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Guide to Using the Australian Archean Mafic-Ultramafic Magmatic Events Map

Record
2009/41

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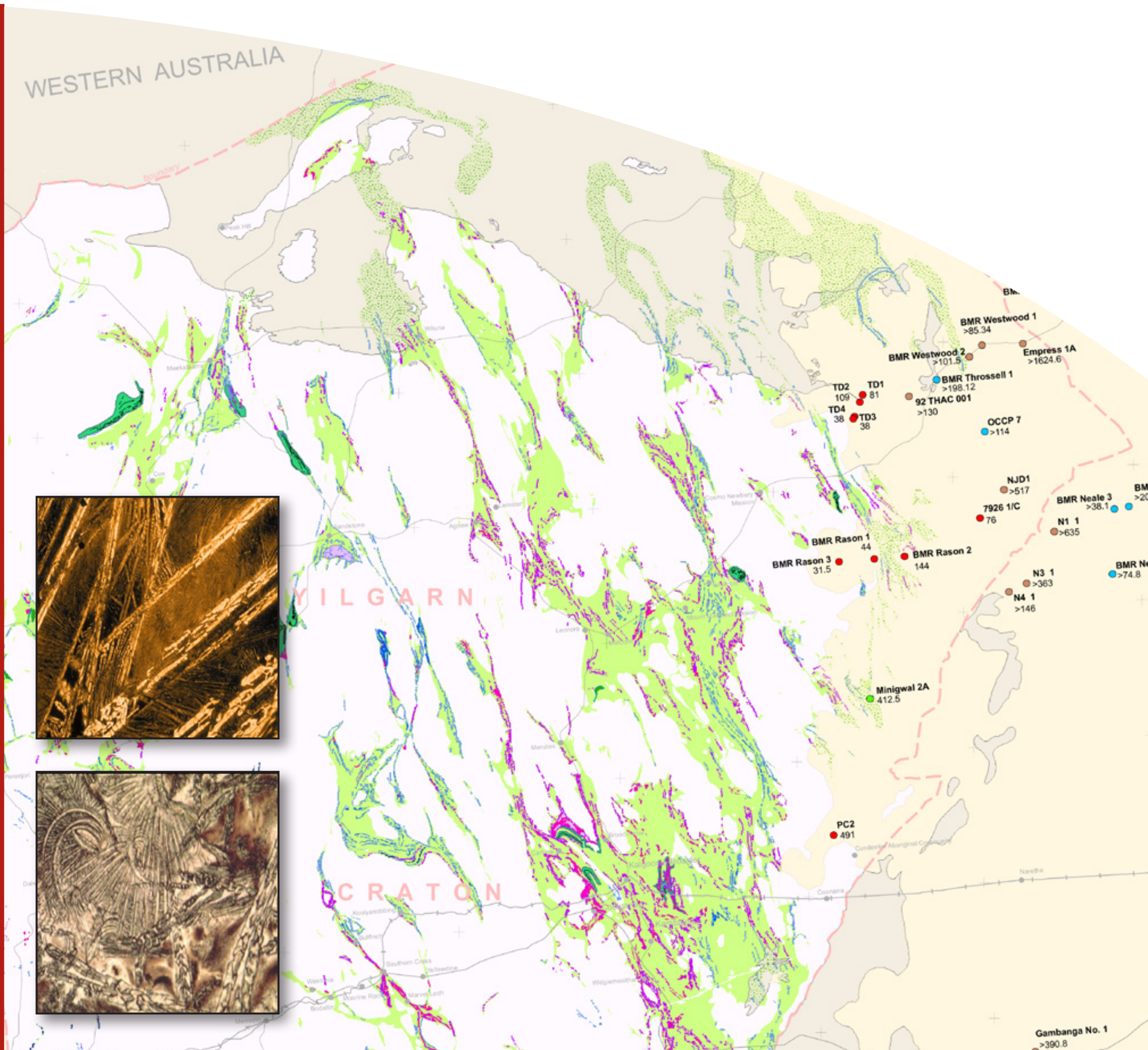

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

Guide to Using the Australian Archean Mafic-Ultramafic Magmatic Events Map

GEOSCIENCE AUSTRALIA
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by

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Cover Illustration: Part of the 'Australian Archean Mafic-Ultramafic Magmatic Events: Yilgarn Craton, Western Australia (Sheet 2 of 2)' map. This map, which is based on the interpretation of aeromagnetic data, depicts outcropping mafic-ultramafic igneous rocks, layered mafic-ultramafic intrusions, and interpreted subsurface extensions of equivalent rocks under cover in the northeastern corner of the Yilgarn Craton. The Archean greenstone sequences are depicted by a green screen for outcrop and stipple for undercover. The interpreted margin of the Yilgarn Craton is indicated by a dashed pink line. The inset photographs are bladed (top) and comb (bottom) spinifex textures that are distinctive features of Archean komatiitic rocks that are important hosts of nickel sulphides.

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Executive Summary

This Record provides information to assist in the use of two web-based map sheets (Hoatson et al. 2009a,b) that show the continental extent and age relationships of Archean mafic and ultramafic rocks and associated mineral deposits throughout Australia. The Archean Eon, as recently ratified by the International Commission on Stratigraphy (www.stratigraphy.org), extends from ~4000 million years to 2500 million years (or Ma) (Gradstein et al., 2004; Ogg et al., 2008).

Archean mafic and ultramafic igneous rocks with reliable ages in Australia are largely confined to the older crustal components in Western Australia and South Australia. In this study, twenty-six Archean Magmatic Events (AME) ranging in age from the Eoarchean ~3730 Ma (AME 1) to the late Neoarchean ~2520 Ma (AME 26) have been identified in the Yilgarn and Pilbara cratons, Sylvania Inlier, and Hamersley Basin of Western Australia, and the Gawler Craton of South Australia. The Archean time period in Australia is noteworthy for some of the largest layered mafic-ultramafic intrusions (e.g., Windimurra, Munni Munni, Gidley Granophyre), extensive continental flood basalts (various mafic volcanic formations in the Fortescue Group) and coeval mafic dyke swarms (Black Range Dolerite), differentiated mafic sills (Golden Mile Dolerite), and the widespread occurrence of primitive olivine-bearing ultramafic rocks called komatiites (Kambalda Komatiite) which contain world-class deposits of nickel sulphides (Kambalda, Mount Keith, Perseverance).

The Archean mafic-ultramafic magmatic record for Australia commences with the ~3730 Ma Manfred Event in the Narryer Terrane of the Yilgarn Craton. Gabbroic rocks in the Manfred Complex are the oldest known rocks in Australia that have been dated. The Narryer Terrane appears to be anomalous (exotic accreted origin?) in its age context relative to the other terranes of the Yilgarn Craton. Mafic-ultramafic magmatic events in the Pilbara Craton spanning the interval ~3500 million years to ~2925 million years have a relatively wide frequency, occurring every ~20 to ~200 million years. In contrast, the Neoarchean period from ~2820 million years to ~2665 million years represents an extremely busy evolutionary phase with multiple overlapping coeval events recorded for the Pilbara and Yilgarn cratons, Hamersley Basin, and Sylvania Inlier. During this ~160 million year period, fifteen mafic and ultramafic magmatic events occur every ~10 to ~15 million years in the magmatic event record. This dynamic period appears to represent a continuum of magmatic events which may not be accurately resolved into distinct magmatic episodes by available geochronology. The youngest Archean magmatic events at ~2560 million years and ~2520 million years are represented in the central Gawler Craton of South Australia.

Therefore, the general sequential development of Archean mafic-ultramafic magmatism in Australia commences during the Eoarchean in the northwest Yilgarn Craton followed by the Pilbara Craton, and then it becomes more widespread in the early Neoarchean with several coeval contributions from the Yilgarn and Pilbara cratons, Hamersley Basin, and Sylvania Inlier. The Australian Archean mafic-ultramafic magmatic record concludes in the late Neoarchean with two isolated magmatic events recorded in the Gawler Craton.

The delineation of AME for this study is based on several hundred published ages of mafic and ultramafic rocks and their spatially associated rocks (e.g., interlayered pyroclastic rocks, felsic footwall and hangingwall units, dykes). Basic requirements for inclusion of a published age were: measurement by robust geochronological methods; high confidence in its interpretation; and consistency with other field relationship evidence. Over 95 per cent of the ages compiled in this study were derived from U-Pb zircon and baddeleyite dating of mafic-ultramafic rocks and their spatially associated rocks.

Solid-geology base maps were used for the representation of the AME on the main 1:5 000 000 map of sheet 1. The solid-geology maps provide insight into the total areal extent of the magmatic system, which is an important criterion when assessing mineral potential. The Archean mafic and ultramafic rock units presented are colour-coded to the different magmatic events. The temporal and spatial

relationships of these events are represented on a Time–Space–Event Chart on Sheet 1. The main map and Time–Space–Event Chart present important correlations of mineralised magmatic systems under shallow cover and in under-explored provinces. The full geographic extent of the mafic-ultramafic magmatic systems is shown, and significant extensions to some igneous provinces are evident. Sheet 2 focuses on the interpreted distribution and characterisation of economically important Archean mafic-ultramafic rocks in the Yilgarn Craton. It depicts outcropping mafic-ultramafic igneous rocks, layered mafic-ultramafic intrusions, and interpreted subsurface extensions of equivalent rocks under cover. In particular, potential new areas of komatiitic rocks are indicated under alluvial cover and younger sedimentary basins that elsewhere in the craton host significant resources of nickel, copper, and the platinum-group elements (PGEs). The komatiitic rocks of the Yilgarn Craton have been assigned to seven major groups on the basis of their ages of emplacement and Al_2O_3/TiO_2 ratios. The nickel resource endowment and crustal neodymium model ages of the Yilgarn Craton are also represented on sheet 2.

The new Time–Space–Event Chart highlights three significant periods of mineralisation associated with mafic-ultramafic magmatism. These are: ~2925 Ma—platinum-group elements (PGEs)-nickel-copper (Munni Munni Intrusion: AME 8) and nickel-copper-PGEs (Radio Hill Intrusion: AME 8); ~2800 Ma—titanium-vanadium (Windimurra Intrusion: AME 11); and ~2705 Ma—nickel-copper±PGEs associated with komatiitic rocks (eastern Yilgarn Craton: AME 19). The latter period overlaps with similar nickel sulphide deposits in the Abitibi Belt of Canada. Australia appears to lack coeval analogues to the mineralised ~2585 Ma Great Dyke of Zimbabwe, although this could be due to lack of identification and dating of mafic dyke systems in covered Precambrian terranes.

This map, when used in association with the ‘Australian Proterozoic Mafic-Ultramafic Magmatic Events’ map published in 2008 (GeoCat 66114; GA Record 2008/15: Hoatson et al., 2008), summarises the temporal and spatial evolution of Precambrian mafic-ultramafic magmatism in Australia. These maps provide a national framework for investigating under-explored and potentially mineralised environments, and assessing the role of the mantle and mafic-ultramafic magmatism in the development of the Australian continent.

Aims and Scope of Study

This Record is a user guide for the 'Australian Archean Mafic-Ultramafic Magmatic Events' map produced by Geoscience Australia (GA). Production of this two-sheet web-based map was undertaken within the Mineral Exploration Promotion Project of the Onshore Energy and Minerals Division (OEMD), in close collaboration with the state/territory geological surveys and other organisations. In particular, the Geological Survey of Western Australia (GSWA), Primary Industries and Resources, South Australia (PIRSA), and the NTGS made available their most recent geological and geochronological datasets (Appendix 1).

The main aims of this study are to: (1) summarise the temporal and spatial evolution of Archean mafic-ultramafic magmatism in Australia; (2) provide a national framework for investigating under-explored and potentially mineralised environments; and (3) assist our understanding of the role of the mantle and mafic-ultramafic magmatism in the development of the Australian continent. The locations of magmatic units, correlations across the continent, temporal associations of mineralisation with both primitive and evolved mafic-ultramafic rocks, and the relationship of magmatism to the evolving crustal structure of the continent, are all features readily evident from the new map.

The Archean Eon spanning the period ~4000 million years to 2500 million years was the time interval chosen for this study. It was known at the beginning of the study that the oldest mafic-ultramafic rocks reliably dated in Australia were ~3730 Ma gabbros from the Narryer Terrane of the Yilgarn Craton (Kinny et al., 1988, 1990; Wilde et al., 2001; Wilde and Spaggiari, 2007). The Eoarchean age of these gabbros therefore precluded the Hadean Eon (~4600 Ma to 4000 Ma) from being a part of this study. The oldest magmatic event (AME 1) was defined at ~3730 Ma, whereas the youngest event (AME 26) for komatiitic rocks in the Gawler Craton of South Australia occurs in the late Neoarchean at ~2520 Ma. A comprehensive literature search of government and company written publications, university theses, and discussions with colleagues from the GSWA, PIRSA, and the NTGS indicated that mafic and ultramafic igneous rocks with confirmed Archean crystallisation ages are restricted to Western Australia and South Australia. Mafic rocks are spatially associated with felsic rocks of confirmed Archean age in the older parts of the Northern Territory, but the crystallisation ages of the former rocks have not been established. For example, a granitic gneiss from the eastern-most region of the Pine Creek Orogen has yielded a magmatic crystallisation age of 2671 ± 3 Ma (Hollis et al., 2009), the oldest exposed Archean basement yet recognised in the North Australian Craton**.** High-sensitive geochronological studies in the future are likely to identify mafic-ultramafic rocks of Archean age in the older crustal components of the Northern Territory.

The scope and impacts of this study are very much limited to the availability of reliable and published geochronological data. There is an increasing acceptance in recent times that robust emplacement ages of mafic and ultramafic magmatic systems are critical to the development of spatial time correlations and geotectonic frameworks at local, province, and continent scales (e.g., the geochronological study of mafic-ultramafic intrusions in the Arunta Region of central Australia by Claoué-Long and Hoatson, 2005).

This new national map complements the recently published Proterozoic magmatic event map series (Hoatson et al., 2008; https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=66624), and shows for the first time, the geographic extent and age relationships of Archean mafic and ultramafic rocks and associated mineral deposits throughout the continent. Twenty-six major Archean magmatic events are identified, and a Time–Space–Event chart and associated maps focus on the distribution and characterisation of these prospective rocks under cover in the Yilgarn Craton. The Archean and Proterozoic maps should be a useful reference for those searching for nickel, platinum-group elements (PGEs: platinum, palladium, rhodium, iridium, osmium, and ruthenium), chromium, titanium, vanadium, and cobalt in the Precambrian provinces of Australia.

Distribution of Archean Mafic-Ultramafic Igneous Rocks in Australia

The Archean Eon is a chronometrically defined subdivision of the Precambrian (~4600 Ma to 542 Ma: Nelson, 2008). The International Commission on Stratigraphy (ICS at www.stratigraphy.org) has recently redefined the Archean to encompass the geological period ~4000 million years to 2500 million years (Ogg et al., 2008). Previous time schemes (Gradstein et al., 2004) often showed the Archean Eon persisting to ~4600 million years with this lower limit not formally defined. This particular study will follow the guidelines of the ICS with the base of the Archean recognised at 4000 million years. The Archean is preceded by the informal Hadean Eon (~4600 Ma to 4000 Ma) and is followed by the Proterozoic Eon (2500 Ma to 542 Ma). The ICS has subdivided the Archean Eon into Eoarchean (4000 Ma to 3600 Ma), Paleoarchean (3600 Ma to 3200 Ma), Mesoarchean (3200 Ma to 2800 Ma), and Neoarchean (2800 Ma to 2500 Ma) eras.

Although the oldest time periods of Earth's history—the Hadean and Archean eons—constitute more than 45% of the total geological timescale, outcropping rocks older than 3800 million years are rarely found at the Earth's surface. One of the few examples of events documented prior to 4000 million years are a few zircon grains in ~3.3 Ga quartzitic metasedimentary rocks from the Narryer Terrane in the Yilgarn Craton of Western Australia. Froude et al. (1983) reported that four detrital zircons (from 102 analysed grains) in the quartzites had a U-Pb age of ~4.1 Ga to 4.2 Ga. Subsequent to this early discovery, a further 70 000 zircon grains from the same rocks have been dated. Kinny et al. (1988, 1990), Wilde et al. (2001), and Wilde and Spaggiari (2007) have documented detrital zircons up to 4404 Ma, the oldest terrestrial material on Earth, and rocks with U-Pb zircon ages ranging up to 3730 Ma, the oldest known rocks in Australia. The latter rocks from the Manfred Complex are of igneous origin and of mafic composition (leucogabbro and meta-anorthosite). They also constitute the oldest AME ('AME 1: Manfred Event') defined in this national study.

Archean mafic and ultramafic igneous rocks in the Australia continent are largely confined to the older crustal components (cratons, inliers, and basins) in Western Australia and South Australia. The Pilbara and Yilgarn cratons of Western Australia contain predominantly Paleoarchean to Neoarchean basaltic and komatiitic volcanics and Mesoarchean mafic-ultramafic intrusions, and the Gawler Craton in South Australia is represented by late Neoarchean basaltic and komatiitic volcanics and mafic-ultramafic intrusions. Neoarchean flood basalts are well developed in the platform sedimentary-volcanic sequences of the Hamersley Basin along the southern margin of the Pilbara Craton.

Recent geochronological studies have highlighted new occurrences of Archean-aged rocks in Australia. In most of these cases the dated rocks are of felsic composition, but unassigned mafic rocks are often associated with these dated rocks. For example, Fraser et al. (2008) identified Mesoarchean granitic rocks (~3150 Ma) on the Eyre Peninsula of the Gawler Craton, South Australia. These rocks are approximately 500 million years older than the oldest previously-dated rocks from South Australia, making these the oldest rocks outside the Pilbara and Yilgarn cratons. Undated dyke-like amphibolite bodies are associated with the Mesoarchean granites (pers. comm., G. Fraser, GA, 2009). Relatively small occurrences of felsic-dominated basement rocks of Archean age occur in some orogenic domains of the Northern Territory (e.g., the Billabong Complex in the Tanami Region: Crispe et al., 2007, and in the Pine Creek Orogen, and Rum Jungle, Waterhouse, and Nanambu complexes: Hollis et al., 2009). However, mafic-ultramafic rocks spatially associated with these Neoarchean felsic basement rocks are rare, not widespread, and their crystallisation ages have not been substantiated. The following statement (personal communication: Julie Hollis, Northern Territory Geological Survey (NTGS), 5 November 2008) summarises the potential occurrence of Archean mafic-ultramafic rocks in the Northern Territory. "There are very minor proportions of amphibolites within the Archean felsic gneisses in west Arnhem Land, though the age of these is unknown. I am assuming they are deformed mafic dykes, which could well make them Paleoproterozoic (two new SHRIMP dates give ages of 2671 ± 3 Ma and 2640 ± 4 Ma for the host Archean felsic gneisses: Hollis et al., 2009). There are no age data for those mafic components of those gneisses. Other than that possibility, I know of no Archean mafic or ultramafic rock occurrences in the Northern Territory." This conclusion has been supported by other geologists from the NTGS.

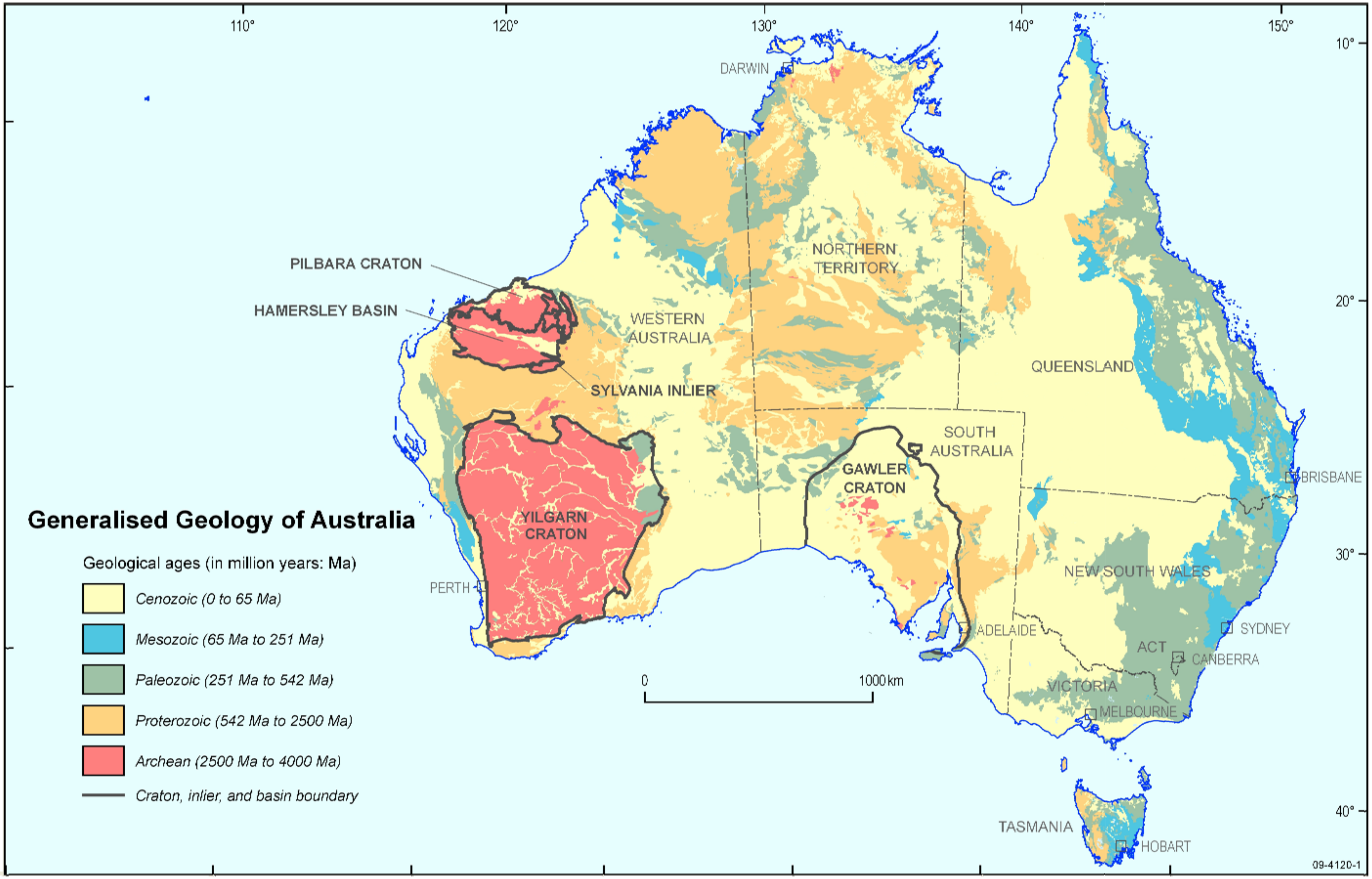
High-sensitive geochronological studies in the future are likely to confirm new occurrences of Archean mafic-ultramafic rocks in Australia. Many Precambrian provinces in Australia have been inferred to contain metamorphosed lithological components of Archean age (Nelson, 2008). For example, zircons of Archean age, but of unknown or uncertain origin, have been reported in gneissic rocks from the Broken Hill–Olary Region of New South Wales–South Australia (Nutman and Ehlers, 1998) and the Billabong Complex in the Tanami Region of the Northern Territory (Page et al., 1995). The distribution of established Archean rocks in the Australian continent is shown in Figure 1. This generalised map encompasses Archean rock types of all compositions and origins.

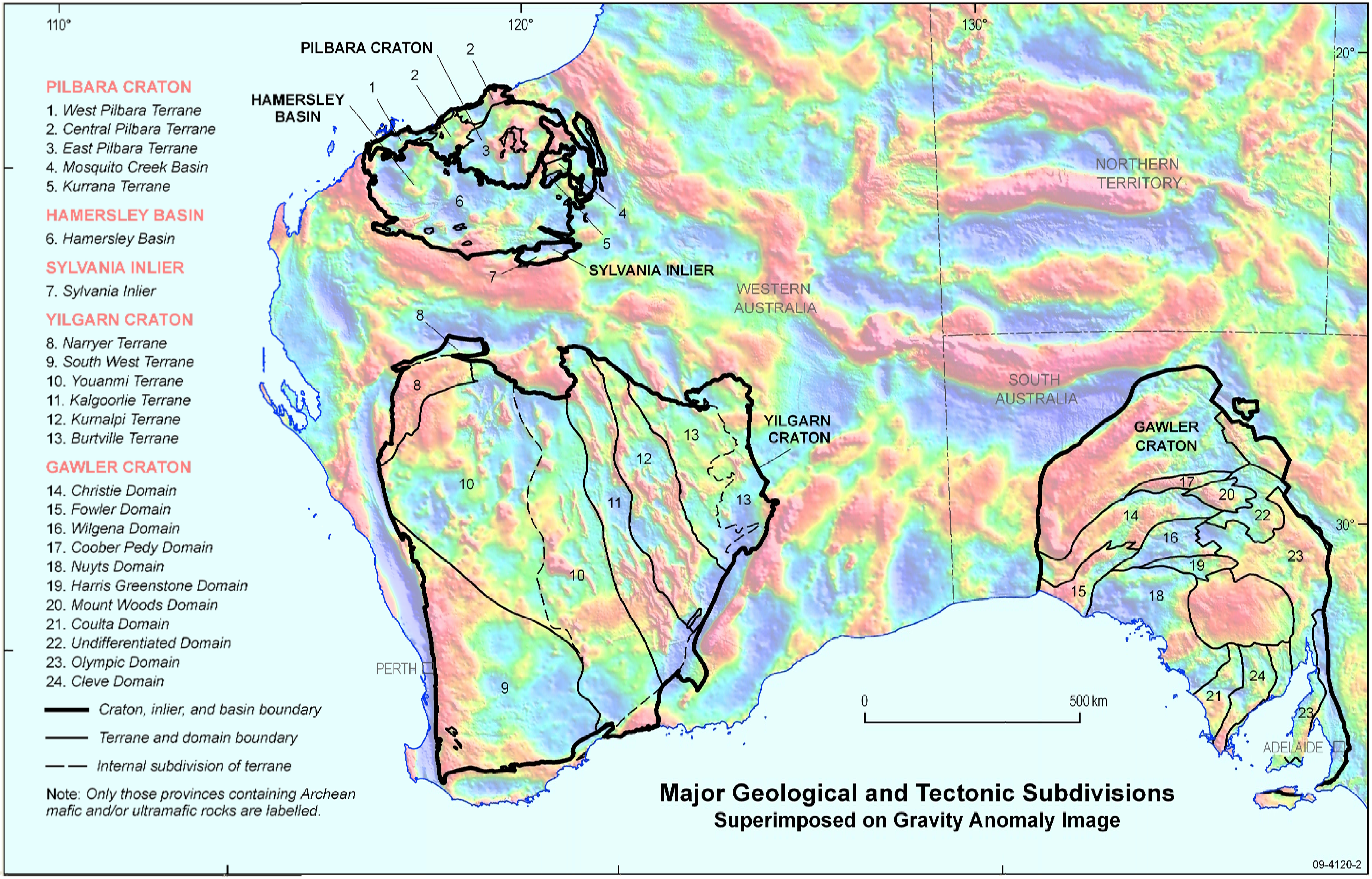
Mafic and ultramafic igneous rocks with confirmed Archean crystallisation/emplacement ages occur in five major crustal provinces in mainland Australia (Figure 1). These provinces include the Pilbara Craton, Hamersley Basin, Sylvania Inlier, and Yilgarn Craton in Western Australia, and the Gawler Craton in South Australia. The major Archean crustal provinces in Western Australia all tectonically stabilised before ~2.4 Ga, whereas the geological evolution of the Gawler Craton, which commenced at least in the early Mesoarchean (~3150 Ma) persisted well into the early Mesoproterozoic (~1450 Ma). All the provinces (except the Hamersley Basin) generally share geological framework elements that are typical of Archean granite-greenstone terranes seen elsewhere in the world. Such common elements include: sub-parallel linear and sinuous greenstone sequences; elongate, ovoid, and domal granitic bodies; coeval komatiitic, basaltic (tholeiitic), and felsic volcanics; metasedimentary rocks; province-wide shear systems; and linear tectonic patterns. Typical greenstone sequences involve mafic and ultramafic komatiites, through tholeiitic (most abundant) to more felsic calc-alkaline volcanics, followed by sediments that include chert, banded iron formation, sandstone, and turbidites.

One of the most distinctive features of Archean granite-greenstone terranes throughout the world is the presence of olivine-rich rocks called komatiites (Arndt and Nisbet, 1982). Komatiitic rocks are generally considered to be derived from very hot (~1600 degrees Celsius, some 400 degrees hotter than magmas erupting from volcanoes today) and magnesium-rich magmas. They were named after the type location in the Komati River Valley in the Barberton Mountain Land of South Africa. Komatiitic rocks often display spectacular plate- and needle-like crystals of olivine and pyroxene ascribed to the rapid quenching of the high-MgO magmas (see photographs on front cover of this Record). These textures were named 'spinifex texture' from its resemblance to clumps of spinifex grass. Komatiitic rocks are prospective for Ni-Cu-PGE sulphide mineralisation, with such world-class deposits (containing >1 million tonnes of contained nickel metal) as Kambalda, Mount Keith, Perseverance, Yakabindie, and Honeymoon Well from the Yilgarn Craton of Western Australia. Komatiitic rocks have been documented throughout the Archean (~3.3 Ga, ~3.2 Ga, ~3.1 Ga, ~2.9 Ga, ~2.8 Ga, ~2.7 Ga, ~2.5 Ga) from all three major Archean cratons of Australia—Pilbara (Van Kranendonk et al., 2006), Yilgarn (Barnes, 2006), and Gawler (Hoatson et al., 2005).

Figure 1 (on page 6): *Generalised geology of Australia. The five major crustal provinces shown (Pilbara Craton, Hamersley Basin, Sylvania Inlier, Yilgarn Craton, and Gawler Craton) contain documented Archean mafic-ultramafic rocks that form the basis of this study.*

Figure 2 (on page 7): *Geological and tectonic subdivisions (Terrane, Basin, Inlier, and Domain) of the major crustal provinces (see Figure 1) that are used in this study. Only those subdivisions containing Archean mafic and/or ultramafic rocks are labelled. The geological subdivisions are from Cassidy et al. (2006), Fairclough et al. (2003), and the Geological Survey of Western Australia 1:2 500 000 Tectonic Units of Western Australia, June 2001, dataset. The backdrop image is a diffused Gravity Anomaly Image from Bacchin, et al. (2008): Gravity Anomaly Map of the Australian Region (3rd Edition), GeoCat Number 65682.*


Generalised Geology of Australia
Geological ages (in million years: Ma)
Cenozoic (0 to 65 Ma)
Mesozoic (65 Ma to 251 Ma)
Paleozoic (251 Ma to 542 Ma)
Proterozoic (542 Ma to 2500 Ma)
Archean (2500 Ma to 4000 Ma)
Craton, inlier, and basin boundary
110°
120°
130°
140°
150°
10°
20°
30°
40°
PILBARA CRATON
HAMERSLEY BASIN
SYLVANIA INLIER
YILGARN CRATON
GAWLER CRATON
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
ACT
VICTORIA
TASMANIA
DARWIN
PERTH
ADELAIDE
BRISBANE
SYDNEY
CANBERRA
MELBOURNE
HOBART
0
1000 km
09-4120-1


110°
120°
130°
20°
30°
PILBARA CRATON
HAMERSLEY BASIN
SYLVANIA INLIER
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
YILGARN CRATON
GAWLER CRATON
PERTH
ADELAIDE
0
500 km
PILBARA CRATON
1. West Pilbara Terrane
2. Central Pilbara Terrane
3. East Pilbara Terrane
4. Mosquito Creek Basin
5. Kurrana Terrane
HAMERSLEY BASIN
6. Hamersley Basin
SYLVANIA INLIER
7. Sylvania Inlier
YILGARN CRATON
8. Narryer Terrane
9. South West Terrane
10. Youanmi Terrane
11. Kalgoorlie Terrane
12. Kurnalpi Terrane
13. Burtville Terrane
GAWLER CRATON
14. Christie Domain
15. Fowler Domain
16. Wilgena Domain
17. Coober Pedy Domain
18. Nuyts Domain
19. Harris Greenstone Domain
20. Mount Woods Domain
21. Coulta Domain
22. Undifferentiated Domain
23. Olympic Domain
24. Cleve Domain
Craton, inlier, and basin boundary
Terrane and domain boundary
Internal subdivision of terrane
Note: Only those provinces containing Archean mafic and/or ultramafic rocks are labelled.
Major Geological and Tectonic Subdivisions
Superimposed on Gravity Anomaly Image
09-4120-2

Future field mapping and geochronology-geochemical programs, and interpretation of more sophisticated geophysical data will continue to refine the character and spatial distribution of the Archean crustal components of the continent. The major crustal provinces of the Pilbara Craton, Hamersley Basin, Sylvania Inlier, Yilgarn Craton, and Gawler Craton (Figure 1) contain documented occurrences of Archean mafic-ultramafic igneous rocks and form the basis of this study. Stratigraphic, geochronological, and structural data have been used to divide each of these major crustal provinces into smaller components, which are termed differently in Western Australia (Terrane) and South Australia (Domain). These crustal components are shown in Figure 2.

The following summary of the broad geological settings of the major crustal provinces containing Archean mafic-ultramafic rocks is derived in part from the important references shown in parentheses.

