Archaean granites of the Yilgarn & Pilbara cratons, Western Australia

D.C. Champion[1] and R.H. Smithies[2]

[1] Australian Geological Survey Org., GPO Box 378 Canberra, ACT, Australia

[2] Geological Survey of Western Australia 100 Plain Street East Perth, WA, Australia

Granites of the tonalite-trondhjemite-granodiorite (TTG) suite are commonly thought to be the dominant granite type in Archaean terranes, with their dominance decreasing towards the end of the Archaean concurrent with the onset of significant reworking of older continental crust and the production of more potassic granites (Martin 1994). This broadly established sequence is, however, over simplified. Clearly different granites, including high-Mg varieties, alkaline/sub-alkaline granites, and granites with A-type affinities, are also important in the Archaean. More importantly, the increasing recognition of granites with evidence for an enriched-mantle component is providing constraints on both crustal growth mechanisms and possible tectonic environments.

Archaean granites in Australia are best preserved in the Pilbara and Yilgarn Cratons, Western Australia. Both are examples of Archaean granite-greenstone terrains dominated (>65%) by granites (and orthogneisses). This paper compares and contrasts granites from the central and eastern parts of the Pilbara Craton (CEP) with those from the Eastern part of the Yilgarn Craton (EY). Geological data combined with a compilation of >1200 geochemical analyses are utilised to identify both broad regional granite groups and secular changes within the both regions. Although the cratons exhibit different pre-histories it is notable that they share a somewhat similar pattern of granite evolution.

Regional geology

Central and eastern Pilbara Craton (CEP)

The granite-greenstone terrain of the exposed northern part of the Pilbara Craton (45,000 km^2), has been subdivided (Hickman 1999), into the East and West Pilbara Granite-Greenstone Terranes (EPGGT & WPGGT, respectively), which are separated by the NE-trending ca. 3.01-2.94 Ga Mallina Basin. The greenstones and granites of the Pilbara Craton were formed episodically over an 800 Ma period, from ca. 3.6 Ga to younger than 2.8 Ga. Known periods of granite intrusion in the CEP (i.e. the EPGGT and Mallina Basin), include ca. 3.47-3.41, ca. 3.33-3.31, 3.24, 3.1, 3.0-2.93 Ga, ca. 2.85 Ga and ca. 2.76 Ga, together totalling an area of ~25,000 km^2, most of which relating to the 3.47-3.41, 3.3 and 3.0-2.93 Ga events. The younger events (post 3.1 Ga) are concentrated within the Mallina Basin (Smithies et al. this volume) and the western part of the EPGGT.

Eastern Yilgarn Craton (EY)

The Yilgarn Craton (>600,000 km^2), although including two gneiss terrains (Narryer, and South-west), is dominated by three recognised granite-greenstone terrains, the ca. 3.0 to 2.63 Ga Murchison, and Southern Cross Provinces, and, to the east, the >2.76-2.63 Ga Eastern Goldfields Province. The EY, as defined here, comprises the eastern third of the Southern Cross Province (SCP) and all the Eastern Goldfields Province (EGP), with the boundary between the two areas approximating the easternmost limit of ca. 2.9-3.0 Ga greenstone belts. In contrast to the CEP, greater than 95 percent of the voluminous granites in the EY (>250,000 km^2), developed over a narrow interval (2.72-2.63 Ga), with the majority of those in the EGP emplaced over a 40 m.y. period (2.68-2.64 Ga). Indirect evidence (e.g. inherited zircons, Sm-Nd isotopic data), however, does suggest the presence of pre-existing felsic crust that may range in age from >3.0 Ga in the west to 2.8 Ga in the eastern part of the EY.

Granite geochemistry and secular changes

Central and eastern Pilbara Craton (CEP)

The early Pilbara granites (ca. 3.45 Ga), best documented in the Shaw Batholith, are similar to typical Archaean TTGs elsewhere, i.e. they have an expanded silica range (62->70% SiO_2), are sodic (medium-K), LREE-enriched, HREE- and Y-depleted [$(Y)_N$ mostly < 10], and Sr-undepleted with little or no Eu anomalies (e.g. Bickle et al. 1993). Such compositions are consistent with derivation at high pressures (garnet stable) from a mafic crustal source (thickened crust or subducted slab). Low Mg numbers (Mg# <45) may suggest a

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thickened crust origin (Smithies 2000), consistent with the presence of HREE- and Y-undepleted granites. Available isotopic data indicate a minor contribution from pre-existing felsic crust (Bickle et al. 1993).

