

Building the Proterozoic Albany–Fraser Orogen on the Yilgarn Craton margin: setting the scene for Tropicana

by

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The Yilgarn Craton is truncated by Proterozoic orogens on all sides, with little or no indication of its former extent. Its southern and southeastern margins are cut by the Albany–Fraser Orogen, which is divided into the Northern Foreland (representing reworked Yilgarn Craton) and the Paleo- to Mesoproterozoic Kepa Kurl Booya Province (representing the pre-amalgamation basement components). The Kepa Kurl Booya Province is divided into the Biranup, Fraser, and Nornalup Zones, respectively, from northwest to southeast (Fig. 1; Spaggiari et al., 2009). These are intruded by Mesoproterozoic granitic rocks of the Recherche and Esperance Supersuites, and overlain by various cover rocks. High-temperature metamorphism and deformation have affected the majority of the orogen, making it difficult to distinguish reworked Archean Yilgarn Craton rocks from orogenic Proterozoic rocks without the aid of geochronology. Such a distinction is fundamental to understanding the tectonic evolution of both the craton margin and the orogen, and consequently the formation of gold deposits such as Tropicana, and other gold deposits within the orogen (Fig. 1). The most popular exploration model for Tropicana is that of reworked Archean gold, yet there are no published data to support such a model. It is also not clear whether this model is applicable on a regional scale, away from the Tropicana–Havana area.

Biranup Zone

Geophysical imagery and geochronology* indicate that the dominantly 1690 to 1660 Ma Biranup Zone wraps the entire exposed length of the southern and southeastern Yilgarn Craton over a distance of at least 1200 km, and is the principal unit adjoining the craton (Fig. 1). In the eastern Biranup Zone, granitic rocks dated between 1690 and 1680 Ma intruded psammitic to semipelitic metasedimentary rocks very shortly after their deposition (Fig. 2). Dating of folded leucosomes and cross-cutting pegmatites indicates that folding and migmatization of both the metasedimentary and granitic rocks occurred at c. 1680 Ma. This deformation event was followed by the intrusion of a suite of granitic to gabbroic rocks and their hybrids, dated at c. 1665 Ma.