1. **Pilbara Craton** (Van Kranendonk et al., 2002, 2006, 2007; Hickman and Van Kranendonk, 2008; Nelson, 2008): The ~3.72–2.83 Ga Pilbara Craton in the north-western part of Western Australia covers an area of ~230 km (north-south) by ~530 km (east-west: Figures 1 and 2). The southern ~70% of the craton is concealed by unconformably overlying ~2.77–2.45 Ga rocks of the Hamersley Basin. The Pilbara Craton was recently redefined (Van Kranendonk et al., 2006, in press; Hickman and Van Kranendonk, 2008) to exclude the overlying rocks of the Hamersley Basin. The granite-greenstone basement rocks and associated sedimentary basins of the Pilbara Craton record a near continuous, ~900 million-year record of Earth's history prior to the deposition of the platform sedimentary and volcanic rocks of the Hamersley Basin. The Pilbara Craton comprises three principal components: (a) low-grade volcano-sedimentary rocks that form greenstone belts around granite batholiths; (b) granitic rocks which form either large composite complexes or single intrusions; and (c) late sedimentary basins containing coarse clastic sedimentary rocks. Stratigraphic, geochronological, and structural data have been used to divide the craton into four terranes (West Pilbara, Central Pilbara, East Pilbara, and Kurrana) and one sedimentary basin (Mosquito Creek). Details of the stratigraphic and geochronological frameworks of these terranes and basins are provided by Van Kranendonk et al. (2002, 2006, in press) and Hickman and Van Kranendonk (2008). The ~3.5 to ~3.1 Ga mafic-ultramafic rocks in the greenstone belts of the craton (defined here as AME 2 to AME 6) largely consist of tholeiitic pillow basalt, siliceous high-magnesian basalt, high-Mg basalt, basaltic komatiite, serpentinite, and minor komatiite. The basaltic rocks dominate the volcanic stratigraphy and in places they attain several kilometres in thickness. In contrast to the Yilgarn Craton, komatiitic sequences in the Pilbara Craton are generally older (~3.5 Ga to ~3.1 Ga), are thinner, poorly developed, and contain no known significant Ni-Cu sulphide deposits. The oldest reliably dated mafic-ultramafic rock from the Pilbara Craton is a 3578 ± 4 Ma (SHRIMP U-Pb zircon: McNaughton et al., 1988) gabbroic anorthosite enclave in a granodiorite. The source rocks for the enclaves is unknown (hence not used to define an event in this study), but they are considered fragments of the basement to the greenstone sequences. Large layered mafic-ultramafic intrusions (Munni Munni, Radio Hill, Andover, Mount Sholl, Balla Balla: AME 8) and granophyric-doleritic sheet-like bodies (Gidley Granophyre: AME 17) were emplaced into the west Pilbara greenstone stratigraphy at ~2.92 Ga and ~2.72 Ga, respectively. These mafic-ultramafic intrusions are prospective for orthomagmatic deposits of nickel, copper, PGEs, titanium, and vanadium (Hoatson and Sun, 2002). Nickel-copper sulphides at Radio Hill have been mined, whereas most of the other intrusions contain subeconomic resources of base and precious metals. Large north-northeast-trending 2772 ± Ma dolerite dykes of the Black Range Dolerite Suite (AME 13) that traverse the craton are coeval (and possibly comagmatic) with continental flood basalts in the Fortescue Group of the Hamersley Basin (Wingate, 1999).

2. **Hamersley Basin** (Tyler, 1991; Thorne and Trendall, 2001; Blake et al., 2004; Trendall et al., 2004): The basement rocks of the Pilbara Craton are unconformably overlain by volcanic and sedimentary rocks of the ~2.77–2.45 Ga Hamersley Basin (Figures 1 and 2). Thorne and Trendall (2001) have defined the Hamersley Basin to encompass the depositional basinal environments associated with the Mount Bruce Supergroup. This supergroup represents a broad

unified stratigraphy that was deposited in a series of related tectonic settings, which evolved from rifted continent, to a passive margin, to a convergent margin over a period spanning more than 300 million years. The lower stratigraphic part of the Hamersley Basin—the Fortescue Group—contains a significant thickness of mafic and minor ultramafic rocks. There are at least eight major episodes of basaltic-dominated magmatism in the group ranging in age from ~2.77 Ga (Bellary Formation–Mount Roe Basalt) to possibly as young as ~2.63 Ga (Jeerinah Formation). With the exception of the 2741 ± 3 Ma Kylena Basalt (AME 16), the 2715 ± 2 Ma Maddina Basalt (AME 18), and their lateral equivalents the Boongal and Bunjinah formations, respectively, very few of these basaltic episodes have reliable absolute crystallisation ages. The basaltic rocks of the basin were deposited both subaqueously and subaerially and are mainly basaltic andesite in composition. High-Mg komatiitic lavas (Pyradie Formation) and mafic sills (Jeerinah Formation) also form minor components in the Fortescue Group. Mafic-ultramafic rocks comprise a very minor stratigraphic component of the Neoarchean-Paleoproterozoic Hamersley Group that overlies the Fortescue Group. Mafic sills of the Weeli Wolli Dolerite are the major mafic component in the upper part of the Hamersley Group, but these are reliably dated at early Paleoproterozoic (~2450 Ma: Barley et al., 1997). Chemical sedimentary rocks (e.g., banded iron formation, dolomite, chert) dominate the Hamersley Group stratigraphy. The geological history of the Hamersley Basin records evolution from a rift phase for the Fortescue Group to a more passive-margin phase typical of the Hamersley Group when banded iron formation was deposited on an outer continental shelf during a period of tectonic quiescence.

3. **Sylvania Inlier** (Tyler, 1991; Tyler et al., 1991): The Sylvania Inlier is a small elongated Archean (>~2.75 Ga) granite-greenstone province that covers an area of ~5600 km^2 along the southeastern margin of the Hamersley Basin (Figures 1 and 2). Previous investigators (Daniels and MacLeod, 1965) originally referred to this inlier as the 'Sylvania Dome', believing it to be analogous to domical structures containing granite-greenstone sequences observed in the southwestern Hamersley Basin. However, Tyler (1991) showed that the structural controls in this region are complex and that the outcrop pattern cannot be simply regarded as domical, and consequently the term inlier was proposed. The Sylvania Inlier comprises layered sequences of low- to medium-grade metavolcanics, mafic and ultramafic intrusions, and metasedimentary rocks, which have been intruded extensively by granitoid rocks. The rocks of the greenstone belts were deposited near exposed granitic basement. All these basement rocks have been unconformably overlain by mafic and felsic volcanic and intrusive rocks, carbonate and clastic sedimentary rocks, and banded iron formation, all of which were deposited in the Hamersley Basin. The largest greenstone belt in the Sylvania Inlier, and containing the most diverse stratigraphy of mafic-ultramafic rocks, is the Jimblebar greenstone belt. This arcuate belt in the northeastern part of the inlier contains mafic, ultramafic, and felsic volcanics, together with clastic metasedimentary rocks, chert, and banded iron formation. Deformed and metamorphosed mafic and ultramafic sills intrude the greenstone sequence. The Coobina ultramafic intrusion is a 10 km long dyke and sill-like body which crops out at the eastern end of the Jimblebar greenstone belt. This strongly tectonised body contains more than 200 pods and lenses of chromitite interlayered with serpentinite rocks. The chromitite bodies, which occur at the junction between a feeder dyke and the sill, have been intermittently mined over the past few decades. Coobina is the largest chromium deposit mined in Australia. Other intrusions in the Sylvania Inlier include metagabbroic bodies that have intruded the Western Creek greenstone belt in the northwest part of the inlier. Numerous mafic dykes of various relative ages and orientations traverse the Sylvania Inlier. Prominent among these dykes are the 2747 ± 4 Ma dolerites of the Sylvania dyke swarm (Wingate, 1999) that constitute the type example of the AME 15 defined in this study. These dykes could be feeders to voluminous 2741 ± 3 Ma basalts in the Kylena Basalt of the Fortescue Group, Hamersley Basin. No other mafic-ultramafic rocks in the Sylvania Inlier have reliable crystallisation ages. Tyler (1991) notes that field relationships in the Sylvania Inlier resemble those in the Pilbara Craton. However, there are differences in isotope and rare-earth-element patterns, suggesting separate evolution of the inlier prior to ~3.0 Ga. The role of the Sylvania Inlier as cratonic basement to

the Hamersley Basin implies that it is older than most of the granite-greenstone belts of the Yilgarn Craton.

4. **Yilgarn Craton (**Barnes, 2006; Cassidy et al., 2006; Hoatson et al., 2006; Blewett 2008a,b): The ~3.7–2.6 Ga Yilgarn Craton is a large body of Archean crust covering an area of at least 655 000 km^2 in the southwestern corner of Western Australia (Figures 1 and 2). The craton contains the largest variety and most widespread development of Archean mafic-ultramafic rocks in Australia. In many cases these rocks represent the global-type example of a particular compositional group (e.g., Kambalda-type komatiites) and they host several world-class deposits of nickel (Kambalda, Mount Keith) and gold (Kalgoorlie deposits hosted by the Golden Mile Dolerite). The Yilgarn Craton is composed predominantly of granitic and monzogranitic rocks and bimodal (mafic-ultramafic and dacitic) volcanic greenstones sequences, with relatively minor clastic sedimentary rocks and banded iron formation. The granitic and greenstone rock sequences throughout the craton mostly range in age from ~2.96 Ga to ~2.63 Ga, although some mafic igneous rocks as old as ~3.73 Ga (AME 1) occur in the northwestern parts of the craton (Narryer Terrane). Granite, monzogranite, and granitic gneiss constitute 80% of the Yilgarn Craton. The greenstone belts, which are composed largely of basalt with lesser felsic volcanic sedimentary and ultramafic rocks (including komatiites), comprise the complementary 20% of the craton. Cassidy et al. (2006) have subdivided the craton into six tectono-stratigraphic terranes. From west to east across the craton, these include the Narryer, South West, Youanmi, Kalgoorlie, Kurnalpi, and Burtville terranes, with the Kalgoorlie, Kurnalpi, and Burtville terranes collectively constituting the Eastern Goldfields Superterrane. The stratigraphic architecture and geodynamical setting of this superterrane is summarised by Blewett (2008a,b). Each terrane in the Yilgarn Craton is divided into structurally-bound domains that preserve dismembered, thrust repeated parts of greenstone successions and locally have distinct volcanic-facies relationships (Cassidy et al., 2006). The terranes and internal crustal domain components are generally bounded by regional interconnected fault systems (e.g., Ida, Hootanui, Ockerburry, and Waroonga). Along the western margin of the craton, the Narryer and South West terranes are dominated by granite and granitic gneiss, whereas the remaining four terranes towards the east are composed of generally north-northwest-trending linear greenstone belts that traverse the full extent of the craton separated by extensive granite and granitic gneiss. The ultramafic and mafic rocks in the greenstone belts host significant nickel sulphide and laterite mineralisation. Australia's nickel sulfide production is dominated by the ~2705 Ma komatiite-hosted deposits in the Kalgoorlie Terrane (AME 19). This terrane contains the largest concentration of Archean komatiite-hosted nickel deposits in the world, and includes such world-class (>1 Mt contained Ni) examples as Mt Keith, Honeymoon Well, Yakabindie, Perseverance, and the Kambalda group (Barnes, 2006; Hoatson et al., 2006). Other mineralised komatiite sequences occur in the Southern Cross Domain (eastern part of Youanmi Terrane) and Kurnalpi Terrane, however, those from the Murchison Domain (western part of Youanmi Terrane) and South West Terrane appear to be poorly mineralised. Areally large and thick ~2.8 Ga layered mafic-ultramafic intrusions (Windimurra, Narndee: AME 11) in the Youanmi Terrane have created exploration interest for titanium, vanadium, and PGEs, with cyclic titaniferous magnetitite layers in the Windimurra deposit intermittently mined.

5. **Gawler Craton:** (Daly and Fanning, 1993; Daly et al., 1998; Ferris et al., 2002; Swain et al., 2005; Fanning et al., 2007; Reid, 2007; Hand et al., 2007; Reid and Daly, 2009): The Gawler Craton is an early Mesoarchean (at least ~3150 Ma) to Mesoproterozoic (~1450 Ma) province that covers much of the southern central part of South Australia (Figures 1 and 2). The geological history between ~3150 Ma and ~2560 Ma for the craton is currently not well understood. The Gawler Craton contains the youngest known Archean mafic and ultramafic rocks in the Neoarchean (less than ~2560 Ma) in Australia. Hand et al. (2007) suggest that the evolution of the craton can be separated into two major phases. The first (relevant to this study) is a short time interval in the Late Archean (~2560 to ~2500 Ma), and the second phase

encompassed the Paleoproterozoic and early Mesoproterozoic (~1900 to ~1450 Ma). The craton was essentially stable for the intervening period 2400 to 2000 million years. Late Archean mafic-ultramafic rocks in the Gawler Craton are largely confined to the Mulgathing Complex (central-western part of craton) and the Sleaford Complex (southern part of craton), which are two spatially separate terranes that are basement components of the craton (Reid and Daly, 2009). The oldest known basement rocks, gneissic granites, have recently been dated at ~3150 million years old from the Eyre Peninsula (Fraser et al., 2008: see above), but due to their felsic composition, these rocks are not included in this study. Geochemical, isotopic, and geochronological data suggest that the Mulgathing and Sleaford complexes have similar histories and probably represent components of a single late Archean belt (Swain et al., 2005). The two complexes are prospective for a range of commodities including gold, nickel, copper, PGEs, and iron ore (Reid and Daly, 2009). The Mulgathing and Sleaford complexes are dominated by aluminous metasedimentary and carbonate rocks, banded iron formation, siliceous rocks, and broadly coeval mafic-ultramafic and felsic volcanics. These volcanosedimentary rocks were intruded by a series of Neoarchean to Paleoproterozoic felsic to intermediate intrusive bodies (Glenloth Granite, Dutton Suite). Mafic granulite, amphibolite, tholeiitic basalt, and mafic-ultramafic intrusive rocks have been widely documented in both the Mulgathing and Sleaford complexes, but these rocks have no age control and have been consequently assigned here as Undefined Event. For example, the Hopeful Hill Basalt is intruded by 2458 ± 10 Ma Glenloth Granite and hence the basalt may be Archean or earliest Paleoproterozoic in age (similar uncertain age scenarios apply to the South Lake Gabbro and Aristarchus Peridotite). The confirmed Archean mafic-ultramafic magmatic record of the Gawler Craton commenced with basalts (AME 25) associated with 2558 ± 6 Ma calc-alkaline volcanism (Devils Playground volcanics) in the Mulgathing Complex. Coeval komatiites (AME 26) in both the Mulgathing and Sleaford complexes were emplaced at ~2520 Ma in the Harris greenstone belt (Hoatson et al., 2005) and with the Hall Bay Volcanics on the western Eyre Peninsula (Teale et al., 2000). Despite active exploration, none of the two komatiitic sequences in the craton are known to be significantly mineralised. The komatiites and high-magnesium basalts at Lake Harris were shown by Hoatson et al. (2005) to be predominantly low in sulphur (<600 ppm) and to have high Pd and Pt contents (5–30 ppb) indicative of derivation in a S-undersaturated environment. The Lake Harris Komatiite is the youngest and eastern most known occurrence of komatiitic rocks in Australia (Hoatson et al., 2005).

Archean Large Igneous Provinces

Large Igneous Provinces (LIPs) are formed by the rapid and voluminous emplacement of mafic, ultramafic, and/or felsic magmas in intraplate settings (Ernst and Buchan, 2001). These transient magmatic events are believed to be related to large-scale processes in the Earth’s upper and/or lower mantle region not related to normal plate margin magmatism (Coffin and Eldholm, 2001). Such ‘magmatic environments’ as volcanic passive margins, oceanic plateaus, submarine ridges, seamount groups, and ocean basin flood basalts do not originate at seafloor spreading centres. Most LIPs are thought to be associated with mantle upwellings (e.g., mantle plumes), and they are preserved as coeval continental flood basalts, layered mafic-ultramafic intrusions, mafic sills, and large mafic dyke swarms. LIPs typically evolve over extremely short geological time periods of a few million years or less. Bryan and Ernst (2008) have redefined LIPs as magmatic provinces with areal extents >0.1 Mkm^2, igneous volumes >0.1 Mkm^3, and maximum lifespans of ~50 million years that have intraplate tectonic settings or geochemical affinities, and are characterised by igneous pulse(s) of short duration (~1 to 5 Ma), during which a large proportion (>75%) of the total igneous volume has been emplaced. Sheth (2007) proposed that LIPs have outcrop areas >50 000 km^2, and they are independent of composition, tectonic setting, or emplacement mechanisms.

In contrast to the 'Australian Proterozoic Mafic-Ultramafic Magmatic Events' study (Hoatson et al., 2008), where five major LIPs (Kalkarindji: ~520 Ma; Gairdner: ~825 Ma; Warakurna: ~1070 Ma; Marnda Moorn: ~1210 Ma; Hart: ME 10 ~1780 Ma) were identified, potential LIPs in the Archean Eon are not as well defined and consequently they are not highlighted on the two new Archean map sheets. However, it is apparent that certain mafic-ultramafic magmatic systems defined in this study (AME 13, 16, 18, ?19) are voluminous and have geotectonic settings consistent with a possible LIP. For example, Neoarchean mafic-ultramafic magmatism associated with the Fortescue Group in the Pilbara Craton and Hamersley Basin region of Western Australia may be regarded as a LIP. Similar-aged rocks to that Fortescue Group occur in other crustal province (e.g., the Yilgarn Craton) highlighting the potential for extending the spatial distribution of certain LIPs (see discussion of AME 18 below). See the relevant time-slice maps in Appendix 10 for a summary of the spatial distribution of each AME.

Subaerial and subaqueous continental flood basaltic lavas ranging in age from ~2.77 Ga to ~2.70 Ga are extensive along the southern margin of the Pilbara Craton in the Hamersley Basin. These lavas are within the lower part of the Fortescue Group (Thorne and Trendall, 2001), which is a shallow dipping to flat-lying succession of sedimentary rocks, mafic, felsic, and minor ultramafic (rare komatiite) volcanics, mafic sills, mafic-ultramafic layered intrusions and dykes (Black Range Dolerite Suite). The total succession is about 6.5-kilometres thick and covers about 40 000 km^2. The mafic volcanics form stacked sequences of flood basalts that have tholeiitic and calc-alkaline affinities. Pirajno and Morris (2005) discuss the possible links of the Fortescue Group basaltic rocks with mantle plumes, and the Ni-Cu-PGE potential of these magmatic systems. The geotectonic setting of these rocks has been variably interpreted as a rift-to-passive margin, to a more complex rift and breakup-shelf subsidence environment (Thorne and Trendall, 2001).

This study has identified three major mafic volcanic sequences in the Fortescue Group that have been reliably dated (see Appendices 4 and 11) and therefore have AME status. These basaltic sequences occur in the: (1) 2715 ± 2 Ma Maddina Formation (AME 18); (2) 2741 ± 3 Ma Kylena Formation (AME 16); and (3) 2775 ± 10 Ma Mount Roe Basalt (and its coeval 2772 ± 2 Ma Black Range Dolerite Suite, AME 13). Significantly, some of these formations are areally extensive thus appearing to satisfy one of the basic criterions for establishing a LIP, e.g., coeval mafic-ultramafic rocks that occur in the west and east Pilbara terranes, Hamersley Basin, and three terranes (South West, Youanmi, Kalgoorlie) of the Yilgarn Craton have collectively been assigned to AME 18 (i.e., type example of this event is the 2715 Ma Maddina Formation; see AME 18 time-slice map in Appendix 10). Similarly, mafic volcanics in the 2741 Ma Kylena (AME 16) and 2775 Ma Mount Roe (AME 13) formations have coeval representatives in other cratons and basins of Western Australia. It must be emphasised that these additional occurrences are expressed only by time-equivalence of extrusion and/or intrusion; cogenetic magmatism across crustal provinces is not necessarily implied. Detailed geochronology, petrochemical, and tectonic reconstruction studies are required to test if these isolated mafic-ultramafic rock occurrences truly represent a LIP as strictly defined by Ernst and Buchan (2001) and Bryan and Ernst (2008).

LIPs may include such rock associations as komatiites, high-Mg basalts, flood basalts, dyke swarms, and layered mafic-ultramafic intrusions. Archean komatiitic rocks, in particular, are a ubiquitous feature of synformal greenstone belts in the Pilbara and Yilgarn cratons. Widespread komatiites and associated mafic-ultramafic magmatic rocks in the Pilbara Craton from about 3.5 Ga to ~2.9 Ga have been suggested by various investigators to be of possible LIP origin. This study identified such ultramafic-mafic rocks at ~3490 Ma (AME 2), 3470 Ma (AME 3), 3350 Ma (AME 4), 3175 Ma (AME 5), 3115 Ma (AME 6), and 2925 Ma (AME 8). Other AME may potentially meet the definition of LIPs, but their attribution will require further work. For example, Campbell and Hill (1988) postulated that the greenstone sequences containing komatiites in the Eastern Goldfields Superterrane of the Yilgarn Craton formed from major thermal disturbances in the mantle. Therefore, do these economically important ~2.7 Ga ultramafic rocks (AME 19) represent an Archean flood basalt province?

Studies of mantle plume events over Earth's history by Abbott and Isley (2002) have shown that about 66 per cent of superplume events last less than 8 million years and that the average duration of Archean and Phanerozoic superplume events varies between 13 ± 7 and 12 ± 3 million years, respectively. However, they state that the largest Precambrian superplume events erupted at least ten times more lava than the largest Phanerozoic superplume event. During the Archean, Abbott and Isley (2002) identified six major geological periods correlating with interpreted superplume eras/events. In descending importance (with corresponding AME having approximating age range shown in brackets) these eras/events occur from: 2775 Ma to 2696 Ma (AME 13 to AME 20); 2610 Ma to 2582 Ma (no event correlation); 2903 Ma to 2899 Ma (no event correlation); 2787 Ma to 2784 Ma (AME 12); 3510 Ma to 3460 Ma (AME 2 to AME 3); and 2506 Ma to 2504 Ma (no event correlation).

Methods

SOURCES OF GEOCHRONOLOGICAL DATA AND DIGITAL DATASETS

The geological and geochronological data which underpin this study were obtained from extensive searches of published and unpublished literature. Information was sourced from scientific journals and publications produced by the Bureau of Mineral Resources and its successors the Australian Geological Survey Organisation and Geoscience Australia. Other useful information and data sources were the Commonwealth Scientific Industrial Research Organisation, and the State and Northern Territory geological surveys. Publications from the geological surveys included first, second, and third Edition 1:100 000 and 1:250 000 geological maps and their respective explanatory notes, bulletins, reports, and records. Unpublished information was obtained from company exploration reports and university theses. In some cases, e.g., the ages of Warrawoona Volcanics from the Pilbara Craton, were obtained from university-based geochronologists in Europe. Unpublished geochronological data were sourced from university theses and from OZCHRON—Geoscience Australia's national database of age determinations on Australian rock samples (http://www.ga.gov.au/oracle/ozchron/index.jsp). Mineral resource data are from OZMIN—Geoscience Australia's national database of mineral deposits and resources, which is updated annually. It can be accessed through the Australian Mines Atlas—database of Australian minerals and energy deposits, mines, resources, and processing centres (http://www.australianminesatlas.gov.au/).

There exists no single solid-geology map for all Australia. Consequently, the base maps used are the most current solid-geology coverages available from GSWA and PIRSA (Appendix 1). The advantage of solid-geology maps, over outcrop-based equivalents, is that they can provide an insight into the total areal extent of rock units (e.g., extensions under the cover of younger rocks, or regolith), and hence the volume of the magmatic systems, which is an important criterion when assessing mineral potential. The actual total volumes of magmatic systems cannot be determined in most cases due to the inherent uncertainties in estimating thicknesses and amounts of erosion.

Other thematic digital datasets were integrated with the solid-geology coverages to achieve a more complete spatial representation of Archean mafic-ultramafic rocks. These include the province-wide coverage of Archean (specific age unknown) mafic dykes and sills in Western Australia (Thorne and Trendall, 2001). This dyke dataset was largely represented in the Pilbara Craton with no occurrences reported for the Yilgarn Craton. This dyke coverage was particularly important for the regional distribution of the ~2770 Ma Black Range Dolerite Suite (AME 13) in both these crustal provinces. Additional magmatic ages and other geological data supporting the twenty-six AME were incorporated on Sheet 1 as point data (shown as lower case alphabet letters in squares that were colour-coded to the relevant magmatic event).

CHARACTERISATION OF MAFIC-ULTRAMAFIC ROCK UNITS

The geochronological and geological attribution data for the mapped mafic-ultramafic units were compiled for the ArcGIS geodatabase using Microsoft Excel spreadsheets, and arranged by State, and crustal province. The spreadsheets (Appendix 11) are contained in the CD accompanying this Record.

The attribution data for Western Australia and South Australia are presented on two spreadsheets titled 'AGE'—those parameters largely relating to the determined age of the unit—and 'SETTING'—those parameters largely relating to the geological description and tectonic setting of the unit. The first four columns with headings CODE, STRATNO, SUPERGROUP_GROUP_FORMATION_MEMBER, and CRUSTAL PROVINCE are common to both spreadsheets. The CODE attribute is a map code that links each mafic-ultramafic unit entry in the spreadsheet to the polygon/line data on the relevant solid-geology base map, and STRATNO is the stratigraphic number for the mafic-ultramafic unit derived from the Australian Stratigraphic Units Database (ASUD: national database that records information on all Australian stratigraphic units and their usage in literature) (http://www.ga.gov.au/oracle/stratnames/index.jsp). SUPERGROUP_GROUP_FORMATION_MEMBER, pertains to the official Stratigraphic information and data in ASUD, and CRUSTAL PROVINCE is the major regional tectonic-geological unit as defined by the base maps used for each State. All the other criteria used to characterise the mafic-ultramafic units are summarised in Appendix 2, and the spreadsheets containing the attribute data are in Appendix 11.

CHARACTERISATION OF MINERAL DEPOSIT TYPES

The data item MIN_STYLE 1, 2, and 3 in the 'SETTING' spreadsheet of Appendix 11 contains information relating to mineralisation and mineral deposit type associated with the relevant mafic-ultramafic rock unit. Three MIN_STYLE columns are provided in the spreadsheet for multiple deposits. The deposit classification is modified after the classical classification scheme of Cox and Singer (1986). Details of this modified classification are shown in Appendix 3.

DEFINITION OF MAGMATIC EVENTS

An important task in this study was the compilation and evaluation of all available geochronological data that can be used to constrain the timing and duration of the AME. 'Events' in this sense are defined as "probable geological incidents of significance that are suggested by geological, isotopic, or other evidence" (modified after Neuendorf et al., 2005).

The recognition of magmatic events has been made possible by the vastly increased coverage of geochronology data from Precambrian provinces in Australia over the last twenty years. Published ages used in this study were assessed for their geochronological methods, the interpretation confidence, and consistency with other temporal-related evidence, e.g., field relationships of associated rock units.

Twenty-six magmatic events (AME 1 to AME 26) were identified for the Archean Eon. The type examples of these events are listed in Appendix 4 and their distribution with geological time is summarised in Figure 3. As a comparison, Figure 4 shows the distribution of Proterozoic Magmatic Events (Hoatson et al., 2008) with time. It is apparent from Figures 3 and 4 that the geological periods containing the highest frequency of mafic-ultramafic magmatism during the Precambrian evolution of Australia were during the Neoarchean (~2820 Ma to ~2665 Ma) and late Paleoproterozoic (~1910 Ma to ~1590 Ma).

More than 95 per cent of the ages compiled are from U-Pb zircon and U-Pb baddeleyite systems (both by ion microprobe and thermal ionisation techniques). Ar-Ar (hornblende), Re-Os isochron, Pb-Pb isochron, Pb-Pb (galena), and Sm-Nd isotopic studies make up the balance. The criterion of choice in each case was the best available constraint on the magmatic age. Where there is no published age for a mafic-ultramafic unit shown on the Map, or if its age is doubtful, or inconsistent with its field relationships, the unit is assigned as Undefined Event. In some examples (particularly those related to the ages of komatiitic rocks), ages of associated intermediate to felsic volcanic or pyroclastic rocks were used, where the field relationships between the dated felsic rocks and the spatially associated mafic-ultramafic rocks were unequivocal, e.g., the felsic rocks were magmatically interlayered with the mafic-ultramafic rocks.

In the period ~2820 million years to 2660 million years there is an apparent continuum of Archean magmatic ages which may not be accurately resolved into distinct magmatic episodes by available geochronology. Magmatic events are named at 10 million years intervals within this period. It is likely that some of these individual events are part of a single longer-lived event. The rapid frequency of events is particularly prominent in the Kalgoorlie Terrane of the Yilgarn Craton where seven magmatic events have been identified in a relatively short geological period (see the Time–Space–Event Chart in Appendix 5).

In some rare cases, an assessment was required to ascertain the origin of particular Archean rocks for their inclusion in this study. One example concerns granophyric bodies which are often a widespread stratigraphic component of Archean igneous rock terranes. For example, granophyric rocks are found in the ~2675 Ma Golden Mile Dolerite (AME 22) in the Kalgoorlie Terrane and in the ~2725 Ma Gidley Granophyre (AME 17) layered mafic intrusion in the west Pilbara Terrane. These granophyric rocks are intimately associated with other mafic igneous rocks, such as dolerite and gabbro, and thus they form an important evolved component of the mafic stratigraphy. Whereas, large granophyric bodies that are comagmatic with the ~2764–2757 Ma Gregory Granitic Complex and overlying comagmatic Koongaling Volcanic Member (Williams, 2003, 2004) in the Pilbara Craton were excluded from this study. These granophyric rocks have no known spatially associated mafic and/or ultramafic rocks and they appear to be derived from a parent magma of felsic compositional affinity.

Informal Magmatic Event names are derived from the published names of reliably dated mafic±ultramafic rock units (e.g., Black Range, Munni Munni, Gidley Granophyre). In other cases, a name for a prominent deposit (Kambalda nickel deposit) hosted by the mafic±ultramafic rock unit was used. The name of the most voluminous or prominent magmatic system was used for the naming of each Magmatic Event. For example, the ~2520 Ma Lake Harris Magmatic Event 26 was named after the komatiites in the Harris Greenstone Domain of the Gawler Craton, rather than the relatively smaller occurrence of coeval komatiites near Mount Hope on the Eyre Peninsula in the southern part of the Gawler Craton.

Archean Magmatic Events in this study are abbreviated to AME. This acronym contains the prefix ‘A’ to differentiate the Archean events from similar numbered events defined in the previous Proterozoic study (Hoatson et al., 2008) which used the acronym ME. Two codes in parenthesis (m) or (mu) attached to each AME name indicate the composition of the igneous rocks constituting that event. The (m) code signifies that only mafic rocks are present, whereas (mu) indicates that both mafic and ultramafic rocks are present even if the ultramafic component may constitute only a few percent of the total mafic-ultramafic rock assemblage.

SPATIAL REPRESENTATION OF MAGMATIC EVENTS

The digital solid-geology datasets vary considerably in their attribution of polygon data for different crustal provinces within the state (e.g., Pilbara versus Yilgarn cratons), and also for provinces between states (Yilgarn versus Gawler cratons). This variation has a major impact on the way the magmatic events are portrayed on the new National map. Most Archean mafic and ultramafic rocks in the Yilgarn Craton are not designated an AME because the solid-geology datasets provided by GSWA do not contain stratigraphic Formation or Member information for these rocks. Consequently, most solid-geology rock polygons in the Yilgarn Craton are shown as Undefined Event since their stratigraphic details are unknown (and therefore their age is unknown). In contrast, most mafic and ultramafic rocks in the Pilbara Craton and Hamersley Basin have some formal stratigraphic characterisation and therefore, if reliably dated, can be assigned to an AME. The paucity of stratigraphic information for the rock units in the Yilgarn Craton relative to the Hamersley Basin, for example, is attributed to the better preservation of geological formations, the more systematic and well dated layer-cake-type stratigraphy, for the latter crustal province. A map showing robust stratigraphic correlations between mafic and ultramafic units in the Yilgarn Craton will greatly enhance our understanding of AME. One of the critical elements underpinning such stratigraphic correlations is U-Pb zircon and baddeleyite geochronological data of mafic-ultramafic rocks, similar to that undertaken in the Arunta Region of central Australia (Claoué-Long and Hoatson, 2005) and in the Halls Creek Orogen of the East Kimberleys (Page and Hoatson, 2000).

One of the primary functions of the 1:5 000 000 feature map on Sheet (1) is to highlight the spatial and temporal correlations of magmatic events at scales ranging from crustal province to continent wide. The twenty-six identified events are assigned a colour code in the colour spectrum from purple through blue, green, yellow, and red to mauve as a simple visual cue of relative age from old to young.

Available solid-geology maps do not always directly represent the presence of mafic-ultramafic rocks. Large igneous rock units are usually denoted with a discrete polygon. However, small units of mafic-ultramafic rocks are often subsumed as a minor component of a regional rock package. It is necessary to include both types of unit in this compilation to properly represent the geographic extent, correlation and likely volume of each AME. Accordingly a two-fold system of colour scheme has been deployed for the main legend of Sheet 1:

1. Bold colours are used where the mafic-ultramafic rocks constitute the dominant component of a map unit.

2. Pale colours of the same hue denote the presence of a minor component of coeval mafic-ultramafic rocks within a regional package of rocks: this is applied to map units of associated sedimentary, metamorphic, and felsic igneous rocks where they include minor mafic-ultramafic units. Of the 26 AME defined, only 5 of these events contain subordinate mafic-ultramafic rocks. This contrasts with the National Proterozoic Magmatic Events study (Hoatson et al., 2008), where 60% of the 30 magmatic events have polygons containing subordinate mafic-ultramafic rocks.

Examples of this dual colour legend occur in all areas of the map. For example, the large area of Undefined Event (pale grey colour) shown in the central Gawler Craton, does not denote a large mafic magmatic unit: it simply represents a volumetrically small but regionally widespread component of metabasalt, amphibolite, and mafic granulite in the Mulgathing Complex, which is dominated by metamorphic rocks of different compositions. Small labels (e.g., AME 26) colour-coded to the magmatic event are placed adjacent to rock units and various commentary points on the main maps to facilitate the regional extent of the AME across the continent.

A problem encountered in construction of this new National map has been the variable treatment of mafic dyke swarms in regional solid-geology maps. Individual dykes are small bodies and map compilers frequently omit them from regional-scale maps. This is unfortunate, because the collective importance of a swarm of dykes can be significant. Particular effort has therefore been made to source map representation of mafic dykes, such as the province-wide dataset of Archean mafic dykes and sills in Western Australia (Thorne and Trendall, 2001).

GIS TECHNIQUES

The Australian Archean Mafic-Ultramafic Magmatic Events map is produced using ArcGIS version 9.3. The feature files showing the distribution of mafic and ultramafic rocks and the attributes of AME are stored in the geodatabase of ArcGIS. The ArcGIS feature files are grouped by events to obtain maps of individual magmatic events. These maps show the regional distribution of mafic and ultramafic rocks for a particular event (see Appendices 4 and 5). Since the geological datasets from the State and Northern Territory geological surveys do not follow standardised attributes for rocks, it was not possible to create a seamless nation-wide dataset of Archean mafic and ultramafic rocks. The inclusion of an ASUD identifier, however, will allow the integration of the mafic and ultramafic rocks dataset with other national-scale datasets in GA, such as OZCHEM (national database of whole-rock and stream-sediment geochemistry: http://www.ga.gov.au/gda/index.jsp).

