Melting, mixing, and emplacement: evolution of the Fraser Zone, Albany–Fraser Orogen

by

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The Fraser Zone of the Albany–Fraser Orogen is an approximately 425 km long, up to 50 km wide, northeast-trending, fault-bounded unit that lies between the predominantly Paleoproterozoic basement rocks of the Biranup and Nornalup Zones (Fig. 1). As indicated by its dense gravity signature (Fig. 2), the Fraser Zone is dominated by metagabbroic rocks. Only the southwestern portion is exposed, which contains the c. 1305–1290 Ma Fraser Range Metamorphics. These comprise thin to voluminous sheets of metagabbroic rocks that range in thickness from several centimetres up to several hundred metres, interlayered with sheets of monzogranitic to syenogranitic gneisses, pyroxene-bearing granitic gneisses, and hybrid, metamorphosed magmatic rocks. The magmatic rocks are interlayered at various scales with amphibolite to granulite facies pelitic, semipelitic to calcic, and locally iron-rich metasedimentary rocks of the Mesoproterozoic Arid Basin. The Fraser Zone has been previously interpreted as an exhumed block of lower crust (Doepel, 1975), a layered mafic intrusion emplaced into older basement represented by the granitic and metasedimentary rocks (Myers, 1985), multiple accreted magmatic oceanic arcs (Condie and Myers, 1999), and an oceanic arc related to southeast-dipping subduction, accretion, and collision of the Mawson Craton (Bodorkos and Clark, 2004). We interpret the Fraser Zone as a structurally modified, lower crustal hot-zone where voluminous gabbroic magmas were variably mixed with contemporaneous granitic magma and country-rock melts. The presence of these gabbroic magmas, regional granite magmatism, and previously published peak metamorphic conditions in the metasedimentary rocks of >800°C and 8–9 kbars (Oorschot, 2011), are all indicative of a regional thermal anomaly from at least 1305–1290 Ma that coincided with the formation of the Fraser Zone. Based on these findings, and on a range of other recent geological evidence, the preferred tectonic setting is either a distal back-arc or an intercontinental rift (Spaggiari et al., 2011; Smithies et al., 2013). We summarize the main features below.

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Arid Basin

The c. 1450–1305 Ma Arid Basin is a regionally extensive basin system containing metasedimentary rocks of highly variable compositions that have maximum depositional ages that are younger than the 1710–1650 Ma Biranup Orogeny, but have been affected by Stage I of the Albany–Fraser Orogeny (1345–1260 Ma). The Arid Basin represents the second major cycle of erosion and sediment deposition in the orogen, and includes the metasedimentary component of the Fraser Range Metamorphics, as well as the Malcolm Metamorphics (formerly the Malcolm Gneiss), and the Gwynne Creek Gneiss in the northeast (Fig. 1; Spaggiari et al., 2011). The tectonic setting of the Arid Basin is not known, but basin formation, generation of the Fraser Zone intrusions, regional granite magmatism (1330–1280 Ma Recherche Supersuite), high-temperature metamorphism, and the inferred regional thermal anomaly are almost certainly directly linked.

In the Fraser Zone, the thickest exposures of Arid Basin metasedimentary rocks lie along its northwestern edge, and are typically interlayered with sheets or sills of mafic granulite or amphibolite derived from the gabbroic intrusions. Whereas pelitic and semipelitic rocks dominate the metasedimentary component in the southern part of the Fraser Zone, the northern exposed section contains metasedimentary rocks that have calc-silicate affinities, and may represent metamorphosed marls, or volcaniclastic protoliths. Partial melts of the metasedimentary rocks of the Arid Basin are inferred to have contaminated some of the gabbroic intrusions in the Fraser Zone, forming one of two groups of hybrid rocks (Smithies et al., 2013).

