Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

RECORD 2017/15

SGTSG MID-CONFERENCE FIELD TRIP GUIDE: THE WESTERN NORNALUP ZONE, ALBANY–FRASER OROGEN, WESTERN AUSTRALIA

by
NE Timms

Geological Survey of Western Australia

Curtin University

Government of **Western Australia**
Department of **Mines, Industry Regulation and Safety**

Record 2017/15

SGTSG MID-CONFERENCE FIELD TRIP GUIDE: THE WESTERN NORNALUP ZONE, ALBANY–FRASER OROGEN, WESTERN AUSTRALIA

by
NE Timms

Perth 2017

Geological Survey of Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon Bill Johnston MLA

DIRECTOR GENERAL, DEPARTMENT OF MINES, INDUSTRY REGULATION AND SAFETY
David Smith

EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Rick Rogerson

REFERENCE
The recommended reference for this publication is:
Timms, NE 2017, SGTSG Mid-conference Field Trip Guide: The Western Nornalup Zone, Albany–Fraser Orogen, Western Australia: Geological Survey of Western Australia, Record 2017/15, 20p.

National Library of Australia Card Number and ISBN 978-1-74168-780-4

Grid references in this publication refer to the Geocentric Datum of Australia 1994 (GDA94). Locations mentioned in the text are referenced using Map Grid Australia (MGA) coordinates, Zone 50. All locations are quoted to at least the nearest 100 m.

About this publication
This Record is a field guide prepared for the mid-conference field trip for the Structural Geology and Tectonics Specialist Group (SGTSG) of the Geological Society of Australia conference in Denmark, 2017. GSWA is releasing the information as part of its Record Series to ensure a wider distribution of the results. Curtin University and CSIRO are responsible for the scientific content of the Record and the drafting of figures. No editing has been undertaken by GSWA.

Published 2017 by Geological Survey of Western Australia
This Record is published in digital format (PDF) — it and the digital appendix are available online at <www.dmp.wa.gov.au/GSWApublications>.

Further details of geological products and maps produced by the Geological Survey of Western Australia are available from:
Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Telephone: +61 8 9222 3459   Facsimile: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications

Cover image: Elongate salt lake on the Yilgarn Craton — part of the Moore–Monger paleovalley — here viewed from the top of Wownaminya Hill, 20 km southeast of Yalgoo, Murchison Goldfields. Photograph taken by I Zibra for the Geological Survey of Western Australia

SGTSG Denmark 2017

Biennial Meeting of the Specialist Group in Tectonics and Structural Geology, Geological Society of Australia

Denmark Riverside Club, Denmark, WA

8-12 November 2017

Mid-conference Field Trip Guide: The Western Nornalup Zone, Albany-Fraser Orogen, Western Australia

Thursday 9th November, 2017

Nicholas E. Timms[1]

email n.timms@curtin.edu.au

With contributions from Katy Evans[1], Paul Wilkes[2], Tim Johnson[1], Milo Barham[1], Steve Reddy[1], and Peter Collins[1].

[1] Curtin University, Perth, GPO Box U1987, Western Australia

[2] CSIRO, Perth, Western Australia

Table of Contents

Wave at Lowlands Beach (image = Steve Reddy)

Curtin University | THE UNIVERSITY OF WESTERN AUSTRALIA | Geological Survey of Western Australia | CSIRO | PESA Petroleum Exploration Society of Australia | Denmark Riverside Club Inc. | IUGS TecTask | Great Southern Science Council | Geo conferences (WA) Inc. | PERTH CONVENTION BUREAU | Geological Society of Australia

Welcome to southwest Western Australia

The objective of this field trip is to bring the delegates of SGTSG Denmark 2017 together in the field and take a glimpse of the spectacular geology within reach of the conference venue. We will focus on rocks of the Nornalup Zone of the Albany-Fraser Orogen, which are exposed on numerous coastal sections in the region. This field guide has been assembled to provide some background on the local geology, give a few details about key localities, and highlight some points for discussion. We aim to visit three localities during the trip, time permitting. However, the conference organizers know many more fantastic outcrops in the area – just ask for advice if you are considering taking yourself on a self-guided trip throughout the week.

On behalf of the SGTSG 2017 Committee, welcome to southwest Western Australia! We hope that you enjoy yourselves. *Nick Timms*

Introduction to the geology of southwest Western Australia

The following review attempts to reflect current state of understanding of the geology of southwest Western Australia, incorporating contemporary nomenclature and the most recent available data. A thorough review on the historical development of ideas is not offered to keep this document succinct. Readers are directed elsewhere for detailed reviews, e.g., Fitzsimons and Buchan (2005); Spaggiari et al. (2009); Spaggiari et al. (2011); Mole et al. (2012); Spaggiari et al. (2014). Research in the area is ongoing, and a variety of new data are currently being acquired. Some ideas summarized here may be subject to change!

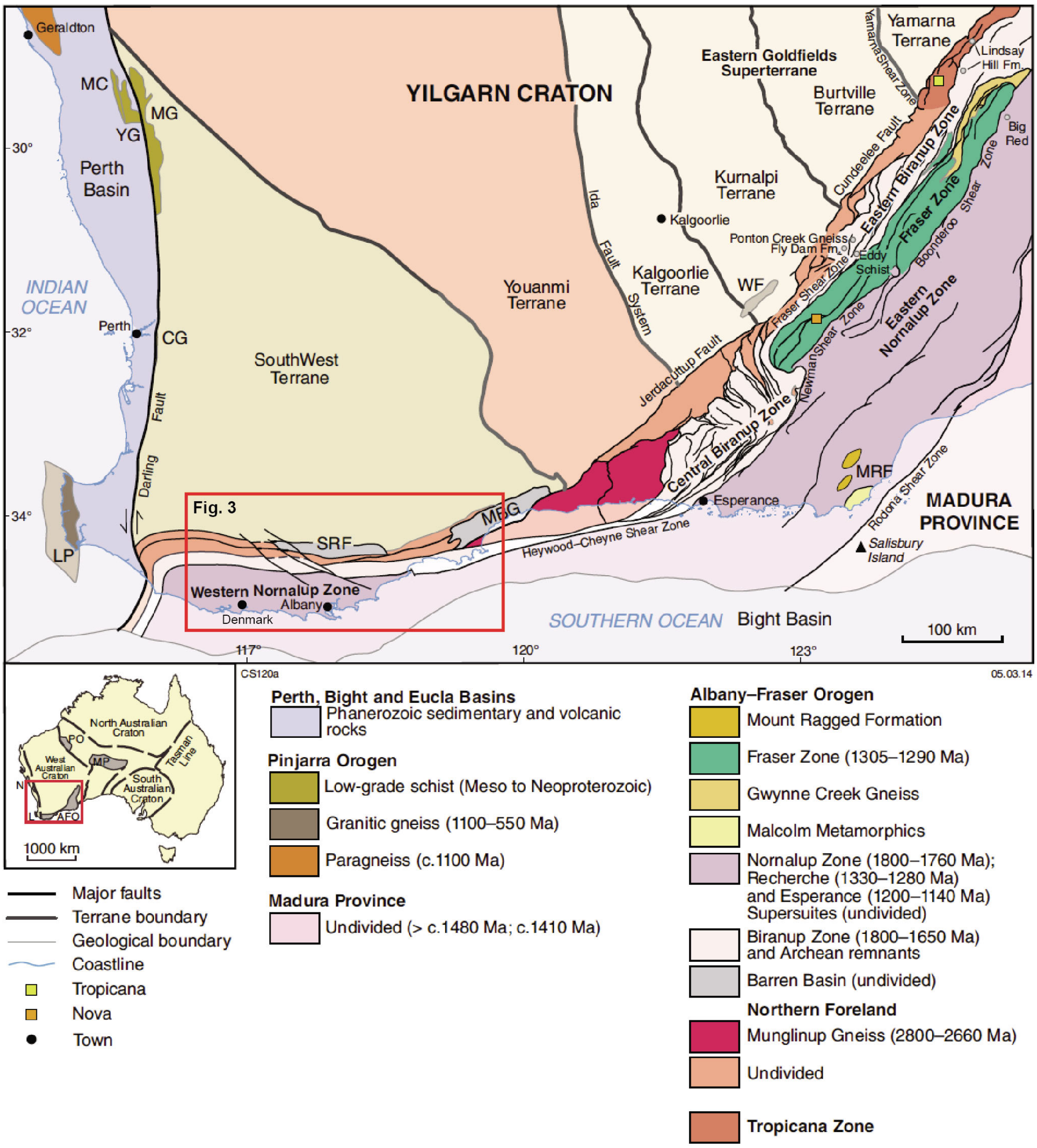


***Figure 1**. Simplified, pre-Mesozoic interpreted bedrock geology of the Albany–Fraser Orogen and tectonic subdivisions of the Yilgarn Craton. Abbreviations used: SRF = Stirling Range Formation; MBG = Mount Barren Group; WF = Woodline Formation; MRF = Mount Ragged Formation; CG = Cardup Group; LP = Leeuwin Complex; MC = Mullingarra Complex; MG = Moora Group. Inset: AFO = Albany–Fraser Orogen; MP = Musgrave Province; PO = Paterson Orogen; L = Leeuwin Complex; N = Northhampton Complex. From Spaggiari et al. (2014). See pre-conference field guide for updated map.*

The southern and western margins of the Yilgarn Craton

On this excursion, we will visit rocks of the Proterozoic Albany-Fraser Orogen, which truncates and partially rework the southern margin of the Archean Yilgarn Craton. The Yilgarn Craton broadly comprises Eastern Goldfield Superterrane and the Western Yilgarn Craton, juxtaposed along the Ida Fault System. (Fig. 1). The latter formed by accretion of several NW-SE trending greenstone belts intruded by granites, forming the Kalgoorlie, Kurnalpi, Burtville and Yamarna Terranes from west to east, respectively (Fig. 1). The former contains the South West and Youanmi Terranes in contact with the Albany-Fraser Orogen, which preserve an older, more complex history with gneisses, BIFs, metasedimentary rocks, greenstone belts and granitoid intrusions (Wilde, 1980; Pidgeon and Wilde, 1990; Nemchin and Pidgeon, 1999; Wyche et al., 2004). Detrital zircon populations from the Western Yilgarn Craton indicate protracted crustal evolution back as far as 4.4 Ga (Wilde et al., 2001). Granitoid activity was