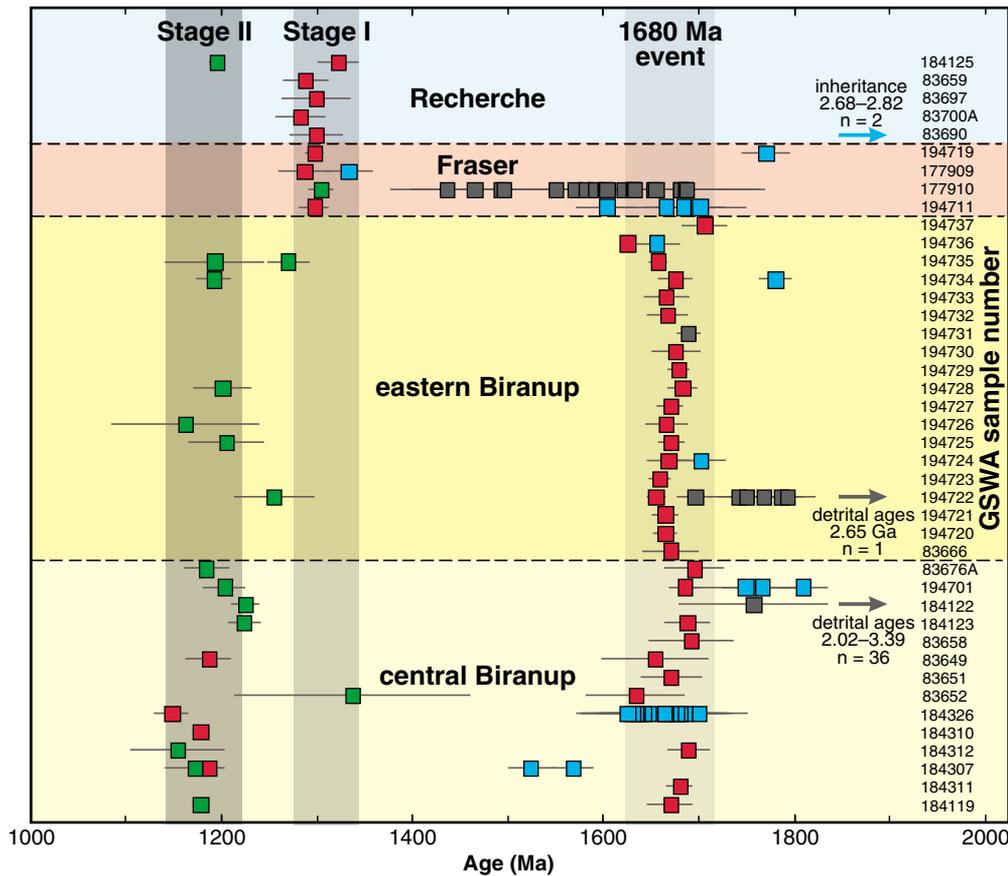
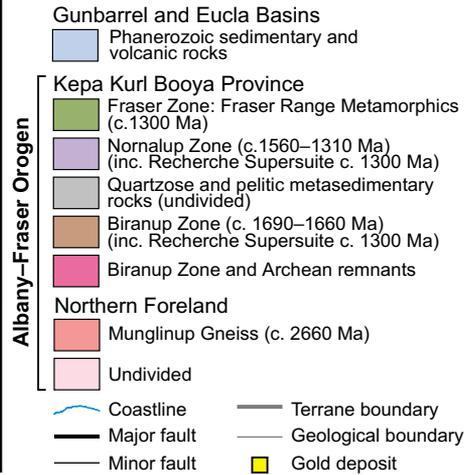
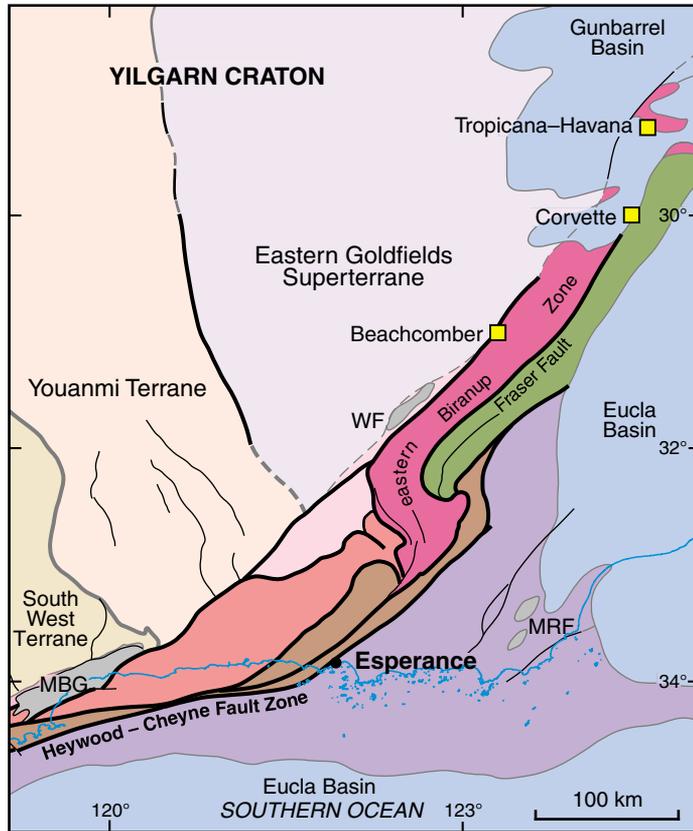
* Individual geochronology records for each sample will be available online at <<http://www.dmp.wa.gov.au/geochron>>

The sequence of events indicates rapidly evolving crust within a dynamic tectonic environment between 1690 and 1660 Ma. However, it is not clear whether the Biranup Zone formed directly on the Yilgarn Craton margin, perhaps as a continental arc, or whether it is an exotic terrane that was subsequently accreted onto the Yilgarn Craton margin. From more than 30 samples dated so far, virtually no Archean zircon inheritance has been recorded (Fig. 2), which favours the latter interpretation, as does the alkaline composition of rapakivi-textured metagranitic rocks. There is also no direct evidence of a tectonothermal event at this time in the southeastern Yilgarn Craton.