Summary of the age relationships of the Fraser Range Metamorphics

All isotopic results from the Fraser Zone indicate a short time interval for sediment deposition, coeval mafic and felsic igneous crystallization, and near coeval granulite-facies metamorphism. Maximum depositional ages of the metasedimentary rocks indicate they were deposited immediately prior to magmatism. For example, garnet–biotite metasedimentary gneiss south of Verde Austral quarry (Fig. 2) yielded a maximum depositional age

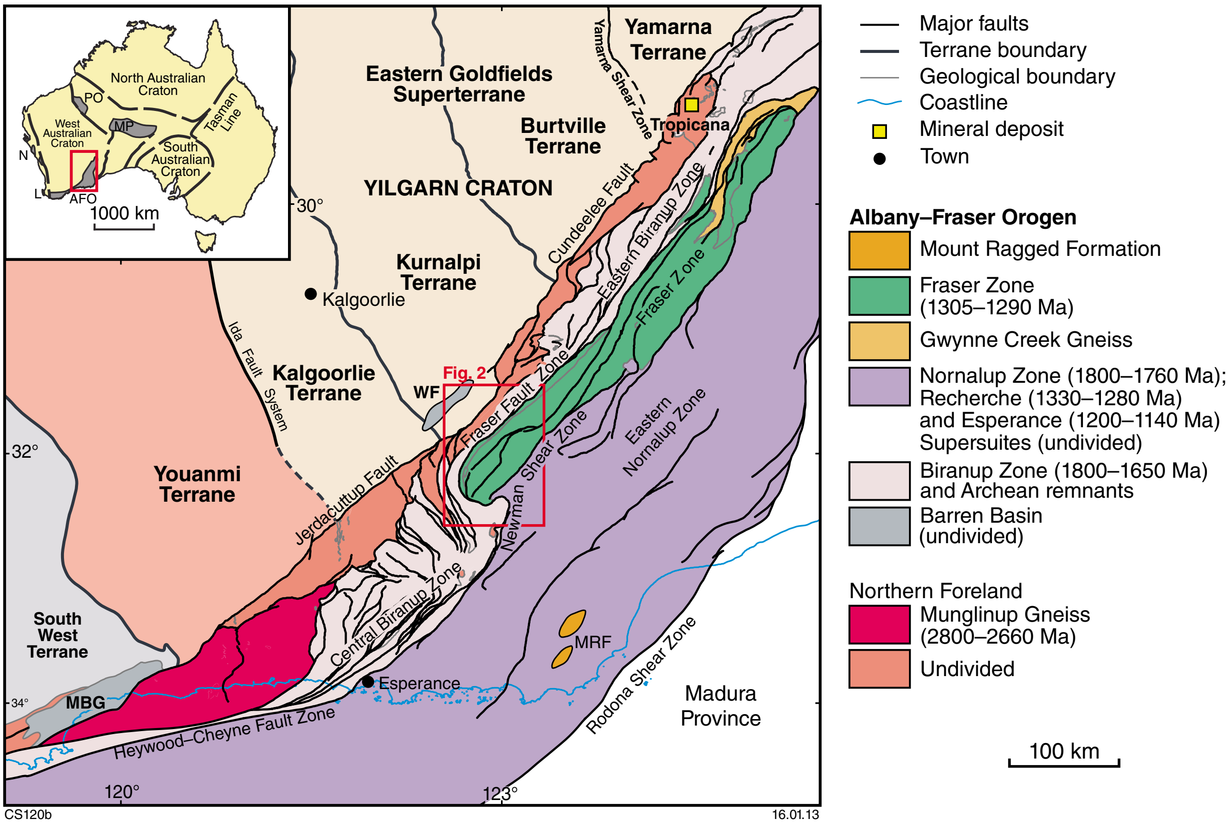

Figure 1. **Simplified, pre-Mesozoic interpreted bedrock geology of the eastern Albany–Fraser Orogen and tectonic subdivisions of the Yilgarn Craton (from Spaggiari et al., 2011) Abbreviations used: MBG – Mount Barren Group; WF – Woodline Formation; MRF – Mount Ragged Formation; AFO – Albany–Fraser Orogen; MP – Musgrave Province; PO – Paterson Orogen; L – Leeuwin Province; N – Northhampton Province**