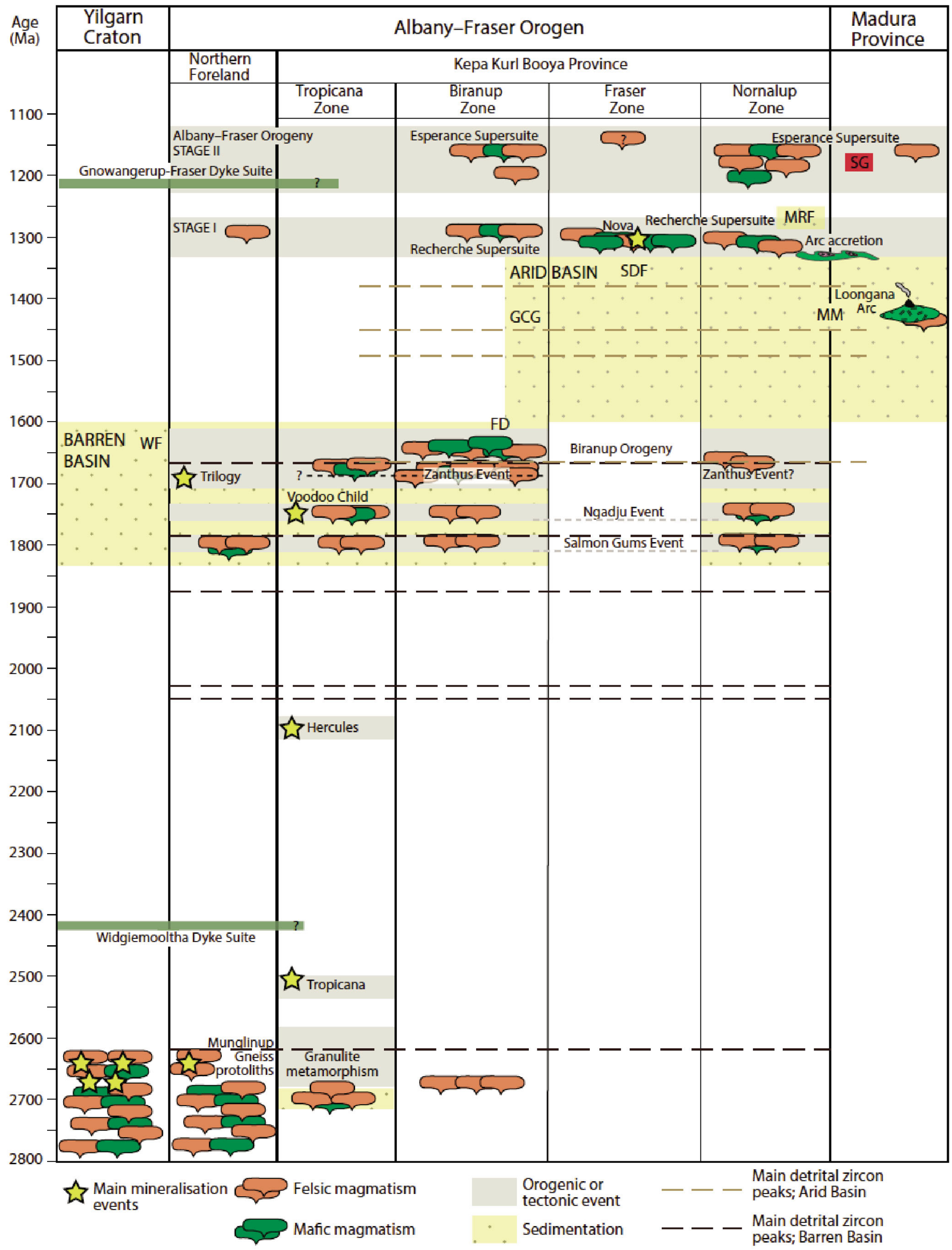


***Figure 2**. Time-space plot showing events of the Albany-Fraser Orogen and adjacent Yilgarn Craton and Madura Province, after Spaggiari et al. (2014). Abbreviations used: FD = Fly Dam Formation; GCG = Gwynne Creek Gneiss; Malcolm Metamorphics; MRF = Mount Ragged Formation; SDF = Snowys Dam Formation; SG = Salisbury Gneiss; WF = Woodline Formation.*

long-lived with systematically younger emplacement in almost continuous pulses across the southwest–central Yilgarn Craton at 3000–2820, 2805–2720, and 2720–2600 Ma (Mole et al., 2012). Terranes shared at least 150 Ma granite activity prior to final Craton amalgamation at ca. 2650 Ma (Mole et al., 2012). However, the Yilgarn is very poorly-exposed along its southern margin and is consequently understudied in this location.

The western margins of the Yilgarn Craton and Albany-Fraser Orogen are bound by the N-S trending Darling Fault and the Paleozoic-Recent Perth Basin beyond (Playford et al., 1976; Harris, 1994b; Song and Cawood, 2000; Olierook et al., 2015). A sweeping southward deflection of the Albany-Fraser Orogen and augen gneiss and mylonite domains in the Yilgarn Craton close to the Darling Fault has led to the interpretation that the Darling Fault nucleated on a pre-existing, large-scale sinistral ductile shear zone (Bretan, 1986; Dentith et al., 1993; Harris, 1994a; Beeson et al., 1995). West of the Darling Fault are numerous Proterozoic inliers of the Pinjarra Orogen – the Leeuwin, Mullingarra and Northampton Complexes – that are not related to the Albany-Fraser Orogen (Fig. 1) (Fitzsimons, 2003) and references therein.

The Albany-Fraser Orogen

The margins of all of the terranes of the Yilgarn Craton have been truncated, intruded and reworked in the Albany-Fraser Orogen in a domain referred to as the Northern Foreland, which has been thrust over the pristine Yilgarn Craton (Fig. 1) (Kirkland et al., 2011; Spaggiari et al., 2014; Spaggiari et al., 2015). The Munglinup Gneiss comprises orthogneiss with 2717-2640 Ma protolith ages interlayered with metamorphosed mafic rocks and minor metachert (jaspilite), amphibolitic schist, serpentinite, and metamorphosed ultramafic rocks (Spaggiari et al., 2014). Peak metamorphism reached granulite facies conditions in places, and occurred between 1210 to 1180 Ma. Significant mineral deposits at Tropicana and Nova are located in the Northern Foreland (Fig. 1).

Outboard of the Northern Foreland lies Proterozoic crystalline rocks of the Kepa Kurl Booya Province and deformed remnants of sedimentary basins that collectively form the Albany-Fraser Orogen (Spaggiari et al., 2014). Fault-bound lithotectonic zones have been defined with increasing distance from the Yilgarn Craton: Tropicana, Biranup, Fraser, and Nornalup Zones, respectively (Fig. 1) (Spaggiari et al., 2014). Protolith ages and metamorphic conditions in these zones are variable. Metasedimentary rocks define three spatially- and temporally-distinct basins: the 1815–1600 Ma Barren Basin, the 1455–1305 Ma Arid Basin, and the 1280–1215 Ma Ragged Basin (Figs 1, 2) (Spaggiari et al., 2014; Waddell et al., 2015). Mesoproterozoic granitic intrusions occur throughout the Biranup and Nornalup Zones in two pulses: ca. 1330–1280 Ma (Recherche Supersuite) and ca. 1200–1125 Ma (Esperance Supersuite) (Fig. 2). Granite emplacement and metamorphism during these times define Stages I and II of the Albany–Fraser Orogeny, respectively (Fig. 2).

Biranup Zone in the west Albany-Fraser Orogen

In the western Albany-Fraser Orogen, rocks of the Biranup Zone are exposed west of Albany along the coast in the vicinity of Bremer Bay, and we won't be visiting them on this field trip (Fig. 3). The Biranup Zone forms a belt of high-grade metamorphic rocks between the Nornalup Zone and the Yilgarn Craton. It consists of a complex mix of intensely deformed high-grade felsic orthogneisses that are interlayered with minor metasedimentary rocks (mainly quartzite, BIF and pelitic rocks), mafic (metagabbro) intrusions and lesser amounts of hybrid rocks.

The rocks are more intensely deformed than the Nornalup Zone, and primary layering is transposed by the deformation. Metamorphism outlasted deformation, hence the rocks are recrystallised with granoblastic textures and have mineral assemblages in the granulite facies.

Rocks of the Biranup Zone are considered to have been deep contintental crust. Ages range from 1810 to 1625 Ma, with later emplacement as tectonic slices to shallower crustal levels at about 1.2—1.1 Ga.

Nornalup Zone in the west Albany-Fraser Orogen

The Nornalup Complex forms the southern part of the orogen is juxtaposed with the Biranup Zone by the Heywood-Cheyne Shear Zone (or its western correlative equivalent), and is exposed along the southern coast in the Walpole-Denmark-Albany region (Fig. 1). It consists of felsic (quartzo-feldspathic) gneiss derived from granitic rocks and pelitic-semipelitic metasedimentary rocks. Rocks of the complex are strongly deformed (though not as intensely as rocks of the Biranup Complex) and are recrystallised during metamorphism in upper amphibolite facies, and locally to hornblende-granulite facies. The metasedimentary rocks are generally migmatitic or gneissose. Evidence of partial melting and pegmatite dykes are common. Protracted ductile deformation, anatexis and emplacement of pegmatites between ca. 1187 and 1150 Ma (Bodorkos and Clark, 2004; Spaggiari et al., 2009).

These high-grade orthogneisses and paragneisses are intruded by sheet-like bodies of granitoids of the Recherche and Esperance Supersuites, which include porphyritic granitic rocks of the large 1190 to 1170 Ma Burnside Batholith (Fig. 3), which is assigned to the Esperance Supersuite (Pidgeon, 1990; Black et al., 1992; Fitzsimons and Buchan, 2005). The granitoids range in composition from diorite through granodiorite to granite. The granitic intrusions include older slightly deformed phases, which are cut by younger, less deformed phases. The granitic intrusions are well exposed in the Albany area, where the late granitoids commonly form prominent rounded tors, similar to the large tors of porphyritic granitoids that make up the Porongurup Range to the north of Albany.