The Biranup Zone was extensively reworked at high temperatures along its entire length mainly between 1200 and 1180 Ma (equivalent to the c. 1215–1140 Ma Stage II of Clark et al., 2000; Fig. 2). Interestingly, there is no conclusive evidence of Stage I (c. 1345–1280 Ma), which is recorded prominently in the adjoining Fraser Zone to the southeast. The oldest metamorphic age in the Biranup Zone, at c. 1270 Ma, is about 10 Ma younger than granitic magmatism in the Fraser Zone (Kirkland et al., 2010). However, a common connection between the eastern Biranup and Fraser Zones is indicated by a record of uplift and cooling between Stages I and II.

Figure 1. Preliminary geological sketch map of the eastern Albany–Fraser Orogen and east Yilgarn Craton (adapted from Spaggiari et al., 2009) showing locations of the main gold prospects and deposits. MBG = Mount Barren Group; MRF = Mount Ragged Formation; WF = Woodline Formation. Inset map shows the location of Mesoproterozoic tectonic units of Australia; MP = Musgrave Province; PO = Paterson Orogen; N = Northampton Complex; L = Leeuwin Complex; AFO = Albany–Fraser Orogen.

Figure 2. Time–space diagram for the Albany–Fraser Orogen. The diagram includes all ion microprobe (SHRIMP) U–Pb zircon and baddeleyite ages determined by the Geological Survey of Western Australia within the region. Within each major lithostratigraphic domain (Recherche Supersuite, Fraser Zone, eastern and central Biranup Zone) the data are arranged in geographic order from southwest at the base to northeast at the top, and show no apparent trends. Note that sample 194722 is a mylonitized, pegmatite-bearing metasedimentary rock, and hence contains both magmatic and detrital components. n = number of zircons.



Fraser Zone

The c. 1305–1290 Ma Fraser Zone is dominated by amphibolite to granulite facies metagabbroic rocks that impart a distinct, high gravity signature. The Fraser Zone is presently in fault contact with the Biranup Zone (e.g. along the Fraser Fault in the south), but limited U–Pb data indicate inheritance of zircons with ages similar to those in the Biranup Zone (Fig. 2). These data imply a spatial connection at c. 1300 Ma, which is consistent with the shared uplift history recorded between Stages I and II. In contrast to the Biranup Zone, there is no geochronological record of Stage II activity in the Fraser Zone (Fig. 2), although it is possible that major structures such as the Fraser Fault may have placed these rocks at a higher structural level that was not favourable for zircon growth.

The exposed section of the Fraser Zone in the south is dominated by the Fraser Range Metamorphics, a sheeted complex of gabbroic to granitic rocks that appear to have intruded and migmatized pelitic to calcic metasedimentary rocks. These rocks have all undergone granulite-facies metamorphism close to the time of intrusion, indicating that they represent a thick piece of hot mafic crust (a lower crustal hot zone) that has been structurally modified. Previous interpretations have suggested that the Fraser Zone represents a collage of remnant magmatic arcs (Condie and Myers, 1999), which fits with the known lithologies, although more geochemical data are required to verify this hypothesis.

The scene at Tropicana

The Tropicana–Havana gold deposit lies just east of a major northeast-trending fault marking the edge of the Yilgarn Craton (Fig. 1). The deposit lies within a zone of dominantly northwest-trending magnetic highs cut by northeast- to east-trending shear zones and mafic dykes, and within a northwest-trending, moderate gravity anomaly. The gold is reported to be hosted by Archean garnetiferous gneiss and K-feldspar-rich quartzofeldspathic gneiss (Doyle et al., 2009). However, on a regional scale, the surrounding lithologies are dominated by northeast-trending Biranup Zone metagranitic rocks, including an extensive suite of metasyenogranites mingled with metagabbro. Minor occurrences of metamorphosed mafic to ultramafic rocks and banded iron-formation are suggestive of Archean greenstones, although other interpretations are feasible. Possible scenarios to explain the margin setting include: (1) the Biranup Zone formed in situ along the margin of the Yilgarn Craton at c. 1680 Ma; (2) the Biranup Zone is tectonically interleaved with the reworked margin of the Yilgarn Craton; (3) the Biranup Zone contains remnants of Archean rocks that may be rifted fragments of the Yilgarn Craton, or may be exotic Archean rocks; or (4) the Tropicana area is part of the Biranup Zone and was accreted to the Yilgarn Craton margin, and the reported Archean component is inherited material.

