LATE ARCHEAN CONVERGENT AND DIVERGENT CONTINENTAL MARGINS

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Summary

Late-Archaean granite-greenstone terranes record a convergent margin tectonic cycle. Most start with ~2.77 Ga submarine arc and back-arc basin volcanism, with a major pulse of calc-alkaline, tholeiitic and komatiitic volcanism between 2.72 and 2.69 Ga. Basin closure and terrane accretion started at about 2.69 Ga in the Abitibi Belt, but with development of 2.69 to 2.65 Ga submarine extensional back-arc basins in the Yilgarn, Slave and Zimbabwe Cratons. In the eastern Yilgarn regional granitoids were emplaced during this period rather than during subsequent compressive deformation. Closure of basins resulted in remnant ocean flysch and molasse sedimentation and compressive and strike-slip deformation by 2.63 Ga.

The Pilbara and Kaapvaal Cratons contain examples of Late Archaean rift and passive-magin environments. Both functioned as stable continental lithosphere by 2.88 Ga. In the Pilbara ~2.77 to 2.74 Ga continental tholeiites and clastic sedimentary rocks were deposited in an intracontinental rift basin on older crust. Overlying 2.725 to 2.715 Ga flood basalts were deposited in a superposed rift basin. Submarine facies developed in the south with a marine transgression by 2.68 Ga. Successful rifting of the southern margin of the craton followed emplacement of sills and pillowed tholeiies. Overlying ~2.6 Ga shales and iron formations represent a sediment-starved passive margin basin. The Kaapvaal Craton records a parallel history.

Comparison of coeval divergent and convergent continental margins indicates that Archaean and younger tectonic cycles did not differ significantly in either style or duration.

Convergent Margins

The granitoid-greenstone terranes of the Norseman-Wiluna Belt in the Australian Yilgarn Craton and the Abitibi Belt in the Canadian Superior Province are the Earth's largest and most intensely mineralized Late Archaean greenstone belts. Both contain extensive (>800 km strike length) submarine volcanic assemblages comprising Al-depleted and undepleted komatiites, tholeiites and calc-alkaline volcanic rocks that were erupted between 2.74 and 2.69 Ga. Peak arc magmatism in the Slave Craton and the important komatiite-bearing Upper Bulawayan greenstone successions in Zimbabwe (Upper Bulawayan) are also the same age as are komatiite-bearing greenstones in India and Scandanavia.

In the Norseman-Wiluna and Abitibi Belts, the 2.74 to 2.69 Ga successions either overlie, or are juxtaposed against, older (2.78 to 2.74 Ga), less well mineralized, successions in which komatiites (commonly Al-depleted) are less abundant and Algoma-type oxide-facies BIF are common. These assemblages are abundant in adjacent greenstone terranes, including the Murchison Terrane in the Yilgarn and the Wabigoon Belt in the Superior Province.

The 2.74 to 2.69 Ga successions contain both Al-depleted and undepleted komatiites, which crystallized from high temperature (>1500 °C) melts with compositions implying derivation from deep mantle sources. In the Norseman-Wiluna Belt, the komatiites, which overlie tholeiites, were erupted subaqueously through continental crust and host about 25% of the world's identified Ni resources. Identified resources are ~5 million tonnes of contained Ni in sulphide mineralization, and ~4 million tonnes of contained Ni in laterites derived by weathering of these komatiites. World class deposits include high-grade massive-sulphide mineralization at Kambalda and large tonnages of lower-grade disseminated mineralization at Agnew and Mount Keith. Similar Ni sulphide deposits, such as the Langmuir deposits in the Shaw Dome, are known in the Abitibi Belt, but are smaller than Norseman-Wiluna Belt counterparts.