While the 3.3 Ga granites locally share many characteristics with the 3.45 Ga group (e.g. sodic (medium-K), Sr-undepleted, Y-depleted), these granites tend to be more silica-rich (65-75% SiO_2), extend to more potassic compositions, and do not appear to be as strongly HREE-depleted (e.g. Mount Edgar batholith, Collins 1993). The 3.3 Ga group also includes numerous granites that are potassic (medium to high-K), Sr-depleted, and HREE-undepleted, such as those in the Corunna Downs Batholith (Davy 1988). These latter granites represent crustal reworking, presumably over a range of pressures including those at which plagioclase was stable (e.g. Barley & Pickard 1999). The origin of the 3.3 Ga granites in the Mt Edgar Batholith is more equivocal; they could possibly represent new crust growth, or as suggested by Collins (1993), reworking of older TTG-type granites. Regardless, it is evident from the Sm-Nd data (Nd depleted-mantle model ages (T_{DM}) of 3.4-3.6 Ga), that a significant component of pre-existing crust must have been involved in their genesis.

A dichotomy is present within the post 3.3 Ga granites of the CEP. Within the EPGGT, the ca. 2.93 Ga granites are felsic (68-76% SiO_2), characterised by high K_2O/Na_2O, generally high Rb/Sr and variable HREE-enrichment, with moderate to strong negative Eu anomalies. The 'post-tectonic' ca. 2.85 Ga granites, such as the Cooglegong, Moolyella and Numbana granites are high-silica granites (>72% SiO_2) with high K_2O/Na_2O, Y and HREE contents, generally high to very high Rb/Sr, and large negative Eu anomalies. They are typically associated with Sn, and are chemically similar to Phanerozoic I-type 'tin' granites. Apart from the western margin of the EPGGT, the 2.93 and 2.85 Ga granites have similar evolved Nd signatures, (T_{DM} between 3.3-3.6 Ga), reflecting their dominant crustal origin. Importantly, the compositions of granites in the EPGGT show a greater crustal contribution with decreasing age, i.e. from 3.45 to 2.85 Ga, they become more potassic, more siliceous, with an increasing role for plagioclase (both in the source and by fractional crystallisation).

The granite evolution in the Mallina Basin and western part of the EPGGT is more complex, and largely reflects post 3.3 Ga juvenile crust formation (as shown by young T_{DM} ages of 3.2 to 2.96 Ga), related to tectonic process in the west Pilbara and formation of the Mallina Basin (Champion & Smithies 2000; Smithies & Champion 2000). A large variety of (<3.2-2.93 Ga) granites are present, including (in probable order of decreasing age):

a) a sodic TTG suite with strong similarities to the 3.45 Ga granites though Y-undepleted;

b) a felsic medium- to high-K group with many similarities to the Mount Edgar-type 3.3 Ga granites, though mostly Y-undepleted;

c) a group (57-67% SiO_2) characterised by high MgO, Mg#, Cr, Ni and elevated LILE, that appear to represent sanukitoids and their felsic derivatives (Smithies & Champion 2000);

d) a group of sub-alkaline granites with a distinctive anhydrous mineralogy (including a sodic clinopyroxene) and distinctive A-type compositions; and

e) a felsic (68-77% SiO_2) series characterised by high K_2O/Na_2O, generally high Rb/Sr and variable HREE-enrichment, similar to the 2.93 Ga granites of the EPGGT.

Notably, the 2.85 Ga granite group does not extend into the Mallina Basin or further west. It is evident that the western CEP contains a similar progression of granite types as present in the EPGGT (from TTG to fractionated granite), although the sequence in the former was produced over a significantly shorter time period (<100 m.y. versus >650 m.y.). More importantly, the granites in the western CEP provide evidence for sub-crustal metasomatism (alkaline/sub-alkaline granites) and mantle-enrichment (sanukitoids), most probably related to prior subduction (Smithies & Champion 2000).

