# Archean tectonics in the Pilbara and Yilgarn Cratons

**by S. F. Chen, A. H. Hickman, and P. B. Groenewald**

***Abstract***

Western Australia has two Archean cratons — the well-exposed 3.72 – 2.83 Ga Pilbara Craton and the poorly exposed 3.01 – 2.62 Ga Yilgarn Craton (with minor older components, up to 3.73 Ga, in the western parts) that evolved independently until they collided during the Paleoproterozoic to produce the intervening Capricorn Orogen. Together, both cratons have recorded more than 1000 Ma of Archean geological history, and although they evolved independently, they do exhibit certain common evolutionary trends that are evident in many of the world's Archean cratons.

In the Paleoarchean East Pilbara Terrane, greenstone stratigraphy shows several cycles of mafic(–ultramafic)–felsic volcanic rocks, overlain by a thick Mesoarchean clastic sedimentary assemblage. The granites were generally coeval with greenstones, and the earlier tonalite–trondhjemite–granodiorite-type granites had given way to K-rich granites, and regional dome-and-basin structural patterns were developed mainly by vertical tectonic processes.

In the areas dominated by Mesoarchean to Neoarchean granite–greenstone belts, particularly in the Yilgarn Craton, localized greenstone stratigraphy defines a temporal change from mafic(–ultramafic) volcanic rocks to felsic volcanic rocks to clastic sedimentary rocks, although there are some significant exceptions. The majority of granites are younger than greenstones, and the dominant monzogranites were recycled from early crust. Structures with preferred orientations were formed mainly by horizontal tectonic processes.

In both the Pilbara and Yilgarn Cratons, pre-existing early crust, as indicated by Nd isotopic ages, and xenocrystic and detrital zircon ages, was largely recycled into granites.

**KEYWORDS:** Pilbara Craton, Yilgarn Craton, Archean, tectonics, crust, recycling.

## *Introduction*

The Pilbara Craton (Fig. 1) comprises five granite–greenstone terranes — the East Pilbara Terrane, the dominantly granitic Kurrana Terrane, and the Karratha, Sholl, and Regal Terranes that together form the West Pilbara Superterrane — and a partly stacked series of basins — the Gorge Creek, Whim Creek, Mallina, Lalla Rookh, and Mosquito Creek Basins that form the De Grey Superbasin (Van Kranendonk et al., 2006). The terranes are separated from the basins by unconformities ranging in age from 3.05 Ga to older than 2.93 Ga. Greenstones in the terranes are dominantly volcanic, whereas, with the exception of the Whim Creek Basin, the basins are dominantly sedimentary.

In the Yilgarn Craton (Fig. 2; Cassidy et al., 2006) the 3.73 – 2.62 Ga Narryer Terrane and the 3.2 – 2.62 Ga South West Terrane are dominated by granite and granitic gneiss; and the 3.01 – 2.62 Ga Youanmi Terrane and the 2.72 – 2.63 Ga (locally >2.73 Ga) Eastern Goldfields Superterrane contain greenstone belts surrounded by granitic expanses. As in the Pilbara Craton, thick clastic sedimentary rocks overlie volcanic greenstones in parts of the Yilgarn Craton.

In this paper we highlight recent scientific work and advances in understanding the similarity and differences in granitic magmatism, greenstone volcanism, clastic sedimentation, structural styles, and tectonic processes of the two cratons, and then discuss the evidence for the presence and recycling of early crust, and the crustal evolution trends from the Paleoarchean to Neoarchean.

## *Granitic magmatism*

In the Pilbara Craton the oldest (3.49 – 3.41 Ga), dominantly tonalite–trondhjemite–granodiorite (TTG)-type granites are only in the East Pilbara Terrane. The 3.32 – 3.29 Ga granites ranging from tonalite

