U–Pb zircon dating of Archaean greenstones from the Eastern Goldfields

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Abstract

U–Pb zircon dates for eight felsic rocks from the Eastern Goldfields are reported. Felsic volcanic and volcaniclastic rocks from five localities within three tectonostratigraphic domains were deposited during 2673–2684 Ma. A dacite interleaved with komatiitic rocks of the Kalgoorlie Terrane has been dated at 2709 ± 11 Ma and a felsic tuff interleaved with ultramafic rocks of the Bulong Complex of the Gindalbie Terrane was deposited at 2705 ± 4 Ma. A felsic porphyry, previously believed to be a felsic volcanic unit near the base of the Kalgoorlie Terrane stratigraphy, was intruded at 2658 ± 6 Ma. The new geochronological data suggest that the stratigraphic complexity observed within mapped tectonostratigraphic domains and terranes of the Eastern Goldfields greenstones is at least in part due to the rapid and localized deposition of felsic volcanic rocks in and adjacent to isolated volcanic centres in a highly active tectonic environment.

The new data indicate that the Eastern Goldfields greenstones formed at the same time as similar greenstones of the Abitibi Subprovince of Canada, and that at least some of the major tectonic episodes, including episodes of granitoid intrusion, were also contemporaneous.

KEYWORDS: Eastern Goldfields, greenstone, uranium–lead–zircon dating, geochronology, Archaean.

Over the last ten years, a team of geologists from the Geological Survey of Western Australia (GSWA) has been mapping the geology of the Eastern Goldfields region of the Archaean Yilgarn Craton. The results of this painstaking mapping work are now becoming available. The detailed 1:100 000 geological maps and 1:250 000 interpretative terrane maps arising from this work (the Kalgoorlie interpretative map was released in 1990 (Swager et al., 1990) and the Kurnalpi interpretative terrane map is due to be released soon) reveal the complex relationships between adjacent greenstone belts and granitoid rocks in the Eastern Goldfields, and provide an excellent basis for the investigation of the processes by which Archaean granite–greenstone terranes formed.

The mapping of the Eastern Goldfields greenstones has delineated a series of fault-bounded tectonostratigraphic domains (Swager, 1993; Fig. 1). Within each of these domains, a relatively coherent regional stratigraphy can be established. Where it can be demonstrated that adjacent domains share a common geological history, these domains can be united into a terrane; however, it is not always possible to confidently establish stratigraphic relationships between adjacent domains based solely on field evidence. In order to understand how these domains were assembled and to investigate relationships between adjacent greenstone domains, and between greenstones and granitoids, GSWA geoscientists are undertaking a comprehensive program of U–Pb zircon dating in the Eastern Goldfields using the Perth Consortium Sensitive High-Resolution Ion Microprobe (SHRIMP).

The Perth SHRIMP was commissioned by the Minister for Mines, the Hon. George Cash, in December 1993. Located at Curtin University of Technology, the instrument is operated by staff from Curtin, the University of Western Australia, and the GSWA. The SHRIMP is used to determine the age of a rock by measuring the change in abundance, due to radioactive decay, of elements occurring within zones 30 microns in diameter in individual mineral grains.

The Eastern Goldfields dating program is currently in its early stages, with only eight of the anticipated 25 dates completed. Nevertheless, these preliminary results provide insight into the formation of the granite–greenstone terranes of the Eastern Goldfields.

The Kalgoorlie Terrane

Within the Eastern Goldfields greenstones, the six westernmost tectonostratigraphic domains (Bullabulling, Coolgardie, Ora Banda, Kambalda, Boorara, and Parker Domains) are believed to