Mineralization at Tropicana–Havana is described as syn-deformational but younger than the peak amphibolite to granulite facies metamorphic event (Doyle et al., 2009). Assuming the deformation and metamorphism are related

to the Albany–Fraser Orogeny (and are not Archean), this implies that mineralization may have occurred during Stage II (c. 1215–1140 Ma), consistent with metamorphic ages in the eastern Biranup Zone (Fig. 2). However, the extent of the Stage II event in the Tropicana–Havana area is not yet fully understood.

Future work

Although significant progress on understanding the regional evolution of the Albany–Fraser Orogen has been made, there are still many unresolved problems, such as the existence and nature of any Archean components within the Biranup Zone. Geochemical analysis of rocks from both the Biranup and Fraser Zones is underway to identify and map out the magmatic suites, and to help interpret tectonic settings. The Lu–Hf isotopic composition of dated zircons from both the Yilgarn Craton and the orogen will allow a comparison of source materials, as well as indicating the degree to which juvenile material or reworked crustal sources have contributed to magmatism. Monazite dating combined with P–T–t analysis will also be used to help determine the regional extent of overprinting events. Monazite is more susceptible to dissolution than zircon, so is more likely to record the overprinting history rather than inheritance. These results will be interpreted in conjunction with structural and geophysical data to provide a greater understanding of the relationships between the tectonic assemblages. Although the exploration model of reworked Archean gold may be sound, alternative models, based on the current regional dataset, should also be considered.

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REE, lithium, potash, and phosphate mineralization in Western Australia

by DJ Flint

Rare earth elements

The not-so-rare rare earth elements (REE) have become strategically important globally — the former Chinese premier, Deng Xiaoping, once said ‘The Middle East has oil. China has rare earths’ (Dowling, 2010). Along with many other uses, REE are components of many modern electronic products including flat-panel displays, hard-disk drives and iPods. China currently supplies 95% of the world’s rare earths, but is restricting supply. New significant resources to supply the rest of the world in the near term are limited, and Western Australia (via the Mount Weld REE–tantalum–niobium–phosphorus project) is positioned to meet the growing demand (and expected supply shortage) for these elements. The Mount Weld REE–Ta–Nb–P carbonatite was discovered in 1988 and partly developed in 2008, but problems with continuity of funding arose during the global economic crisis in early 2009. Control of the project owners — Lynas Corporation Ltd — almost passed to the China Nonferrous Metal Mining Group, but was refused by the Australian Foreign Investment Review Board. The Central Lanthanide deposit at Mount Weld is estimated to contain resources totalling 12.2 Mt at 9.7% REO at a cutoff grade of 2.5% REO, yielding 1.18 Mt of contained REO. The Central Lanthanide deposit contains predominantly light REO from CeO₂ (46.7%), La₂O₃ (25.5%), Nd₂O₃ (18.5%), Pr₆O₁₁ (5.32%), Sm₂O₃ (2.27%), to Eu₂O₃ (0.44%), together with minor proportions of heavy REO: Dy₂O₃ (0.124%), and Tb₄O₇ (0.07%) (Lynas Corporation, 2010). Other known REE prospects and their settings include Cummins Range (carbonatite intrusion), Cundeleece (alkaline ultramafic intrusion with carbonatitic affinities), Brockman (trachyte and related tuffs), Yangibana (dykes and sills of carbonatite and fenitized rocks, with iron oxide veins containing uranium and REE; Pirajno, in prep.), and John Galt, which is xenotime in lithic quartz sandstone of the Proterozoic Red Rock Formation (Fetherston, 2008).