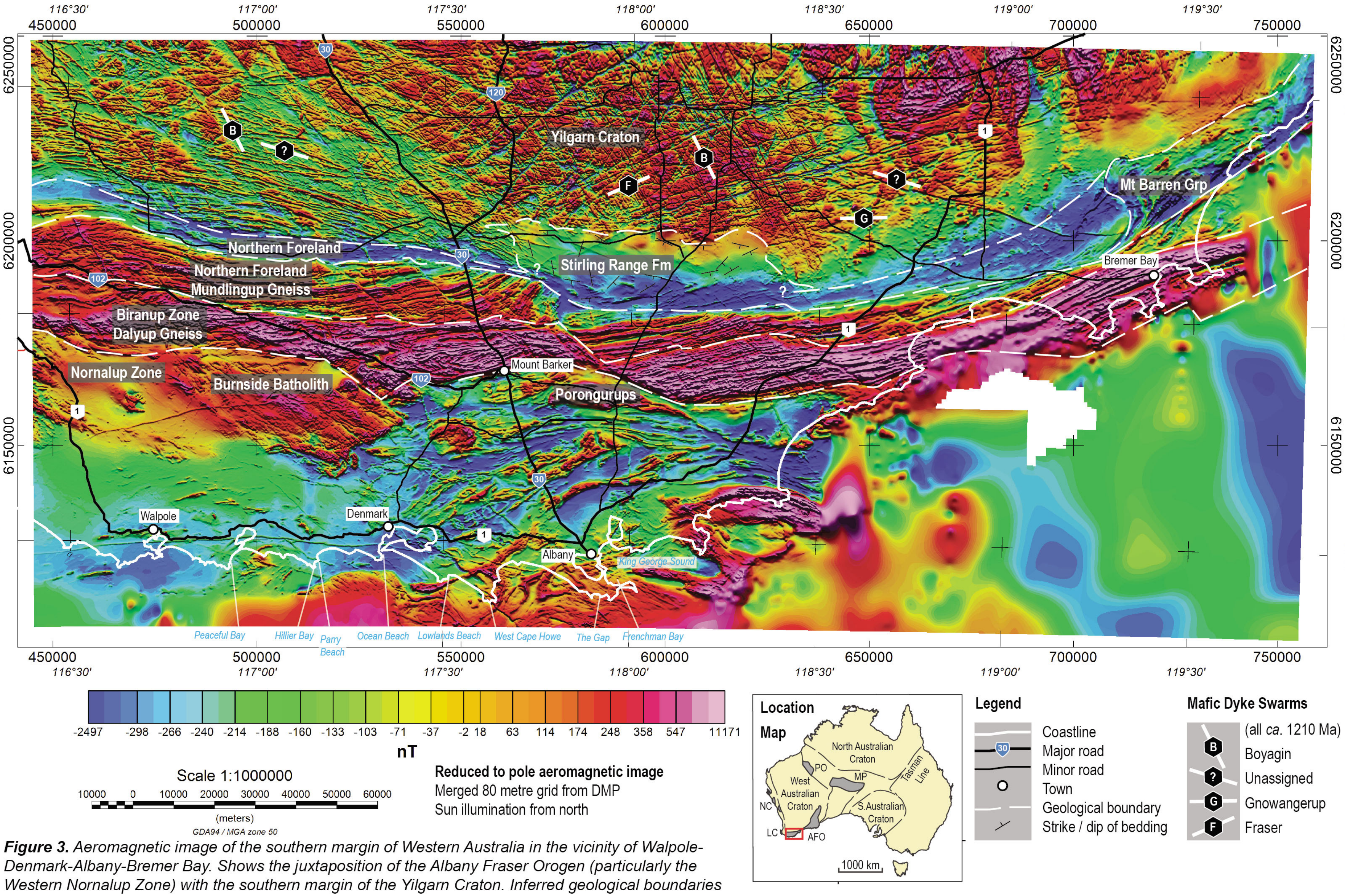


Figure 3. *Aeromagnetic image of the southern margin of Western Australia in the vicinity of Walpole-Denmark-Albany-Bremer Bay. Shows the juxtaposition of the Albany Fraser Orogen (particularly the Western Nornalup Zone) with the southern margin of the Yilgarn Craton. Inferred geological boundaries follows the terminology and interpretation of Spaggiari et al. (2014). Structural trends in the Stirling Range Formation after Muhling and Brakel (1985).*

The Barren Basin

The Palaeoproterozoic metasedimentary Barren Basin, which includes the Stirling Range Formation, and the Mount Barren Group, evolved between 1815–1600 Ma, and is thought to have extended at least 1000 km along the southern and southeastern Yilgarn Craton Margin. The majority of sedimentary units of the Barren Basin are quartz-rich lithologies that include cross-bedded sandstones, pure sandstones now metamorphosed to quartzites, pebbly sandstones and siltstones. The most common inferred sedimentary environment is that of moderate to high energy, fluvial to shallow marine, conditions, indicative of a broad and relatively shallow basin.

The Stirling Range Formation is one of the oldest formations in the Barren Basin, with deposition prior to around 1800 Ma. Three units have been distinguished within the Stirling Range Formation: lower and upper units of quartzite and a middle unit of quartzite, slate and phyllite. The gentle southerly dip of beds making up the Formation probably reflects the long limbs of large asymmetric folds that were re-folded by large-scale open easterly trending folds.

The Mount Barren Group is a sequence of quartzite, pelitic schist, and minor conglomerate deposited on the southern margin of the Yilgarn Craton during the Palaeoproterozoic. It is divided into three distinct stratigraphic units: the Steere Formation, Kundip Quartzite and Kybulup Schist. The Steere Formation unconformably overlies the Yilgarn Craton and consists of a basal conglomerate and overlaying quartzite with minor amounts of pelitic schist and dolomite. The thickness of the Steere Formation varies from 5 to 15 m and is poorly exposed. The Kundip Quartzite overlies the Steere Formation and varies in thickness from 10 to 200 m. The Kundip Quartzite consists of predominantly quartzite, with minor conglomerate, breccia, and pelitic bands present. The Kybulup Schist is the uppermost unit in the Mount Barren Group and consists of pelitic to psammopelitic schist and minor quartzite. The metamorphic grade of the Kybulup Schist increases from greenschist facies at Point Ann to upper amphibolite facies at West Beach.

During the late Mesoproterozoic, the Mount Barren Group was affected by two major deformation events (Fig. 2). The first deformation event (DA) resulted in the formation of three generations of folds, and a maximum metamorphic grade of upper amphibolite facies (only seen in the southeast part of the Mount Barren Group, near Ravensthorpe). This high metamorphic grade indicates that part of the Mount Barren Group was buried up to a depth of 30 km during this deformation/metamorphic event. The second deformation event (DB) resulted in the formation of a single phase of folding. North- to northwest-directed thrusting and folding in the Stirling Range Formation, Mount Barren Group, Mount Ragged Formation and Northern Foreland is thought to be contemporaneous with other Stage II events (Clark et al., 2000; Kirkland et al., 2011; Waddell et al., 2015).

Mafic dyke swarms

The Albany-Fraser Orogen and the adjacent Yilgarn Craton contain several differently oriented sets (swarms) of mafic dykes that are clearly visible on aeromagnetic surveys, but are mostly unexposed (Fig. 3). Four intersecting swarms are visible on the Yilgarn Craton adjacent the western Albany-Fraser Orogen trending NW-SE, E-W and ENE-WSW sets that are attributed to the Boyagin, Gnowangerup, and Fraser dyke swarms, respectively, plus a WNW-ESE trending set that is unassigned (Fig. 3) (Myers, 1990; Harris and Li, 1995). Most dykes terminate at the interface with the Albany-Fraser Orogen (Fig. 3). However, similar-trending aeromagnetic lineations can be seen in the Albany-Fraser Orogen, albeit much more sparsely distributed, are interpreted as related mafic dykes (Fig. 3). SHRMP U-Pb dating of zircon, zirconolite and baddeleyite in these dykes yields ages of ca.1218 Ma to ca. 1202 Ma that are mostly within uncertainty of one another (Evans, 1999; Qiu et al., 1999; Wingate et al., 2000; Pidgeon and Nemchin, 2001; Pidgeon and Cook, 2003; Rasmussen and Fletcher, 2004; Wingate and Kirkland, 2011; Pisarevsky et al., 2014). These ages are interpreted to represent major dyke emplacement during a short-lived, mantle-derived magmatic pulse of the Marnda Moorn large igneous province during the late Mesoproterozoic (Pisarevsky et al., 2014; Wang et al., 2014). Emplacement of the Marnda Moorn dyke swarms was synchronous with Stage II tectonism of the Albany-Fraser Orogen (Fig. 2) (Clark et al., 2000; Adams, 2012). Most dykes are sub-parallel to the Albany-Fraser Orogen, which has led to suggestions that the dyke swarms provided precursor mechanical weaknesses for localisation of orogenesis. Meta-mafic lenses in the Munglinup Gneiss in the Northern Foreland are interpreted to be deformed remnants of these dyke swarms. Many mafic dykes are exposed on the coastal outcrops of the Nornalup Zone in the Walpole-Denmark-Albany region, some of which we will visit on this field trip.

Cooling and exhumation of the Albany-Fraser Orogen

The end of Stage II, defined by the end of Esperance Supersuite magmatism, delimits the end of the Albany-Fraser Orogeny (Clark et al., 2000). Hornblende, biotite and muscovite $^{40}Ar/^{39}Ar$ thermochronology indicate differential timing and rates of cooling and exhumation along and across the Albany-Fraser Orogen (Fig. 4) (Scibiorski et al., 2015; Scibiorski et al., 2016). After discounting samples that suffer from excess ^{40}Ar, biotite cooling ages in the western Biranup and Nornalup Zones of ca. 1172–1144 Ma indicate rapid cooling rates of 22-33 °C/Ma, with the Biranup Zone recording higher values (Fig. 4) (Scibiorski et al., 2015). In contrast, biotite and muscovite cooling ages in equivalent zones in the eastern Albany-Fraser Orogen ca. 1171-1158 Ma indicate much slower cooling rates of 8.2-9.5 °C/Ma and commenced 20 Myr earlier (Fig. 4) (Scibiorski et al., 2016). Nevertheless, the data indicate rapid exhumation following peak metamorphism at ca. 1180 Ma. The differences in rates have been linked to the 45° variation in strike of the Albany-Fraser Orogen, particularly changes in proportions of orthogonal thrusting vs transcurrent kinematics during a uniform NE-directed convergence direction in an overall transpressive system (Fig. 4d, e) (Scibiorski et al., 2016). However, structures responsible for syn-orogenic exhumation have not been identified.