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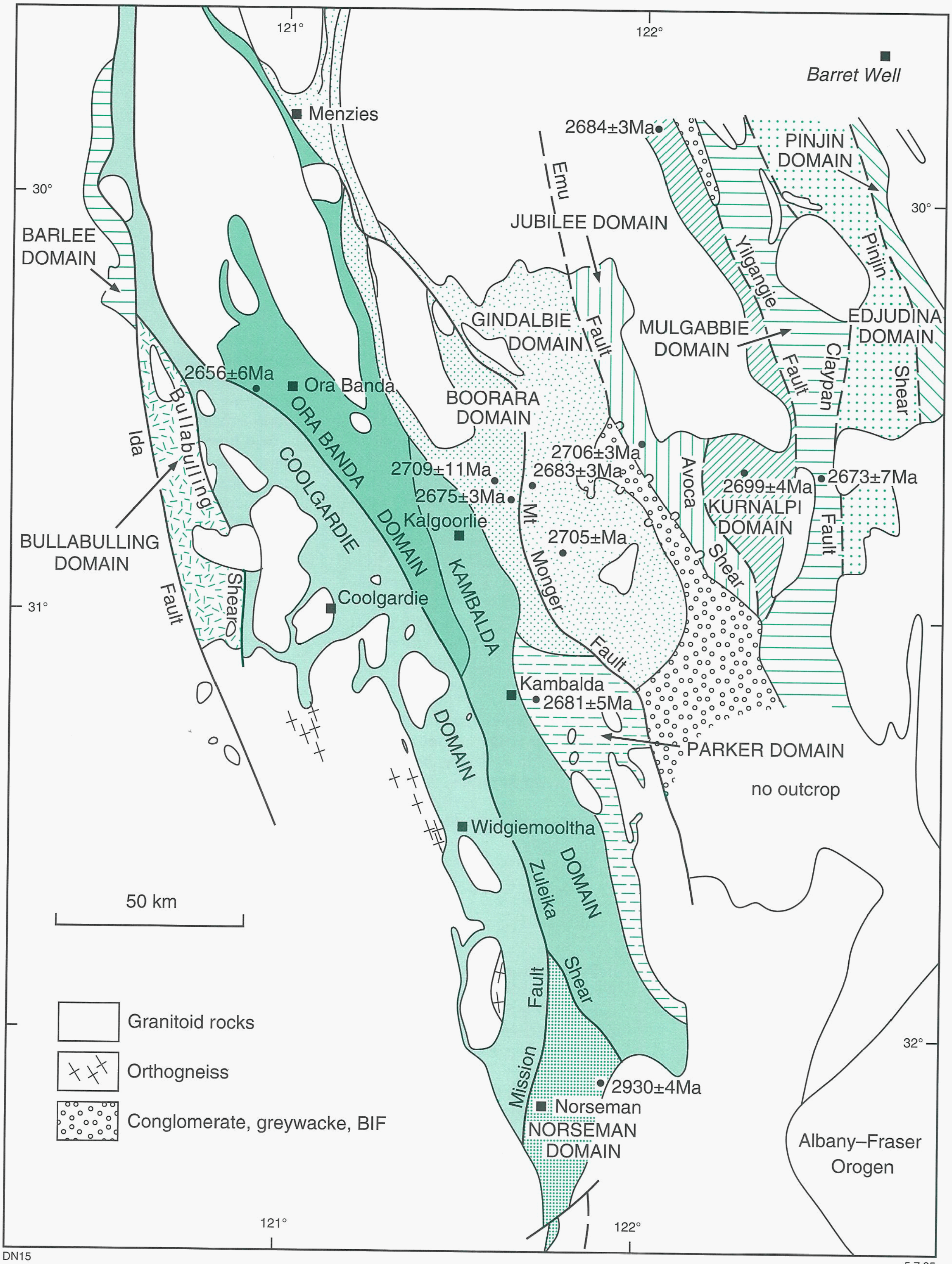

Figure 1. Regional geological map (based on figure 1 of Swager, 1993) of the Eastern Goldfields granite–greenstone terranes, showing tectonostratigraphic domains and their bounding faults. Geochronology sampling sites are also shown

contain parts of a single, relatively simple stratigraphic sequence, and have been grouped into the Kalgoorlie Terrane (Swager et al., 1990; Fig. 1). In general terms, the Kalgoorlie Terrane stratigraphy consists of a lower basalt unit, an overlying unit dominated by ultramafic (komatiitic) and mafic flows, an upper basalt unit, and an uppermost felsic volcanic and volcaniclastic unit, commonly referred to as the Black Flag Group. Claoué-Long et al. (1988) dated a volcanogenic sedimentary rock overlying the ultramafic unit near Kambalda at 2692 ± 4 Ma (all errors given are at 95% confidence).

Three samples from the Kalgoorlie Terrane have been dated so far as part of the GSWA study. The depositional age of a felsic volcanic rock from the Black Flag Group in the Parker Domain was determined to be 2681 ± 5 Ma. A thick dacitic flow within the komatiite unit in the Boorara Domain was dated at 2709 ± 11 Ma. These preliminary data provide support for the concept, developed entirely from field observations, of a relatively simple general stratigraphic sequence for the entire Kalgoorlie Terrane, but it is also apparent that the inferred simple stratigraphic succession has been disrupted in places by the localized eruption of felsic volcanic rocks from isolated vents, both during and after the eruption of the komatiitic lavas. These two new dates indicate that deposition of the komatiite and Black Flag units of the Kalgoorlie Terrane stratigraphy occurred over a period of at least 12 million years.

A felsic schist within the Ora Banda Domain, previously thought to represent a deformed felsic volcanic unit near the base of the Kalgoorlie Terrane stratigraphy, was dated at 2658 ± 6 Ma. This unit is now interpreted to represent an intrusive porphyry associated with the Siberia Monzogranite.