A crustal neodymium model age surface (cell size 1 km) for the Yilgarn Craton (see Sheet 2) is calculated using the interpolating grid routine in ArcGIS. The interpolating method consists of Inverse Distance Weighted with a fixed search radius (number of neighbours is 12).

Maps and Reports

Bibliographic and metadata details of the maps derived from the ‘Australian Proterozoic and Archean Mafic-Ultramafic Magmatic Events’ map series can be found using GeoCat (GA’s catalogue database of products: http://www.ga.gov.au/oracle/agsocat/textonly.jsp). The study was a staged process and earlier related maps were published as Proterozoic and Archean components. The map and report products from the Precambrian study are chronologically itemised below:

Archean study
2009:

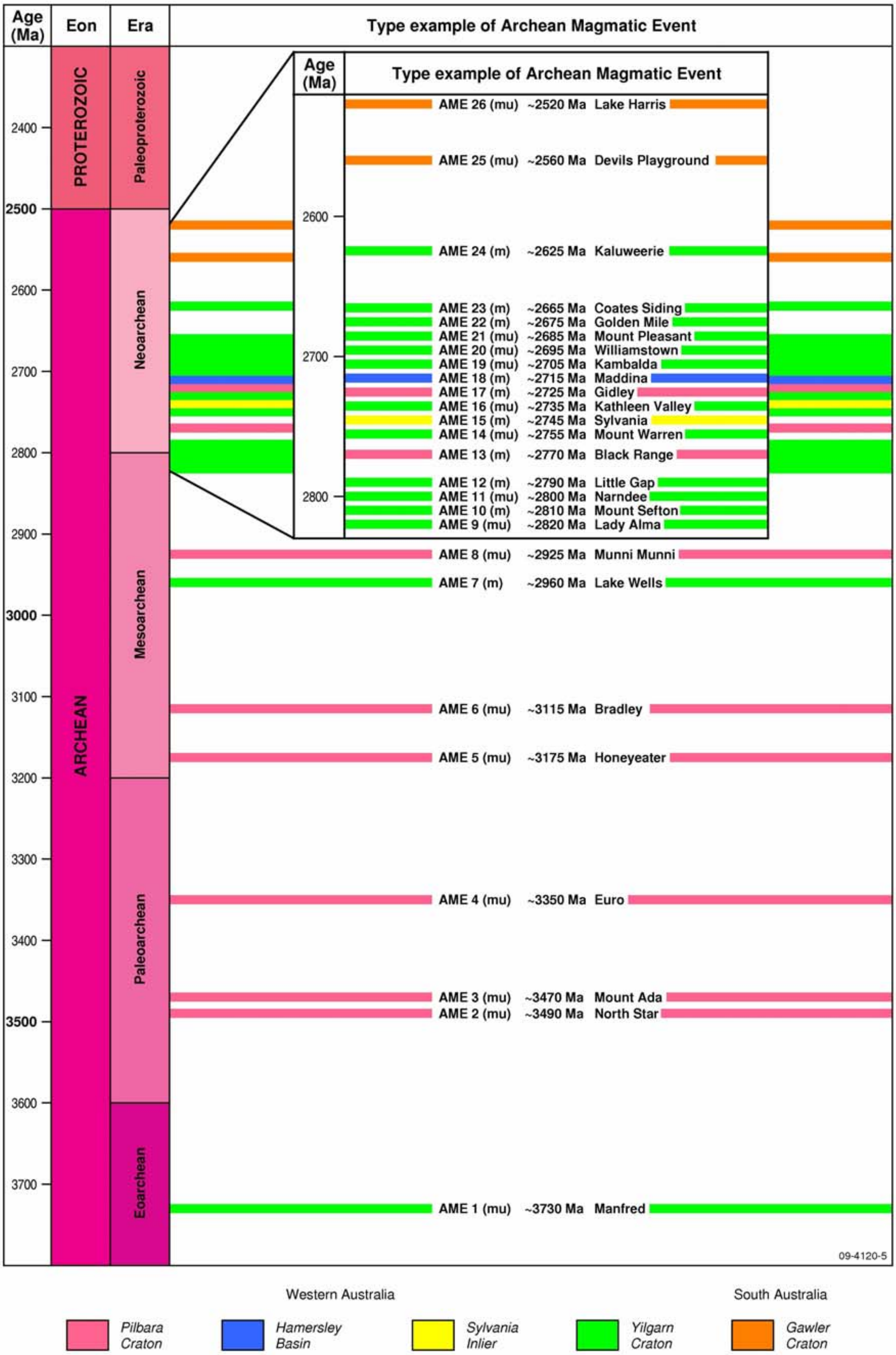
1. Hoatson, D.M., Jaireth, S., Whitaker, A.J., Champion, D.C. and Claoué-Long, J.C., 2009. Australian Archean Mafic-Ultramafic Magmatic Events, Sheet 1 of 2 (1:5 000 000 scale map), Geoscience Australia, Canberra, published September 2009, GeoCat 69347;
2. Hoatson, D.M., Jaireth, S., Whitaker, A.J., Champion, D.C. and Claoué-Long, J.C., 2009. Australian Archean Mafic-Ultramafic Magmatic Events: Yilgarn Craton, Western Australia, Sheet 2 of 2 (1:3 000 000 and 1:6 000 000 scale maps), Geoscience Australia, Canberra, published September 2009, GeoCat 69347;
3. Hoatson, D.M., Jaireth, S., Whitaker, A.J., Champion, D.C. and Claoué-Long, J.C., 2009. Guide to Using the Australian Archean Mafic-Ultramafic Magmatic Events Map. Geoscience Australia Record 2009/41 (this publication), GeoCat 69935; and
4. Appendix 10 of this Record provides individual time-slice maps for each of the twenty-six Archean Magmatic Events.

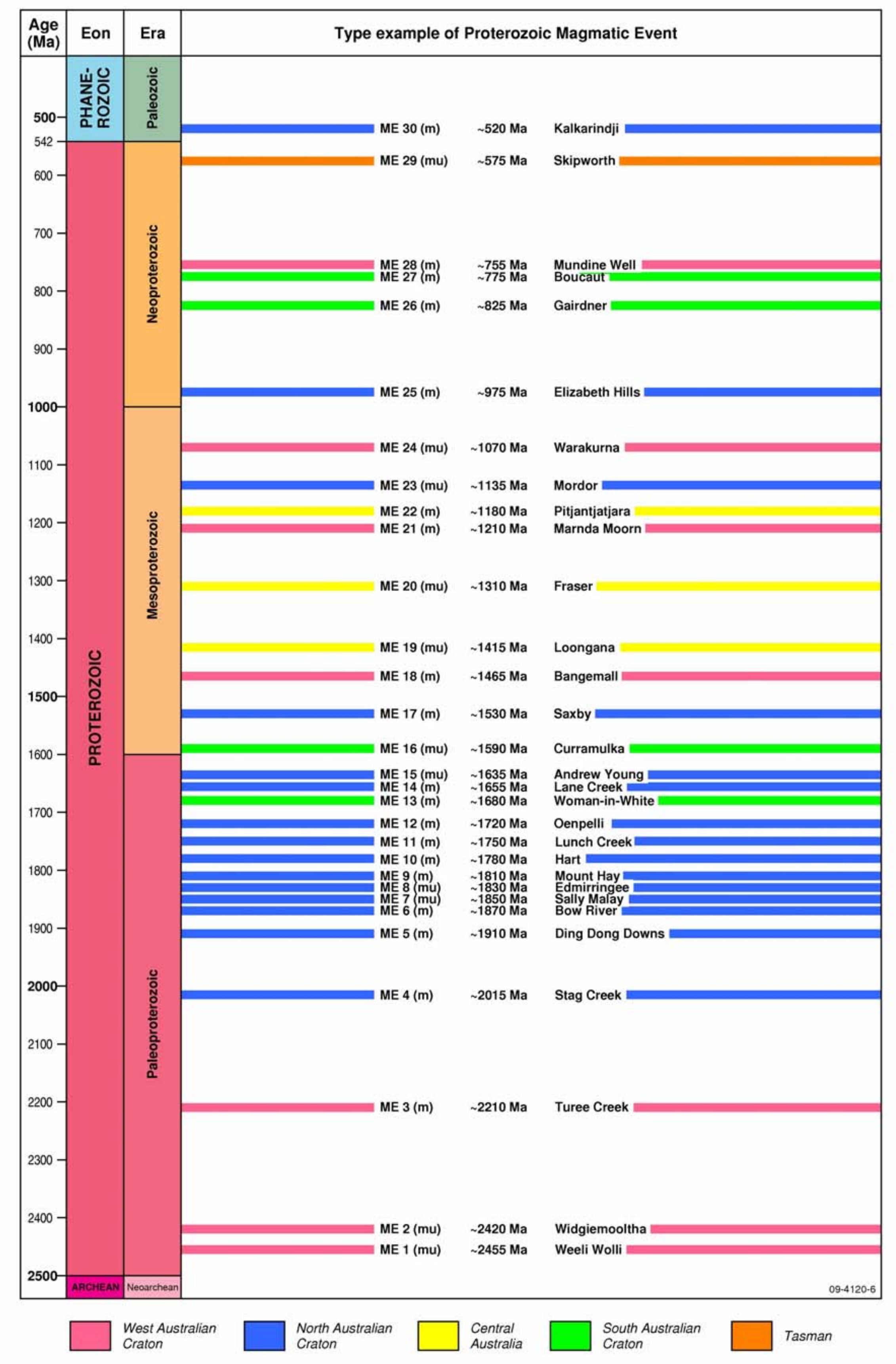
Proterozoic study
2008:

5. Hoatson, D.M., Claoué-Long, J.C. and Jaireth, S., 2008. Australian Proterozoic Mafic-Ultramafic Magmatic Events, Sheet 1 of 2 (1:5 000 000 scale map), Geoscience Australia, Canberra, published July 2008, GeoCat 66114;
6. Hoatson, D.M., Claoué-Long, J.C. and Jaireth, S., 2008. Australian Proterozoic Mafic-Ultramafic Magmatic Events, Sheet 2 of 2 (1:10 000 000 scale maps), Geoscience Australia, Canberra, published July 2008, GeoCat 66114;
7. Hoatson, D.M., Claoué-Long, J.C. and Jaireth, S., 2008. Guide to using the 1:5 000 000 Map of Australian Proterozoic Mafic-Ultramafic Magmatic Events. Geoscience Australia Record 2008/15, GeoCat 66624;
8. Appendix 9 of Record 2008/15 provides individual time-slice maps of Australia for each of the thirty Proterozoic Magmatic Events, GeoCat 66624;

Figure 3 (on page 18): *Distribution of type examples of Archean Mafic-Ultramafic Magmatic Events with time. Note that the ‘time interval’ for Archean Magmatic Events is ± 10 million years.*

Figure 4 (on page 19): *Distribution of type examples of Proterozoic Mafic-Ultramafic Magmatic Events (Hoatson et al., 2008) with time. Note that the ‘time interval’ for Proterozoic Magmatic Events is ± 20 million years. Figures 3 and 4 indicate that the geological periods containing the highest frequency of mafic-ultramafic magmatism during the Precambrian evolution of Australia occurred during the Neoarchean (~2820 Ma to ~2665 Ma) and late Paleoproterozoic (~1910 Ma to ~1590 Ma).*


Age (Ma)
Eon
Era
Type example of Archean Magmatic Event
PROTEROZOIC
Paleoproterozoic
ARCHEAN
Neoarchean
Mesoarchean
Paleoarchean
Eoarchean
AME 26 (mu) ~2520 Ma Lake Harris
AME 25 (mu) ~2560 Ma Devils Playground
AME 24 (m) ~2625 Ma Kaluweerie
AME 23 (m) ~2665 Ma Coates Siding
AME 22 (m) ~2675 Ma Golden Mile
AME 21 (mu) ~2685 Ma Mount Pleasant
AME 20 (mu) ~2695 Ma Williamstown
AME 19 (mu) ~2705 Ma Kambalda
AME 18 (m) ~2715 Ma Maddina
AME 17 (m) ~2725 Ma Gidley
AME 16 (mu) ~2735 Ma Kathleen Valley
AME 15 (m) ~2745 Ma Sylvania
AME 14 (mu) ~2755 Ma Mount Warren
AME 13 (m) ~2770 Ma Black Range
AME 12 (m) ~2790 Ma Little Gap
AME 11 (mu) ~2800 Ma Narndee
AME 10 (m) ~2810 Ma Mount Sefton
AME 9 (mu) ~2820 Ma Lady Alma
AME 8 (mu) ~2925 Ma Munni Munni
AME 7 (m) ~2960 Ma Lake Wells
AME 6 (mu) ~3115 Ma Bradley
AME 5 (mu) ~3175 Ma Honeyeater
AME 4 (mu) ~3350 Ma Euro
AME 3 (mu) ~3470 Ma Mount Ada
AME 2 (mu) ~3490 Ma North Star
AME 1 (mu) ~3730 Ma Manfred
09-4120-5
Western Australia
South Australia
Pilbara Craton
Hamersley Basin
Sylvania Inlier
Yilgarn Craton
Gawler Craton



Age (Ma)
Eon
Era
Type example of Proterozoic Magmatic Event
PHANE-ROZOIC
Paleozoic
PROTEROZOIC
Neoproterozoic
Mesoproterozoic
Paleoproterozoic
ARCHEAN
Neoarchean
500
542
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
ME 30 (m) ~520 Ma Kalkarindji
ME 29 (mu) ~575 Ma Skipworth
ME 28 (m) ~755 Ma Mundine Well
ME 27 (m) ~775 Ma Boucaut
ME 26 (m) ~825 Ma Gairdner
ME 25 (m) ~975 Ma Elizabeth Hills
ME 24 (mu) ~1070 Ma Warakurna
ME 23 (mu) ~1135 Ma Mordor
ME 22 (m) ~1180 Ma Pitjantjatjara
ME 21 (m) ~1210 Ma Marnda Moorn
ME 20 (mu) ~1310 Ma Fraser
ME 19 (mu) ~1415 Ma Loongana
ME 18 (m) ~1465 Ma Bangemall
ME 17 (m) ~1530 Ma Saxby
ME 16 (mu) ~1590 Ma Curramulka
ME 15 (mu) ~1635 Ma Andrew Young
ME 14 (m) ~1655 Ma Lane Creek
ME 13 (m) ~1680 Ma Woman-in-White
ME 12 (m) ~1720 Ma Oenpelli
ME 11 (m) ~1750 Ma Lunch Creek
ME 10 (m) ~1780 Ma Hart
ME 9 (m) ~1810 Ma Mount Hay
ME 8 (mu) ~1830 Ma Edmirringee
ME 7 (mu) ~1850 Ma Sally Malay
ME 6 (m) ~1870 Ma Bow River
ME 5 (m) ~1910 Ma Ding Dong Downs
ME 4 (m) ~2015 Ma Stag Creek
ME 3 (m) ~2210 Ma Turee Creek
ME 2 (mu) ~2420 Ma Widgiemooltha
ME 1 (mu) ~2455 Ma Weeli Wolli
09-4120-6
West Australian Craton
North Australian Craton
Central Australia
South Australian Craton
Tasman

2007:

9. Hoatson, D.M., Claoué-Long, J.C. and Jaireth, S., 2007. A Synthesis of Australian Proterozoic Mafic-Ultramafic Magmatic Events. Part 2: Northern Territory and South Australia, (1:4 000 000 scale map), Geoscience Australia, Canberra, published July 2007, GeoCat 65257; and

2006:

10. Hoatson, D.M., Jaireth, S., Jaques, A.L. and Huleatt, M.B., 2006. A Synthesis of Australian Proterozoic Mafic-Ultramafic Magmatic Events. Part 1: Western Australia (1:3 500 000 scale map), Geoscience Australia, Canberra, published October 2006, GeoCat 64813.

In addition to the above products, a related study that focussed on the evolution of Proterozoic Large Igneous Provinces (LIPs) in Australia was completed in 2009. The main products were a large format, web-based colour map (comprising two sheets) and an accompanying GA Record 2009/44. The spatial representation of the LIPs on Sheet 1, mapped at 1:5 000 000 scale, indicate continent-scale crustal controls on their regional distribution. An innovative series of time slices on Sheet 2 also highlight the repeated use during the Proterozoic of certain structural corridors and crustal elements for the emplacement of these voluminous mafic-dominated magmatic systems. Products from this study include:

2009:

1. Claoué-Long, J.C. and Hoatson, D.M., 2009. Australian Proterozoic Large Igneous Provinces, Sheets 1 and 2 (1:5 000 000, 1:7 500 000, and 1:15 000 000 scale maps), Geoscience Australia, Canberra, GeoCat 69213; and
2. Claoué-Long, J.C. and Hoatson, D.M., 2009. Guide to using the Map of Australian Proterozoic Large Igneous Provinces. Geoscience Australia Record 2009/44, GeoCat 70008.

The maps can be downloaded free on-line in pdf and jpeg formats from Geoscience Australia's general map website http://www.ga.gov.au/map/index.jsp under the major heading 'Maps of Australia' and the sub-headings 'Minerals maps', and 'Mafic-Ultramafic Magmatic Events. Under this sub-heading, all the Archean maps and report products can be downloaded via their respective GeoCat product description entries (GeoCat Number 66624 for Proterozoic resource package, GeoCat Number 69347 for Archean maps, and 69935 for this GA Record 2009/41; note in the future, individual products on the www may be assigned to specific 'Resource packages, e.g., Archean resource package).

The direct www links to the maps are:

Australian Archean Map (Sheet 1):
http://www.ga.gov.au/image_cache/GA15395.pdf
http://www.ga.gov.au/image_cache/GA15393.jpg

Australian Archean Map (Sheet 2):
http://www.ga.gov.au/image_cache/GA15396.pdf
http://www.ga.gov.au/image_cache/GA15394.jpg

Australian Proterozoic Map (Sheet 1):
http://www.ga.gov.au/image_cache/GA11507.pdf
http://www.ga.gov.au/image_cache/GA11511.jpg

Australian Proterozoic Map (Sheet 2):
http://www.ga.gov.au/image_cache/GA11506.pdf
http://www.ga.gov.au/image_cache/GA11510.jpg

Australian Proterozoic Large Igneous Provinces Map (Sheet 1):
http://www.ga.gov.au/image_cache/GA15339.pdf
http://www.ga.gov.au/image_cache/GA15415.jpg

Australian Proterozoic Large Igneous Provinces Map (Sheet 2):
http://www.ga.gov.au/image_cache/GA15340.pdf
http://www.ga.gov.au/image_cache/GA15416.jpg

Earlier State/Northern Territory maps in the series:
Western Australia:
http://www.ga.gov.au/image_cache/GA8798.pdf
http://www.ga.gov.au/image_cache/GA8797.jpg

Northern Territory–South Australia:
http://www.ga.gov.au/image_cache/GA10636.pdf
http://www.ga.gov.au/image_cache/GA10645.jpg

The Australian Archean Mafic-Ultramafic Magmatic Events Map Sheets 1 and 2 are of A0 size in landscape format with dimensions of 82.5 cm by 117.2 cm, excluding margins. The pdf files can be viewed and explored using the zoom function of pdf reader programs. Both the pdf and jpg files can be printed using large-format colour printers. To avoid truncation, or the compression of scales, it is important to select paper sizes and printing protocols appropriate to your plotter when printing large-format images.

In addition to this Record, short promotional articles announcing the release of maps, associated reports, and their web links appeared in:

1. AUSGEO News issue 84: December 2006 (http://www.ga.gov.au/image_cache/GA9416.pdf);
2. AUSGEO News issue 87: September 2007 (http://www.ga.gov.au/image_cache/GA10538.pdf);
3. AUSGEO News issue 91: September 2008 (http://www.ga.gov.au/image_cache/GA11664.pdf);
4. AUSGEO News issue 96: December 2009 (http://www.ga.gov.au/image_cache/GA15752.pdf); and
5. AUSGEO News issue 97: March 2010 (http://www.ga.gov.au/image_cache/GA16739.pdf).

Components of the Map

AUSTRALIAN ARCHEAN MAFIC-ULTRAMAFIC MAGMATIC EVENTS MAP: SHEET 1

Sheet 1 has a stye and content that is similar to the recently published 'Australian Proterozoic Mafic-Ultramafic Magmatic Events' study (Hoatson et al., 2008). The main feature of Sheet 1 is a 1:5 000 000 map that shows the spatial distribution of Archean mafic and/or ultramafic igneous rocks in Australia. State-wide solid-geology digital maps were synthesised to produce the national presentation of mafic-ultramafic rock units, and regional rock packages that include relatively minor coeval mafic-ultramafic igneous rock components. Colour-coding of rock polygons by their age of magmatism provides a visual cue to the spatial and temporal correlations of magmatic units at province and continental scales. Their relationship to the evolution of the continent is shown superimposed on a geological framework of five major crustal provinces (Pilbara Craton, Yilgarn Craton, Gawler Craton, Sylvania Inlier, and Hamersley Basin). These provinces are further subdivided into terrane and domain elements (Figure 2) as proposed by GSWA and PIRSA.

In this study, the terrane framework of the Pilbara Craton was slightly modified from Van Kranendonk et al. (2006, 2007) and Hickman and Van Kranendonk (2008). The craton was divided from west to east into five crustal components: West Pilbara Terrane, Central Pilbara Terrane, East Pilbara Terrane, Mosquito Creek Basin, and Kurrana Terrane. The boundaries between the terranes are the same as reported by Van Kranendonk et al. (2006, 2007) and Hickman and Van Kranendonk (2008), but some of the terrane names (e.g., Central Pilbara Tectonic Zone) were informally simplified. Van Kranendonk et al. (in press) provide the latest version of the evolving terrane framework of the Pilbara Craton. The boundaries of the Sylvania Inlier and Hamersley Basin crustal provinces are unchanged from a digital map file provided by GSWA called 1:2 500 000 Tectonic Units of Western Australia, June 2001, Geological Survey of Western Australia.

For the Yilgarn Craton, Cassidy et al. (2006) used new geophysical, geochemical, isotopic, and geochronological data to revise the geological framework of the craton. They subdivided the craton into six terranes that are in part bounded by regional interconnected fault systems (e.g., Ida, Hootanui, Ockerburry, and Waroonga). The northwestern and southwestern limits of the craton are defined by the Narryer Terrane and South West Terrane, the central part of the craton is represented by the Youanmi Terrane, and the eastern half of the craton is made up of the Kalgoorlie Terrane, Kurnalpi Terrane, and the Burtville Terrane. The latter three terranes constitute the Eastern Goldfields Superterrane (Blewett 2008a,b).

The Gawler Craton of central South Australia has been subdivided into the various geophysical-geological domains (Figure 2) described by Fairclough et al. (2003). These domains represent more detailed province components of the regional Mulgathing and Sleaford complexes which contain the late Archean to early Paleoproterozoic rocks of the Gawler Craton. The Archean mafic and ultramafic igneous rocks in the craton are most widespread in the Christie, Harris Greenstone, Olympic, Wilgena, and Undifferentiated domains (all part of the Mulgathing Complex in the central part of the craton), and in the Coulta Domain (part of the Sleaford Complex in the southern part of the craton). Most of the mafic-ultramafic rocks in these domains are generally poorly dated (i.e., they are assigned to Undefined Event) and they constitute a subordinate component within a regional rock package.

The readability of mafic-ultramafic rock polygons in the region encompassing the Pilbara Craton, Sylvania Inlier, and Hamersley Basin on the main 1:5 000 000 map is facilitated by an enlarged inset map at 1:2 500 000 scale. Two smaller maps on the sheet show the generalised distribution of Archean rocks of all compositions in Australia, and the major geological and tectonic subdivisions of the crustal provinces are superimposed on a diffused gravity anomaly image. The gravity database is from Bacchin, et al. (2008): Gravity Anomaly Map of the Australian Region (3^{rd} Edition), GeoCat Number 65682.

Sheet 1 contains two commentary legends titled ‘Locations of type examples of dated Archean Magmatic Events’ (indicated by the letters A to Z in circles which are colour-coded to the relevant AME) and ‘Locations of additional ages and other geological data’ (letters a to z in colour-coded squares: see Appendix 6). The two commentary legends are independent of each other (i.e., they are not linked by the same letter), and their portrayals on the main 1:5 000 000 map and its 1:2 500 000 inset map are arranged alphabetically from north to south and west to east across the continent to facilitate finding their location on the map. Further information and references relating to these locational points can be found in the data spreadsheets of Appendix 11.

A Time–Space–Event Chart (Appendix 5) summarises the spatial and temporal correlations of twenty-six magmatic events in fifteen Australian crustal provinces. The chart is a particularly useful way of depicting the geological timing, duration, and spatial extent of geological events. It highlights the lateral extent of magmatic events and important correlations across provinces. For example, it can be seen that some events are isolated to one crustal province (e.g., AME 1–Narryer Terrane), whereas others have widespread presence across several provinces (e.g., AME 13–Black Range Event occurs in three terranes and two basins). In addition, the chart shows that some provinces have experienced multiple magmatic events over a relatively short geological period of time (e.g., seven AME affected the

Kalgoorlie Terrane from 2735 Ma to 2665 Ma). It also draws attention to the sequential development of magmatic events across the continent. It should be emphasised that time-equivalent magmatism in different crustal provinces shown on the chart does not necessarily imply cogenetic magmatism.

The crustal provinces are arranged across the top of the chart in a broad geographical order from north to south and west to east (e.g., Pilbara Craton → Hamersley Basin → Sylvania Inlier → Yilgarn Craton → Gawler Craton). All the events portrayed on the chart are colour-coded to the events shown on the main legend and map of Sheet 1. Three magmatic events known to be mineralised in Australia are highlighted by thin horizontal pink bands across the chart. These mineralised episodes are: ~2925 Ma—platinum-group elements (PGEs)-nickel-copper (Munni Munni Intrusion: AME 8) and nickel-copper-PGEs (Radio Hill Intrusion: AME 8); ~2800 Ma—titanium-vanadium (Windimurra Intrusion: AME 11); and ~2705 Ma—nickel-copper±PGEs associated with komatiitic rocks (eastern Yilgarn Craton: AME 19). The latter mineralised event overlaps with similar nickel sulphide deposits in the Abitibi Belt of Canada.

The Time–Space–Event Chart also shows a fourth mineralised magmatic event (e.g., pink band) that correlates with the ~2585 Ma age of the Great Dyke of Zimbabwe, which hosts economic PGE-bearing chromitites. None of the Precambrian provinces in Australia are known to host a coeval magmatic event equivalent to ~2585 Ma, but it is possible that this reflects the incomplete identification and dating of dyke swarms in Australia. The Paleoproterozoic (~2420 Ma) Widgiemooltha Dyke Swarm in the Yilgarn Craton is distinctive for its age and mode of emplacement as extremely long, parallel, widely-spaced mafic-ultramafic dykes (Hoatson et al., 2008). Systematic dating of Zimbabwe mafic dyke swarms by Söderlund et al. (2009) has indicated that the Sebanga Poort Dyke Swarm matches the Widgiemooltha Event in both age and configuration, and it is the only known match worldwide. The north-northwest-trending Sebanga Poort Dyke Swarm traverses the north-northeast-trending Great Dyke over much of the Archean Zimbabwe Craton. If the two ~2420 Ma dyke swarms in Zimbabwe and Western Australia are fragments of the same intrusion event, then it is possible that time equivalents of the mineralised ~2585 Ma Great Dyke also remain to be identified and dated somewhere in the Yilgarn Craton. Such dykes could be hidden (possibly under cover) within the complex array of Proterozoic and Archean mafic-ultramafic dykes (e.g., ~755 Ma Mundine Well, ~1210 Ma Marnda Moorn, ~2420 Ma Widgiemooltha, ~2675 Ma Golden Mile Dolerite) that characterise the Yilgarn Craton and surrounds.

AUSTRALIAN ARCHEAN MAFIC-ULTRAMAFIC MAGMATIC EVENTS MAP: SHEET 2

Sheet 2 of the new map is focussed entirely on the Yilgarn Craton of Western Australia and it has a more predictive style compared to Sheet 1. The sheet features two 1:3 000 000 maps that show the interpreted distribution and characterisation of economically important Archean mafic-ultramafic rocks in the Yilgarn Craton. One of its main purposes is to identify extensions of potentially fertile Archean mafic-ultramafic rocks under cover.

The 1: 3 000 000 'Interpreted Distribution of Archean Mafic-Ultramafic Rocks' map on sheet 2 depicts outcropping Archean ultramafic-mafic igneous rocks, layered mafic-ultramafic intrusions, and interpreted subsurface extensions of equivalent rocks under younger cover throughout the Yilgarn Craton. Outcrop locations, rock types and regional groupings, e.g., distribution of greenstone belts, were taken from the 1:250 000 Geological Map Series (compiled by the Geological Survey of Western Australia and Geoscience Australia). The distribution of subsurface equivalent rocks within the craton was largely derived from an interpretation of aeromagnetic data contained in the National Airborne Geophysical Database (Geoscience Australia; as at 2007). Stratigraphic continuity was used to assign rock type information from exposed outcrop to adjacent aeromagnetic anomalies over concealed areas. Some anomalies remain unassigned.

The Yilgarn Craton has an area of at least 660 000 km^2. Granite and greenstone rock sequences throughout the craton mostly range in age from ~3.0 Ga to ~2.6 Ga, although some mafic igneous rocks (gabbro, anorthosite) dated at ~3.7 Ga occur in the west. Greenstone belts, which are composed largely of mafic volcanic rocks with lesser felsic volcanic, sedimentary, and ultramafic rocks, make up approximately 20% of the craton. Granite and granitic gneiss (shown in pale pink) constitute the other 80%. Ultramafic rocks (purple), which host significant nickel mineralisation, within regionally extensive north-northwest-trending linear greenstone belts (pale green), are also depicted on the map.

Strata-coincident aeromagnetic anomalies of at least moderate magnetisation generally correlate with banded iron formation (BIF: blue), or olivine-rich ultramafic rocks (komatiite; serpentinisation alteration produces magnetite as a co-product: purple), or magnetite-rich layers (black) in layered mafic and mafic-ultramafic intrusions (dark green). Units with extreme magnetisation (+ 1500 nT above average Yilgarn rock magnetisation) are almost exclusively associated with BIF. Generally, however, the amplitude of magnetic anomalies, from very high to moderately low levels, is not unique to any of the three rock associations, and reflects, amongst other things, magnetite content, susceptibility, and remanence, in combination with unit thickness, attitude (dip), and depth extent. Thus the distribution of outcropping and interpreted subsurface BIF has also been included both for magnetic interpretation context and to allow for possibly incorrect rock type assignment in areas of cover. This interpretation does not address all subsurface ultramafic rocks. Ultramafic rock types such as pyroxenites and high-magnesium basalts are generally poorly magnetised and are not readily mapped by aeromagnetic data.

The Yilgarn Craton, as portrayed by Whitaker and Bastrakova (2002), extends under laterally extensive Paleoproterozoic (brown) basin cover in the north, and both Paleoproterozoic basin cover and Phanerozoic (beige) cover in the southeast and east. The subsurface boundaries of the craton in these areas were located by gradients in aeromagnetic and gravity data which truncate the widespread internal north to north-northwest lithological/anomaly trends. Across these boundaries the crust is inferred to be different in composition and to have undergone different deformational histories. The interpreted extent of subsurface greenstone belts underneath basin and alluvial cover (indicated by paler green with stipple) was also defined using a combination of aeromagnetic and gravity data.

Greenstone belts under the cover may also be prospective for komatiite-related nickel sulphide deposits as inferred from the presence of ultramafic rocks in regionally adjacent sub-cropping belts. The thicker cover precludes geophysical mapping of all but extremely magnetised BIF units in these belts. Selected drillhole data from various sources have been added in the area of cover to provide information on depths to basement.

The 1: 3 000 000 'Interpreted Characterisation of Komatiites' map on sheet 2 characterises the komatiitic rocks of the Yilgarn Craton in relation to their broad interpreted ages of emplacement (U-Pb zircon and baddeleyite ages) and compositional data (Al_2O_3/TiO_2 ratios). The rock polygons on the base map are from the 1:3 000 000 'Interpreted Distribution of Archean Mafic-Ultramafic Rocks' map (see above).

The geochronology data (most ages are summarised in Hoatson et al., 2006) of the Archean komatiitic sequences shown on this map include: U-Pb zircon-baddeleyite ages of pyroclastic and felsic igneous units intercalated with komatiitic sequences (i.e., providing direct age of komatiites); felsic footwall units (maximum age); felsic hangingwall units (minimum age); and felsic dykes cutting the komatiitic sequences (minimum age). Most of the ages in the west Yilgarn Craton prefixed by a ? indicate that the stratigraphic relationship between the dated rock and associated komatiitic rock has not been determined. Those ages shown with an * may have questionable geochronological significance based on recent rock dating and field mapping undertaken by the Geological Survey of Western Australia.

The komatiitic rocks of the Yilgarn Craton can be divided into two broad compositional groups (Barnes et al., 2004): (1) Al-undepleted komatiites (AUDK) or 'Munro-type' komatiites–Al_2O_3/TiO_2 ratios generally vary between 15 and 25, and they are typically depleted in incompatible trace elements; and

(2) Al-depleted komatiites (ADK) or 'Barberton-type' komatiites–Al_2O_3/TiO_2 ratios are <15, and they are enriched in incompatible trace elements. The compositional data for the komatiitic samples (Appendix 7) are from Barnes et al. (2004), Lesher and Keays (2002), Barley et al. (2006), Chen et al. (2005), and Reudavey (1990). Most of the komatiitic samples shown on the map have MgO contents greater than 18% and are therefore potentially derived from primitive ultramafic magmas. AUDK are depicted on the map as a small blue square and its location name in blue text, whereas ADK are indicated as a small red square and its location name in red text. If a location has representatives of both AUDK and ADK, then a black triangle is shown (e.g., for the Mount Windarra and Sandstone regions).

The two chemical groups (AUDK, ADK) of komatiites are inferred to result from different melting conditions in the mantle, with a garnet residue indicated by the Al-depleted lavas (Barnes et al., 2004). Large-tonnage nickel sulphide deposits (Mount Keith) are generally associated with ~2.70 Ga AUDK, whereas smaller high-grade deposits (Flying Fox) are often associated with older ~3.00-2.80 Ga ADK.