Gondwana amalgamation and breakup

As far as it is known, tectonic quiescence followed cessation of the Albany-Fraser orogeny at ca. 1144 Ma. The Walpole-Denmark-Albany region of the orogen was not directly affected by Pinjarra Orogen (younger than ca. 1090 Ma) and the amalgamation of Gondwana ca. 550-500 Ma that was prevalent on the western margin of Western Australia (Fitzsimons, 2003; Janssen et al., 2003) and responsible for recrystallization and resetting of $^{40}Ar/^{39}Ar$ ages of micas on the western margin of the Yilgarn Craton (Lu et al., 2015).

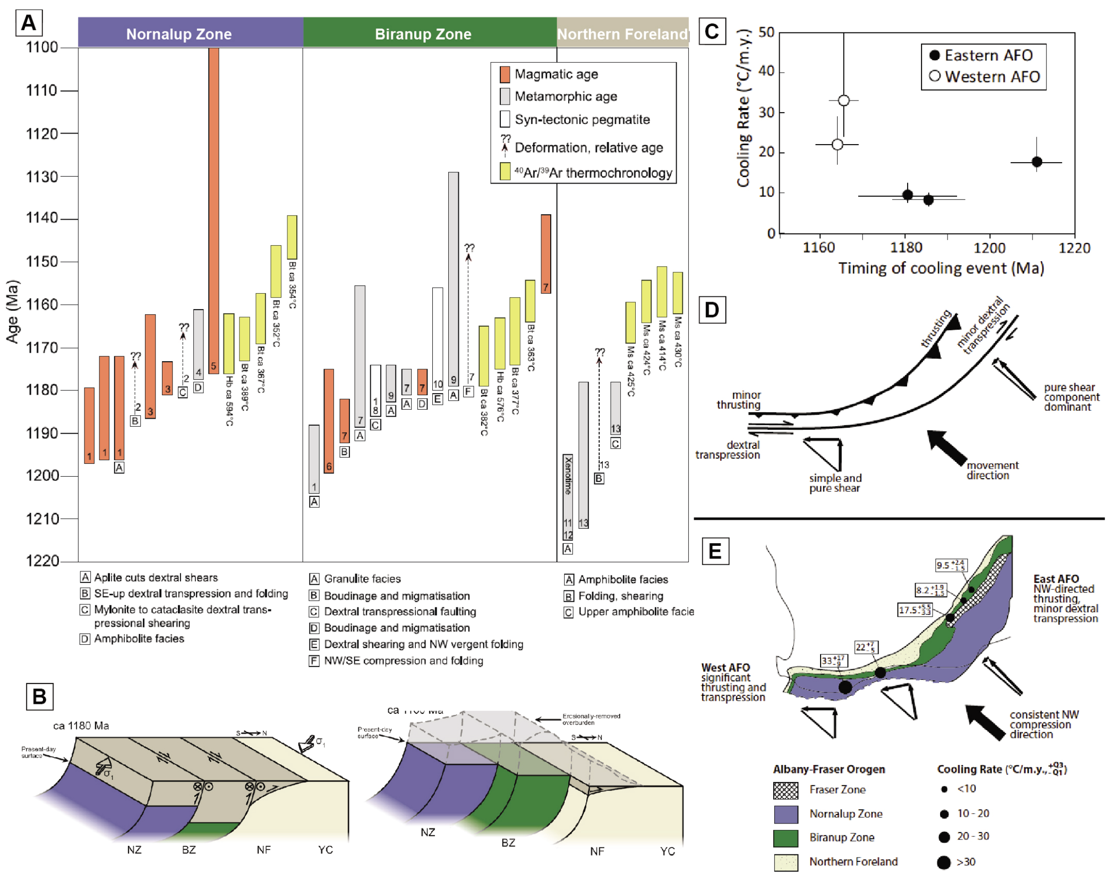


Figure 4. Differential cooling and exhumation across and along the Albany-Fraser Orogen after Scibiorski et al. (2015) and Scibiorski et al. (2016) and references therein. (a) Summary of SHRIMP U/Pb zircon and $^{40}Ar/^{39}Ar$ data of Stage II from the western and central Albany-Fraser Orogen. Data bars are shown at 2σ uncertainty level. (b) Schematic diagram showing transpression-related exhumation of the western Albany-Fraser Orogen from ca 1180 to ca 1160 Ma. (c) Comparison of cooling ages and cooling rates in the eastern and western Albany-Fraser Orogen from $^{40}Ar/^{39}Ar$ data. (d) Schematic diagram showing changes in kinematics associated with single convergence direction for a curved orogen. (e) Simplified map of the Albany-Fraser Orogen showing differential cooling rates from east to west, explained in terms of spatial differences in the proportions of orthogonal convergence vs transcurrent movement.

However, the region has been susceptible to resetting of the Rb-Sr system in biotite to as young as ca. 418 Ma in the vicinity of Walpole (Libby and de Laeter, 1998).

The N-S trending Perth Basin to the west developed initially as an intracontinental rift basin since at least Permian. Continental breakup occurred initially along the western margin of Australia and Greater India, and was synchronous with ca. 137 to 130 Ma Bunbury Basalt volcanism in the Perth Basin (Olierook et al., 2016). The development of the southern rift system along the southern margin of Australia is summarised by Totterdell et al. (2000) and Totterdell and Bradshaw (2004). Rifting initiated during the Late Jurassic, initially with along a NW-SE azimuth, when fluvial and lacustrine sediment-filled half grabens developed in the Bight and Druntoon Basins (Willcox and Stagg, 1990). This was followed by thermal subsidence phase in the Early Cretaceous as a NNE-SSW-oriented extensional regime was established (Willcox and Stagg, 1990; Totterdell et al., 2000). Accelerated rifting and breakup was diachronous along the southern margin, initiating in the west near the India-Antarctica-Australia triple junction at ca. 90-87 Ma, systematically migrated eastwards, concluding in entire margin breakup ca. 45 m.y. later (Sayers et al., 2001; Halpin et al., 2008; Direen, 2012). The southern rift system has been influenced by deep-seated pre-existing basement structures throughout basin evolution, particularly NW-SE trending shear zones (Teasdale et al., 2003; Totterdell and Bradshaw, 2004). Commencement of sea-floor spreading is defined by the earliest magnetic anomaly in the Bight region, which occurred at ca. 83 Ma (Sayers et al., 2001), which was followed by thermal subsidence and establishment of a passive margin.

Where is the rest of the Albany-Fraser Orogen now?

The Albany-Fraser Orogen plays an important role in tectonic reconstructions of Gondwana. However, the location of Antarctica's counterpart to the Albany-Fraser Orogen is not abundantly clear, and reconstructions are not unanimously agreed upon (Fig. 6). Paleo-continent reconstruction has been attempted by many researchers using various approaches over the years (Powell, 1988; Norvick et al., 2001; Fitzsimons, 2003; Veevers et al., 2007; Boger, 2011; Williams et al., 2011; White et al., 2013; Aitken et al., 2016; Maritati et al., 2016; Morrissey et al., 2017; Tucker et al., 2017). Previous reconstructions have placed variable emphasis on matching the geology. Valid reconstructions need to consider matches of the positions major pre-existing structures, geophysical anomalies, sedimentary basins, as well as the tectonic (P-T-t) histories and detrital provenance histories of the rocks themselves. Some previous reconstructions have suffered from correlation issues due to poor geological constraints, particularly from Antarctica. It is clear that rigorous reconstruction requires consideration of continental motion on a spherical body, and needs to be consistent with sea-floor spreading and extensional structures of the intervening basin(s), which are taken into account using G-Plates. However, a solution that satisfies all of these criteria is yet to be found.

Unconformable Cenozoic to recent sedimentary rocks

Rocks of the Cenozoic Plantagenet Group and the Mid- to Late-Pleistocene Tamala Limestone (formerly coastal limestone) were deposited directly on to crystalline basement along the southwestern coast of Western Australia (Playford et al, 1976; Quilty et al., 1974). The Tamala Limestone developed adjacent to the coast and along parts of the drowned continental shelf from north of Shark Bay to Esperance on the south coast of WA (Playford et al., 1976; Hearty and O'Leary, 2008; Jorgensen, 2012; Brooke et al., 2014). Given its extensive development (over 1000 km of latitude in a belt several tens of kilometres wide) the Tamala Limestone represents some of the most extensive deposits of this kind and age in the world. Sedimentary units in the region are dominated by calcarenite and aeolianites with subordinate palaeosols, calcretised horizons as well as beach and shallow marine deposits (Playford et al., 1976). Calcite-cemented sandstone with large-scale dune cross-bedding is common. The carbonate cement influences the weathering and erosion giving this unit the appearance of limestone. Palaeosols are developed locally, which represent interdune facies. Basal conglomerate is commonly present that can contain locally-derived clasts up to boulder size.

Topography on the unconformity indicates a non-planar palaeo-erosion surface, and the units lacks stratigraphic marker horizons that can be traced over long distances across the region. Nevertheless, marine units and aeolian units that have been dated elsewhere indicate that deposition must have occurred when sea-levels were at a relative highstand and greater carbonate production was facilitated in the more expansive shallow shelf water body (Hearty and O'Leary, 2008). Accelerated Australia-Antarctica rifting coincided with the Eocene climate optimum and consequent eustatic high, whereas glacioeustacy and the influence of the proto-Leeuwin current contributed more recently (Shafik, 1992; Wyrwoll et al., 2009). Recent uplift indicated by modern river profiles in the southwest is due to dynamic topography (Sandiford, 2003; Barnett-Moore et al., 2014).