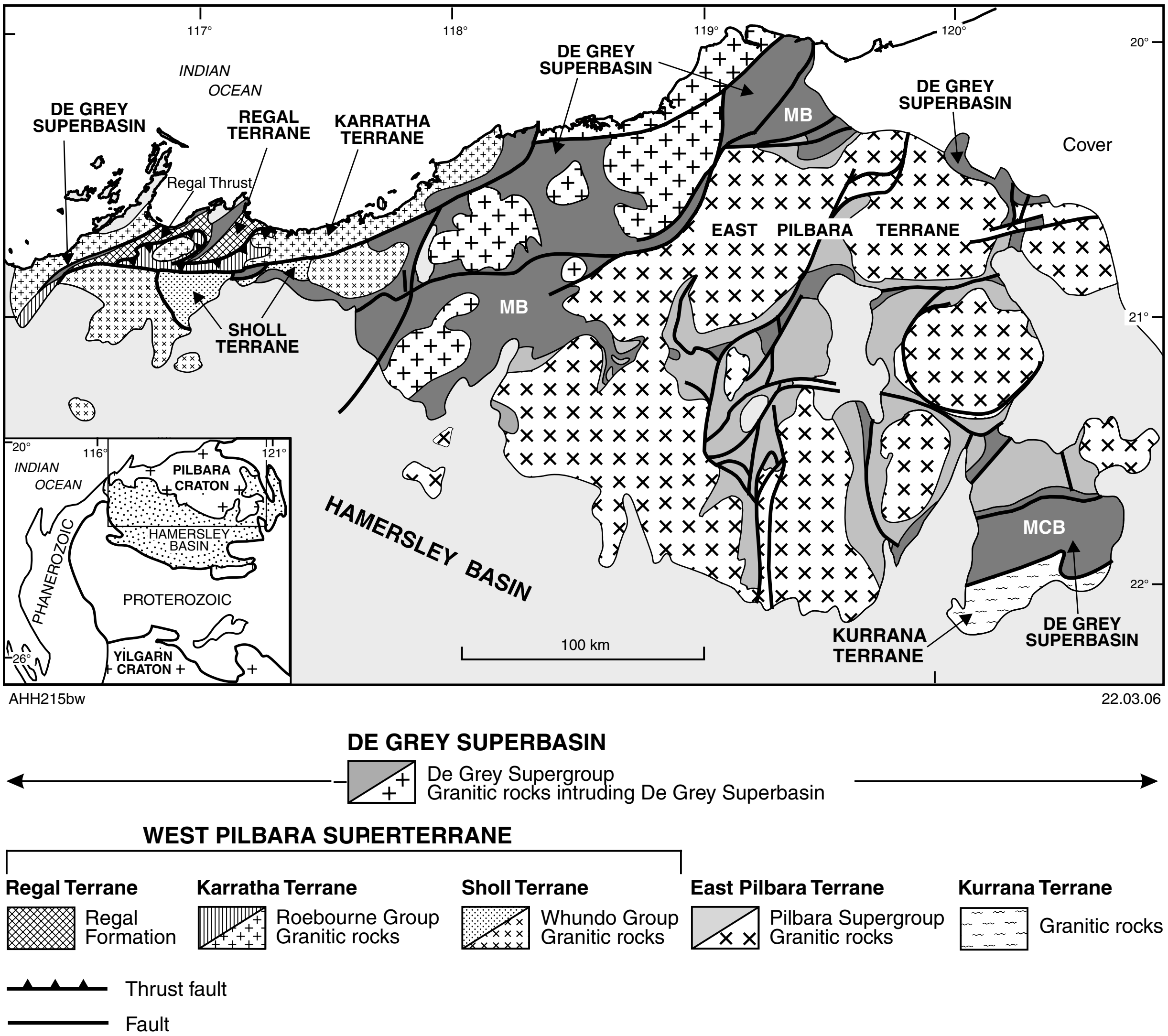


***Figure 1.** Simplified geology of the Pilbara Craton, with terrane subdivision after Van Kranendonk et al. (2006). MB = Mallina Basin; MCB = Mosquito Creek Basin*

through monzogranite to syenogranite are restricted to the eastern half of the East Pilbara Terrane. The 3.27 – 3.23 Ga granites (mostly monzogranite) are mainly in the East Pilbara Terrane, but locally also in the West Pilbara Superterrane, where they are interpreted to be in a rifted fragment of the East Pilbara Terrane. The 3.02 – 2.97 Ga granites are only in the West Pilbara Superterrane, with no age equivalents in the East Pilbara Terrane, and the majority is relatively potassic. The 2.97 – 2.92 Ga granites (dominantly mozogranite to syenogranite) are in the Mallina Basin, West Pilbara Superterrane, and western part of the East Pilbara Terrane. The 2.88 – 2.83 Ga granites of mainly monzogranite are in the Mallina Basin and East Pilbara Terrane. Paleoarchean granites are mainly in the East Pilbara Terrane, where the majority of granites are coeval with felsic volcanism. Granites in the West Pilbara Superterrane and Mallina Basin were intruded mainly in the Mesoarchean. True TTG-type granites are rare and represent the oldest (>3.4 Ga) granite magmatism in the East Pilbara Terrane. In general, granite magmatism becomes more potassium-rich as it gets younger as a result of continual recycling of felsic crust (Champion and Smithies, 2001).

