method to address these data gaps, although the majority of the key areas of interest are concealed by many kilometres of cover. More details of the seismic and electrical nature of the lower crust and lithosphere will be a product of the forthcoming passive seismic WA-Array and Australian Lithospheric Architecture Magnetotelluric Program (AusLAMP), which will both commence across Western Australia in 2022.

Conclusions

This compilation of the major crustal boundaries of Western Australia is the most comprehensive for any part of the continent and involved the integration of all available relevant data, and robust internal consistency and geometrical checks via an iterative process of 2D mapping and 3D modelling. When combined with the detailed attribution of the various segments of the boundaries, it provides a useful tool for assessing the tectonic assembly and breakup of Western Australia and the consequent implications for mineral and petroleum exploration. Due to the highly interpretive nature of this compilation that is heavily biased by current knowledge, combined with the limited absolute constraints on many boundaries, this model will be subject to ongoing revision as new data are acquired and knowledge of the geological evolution of the State evolves.

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Appendix

List of components of 3D geomodel

Table 1. Major crustal boundaries

Object	*Comment*	*Reference*	*Feature category*	*Spatial type*
Aileron_south	The boundary between the older Aileron Province to the north and the younger Warumpi Province to the south; includes the Central Australian Suture	Selway et al. (2009) Shaw et al. (1991)	Geology	Surface
Bandee_internal	A lithospheric boundary within the Bandee Seismic Province (SP), which appears to limit the southern extent of the Lower Bandee SP; imaged in 10GA-CP2; includes the Talga and Perry Faults	Thorne et al. (2011)	Geology	Surface
Baring_Downs_Fault	The boundary between the Bandee and Carlathunda – Ripon Hills SP; possibly pre-dates the Fortescue Basin; interpreted as a normal fault; imaged in 10GA-CP1	Johnson et al. (2011) Thorne et al. (2011)	Geology	Surface
Burtville_east	The boundary between the Burtville and Yamarna Terranes of the Eastern Goldfields Superterrane (EGS); interpreted as a normal fault; imaged in 01AGS-NY1; includes the Yamarna Fault System	Goleby et al. (2003) Lindsay et al. (2019)	Geology	Surface
Central_Lamboo_east	Boundary between the Central and Eastern Lamboo Provinces; includes the Syenite Camp, Angelo and Osmond Faults	Griffin and Tyler (1992) Phillips et al. (2016)	Geology	Surface
Central_Lamboo_west	A reverse fault system between the Western and Central Lamboo Provinces; includes the Gidden – Springvale – Bow River – Carr Boyd Fault System	Phillips et al. (2016) Sheppard et al. (1999)	Geology	Surface
Coompana_west	The vertical strike-slip fault with sinistral shear between the Madura and Coompana Provinces and their underlying seismic provinces; includes the Mundrabilla Shear Zone	Dutch et al. (2015) Spaggiari et al. (2017)	Geology	Surface
CPTZ_east	Sinistral strike-slip boundary between the Central Pilbara Tectonic Zone (CPTZ) and the East Pilbara Terrane; includes the Tabba Tabba Shear Zone	Smithies (1999)	Geology	Surface
CPTZ_west	Strike-slip boundary between the West Pilbara Superterrane and the CPTZ; includes the Scholl Shear Zone	Hickman (2016)	Geology	Surface
Gascoyne_internal	Lithospheric structure within the Glenburgh Terrane; imaged in 10GA-CP2; includes the Chalba, Deadman and Turner Faults and continues beneath the South Carnarvon Basin	Johnson et al. (2011)	Geology	Surface
Kalgoorlie_east	The boundary between the Kalgoorlie and Kurnalpi Terranes of the EGS; it dips to the east as per the pmd*CRC model, rather than to the west as seen in the BMR91-EGF1 interpretation; includes the Celia, Perseverance and Ockerburry Faults	Cassidy (2006) Goleby et al. (1993)	Geology	Surface
Kimberley_south	The inferred southern extent of the Kimberley Craton; normal fault imaged in 14GA-CC1 and in passive seismic data; includes the Fenton Fault System	Zhan (2017)	Geology	Surface
Kurnalpi_east	The boundary between the Kurnalpi and Burtville Terranes of the EGS; imaged in 01AGS-NY1; includes the Hootanui Fault System	Goleby et al. (1993)	Geology	Surface
Kurrana_west	The rifted boundary between the Kurrana and East Pilbara Terranes of the Pilbara Craton	Hickman and Van Kranendonk (2012)	Geology	Surface
Lamboo_north	The northern boundary of the Lamboo Province, equating to the southern margin of the Kimberley Basin; includes the Inglis and Ivanhoe Faults	Phillips et al. (2016)	Geology	Surface
Lamboo_south	The southern margin of the Lamboo Province with the volume of crust to the south of undefined origin, which in the model is assigned to the Kimberley Craton; includes the Sisters structure and the Pinnacle Fault	Phillips et al. (2016)	Geology	Surface
Lasseter_Shear_Zone_west	The sinistral strike-slip fault within Lamboo Province of the Kimberley Craton; under the Canning Basin, it bounds the eastern side of the Punmu SP; the southern end continues into the western boundary of the Musgrave Province; imaged in 18GA-KB1 as a wide disrupted zone to the east of a better defined fault; includes the Halls Creek Fault	Doublier et al. (2020a) Phillips et al. (2016)	Geology	Surface
Leeuwin_east	A normal fault that forms the eastern boundary of the Leeuwin Inlier with the rest of the Pinjarra Orogen; includes the Dunsborough Fault	Iasky (1993)	Geology	Surface
Madura_west	A wide, east-dipping high-strain zone showing west-directed thrusting overprinted by sinistral shearing that forms the western boundary of the Madura Province with the Kepa Kurl Booya Province, both of the Albany–Fraser Orogen; imaged in 11GA-AF3 and includes the east Rodona Shear Zone	Dutch et al. (2015) Spaggiari et al. (2017)	Geology	Surface
Marymia_south	The thrust that separates the Marymia Inlier from the other terranes of the Yilgarn Craton. The similarities of the granite–greenstone succession in the Marymia Inlier to the Narryer Terrane suggest that it was probably initiated as a thrust or reverse fault in the Archean. It was probably a normal fault during deposition of the Proterozoic Yerrida and Bryah Basins; includes the Goodin and Jenkin Faults	Lindsay et al. (2020)	Geology	Surface
Musgrave_internal	A reverse lithospheric boundary within the Musgrave Province imaged in 12GA-YO1; includes the Iragana, Mitika and Mann Faults	Howard et al. (2013) Quentin de Gromard et al. (2017)	Geology	Surface
Musgrave_south	The southward-dipping southern boundary between the Musgrave Province with the Rudall Province to the west and the Coompana Province to the south; imaged in 12GA-YO1; includes the Windulara Fault	Korsch et al. (2013)	Geology	Surface
Musgrave_west	The buried western extent of the Musgrave Province. Towards the north it merges with the Lasseter Shear Zone and towards the south with the Musgrave south boundary		Geology	Surface
NAC_west	The almost-vertical strike-slip boundary between the North Australian Craton and the Lamboo Province; imaged in 18GA-KB1; includes the Balgo Fault, the eastern component of the Lasseter Shear Zone	Doublier et al. (2020a,b)	Geology	Surface
Narryer_southeast	The boundary between the Narryer Terrane and the Youanmi Terrane, interpreted as a thrust fault; imaged in 11GA-YU1 and 11GA-SC1; includes the Yalgar Fault	Romano et al. (2014)	Geology	Surface
Northern_Foreland_south	The shallowly southeast-dipping edge of the Northern Foreland as it passes under the Kepa Kurl Booya Province of the Albany–Fraser Orogen; imaged in 12GA-AF1 and 3, in the southern part includes the Millers Point Thrust and Bremer Fault. In the eastern part includes the Red Island Shear Zone, the Bishop's Hat Shear Zone and the Frog Dam Shear Zone	Spaggiari et al. (2015b) Thom and Chin (1981)	Geology	Surface
Pilbara_east_exposed	A lithospheric boundary within the Pilbara Craton interpreted to have normal movement, which separates Gregory Suite rocks from the rest of the Pilbara Craton; seen in 18GA-KB1 and includes the Pearana southwest fault	Doublier et al. (2020a,b)	Geology	Surface
Pilbara_south	The southward-dipping series of thrusts that separate the Bandee part of the Pilbara Craton from the Glenburgh Terrane; imaged in 10GA-CP2 and includes Caylie Fault north, Quartzite Well Fault, Lyons River Faults and Tangadee lineament	Johnson et al. (2011)	Geology	Surface
Pilbara_south_concealed	A lithospheric thrust/reverse fault within the Pilbara Craton along the trace of the Mindle Shear Zone		Geology	Surface
Pilbara_south_exposed	A lithospheric boundary with various senses of movement. Imaged in 10GA-CP1 although the seismic line lies parallel to the strike of the boundary so it is not imaged well; includes the Nanjilgardy and Lawloit Range Faults	Thorne et al. (2011)	Geology	Surface
Rudall_east	An inferred bounding surface between the Tabletop Terrane of the Rudall Province and the Punmu SP		Geology	Surface