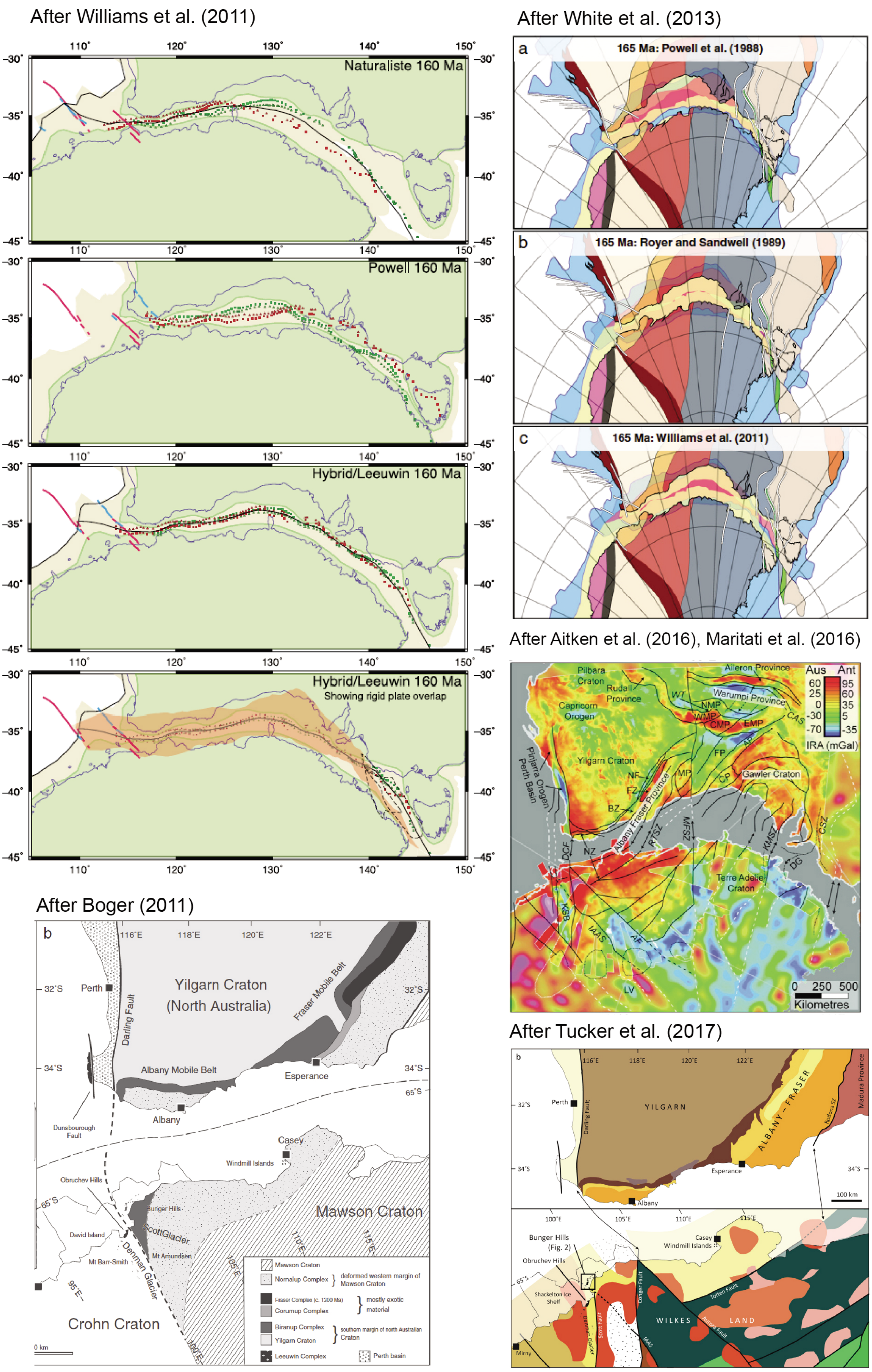


Figure 5. *A selection of different plate reconstructions that highlight discrepancies of the correlation between Australia and Antarctica.*

Gneisses at Parry Beach (image – Catherine Spaggiari)

Field localities

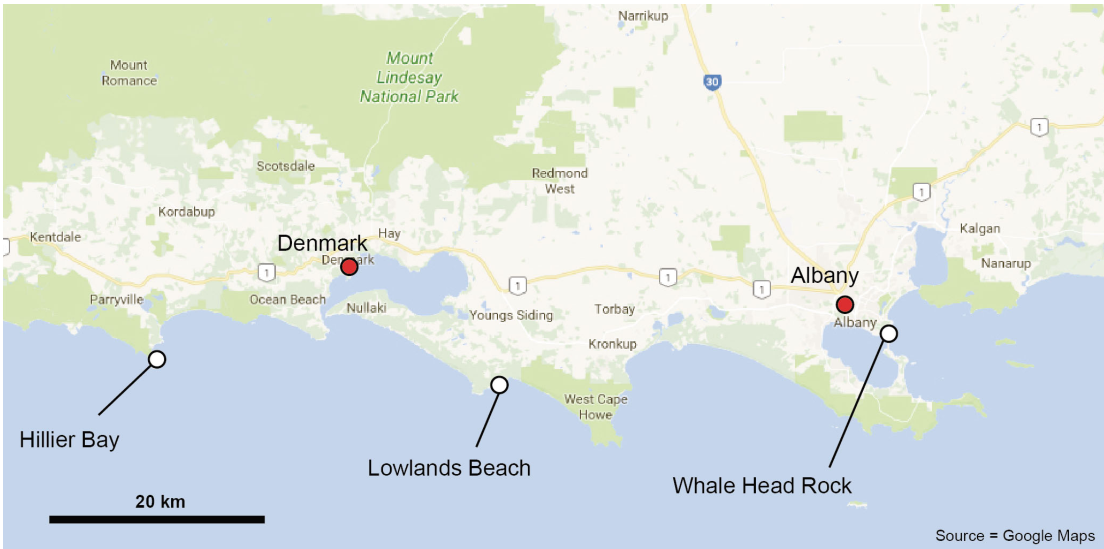


Figure 6. *Map of the field localities for this excursion.*

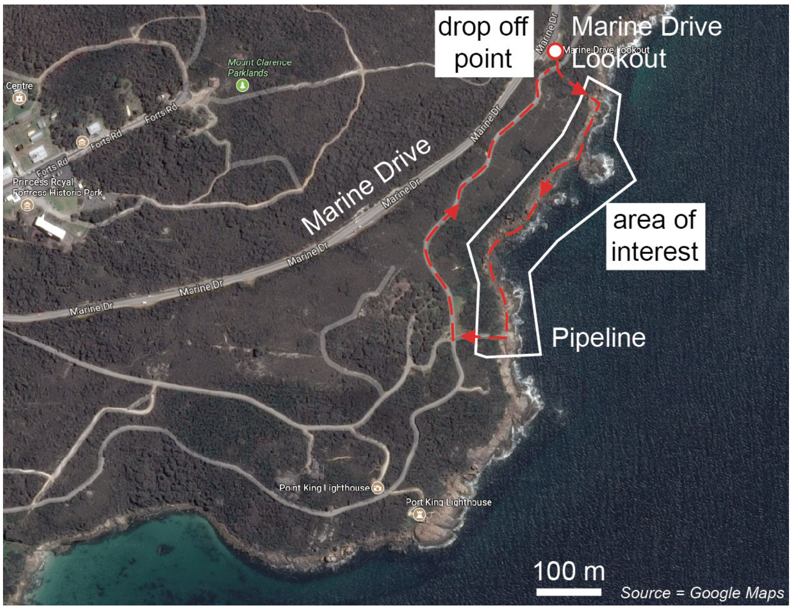
Whale Head Rock, Nornalup Zone, Albany-Fraser Orogen

How to get there

'Whale Head Rock' is the section of shoreline between Wooding Point and King Point on the west side of King George Sound. From a carpark and viewing lookout on Marine Drive, a walking track leads down to the foreshore.

Specific Hazards

- *Keep alert for large waves that may surge over smooth rock surfaces that slope into the water.*
- *Take extra care when walking on large boulders that may move underfoot.*



Geology

Granite, which is gneissic in places, and pelitic metasedimentary rocks (some migmatised) are exposed along the foreshore below the carpark. South of a small rocky cove the pelitic metasedimentary rocks have been intruded by granite.

Points for discussion

- **Xenoliths and enclaves** – What is the significance of amphibolite-dominated xenoliths in the north, and metasedimentary-dominated xenoliths in the south?
- **Different generations of granitoids** – When were the granites emplaced, what is their geochemistry and tectonic significance?
- **Timing of the metasedimetary rocks** – When did they form, and what was the basin setting?
- **Rotten green rocks** – What is this – calc-silicate protolith or an alteration assemblage?
- **Metamorphic conditions** – what pressure and temperature conditions did these rocks reach, and when? (Fig. 7)