The komatiitic rocks of the Yilgarn Craton were assigned to seven major geographical groups on the basis of their range of ages of emplacement and Al_2O_3/TiO_2 compositions. These groups are shown on the map with a numbered transparent coloured zone that generally trends north-northwest (parallel to the regional greenstone belts) across the craton. The regional spatial distribution of these zones (i.e., in terms of their relative ages) across the craton broadly correlates with similar age trends evident in the Crustal Neodymium Model Ages map (see below).

The 'Nickel Sulphide Resources' 1:6 000 000 map on sheet 2 shows the nickel sulphide resource endowment (in various hues of brown) for the Southern Cross Domain, Kalgoorlie Terrane, and Kurnalpi Terrane in the Yilgarn Craton. The total metal (past production and remaining resources of nickel) status of individual nickel sulphide deposits is also indicated by a specific sized circle symbol (coloured to various hues of purple). The Kalgoorlie Terrane is the most nickel-endowed province with total nickel metal amounting to ~12 Mt. Data are from OZMIN—Geoscience Australia's national database of mineral deposits and resources.

The 1:6 000 000 'Crustal Neodymium Model Ages' map on sheet 2 shows the model-based 'average' age of the crust as indicated by granitic rocks for the Yilgarn Craton (using a two-stage evolution of Sm/Nd and assuming a depleted mantle; Champion and Cassidy, 2008). Sample locations are not uniformly distributed across the Yilgarn Craton. The model age surface (cell size of 1 km) was calculated using an interpolating grid routine in ArcGIS. The interpolating method involved was an Inverse Distance Weighted with a fixed search radius (number of neighbours is 12).

To investigate possible correlations between metal endowment and model ages of the crust (neodymium data), the outlines of the nickel sulphide resource endowment regions (from the Nickel Sulphide Resources map described above) for the Southern Cross Domain, Kalgoorlie Terrane, and Kurnalpi Terrane were superimposed on the contoured neodymium model age data. The most endowed terrane—the Kalgoorlie Terrane—was found to be associated with intermediate age crust (neodymium two-stage model ages of 3.02 to 2.87 Ga).

Certain publications that were particularly valuable in providing stratigraphical and geochronological data for this Archean study are shown in Appendix 8. A compilation of all the references used in the study can be found in Appendix 9.

Conclusions

The ‘Australian Archean Mafic-Ultramafic Magmatic Events’ map summarises the continental extent and age relationships of Archean mafic and ultramafic rocks and associated mineral deposits throughout Australia. The Archean Eon (~4000 million years to 2500 million years) represents an early part of Earth’s history that is represented in Australia by some of the largest layered mafic-ultramafic intrusions (e.g., Windimurra, Munni Munni, Gidley Granophyre), extensive continental flood basalts (Fortescue Group) and coeval mafic dyke swarms (Black Range Dolerite), economically important differentiated mafic sills (Golden Mile Dolerite), and the widespread occurrence of unusual olivine-rich ultramafic rocks called komatiites (Kambalda Komatiite), which contain world-class deposits of nickel sulphides (Kambalda, Mount Keith, Perseverance).

Archean mafic and ultramafic igneous rocks with reliable crystallisation ages in Australia are confined to the older crustal components in Western Australia and South Australia. These crustal components include the Pilbara Craton, Hamersley Basin, Sylvania Inlier, Yilgarn Craton, and Gawler Craton. Potentially similar aged rocks may occur in the older crustal provinces of the Northern Territory, but these rock sequences have not been reliably dated.

In this study, twenty-six Archean Magmatic Events (AME) ranging in age from the Eoarchean ~3730 Ma (AME 1) to the late Neoarchean ~2520 Ma (AME 26) were identified. The new national map has been made possible by the relative abundance of robust geochronological data produced in recent years, and by advances in the coverage of solid-geology mapping over much of Australia. The mafic-ultramafic magmatic event series defined is based on several hundred published age measurements, of which over 95 per cent are derived from recent Uranium-Lead dating of zircon and baddeleyite. In contrast to the Proterozoic time period (2500 million years to 542 million years: Hoatson et al., 2008), the AME defined in this study contain a greater abundance of ultramafic rocks relative to mafic rocks. Sixteen (AME 1 to 6, 8, 9, 11, 14, 16, 19 to 21, 25 to 26) of the twenty-six AME have a significant stratigraphic component of ultramafic rocks (e.g., komatiite, dunite, peridotite). The greater abundance of these more primitive, high-temperature rocks increases the potential for orthomagmatic deposits that contain such metals as chromium, nickel, and the PGEs.

Colour-coding of mafic and ultramafic rock units by their age of magmatism provides a visual cue to the spatial and temporal correlations of mafic-ultramafic magmatic units at province and continental scales on Sheet 1. The general sequential development of Archean mafic-ultramafic magmatism in Australia commenced in the northwest Yilgarn Craton, with 3730 ± 6 Ma gabbroic rocks in the Manfred Complex being the oldest known dated rocks in Australia. This was followed by the Pilbara Craton, and then mafic-ultramafic magmatic events became more widespread in the early Neoarchean with several coeval contributions from the Yilgarn and Pilbara cratons, Hamersley Basin, and Sylvania Inlier. The national Archean mafic-ultramafic magmatic record concluded in the late Neoarchean with two isolated magmatic events (AME 25–2560 Ma and AME 26–2520 Ma) confined to the Gawler Craton.

The Time–Space–Event Chart on sheet 1 is a particularly useful way of depicting the geological timing, duration, and spatial extent of geological events. It highlights the lateral extent of magmatic events and potential correlations across provinces. For example, it can be seen that some events are isolated to one crustal province (e.g., AME 1–Narryer Terrane), whereas others have widespread presence across several provinces (e.g., AME 13–Black Range Event occurs in three terranes and two basins). In addition, the chart shows that some provinces have experienced multiple magmatic events over a relatively short geological period of time (e.g., seven AME appear to have affected the Kalgoorlie Terrane from 2735 Ma to 2665 Ma).

The new national map will be of interest to explorers searching for nickel, platinum-group elements, chromium, titanium, vanadium, and cobalt. The Time–Space–Event Chart highlights three significant periods of mineralisation associated with mafic-ultramafic magmatism. They are:

- ~2925 Ma—platinum-group elements-nickel-copper (Munni Munni Intrusion: AME 8) and nickel-copper-platinum group elements (Radio Hill Intrusion: AME 8)
- ~2800 Ma—titanium-vanadium (Windimurra Intrusion: AME 11)
- ~2705 Ma—nickel-copper±platinum-group elements associated with komatiitic rocks (Kambalda-Wiluna region: AME 19).

Of these three events (AME 8, 11, 19), only AME 19, which contains the komatiitic–associated nickel sulphide deposits that feature in the Kalgoorlie and Kurnalpi terranes of the Yilgarn Craton, is known to contain significant economic resources of metals. The Windimurra (AME 11) and Radio Hill (AME 8) intrusions have experienced intermittent phases of mining over the past few decades, and the Munni Munni Intrusion (AME 8) has not been mined. Significant high-grade nickel sulphide deposits (e.g., Spotted Quoll, Flying Fox, Maggie Hays) in the Southern Cross Domain of the Yilgarn Craton are hosted by komatiitic sequences that are probably older (~3.0 billion years to ~2.8 billion years) than those identified in AME 19. The ~2.7 Ga nickel deposits in the Kambalda-Wiluna region (AME 19) are coeval and very similar to the nickel sulphide deposits in the Abitibi Belt of Canada. Australia appears to lack coeval analogues to the mineralised ~2585 Ma Great Dyke of Zimbabwe, although this could be due to lack of discovery in covered Precambrian terranes.

The new map highlights potential comagmatic relationships between various coeval mafic-ultramafic rock associations, which in turn may have economic implications. Two such obvious examples are the 2747 ± 4 Ma dolerites of the Sylvania dyke swarm (Wingate, 1999) that could also be feeders to the voluminous platform mafic volcanics of the 2741 ± 3 Ma Kylena Basalt in the Fortescue Group, Hamersley Basin. Similarly, mafic dykes of the extensive 2772 ± 2 Ma Black Range Dolerite Suite are coeval and spatially overlap with basaltic sequences of the 2775 ± 10 Ma Mount Roe Basalt in the Hamersley Basin and Pilbara Craton. The large volumes of mafic volcanic sequences in the Fortescue Group (at least 250 000 km^3) and their possible comagmatic associations with large dyke suites (Sylvania dyke swarm, Black Range Dolerite Suite) indicate potential for feeder conduit or basal contact style Ni-Cu-±PGE mineralisation. This type of sulphide mineralisation is seen in the world-class Voisey's Bay deposit in Canada (Evans-Lamswood et al., 2000) and in the nearby ~2925 Ma Radio Hill and Mount Sholl mafic-ultramafic intrusions of the west Pilbara Craton (Hoatson et al., 1992).

Sheet 2 is focussed on the Yilgarn Craton. The two large 1:3 000 000 maps on the sheet show the interpreted distribution (left map) and characterisation (right map) of economically important Archean mafic-ultramafic rocks across the whole craton. Lateral strike extensions of prospective geological units, such as the large layered mafic-ultramafic intrusions of AME 11 (e.g., Windimurra, Narndee, Youanmi. Barrambie), banded-iron formations, and greenstone sequences are highlighted under areas of shallow cover. Also of economic significance are potential areas of komatiitic rocks shown under alluvial cover and younger sedimentary basins that elsewhere in the craton host significant resources of nickel, copper, and the PGEs. Examples include the northern extensions of the well mineralised Norseman-Wiluna and Duketon greenstone belts beneath the Proterozoic sedimentary basins along the northern margin of the craton. Other irregular greenstone belts are interpreted to occur under cover further to the east in the northeast corner of the Yilgarn Craton. Selected drillhole data, which show bottom-hole lithologies and provide estimates of the thickness of cover and Proterozoic rock sequences, indicate that most of these greenstone belts are amenable to drilling.

The komatiitic rocks of the Yilgarn Craton were divided into two broad compositional groups: (1) Al-undepleted komatiites (AUDK)–Al_2O_3/TiO_2 ratios generally vary between 15 and 25 and they are typically depleted in incompatible trace elements; and (2) Al-depleted komatiites (ADK)–Al_2O_3/TiO_2 ratios are <15 and they are enriched in incompatible trace elements. Large-tonnage nickel sulphide deposits (Mount Keith) are generally associated with ~2.70 Ga AUDK, whereas smaller high-grade deposits (Flying Fox) are often associated with older ~3.00–2.80 Ga ADK.

The komatiitic rocks of the Yilgarn Craton were assigned to seven major geographical groups on the basis of their Al_2O_3/TiO_2 compositions and interpreted ages of emplacement. These elongated geographic zones generally trend north-northwest (parallel to the regional greenstone belts) across the craton. The regional spatial distribution of these zones (i.e., in terms of their relative ages) across the craton broadly correlates with similar age trends evident from Crustal Neodymium Model Ages data. The most endowed terrane—the Kalgoorlie Terrane (~12 Mt Ni)—was found to be associated with intermediate age crust (neodymium two-stage model ages of 3.02 to 2.87 Ga).

The new national magmatic events map and its derivative charts provide a framework for the exploration of orthomagmatic and hydrothermal mineral deposits, and for assessing their generation in geodynamic processes that range in scale from the local to the continent-wide. Users are encouraged to overlay and integrate their own datasets (e.g., structural, geochemical, and isotopic data), and to evaluate:

- the spatial distribution of Archean mafic and ultramafic rocks, their geological settings, the frequency of emplacement and potential coeval relationships;
- the identification of voluminous magmatic systems, such as Large Igneous Provinces,
- the secular variation of broad magma composition, e.g., ultramafic-dominated systems *versus* mafic-dominated systems, and relationships with mineralisation;
- the magnitude of each magmatic system which has implications for structural frameworks, tectonic settings, and metallogenesis;
- correlatives of magmatic units that are mineralised elsewhere in the Australian continent, and in other continents;
- associated favourable reactive (e.g., carbonaceous, sulphur-bearing) country rocks that may potentially induce contamination and sulphur saturation of mafic-ultramafic magmatic systems during emplacement; and
- the spatial distribution of extrusive *versus* intrusive magmatic components within each Archean Magmatic Event, as an indication of erosional levels and potential vectors to favourable mineralised environments, such as feeder conduits and basal contacts of intrusive bodies.

One of the most important advances for the future will be the expansion of modern geochronology techniques to mafic-ultramafic rocks, a neglected target for geochronology in comparison with felsic igneous rocks, metamorphic terranes, and sedimentary basins. The way forward has been shown in selected Australian Precambrian provinces by Page and Hoatson (2000), Wingate et al. (2000, 2002, 2004), Hoatson and Sun (2002), Claoué-Long and Hoatson (2005), Fanning (1997), Fanning et al. (2007), and Reid (2007). The process of successfully obtaining U-bearing zircon and baddeleyite from mafic (and even ultramafic) intrusions, using an integrated approach of field and geochemical criteria to guide sampling, opens the possibility of routinely dating mafic-ultramafic magmatic systems (Page and Hoatson, 2000; Claoué-Long and Hoatson, 2005). The new Archean map highlights abundant mafic and ultramafic rock units whose age and event affiliations are undefined. The stratigraphic mapping and dating of these rocks can reveal new magmatic events or increase the spatial extent of magmatic events previously defined.

The new 'Australian Archean Mafic-Ultramafic Magmatic Events' map (GeoCat 69347) when used in association with the 'Australian Proterozoic Mafic-Ultramafic Magmatic Events' map published in 2008 (GeoCat 66114; GA Record 2008/15: GeoCat 66624), summarise the temporal and spatial evolution of Precambrian mafic-ultramafic magmatism in Australia. These maps provide a national framework for investigating under-explored and potentially mineralised environments, and assessing the role of mafic-ultramafic magmatism in the development of the Australian continent.

All the maps and reports produced from this study can be downloaded free on-line in pdf and jpeg formats from Geoscience Australia's general map website http://www.ga.gov.au/map/index.jsp under the major heading 'Maps of Australia' and the sub-headings 'Minerals maps', 'Thematic mineral events maps, and 'Mafic-Ultramafic Magmatic Events. Under this last sub-heading, all the Archean maps and report products can be downloaded via their respective GeoCat product description entries (GeoCat

Number 66624 for Proterozoic resource package, GeoCat Numbers 69347 for Archean maps, and 69935 for this GA Record 2009/41).

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Appendix 1. Digital Geological and Geophysical Datasets Used in this Study

Geological base maps and solid-geology rock polygons (Sheet 1):
Western Australia
Distribution of Precambrian mafic and ultramafic rocks in Western Australia:1:500 000 Interpreted Bedrock Geology Map of Western Australia, Geological Survey of Western Australia (2008).
South Australia
Cowley, W.M. (Compiler), 2006. Solid geology of South Australia. Department of Primary Industries and Resources, South Australia. Mineral Exploration Data Package 15 (version 1.1.).

Geological and tectonic province boundaries (Sheets 1 and 2):
Yilgarn Craton
Cassidy, K.F., Champion, D.C., Krapez, B., Barley, M.E., Brown, S.J.A., Blewett, R.S., Groenewald, P.B. and Tyler, I.M., 2006. A revised geological framework for the Yilgarn Craton, Western Australia. Geological Survey of Western Australia, Record 2006/8, 8 pp.
Pilbara Craton, Hamersley Basin, Sylvania Inlier
1:2 500 000 Tectonic Units of Western Australia, June 2001, Geological Survey of Western Australia.
Gawler Craton
Fairclough, M.C., Schwarz, M.P. and Ferris, G.M., 2003. Interpreted crystalline basement geology of the Gawler Craton, South Australia, Geological Survey, Special map, 1:1 000 000 scale.

Distribution of Archean dolerite dykes and sills in Western Australia (Sheet 1):
Thorne, A.M. and Trendall, A.F., 2001. Geology of the Fortescue Group, Pilbara Craton, Western Australia. Geological Survey of Western Australia, Bulletin 144, 249 pp.

Geological and geophysical datasets (Sheet 2):
Interpreted distribution of Archean mafic and ultramafic rocks
Whitaker, A.J. and Bastrakova, I.V., 2002. Yilgarn Craton aeromagnetic interpretation (1:1 500 000 scale map), Geoscience Australia.

Geochronology of Archean mafic and ultramafic rocks (Sheet 2):
Hoatson, D.M., Jaireth, S. and Jaques, A.L., 2006. Nickel sulphide deposits in Australia: Characteristics, resources, and potential. Ore Geology Reviews, 29, 177–241.

Van Kranendonk, M.J. and Ivanic, T.J., 2009. A new lithostratigraphic scheme for the northeastern Murchison Domain, Yilgarn Craton. Geological Survey of Western Australia Annual Review 2007–08, 35–53.

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Compositional data of komatiitic rocks (Sheet 2):
Barley, M.E., Blewett, R.S., Cassidy, K.F., Champion, D.C., Czarnota, K., Doyle, M.G., Krapez, B., Kositcin, N., Pickard, A.L. and Weinberg, R.F., 2006. Tectonostratigraphic and structural architecture of the eastern Yilgarn Craton. Final AMIRA Report P763/pmd*CRC Project Y1, December 2006.

Barnes, S.J., Hill, R.E.T., Perring, C.S. and Dowling, S.E., 2004. Lithogeochemical exploration for komatiite-associated Ni-sulfide deposits: strategies and limitations. Mineralogy and Petrology, 82, 259–293.

Lesher, C.M. and Keays, R.R., 2002. Komatiite-associated Ni-Cu-PGE deposits: geology, mineralogy, geochemistry, and genesis. *In*: Cabri, L.J. (editor), The Geology, Geochemistry, Mineralogy and Mineral Beneficiation of Platinum-Group Elements. Canadian Institute of Mining, Metallurgy and Petroleum, Special Volume 54, 579–617.

Nickel sulphide resources for deposits and regional nickel endowment (Sheet 2):
OZMIN–Geoscience Australia's national database of mineral deposits and resources.

Neodymium model ages (Sheet 2):
Champion, D.C. and Cassidy, K.F., 2008. Geodynamics: Using geochemistry and isotopic signatures of granites to aid mineral systems studies: an example from the Yilgarn Craton. *In*: Korsch, R.J. and Barnicoat, A.C. (editors), New Perspectives: The Foundations and Future of Australian Exploration. Abstracts for the 11–12th June 2008 pmd*CRC Conference. Geoscience Australia, Record 2008/09, 7–16.

Appendix 2. Attributes, Definitions, and Values Used for Characterising Archean Mafic-Ultramafic Units in Appendix 10 (Data spreadsheets: Age and Setting in pocket of this Record)

Age and Setting Spreadsheets:

CODE
Code of mafic±ultramafic rock units listed in the solid-geology digital datasets that were used for each State (see Appendix 1 for relevant State datasets)

STRATNO
Stratigraphic unit number from the Australian Stratigraphic Units Database (ASUD)

SUPERGROUP_GROUP_FORMATION_MEMBER
Stratigraphic unit names for Supergroup, Group, Formation, and Member, etc, from the Australian Stratigraphic Units Database (ASUD)

CRUSTAL_PROVINCE
Major and minor Australian geological and tectonic provinces (under state titles in Appendix 11):
Yilgarn Craton
Cassidy, K.F., Champion, D.C., Krapez, B., Barley, M.E., Brown, S.J.A., Blewett, R.S., Groenewald, P.B. and Tyler, I.M., 2006. A revised geological framework for the Yilgarn Craton, Western Australia. Geological Survey of Western Australia, Record 2006/8, 8 pp
Pilbara Craton
1:2 500 000 Tectonic Units of Western Australia, June 2001, Geological Survey of Western Australia
Gawler Craton
Fairclough, M.C., Schwarz, M.P. and Ferris, G.M., 2003. Interpreted crystalline basement geology of the Gawler Craton, South Australia, Geological Survey, Special map, 1:1 000 000 scale

Age Spreadsheet:

STRATAGE
General stratigraphic age from published maps/reports
Archean (>2500 Ma)
Paleoproterozoic (2500–1600 Ma)

AGE_CHRON
Absolute measured age (in million years: Ma) from published reports, maps, etc

ERROR
Calculated error in ± million years

METHOD
Sensitive High Resolution Ion Micro Probe (SHRIMP), U-Pb (zircon or baddeleyite), conventional U-Pb zircon, TIMS, Ar-Ar (hornblende), Re-Os isochron, Pb-Pb isochron, etc

AGE_COMMENT
Additional information regarding measured age

REFERENCE
Reference for absolute age

GAREF
GAREF number of reference for determined age from Geoscience Australia's Bibliographic Reference Database GAREF

NATIONAL_MAG_EVENT
Archean Magmatic Event (AME 1 to AME 26 and Undefined) defined in the National study. Information shown includes: Informal event name, approximate age of event (in million years: Ma) defined in the National study, AME number (1 to 26), and whether event contains mafic (m) and/or ultramafic (u) rocks. The type example of the dated Archean Magmatic Event is indicated by a horizontal pale blue bar across the total spreadsheet

MINAGE
Relative minimum age (in million years: Ma) from published reports, maps, etc

ERROR
Calculated error in ± million years

METHOD
Geochronological method used: Sensitive High Resolution Ion Micro Probe (SHRIMP) U-Pb (zircon), conventional U-Pb, Rb-Sr, etc

REFMINAGE
Reference for minimum age data

GAREF
GAREF number of reference for minimum age from Geoscience Australia's Bibliographic Reference Database GAREF

MAXAGE
Relative maximum age (in million years: Ma) from published reports, maps, etc

ERROR
Calculated error in ± million years

METHOD
Geochronological method used: Sensitive High Resolution Ion Micro Probe (SHRIMP) U-Pb (zircon), U-Pb (zircon), Sm-Nd (depleted mantle model: T_{DM}), etc

REFMAXAGE
Reference for maximum age data

GAREF
GAREF number of reference for maximum age from Geoscience Australia's Bibliographic Reference Database GAREF

INDEX250
Name of relevant 1:250 000 geological sheet

REFINDEX250
Reference of relevant 1:250 000 geological sheet

GAREF
GAREF number of reference for 1:250 000 geological sheet from Geoscience Australia's Bibliographic Reference Database GAREF

INDEX100
Name of relevant 1:100 000 geological sheet

REFINDEX100
Reference of relevant 1:100 000 geological sheet

GAREF
GAREF number of reference for 1:100 000 geological sheet from Geoscience Australia's Bibliographic Reference Database GAREF

Setting Spreadsheet:

COMP_BULK
Bulk composition of mafic±ultramafic body:

- Mafic
- Ultramafic
- Alkaline
- Intermediate
- Tholeiitic (T)
- Komatiitic (K)

SETTING
Broad emplacement setting of mafic±ultramafic body:

- Intrusive
- Extrusive
- Hypabyssal

ROCKTYPE
The following list summarises the more common mafic-ultramafic-(felsic) rocks of igneous-metamorphic-pyroclastic origin compiled in this Archean study. Alkaline igneous rocks (e.g., trachyte, syenite, kimberlite, lamprophyre) have generally been excluded from the compilation, except where these rocks are spatially associated with other rock sequences (e.g., of tholeiitic origin).

- granophyre, granophyric gabbro
- anorthosite, anorthositic gabbro
- gabbro, olivine gabbro, magnetite gabbro, leucogabbro, ferrogabbro, melanogabbro, hybridised gabbro, quartz gabbro, gabbronorite, norite
- plagioclase websterite, olivine websterite
- troctolite
- pyroxenite, orthopyroxenite, olivine orthopyroxenite, clinopyroxenite
- dunite, peridotite, lherzolite, harzburgite, serpentinite, chloritic rocks
- komatiite, komatiitic basalt
- basalt (olivine, tholeiitic, magnesian, high-magnesian, siliceous high-magnesian, high-al, breccia, spinifex, pillow, aphyric, amygdaloidal, meta), basaltic andesite
- amphibolite, granulite, mafic granulite, migmatite
- dolerite, quartz dolerite, hornblende dolerite
- syenite, quartz syenite, monzonite, tonalite
- diorite, quartz diorite
- tuff, lapilli tuff, pumice, accretionary lapilli, agglomerate
- peperite, breccia, basaltic breccia

hyaloclastite, basaltic hyaloclastite
volcaniclastic sandstone
schist, talc-chlorite schist, talc-carbonate schist, mafic schist, actinolite-chlorite ultramafic rock

ABUNDANCE
Relative abundance of mafic±ultramafic rock component to other rocks in Formation, Group, etc
Major: mafic±ultramafic rocks comprise a major component of total rock package
Minor: mafic±ultramafic rocks comprise a minor component of total rock package

MODE_OCCURRENCE
Style/form of mafic±ultramafic body:
Dyke, layered dyke, massive dyke
Sill, composite sill
Plug
Lava
Xenolith
Raft
Feeder conduit
Flood basalt
Lava flow, lava channel, basaltic flow
Komatiitic flow, komatiitic intrusion
Intrusion, layered intrusion, massive intrusion
Fault-bounded intrusion
Tectonised intrusion
Volcaniclastic sheet deposit

THICKNESS
Stratigraphic thickness (in metres) of mafic±ultramafic rocks

COUNTRYROCK
Major country rocks for intrusive mafic±ultramafic body, or associated rock types if extrusive

MIN_STYLE 1
Mineralisation/deposit style, using modified version of Cox and Singer (1986) classification (e.g., 1. Basal mafic-ultramafic Ni-Cu; 2. Stratabound mafic-ultramafic Cr-PGE). See Appendix 3

MIN_STYLE 2
Mineralisation/deposit style, using modified version of Cox and Singer (1986) classification (e.g., 1. Basal mafic-ultramafic Ni-Cu; 2. Stratabound mafic-ultramafic Cr-PGE). See Appendix 3

MIN_STYLE 3
Mineralisation/deposit style, using modified version of Cox and Singer (1986) classification (e.g., 1. Basal mafic-ultramafic Ni-Cu; 2. Stratabound mafic-ultramafic Cr-PGE). See Appendix 3

MINERAL_RESOURCES
Mineral resources from OZMIN–Geoscience Australia's national database of mineral deposits and resources, and/or relevant publications

GEOTECTONICS
Published comment about geotectonic setting of mafic±ultramafic rocks

REFERENCE
Reference for geotectonics comment

GAREF
GAREF number of reference for geotectonics from Geoscience Australia’s Bibliographic Reference Database GAREF

REFERENCE
General reference for mafic±ultramafic rocks, formation, mineralisation, and/or deposit

GAREF
GAREF number of general reference for mafic±ultramafic rocks, formation, mineralisation, and/or deposit from Geoscience Australia’s Bibliographic Reference Database GAREF

Appendix 3. Revised Classification of Deposit Types Associated with Mafic-Ultramafic Rocks

Model Number (Cox and Singer, 1986)	Deposit Classification (Cox and Singer, 1986)	Revised Model Number	Revised Deposit Classification
1, 7A	Stratiform mafic-ultramafic Ni-Cu	1	Basal mafic-ultramafic Ni-Cu
2A	Stratiform mafic-ultramafic Cr	2	Stratabound mafic-ultramafic Cr-PGE
2B	Stratiform mafic-ultramafic PGE	3	Stratabound mafic-ultramafic PGE-Ni-Cu
3, 7B	Stratiform mafic-ultramafic Fe-Ti-V	4	Stratabound mafic-ultramafic Fe-Ti-V
5A	Duluth Cu-Ni-PGE	NA	
5B	Noril'sk Cu-Ni-PGE	NA	
6A, 6B	Komatiitic Ni-Cu	5	Komatiitic Ni-Cu
7A	Synorogenic-synvolcanic Ni-Cu	NA	
7B	Anorthosite Ti	NA	
8A	Alpine-type podiform chromite	NA	
8C	Limassol Forest Co-Ni	NA	
8D	Serpentine-hosted asbestos	6	Serpentine-hosted asbestos
9	Alaskan PGE	NA	
18E	Carbonate-hosted asbestos	NA	
27C	Silica-carbonate Hg	NA	

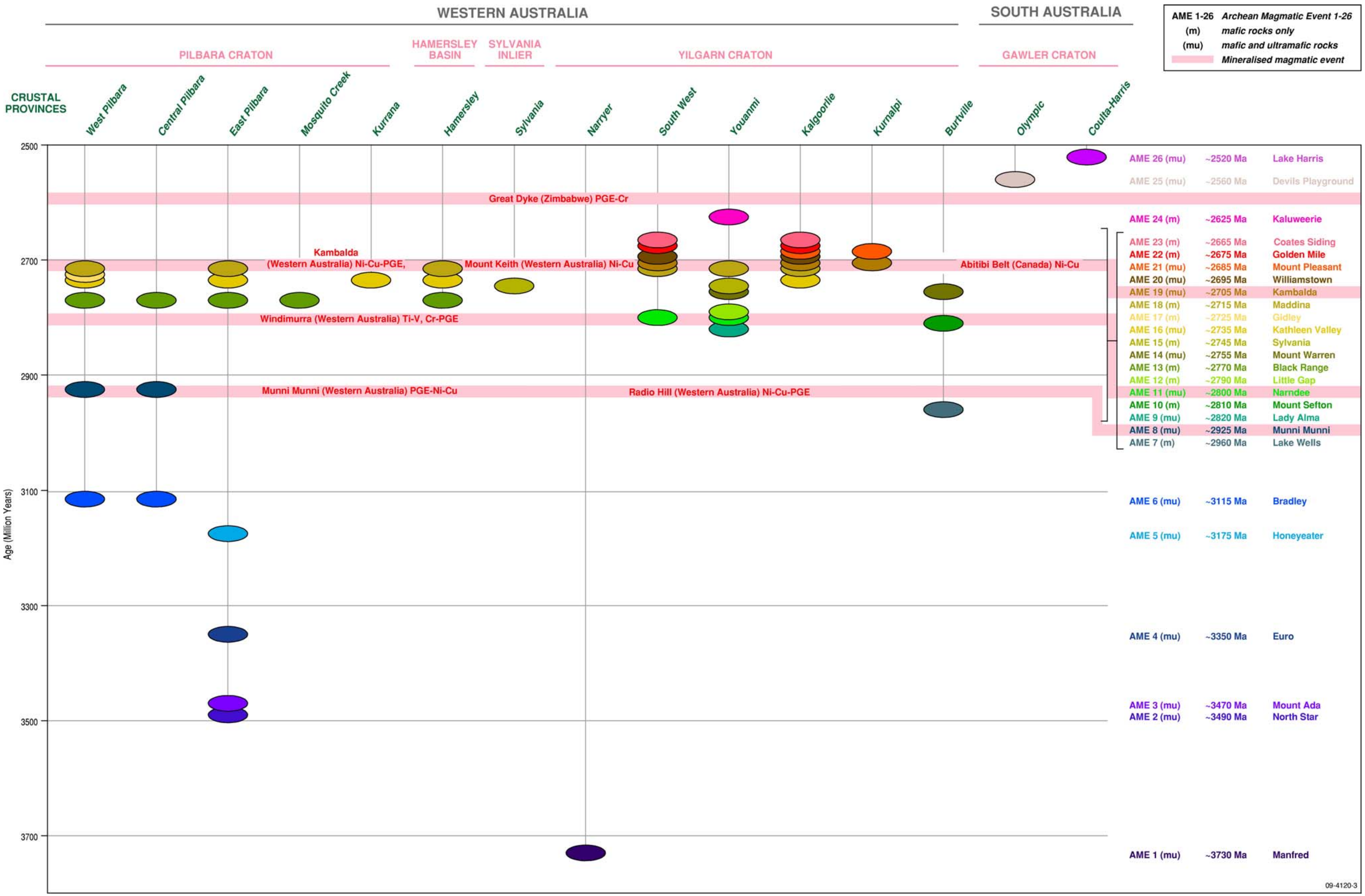
NA: Not applicable to Archean mineralising systems in Australia