Table 1. continued

Object	*Comment*	*Reference*	*Feature category*	*Spatial type*
Rudall_internal	Lithospheric boundary between the Talbot–Connaughton and Table Top Terranes of the Rudall Province; imaged on 18GA-KB1 and includes the West Barnicarndy and Camel Tabletop Fault	Doublier et al. (2020a,b)	Geology	Surface
Rudall_west	The boundary of the Rudall Province with the Warrawagine SP in the north, the Glenburgh Terrane in the centre, and further south, with the Yilgarn Craton. Imaged in 18GA-KB1 and includes the Marboo and Vines Faults at the surface and the Gingarrigan Creek Detachment at depth	Doublier et al. (2020a,b)	Geology	Surface
South West_east	The boundary between the Youanmi Terrane and the Southwest Terrane of the Yilgarn Craton. To the southwest, magmatic ages are <2.7 Ga whereas to the northeast, older magmatism is widespread	Quentin de Gromard (2021) Wilde et al. (1996)	Geology	Surface
WAC_west	The steeply dipping normal fault that bounds the western edge of the West Australian Craton with the Pinjarra Orogen to the west; imaged in 11GA-SC1 and NN92-01 and includes the Darling, Wandagee and Yanrey Faults	Mory and Haig (2011) Thyer and Everingham (1956)	Geology	Surface
Warumpi_south	A steeply south-dipping reverse fault, which is entirely undercover and hence highly speculative, forming the boundary between the Warumpi Province and the Musgrave Province		Geology	Surface
Willowra_Suture	The boundary between the Aileron Province and Granites–Tanami Orogen of the North Australian Craton; imaged on 05GA-T1 in the Northern Territory	Goleby et al. (2009)	Geology	Surface
Yarlarweelor_north	The northern boundary of the Yarlarweelor Gneiss Complex with the Glenburgh Terrane; imaged on 10GA-CP3 and includes the Errabiddy Shear Zone	Johnson et al. (2011)	Geology	Surface
Yarlarweelor_south	The southerly boundary of the Yarlarweelor Gneiss Complex with the Narryer Terrane to the south and the Marymia Inlier to the east; imaged on 10GA-CP3 and 11GA-SC1 and includes the Mt Rebecca, Meeberrie and Kerba Faults	Johnson et al. (2011) Korsch et al. (2014)	Geology	Surface
Yilgarn_north	This low-angle south-dipping thrust forms the boundary between the Yilgarn Craton in the south with the Glenburgh Terrane in the north; imaged in 10GA-CP2 and 3 and includes the Salvation, Yamada, Turner, Deadman and Cardilya Faults	Johnson et al. (2011)	Geology	Surface
Yilgarn_southeast	The shallow southeast-dipping southern margin of the Yilgarn Craton with the Albany–Fraser Orogen; includes the Manjimup Fault in the southwest, Yarracarrup Fault and Jerdacuttup Fault in the southeast	Beeson et al. (1988) Spaggiari et al. (2015b)	Geology	Surface
Youanmi_east	The eastern boundary of the Youanmi Terrane with the EGS. Marked by a distinct change in Nd isotope model ages with a dominance of <3 Ga ages to the east and >3 Ga to the west. Imaged in BMR91-EGF1 and 11GA-YU2, and includes the Ida Fault, Ballard Fault, Kunanalling Shear Zone and Waroonga Shear Zone	Goleby et al. (1993) Zibra et al. (2014b)	Geology	Surface
Youanmi_internal	A transcrustal reverse fault that traverses the Youanmi Terrane; imaged in 11GA-YU2 and includes the Youanmi Shear Zone	Zibra et al. (2014b)	Geology	Surface