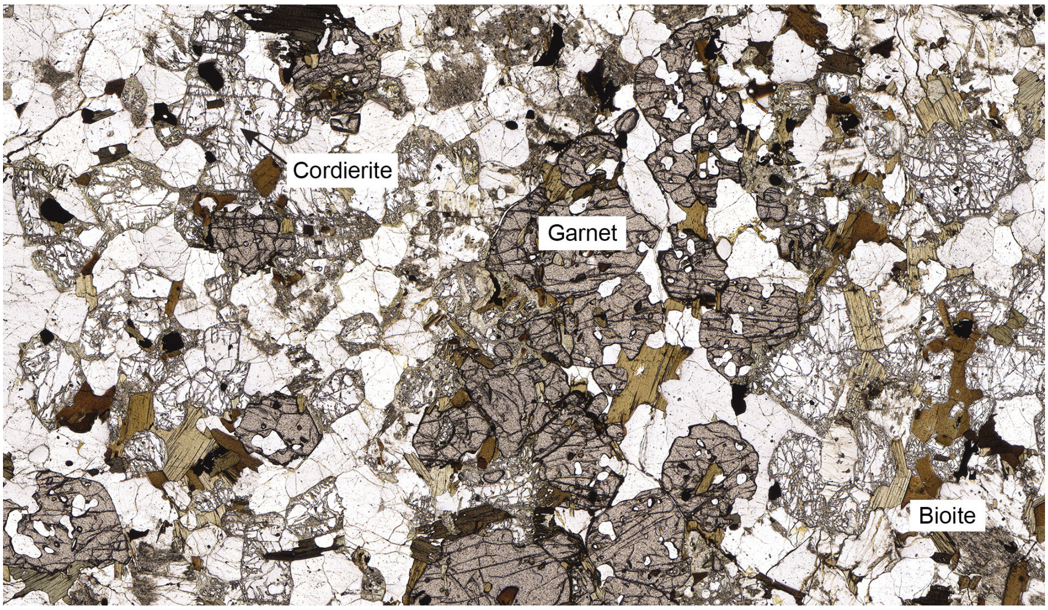


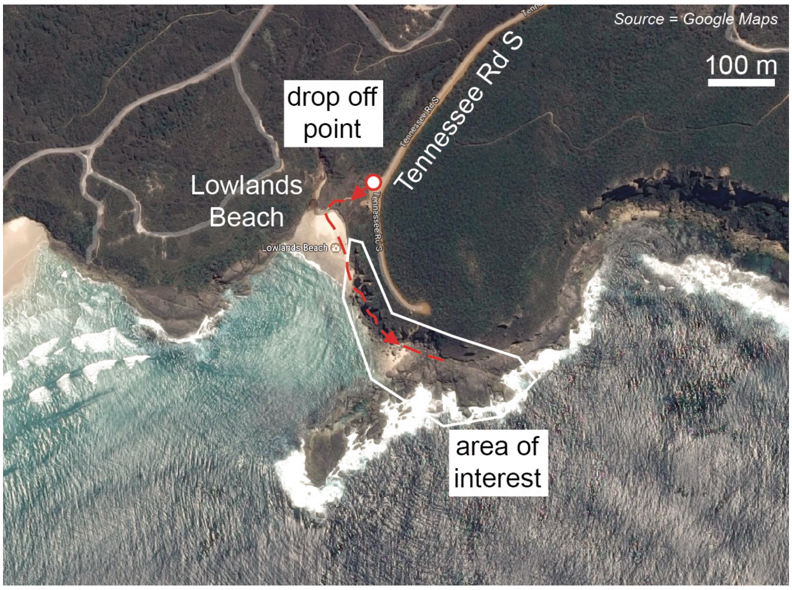
Figure 7. *Cordierite-garnet-quartz-biotite gneiss at Whale Head Rock.*

Shear zone at Whale Head Rock (image – Steve Reddy)

Lowlands Beach, Nornalup Zone, Albany-Fraser Orogen, & Cenozoic-Pleistocene sedimentary rocks

How to get there

Lowlands Beach, on the eastern side of Knapp Head, is ~34 km west of Albany along the Lower Denmark (Albany-Torbay) Road then south along Tennessee Road South past 'South Downs'. A track leads down from the car park (at end of road) to the beach and large rock pavements at the eastern end of Lowlands Beach.



Specific Hazards

- *Beware of large waves that may surge over smooth foreshore rock pavements.*
- *Lowlands Beach is NOT a safe swimming beach if there is a large swell.*
- *Do NOT climb cliffs or stand beneath an overhang.*

Geology

Granitic rocks equivalent to the Proterozoic Burnside Batholith (1.2-1.1 Ga) are well exposed on the expansive rock pavements beneath the cliffs at the eastern end of Lowlands Beach. The granitic rocks have been intruded by a number of dolerite dykes, also of Proterozoic age.

The Proterozoic rocks are overlain unconformably by limestone of the Plantagenet Group (Tertiary). This limestone crops out on the beach and forms the large cliffs above the beach. Sedimentary features in the limestone include large-scale planar cross bedding and columnar vertical features, which may be preserved tree trunks. .

The **unconformity** represents a **hiatus** of about 1,100 million years. Evidence of the unconformity can be seen at the base of the cliff, where boulders of granite and gneiss are enclosed in the basal unit of the Plantagenet Group.

Points for discussion

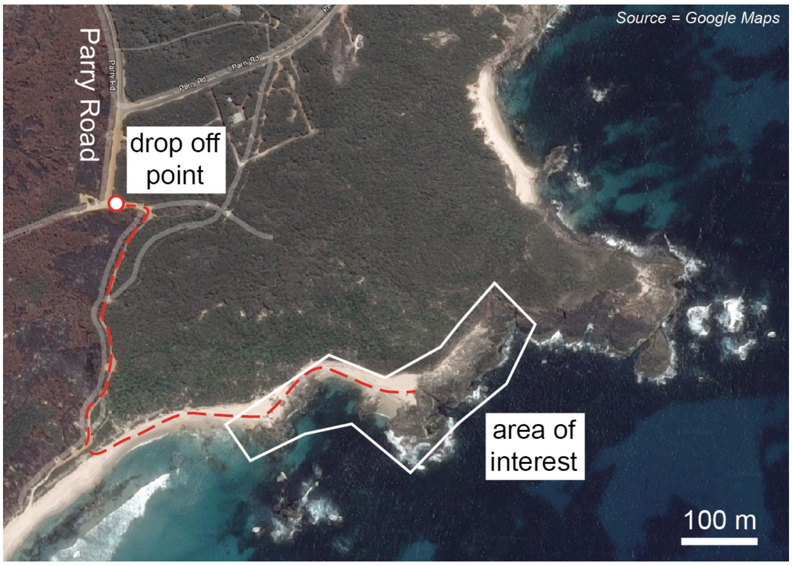
- **Xenoliths and enclaves** – What do they represent, and what is their significance?
- **Different generations of granitoids** – When were the granites emplaced, what is their geochemistry and tectonic significance?
- **Joint and fracture sets** – When did they form, and at what conditions? What is the significance of epidote-bearing fractures?
- **Mafic dykes** – What is the age of the mafic dykes? Can they be related to any of the dyke swarms seen in the Yilgarn Craton? What is their geodynamic setting?
- **Unconformity** – How is the unconformity expressed across the outcrop?

Mafic dykes at Lowlands Beach (image – Nick Timms)

Hillier Bay, Nornalup Zone, Albany-Fraser Orogen

How to get there

Take Parry Beach Road south off the South Coast Highway. Continue past the Parry Beach turn off to the end of the sealed road (bus can turn around at leisure and park in the dead end at the T-junction). Walk down to Hillier Bay by turning east at the T-junction and following the track down south to the sea. Outcrops are to the east of where the track comes out onto the beach. Total walk from the T-junction is 10-15 minutes.



Specific Hazards

- *Waves may surge over rocky pavements at high tide or in a significant swell.*
- *Take extra care climbing and walking over boulders.*

Geology

Amphibolite facies paragneisses and orthogneisses of the Nornalup Complex are well exposed on the foreshore at Hillier Bay, and have been mapped in detail by Chapman (1995). Paragneissic protoliths are either S-type granitic rock or sedimentary rock. Orthogneissic protoliths include gabbro intruded by leucogranite. Paragneisses are the oldest lithological units and have the oldest foliation.

Gneissic rocks have been subjected to four deformation events:

D1: early transpositional folding (F1) and transpositional foliation (F1).
D2: subhorizontal shear zones (S2) with the hangingwall side moved to the northwest.
D3: subvertical shear zones (S3) trending 245 and southeast side down and associated upright open folds.
D4: brittle faulting and accompanying dolerite intrusion.

Progressive prograde metamorphism during D1 and D2 reached upper amphibolite facies during a major tectonic event at about 1300 Ma. D3 deformation and metamorphism occurred during an 1190 Ma event, which is partly constrained by the Parry Beach Adamellite (1190 Ma).

The rocks here are a complex sequence of partially melted orthogneisses and paragneisses. Main units are a grey foliated biotite-bearing grey gneiss, mostly of granodioritic composition, but (Chapman, 1995) also notes garnet-bearing material, mafic amphibole-bearing gneisses, and leucocratic material, which occurs as coarse pegmatites, and as finer-grained vein material that picks out structures and defines the foliation. There are several small outcrops (10-20 m in each dimension) and there is also extensive pavement outcrop.