Komatiite-tholeiite associations are broadly coeval with tholeiitic to calc-alkaline volcanic arc and arc-basin associations, which, in the Abitibi Belt, comprise a major volcanogenic massive Cu-Zn sulphide province, with total tonnage mined and minable reserves to 1990 of 423.5 million tonnes with an average grade of 2.1% Cu and 4.4% Zn. Large examples include Kidd Creek, near Timmins, the Horne deposit at Rouyn-Noranda and the Mattagami and Val d'Or Cu-Zn camps. The main, distal, interflow sedimentary rocks in these oceanic arc associations are sulphidic exhalites, sulphidic carbonaceous shales, and Algoma-type BIF, with first-cycle volcanogenic clastic sedimentary rocks proximal to volcanic centres. The Algoma-type BIF have also been significant historic iron producers, with the Adams mine near Kirkland Lake (~100 million tonnes at 12-26% Fe) a typical example. Iron in the BIF was most likely derived from intrabasinal hydrothermal activity. In contrast to the oceanic arcs of the highly mineralised Abitibi Belt, 2.74 to 2.70 Ga calc-alkaline magmatism in the Norseman-Wiluna Belt formed emergent volcanic islands, at least partly underlain by continental crust, with only limited base metal-sulphide mineralization.

The 2.69 to 2.67 Ga Timaskaming Group in the Abitibi Belt comprises post-accretion alkaline volcanism and clastic sedimentation in strike-slip basins. In contrast, the Kalgoorlie and Gindalbie terranes of the Norseman-Wiluna Belt recorded a phase of widespread deposition of marine sulphidic black shales (the Black Flag Group), accompanied by marine to subaerial calc-alkaline volcanism, and related granitoid emplacement, during this period. Continental arc magmatism was followed after 2.66 Ga by in remnant ocean flysch and molasse clastic sedimentation related to basin closure.

In both the Yilgarn Craton and Superior Province, deformation, emplacement of granitoid batholiths and lode-gold mineralization followed within 10 m.y. of volcanism and sedimentation. Lode-gold mineralization post-dated the majority of granitoids and was deposited from deeply sourced, low salinity fluids. The Abitibi and Norseman-Wiluna Belts contain the Earth's major resource of this type of gold deposit (~9,000 tonnes contained Au). The Golden Mile, Kalgoorlie, and Hollinger-McIntyre, Timmins, goldfields of this type have production and reserves of more than 1,000 tonnes Au and there are several goldfields with more than 100 tonnes Au endowment. Mineralization in the southern Abitibi Belt has been dated at between 2.7 and 2.67 Ga, whereas that in the Norseman-Wiluna Belt is younger and largely dated at ~2.63 Ga.

In Zimbabwe, ~2.8 Ga Lower Bulawayan greenstones are overlain by, or tectonically juxtaposed against, ~2.72 to 2.68 Ga Upper Bulawayan greenstones, which contain both komatiite-tholeiite assemblages with Ni sulphide mineralization, and calc-alkaline assemblages. Shamvian volcanic and sedimentary successions, which overlie Upper Bulawayan greenstones in Zimbabwe, are similar in style and age at 2.68-2.66 Ga to those in Australia, with sedimentation followed by orogeny, granitoid emplacement and lode-gold mineralization. These events are less well constrained by U-Pb zircon dating, but gold mineralization appears restricted to a period of deformation between 2.66 and 2.6 Ga. Lode gold deposits in greenstone belts in Zimbabwe have total reserves and production of more than 2,000 tonnes contained Au. This is less than the Abitibi and Norseman-Wiluna Belts, but still a significant resource.

Late Archaean greenstone volcanism in the Slave Craton was also initiated at about 2.8 Ga, with peak arc volcanism, plutonism and volcanogenic massive sulphide mineralization between ~2.72 and 2.67 Ga, and subsequent sedimentation, emplacement of crustally derived granitoids, metamorphism and lode-gold mineralization by 2.6 Ga. Au mineralization at one deposit has been constrained to between 2.67 and 2.65 Ga by dating single titanite grains in alteration zones surrounding a mineralized shear zone in one of the deposits.

Although different in detail, the tectonic and metallogenic histories of most Late Archaean cratons have broadly similar magmatic, thermal and deformational histories. The evolution of the Superior Province involved the submarine eruption of multiple magnesian basalt (komatiite), tholeiite and calc-alkaline volcanic assemblages starting at ~2.78 Ga. The magnesian basalts (komatiites) were most likely generated from individual intrabasinal mantle plumes. Submarine magmatism culminated with the eruption of extensive suites of Al-depleted and undepleted komatiites between 2.72 and 2.7 Ga. It is most likely that that komatiite-tholeiite assemblages were then accreted to older continental crust or oceanic arcs, and superimposed locally by by further calc-alkaline magmatism. Extensive hydrothermal activity resulted in volcanogenic massive sulphide mineralization in anoxic submarine basins in arc environments, with sulphidic carbonaceous sediments providing sulphur for Ni mineralization in areas of komatiite volcanism. Arc and plume magmatism were accompanied by sedimentation, including carbonaceous shales, and followed by further orogenic deformation, granitoid emplacement, and late tectonic, hydrothermal gold mineralization. The interpreted tectonic and metallogenic evolution of the Superior Province is comparable with that of southwestern Pacific island arcs and back arc basins.