In the Yilgarn Craton granites and granitic gneisses were emplaced at 3.73 – 2.62 Ga in the Narryer Terrane, at 3.01 – 2.62 Ga in the Youanmi Terrane, and mostly at 2.72 – 2.63 Ga in the Eastern Goldfields Superterrane (Cassidy et al., 2006; Geological Survey of Western Australia, 2005). The granitic rocks in the Yilgarn Craton are dominated by monzogranite, with minor TTG, granodiorite, sanukitoid, and syenite. The majority of granites are younger than greenstones, although some older granites are coeval with felsic volcanism in greenstone belts. On the basis of geochemistry, Champion and Sheraton (1997) and Cassidy

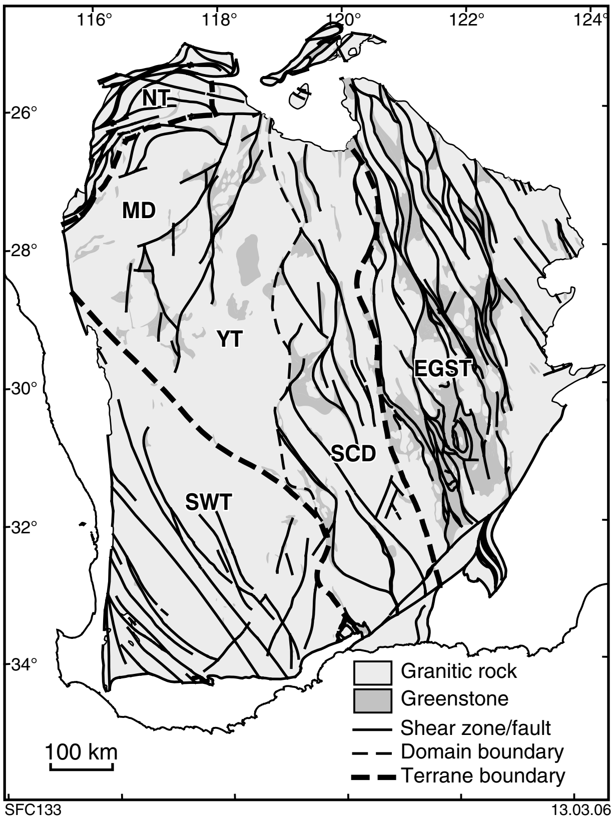


***Figure 2.** Simplified geology of the Yilgarn Craton, with terrane subdivision after Cassidy et al. (2006). EGST = Eastern Goldfields Superterrane; NT = Narryer Terrane; SWT = South West Terrane; YT = Youanmi Terrane that includes the Murchison Domain (MD) and Southern Cross Domain (SCD)*

et al. (2002) subdivided the granites in the Yilgarn Craton into five groups (the High-Ca, Mafic, Low-Ca, and High-HFSE Groups; and the Syenitic Group that is restricted to the Eastern Goldfields Superterrane). A major change at 2.65 Ga from High-Ca granites to Low-Ca granites indicates a distinct change in the tectono-thermal regime of the crust. The Low-Ca granites have similar ages across the craton, implying that a similar process occurred craton-wide at this stage (Champion and Smithies, 2001; Cassidy et al., 2002).

## *Greenstone stratigraphy*

In the East Pilbara Terrane of the Pilbara Craton, greenstones (up to 20 km thick) are composed of four dominantly volcanic groups (the 3.52 – 3.20 Ga Warrawoona, Kelly, Sulphur Springs, and Soanesville Groups) that are overlain, across a regional unconformity, by the sedimentary basin successions of the 3.05 – 2.93 Ga De Grey Supergroup (Van Kranendonk et al., 2006). Greenstone stratigraphy of the East Pilbara Terrane shows several cycles from mafic–ultramafic volcanism to felsic volcanism. The greenstone succession of the 3.28 – 3.25 Ga Karratha Terrane of the West Pilbara Superterrane commences with ultramafic and mafic rocks that pass upwards into felsic volcanic and sedimentary rocks. The lower part of greenstone succession in the Sholl Terrane comprises ultramafic and mafic rocks and the top is felsic volcanic, but the central section contains both mafic and felsic volcanic rocks. The geochemical features of the Whundo Group within the Sholl Terrane provide unambiguous evidence of modern-style subduction processes at 3.12 Ga in the Mesoarchean (Smithies et al., 2005). The basal stratigraphy of the Regal Terrane is ultramafic, but most of the preserved greenstone succession consists of basalts. Within the De Grey Superbasin the basal 3.05 – 3.02 Ga Gorge Creek Basin extends 500 km east–west and up to 200 km north–south, and contains banded iron-formation and predominantly fine-grained clastic sedimentary rocks. The 3.1 – 3.0 Ga Whim Creek Basin is volcanic and restricted to the northwestern margin of the Mallina Basin, whereas the 2.97 – 2.93 Ga Mallina Basin and Mosquito Creek Basin are composed of siliciclastic turbidites (Van Kranendonk et al., 2006).