Appendix 4. Type Examples of Archean Mafic-Ultramafic Magmatic Events

Magmatic Event	Informal Event Name	Event Age	Representative Formation/Unit–Dated Rock Type	Craton/ Basin/Inlier	Age (Ma)	Method	Geochronology Reference	General Reference
AME 26 (mu)	**Lake Harris**	~2520 Ma	Lake Harris Komatiite–volcaniclastic rock interbedded with komatiite	Gawler	2522 ± 8	SHRIMP U-Pb (zircon)	Swain et al. (2005)	Hoatson et al. (2005)
AME 25 (mu)	**Devils Playground**	~2560 Ma	*Devils Playground volcanics*–rhyodacite interbedded with basalt	Gawler	2558 ± 6	U-Pb ID-TIMS (zircon)	Reid (2007)	Cowley and Fanning (1991)
AME 24 (m)	**Kaluweerie**	~2625 Ma	*Kaluweerie*–granophyric dolerite	Yilgarn	2627 ± 6	SHRIMP U-Pb (zircon)	Nelson (1998)	Nelson (1998)
AME 23 (m)	**Coates Siding**	~2665 Ma	*Coates Siding*–gabbro	Yilgarn	2664 ± 6	SHRIMP U-Pb (zircon)	Wilde and Pidgeon (2006)	Wilde (2001)
AME 22 (m)	**Golden Mile**	~2675 Ma	Golden Mile Dolerite–granophyre	Yilgarn	2675 ± 2	SHRIMP U-Pb (zircon)	Woods (1997; unpublished data)	Bateman et al. (2001)
AME 21 (mu)	**Mount Pleasant**	~2685 Ma	Mount Pleasant Sill	Yilgarn	2687 ± 5	U-Pb (zircon)	Campbell (1988; unpublished data)	Witt et al. (1991)
AME 20 (mu)	**Williamstown**	~2695 Ma	Williamstown Peridotite–granophyric quartz gabbro	Yilgarn	2696 ± 5	SHRIMP U-Pb (zircon)	Fletcher et al. (2001)	Bateman et al. (2001)
AME 19 (mu)	**Kambalda**	~2705 Ma	Kambalda Komatiite–felsic tuff interbedded with komatiite	Yilgarn	2705 ± 4	SHRIMP U-Pb (zircon)	Nelson (1997)	Barnes (2006)
AME 18 (m)	**Maddina**	~2715 Ma	Maddina Basalt–felsic tuff interbedded with basalt	Hamersley	2715 ± 2	SHRIMP U-Pb (zircon)	Blake et al. (2004)	Van Kranendonk et al. (2006)
AME 17 (m)	**Gidley**	~2725 Ma	Gidley Granophyre–gabbro	Pilbara	2725 ± 3	SHRIMP U-Pb (baddeleyite)	Wingate (1997)	Hickman and Strong (2003)
AME 16 (mu)	**Kathleen Valley**	~2735 Ma	Kathleen Valley Gabbro–quartz gabbro	Yilgarn	2736 ± 3	SHRIMP U-Pb (zircon)	Liu et al. (2002)	Liu et al. (2002)
AME 15 (m)	**Sylvania**	~2745 Ma	Sylvania dyke swarm–dolerite	Sylvania	2747 ± 4	SHRIMP U-Pb (zircon)	Wingate (1999)	Wingate (1999)
AME 14 (mu)	**Mount Warren**	~2755 Ma	*Mount Warren*–leucogabbro	Yilgarn	2755 ± 5	SHRIMP U-Pb (zircon)	Wingate et al. (in prep d)	Hall et al. (2009)
AME 13 (m)	**Black Range**	~2770 Ma	Black Range Dolerite Suite–dolerite	Pilbara	2772 ± 2	SHRIMP U-Pb (baddeleyite)	Wingate (1999)	Wingate (1999)
AME 12 (m)	**Little Gap**	~2790 Ma	Un-named dolerite, Little Gap–dolerite	Yilgarn	2792 ± 5	SHRIMP U-Pb (zircon)	Wang (1998)	Van Kranendonk and Ivanic (2009)
AME 11 (mu)	**Narndee**	~2800 Ma	Narndee Intrusion–gabbronorite	Yilgarn	2800 ± 6	SHRIMP U-Pb (zirc & badd)	Wingate et al. (in prep b)	Ivanic et al. (in review)
AME 10 (m)	**Mount Sefton**	~2810 Ma	*Mount Sefton leucogabbro*–-pegmatoidal leucogabbro	Yilgarn	2812 ± 5	SHRIMP U-Pb (zircon)	Wingate et al. (in prep c)	Hall et al. (2009)
AME 9 (mu)	**Lady Alma**	~2820 Ma	Lady Alma Intrusion–gabbro	Yilgarn	2821 ± 5	SHRIMP U-Pb (zircon)	Wang (1998)	Van Kranendonk and Ivanic (2009)
AME 8 (mu)	**Munni Munni**	~2925 Ma	Munni Munni Intrusion–ferrogabbro pegmatite	Pilbara	2925 ± 16	SHRIMP U-Pb (zircon)	Arndt et al. (1991)	Hoatson et al. (1992)
AME 7 (m)	**Lake Wells**	~2960 Ma	*Lake Wells Station* felsic volcaniclastic rock interbedded with basalt	Yilgarn	2961 ± 5	SHRIMP U-Pb (zircon)	Wingate et al. (in prep a)	Hall et al. (2009)
AME 6 (mu)	**Bradley**	~3115 Ma	Bradley Basalt–felsic tuff interbedded with basalt	Pilbara	3115 ± 5	SHRIMP U-Pb (zircon)	Nelson (1996)	Van Kranendonk et al. (2006)
AME 5 (mu)	**Honeyeater**	~3175 Ma	Honeyeater Basalt–tuff interbedded with basalt	Pilbara	3176 ± 3	SHRIMP U-Pb (zircon)	Van Kranendonk et al. (in press)	Van Kranendonk et al. (2006)
AME 4 (mu)	**Euro**	~3350 Ma	Euro Basalt–volcaniclastic sandstone interbedded with chert and basalt	Pilbara	3350 ± 3	SHRIMP U-Pb (zircon)	Nelson (2005)	Van Kranendonk et al. (2006)
AME 3 (mu)	**Mount Ada**	~3470 Ma	Mount Ada Basalt–tuff interbedded with basalt	Pilbara	3469 ± 3	SHRIMP U-Pb (zircon)	Nelson (1999)	Van Kranendonk et al. (2006)
AME 2 (mu)	**North Star**	~3490 Ma	North Star Basalt–pyroxenite lens interbedded with basalt	Pilbara	3490 ± 15	$^{40}Ar/^{39}Ar$ (hornblende)	van Koolwijk et al. (2001)	Van Kranendonk et al. (2006)
AME 1 (mu)	**Manfred**	~3730 Ma	Manfred Complex–leucogabbro and meta-anorthosite	Yilgarn	3730 ± 6	SHRIMP U-Pb (zircon)	Kinny et al. (1988)	Wilde and Spaggiari (2007)

Stratigraphic names in italics indicate informal stratigraphic name or locational name

Appendix 5. Time–Space–Event Chart of Australian Archean Mafic-Ultramafic Magmatic Events



Appendix 6. Additional Ages and Other Geological Data on Sheet 1

Bradley Event AME 6 (mu): ~3115 Ma;
3117 ± 3 Ma (SHRIMP U-Pb zircon) tuff interbedded with basalt of Woodbrook Formation, Woodbrook Homestead, Pilbara Craton

Bradley Event AME 6 (mu): ~3115 Ma;
(1) 3125 ± 4 Ma (SHRIMP U-Pb zircon) felsic tuff from top of Nallana Formation that underlies the Bradley Basalt, Mount Sholl; and
(2) 3116 ± 3 Ma (SHRIMP U-Pb zircon) rhyodacite interbedded with metabasalt of Bradley Basalt, Mount Fisher, Pilbara Craton

Munni Munni Event AME 8 (mu): ~2925 Ma;
(1) 2927 ± 13 Ma (Sm-Nd mineral isochron) PGE-bearing porphyritic websterite;
(2) 2925 ± 2 Ma (SHRIMP U-Pb zircon-baddeleyite) pegmatitic gabbro; and
(3) 2924 ± 5 Ma (SHRIMP U-Pb zircon) monzonite dyke cutting Munni Munni Intrusion, Pilbara Craton

Honeyeater Event AME 5 (mu): ~3175 Ma;
3182 ± 2 Ma (SHRIMP U-Pb zircon) unnamed subvolcanic sill of Dalton Suite that intrudes Soanesville Group sedimentary rocks, Sulphur Springs, Pilbara Craton

Maddina Event AME 18 (m): ~2715 Ma;
2717 ± 2 Ma dacite interlayered with basalt and shoshonitic rocks of Maddina Formation, Booloomba Pool, Hamersley Basin

Kathleen Valley Event AME 16 (mu): ~2735 Ma;
2741 ± 3 Ma (SHRIMP U-Pb zircon) tuff directly underlying and chemically related to overlying basalt of Kylena Basalt, Nullagine, Hamersley Basin

Black Range Event AME 13 (m): ~2770 Ma;
2775 ± 10 Ma (SHRIMP U-Pb zircon) felsic volcanic rock near base of Mount Roe Basalt, Wyloo Dome, Hamersley Basin

Narndee Event AME 11 (mu): ~2800 Ma;
2799 ± 2 Ma (SHRIMP U-Pb zircon) volcaniclastic unit conformably underlying komatiite, Lordy Bore, Meekatharra, Yilgarn Craton. Greenstones in the Meekatharra to Cue area of the Murchison Domain range in age from ~2820 Ma to ~2720 Ma and have been divided into three groups by GSWA, each containing basaltic and komatiitic basaltic rocks. To the south and southwest, at Yalgoo and at Mount Gibson, mafic to ultramafic volcanic rocks are overlain by felsic volcanic rocks, and/or intruded by granitic rocks in the range 2935 Ma to 2919 Ma, and are thus older than these ages

Mount Warren Event AME 14 (mu): ~2755 Ma;
2761 ± 1 Ma (TIMS U-Pb zircon) rhyolitic tuff associated with high-Mg basalt and komatiite, Emily Well, Cue, Yilgarn Craton

Mount Warren Event AME 14 (mu): ~2755 Ma;
2755 ± 5 Ma (SHRIMP U-Pb zircon) hornblende plagiogranite interpreted to be fractionate of layered gabbro intrusion, Hootanui Well, Duketon, Yilgarn Craton

Sylvania Event AME 15 (m): ~2745 Ma;
2745 ± 4 Ma (TIMS U-Pb zircon) felsic tuff associated with high-Mg basalt and komatiite, Dalgaranga Homestead, Yilgarn Craton

Maddina Event AME 18 (m): ~2715 Ma;
2719 ± 6 Ma (SHRIMP U-Pb zircon) granophyric unit of Dalgaranga Gabbro,
Dalgaranga Homestead, Yilgarn Craton

Kambalda Event AME 19 (mu): ~2705 Ma or Williamstown Event AME 20 (mu): ~2695 Ma;
2698 ± 5 Ma (SHRIMP U-Pb zircon) volcaniclastic dacite interlayered with komatiite, Murrin Murrin, Yilgarn Craton

Mount Pleasant Event AME 21 (mu): ~2685 Ma;
2684 ± 3 Ma (SHRIMP U-Pb zircon) felsic volcanic rock intercalated with tholeiitic basalt, Jump Up Dam, Lake Rebecca, Yilgarn Craton

Coates Siding Event AME 23 (m): ~2665 Ma;
2661 ± 3 Ma (SHRIMP U-Pb zircon) Mount Vetters granophyric dolerite, Mount Vetters Homestead, Yilgarn Craton

Kambalda Event AME 19 (mu): ~2705 Ma;
2706 ± 5 Ma, and 2704 ± 4 Ma (SHRIMP U-Pb zircon) rhyolitic rocks intercalated with komatiite of Kambalda Komatiite, Black Swan nickel mine, Yilgarn Craton

Mount Pleasant Event AME 21 (mu): ~2685 Ma;
2683 ± 3 Ma (SHRIMP U-Pb zircon) felsic tuff associated with basalt, Reidy Swamp,
Kanowna, Yilgarn Craton

Kambalda Event AME 19 (mu): ~2705 Ma;
2708 ± 7 Ma (SHRIMP U-Pb zircon) dacite coeval with komatiite, Ballarat-Last Chance mine, Kalgoorlie, Yilgarn Craton

Golden Mile Event AME 22 (m): ~2675 Ma;
2675 ± 3 Ma (SHRIMP U-Pb zircon) felsic volcanic breccia associated with basalt of Black Flag Beds, Harry Dam, Perkolilli, Kanowna, Yilgarn Craton

Kambalda Event AME 19 (mu): ~2705 Ma;
2708 ± 5 Ma (SHRIMP U-Pb zircon) volcaniclastic unit intercalated with komatiite,
Bulong, Yilgarn Craton

Golden Mile Event AME 22 (m): ~2675 Ma or Mount Pleasant Event AME 21 (mu): ~2685 Ma;
(1) 2681 ± 5 Ma (SHRIMP U-Pb zircon) felsic volcanic rock intercalated with basalt of Black Flag Beds, drillhole NFD–003, 168–169 m, Nelson's Fleet, Yilgarn Craton; and
(2) 2680 ± 9 Ma (SHRIMP U-Pb zirconolite) Golden Mile Dolerite, Mount Charlotte gold mine, Yilgarn Craton

Maddina Event AME 18 (m): ~2715 Ma;
2714 ± 5 Ma (SHRIMP U-Pb zircon) gabbroic sill, feeder to overlying basaltic flows, cuts lower part of Woolyeenyer Formation, Norseman, Yilgarn Craton

Maximum ages of komatiitic rocks in the Yilgarn Craton:
(1) komatiitic basalt of Woolyeenyer Formation overlies 2930 ± 4 Ma (SHRIMP U-Pb zircon) rhyolite of the Upper Penneshaw Formation near Norseman;
(2) komatiites younger than ~2870 Ma (SHRIMP U-Pb zircon) in the Mount Windarra region; and
(3) komatiites that cut 2921 ± 4 Ma (SHRIMP U-Pb zircon) felsic volcanic rocks and a 2903 ± 5 Ma (SHRIMP U-Pb zircon) hangingwall felsic volcanic unit of the Honman Formation at the Maggie Hays nickel mine ‘constrain’ the age of the komatiites between ~2920 Ma and ~2900 Ma. The ultramafic-

felsic rock relationships at the Maggie Hays mine are controversial, thus a new Archean Magmatic Event at ~2910 Ma has not been defined using these ages

Multiple Archean Magmatic Events near Boddington—Maddina Event AME 18 (m): ~2715 Ma, Kambalda Event AME 19 (mu): ~2705 Ma, Williamstown Event AME 20 (mu): ~2695 Ma, Golden MileEvent AME 22 (m): ~2675 Ma;
basalts with associated intermediate volcanics and volcaniclastic rocks emplaced between 2714 Ma and 2696 Ma and at ~2675 Ma, Boddington gold mine region, Yilgarn Craton

Narndee Event AME 11 (mu): ~2800 Ma;
2798 ± 16 Ma (SHRIMP U-Pb zircon) interpreted protolith age of unnamed two-pyroxene mafic granulite, Katanning, Yilgarn Craton

Lake Harris Event AME 26 (mu): ~2520 Ma;
2520 ± 7 Ma (SHRIMP U-Pb zircon) felsic volcanic rocks intercalated with subordinate mafic rocks, Hall Bay Volcanics, Mount Hope, Eyre Peninsula, Gawler Craton. Drilling has also intersected komatiitic rocks in the Mount Hope—Moorlands region

Appendix 7. Compositional Data of Komatiitic Rocks from the Yilgarn Craton

Location/Sample (on Sheet 2)	AUDK *vs* ADK[1]	Longitude	Latitude	Geological Province
Data from Barnes et al. (2004) and Lesher and Keays (2002)				
Binti Binti	AUDK	121.827003	-30.191450	Eastern Goldfields Superterrane
Black Swan	AUDK	121.651994	-30.393392	Eastern Goldfields Superterrane
Cooke	AUDK	121.534600	-31.444270	Eastern Goldfields Superterrane
Emu Lake	AUDK	121.956802	-30.288530	Eastern Goldfields Superterrane
Ghost Rocks	AUDK	120.858597	-29.542459	Eastern Goldfields Superterrane
Gibb	AUDK	121.680191	-31.181274	Eastern Goldfields Superterrane
Honeymoon Well	AUDK	120.379031	-26.920375	Eastern Goldfields Superterrane
Kambalda	AUDK	121.749747	-31.340037	Eastern Goldfields Superterrane
Kingston	AUDK	120.415802	-26.964860	Eastern Goldfields Superterrane
Kurrajong	AUDK	120.599220	-28.048200	Eastern Goldfields Superterrane
Long	AUDK	121.677505	-31.178543	Eastern Goldfields Superterrane
Marriott-Mt Clifford	AUDK	120.991479	-28.449127	Eastern Goldfields Superterrane
Marshall Pool dunite	AUDK	120.986099	-28.314470	Eastern Goldfields Superterrane
McEwen	AUDK	121.518480	-31.402313	Eastern Goldfields Superterrane
McLeay	AUDK	121.678500	-31.195690	Eastern Goldfields Superterrane
Miranda Well	AUDK	120.622855	-27.686160	Eastern Goldfields Superterrane
Mt Edwards 132N	AUDK	121.541011	-31.452790	Eastern Goldfields Superterrane
Mt Edwards 26N	AUDK	121.541732	-31.482256	Eastern Goldfields Superterrane
Mt Edwards	AUDK	121.541053	-31.452845	Eastern Goldfields Superterrane
Mt Keith	AUDK	120.544744	-27.228766	Eastern Goldfields Superterrane
Mt Windarra	AUDK, ADK	122.233016	-28.485150	Eastern Goldfields Superterrane
Murrin Murrin	AUDK	121.893000	-28.766800	Eastern Goldfields Superterrane
Nepean	AUDK	121.085739	-31.163663	Eastern Goldfields Superterrane
Perseverance	AUDK	120.697235	-27.788893	Eastern Goldfields Superterrane
Redross	AUDK	121.647159	-31.683245	Eastern Goldfields Superterrane
Ringlock	AUDK	121.410103	-30.143430	Eastern Goldfields Superterrane
Scotia	AUDK	121.455623	-30.180530	Eastern Goldfields Superterrane
Siberia	AUDK	120.974800	-30.175800	Eastern Goldfields Superterrane
Victor	AUDK	121.678421	-31.138930	Eastern Goldfields Superterrane
Wannaway	AUDK	121.521158	-31.603747	Eastern Goldfields Superterrane
Widgie 3	AUDK	121.587524	-31.519135	Eastern Goldfields Superterrane
Widgie Townsite	AUDK	121.574814	-31.502853	Eastern Goldfields Superterrane
Yakabindie	AUDK	120.577527	-27.455491	Eastern Goldfields Superterrane
Cosmic Boy	ADK	119.738992	-32.581564	Southern Cross Domain
Digger Rocks	ADK	119.810395	-32.715765	Southern Cross Domain
Flying Fox	ADK, AUDK	119.688987	-32.418462	Southern Cross Domain
Maggie Hays	ADK	120.516998	-32.222472	Southern Cross Domain
North Ironcap	ADK	119.684196	-32.359829	Southern Cross Domain
Rat Bat	ADK	119.737890	-32.545963	Southern Cross Domain
Data from Barley et al. (2006: AMIRA study)				
96969053	AUDK	121.955328	-27.494843	Burtville Terrane
94969404	AUDK	121.937158	-27.457920	Burtville Terrane
2001969030	AUDK	122.521034	-28.927521	Burtville Terrane
92964062	AUDK	122.635804	-29.101555	Burtville Terrane
95969377	AUDK	122.371034	-28.103478	Burtville Terrane
2004969234	AUDK	122.412209	-28.230812	Burtville Terrane
95969228	AUDK	122.410727	-28.188822	Burtville Terrane
2004969233	AUDK	122.412268	-28.231182	Burtville Terrane
92964169	AUDK	122.536444	-29.177885	Burtville Terrane
92964026B	ADK	122.531879	-29.086811	Burtville Terrane
95969281	AUDK	122.409302	-28.151445	Burtville Terrane

94968756	AUDK	120.544439	-27.244206	Kalgoorlie Terrane
90967585C	AUDK	120.555477	-29.319164	Kalgoorlie Terrane
95967513	ADK	120.941715	-26.841424	Kalgoorlie Terrane
94962106	AUDK	120.583475	-27.462162	Kalgoorlie Terrane
94962084	AUDK	120.571272	-27.451701	Kalgoorlie Terrane
90964222	AUDK	120.499580	-29.264354	Kalgoorlie Terrane
90967588	AUDK	120.560358	-29.345893	Kalgoorlie Terrane
94968708	AUDK	120.510585	-27.182195	Kalgoorlie Terrane
94962077	AUDK	120.576481	-27.443425	Kalgoorlie Terrane
94962088	AUDK	120.574659	-27.456378	Kalgoorlie Terrane
95967458	ADK	120.927816	-26.868739	Kalgoorlie Terrane
2004969020	AUDK	121.925728	-31.023673	Kurnalpi Terrane
2004967023	AUDK	121.942248	-31.043731	Kurnalpi Terrane
2004967046	AUDK	122.071926	-31.028498	Kurnalpi Terrane
95969572	AUDK	122.216447	-28.953982	Kurnalpi Terrane
2004967047	AUDK	122.070885	-31.028896	Kurnalpi Terrane
2004967063	AUDK	122.205904	-29.295646	Kurnalpi Terrane
2003969014	AUDK	121.834153	-30.883333	Kurnalpi Terrane
94969352	AUDK	121.530892	-27.487625	Kurnalpi Terrane
2004969054	AUDK	121.806431	-30.755479	Kurnalpi Terrane
AW24	ADK	121.694629	-28.742358	Kurnalpi Terrane
2004969056	AUDK	121.808127	-30.752599	Kurnalpi Terrane
89964076	AUDK	121.767093	-28.935851	Kurnalpi Terrane
2004967062	AUDK	122.187596	-29.280284	Kurnalpi Terrane
2004969061	AUDK	121.828576	-30.754878	Kurnalpi Terrane
2004969190	AUDK	122.353831	-29.445061	Kurnalpi Terrane
2004969142	AUDK	122.096602	-29.154088	Kurnalpi Terrane
2004967044	AUDK	122.075041	-31.028114	Kurnalpi Terrane
2004967052	AUDK	122.181167	-29.290011	Kurnalpi Terrane
2004969182	ADK	122.454904	-29.444466	Kurnalpi Terrane
2004969140	AUDK	122.093832	-29.155757	Kurnalpi Terrane
94967517	AUDK	121.316276	-27.235231	Kurnalpi Terrane
2004969055	AUDK	121.808207	-30.753763	Kurnalpi Terrane
2004967067	AUDK	122.224303	-29.296991	Kurnalpi Terrane
2004969154	AUDK	122.129151	-29.190955	Kurnalpi Terrane
AM03-102	AUDK	121.777672	-28.976856	Kurnalpi Terrane
2003967009	AUDK	121.856784	-30.894249	Kurnalpi Terrane
2004969209	AUDK	122.439987	-29.319604	Kurnalpi Terrane
2004967053	AUDK	122.182951	-29.283333	Kurnalpi Terrane
2004967096	AUDK	122.183745	-29.249313	Kurnalpi Terrane
2004969169	AUDK	122.078462	-29.146331	Kurnalpi Terrane
2004969137	AUDK	122.077711	-29.145277	Kurnalpi Terrane
2004967043	AUDK	122.079977	-31.024765	Kurnalpi Terrane
2004967097	AUDK	122.184700	-29.250898	Kurnalpi Terrane
Data from Chen et al. (2005) and Reudavey (1990)				
Komatiitic rocks: Sandstone region	AUDK, ADK	various	various	Youanmi Terrane
Komatiitic rocks: Gabanintha region	ADK	various	various	Youanmi Terrane

[1]Al-undepleted komatiites (AUDK) or ‘Munro-type’ komatiites–Al_2O_3/TiO_2 ratios generally vary between 15 and 25, and they are typically depleted in incompatible trace elements; and Al-depleted komatiites (ADK) or ‘Barberton-type’ komatiites–Al_2O_3/TiO_2 ratios are <15, and they are enriched in incompatible trace elements.

Appendix 8. Important Publications Containing Stratigraphical and Geochronological Data

Pilbara Craton:

Arndt, N.T., Nelson, D.R., Compston, W., Trendall, A.F. and Thorne, A.M., 1991. The age of the Fortescue Group, Hamersley Basin, Western Australia, from ion microprobe zircon U-Pb results. Australian Journal of Earth Sciences, 38, 261–281.

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Blewett, R.S., 2008a. pmd*CRC Project, Y4 Final Report–Parts I & II, January 2005–July 2008. Concepts to targets: a scale-integrated mineral systems study of the Eastern Yilgarn Craton, 162 pp.

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Appendix 10. Time-Slice Maps of Archean Mafic-Ultramafic Magmatic Events

The following series of 29 Time-Slice Maps commences with geological and tectonic subdivisions used as a template for the Time-Slice Maps, followed by a composite map showing all the Archean Magmatic Events (AME 1 to AME 26) and Undefined Event (magmatic age unknown), followed by Undefined Event, and then a continuous series of 26 maps progress from the youngest identified Archean Magmatic Event (AME 26) to the oldest Archean Magmatic Event (AME 1).

The spatial distribution of the nominated magmatic event for each map is depicted by red colour polygons or point location symbols. The type occurrence of the dated Archean Magmatic Event is shown as a coloured dot symbol, whereas other samples of the same magmatic event are indicated by red square symbols. For each Archean Magmatic Event, (m) indicates mafic rocks only, and (mu) indicates mafic and ultramafic rocks.

Major geological and tectonic subdivisions. Theses subdivisions are from the sources listed in Appendix 1**:**
Yilgarn Craton
Cassidy, K.F., Champion, D.C., Krapez, B., Barley, M.E., Brown, S.J.A., Blewett, R.S., Groenewald, P.B. and Tyler, I.M., 2006. A revised geological framework for the Yilgarn Craton, Western Australia. Geological Survey of Western Australia, Record 2006/8, 8 pp.
Pilbara Craton, Hamersley Basin, Sylvania Inlier
1:2 500 000 Tectonic Units of Western Australia, June 2001, Geological Survey of Western Australia.
Gawler Craton
Fairclough, M.C., Schwarz, M.P. and Ferris, G.M., 2003. Interpreted crystalline basement geology of the Gawler Craton, South Australia, Geological Survey, Special map, 1:1 000 000 scale.

Composite Map of all Archean Magmatic Events (AME 1 to AME 26) and Undefined Event. The general sequential development of Archean mafic-ultramafic magmatism in Australia commences during the Eoarchean in the northwest Yilgarn Craton, followed by the Pilbara Craton, and then it becomes more widespread in the early Neoarchean with several coeval contributions from the Yilgarn and Pilbara cratons, Hamersley Basin, and Sylvania Inlier. The Australian Archean mafic-ultramafic magmatic record concludes in the late Neoarchean with two isolated magmatic events recorded in the Gawler Craton.

Undefined Event (magmatic age unknown). Where there is no published age for a mafic-ultramafic unit shown on the Map, or if its age is doubtful, or inconsistent with its field relationships, the unit is assigned as Undefined Event. Most Archean mafic and ultramafic rocks in the Yilgarn Craton are not designated an AME because the solid-geology datasets provided by the Geological Survey of Western Australia do not contain stratigraphic Formation of Member information for these rocks. Consequently, most solid-geology rock polygons in the Yilgarn Craton are shown as Undefined Event since their stratigraphic details are unknown (and therefore their age is unknown). In contrast, most mafic and ultramafic rocks in the Pilbara Craton and Hamersley Basin have some formal stratigraphic characterisation, and therefore if reliably dated, can be assigned to an AME. The paucity of stratigraphic information for the rock units in the Yilgarn Craton relative to the Hamersley Basin, for example, is attributed to the better preservation of geological formations at the surface, the more systematic and predictable layer-cake-type stratigraphy, and more robust geochronological data, for the latter crustal province.

AME 26 (mu) ~2520 Ma Lake Harris Event. Named after dated volcaniclastic rock interbedded with komatiite from Lake Harris Komatiite, Gawler Craton. Correlatives in Harris Greenstone Domain and Coulta Domain.

AME 25 (mu) ~2560 Ma Devils Playground Event. Named after dated rhyodacite interbedded with basalt of Devils Playground volcanics, Gawler Craton, South Australia. The Australian Archean mafic-ultramafic magmatic record concludes in the late Neoarchean with two isolated magmatic events (AME 25 and AME 26) recorded in the Gawler Craton.

AME 24 (m) ~2625 Ma Kaluweerie Event. Named after dated granophyric dolerite from Kaluweerie, Yilgarn Craton. This is the final major mafic-ultramafic magmatic event documented in the Yilgarn Craton.

AME 23 (m) ~2665 Ma Coates Siding Event. Named after dated gabbro from Coates Siding, Yilgarn Craton. Correlatives in South West Terrane and Kalgoorlie Terrane.

AME 22 (m) ~2675 Ma Golden Mile Event. Named after dated granophyre from Golden Mile Dolerite, Yilgarn Craton. Correlatives in Kalgoorlie Terrane and South West Terrane.

AME 21 (mu) ~2685 Ma Mount Pleasant Event. Named after dated Mount Pleasant sill, Yilgarn Craton. Correlatives in Kalgoorlie Terrane and Kurnalpi Terrane.

AME 20 (mu) ~2695 Ma Williamstown Event. Named after dated granophyric quartz gabbro from Williamstown Peridotite, Yilgarn Craton. Correlatives in Kalgoorlie Terrane and South West Terrane.

AME 19 (mu) ~2705 Ma Kambalda Event. Named after dated felsic tuff interbedded with komatiite of the Kambalda Komatiite, Yilgarn Craton. Correlatives in Kurnalpi Terrane, Kalgoorlie Terrane, and South West Terrane.

AME 18 (m) ~2715 Ma Maddina Event. Named after dated felsic tuff interbedded with basalt of Maddina Basalt, Pilbara Craton. Correlatives in Hamersley Basin, West Pilbara Terrane, East Pilbara Terrane, and South West Terrane, Youanmi Terrane, and Kalgoorlie Terrane. This is the final major mafic-ultramafic magmatic event documented in the Pilbara Craton and Hamersley Basin.

AME 17 (m) ~2725 Ma Gidley Event. Named after dated gabbro from Gidley Granophyre, Pilbara Craton. This event is confined to the Dampier Archipelago in the West Pilbara Terrane.

AME 16 (mu) ~2735 Ma Kathleen Valley Event. Named after dated quartz gabbro from Kathleen Valley Gabbro, Yilgarn Craton. Correlatives in Kalgoorlie Terrane, Hamersley Basin, West Pilbara Terrane, East Pilbara Terrane, and Kurrana Terrane.

AME 15 (m) ~2745 Ma Sylvania Event. Named after dated dolerite from Sylvania dyke swarm, Sylvania Inlier. Correlatives in Sylvania Inlier and Youanmi Terrane.

AME 14 (mu) ~2755 Ma Mount Warren Event. Named after dated leucogabbro from Mount Warren, Yilgarn Craton. Correlatives in Burtville Terrane and Youanmi Terrane.

AME 13 (m) ~2770 Ma Black Range Event. Named after dated dolerite from Black Range Dolerite Suite, Pilbara Craton. Correlatives in East Pilbara Terrane, West Pilbara Terrane, Central Pilbara Terrane, Mosquito Creek Terrane, and Hamersley Basin.

AME 12 (m) ~2790 Ma Little Gap Event. Named after dated un-named dolerite from Little Gap dolerite, Yilgarn Craton.

AME 11 (mu) ~2800 Ma Narndee Event. Named after dated gabbronorite from Narndee Intrusion, Yilgarn Craton. Correlatives in Youanmi Terrane and South West Terrane.

AME 10 (m) ~2810 Ma Mount Sefton Event. Named after dated pegmatoidal leucogabbro from Mount Sefton leucogabbro, Yilgarn Craton.

AME 9 (mu) ~2820 Ma Lady Alma Event. Named after dated gabbro from Lady Alma Intrusion, Yilgarn Craton. The Neoarchean period from ~2820 million years (AME 9) to ~2665 million years (AME 23) represents an extremely busy evolutionary phase with multiple overlapping coeval events recorded for the Pilbara and Yilgarn cratons, Hamersley Basin, and Sylvania Inlier.

AME 8 (mu) ~2925 Ma Munni Munni Event. Named after dated ferrogabbro pegmatite from Munni Munni Intrusion, Pilbara Craton. This AME is confined to the Pilbara Craton with correlatives documented in the West Pilbara Terrane and Central Pilbara Terrane.

AME 7 (m) ~2960 Ma Lake Wells Event. Named after dated felsic volcaniclastic rock interbedded with basalt from Lake Wells Station, Yilgarn Craton. Outside the Manfred Complex in the Narryer Terrane (AME 1), the Lake Wells Event in the Burtville Terrane is the oldest mafic-ultramafic magmatic event documented in the Yilgarn Craton.

AME 6 (mu) ~3115 Ma Bradley Event. Named after dated felsic tuff interbedded with basalt of Bradley Basalt, Pilbara Craton. Correlatives in West Pilbara Terrane and Central Pilbara Terrane.

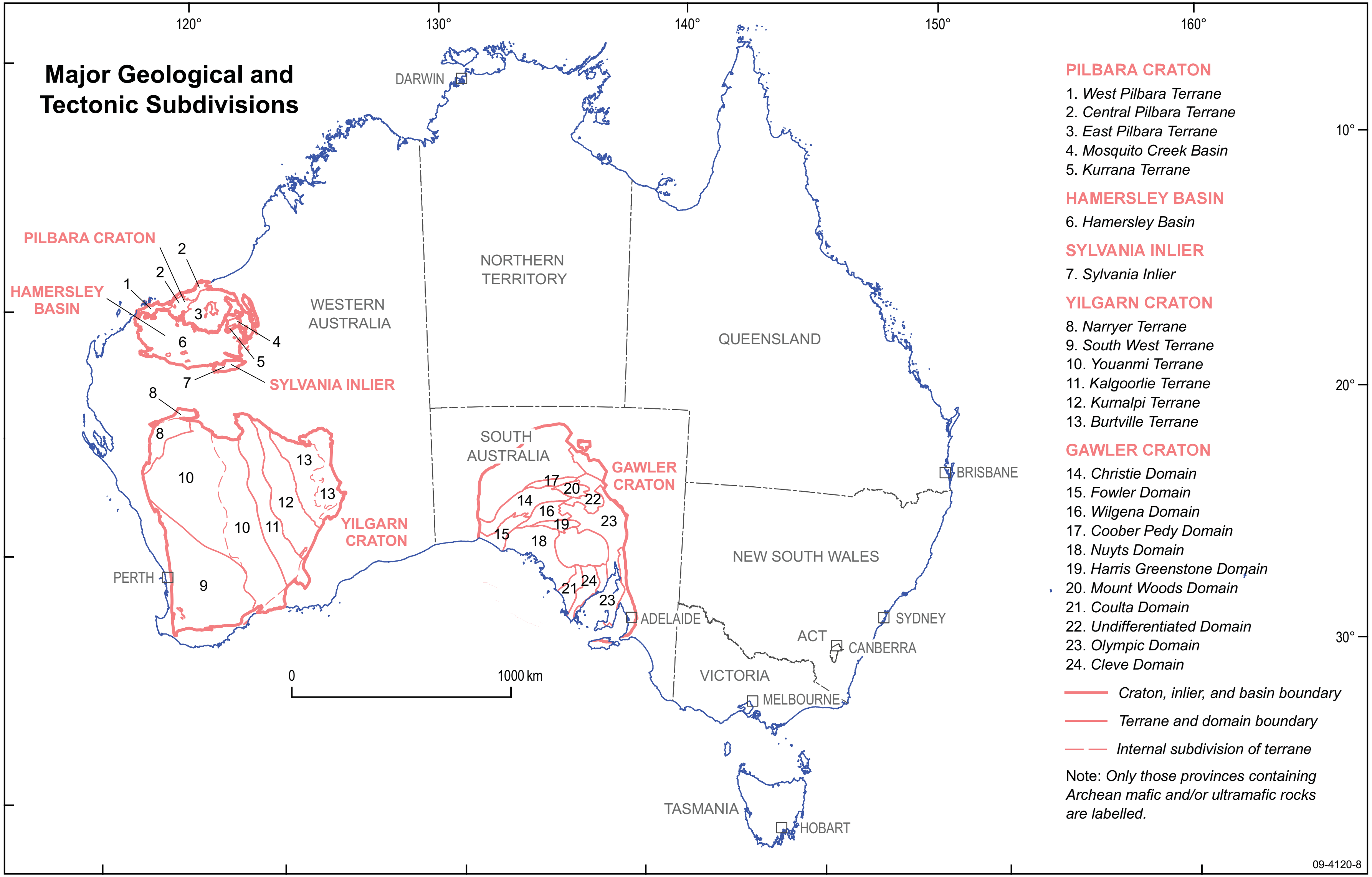
AME 5 (mu) ~3175 Ma Honeyeater Event. Named after dated tuff interbedded with basalt of Honeyeater Basalt, Pilbara Craton.