Eastern Yilgarn Craton (EY)

Champion & Sheraton (1997) subdivided the EY granites into two major groups (High-Ca, Low-Ca), that comprise over 60% and 20%, respectively, of the total granites. The High-Ca granites (2.76-2.655 Ga), share many similarities with the 3.3 Ga Mount Edgar-type EPC granites, both being TTG-like but more LILE-enriched and felsic (68-77% SiO_2). The High-Ca granites also include a Sr-depleted, Y-undepleted subgroup that forms a geochemical continuum with the main group. Like the 3.3 Ga CEP granites, the origin of the High-Ca granites is equivocal. The data suggest derivation at high pressures either within thickened crust or by crustal-contaminated slab-derived melts, although Sm-Nd and inherited zircon data and the range in chemistry support the former. Regardless, it is evident that a significant component of pre-existing crust must have been involved in their genesis.

The younger and clearly crustal-derived Low-Ca granites (2.655-2.63 Ga) are characterised by high-LILE, strong enrichments in the LREE and some HFSE, and compositions consistent with crystal fractionation. Like the High-Ca group, the Low-Ca group also includes both Y-undepleted and Y-depleted granitoids, although both subgroups are Sr-depleted. Champion & Sheraton (1997) suggested a tonalitic precursor for these rocks, probably not unlike some of the 3.45 Ga TTG granites of the EPC. The isotopic data suggest that the High-Ca and Low-Ca granites were derived from distinct source reservoirs, consistent with the chemical data that suggests the High-Ca granites were generated at higher pressures than the Low-Ca granites. Notably, the

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Low-Ca granitoids exhibit a pronounced Nd isotopic polarity spanning six ε_{Nd} units (+2.5 in the east to -4.5 in the west, Champion & Sheraton 1997) requiring the existence of an older temporally-zoned tonalitic crust, above the source protolith for the High-Ca granites.

Minor granite types in the EY, include: a) crustal-derived high SiO_2 (>70% SiO_2) High-HFSE group (2.72-2.66 Ga), with elevated FeO*, Zr, Y (i.e. distinctive A-type characteristics), but low LILE contents, especially Rb; b) mafic (<60 to >70% SiO_2) granites (2.69-2.65 Ga) that exhibit large between-suite variations in LILE and LREE but only minor isotopic variation; and c) syenites (2.665-2.64 Ga). Notably, like in the CEP, the syenitic rocks provide evidence for sub-crustal metasomatism, while the high-LILE mafic granites contain good evidence for a LILE-rich mantle-derived component in their generation. ε_{Nd} values for the mafic granites and syenites overlap with those of the High-Ca granites but extend to more primitive values (+1 to +2.5).

Discussion

It is clear that granite types in both the CEP and EY exhibit an overall tendency to become more potassic (higher LILE contents), but also more variable in composition with time. This reflects initial continental crustal growth, and subsequent reworking, to produce an increasingly mature and heterogeneous crust, occurring either over a long period (eastern CEP), or very rapidly (EY, western CEP). It is also evident that a small subset of the post 3.0 Ga granites in both the CEP and EY are characterised by a LILE-rich mafic component most probably derived from subduction-modified mantle (e.g. Smithies & Champion 2000). This suggests that modern-day convergent margin processes operated, at least locally, in the late Archaean. Finally, it is evident that TTG magmatism, often regarded as a voluminous characteristic of Archaean terrains, is, at the present exposure level, relatively poorly represented in both the Pilbara and Yilgarn cratons, and particularly the latter. Volumetrically, more important in these regions, are TTG-like granites which combine a high pressure (Y-depleted Sr-undepleted) signature, with more felsic and more potassic (LILE-richer) compositions. The presence of such granites, interpreted as transitional TTGs, can be taken as indicative of the involvement of pre-existing felsic continental crust at the time of their genesis, unlike more typical TTGs.

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