Lithium

The light metal lithium is another commodity in high demand in recent times, with interest particularly driven by its use in lithium-ion batteries for electric vehicles (broadly speaking, the mobile energy storage industry). Western Australia has a long history of lithium production from spodumene pegmatites at Greenbushes and Ravensthorpe

(Mount Cattlin). Talison Lithium Ltd, from mining at Greenbushes, is the world’s largest producer of lithium minerals. The Greenbushes pegmatite contains up to 50% spodumene, but averages 3.5%–4.5% Li₂O. Recent annual production of spodumene concentrate from Greenbushes is at the rate of approximately 200 000 tpa of various grades; low-grade products are of >5.0% and >6.0% Li₂O, with a high-grade product of >6.4% Li₂O (Miller, 2009). Much of Western Australia’s past production of spodumene was treated in China to produce lithium carbonate — for feedstock for the chemical industry. This is the same route being taken for the new Mount Cattlin lithium–tantalum mine owned by Galaxy Resources Ltd. The mine, which is under construction, has global resources totalling 14.4 Mt at 1.08% Li₂O and 153 ppm Ta₂O₅ (Galaxy Resources, 2010). In late 2009, Haddington Resources Ltd announced the discovery of a lithium–tantalum pegmatite, with rock-chip sampling results up to 5% Li₂O. The discovery was in the Pilbara at Pilgangoora, in the vicinity of historic tin–tantalum mining (Haddington Resources, 2009). About 80% of the world’s lithium is obtained from continental salt-lake brines in South America, and Australia’s first lithium of this style was found by Reward Minerals Ltd in 2008 at Dumbleyung, extraordinarily while exploring for potash. The brines contain 530 mg/L lithium and 1000 mg/L potassium (Reward Minerals, 2009), with the lithium grade comparable to the average resource grade of the Atacama (Clarke, 2009). Western Australia also has potential for lithium-rich clay (hectorite) in a similar setting as bentonite, that is, as secondary clays in paleodrainage channels and lacustrine environments.

The fertiliser elements — potassium and phosphorus

Australia currently does not produce potassium minerals and imports about 50 000 t of potassium sulfate annually. Australia moved a big step closer to its first potassium mine after the discovery by Reward Minerals Ltd – Holocene Pty Ltd in 2006 of potassium-rich brine at Lake Disappointment, 300 km east of Newman, with average brine grades of around 3.17% K₂SO₄ (Fetherston, 2008). However, 2009 was disappointing as agreement could not be reached with the Martu people, the Native Title Tribunal decided against the grant of a mining lease, and an appeal to the Commonwealth Attorney General was unsuccessful (Gregory, 2009).

Potassium is found within evaporitic sequences, either in modern playas such as Lake Disappointment, Lake Auld (450 km east of Newman), and Lake Mackay (bordering the Northern Territory) or in older buried evaporitic sequences, such as the Yaringa Evaporite Member of the Dirk Hartog Formation (Southern Carnarvon Basin). Reward Minerals now has substantial inferred resources at Lake Mackay (20 Mt of contained K_2SO_4). Historically, Western Australia has produced potassium from alunite (potassium aluminium sulfate) at Lake Chandler (near Merredin) during the 1940s and the deposit is currently being assessed by ActivEX Ltd.

There are 85 sites of known phosphorus mineralization in Western Australia, in addition to the indurated guano (rock phosphate) of Christmas Island. The geological settings of these sites range from apatite within carbonatite and in overlying regolith (e.g. Mount Weld, Cummins Range), phosphate nodules in marine sediments (e.g. Langey Crossing and Liveringa in the Paleozoic of the Canning Basin; at Cardabia and Wandinny Dam in the Cretaceous of the Carnarvon Basin south of Exmouth; and at Wagon Creek in the Paleozoic Southern Bonaparte Basin), glauconite in marine sandstones near Dandaragan (North Perth Basin), variscite in hydrothermal veins (Mount Deverell in the Edmund Basin), apatite in layered mafic-ultramafic intrusives (Balla Balla in the Pilbara), and recent guano from sea birds, bats, and even wallabies (found in Jingemia Cave and Jurien Bay Cave). All have been variously explored and some are marginally economic. The deposit most likely to be mined first is Balla Balla, where the apatite is a potential by-product to the iron-vanadium-titanium magnetite mineralization.

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