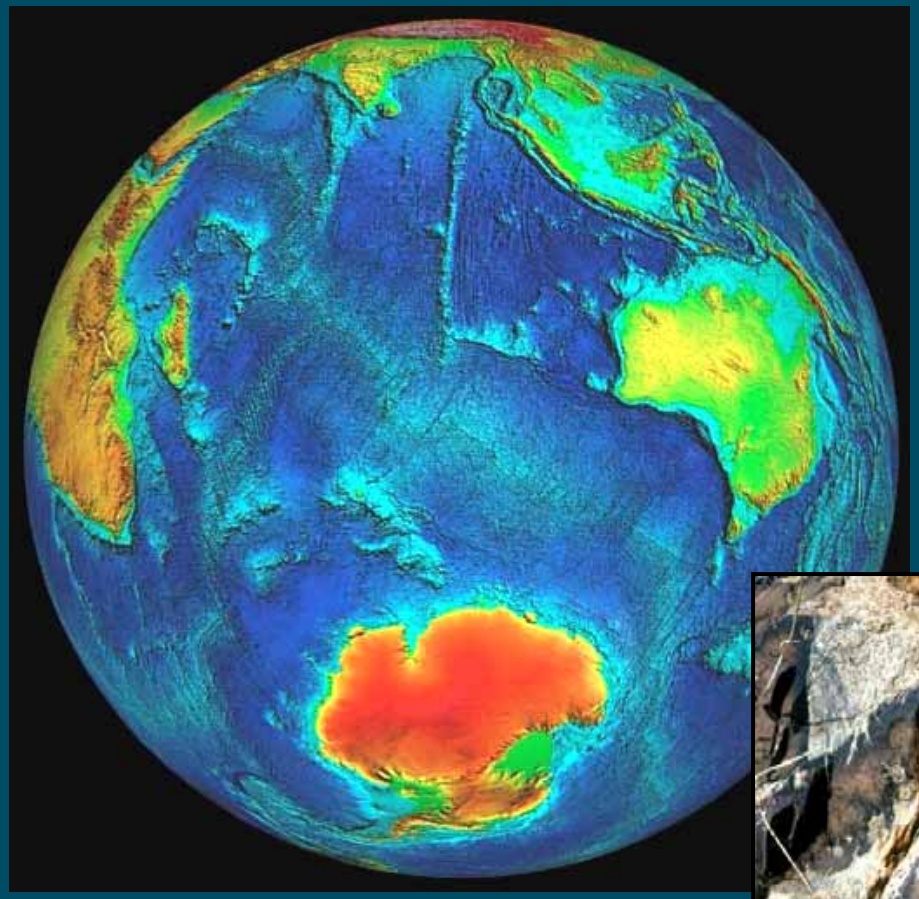

Proterozoic Mafic-Ultramafic Magmatism in Australia: Geological Settings and Metallogeny

Dean Hoatson, Jon Claoué-Long & Subhash Jaireth

Contributions from:

Lynton Jaques & Mike Huleatt

Australian Government

Geoscience Australia

Australian Nickel Conference

22-23rd October 2008

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Critical Questions for Explorers …