Table 2. Layered boundaries and seismic province boundaries

Object	*Comment*	*Reference*	*Feature category*	*Spatial type*
Layered_boundaries				
Basins_base	The base of all basins from the Proterozoic and younger. The depth is estimated from the SEEBASE2020_WA_contours where present, magnetotelluric and seismic profiles. The surface extent follows the extent of the basins defined within the 1:500 000 tectonic units of Western Australia digital layer. Basins include: Amadeus, Arid, Ashburton, Badgeradda, Barren, Bastion, Bight, Birrindudu, Bresnahan, Bryah, Canning, Carr Boyd, Collier, Earaheedy, Edmund, Kimberley, Louisa, Moora, Murraba, Northern Carnarvon, Officer, Ord, Osmond, Perth, Ragged, Red Rock, Roebuck, Salvation, Scorpion, Bonaparte, Southern Carnarvon, Tanami, Texas Downs, Victoria, Wolfe, Yandanooka, Yeneena and Yerrida	Geognostics Australia Pty Ltd (2020) GSWA (2017)	Topography	Surface
Bathymetry_topography	Bathymetry and topography smoothed to 10 km grid size		Geology	Surface
Fortescue_Hamersley_Basin_base	Base of the Fortescue, Hamersley and Turee Creek Basins; imaged in 10GA-CP1 and 2 and in 18GA-KB1	Doublier et al. (2020a,b) Johnson et al. (2011) Thorne et al. (2011)	Geology	Surface
Burringurrah_Domain_base	The base of the granite batholiths and metasediments of the Gascoyne Province, which lie above the Glenburgh Terrane and pre-date the base of the Edmund Basin; imaged in 10GA-CP2	Ivanic et al. (2013) Johnson et al. (2011) Romano et al. (2014)	Geology	Surface
Moho_WA_2021	Constructed from measurements from receiver function studies of passive seismic stations, picks from all seismic reflection and refraction surveys, picks from magnetotelluric profiles in the Kimberley and AuSREM_Moho 2012 for areas where there is none of the previously mentioned data	Dentith et al. (2018) Reading et al. (2003, 2012) Reading and Kennett (2003) Salmon et al. (2012) Sippl et al. (2018)	Geology	Surface
Seismic_Provinces				
Babool_SP	Top surface of the part of the EGS SP that underlies the Yamarna Terrane; imaged on 01GA-NY1, 11GA-YO1 and 12GA-T1	Goleby et al. (2003) Korsch et al. (2013) Occhipinti et al. (2015)	Geology	Surface
Bandee_lower_SP	Top surface of the lower part of the Bandee SP of the Pilbara Craton; imaged in 10GA_CP1 and 2	Johnson et al. (2011) Thorne et al. (2011)	Geology	Surface
Carlathunda_Ripon_Hills_SP	Top surface of the lower crust of the East Pilbara Terrane; imaged on 10GA-CP1 and in 18GA-KB1	Doublier et al. (2020a,b) Thorne et al. (2011)		
EGS_lower_crust	Top surface of the un-named parts of the lower crust of the EGS under the Kalgoorlie and Burtville Terranes. These lower regions have not been imaged in seismic lines, but inferred to be there as most other Archean cratons are underlain by seismic provinces	Goleby et al. (1993)	Geology	Surface
Forrest_Lakes_SP	Top surface of the SP that underlies the Coompana Province and overlies the Old Homestead SP; imaged in 14GA-EG1	Dutch et al. (2015) Spaggiari et al. (2017)	Geology	Surface
Gunnadorrah_SP	Top surface of the SP that underlies the Albany–Fraser Orogen and the Madura Province; imaged in 11GA-AF1 to 3, 11GA-T1 and 14GA-EG1	Dutch et al. (2015) Spaggiari et al. (2015b, 2017)	Geology	Surface
Kimberley_lower_crust	The base of the highly resistive zone; imaged in the Kimberley MT profiles	Spratt et al. (2014)	Geology	Surface
Kiwirrkurra_SP	Top surface of the SP that underlies the Aileron and Waumpi Provinces; imaged in 18GA-KB1	Doublier et al. (2020a,b)	Geology	Surface
MacAdam_SP	Top surface of the SP that underlies the Glenburgh Terrane; imaged in 10GA-CP2 and 3	Johnson et al. (2011)	Geology	Surface
Old_Homestead_SP	Top surface of the SP that underlies the Forrest Lakes SP; imaged in 14GA-EG1	Spaggiari et al. (2017)	Geology	Surface
Pilbara_lower_crust	Top surface of the lower crust that is assumed to underlie the terranes of the Pilbara Craton other than the Carlathunda-Ripon Hills SP		Geology	Surface
Punmu_lower_SP	Top surface of the SP that underlies the Punmu upper SP; imaged in 18GA-KB1	Doublier et al. (2020a,b)	Geology	Surface
Rudall_lower_crust	Lower crust to the Rudall Province; not imaged, but assumed to be present			
South_West_lower_crust	Underlies the South West Terrane; imaged with poor spatial resolution in refraction line 83BMR-AOB	Dentith et al. (2000)	Geology	Surface
Tikelmungulda_SP	Top surface of the SP that underlies the Musgrave Province; imaged in 12GA-YO1	Howard et al. (2013) Korsch et al. (2013)	Geology	Surface
Udarra_SP	Top surface of the part of the EGS SP that underlies the Kurnalpi Terrane; imaged in 11GA-AF2	Spaggiari et al. (2015b)	Geology	Surface
Yarraquin_SP	Top surface of the SP that underlies the Youanmi Terrane; imaged in 11GA-YU1 to 3 and 11GA-AF2	Romano et al. (2014) Zibra et al. (2014a,b)	Geology	Surface
Youanmi_lower_crust	Top surface of the lower crust of the Youanmi Terrane.	Romano et al. (2014) Zibra et al. (2014a,b)	Geology	Surface