The tectonic evolution of the Yilgarn, Zimbabwe and Slave Cratons is similar, but slightly more complex than that of the Superior Province. In the Yilgarn and Slave Cratons, 2.8 to 2.74 Ga volcanic successions were erupted on to, or adjacent to, older granitoid-greenstone terranes. In all cratons, peak submarine volcanism occurred between 2.72 and 2.69 Ga, with extensive komatiites, tholeiites and calc-alkaline volcanic rocks in the Noseman-Wiluna Belt of the Yilgarn Craton, and in Zimbabwe, and arc volcanism in the Slave Province. Komatiite volcanism in the Norseman-Wiluna Belt is interpreted to have taken place in a marginal basin adjacent to a pre-existing continental-margin arc. The presence of extensive continental crust is indicated by contamination of erupted lavas and by widespread xenocrystic zircons (up to 3.6 Ga) in volcanic and plutonic suites in the terrane.

Submarine volcanism was followed by further continental arc magmatism and sedimentation, with marginal basins and remnant oceans closed by 2.66 Ga. Closure culminated in orogeny, and craton-wide emplacement of crustally derived granitoids, followed by gold mineralization after 2.65 Ga. The continental infrastructure and presence of crustally derived granitoids, and tectonic and metallogenic history of the Yilgarn Craton is comparable with that of complex convergent environments such as in the Indonesian Archipelago or Borneo. It is likely that the Zimbabwe and Slave cratons, which also had a continental infrastructure during the Late Archaean, represent similar settings.

Barley et al. (1998) have pointed out that the order and relative timing of tectonic and metallogenic events in the Yilgarn Craton and Superior Province, between 2.8 and 2.6 Ga, parallels that recorded from the opening and closing of marginal basins of the external ocean during the breakup of supercontinents in the early Paleozoic or Mesozoic. As in the Mesozoic, the Archaean first-order tectonic cycle can be divided into four stages or supercycles (e.g. Krapez, 1997). The early stage from ~2.78 Ga involved development of marginal basins such as preserved in the Wabigoon Belt and Murchison Terrane. This was followed by a second stage from ~2.73 Ga of enhanced marginal basin magmatism with intrabasinal plume activity recorded by komatiites in the Abitibi and Norseman-Wiluna Belts as well as many other greenstone belts.

Some of the marginal basins had begun to close by 2.68 Ga, thereby coinciding with a peak in granitoid magmatism and orogeny until ~2.64 Ga. By analogy with margins of the Mesozoic Pacific, the period of orogeny and granitoid magmatism between ~2.68 and 2.64 Ga most likely corresponds to a period of plume breakout in the ocean, or oceans which were flanked by the greenstone basins. Both the Superior Province and Yilgarn were stable cratons by 2.60 Ga.

The concept of a Late Archaean global tectonic and metallogenic cycle is strengthened by comparable and contemporaneous patterns of tectonic and metallogenic evolution in several granitoid-greenstone terranes, and also by the coeval evolution of rift and passive-margin successions on continental lithosphere in the Pilbara and Kaapvaal Cratons, which are described below.

Divergent Margins

The Hamersley Province in the Pilbara Craton comprises the Chichester Range (2.78 to 2.6 Ga) and Hamersley Range Megasequences (Blake and Barley, 1992) which together comprise the Mount Bruce Megasequence Set. The Chichester Range Megasequence records the opening megacycle of a Late Archaean global tectonic or supercontinental cycle, wheras the Mount Bruce Megasequence Set is the record of a full Late Archaean to Palaeoproterozoic supercontinental cycle. Krapez (1997) correlates the tectonic environment of the opening megacycle to that of a trailing margin of an Indian-type continent.