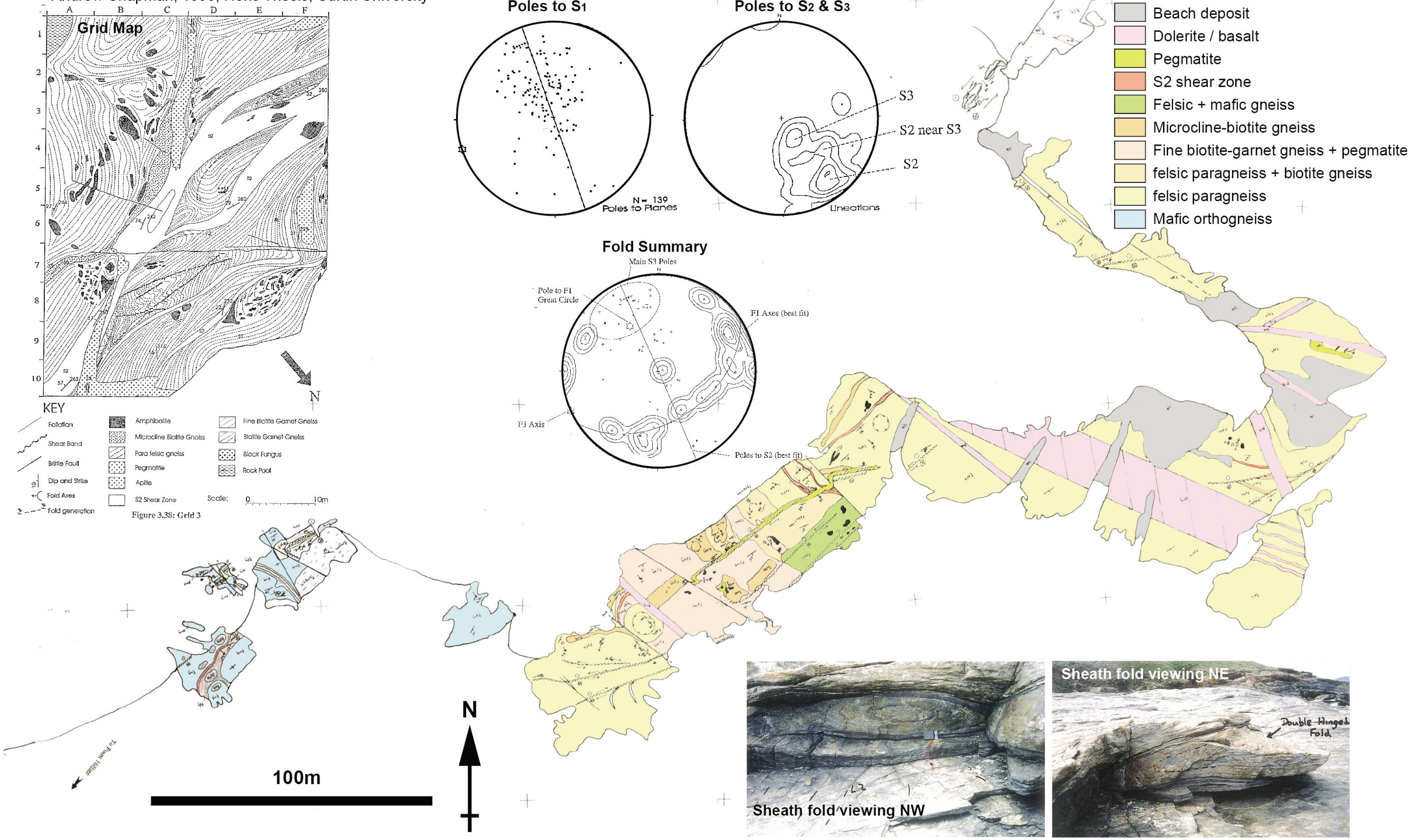
Features of interest include boudinaged melt channels, melt in dilational settings, shear zones with shear sense indicators, dome folds, sheath folds and numerous simple folds, some with sufficient three dimensional exposure to allow measurement of fold axes. It seems likely that the folds have been displaced and rotated within the melt, as they do not have any consistent orientation, so that at least parts of the outcrop are diatexitic. Shear zone orientations across the outcrop are more consistent. Other features of interest include a 3 m wide undeformed mafic dyke and garnet sand.

Points for discussion

- **Sheath folds** – are they a product of single shear event or are they refolded folds?
- **Flat fabric** – What is the tectonic significance of the sub-horizontal fabric?
- **Mafic dyke** – How old are the mafic dykes?
- **Pegmatite** – What is the significance of the pegmatite?

Geological Map of Hillier Bay Gneisses, Albany-Fraser Orogen, Western Australia

Andrew Chapman, 1995, Hons Thesis, Curtin University



References

Adams, M., 2012. Structural and geochronological evolution of the Malcolm Gneiss, Nornalup Zone, Albany-Fraser Orogen, Western Australia. Geological Survey of Western Australia Record 2012/4, 105.

Aitken, A.R.A., Betts, P.G., Young, D.A., Blankenship, D.D., Roberts, J.L., Siegert, M.J., 2016. The Australo-Antarctic Columbia to Gondwana transition. Gondwana Research 29, 136-152.

Barnett-Moore, N., Flament, N., Heine, C., Butterworth, N., and Müller, R. D., 2014. Cenozoic uplift of south Western Australia as constrained by river profiles. Tectonophysics, 622, 186-197.

Beeson, J., Harris, L.B., Delor, C.P., 1995. Structure of the western Albany Mobile Belt (southwestern Australia): evidence for overprinting by Neoproterozoic shear zones of the Darling Mobile Belt. Precambrian Research 75, 47-63.

Black, L.P., Harris, L.B., Delor, C.P., 1992. Reworking of Archaean and early Proterozoic components during a progressive, middle Proterozoic tectonothermal event in the Albany Mobile Belt, Western Australia. Precambrian Research 59, 95-123.

Bodorkos, S., Clark, D.J., 2004. Evolution of a crustal-scale transpressive shear zone in the Albany-Fraser Orogen, SW Australia: 2. Tectonic history of the Coramup Gneiss and a kinematic framework for Mesoproterozoic collision of the West Australian and Mawson cratons. Journal of Metamorphic Geology 22, 713-731.

Boger, S.D., 2011. Antarctica — Before and after Gondwana. Gondwana Research 19, 335-371.

Bretan, P.G., 1986. Deformation processes within mylonite zones associated with some fundamental faults. Imperial College, University of London.

Brooke, B.P., Olley, J.M., Pietsch, T., Playford, P.E., Haines, P.W., Murray-Wallace, C.V., Woodroffe, C.D., 2014. Chronology of Quaternary coastal aeolianite deposition and the drowned shorelines of southwestern Western Australia – a reappraisal. Quaternary Science Reviews 93, 106-124.

Chapman, A.J., 1995. Structural history of the Hillier Bay gneisses, Albany Mobile Belt, Western Australia, Department of Applied Geology. Curtin University, Perth, Western Australia, p. 175.

Clark, D.J., Hensen, B.J., Kinny, P.D., 2000. Geochronological constraints for a two-stage history of the Albany–Fraser Orogen, Western Australia. Precambrian Research 102, 155-183.

Dentith, M.C., Bruner, I., Long, A., Middleton, M.F., Scott, J., 1993. Structure of the eastern margin of the Perth Basin, Western Australia. Exploration Geophysics 24, 455-462.

Direen, N.G., 2012. Comment on “Antarctica — Before and after Gondwana” by S.D. Boger Gondwana Research, Volume 19, Issue 2, March 2011, Pages 335–371. Gondwana Research 21, 302-304.

Evans, T., 1999. Extent and nature of the 1200 Ma Wheatbelt Dyke Swarm, South- western Australia. In: BSc (Hons) thesis). . University of Western Australia, Perth, p. (unpublished).

Fitzsimons, I., Buchan, C., 2005. Geology of the Western Albany-Fraser Orogen, Western Australia – a field guide. Western Australian Geological Survey Record2005/11, 32.

Fitzsimons, I.C.W., 2003. Proterozoic basement provinces of southern and southwestern Australia, and their correlation with Antarctica. Geological Society, London, Special Publications 206, 93-130.

Halpin, J.A., Crawford, A.J., Direen, N.G., Coffin, M.F., Forbes, C.J., Borissova, I., 2008. Naturaliste Plateau, offshore Western Australia: A submarine window into Gondwana assembly and breakup. Geology 36, 807.

Harris, L.B., 1994a. Neoproterozoic sinistral displacement along the Darling mobile belt, Western Australia, during Gondwanaland assembly. Journal of the Geological Society 151, 901-904.

Harris, L.B., 1994b. Structural and tectonic synthesis for the Perth Basin, Western Australia. Journal of Petroleum Geology 17, 129-156.

Harris, L.B., Li, Z.X., 1995. Palaeomagnetic dating and tectonic significance of dolerite intrusions in the Albany Mobile Belt, Western Australia. Earth and Planetary Science Letters 131, 143-164.

Hearty, P.J., O’Leary, M.J., 2008. Carbonate eolianites, quartz sands, and Quaternary sea-level cycles, Western Australia: A chronostratigraphic approach. Quaternary Geochronology 3, 26-55.

Janssen, D., Collins, A., Fitzsimons, I., 2003. Structure and tectonics of the Leeuwin Complex and Darling fault zone southern Pinjarra Orogen Western Australia - A field guide.

Jorgensen, D.C., 2012. Quaternary stratigraphy, palaeowinds and palaeoenvironments of carbonate aeolianite on the Garden Island Ridge and in the Naturaliste-Leeuwin region, southwest Western Australia. James Cook University, Townsville, Queensland.

Kirkland, C.L., Spaggiari, C.V., Pawley, M.J., Wingate, M.T.D., Smithies, R.H., Howard, H.M., Tyler, I.M., Belousova, E.A., Poujol, M., 2011. On the edge: U–Pb, Lu–Hf, and Sm–Nd data suggests reworking of the Yilgarn craton margin during formation of the Albany-Fraser Orogen. Precambrian Research 187, 223-247.

Libby, W.G., de Laeter, J.R., 1998. Biotite Rb‐Sr age evidence for Early Palaeozoic tectonism along the cratonic margin in southwestern Australia. Australian Journal of Earth Sciences 45, 623-632.

Lu, S., Phillips, D., Kohn, B.P., Gleadow, A.J.W., Matchan, E.L., 2015. Thermotectonic evolution of the western margin of the Yilgarn craton, Western Australia: New insights from 40 Ar/ 39 Ar analysis of muscovite and biotite. Precambrian Research 270, 139-154.

Maritati, A., Aitken, A.R.A., Young, D.A., Roberts, J.L., Blankenship, D.D., Siegert, M.J., 2016, The tectonic development and erosion of the Knox Subglacial Sedimentary Basin, East Antarctica. Geophysical Research Letters, *43*.

Mole, D.R., Fiorentini, M.L., Thebaud, N., McCuaig, T.C., Cassidy, K.F., Kirkland, C.L., Wingate, M.T.D., Romano, S.S., Doublier, M.P., Belousova, E.A., 2012. Spatio-temporal constraints on lithospheric development in the southwest–central Yilgarn Craton, Western Australia. Australian Journal of Earth Sciences 59, 625-656.

Morrissey, L.J., Payne, J.L., Hand, M., Clark, C., Taylor, R., Kirkland, C.L., Kylander-Clark, A., 2017. Linking the Windmill Islands, east Antarctica and the Albany–Fraser Orogen: Insights from U–Pb zircon geochronology and Hf isotopes. Precambrian Research 293, 131-149.

Muhling, J.R., Brakel, A.T., 1985. Explanatory notes Mount Barker-Albany, Western Australia. Geological Survey of Western Australia, 4.

Myers, J.S., 1990. Albany–Fraser Orogen. Geological Survey of Western Australia Memoir v. 3, 255-263.

Nemchin, A.A., Pidgeon, R.T., 1999. U–Pb ages on titanite and apatite from the Darling Range granite: implications for Late Archaean history of the southwestern Yilgarn Craton. Precambrian Research 96, 125-139.