Table 3. Crustal blocks

These can be viewed either by 'Parent_name', which applies a grouping depending on the craton/province/orogen that the unit belongs to, or by 'Rock unit', which is the unit name within the craton/province/orogen. Some names are shortened so that two objects in the project do not have the same name

Parent_name	*Comment*	*Reference*	*Feature category*	*Spatial type*
Volumes_Albany_Fraser_Orogen	Comprises the Northern Foreland and the Kepa Kurl Booya Province. The Gunnadorrah SP is included as the lower crust to these units		Geology	Surface
Volumes_Basins	Comprises the Basins cover and the Fortescue and Hamersley Basins		Geology	Surface
Volumes_Coompana_Province	Comprises the Coompana Province and the underlying Forrest Lakes SP and Old Homestead SP		Geology	Surface
Volumes_Madura_Province	Comprises the Madura Province		Geology	Surface
Volumes_Musgrave_Province	Contains the Musgrave Province and the underlying Tikelmungulda SP		Geology	Surface
Volumes_NAC_Aileron_Province	The Aileron Province and the underlying Kiwirrkurra SP		Geology	Surface
Volumes_NAC_Warumpi_Province	The southern margin of the North Australian Craton, which is also underlain by the Kiwirrkurra SP			
Volumes_NAC_Granites_Tanami_Orogen	Comprises the Granites–Tanami Orogen		Geology	Surface
Volumes_NAC_Kimberley_Craton	Comprises the Lamboo Province, Kimberley Basement and lower crust and an undefined part that underlies the Canning Basin north of the Fenton Fault		Geology	Surface
Volumes_Pinjarra_Orogen	Comprises the Pinjarra Orogen and the Leeuwin Inlier		Geology	Surface
Volumes_Punmu_Seismic_Province	The basement and lower crust that underlies the Canning Basin. It is unknown if it has Pilbara or Kimberley affinity or has originated from somewhere different		Geology	Surface
Volumes_WAC_Gascoyne_Province	Comprises the Burringurrah Domain, Glenburgh Terrane and the MacAdam SP		Geology	Surface
Volumes_WAC_Paterson_Orogen	The Rudall Province is a parautochthonous part of the Paterson Orogen. It is a Paleo- to Mesoproterozoic orogen between the West Australian Craton and North Australian Craton. Zircons sampled in the province share similar isotopic and age characteristics with that of the Pilbara Craton and the Capricorn Orogen of the West Australian Craton.	Bagas (2004) Tucker et al. (2018)	Geology	Surface
Volumes_WAC_Pilbara_Craton	Comprises the Kurrana, West and East Pilbara Terranes, the CPTZ and the Sylvania Inlier of the main Pilbara Craton and the upper Bandee SP, which is the extended southern margin of the Pilbara Craton. At lower crustal levels it includes the Carlathunda – Ripon Hills SP, Pilbara lower crust, Warrawagine SP, lower Bandee SP and the Rudall lower crust. On the surface it includes the Fortescue and Hamersley Basins		Geology	Surface
Volumes_WAC_Yilgarn_Craton	Comprises the Yilgarn Craton, which is divided into four recognized terranes distinguished by their crustal ages from Nd isotope data and zircon inheritance patterns, greenstone ages and composition and their prospectivity for various minerals. The oldest include the South West and Narryer Terranes, with the younger Youanmi Terrane and the EGS, further subdivided into four terranes (Kalgoorlie, Kurnalpi, Burtville and Yamarna). In addition it also includes the Marymia Inlier and the Yarlarweelor Gneiss Complex. At the lower levels, the EGS is underlain by the Udarra and Babool SPs and presumably similar seismic provinces also underlie the Kalgoorlie and Burtville Terranes. The Youanmi Terrane is underlain by the Yarraquin SP and a distinctive lower crust. The South West Terrane is underlain by a lower crustal layer.	Barley et al. (2003) Cassidy and Champion (2004)	Geology	Surface

Table 4. Volumes (of lithology)