of 1332 ± 21 Ma (single zircon analysis), or the more conservative estimate of 1363 ± 9 Ma (24 youngest analyses; GSWA 194778, preliminary data). Zircon rims from the same sample yielded a metamorphic date of 1298 ± 12 Ma, identical to metamorphic zircons from mafic granulite at the American quarry (Fig. 2; 1292 ± 6 Ma; GSWA 194718, Kirkland et al., 2011). Magmatic crystallization of two-pyroxene metagabbro from the Fraser Range Black quarry has been dated at 1299 ± 3 Ma (Fig. 2, GSWA 194717, preliminary data), and at 1299 ± 10 Ma and 1291 ± 8 Ma from southwest of Symons Hill (Fig. 2, De Waele and Pisarevsky, 2008). Metasyenogranite from near Symons Hill yielded a magmatic crystallisation date of 1298 ± 5 Ma (Kirkland et al., 2011). Similar results, between c. 1300 and 1290 Ma, have been obtained for other metagranitic rocks, and both felsic and gabbroic pegmatitic intrusions. The close correspondence between magmatism and granulite facies metamorphism, predominantly between 1305 and 1290 Ma, implies magmatism as a thermal driver of metamorphism.

Petrogenesis of the Fraser Zone gabbroic rocks

Two broad geochemical groups can be recognized: the ‘main gabbros’ which show no field, petrographic, or geochemical evidence of having interacted with country-rock; and the ‘hybrid gabbros’ which show considerable evidence for such interaction. The main gabbros are dominantly olivine gabbro to olivine gabbronorite containing up to 15% olivine, 35–60% plagioclase, generally greater abundances of clinopyroxene to orthopyroxene, up to 20% brown hornblende, up to 10% brown biotite, and up to 5% magnetite (Smithies et al., 2013). The hybrid gabbros commonly include the presence of subhedral K-feldspar phenocrysts (or perthitic or antiperthitic mixtures) and high and unevenly distributed modal proportions of quartz and K-feldspar, which are commonly developed as stringers or blebs. Garnet up to 6 mm or so occurs in some layers. In comparison to the main gabbros, they typically contain less, or no, olivine.

The hybrid gabbros can be further subdivided geochemically into low La/Th rocks that have incorporated material from contemporaneous high-Th monzogranitic sheets (Group 1 hybrid gabbros), and high La/Th rocks that have assimilated low-degree partial melts of metasedimentary country-rock at the level of emplacement (Group 2 hybrid gabbros). The main gabbro is parental to the hybrid gabbros but escaped hybridization during ascent or emplacement. However, they still contain an enriched crustal component acquired at a deeper level. Previous accounts have suggested this enrichment