The oldest rocks in the Hamersley Province (2.78 to 2.76 Ga) represent subaerial continental tholeiites and clastic sedimentary rocks of the 2.77 to 2.74 Ga Nullagine Supersequence which unconformably overlie a granitoid-greenstone terrane. There are two younger successions of basalts and sedimentary rocks which comprise the 2.725 to 2.715 Ga Mount Jope Supersequence. The Mount Jope Supersequence includes flood basalts and a unit containing komatiites, komatiitic basalts and stromatolitic carbonates deposited at 2.715 Ga. In the northern Pilbara, the lavas were subaerial, whereas in the south submarine pillowed flows are common. All subaerial basalts in the Chichester Range Megasequence have been strongly carbonated during Archaean subaerial weathering and synvolcanic hydrothermal alteration.

Similar basic magmatism on the Kaapvaal Craton in southern Africa includes ~2.72 to 2.69 Ga komatiites, tholeiitic flood-basalts and sedimentary rocks in the Ventersdorp Basin. Ventersdorp lavas and sedimentary rocks are unconformably overlain by shales, carbonates and BIF of the 2.59 to 2.4 Ga Transvaal/ Griqualand West Sequences. Uplift and erosion prior to the deposition of the Transvaal/ Griqualand West Sequences may have resulted from collisional tectonics in the Limpopo orogen.

In the Pilbara, deposition continued between 2.7 and 2.6 Ga, with the Jeerinah Formation recording a marine transgression at 2.69 Ga. This unit outcrops over 63,000 km^2, contains up to 200 m thick sulphidic carbonaceous shales, and is intruded by a suite of dolerite sills. The Jeerinah Formation is followed by the Marra Mamba Iron Formation, which is a more than 200 m thick Superior-type BIF. These units, which together form the Marra Mamba Supersequence, were all deposited on a marine continental shelf. The Marra Mamba Iron Formation has resources of > 8,000 million tonnes with greater than 60% iron. It is mined at Mt Newman.

The 2.6 to 2.40 Ga Hamersley Range Megasequence comprises marine shales, carbonates, BIF and a bimodal dolerite-rhyolite suite, overlain by terrigenous sedimentary rocks. Iron ore resources in the Hamersley Range Megasequence are estimated at > 15,000 million tonnes with greater than 60% iron. The Hamersley Range Megasequence and Transvaal/ Griqualand West Sequences were deposited during the second half, or continental assembly stage, of the Late Archaean global-tectonic cycle.

As described above, the order of events on the Pilbara and Kaapvaal Cratons between 2.8 and 2.6 Ga parallels the evolution of rift and passive-margin of the trailing edge of a continent which crossed an internal ocean and collided with another craton (Kaapvaal-Zimbabwe cratons). Periods of flood-basalt and rift magmatism on the Pilbara and Kaapvaal cratons were synchronous with submarine volcanism in the Yilgarn Craton and Superior Province and other granitoid-greenstone terranes. The first supercycle (Pilbara-Kaapvaal cratons) started at ~2.78 Ga with volcanism in intracontinental extensional basins followed by a second supercycle with komatiite-tholeiite volcanism between 2.72 and 2.69 Ga. In the Pilbara, the latter period of magmatism was related to breakup of a large pre-existing continent.

Sulphidic carbon-rich sedimentary rocks in the Jeerinah Formation were deposited during a marine transgression, during or shortly after the global peak in komatiite volcanism. These sedimentary rocks have organic carbon and sulphides with similar isotopic compositions to those in sedimentary rocks from the Norseman-Wiluna and Abitibi Belts. Collectively, these results imply similar reduced conditions in marine basins with very different tectonic settings. Consequently, the rising global sea-level during the intense submarine volcanism recorded in the greenstone terranes may be at least partly responsible for flooding the Pilbara Craton at ~ 2.69 Ga. Extensive carbonaceous shales were deposited as the continental shelf was flooded, followed by intrusion of dolerite sills, and deposition of BIF and thick marine carbonates in shallower water environments. By analogy with the margins of Mesozoic internal oceans, the Jeerinah Formation black shales and Superior-type Marra Mamba Iron Formation were most likely deposited during and after the period of plume breakout which followed breakup at ~2.69 Ga.

References

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