Object	Comment	Reference	Feature category	Spatial type
Aileron_Province_volume	Part of the Arunta Orogen formed before 1700 Ma consisting of metasedimentary successions; imaged at the far eastern end of 18GA-KB1	Scrimgeour (2003)	Geology	Surface
Babool_SP_volume	The lower crust of the Yamarna Terrane of the EGS. The lower crustal component of the EGS has been divided into terranes in a similar manner to the upper crustal component, using the same bounding structures. Imaged in 01GA-NY1, 11GA-YO1 and 12GA-T1	Goleby et al. (2003) Korsch et al. (2013)	Geology	Surface
Bandee_lower_SP_volume	The lower crustal portion of the Bandee SP, imaged in 10GA-CP1 and 2 and identified by its different seismic characteristics from the Bandee upper SP	Johnson et al. (2011) Thorne et al. (2011)	Geology	Surface
Bandee_upper_SP_volume	The upper crustal portion of the Bandee SP, which is overlain by the Archean–Proterozoic Fortescue and Hamersley Basins and the Proterozoic Ashburton Basin. It is seismically different from the Carlathunda SP as shown in 10GA-CP1 and 2. There is no geophysical justification to put a break between the western lobe, which is imaged in 10GA-CP2, and the eastern lobe, which is not imaged. Hence it appears as a large terrane with the eastern lobe lying entirely under Proterozoic and younger basins.	Johnson et al. (2011) Thorne et al. (2011)	Geology	Surface
Basins_volume	The volume containing all basins from the Proterozoic and younger. The depth is estimated from the SEEBASE2020_WA_contours, where present, and MT and seismic profiles. The surface extent follows the extent of the basins defined within the 1:500 000 tectonic units of Western Australia digital layer. Basins include: Amadeus, Arid, Ashburton, Badgeradda, Barren, Bastion, Bight, Birridudu, Bresnahan, Bryah, Canning, Carr Boyd, Collier, Erraheedy, Edmund, Kimberley, Louisa, Moora, Murraba, Northern Carnarvon, Officer, Ord, Osmond, Perth, Ragged, Red Rock, Roebuck Plains, Salvation, Scorpion, Bonaparte, Southern Carnarvon, Tanami, Texas Downs, Victoria, Wolfe, Yandanooka, Yeneena and Yerrida	Geognostics Australia Pty Ltd (2020) GSWA (2017)	Geology	Surface
Burtville_Terrane_volume	A 2.95 – 2.73 Ga granite–greenstone terrane included in the EGS that shares inherited zircon patterns with the Kurnalpi Terrane; imaged on 01GA-NY1	Cassidy et al. (2006) Goleby et al. (2003)	Geology	Surface
Carlathunda_Ripon_Hills_SP_volume	Imaged on 10GA-CP1 as the Carlathunda_SP and 18GA-KB1as the Ripon Hills SP yet in this model, the seismic lines image the same block of the Pilbara, the East Pilbara Terrane	Doublier et al. (2020a,b) Thorne et al. (2011)	Geology	Surface
Central_Pilbara_Tectonic_Zone_volume	A northeasterly trending structural corridor separating the West Pilbara Superterrane and East Pilbara Terrane, now largely covered by the Malina Basin	Hickman and Van Kranendonk (2012)	Geology	Surface
Coompana_Province_volume	The region between the Mundrabilla Shear Zone and the Gawler Craton in South Australia. It is of oceanic to oceanic-arc origin and is now overlain by the Bight and Eucla Basins; imaged in 13GA-EG1	Flint and Daly (1993) Myers et al. (1996) Spaggiari et al. (2020)	Geology	Surface
East_Pilbara_Terrane_volume	A Paleoarchean terrane of the Pilbara Craton showing typical granite–greenstone features with granitic dome-like complexes flanked by curvilinear greenstone belts	Hickman and Van Kranendonk (2012)	Geology	Surface
EGS_lower_crust_volume	The lower crust of the Burtville and Kalgoorlie Terranes of the EGS; not imaged but assumed to be present		Geology	Surface
Forrest_Lakes_SP_volume	The SP that underlies the Coompana Province; imaged in 13GA-EG1	Dutch et al. (2015) Spaggiari et al. (2017)	Geology	Surface
Fortescue_Hamersley_Basins_volume	The Archean–Proterozoic rift basin to passive margin that covers the southern margin of the Pilbara Craton and underlies the Proterozoic Basins of the Capricorn Orogen. Imaged on 97AGS-HB1 to 3, 97AGS-SD1 and 10GA-CP1 and 2, and includes the Fortescue, Hamersley and Turee Creek Basins	Blake and Barley (1992) Johnson et al. (2011) Thorne et al. (2011)	Geology	Surface
Burringurrah_Domain_volume	Includes a range of Neoarchean to Paleoproterozoic gneisses and granites that record the amalgamation of the Archean Pilbara and Yilgarn Cratons to form the West Australian Craton, and over one billion years of subsequent intracontinental crustal reworking. Is prior to the Edmund Basin		Geology	Surface
Glenburgh_Terrane_volume	The Archean terrane between the Pilbara and Yilgarn Cratons. There are no geophysical anomalies that indicate that there is a boundary between the western and eastern lobes of the Glenburgh Terrane. The eastern lobe is completely covered by basins so until there is evidence to suggest otherwise, it is classified as Glenburgh Terrane. Imaged on 10GA-CP2 and 3 and in this model the eastern toe is seen on 11GA-YO1	Johnson et al. (2011)	Geology	Surface
Granites_Tanami_Orogen_volume	An assemblage of Archean to Mesoproterozoic orogens and basins that form the basement to much of northern Australia. The upper crust is seismically distinct and separated from the middle–lower crust by a decollement zone; however, there is no SP assigned to this area so the full thickness of crust is assigned one volume. Imaged in 05GA-T1 and 2	Betts and Giles (2006) Goleby et al. (2009) Huston et al. (2012) Myers et al. (1996)	Geology	Surface
Gunnadorrah_SP_volume	The lower crust of the Albany–Fraser Orogen and Madura Province, which descends into and offsets the Moho; imaged in 12GA-AF1 to 3, 11GA-T1 and 13GA-EG1	Dutch et al. (2015) Spaggiari et al. (2015b, 2017)	Geology	Surface
Kalgoorlie_Terrane_volume	A 2.76 – 2.73 Ga granite–greenstone terrane included in the EGS that shares inherited zircon patterns with the Youanmi Terrane. Imaged in BMR91-EGF1, 99AGS-Y1 to 5 and 01GA-NY1	Cassidy et al. (2006) Goleby and Drummond (2000) Goleby et al. (1993, 2000, 2003) Swager et al. (1997)	Geology	Surface
Kepa_Kurl_Booya_Province_volume	The upper crust of the Albany–Fraser Orogen; imaged in 12GA-AF1 to 3 and 11GA-T1	Occhipiniti et al. (2015) Spaggiari et al. (2015b)	Geology	Surface
Kimberley_basement_volume	The upper crust that underlies the Kimberley Basin, which is approximately 5 km thick and is included in the Basins_cover_volume. The basement in the Kimberley is either Archean, as determined by isotopic data and seismic tomography or Paleoproterozoic as suggested by detrital zircons; imaged in Kimberley MT	Griffin et al. (2000) Saygin and Kennett (2012) Spratt et al. (2014) Tyler et al. (1999)	Geology	Surface
Kimberley_lower_crust_volume	The region between the highly resistive upper crust and the electrical Moho as imaged in the Kimberley MT profiles. It is not present in the eastern Kimberley where steep crustal-scale features are present	Spratt et al. (2014)	Geology	Surface
Kimberley_undefined_volume	A volume of rock north of the Fenton Fault, but south of the Lamboo Province that has been assigned to the Kimberley Craton due to similarities in its seismic character as seen from passive seismic studies	Zhao et al. (2022)	Geology	Surface
Kiwirrkurra_SP_volume	The lower crust underlying the Aileron and Warumpi Provinces; imaged at the far east of 18GA-KB1	Doublier et al. (2020a,b)	Geology	Surface
Kurnalpi_Terrane_volume	A 2.95 – 2.73 Ga granite–greenstone terrane included in the EGS; imaged in BMR91-EGF1 and 01GA-NY1	Cassidy and Champion (2004) Goleby and Drummond (2000) Goleby et al. (1993, 2000, 2003) Swager et al. (1997)	Geology	Surface