In most parts of the Yilgarn Craton correlation of greenstone stratigraphy between greenstone belts has so far been precluded by structural complexity, poor exposure, and limited geochronology. Greenstone stratigraphy in the central Southern Cross Domain of the Youanmi Terrane typically defines a temporal change from 3.0 Ga mafic(–ultramafic) volcanism with local basal quartzite sedimentation to 2.73 Ga felsic–intermediate volcanism to clastic sedimentation (Chen et al., 2003). Watkins and Hickman (1990) extended a lithostratigraphic interpretation of well-exposed greenstone successions in the southern Murchison Domain of the Youanmi Terrane into the northern Murchison Domain, and thereby proposed a regional stratigraphy for the Murchison Domain. In this interpretation a 3.0 Ga succession of komatiite, basalt, banded iron-formation, and felsic volcanic rocks is unconformably overlain by various local 2.8 – 2.7 Ga basin successions of volcanic and clastic sedimentary rocks. However, Pidgeon and Hallberg (2000) rejected this stratigraphy in the northern Murchison Domain on the basis of new geochronological data, where they recognized a similar lithological sequence to that of the Southern Cross Domain. In the Kalgoorlie area of the Eastern Goldfields Superterrane, volcano-sedimentary rocks also define a similar stratigraphic sequence to that of the Southern Cross Domain, but have younger ages (2.7 – 2.65 Ga; Swager, 1997; Krapez et al., 2000).

## Structural styles and tectonic processes

In the Pilbara Craton the East Pilbara Terrane exhibits a regional dome-and-basin structural pattern, with no preferred structural orientations (Van Kranendonk et al., 2002). The 'domes' typically expose cores of granitic rocks and orthogneiss, whereas the 'basins' are developed in low-grade metamorphosed, synformal greenstones. Older granite components are commonly preserved along the margins of the domes, whereas successively younger phases occupy the cores. The contacts of granite domes with greenstones vary from being locally intrusive, or the locus of shearing, to an unconformity with younger supracrustal rocks. Where the contacts are sheared they commonly dip steeply towards greenstones and have a normal movement sense. In greenstones, bedding and foliation typically dip away from the granite domes, and mineral elongation lineations show a radial distribution pattern around the domes. Although some authors (e.g. Blewett, 2002) argued that horizontal extension and shortening was the dominant tectonic mechanism in the East Pilbara Terrane, Hickman (2004) and Van Kranendonk et al. (2002) provided evidence that the structural pattern of the East Pilbara Terrane is not the result of Alpine-style orogeny or cross-folding, but is mainly the product of vertical tectonism (diapirism). In contrast to the East Pilbara Terrane, the West Pilbara Superterrane exhibits a strong northeast-oriented structural grain defined by the elongation of granite complexes, the trend of greenstone belts, fold axes, closely spaced shear zones (e.g. Sholl Shear Zone), and faults. No diapiric domes are present in the West Pilbara Superterrane where all deformation is interpreted to be the result of successive episodes of horizontal shortening (Hickman, 2004). Similarly, structures in the Mallina Basin, Mosquito Creek Basin, and Kurrana Terrane are also derived from horizontal tectonic processes.

In the Yilgarn Craton the Narryer Terrane contains rocks with ages of up to 3.73 Ga, but most of the preserved structures within the terrane were formed by horizontal shortening events during the Neoarchean. In the Youanmi Terrane an early phase of north–south compression produced originally east-trending foliations, thrusts, and folds that are overprinted by northerly trending folds developed during east–west shortening (Myers and Watkins, 1985; Chen et al., 2003). Continued east–west shortening produced northeast-trending dextral shear zones in the Murchison Domain, and both northeast-trending dextral and northwest-trending sinistral shear zones in the Southern Cross Domain that are linked by north-trending contractional zones, forming large arcuate structures (Chen et al., 2001). Similar horizontal shortening events, but with younger ages are recognized in the Eastern Goldfields Superterrane, where early north–south thrusting was succeeded by east–west thrusting and regional folding that was followed by strike-slip shearing. Moreover, pre-, syn-to post-orogenic extensional events have also been documented in the Eastern Goldfields Superterrane by some authors (e.g. Swager, 1997; Blewett et al., 2004). Local dome-and-basin structures in the Yilgarn Craton are interpreted as a result of either diapirism (e.g. Gee et al., 1981) or overprinted folding (Myers and Watkins, 1985). However, most authors agree that the dominant structural patterns in the Yilgarn Craton reflect horizontal tectonic processes.