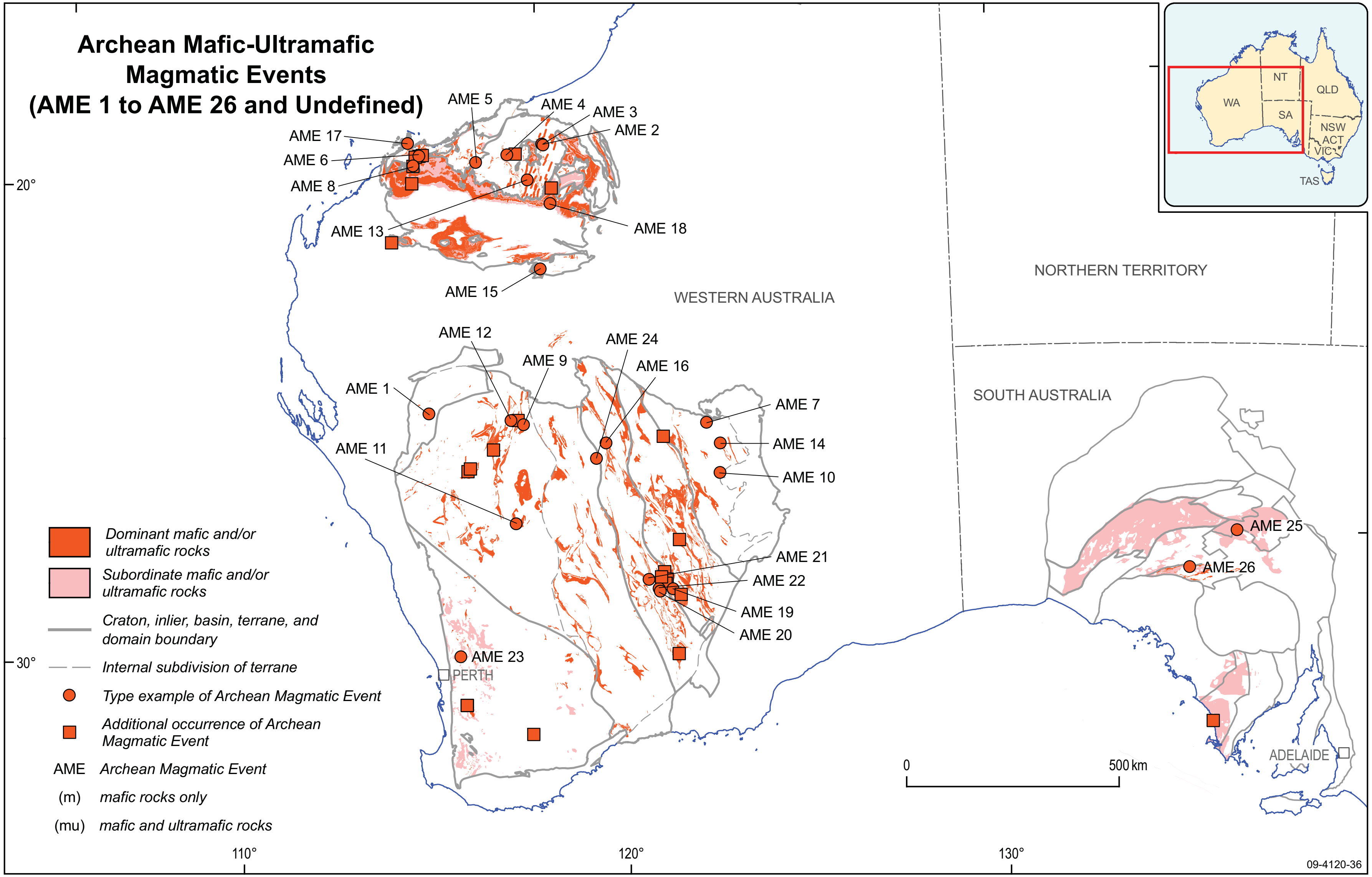
AME 4 (mu) ~3350 Ma Euro Event. Named after dated volcaniclastic sandstone interbedded with chert and basalt of Euro Basalt, Pilbara Craton.

AME 3 (mu) ~3470 Ma Mount Ada Event. Named after dated tuff interbedded with basalt of Mount Ada Basalt, Pilbara Craton (note location of dated sample is very close to AME 2 sample).

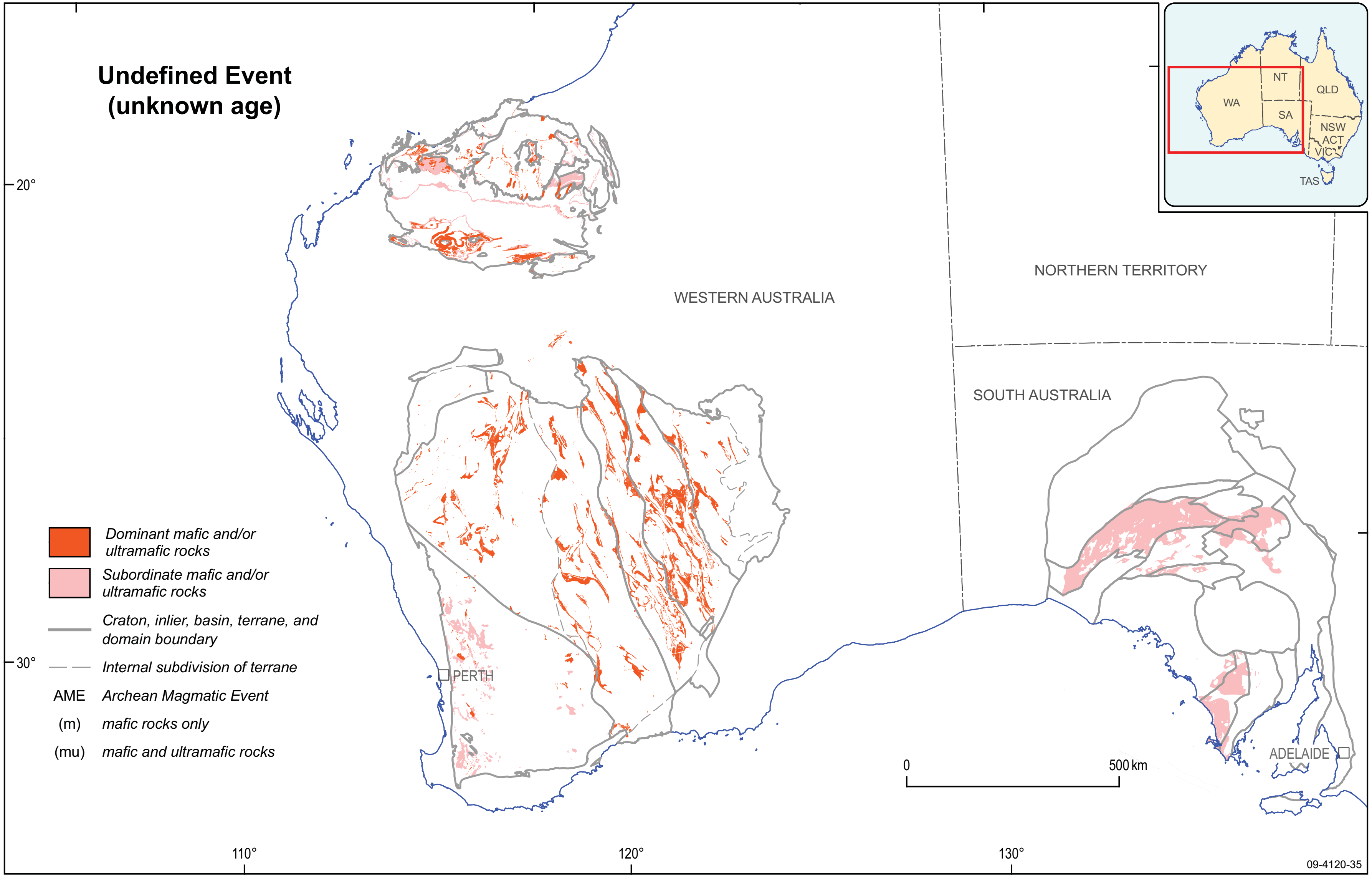
AME 2 (mu) ~3490 Ma North Star Event. Named after dated pyroxenite lens interbedded with basalt of North Star Basalt, Pilbara Craton. The next evolutionary phase for the Archean in Australia involves the Pilbara Craton, with dated mafic-ultramafic rocks in AME 2 to AME 6 reported from the East, Central, and West Pilbara terranes.

AME 1 (mu) ~3730 Ma Manfred Event. The Archean mafic-ultramafic magmatic record for Australia commences with dated leucogabbroic and meta-anorthositic rocks from the Manfred Complex in the Narryer Terrane, northwest Yilgarn Craton. Gabbroic rocks in this layered igneous complex are the oldest known rocks in Australia that have been dated. The Narryer Terrane appears to be anomalous (exotic accreted origin?) in its age context relative to the other juxtaposed terranes of the Yilgarn Craton.

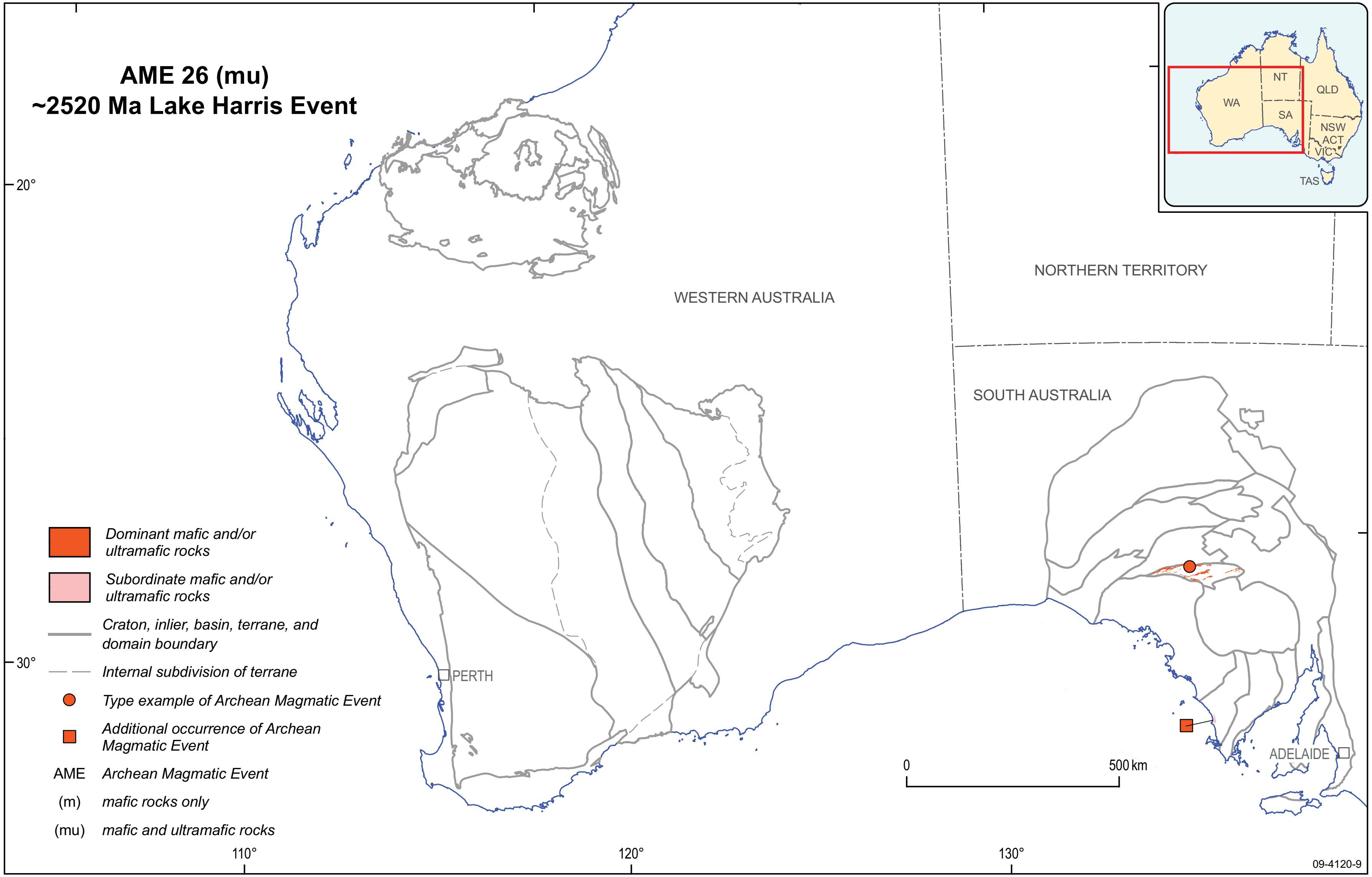

Major Geological and Tectonic Subdivisions
120°
130°
140°
150°
160°
10°
20°
30°
DARWIN
BRISBANE
SYDNEY
CANBERRA
MELBOURNE
ADELAIDE
PERTH
HOBART
WESTERN AUSTRALIA
NORTHERN TERRITORY
QUEENSLAND
SOUTH AUSTRALIA
NEW SOUTH WALES
ACT
VICTORIA
TASMANIA
PILBARA CRATON
HAMERSLEY BASIN
SYLVANIA INLIER
YILGARN CRATON
GAWLER CRATON
0
1000 km
PILBARA CRATON
1. West Pilbara Terrane
2. Central Pilbara Terrane
3. East Pilbara Terrane
4. Mosquito Creek Basin
5. Kurrana Terrane
HAMERSLEY BASIN
6. Hamersley Basin
SYLVANIA INLIER
7. Sylvania Inlier
YILGARN CRATON
8. Narryer Terrane
9. South West Terrane
10. Youanmi Terrane
11. Kalgoorlie Terrane
12. Kurnalpi Terrane
13. Burtville Terrane
GAWLER CRATON
14. Christie Domain
15. Fowler Domain
16. Wilgena Domain
17. Coober Pedy Domain
18. Nuyts Domain
19. Harris Greenstone Domain
20. Mount Woods Domain
21. Coulta Domain
22. Undifferentiated Domain
23. Olympic Domain
24. Cleve Domain
Craton, inlier, and basin boundary
Terrane and domain boundary
Internal subdivision of terrane
Note: Only those provinces containing Archean mafic and/or ultramafic rocks are labelled.
09-4120-8



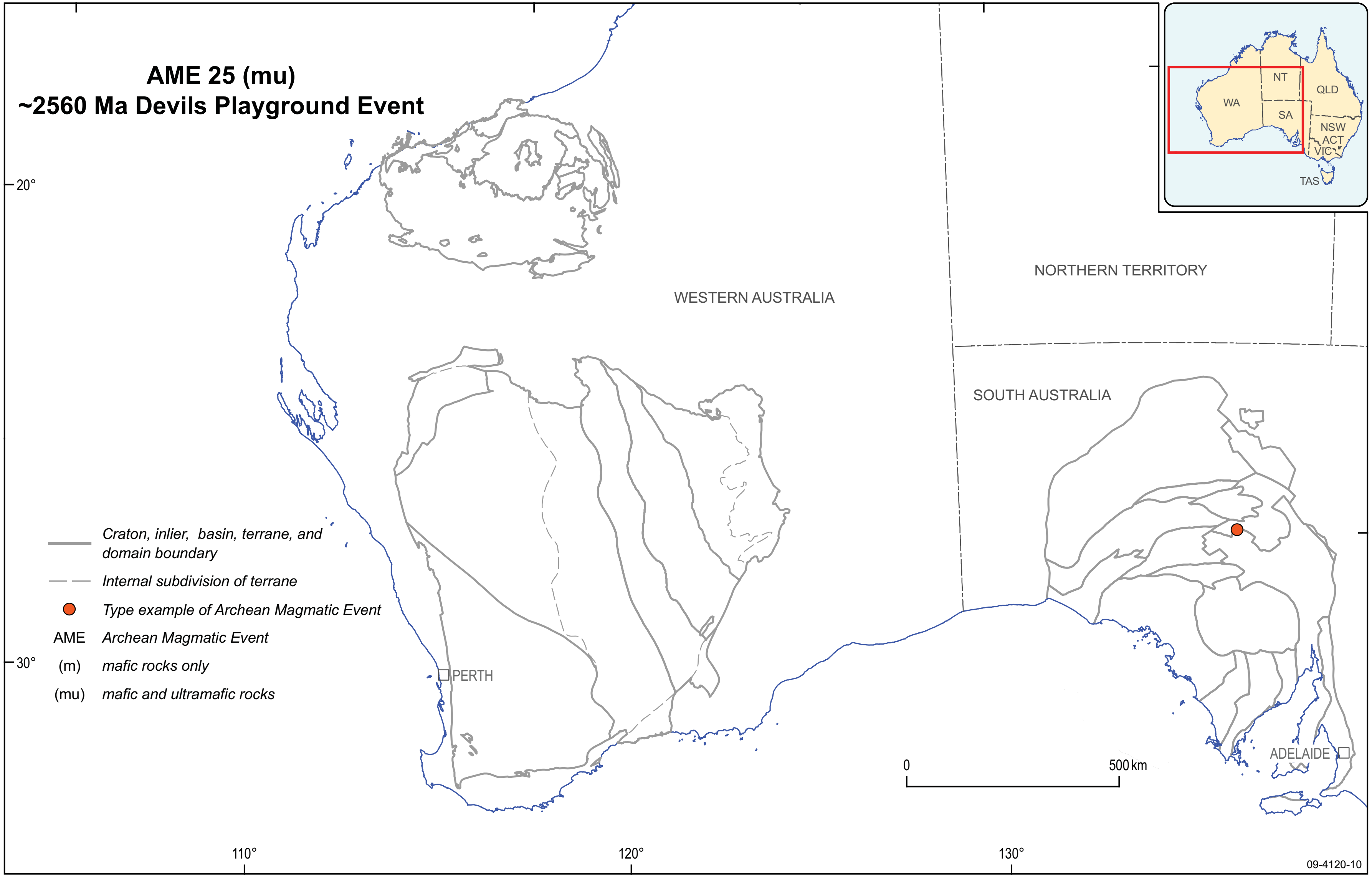
Archean Mafic-Ultramafic Magmatic Events (AME 1 to AME 26 and Undefined)
AME 1
AME 2
AME 3
AME 4
AME 5
AME 6
AME 7
AME 8
AME 9
AME 10
AME 11
AME 12
AME 13
AME 14
AME 15
AME 16
AME 17
AME 18
AME 19
AME 20
AME 21
AME 22
AME 23
AME 24
AME 25
AME 26
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
20°
30°
110°
120°
130°
0
500 km
Dominant mafic and/or ultramafic rocks
Subordinate mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-36



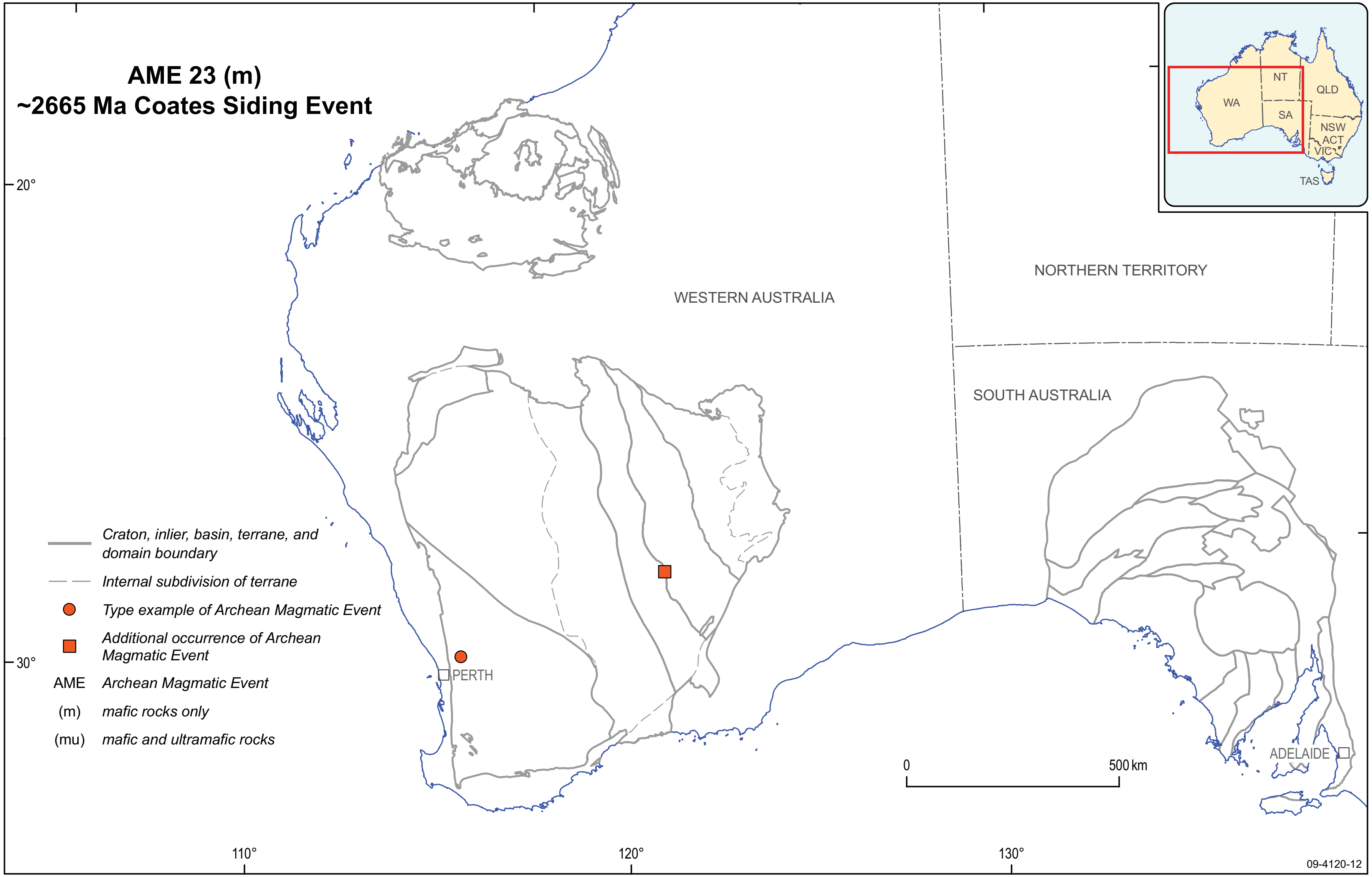
Undefined Event
(unknown age)
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
WA
NT
QLD
SA
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Subordinate mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-35

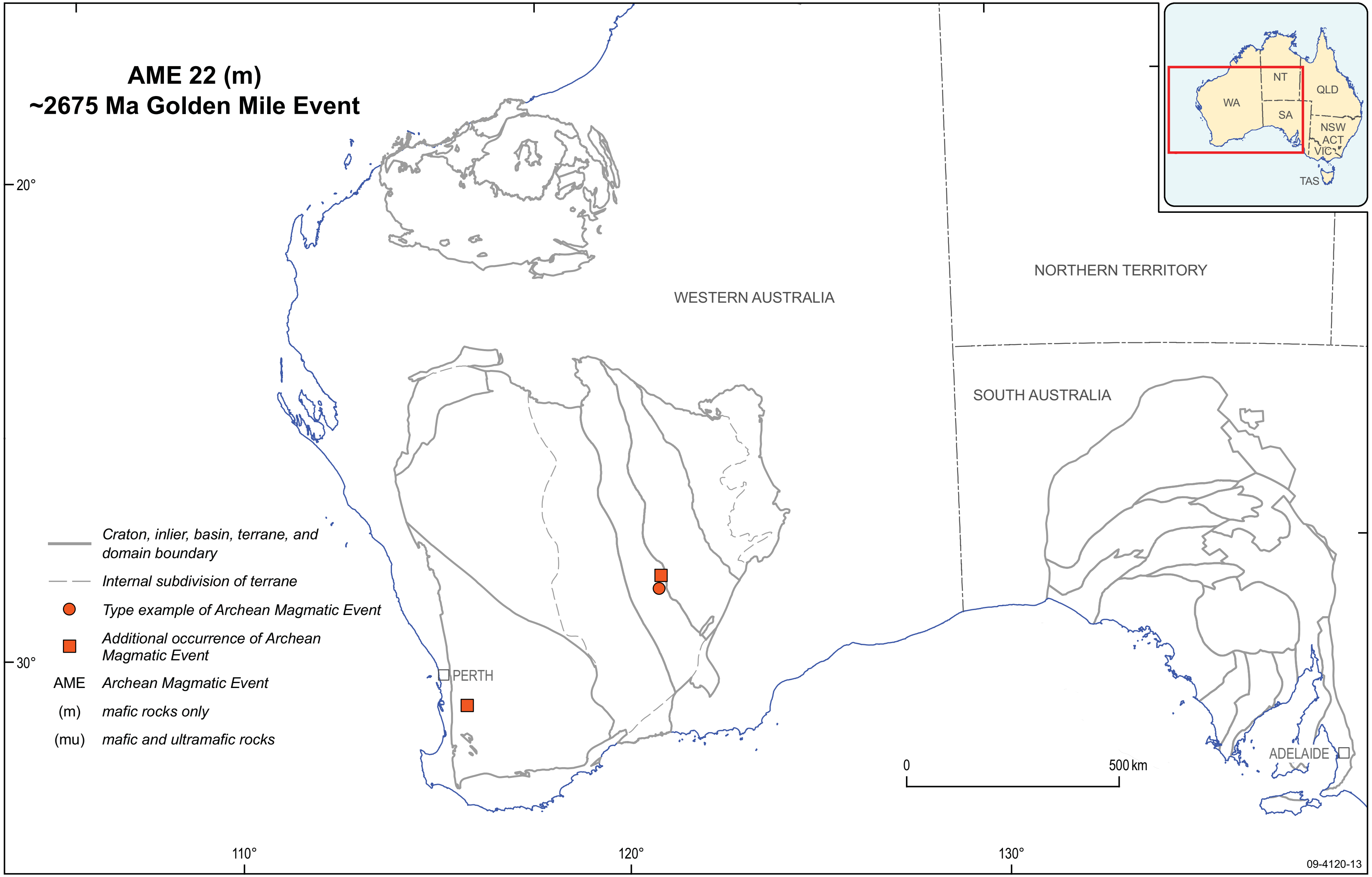


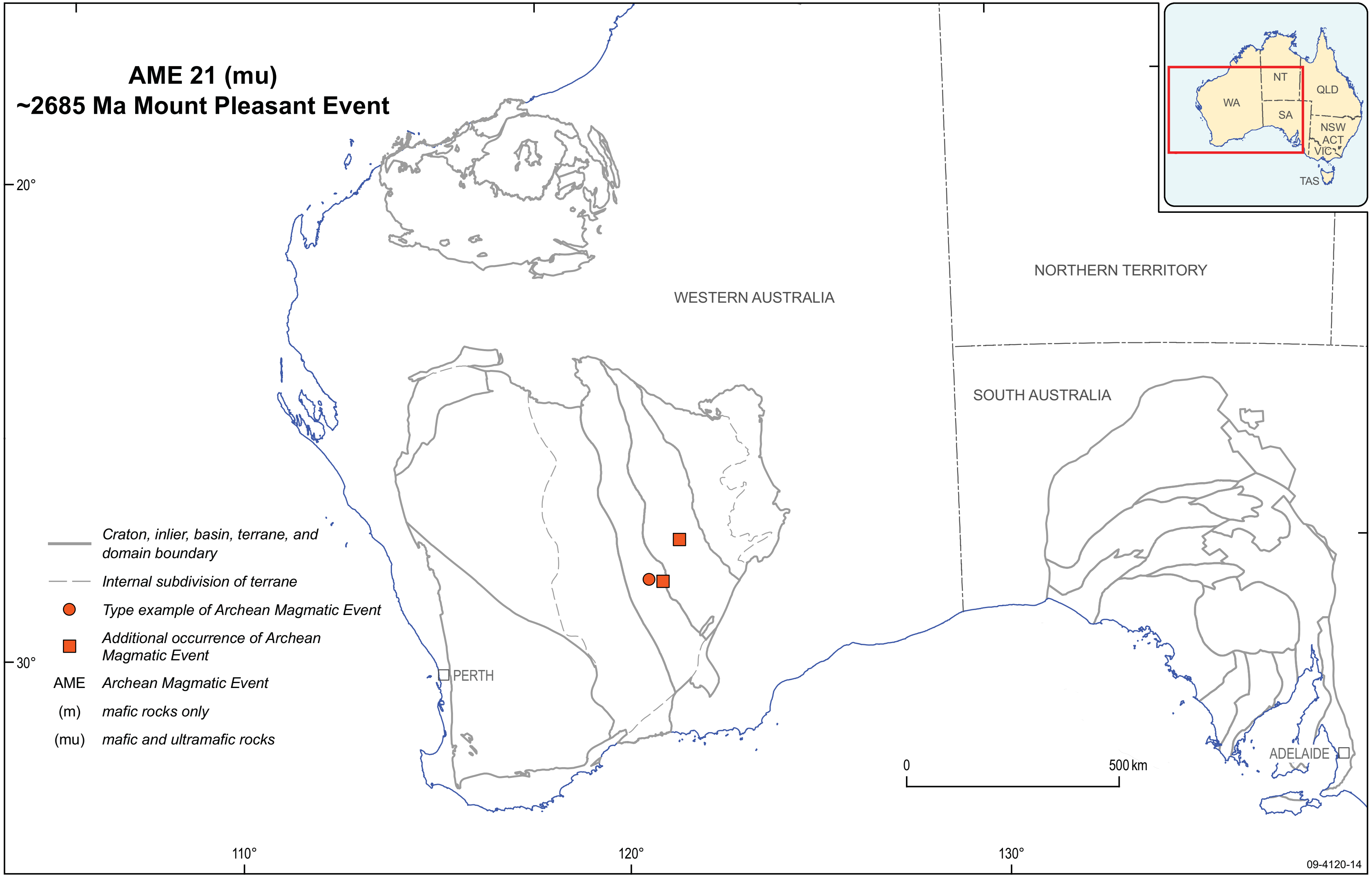
AME 26 (mu)
~2520 Ma Lake Harris Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
20°
30°
110°
120°
130°
0
500 km
Dominant mafic and/or ultramafic rocks
Subordinate mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-9

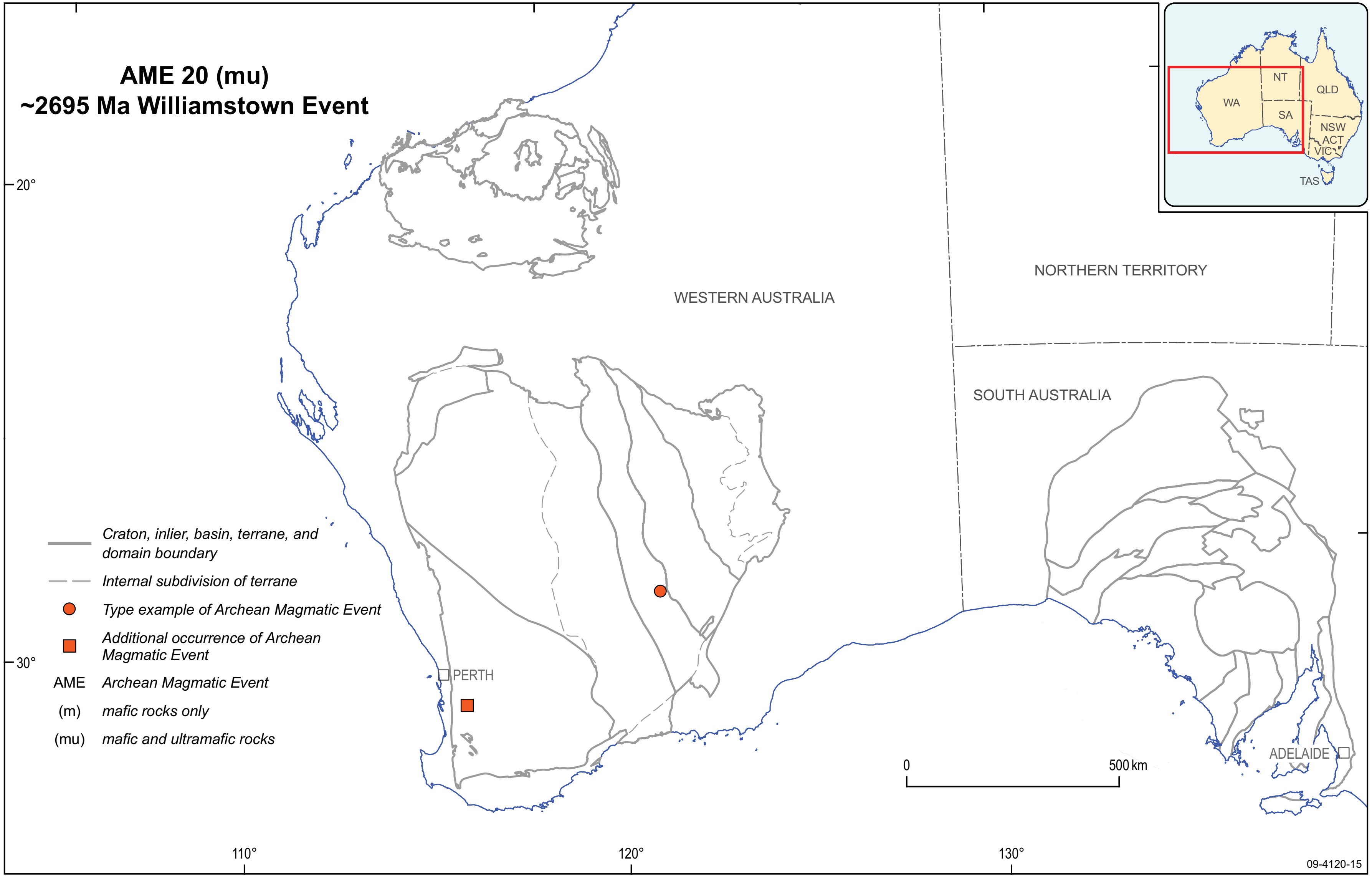

AME 25 (mu)
~2560 Ma Devils Playground Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
09-4120-10