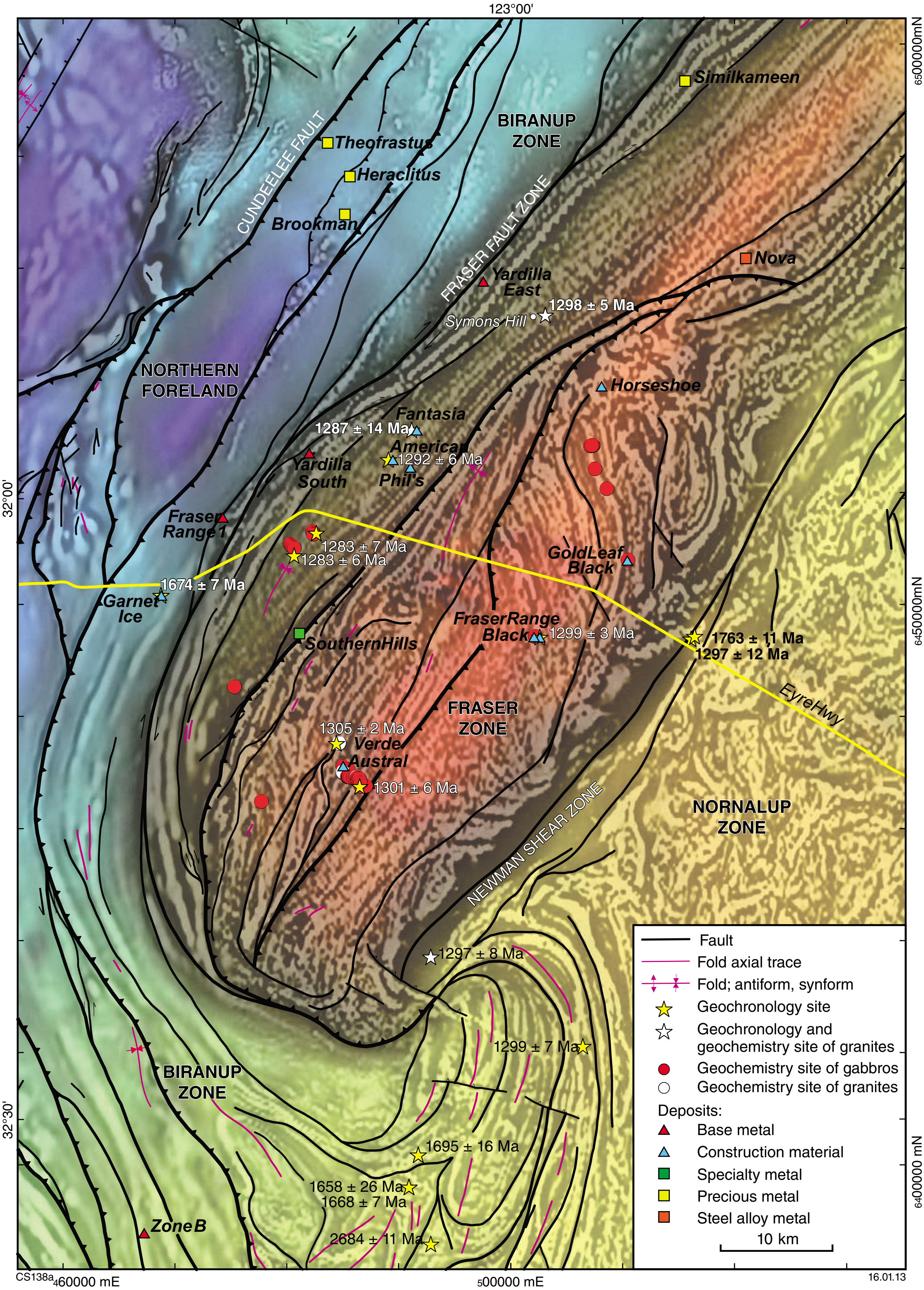

Figure 2. Colour gravity image with black and white, first vertical derivative aeromagnetic drape of the southwestern part of the Fraser Zone, showing major structures, geochemistry sample locations, and U–Pb (SIMS) ages

reflects a subduction addition to the mantle sources of the gabbros during the evolution of a series of oceanic island arcs (Condie and Myers, 1999). All previous and recent Nd- and Hf-isotopic data are inconsistent with that interpretation — trace element enrichments are better explained in terms of assimilation of basement that included a low-Sr component of Archean, or reworked Archean, crust. The presence of this type of crust in the adjacent Biranup Zone, and potentially in the Nornalup Zone (Figs 1 and 2), lends substantial weight to these interpretations. Following early basement contamination, the 'main gabbro' sheets that form the dominant component of the Fraser Zone were emplaced into a lower crustal hot-zone where they variably mixed with contemporaneous granite magma and country-rock melts.

Structural emplacement of the Fraser Zone

The Fraser Range Metamorphics are dominated by a well-developed, northeast-trending, predominantly steeply southeast-dipping foliation, although massive rocks occur locally. In general, this foliation is axial planar to tight to isoclinal, northeast-trending folds of the layering, which are cut by thrust faults and shear zones. Whereas much of the northwestern side of the Fraser Zone is dominated by folding and strongly foliated to mylonitic rocks, the least deformed and thickest examples of metagabbroic sheets occur in the southeast, reflecting a significant difference in strain before reaching the Newman Shear Zone, which defines the southeastern boundary of the Fraser Zone (Fig. 2). Aeromagnetic and gravity data indicate a repetition of this architecture along strike to the northeast, beneath the Eucla Basin.