Table 4. continued

Object	Comment	Reference	Feature category	Spatial type
Kurrana_Terrane_volume	A Paleoarchean terrane of the Pilbara Craton postulated to be a rift fragment of the East Pilbara Terrane	Hickman and Van Kranendonk (2012)	Geology	Surface
Lamboo_Province_volume	Paleoproterozoic meta-igneous and metasedimentary rocks. Includes the northwest-trending Wunaamin Miliwundi Orogen and the northeast-trending Halls Creek Orogen, which records the collision of the Kimberley Craton with the North Australian Craton during the 1832–1808 Ma Halls Creek Orogeny	Griffin and Grey (1990) Thom (1975) Tyler and Griffin (1990) Tyler et al. (1998)	Geology	Surface
Leeuwin_Inlier_volume	An inlier on the west of the Pinjarra Orogen that was created during the Neoproterozoic–Cambrian Pan-African event on the western edge of a mobile belt. It is younger than the rest of the terranes of the Pinjarra Orogen	Wilde and Murphy (1990)	Geology	Surface
MacAdam_SP_volume	The lower crust of the Glenburgh Terrane; imaged on 10GA-CP2 and 3	Johnson et al. (2011)	Geology	Surface
Madura_Province_volume	The upper crust that lies between the eastern margin of the Albany–Fraser Orogen and the Mundrabilla Shear Zone, formed during the Albany–Fraser Orogen Stage I but is now overlain by the Bight and Eucla Basins. It is thought to be of oceanic affinity and includes the Loongana oceanic arc.	Spaggiari et al. (2015a,b)	Geology	Surface
Marymia_Inlier_volume	Part of the Yilgarn Craton whose connection to the rest of the craton is uncertain since it appears as an inlier within Proterozoic basins. Its tectonic history, rock types and timing of mineralization have similarities to the Narryer Terrane, the Youanmi Terrane and the northwards extension of the Eastern Goldfield Superterrane.	Bagas (1998)	Geology	Surface
Musgrave_Province_volume	Upper crust of the Musgrave Province; imaged on 11GA-YO1	Howard et al. (2013) Korsch et al. (2013)	Geology	Surface
Narryer_Terrane_volume	An older slice of the Yilgarn Craton that appears to have been thrust up over the Youanmi Terrane. A 3.73 – 2.6 Ga high-grade gneissic terrane hosting metasedimentary rocks that contain the oldest zircons in the world; imaged in 11GA-YU1 and 10GA-CP3	Johnson et al. (2011) Myers (1988) Romano et al. (2014)	Geology	Surface
Northern_Foreland_volume	Reworked southern margin of the Yilgarn Craton that now forms the western edge of the Albany–Fraser Orogen; imaged in 12GA-AF1 to 3	Spaggiari et al. (2015b)	Geology	Surface
Old_Homestead_SP_volume	A lower crustal seismic province, which is imaged east of the Mundrabilla Shear Zone on 14GA-EG1	Spaggiari et al. (2017)	Geology	Surface
Pilbara_lower_crust	The lower crust that is assumed to lie below all the Pilbara Terranes excluding the Carlathunda – Ripon Hills SP		Geology	Surface
Pinjarra_Orogen_volume	All basement rocks to the west of the West Australian Craton; imaged in 11GA-SC1 and NN92-01	Korsch et al. (2014) Middleton et al. (1995)	Geology	Surface
Punmu_lower_SP_volume	The lower crust underlying the Canning Basin; imaged in 18GA-KB1	Doublier et al. (2020a,b)	Geology	Surface
Punmu_upper_SP_volume	The upper crust underlying the Canning Basin; imaged in 18GA-KB1	Doublier et al. (2020a,b)	Geology	Surface
Rudall_lower_crust_volume	The lower crust lying underneath the Rudall Province of unknown origin		Geology	Surface
Rudall_Province_volume	Rudall Province is a parautochthonous part of the Paterson Orogen. It is a Paleo- to Mesoproterozoic orogen between the West Australian Craton and North Australian Craton; imaged in 18GA-KB1	Bagas (2004) Doublier et al. (2020a,b) Tucker et al. (2018)	Geology	Surface
South_West_lower crust_volume	Seismic refraction studies indicate that there is a lower crustal layer under the South West Terrane although it has not previously been named; imaged on refraction lines 83BMR-AOB	Dentith et al. (2000)	Geology	Surface
South_West_Terrane_volume	The 3.2 – 2.6 Ga South West Terrane of the Yilgarn Craton is dominated by granites and high-grade gneisses that have experienced multiple phases of granite intrusion between c. 2.75 and 2.63 Ga; thought to have accreted to the Younami Terrane after 2.8 Ga	Lu et al. (2021) Tyler and Hocking (2001) Wilde et al. (1996)	Geology	Surface
Sylvania_Inlier_volume	Identified as terrane of the Pilbara Craton by similarities in the greenstone belts to those in the Pilbara terranes; accreted to the craton between 3.0 and 2.76 Ga	Tyler (1991)	Geology	Surface
Tikelmungulda_SP_volume	The lower crust of the Musgrave Province; imaged on 12GA-YO1	Howard et al. (2013) Korsch et al. (2013)	Geology	Surface
Udarra_SP_volume	The lower crust of the Kurnalpi Terrane; imaged on 11GA-AF2	Spaggiari et al. (2015b)	Geology	Surface
Warrawagine_SP_volume	The extended eastern Pilbara crust, which underlies the Fortescue and Hamersley Basins on the eastern margin of the Pilbara Craton; imaged in 18GA-KB1	Doublier et al. (2020a,b)	Geology	Surface
Warumpi_Province_volume	Late Paleoproterozoic province that shows voluminous granitic magmatism, crustal thickening and high-pressure metamorphism during southward subduction and accretion along the southern margin of the Aileron Province	Scrimgeour et al. (2005) Wade et al. (2006)	Geology	Surface
West_Pilbara_Superterrane_volume	The three terranes of the West Pilbara Superterrane that now form a slice on the northwest margin of the Pilbara Craton; includes the Karratha Terrane, a rifted portion of the East Pilbara Terrane, the Regal Terrane, a slice of obducted oceanic crust and the Sholl Terrane, a piece of subduction zone and intra-oceanic arc	Hickman and Van Kranendonk (2012)	Geology	Surface
Yamarna_Terrane_volume	One of the terranes included in the EGS; imaged in 01GA-NY1 and 11GA-T1	Goleby et al. (2003) Lindsay et al. (2019)	Geology	Surface
Yarlarweelor_Gneiss_Complex_volume	Gneissic rock of the Narryer Terrane that forms part of the suture between the Yilgarn Craton and the Glenburgh Terrane; imaged in 10GA-CP3	Johnson et al. (2011)	Geology	Surface
Yarraquin_SP_volume	The middle crust underlying the Youanmi Terrane of the Yilgarn Craton; imaged in 10GA-YU1 to 3	Romano et al. (2014) Zibra et al. (2014a,b)	Geology	Surface
Youanmi_lower_crust_volume	The lower crust seen under the Yarraquin SP. It may continue under the EGS as suggested in 10GA-YU2 but was not positively identified in 01AGS-NY1 so limited here to lying under the Youanmi Terrane	Romano et al. (2014) Zibra et al. (2014a,b)	Geology	Surface
Youanmi_Terrane_volume	The 3.01 – 2.63 Ga Youanmi Terrane of the Yilgarn Craton containing granites and greenstones in a curvilinear structural configuration; imaged on 11GA-YU1 to 3	Cassidy et al. (2006) Romano et al. (2014) Zibra et al. (2014a,b)	Geology	Surface