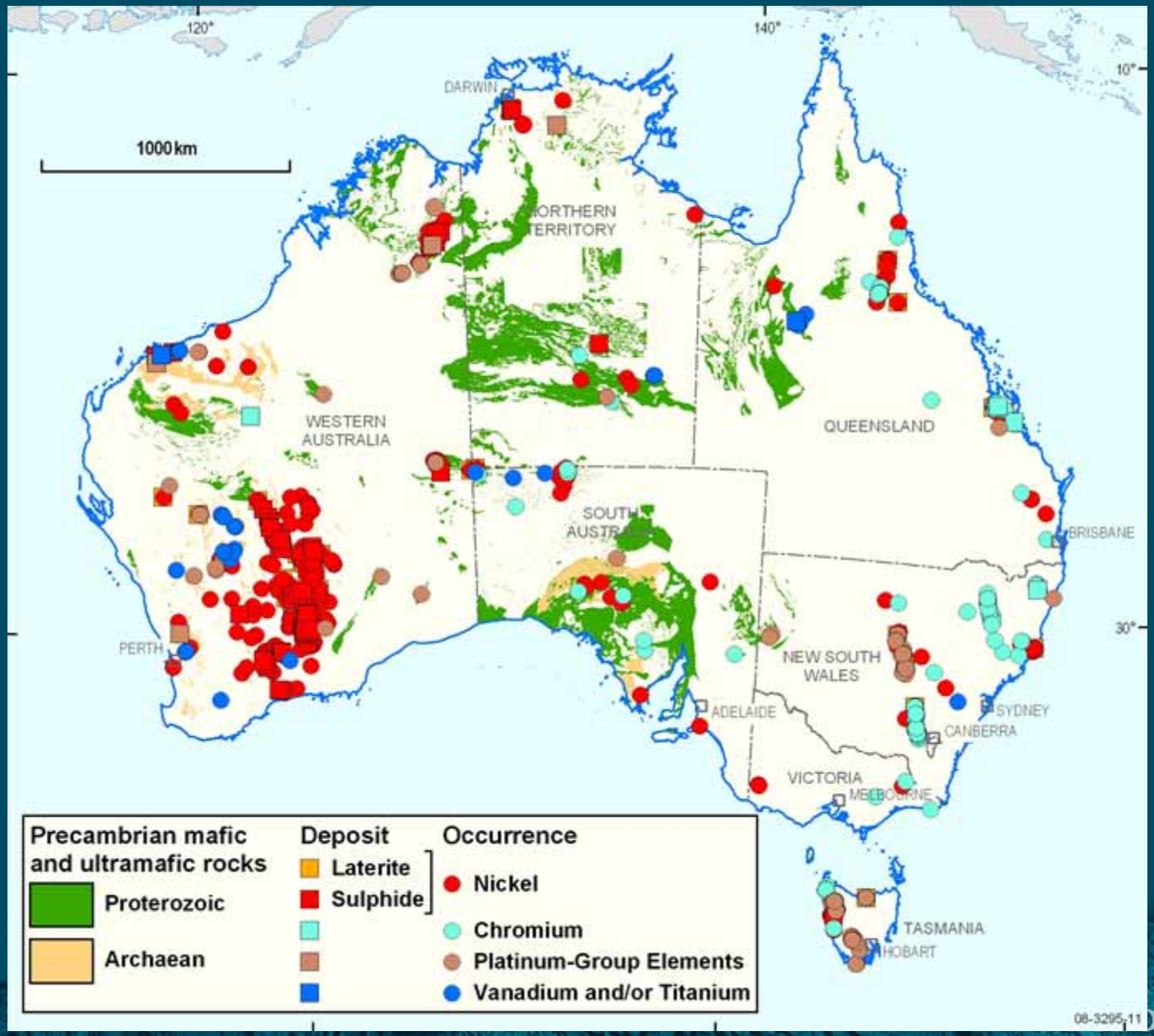
Where are the mafic-ultramafic magmatic systems?

Which Magmatic Events are the big ones?

Which Magmatic Events have ultramafic magmas?

Can crustal structures narrow the exploration focus?

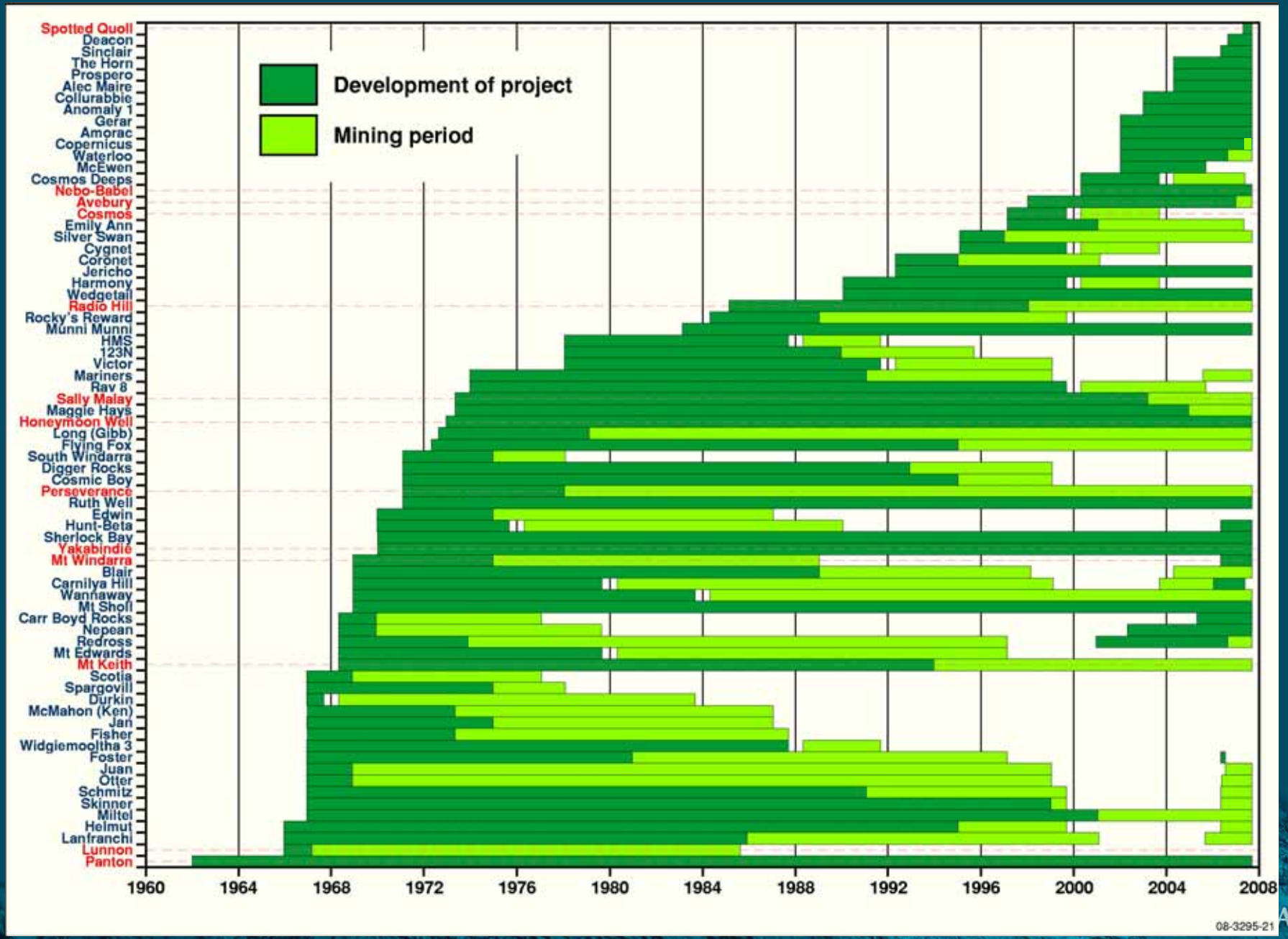
Mafic-Ultramafic Rock Associated Mineral Deposits