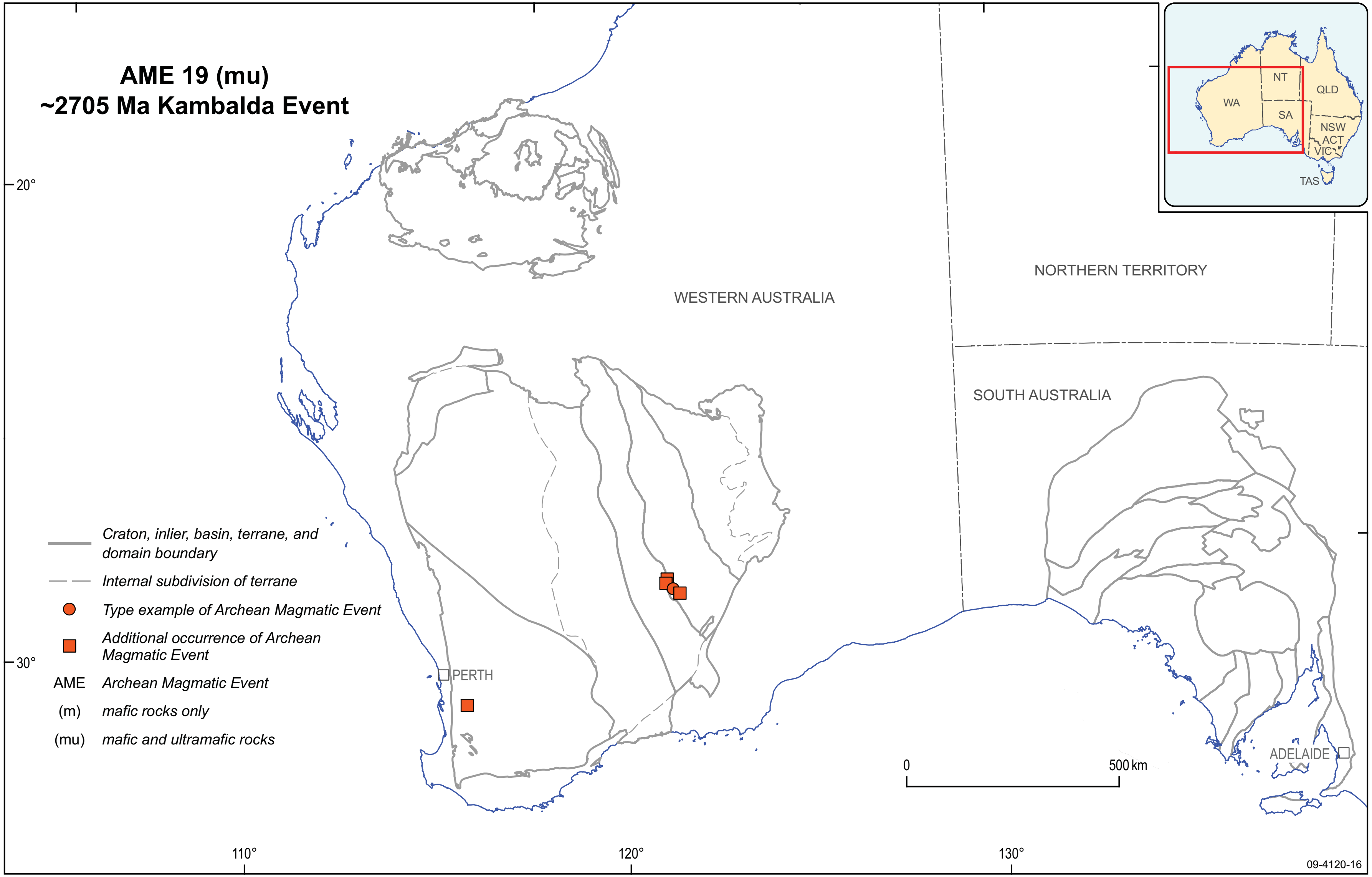

AME 24 (m)
~2625 Ma Kaluweerie Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
WA
NT
QLD
SA
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-11

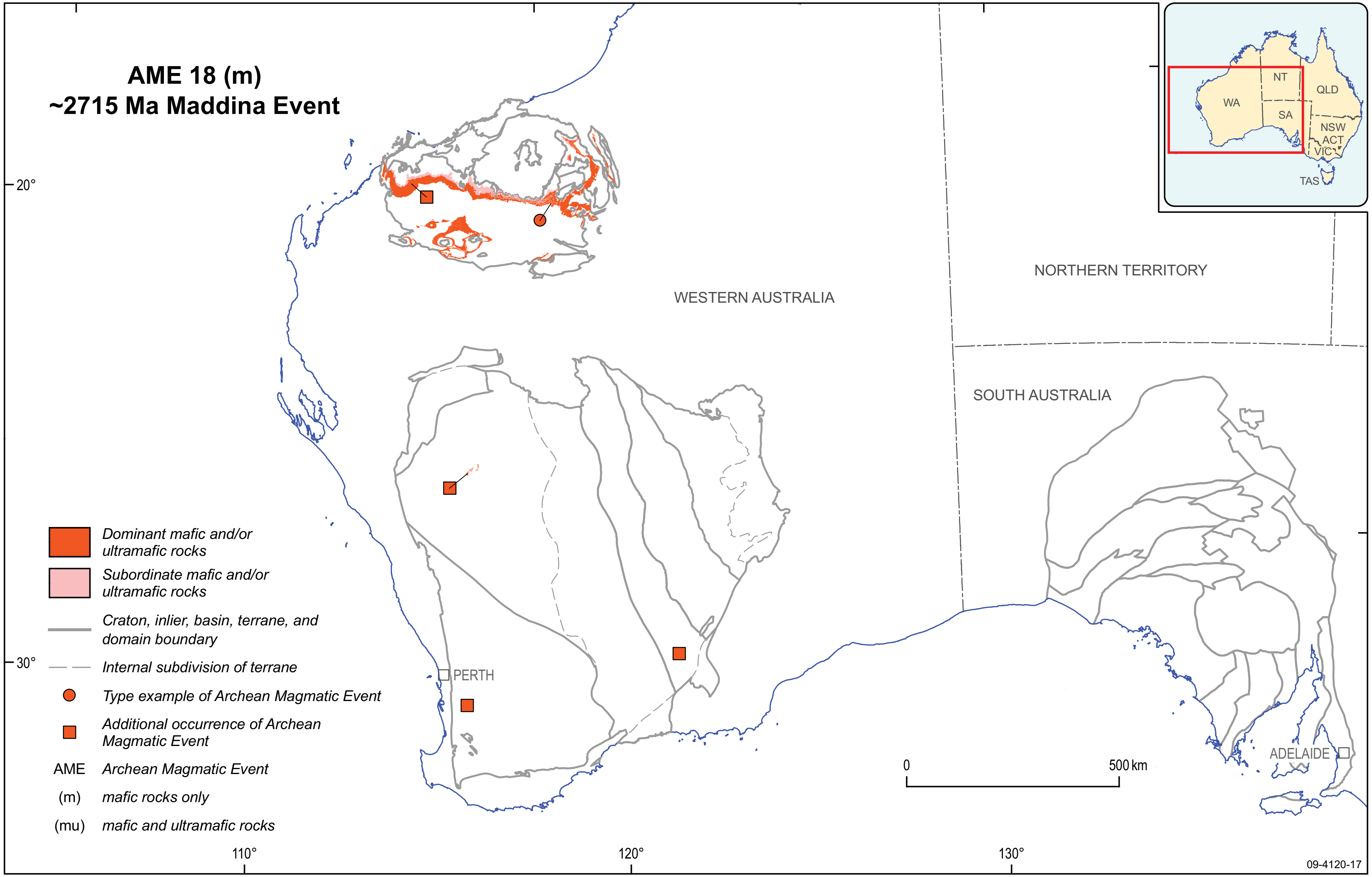

AME 23 (m)
~2665 Ma Coates Siding Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
WA
NT
QLD
SA
NSW
ACT
VIC
TAS
20°
30°
110°
120°
130°
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-12

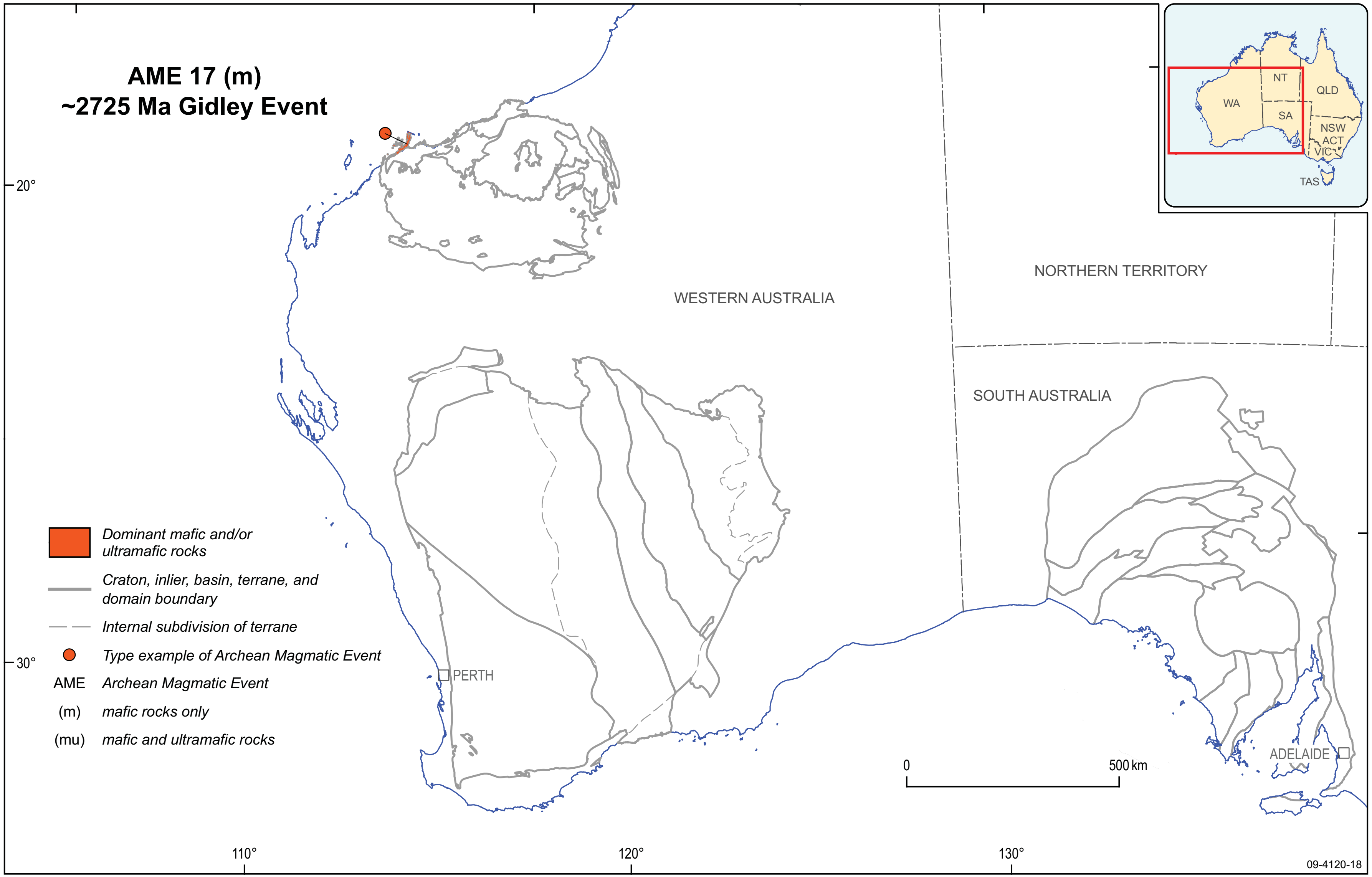

AME 22 (m)
~2675 Ma Golden Mile Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
NT
WA
SA
QLD
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-13

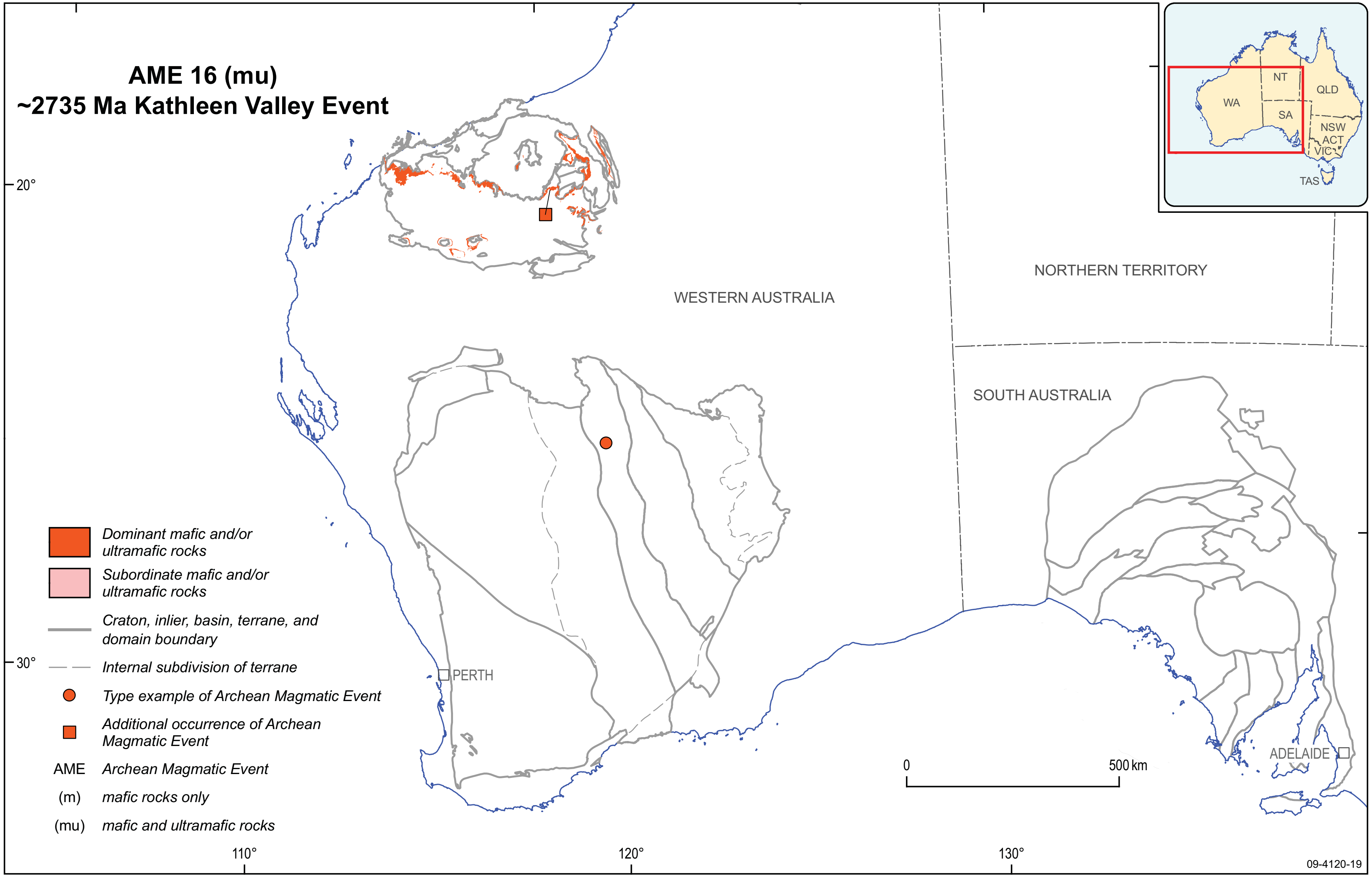

AME 21 (mu)
~2685 Ma Mount Pleasant Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-14

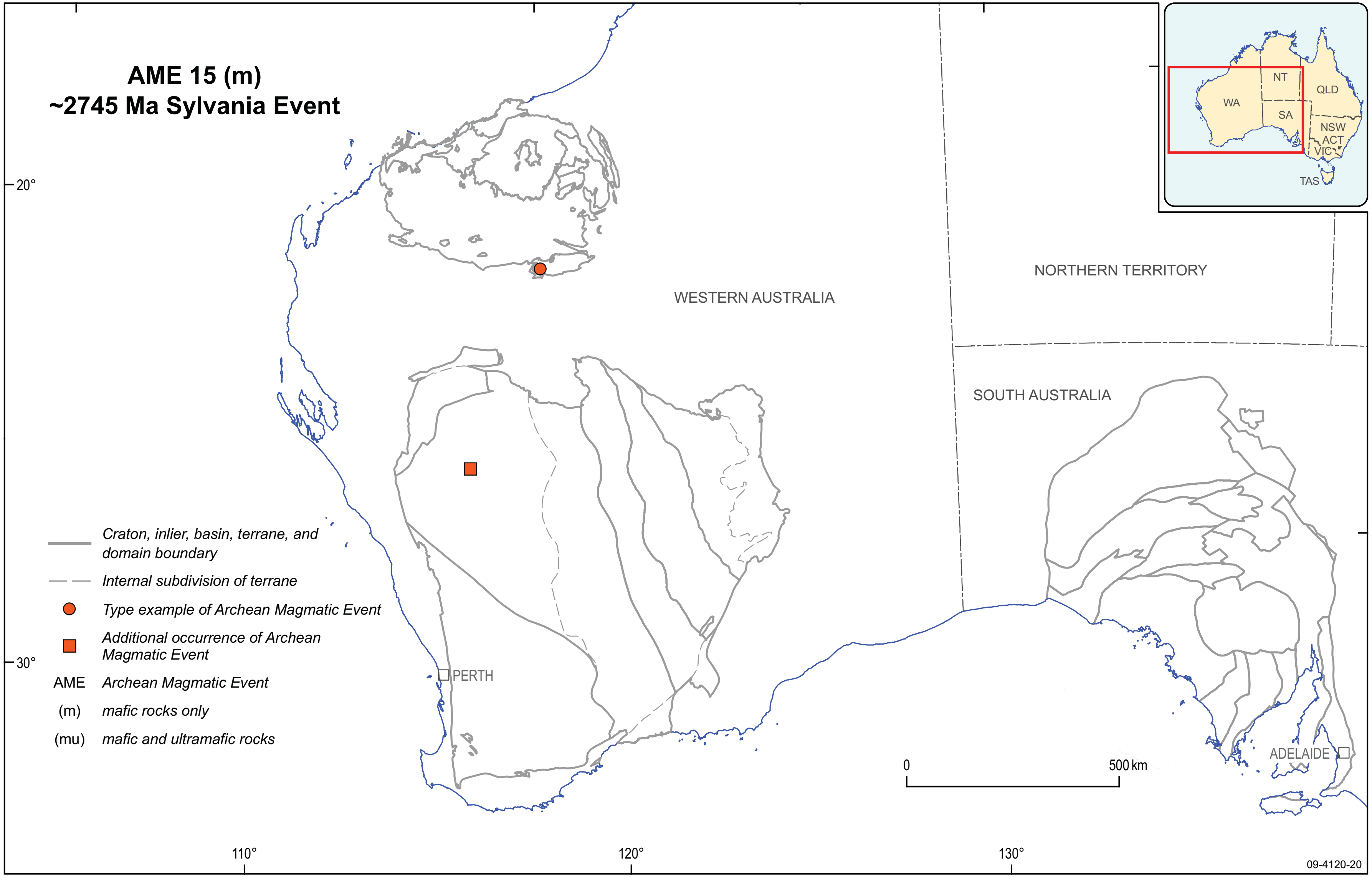

AME 20 (mu)
~2695 Ma Williamstown Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
NT
WA
QLD
SA
NSW
ACT
VIC
TAS
20°
30°
110°
120°
130°
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-15

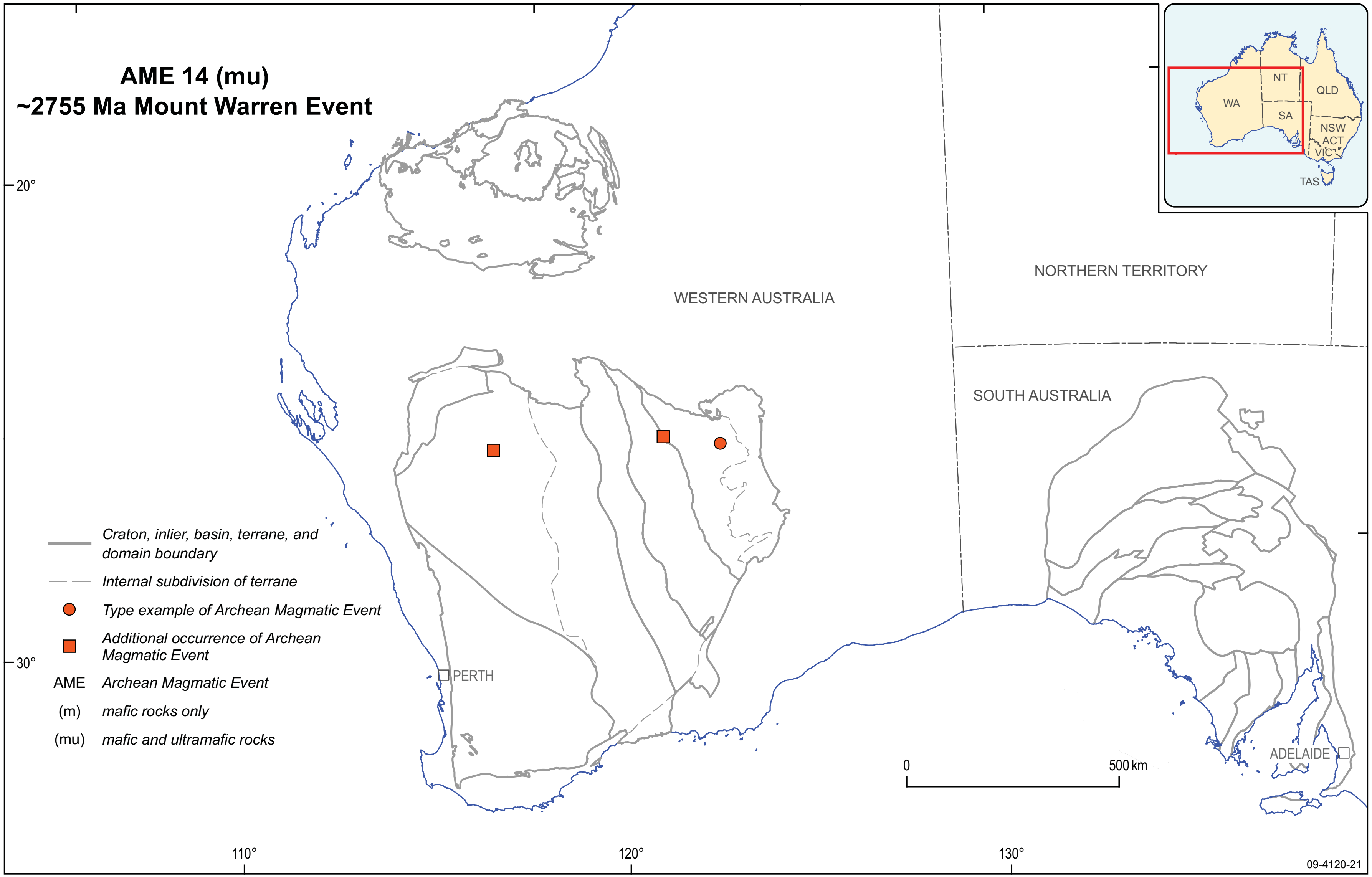

AME 19 (mu)
~2705 Ma Kambalda Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-16

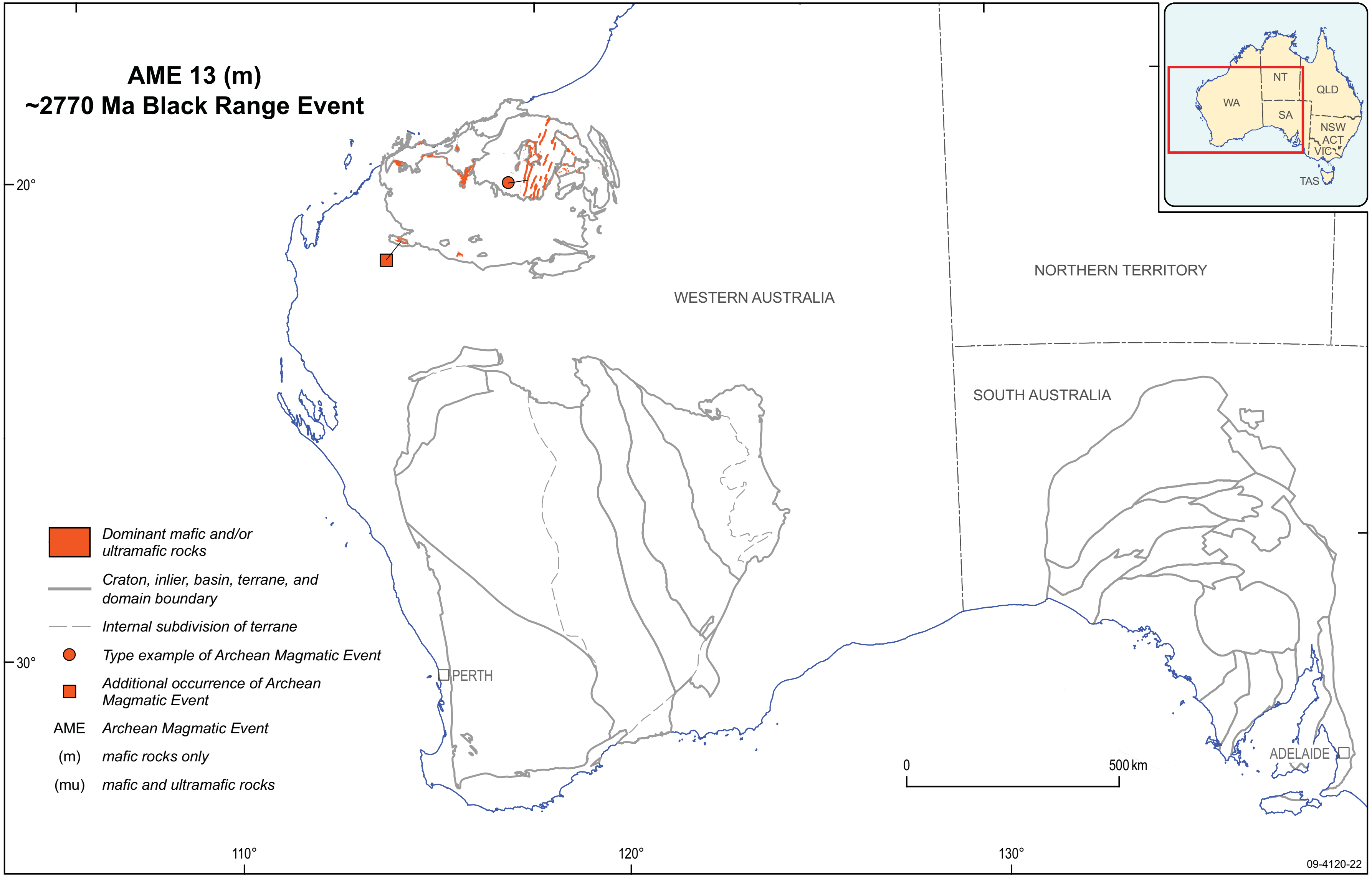

AME 18 (m)
~2715 Ma Maddina Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Subordinate mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-17

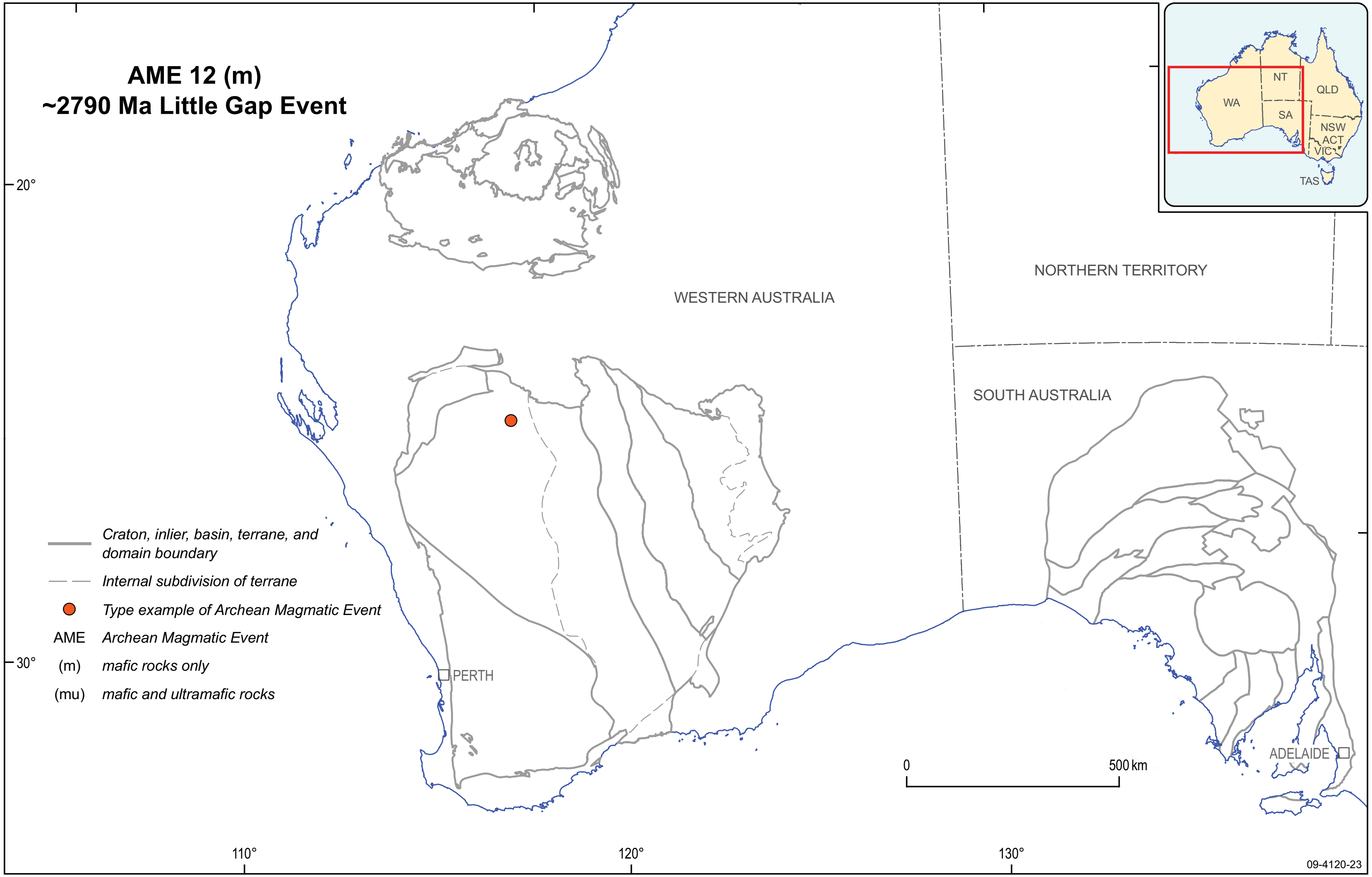

AME 17 (m)
~2725 Ma Gidley Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-18

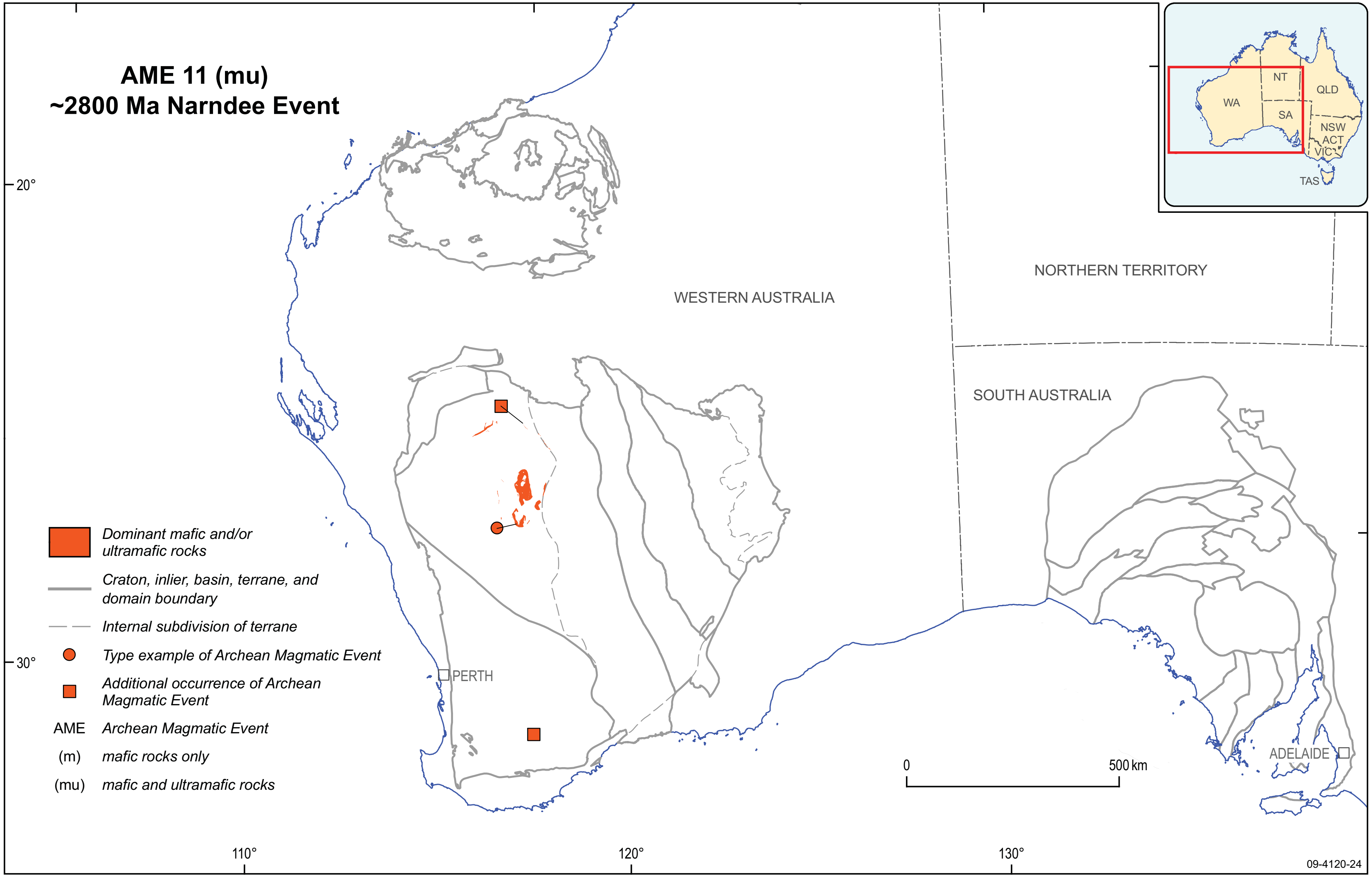

AME 16 (mu)
~2735 Ma Kathleen Valley Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
QLD
SA
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Subordinate mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-19