Table 5. Geophysicsimages

Object	Comment	Reference	Feature category	Spatial type
Bouguer_anomaly	Bouguer anomaly grid at 400 m cell size in gravity units	GSWA (2020a)	Geophysics	Raster
Magnetics_RTP	Reduced to pole magnetic anomaly grid at 80 m cell size		Geophysics	Raster
Magnetics_TMI	Total magnetic intensity grid at 80 m cell size	GSWA (2020b)	Geophysics	Raster
Magnetics_TMI_1vd	First vertical derivative of total magnetic intensity grid at 80 m cell size		Geophysics	Raster

Table 6. Magnetotelluricimages

Object	Comment	Reference	Feature category	Spatial type
MT_Kimberley_C_E_image MT_Kimberley_central_image MT_Kimberley_east_image MT_Kimberley_north_image MT_Kimberley_west_image	Images extracted from MT models from the Kimberley MT campaign conducted by The University of Western Australia, GSWA and funded by the Kimberley Science and Conservation Strategy	Spratt et al. (2014)	Geophysics	Raster

Table 7. Seismic images and seismic surfaces

Each seismic line consists of a planar image draped onto a surface that follows the profile of the common depth point gathers. Due to errors in cartography and draping, the image may be slightly offset from the surface and subsurface features. For more exact information, the SEGY data can often be obtained from GA