Norvick, M.S., Smith, M.A., Power, M.R., 2001. The plate tectonic evolution of eastern Australasia guided by the stratigraphy of the Gippsland Basin, in: Hill, K.C., Bernecker, T. (Eds.), Eastern Australasian Basins Symposium 2001. Petroleum Exploration Society of Australia Special Publication, pp. 15-23.

Olierook, H.K.H., Jourdan, F., Merle, R.E., Timms, N.E., Kusznir, N., Muhling, J.R., 2016. Bunbury Basalt: Gondwana breakup products or earliest vestiges of the Kerguelen mantle plume? Earth and Planetary Science Letters 440, 20-32.

Olierook, H.K.H., Timms, N.E., Wellmann, J.F., Corbel, S., Wilkes, P.G., 2015. 3D structural and stratigraphic model of the Perth Basin, Western Australia: Implications for sub-basin evolution. Australian Journal of Earth Sciences 62, 447-467.

Pidgeon, R.T., 1990. Timing of plutonism in the Proterozoic Albany mobile belt, southwestern Australia. Precambrian Research 47, 157-167.

Pidgeon, R.T., Cook, T.J.F., 2003. 1214±5 Ma dyke from the Darling Range, southwestern Yilgarn Craton, Western Australia. Australian Journal of Earth Sciences 50, 769-773.

Pidgeon, R.T., Nemchin, A.A., 2001. 1.2 Ga Mafic dyke near York, southwestern Yilgarn Craton, Western Australia. Australian Journal of Earth Sciences 48, 751-755.

Pidgeon, R.T., Wilde, S.A., 1990. The distribution of 3.0 Ga and 2.7 Ga volcanic episodes in the Yilgarn Craton of Western Australia. Precambrian Research 48, 309-325.

Pisarevsky, S.A., Wingate, M.T.D., Li, Z.-X., Wang, X.-C., Tohver, E., Kirkland, C.L., 2014. Age and paleomagnetism of the 1210Ma Gnowangerup–Fraser dyke swarm, Western Australia, and implications for late Mesoproterozoic paleogeography. Precambrian Research 246, 1-15.

Playford, P.E., Low, G.H., Cockbain, A.E., 1976. Geology of the Perth Basin, Western Australia. Geological Survey of Western Australia, 124 pp.

Powell, C., Roots, S., Veevers, J.J., 1988. Pre-breakup continental extension in East Gondwanaland and the early opening of the eastern Indian Ocean. Tectonophysics 155, 261–283.

Qiu, Y., McNaughton, N.J., Groves, D.I., Dunphy, J.M., 1999. First record of 1.2 Ga quartz dioritic magmatism in the Archaean Yilgarn Craton, Western Australia, and its significance. Australian Journal of Earth Sciences 46, 421-428.

Quilty, P.G., 1974. Tertiary stratigraphy of Western Australia. Journal of the Geological Society of Australia 21, 301-318.

Rasmussen, B., Fletcher, I.R., 2004. Zirconolite: A new U-Pb chronometer for mafic igneous rocks. Geology 32, 785-788.

Sandiford, M., 2003. Neotectonics of southeastern Australia: linking the Quaternary faulting record with seismicity and in situ stress. Geological Society of America Special Papers, 372, 107-119.

Sayers, J., Symonds, P.A., Direen, N.G., Bernardel, G., 2001. Nature of the continent-ocean transition on the non-volcanic rifted margin of the central Great Australian Bight. Geological Society, London, Special Publications 187, 51-76.

Scibiorski, E., Tohver, E., Jourdan, F., 2015. Rapid cooling and exhumation in the western part of the Mesoproterozoic Albany-Fraser Orogen, Western Australia. Precambrian Research 265, 232-248.

Scibiorski, E., Tohver, E., Jourdan, F., Kirkland, C.L., Spaggiari, C., 2016. Cooling and exhumation along the curved Albany-Fraser orogen, Western Australia. Lithosphere 8, 551-563.

Shafik, S., 1992. Eocene and Oligocene calcareous nannofossils from the Great Australian Bight: evidence of significant reworking episodes and surface-water temperature changes. BMR Journal of Australian Geology and Geophysics, *13*, 131-142.

Song, T., Cawood, P.A., 2000. Structural styles in the Perth Basin associated with the Mesozoic break-up of Greater India and Australia. Tectonophysics 317, 55-72.

Spaggiari, C., Bodorkos, S., Barquero-Molina, M., Tyler, I., Wingate, M., 2009. Interpreted bedrock geology of the south Yilgarn and central Albany–Fraser Orogen, Western Australia. Geological Survey of Western Australia Record 2009/10, 84p.

Spaggiari, C., Kirkland, C., Pawley, M., Smithies, R., Wingate, M., Doyle, M., Blenkinsop, T., Clark, C., Oorschot, C., Fox, L., Savage, J., 2011. The geology of the east Albany–Fraser Orogen — a field guide. Geological Survey of Western Australia Record 2011/23, 97p.

Spaggiari, C., Kirkland, C., Smithies, R., Occhipinti, S.A., Wingates, M., 2014. Geological framework of the Albany-Fraser Orogen, in: Spaggiari, C., Tyler, I.M. (Eds.), Albany-Fraser Orogen Seismic and Magnetotelluric (MT) Workshop 2014: Extended Abstracts. Geological Survey of Western Australia, Record 2014/06, pp. 12-27.

Spaggiari, C.V., Kirkland, C.L., Smithies, R.H., Wingate, M.T.D., Belousova, E.A., 2015. Transformation of an Archean craton margin during Proterozoic basin formation and magmatism: The Albany–Fraser Orogen, Western Australia. Precambrian Research 266, 440-466.

Teasdale, J.P., Pryer, L.L., Stuart-Smith, P.G., Romine, K.K., Etheridge, M.A., Loutit, T.S., Kyan, D.M., 2003. Structural framework and basin evolution of Australia's southern margin. The APPEA Journal 43, 13-47.

Totterdell, J.M., Blevin, J.E., Struckmeyer, H.I.M., Bradshaw, B.E., Colwell, J.B., Kennard, J.M., 2000. Anew sequence framework for the Great Australian Bight: Starting with a clean slate. The APPEA Journal 40, 95-118.

Totterdell, J.M., Bradshaw, B.E., 2004. The structural framework and tectonic evolution of the Bight Basin, in: Boult, P.J., Johns, D.R., Lang, S.C. (Eds.), PESA's Eastern Australian Basins Symposium II. Conference Proceedings. Petroleum Exploration Society of Australia, Special Publication, Adelaide, South Australia, pp. 41-61.

Tucker, N.M., Payne, J.L., Clark, C., Hand, M., Taylor, R.J.M., Kylander-Clark, A.R.C., Martin, L., 2017. Proterozoic reworking of Archean (Yilgarn) basement in the Bunger Hills, East Antarctica. Precambrian Research 298, 16-38.

Veevers, J.J., Powell, C.M., Roots, S.R., 2007. Review of seafloor spreading around Australia. I. synthesis of the patterns of spreading. Australian Journal of Earth Sciences 38, 373-389.

Waddell, P.-J.A., Timms, N.E., Spaggiari, C.V., Kirkland, C.L., Wingate, M.T.D., 2015. Analysis of the Ragged Basin, Western Australia: Insights into syn-orogenic basin evolution within the Albany–Fraser Orogen. Precambrian Research 261, 166-187.

Wang, X.C., Li, Z.X., Li, J., Pisarevsky, S.A., Wingate, M.T., 2014. Genesis of the 1.21 Ga Marnda Moorn large igneous province by plume–lithosphere interaction. Precambrian Research 241, 85-103.

White, L.T., Gibson, G.M., Lister, G.S., 2013. A reassessment of paleogeographic reconstructions of eastern Gondwana: Bringing geology back into the equation. Gondwana Research 24, 984-998.

Wilde, S.A., 1980. The Jimperding Metamorphic Belt in the Toodyay area and the Balingup Metamorphic Belt and associated granitic rocks in the southwestern Yilgarn Craton. Excursion Guide. In 2nd International Archaean Symposium. Geological Society of Western Australia.

Wilde, S.A., Valley, J.W., Peck, W.H., Graham, C.M., 2001. Evidence from detrital zircons for the existence of continental crust and oceans on the Earth 4.4 Gyr ago. Nature 4009, 175-178.

Willcox, J.B., Stagg, H.M.J., 1990. Australia's southern margin: a product of oblique extension. Tectonophysics 173, 269-281.

Williams, S.E., Whittaker, J.M., Müller, R.D., 2011. Full-fit, palinspastic reconstruction of the conjugate Australian-Antarctic margins. Tectonics 30, n/a-n/a.

Wingate, M.T.D., Campbell, I.H., Harris, L.B., 2000. SHRIMP baddeleyite age for the Fraser dyke swarm, southeast Yilgarn Craton, Western Australia. Australian Journal of Earth Sciences 47, 309-313.

Wingate, M.T.D., Kirkland, C.L., 2011. 185931: Quartz Diorite Dyke, Top Camp Well; Geochronology Record 974. Geological Survey of Western Australia, 5.

Wyche, S., Nelson, D.R., Riganti, A., 2004. 4350–3130 Ma detrital zircons in the Southern Cross Granite–Greenstone Terrane, Western Australia: implications for the early evolution of the Yilgarn Craton. Australian journal of Earth Sciences 51, 31-45.

Wyrwoll, K.H., Greenstein, B.J., Kendrick, G.W., Chen, G.S., 2009. The palaeoceanography of the Leeuwin Current: implications for a future world. Journal of the Royal Society of Western Australia, 92, 37-51.

RECORD 2017/15

SGTSG MID-CONFERENCE FIELD TRIP GUIDE: THE WESTERN NORNALUP ZONE, ALBANY–FRASER OROGEN, WESTERN AUSTRALIA

Timms

This Record is published in digital format (PDF) and is available as a free download from the DMIRS website at <www.dmp.wa.gov.au/GSWApublications>.

Further details of geological products produced by the Geological Survey of Western Australia can be obtained by contacting:

Information Centre
Department of Mines, Industry Regulation and Safety
100 Plain Street
EAST PERTH WESTERN AUSTRALIA 6004
Phone: +61 8 9222 3459 Fax: +61 8 9222 3444
www.dmp.wa.gov.au/GSWApublications