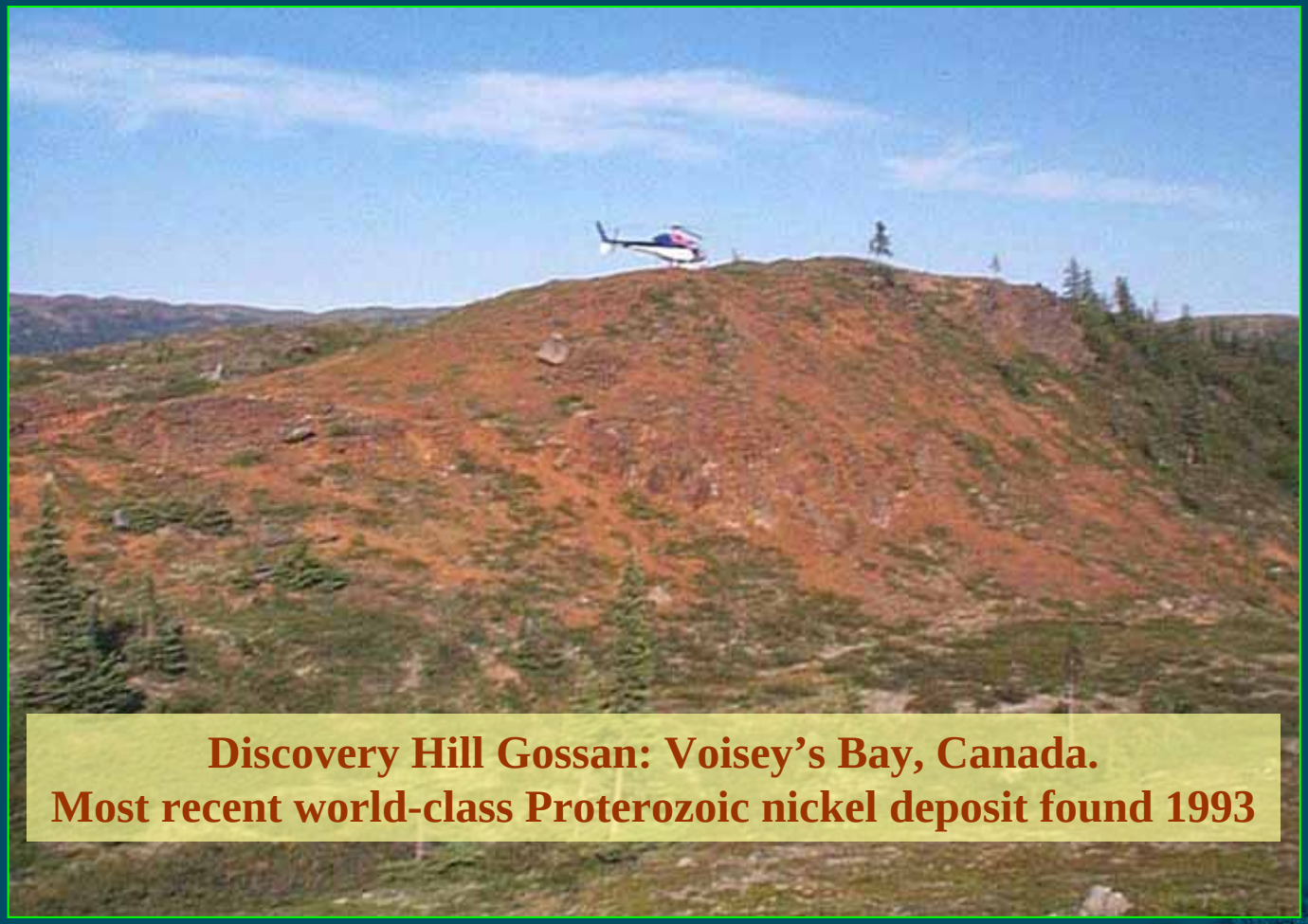
Deposits:
Phanerozoic
Proterozoic
& Archaean