Object	Comment	Reference	Feature category	Spatial type
01AGS_NY1_surface 01AGS_NY2_surface 01AGS_NY3_surface 01AGS_NY4_surface 01AGS_NY1_revision_surface	Northeastern Yilgarn deep seismic reflection survey conducted by GA in conjunction with GSWA with a later interpretation by Lindsay et al. (2019)	Goleby et al. (2003) Lindsay et al. (2019)	Geophysics	Raster
05GA_T1_surface 05GA_T2_surface	Tanami deep seismic reflection survey conducted by GA in conjunction with GSWA and the Northern Territory Geological Survey	Goleby et al. (2009)	Geophysics	Raster
10GA_CP1N_surface 10GA_CP1S_surface 10GA_CP2_surface 10GA_CP3_surface	Capricorn deep seismic reflection survey conducted by GA in conjunction with GSWA and AuScope	Johnson et al. (2012)	Geophysics	Raster
10GA_YU1_surface 10GA_YU2_surface 10GA_YU3_surface	Youanmi deep seismic reflection survey conducted by GA in conjunction with GSWA	Wyche et al. (2014)	Geophysics	Raster
11GA_SC1_surface	Southern Carnarvon deep seismic reflection survey conducted by GA in conjunction with GSWA	Wyche et al. (2014)	Geophysics	Raster
11GA_YO1_surface 11GA_YO1_revision_surface	Yilgarn Craton – Officer Basin – Musgrave Province deep seismic reflection survey conducted by GA in conjunction with GSWA with a later interpretation by Quentin de Gromard et al. (2017)	Neumann (2013) Quentin de Gromard et al. (2017)	Geophysics	Raster
12GA_AF1_surface 12GA_AF2_surface 12GA_AF3_surface 12GA_T1_surface	Albany–Fraser Orogen and Tropicana deep seismic reflection survey conducted by GA in conjunction with GSWA and Tropicana Joint Venture comprising of AngloGold Ashanti Australia Ltd and Independence Group NL	Spaggiari and Tyler (2015)	Geophysics	Raster
13GA_EG1_surface	Eucla–Gawler deep seismic reflection survey conducted by GA in conjunction with GSWA, the Geological Survey of South Australia and AuScope	Dutch et al. (2015) Spaggiari et al. (2017)	Geophysics	Raster
14GA_CC1_surface 14GA_CC2_surface	Canning Coastal deep seismic reflection survey conducted by GA in conjunction with GSWA	Zhan (2017)	Geophysics	Raster
18GA_KB1_surface	Kidson Basin deep seismic reflection survey conducted by GA in conjunction with GSWA	Doublier et al. (2020a,b)	Geophysics	Raster
19CWAS_AN_surface 19CWAS_CCP_surface	Ambient noise (AN) and common conversion point (CCP) images from the China – Western Australia (CWAS) passive seismic campaign conducted by the Chinese Academy of Sciences and GSWA	Zhao et al. written comm.	Geophysics	Raster
83BMR_AOB_refraction_image 83BMR_XOY_refraction_image	Southwest Yilgarn seismic refraction surveys conducted by Australian Geological Survey Organization	Dentith et al. (2000)	Geophysics	Raster
91BMR_EGF1_surface 91BMR_EGF2_surface 91BMR_EGF3_surface	Eastern Goldfields deep seismic reflection survey conducted by Australian Geological Survey Organization	Goleby et al. (2003)	Geophysics	Raster
97AGS_HB1_surface 97AGS_HB2_surface 97AGS_HB3_surface 97AGS_SD1_surface	Hamersley Province seismic reflection conducted by Australian Geological Survey Organization	Cawood and Hollingsworth (2002)	Geophysics	Raster
99AGS_Y1_surface 99AGS_Y2_surface 99AGS_Y3_surface 99AGS_Y4_surface 99AGS_Y5_surface	Yilgarn deep seismic reflection survey over the Eastern Goldfields conducted by the Australian Geodynamics Cooperative Research Centre	Goleby et al. (2000)	Geophysics	Raster
GA280_19_refraction_image	Offshore and onshore seismic refraction survey, line 19 of survey GA280	Tassell and Goncharov (2006)	Geophysics	Raster
NN92_01_surface	New Norcia deep seismic reflection survey	Middleton et al. (1993)	Geophysics	Raster

Table 8. Other objects

Object	*Comment*	*Reference*	*Feature category*	*Spatial type*
Faults				
Border_WA	A surround to the model just off the coastline			Surface
Curves				
Coastline	Coastline of Western Australia		Coastline	Polyline
Major_crustal_boundaries_curve	The ArcGIS shapefile of the 1:2 500 000 Major crustal boundaries of Western Australia on which this model was built	Martin et al. (2021)	Geology	Polyline
SEEBASE2020_WA_contours	Contours to basement from the SEEBASE2020 WA model used in generating the Basins layer	Geognostics Australia Pty Ltd (2020)	Geology	Polyline
Tectonic_units	Tectonic units shapefile from the GSWA digital layer at 1:500 000 scale	GSWA (2017)	Geology	Polyline
Worms_gravity	Multi-edge detection levels from the Bouguer gravity anomaly with continuation heights from 2500 m to 124 000 m with amplitude scaling	Brett (2020)	Geology	Polyline
Points				
AuSREM_Moho_2012	The Australian Seismological Reference Model (AuSREM) is a grid at resolution of 0.5 degrees from a wide range of seismological studies. Points close to other listed Moho points have been removed	Salmon et al. (2012)	Geology	Point
Moho_Hk_points	Depth to Moho from receiver function studies from the SKIPPY, CWAS, COPA, ALFREX and Western Australian temporary arrays and Western Australian permanent stations	Dentith et al. (2018) Reading et al. (2003, 2012) Reading and Kennett (2003) Sippl et al. (2018)	Geology	Point
Moho_MT_picks	Picks of the Moho from the MT surveys in the Kimberley		Geology	Point
Moho_reflection_picks	Picks from the seismic reflection lines. Lines shot before 2012 will have been included in the AuSREM model		Geology	Point
Moho_refraction_picks	Picks from the refraction lines. These have been widely spaced to reflect the lower weighting placed on these points		Geology	Point
Nd_points	Neodymium isotope ages of TRC_Ma (crustal residence time in millions of years) and TDM2_Ma (two-stage depleted mantle model age in millions of years, assuming 147Sm/144Nd value of 0.11)		Geology	Point

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RECORD 2022/7

COMPILATION AND GEOLOGICAL IMPLICATIONS OF THE MAJOR CRUSTAL BOUNDARIES MAP AND 3D MODEL OF WESTERN AUSTRALIA

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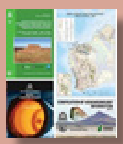

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