## Presence and recycling of early crust

Increasing evidence, particularly from recent studies on Nd model ages, and from xenocrystic and detrital zircon ages, support the presence of early crust that was recycled during subsequent granite intrusion and greenstone deposition in the Pilbara and Yilgarn Cratons. In the East Pilbara Terrane, 3.72 – 3.53 Ga represents a period of early crust formation as determined from xenocrystic and detrital zircon ages as well as from xenoliths of gabbroic anorthosite and migmatitic tonalite orthogneiss (Van Kranendonk et al., 2002). Nd isotopic data indicate that the eastern two-thirds of the East Pilbara Terrane is underlain by older (>3.3 Ga) crust than the western third of the East Pilbara Terrane where there is far less common isotopic evidence of crust older than 3.2 Ga. Early crust is locally present in the West Pilbara Superterrane, as indicated by Nd and zircon ages of 3.5 – 3.3 Ga. For example, much older Nd model ages of 3.48 – 3.43 Ga from the 3.27 – 3.26 Ga Karratha Granodiorite indicate that granitic magma generation involved older crust or enriched lithospheric mantle (Sun and Hickman, 1998).

In the Yilgarn Craton, Nd model ages of granites are significantly older than their crystallization ages, generally 200–300 Ma and sometimes over 500 Ma older (Champion and Sheraton, 1997; Cassidy et al., 2002), which strongly supports the existence of early crust before the intrusion of granites. The Narryer Terrane has the oldest Nd model ages (generally 3.8 – 3.3 Ga), and the Youanmi Terrane comprises a relatively consistent block of 3.3 – 3.1 Ga crust, except for a belt of younger, 3.1 – 2.95 Ga model ages in the northern part of the Murchison Domain. A distinct 'break' that approximates the Ida Fault marks the boundary between the Youanmi Terrane and Eastern Goldfields Superterrane. All granites in the Eastern Goldfields Superterrane have Nd model ages younger than 3.1 Ga, and generally younger than 2.95 Ga (Champion and Sheraton, 1997; Cassidy et al., 2002). The presence and recycling of extensive early crust in the Yilgarn Craton is also indicated by older inherited zircons in younger granites, contamination of mafic and ultramafic rocks by the early crust, and the occurrence of basal quartzites and metasedimentary rocks with detrital zircon ages as old as 4.4 Ga (e.g. Barley, 1986; Wilde et al., 2001). The early crust in the Yilgarn Craton has been largely recycled, probably through crustal reworking, into voluminous Neoarchean granites, and crustal recycling has largely destroyed the basement to the greenstones. This may explain why it is difficult to identify the basement within the craton.

## Conclusions

In the Paleoarchean East Pilbara Terrane, early TTG-type granites (>3.4 Ga) were subsequently recycled into more K-rich granites. In the Mesoarchean to Neoarchean Yilgarn Craton, monzogranite is abundant as a result of crustal recycling.

Greenstone stratigraphy in the Paleoarchean East Pilbara Terrane is common to many greenstone belts, defines several cycles of mafic(–ultramafic)–felsic volcanic rocks, and correlates with episodes of granitic intrusion. In the Mesoarchean West Pilbara Superterrane and the Mesoarchean to Neoarchean Yilgarn Craton, greenstone stratigraphy appears to be localized to individual greenstone belts, some of which show a temporal change from mafic(–ultramafic) volcanism to felsic volcanism to clastic sedimentation. Thick clastic sedimentary rocks were typically deposited in late basins in both the Pilbara and Yilgarn Cratons.

Structures in the Paleoarchean East Pilbara Terrane are characterized by a dome-and-basin pattern, with no preferred structural trends, and tectonic processes are dominated by vertical diapirism. In the Mesoarchean West Pilbara Superterrane and the Mesoarchean to Neoarchean Yilgarn Craton, structures show preferred trends, and tectonic processes are dominated by horizontal extension and shortening.

Crustal recycling played an important role in the formation of Archean granite–greenstone terranes of both the Pilbara and Yilgarn Cratons. The pre-existing early crust was largely recycled into voluminous granites.

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