Late, metagranitic veins containing large euhedral garnets crosscut the foliation and have been dated at 1283 ± 8 Ma (GSWA 194780, preliminary data), indicating that deformation under high temperature conditions took place shortly after emplacement of the gabbroic and granitic sheets. This suggests the stress field may have rapidly switched from extensional or transtensional (accommodating basin formation and magma emplacement) to compressional or transpressional. This switch may also have contributed to the exhumation of the Fraser Zone along the bounding shear zones, possibly by formation of a pop-up architecture between the Biranup and Nornalup Zones.

Metagranitic rocks along the Newman Shear Zone commonly contain a strong subvertical lineation. Locally, the metagranites are L-tectonites, or occur as L-S tectonites in discrete mylonite zones. Kinematic indicators suggest southeast side up. However, less commonly the lineation and kinematics indicate subhorizontal sinistral shear. In contrast, the Fraser Fault Zone, which defines the northwestern boundary of the Fraser Zone, contains strongly mylonitized rocks with a subhorizontal mineral lineation and kinematics indicative of a dextral shear sense. These shear zone fabrics formed under lower temperature conditions than the folding and associated high temperature fabric formation described above, and probably relate to the final emplacement of the Fraser Zone during Stage II of the Albany–Fraser Orogeny (1215–1140 Ma). The differential kinematics suggest southwestward translation of the Fraser Zone, contributing to the formation of the 'S-bend' termination, and potentially a component of clockwise rotation exposing deeper levels on the northwestern side.

Mineralization

Mineralization at the recently discovered nickel–copper sulphide deposit (Nova, Fig. 2) by Sirius Resources NL at The Eye prospect occurs as pyrrhotite, pentlandite, and chalcopyrite, which display typical magmatic textures including massive, matrix, net-textured, breccia, blebby, and disseminated forms (Sirius Resources NL, 2012a). Although described as magmatic, the mineralization does locally crosscut garnet-bearing metamorphic layering (Sirius Resources NL, 2012b). The host rocks are dominantly gabbroic granulites (Sirius Resources NL, 2012a,b), similar to the main and hybrid gabbros described above. Based on the available geochronological data, metamorphism occurred shortly after magmatism, and may have been a significant secondary control on the mineralization. Diamond drillcore of metamorphosed gabbroic to ultramafic rocks that did not intersect the main zone of mineralization (i.e. is structurally above it) contains a non-economic, disseminated sulphide assemblage of pyrrhotite, pentlandite, and chalcopyrite (Gollam, 2012). This is crosscut by lower temperature alteration, including serpentinite and talc–carbonate veins (Gollam, 2012) that have colloidal, vuggy, laminated, and brecciated textures and locally contain sulphides. This indicates a phase of remobilization that probably post-dates the main high temperature, ore-forming event.

With respect to their potential to yield Ni–Cu mineralization, the main gabbros of the Fraser Zone have relatively high Ni/Cu ratios (Ni/Cu = 2–3), which also appears to be a feature of the Nova discovery (e.g. Sirius Resources NL, 2012a,b). In this respect, it is reasonable to relate the host gabbro at Nova to the main gabbro suite. If this is the case, then the entire Fraser Zone may be prospective for similar Ni–Cu sulfide mineralization. Whereas the Ni concentration of the main gabbro is comparable to those of many other basalts globally with similar MgO contents, Cu concentrations are relatively low (average Cu content of main gabbro ~54 ppm). This is also apparent in their low Cu/Zr ratios (typically <1). It is possible that Cu was extracted more efficiently than Ni as a result of early sulfide segregation during magma crystallization, or was retained in the mantle during partial melting. However, at this early stage of investigations, these data only tell us that the Fraser Zone magmas underwent early equilibration with sulphide, and the relatively unaltered state of the rocks suggests that this occurred before final emplacement.

The hybridization processes leading to Group 1 and 2 hybrid gabbros may have caused additional sulfur saturation in these magmas but it remains unclear whether this process was a factor in producing the Nova deposit, or whether the sulphides there were entrained in magma ascending from a deeper crustal level.

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