AME 15 (m)
~2745 Ma Sylvania Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-20

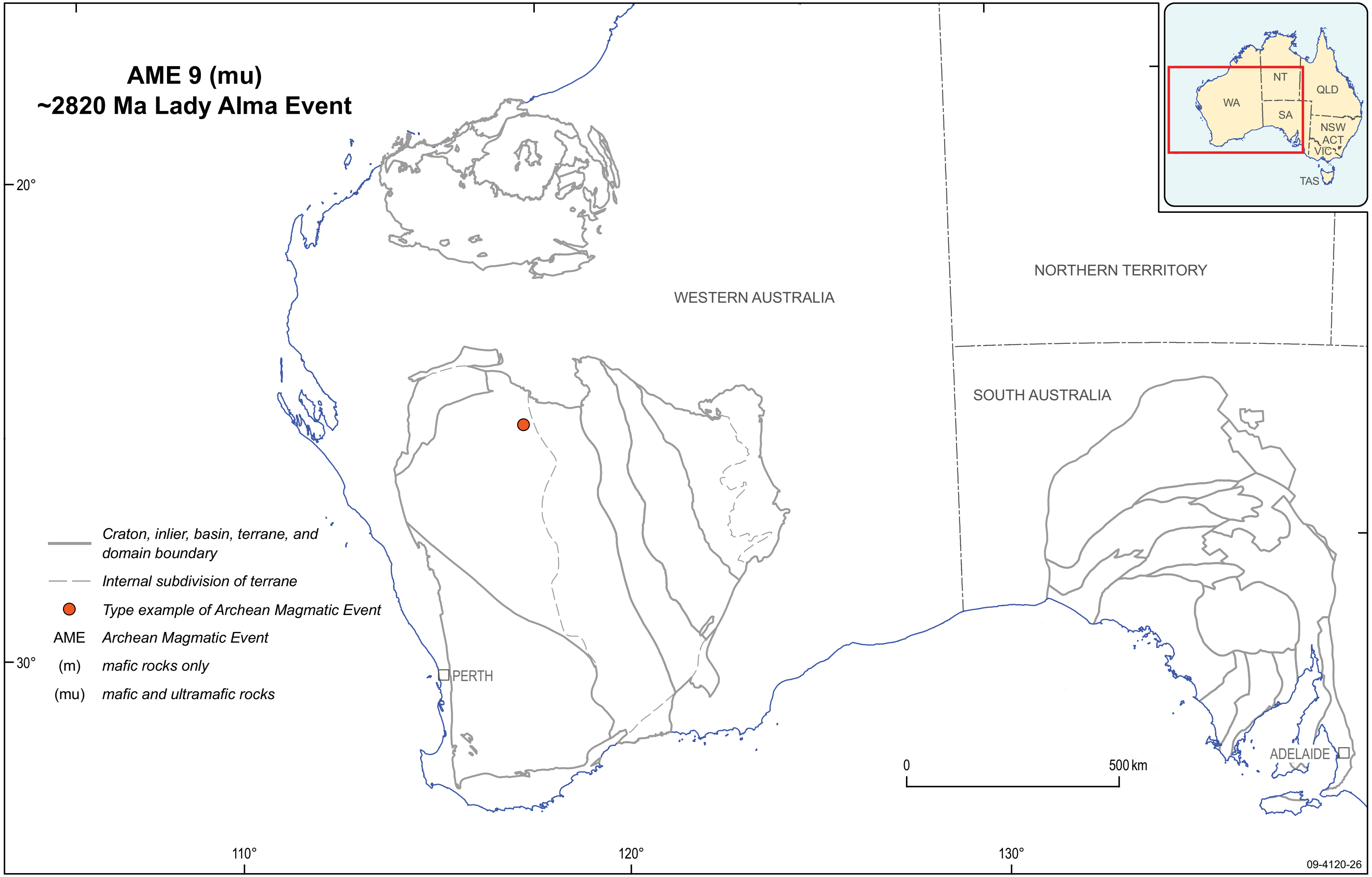

AME 14 (mu)
~2755 Ma Mount Warren Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-21

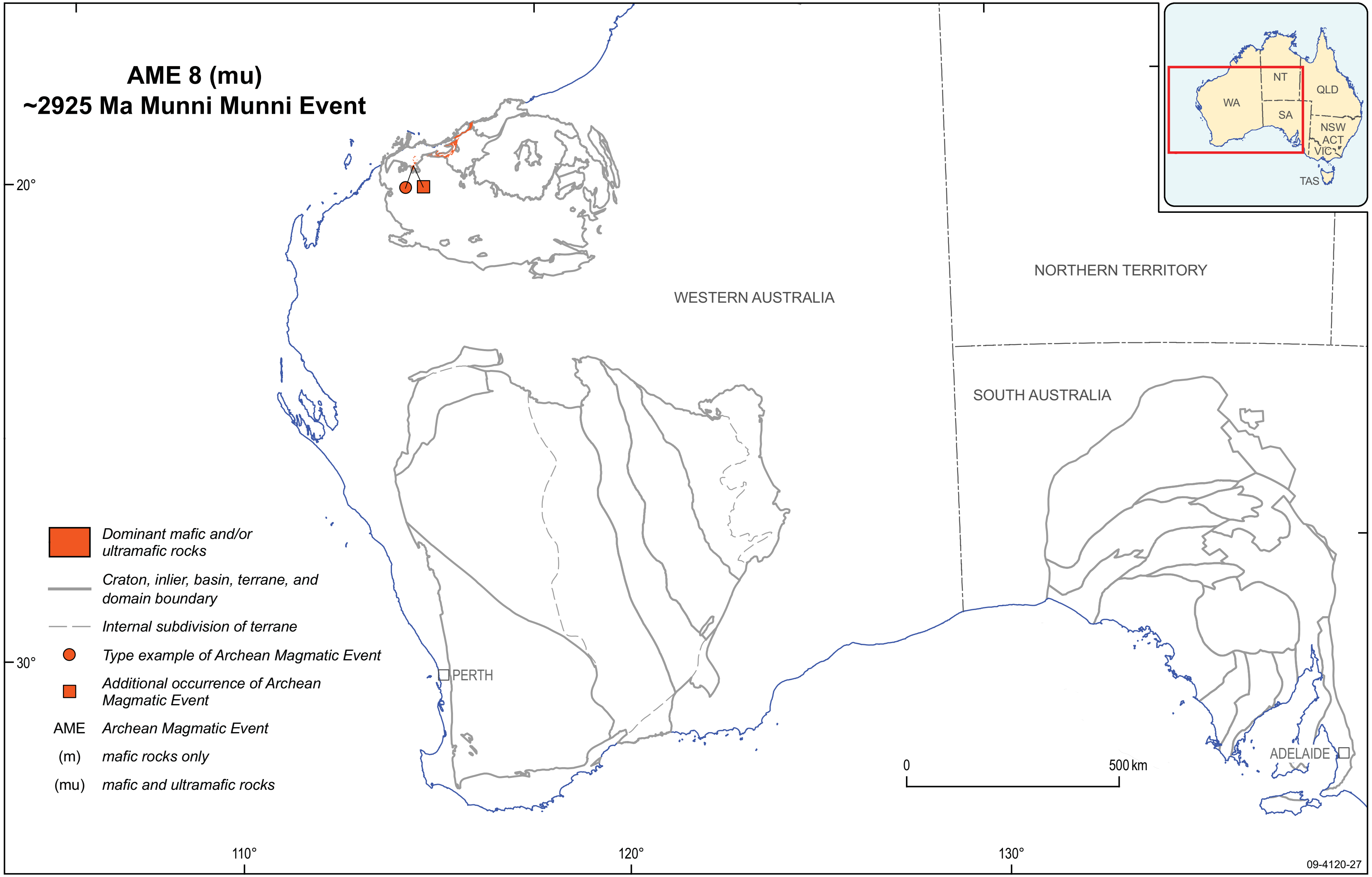

AME 13 (m)
~2770 Ma Black Range Event
NORTHERN TERRITORY
WESTERN AUSTRALIA
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-22


AME 12 (m)
~2790 Ma Little Gap Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
NT
WA
QLD
SA
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-23


AME 11 (mu)
~2800 Ma Narndee Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
SA
QLD
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-24

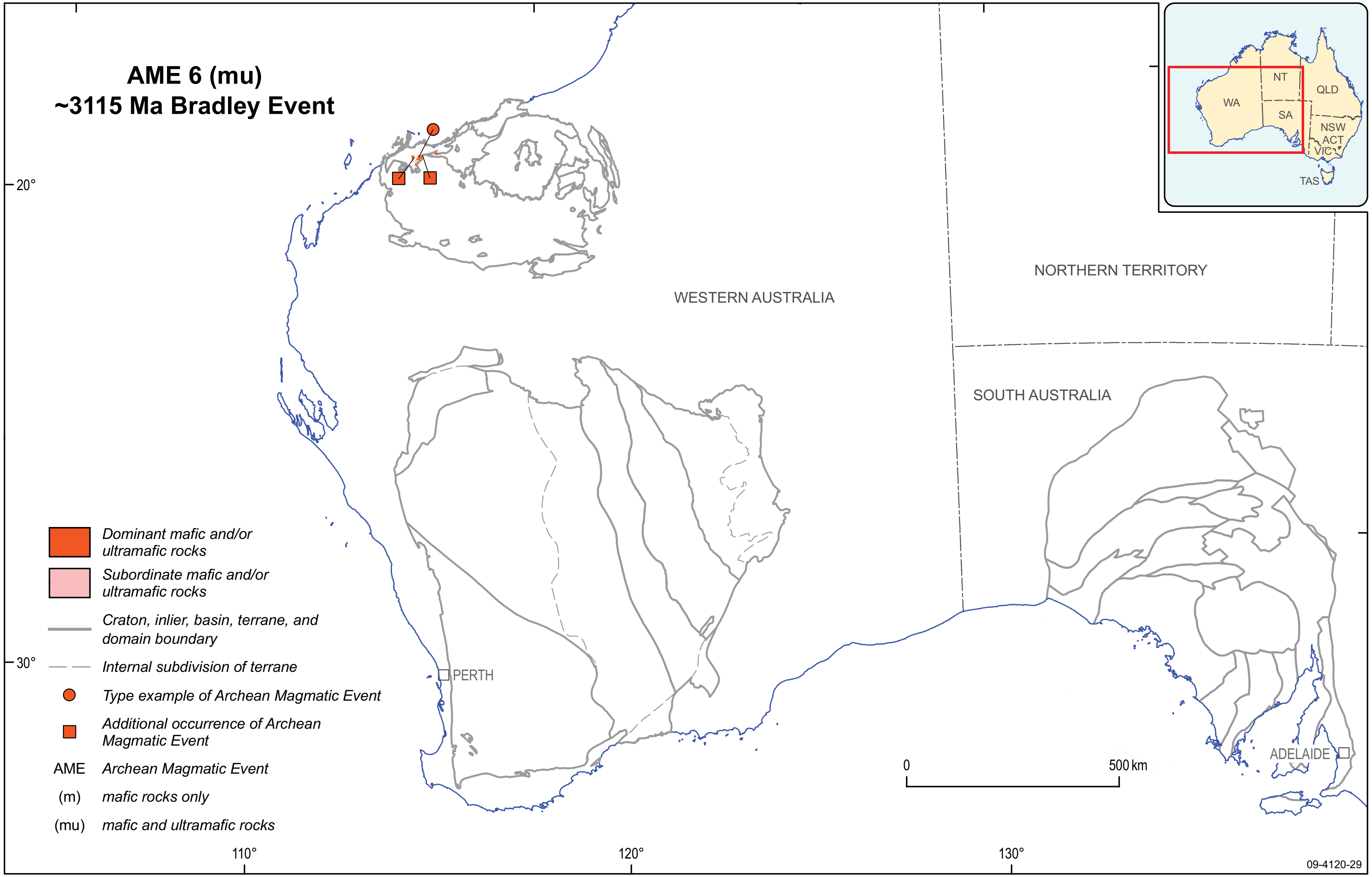

AME 10 (m)
~2810 Ma Mount Sefton Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
NT
WA
QLD
SA
NSW
ACT
VIC
TAS
09-4120-25


AME 9 (mu)
~2820 Ma Lady Alma Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-26

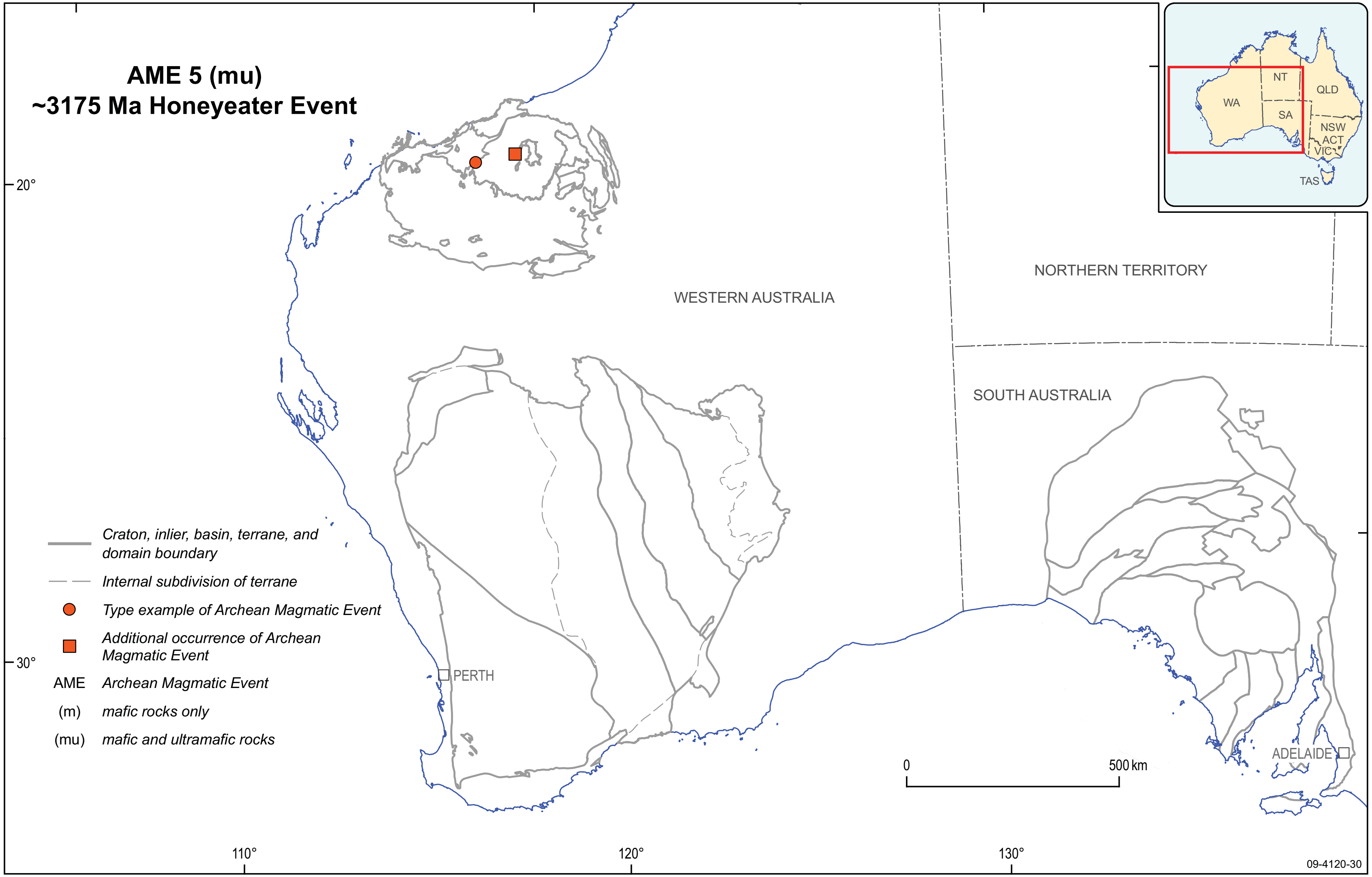


AME 8 (mu)
~2925 Ma Munni Munni Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-27

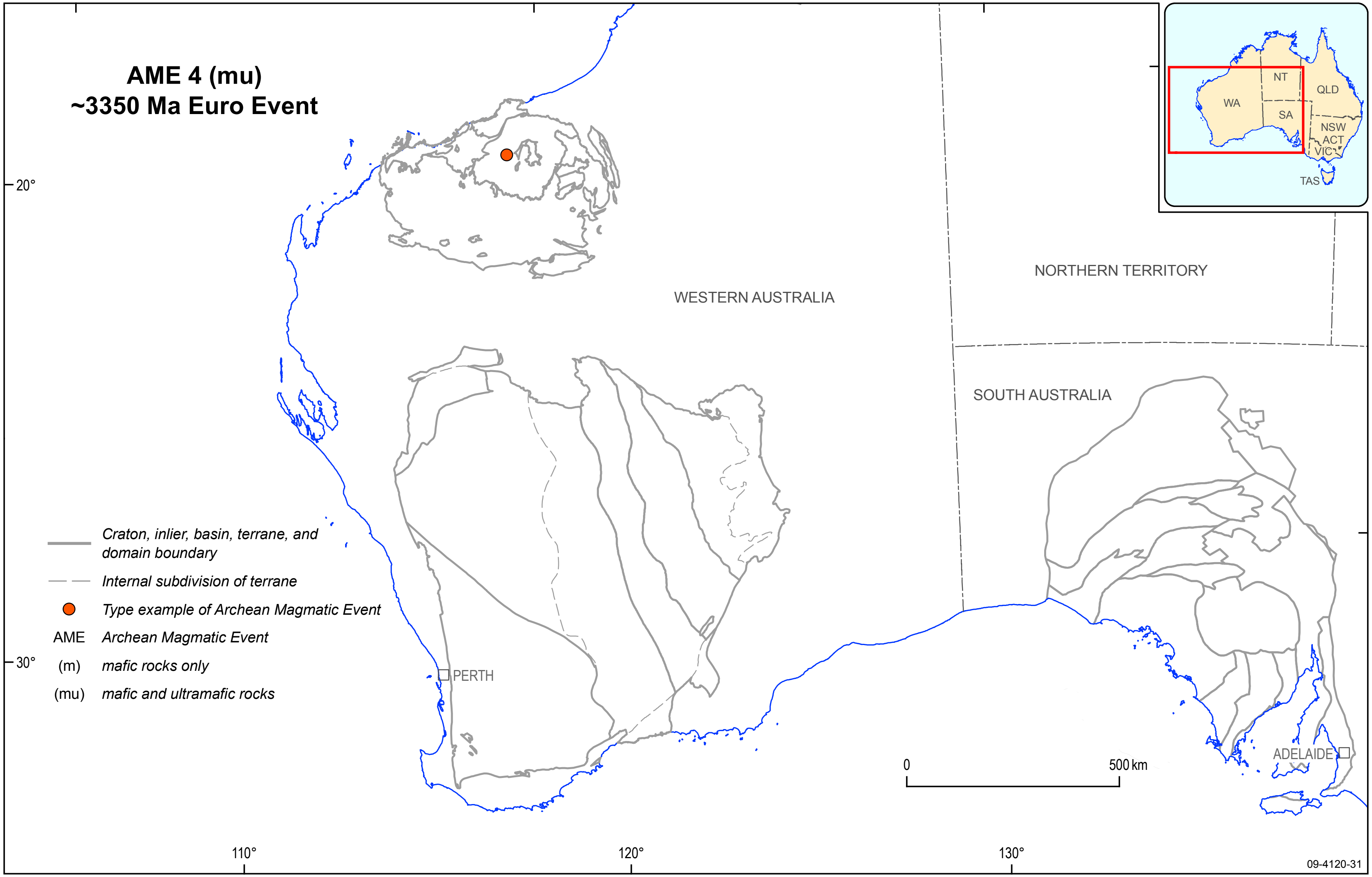

AME 7 (m)
~2960 Ma Lake Wells Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-28



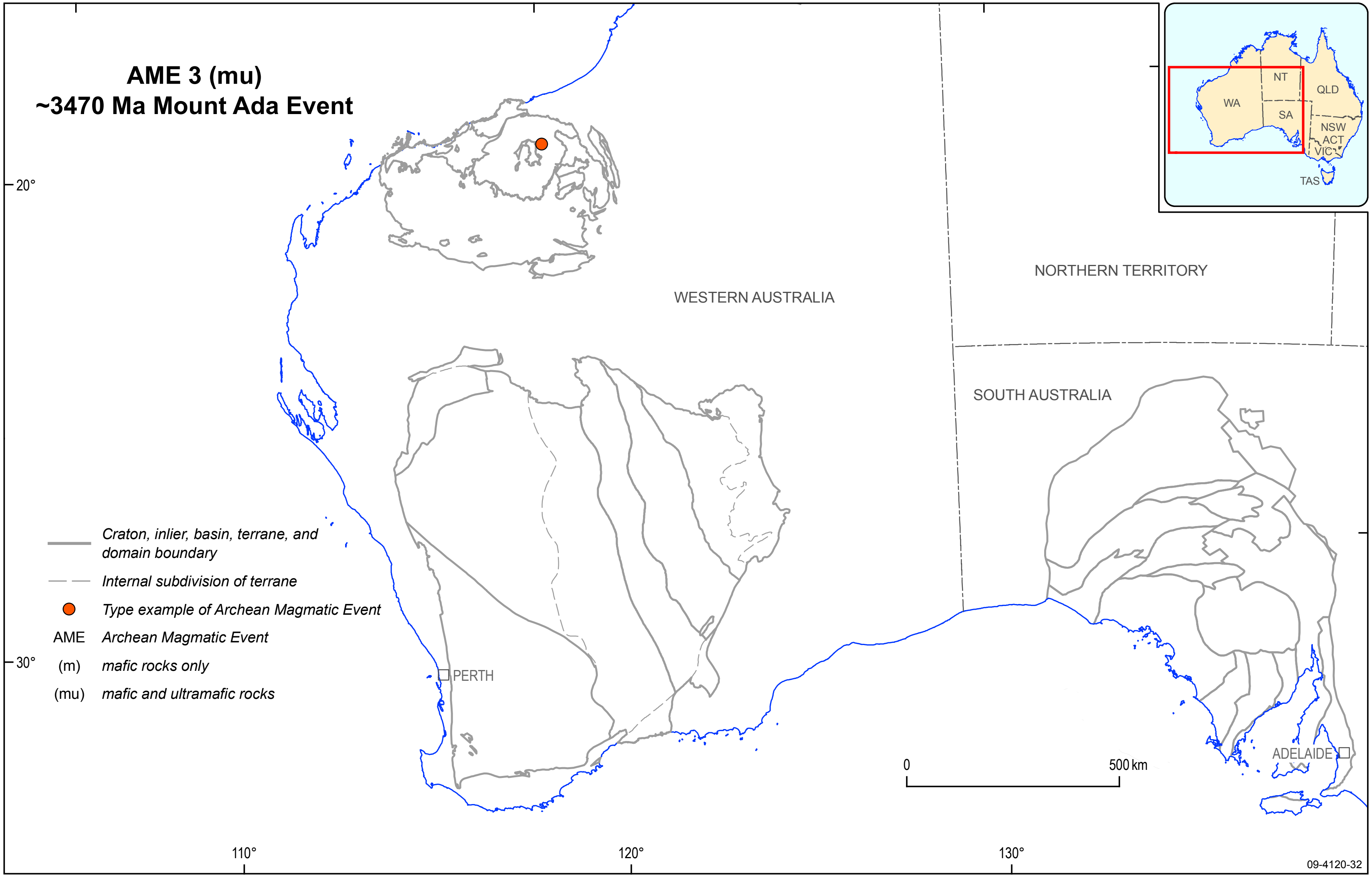
AME 6 (mu)
~3115 Ma Bradley Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
NT
WA
QLD
SA
NSW
ACT
VIC
TAS
Dominant mafic and/or ultramafic rocks
Subordinate mafic and/or ultramafic rocks
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-29

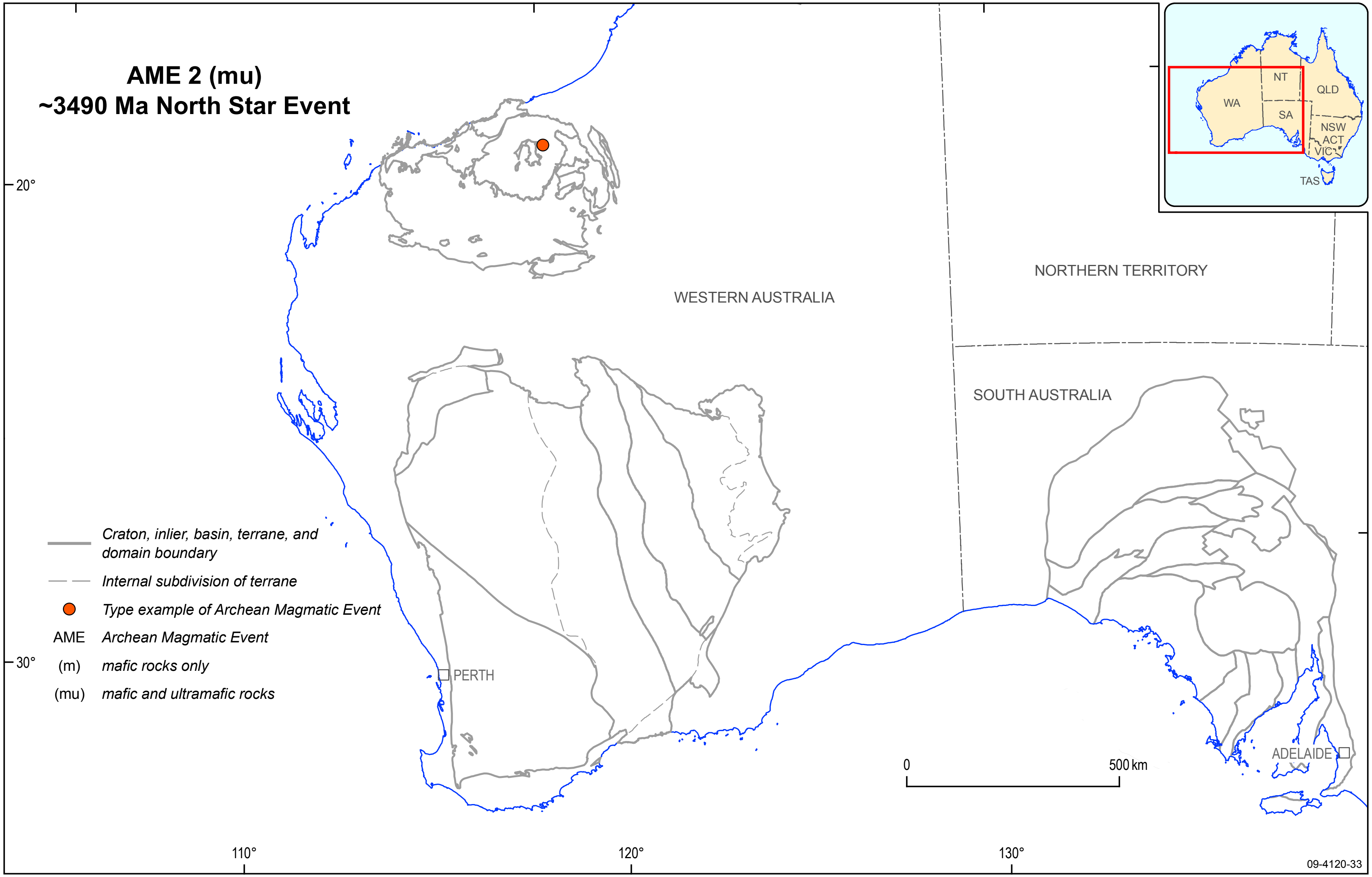


AME 5 (mu)
~3175 Ma Honeyeater Event
20°
30°
110°
120°
130°
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
0
500 km
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
Additional occurrence of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-30

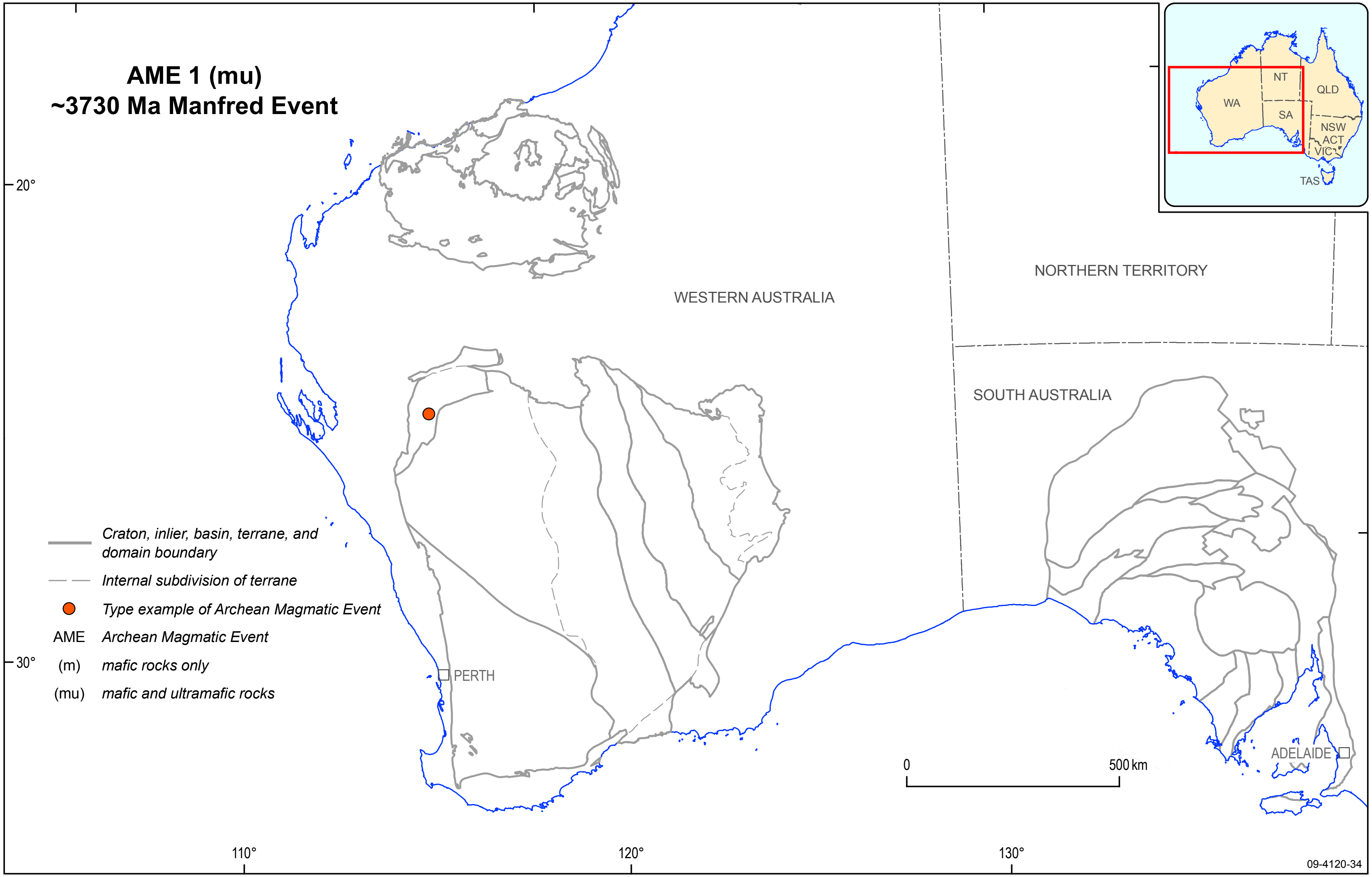


AME 4 (mu)
~3350 Ma Euro Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
09-4120-31


AME 3 (mu)
~3470 Ma Mount Ada Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
WA
NT
QLD
SA
NSW
ACT
VIC
TAS
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-32



AME 2 (mu)
~3490 Ma North Star Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
WA
NT
QLD
SA
NSW
ACT
VIC
TAS
20°
30°
110°
120°
130°
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
09-4120-33


AME 1 (mu)
~3730 Ma Manfred Event
WESTERN AUSTRALIA
NORTHERN TERRITORY
SOUTH AUSTRALIA
PERTH
ADELAIDE
20°
30°
110°
120°
130°
0
500 km
Craton, inlier, basin, terrane, and domain boundary
Internal subdivision of terrane
Type example of Archean Magmatic Event
AME Archean Magmatic Event
(m) mafic rocks only
(mu) mafic and ultramafic rocks
NT
QLD
WA
SA
NSW
ACT
VIC
TAS
09-4120-34

Guide to Using the Australian Archean Mafic-Ultramafic Magmatic Events Map

This CD-ROM contains the above-titled Report as Record 2009/41.pdf

View this .pdf document using Adobe Acrobat Reader (click Adobe.txt for information on readers)

Click on Record2009/41.pdf to launch the document.

Map of Australian Archean Mafic-Ultramafic Magmatic Events (Sheets 1 & 2)

View the two .pdf map sheets using Adobe Acrobat Reader (click Adobe.txt for information on readers)

Click on: GA15395 to launch sheet 1.
Click on: GA15396 to launch sheet 2.

Directory containing electronic appendix on the CD-ROM:

Appendix 11.
Geological and Geochronological Data of Archean Mafic-Ultramafic Rock Units in Australia
Separate .pdf spreadsheet files (viewable only).
—see online directory http://www.ga.gov.au/resources/maps/minerals/index.jsp