The eastern terranes

The eastern terranes contain diverse and complex stratigraphic sequences that predominantly consist of basaltic and ultramafic units, and proximal felsic volcaniclastic units. The structural complexity and lateral discontinuity in the stratigraphies of these terranes make lithostratigraphic correlation between them difficult or impossible. It has therefore been necessary to rely largely on precise, high-quality geochronological data in order to establish the relationships between the various stratigraphic units of these terranes.

The Gindalbie Terrane, located adjacent to the Boorara Domain of the Kalgoorlie Terrane, contains one of the most complex structural–stratigraphic sequences of any terrane in the Eastern Goldfields. In general terms, the lower part of the structural– stratigraphic column is dominated by a calc-alkaline association. This is structurally overlain by komatiitic flows of the Bulong Complex. A bimodal basalt–rhyolite sequence overlies the Bulong Complex, the contact between which is faulted.

U–Pb zircon dating has indicated a depositional age of 2705 ± 4 Ma for a felsic tuff interleaved with ultramafic rocks in the lower part of the Bulong Complex. This date is within error of the date of 2709 ± 11 Ma obtained for a dacite interleaved with the komatiite unit from the Boorara Domain, and is consistent with the minimum age of 2692 ± 4 Ma obtained by Claoué-Long et al. (1988) for the Kapai Slate, which overlies the komatiite unit in the Kambalda Domain. The ultramafic rocks of the Bulong Complex may therefore be correlated with the komatiite unit of the Kalgoorlie Terrane. A date of 2683 ± 3 Ma was also obtained for a felsic tuff from the upper unit of the Gindalbie Terrane. Parts of the upper unit of the Gindalbie Terrane may therefore also be correlated with the Black Flag Group of the Kalgoorlie Terrane.

Rocks of the lower calc-alkaline association of the Gindalbie Terrane have yet to be reliably dated. However, should future geochronological investigations confirm that they predate the Bulong Complex, they may be stratigraphically equivalent to the substantial felsic duplexes underlying the Kalgoorlie Terrane stratigraphy, as inferred from the 1991 Australian Geological Survey Organisation (AGSO) seismic traverse (Goleby et al., 1993).

A quartz–feldspar volcanic breccia containing black aphanitic clasts, sampled near the Mount Monger Fault, was dated at 2675 ± 3 Ma. Its close proximity to the Mount Monger Fault, a major terrane-boundary fault, makes the stratigraphic relations of this sample uncertain. The geochemical characteristics of this sample more closely resemble those of the felsic volcanic rocks of the Gindalbie Terrane than those of the Black Flag Group of the Kalgoorlie Terrane, and the sample is here tentatively assigned to the Gindalbie Terrane.

A date of 2684 ± 3 Ma has been obtained from a thin rhyodacite unit at the base of a basalt sequence from the Kurnalpi Terrane, located further to the east of the Gindalbie Terrane. Within the Mulgabbie Terrane, near the eastern margin of the exposed greenstones, a dacite separating basalt from an andesitic–basaltic sequence was dated at 2673 ± 7 Ma. Despite the complex and diverse lithostratigraphic successions of these terranes, which is evident from field mapping, the geochronological data indicate that all of the terranes from which dates have so far been obtained contain similar felsic volcaniclastic lithologies that were deposited synchronously at c. 2680 Ma.

Deposition of the Eastern Goldfields greenstone successions

The field and geochronological data collected so far indicate that the stratigraphic complexity observed within the domains and terranes of the Eastern Goldfields greenstones is at least in part due to the rapid and localized deposition of felsic volcanic rocks close to isolated volcanic centres. Four of the five dates obtained on felsic volcanic rocks from the eastern terranes agree within their assigned analytical uncertainty (the exception being the date of 2705 ± 4 Ma from the felsic tuff within the Bulong Complex of the Gindalbie Terrane), yet the stratigraphic associations of each of these dated felsic volcanic rocks is unique. The felsic volcanic rocks of the eastern terranes are commonly closely associated, or interleaved, with basaltic rocks, whereas within the Kalgoorlie Terrane basaltic volcanic rocks are rarely found interleaved with felsic volcanic rocks of the Black Flag Group. Lithologically similar felsic volcaniclastic rocks were probably erupted from a number of distinct volcanic centres within the Eastern Goldfields greenstone successions, within a geologically narrow time interval of approximately 15 million years.

Emplacement ages of 2690–2680 Ma for early (pre-D_2) granitoids from the Eastern Goldfields (e.g. Hill et al., 1992) are similar to those obtained for the felsic volcanic rocks. Geochemical and Nd-isotope data suggest that the early granitoids and felsic volcanic rocks were probably at least partly derived from similar sources and may have been cogenetic. It is therefore apparent that the greenstone successions were deposited during emplacement of at least some of the early granitoids, in a tectonically active environment.

Where is the basement to the greenstones?

Multiply deformed monzogranite to granodiorite gneisses are exposed at localities near the western, southern, and eastern margins of the Eastern Goldfields Province greenstones. These gneisses typically preserve upper amphibolite facies mineral assemblages and are characterized by low zircon abundances. Preliminary data obtained on one complex orthogneiss sample, from the Pioneer Dome about 35 km north-northwest of Norseman, indicate the presence of complex zircon age populations, with zircons as old as c. 3300 Ma. It appears likely that these complex gneisses (which are quite different from the comparatively simply deformed granitoids and orthogneisses occurring near major faults along the margins of the greenstones, and in the region to the west and north of Leonora) may represent reworked older crustal basement onto which the greenstones were deposited. Further dating is underway on other examples of the gneisses in order to investigate this possibility. The gneisses may also have provided the source rocks from which the granitoids and felsic volcanic rocks were derived.

Formation of the Eastern Goldfields granite–greenstone terranes

The following evolutionary model of the formation of the Eastern Goldfields granite–greenstone terranes is consistent with the available field and geochronological evidence. At c. 2710–2690 Ma, asymmetric rifting, mainly by north-trending normal faulting of pre-existing granitic and gneissic crust, resulted in the development of a series of adjacent basins into which predominantly basaltic and ultramafic volcanic rocks were deposited. Felsic volcaniclastic rocks were also erupted from a few isolated volcanic centres at the same time as the ultramafic volcanism. At c. 2685 Ma, felsic volcaniclastic rocks were erupted from numerous volcanic centres and early (pre-D_2) granitoids were emplaced mainly as thick sheets into the base of the greenstone sequences. This igneous activity may have been a consequence of heating of the base of the crust during crustal thinning. This was followed at c. 2670–2665 Ma by regional (D_2) compression, involving reactivation of early structures. Additional episodes of granitoid emplacement have been identified at c. 2665–2660 Ma and c. 2630–2600 Ma (Hill et al., 1992).

Tectonic models advocating the involvement of mantle plumes (e.g. Hill et al., 1992) cannot account for the compressional regime responsible for D_2 structures, and the volcanic rocks lack many of the diagnostic geochemical features found in the volcanic rocks of modern subduction zones. Furthermore, the field and geochronological data obtained so far also do not support currently popular tectonic models for the formation of the Eastern Goldfields granite–greenstone terranes by lateral accretion of 'exotic' terranes or by accretion of a series of separate island arcs, although it is possible that future work further to the west and east of the Eastern Goldfields greenstones may identify such terranes or arcs. On present evidence a continental margin back-arc basin setting offers the closest modern analogy of the tectonic setting for the formation of the Eastern Goldfields granite–greenstone terranes. The Kalgoorlie greenstones were probably deposited within a series of narrow back-arc rift basins formed along a continental margin and above an active subduction zone, which was located further to the east of the rift basins.

Global correlation of late Archaean granite–greenstone terranes

The availability of precise geochronological data enables the age of formation of late Archaean granite–greenstone terranes throughout the world to be compared. The new geochronological data obtained as part of this study indicate that greenstones of the Eastern Goldfields of Western Australia formed contemporaneously with similar greenstones of the Abitibi Subprovince of Canada, and that at least some of the major tectonic episodes, such as the major compression events recognized in both provinces and the episodes of granitoid intrusion, were also contemporaneous (Corfu, 1993, recently summarized geochronological data from the Abitibi Subprovince). Models for the formation of late Archaean granite–greenstone terranes must now account for these remarkable similarities.

It is possible that the late Archaean granite–greenstone terranes formed during a major, perhaps global, catastrophic magmatic episode that occurred approximately 2740–2675 million years ago. Campbell and Griffiths (1990) have argued that disturbances at the core–mantle boundary may produce plumes more than 2000 km in diameter near the Earth's surface, and cause catastrophic episodes of voluminous magmatism. Evidence for the eruption of substantial volumes of volcanic rocks during the late Archaean is also found in a number of other Archaean cratons (e.g. the 2765–2685 Ma Fortescue Group flood basalts of the Pilbara Craton and 2715–2700 Ma basaltic rocks of the Ventersdorp Supergroup of the Kaapvaal Craton). However, as briefly mentioned above, such mantle-plume models cannot account for some aspects of the geology of many late Archaean granite–greenstone terranes.

Reliable geochronological data from throughout the Yilgarn Craton are sparse, but those which are available, in addition to those from the Superior Province of Canada, suggest that these cratons may once have been part of a single continent. It is conceivable that the Eastern Goldfields and Abitibi granite–greenstone terranes are dispersed remnants of what may once have been a single granite–greenstone 'superterrane', formed during a major late Archaean subduction and/or collision event, which occurred along the margin of a united Yilgarn–Superior Craton. The comprehensive mapping program and geochronological investigations of the Eastern Goldfields granite–greenstone terranes currently underway will enable these and other hypotheses to be examined.

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