Where are the Proterozoic deposits?

Australian Ni-PGE discoveries 1962 to 2008



Identifying Fertile Provinces



Discovery Hill Gossan: Voisey's Bay, Canada.
Most recent world-class Proterozoic nickel deposit found 1993

Photograph: Data Metallogenica

Proterozoic Mafic-Ultramafic Magmatic Events: Geoscience Australia Initiative to Assist Explorers

Timeframe of Project:

Phase 1 (*2006*): Western Australia

Phase 2 (*2007*): Northern Territory & South Australia

Phase 3 (*2008*): Australia

Phase 4 (2009): (1) Archaean mafic-ultramafic rocks of Australia, and
(2) Proterozoic Large Igneous Provinces

Methods

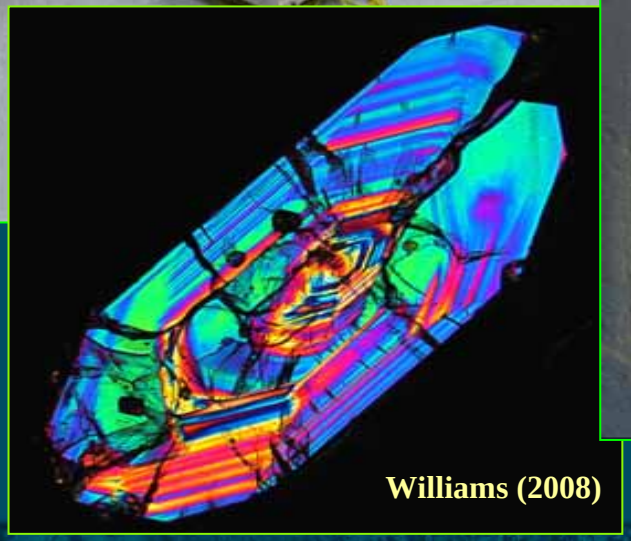
- **Event:** Probable geological incident of significance that is suggested by isotopic, geological, or other evidence

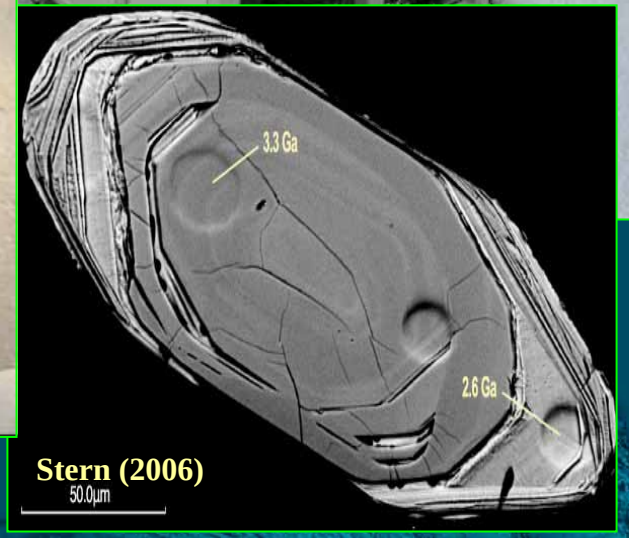
- **Characterisation of Proterozoic Mafic-Ultramafic Rocks:** Province, Formation, Age, Rock Types, Bulk Composition, Setting, Mode of Occurrence, Thickness, Country Rocks, Mineralisation. ARC GIS 9.2 environment

- **Input 1: Magmatic Event Criteria.** Several hundred, reliable (>90% U-Pb zirc/badd) ages of mafic & ultramafic rocks

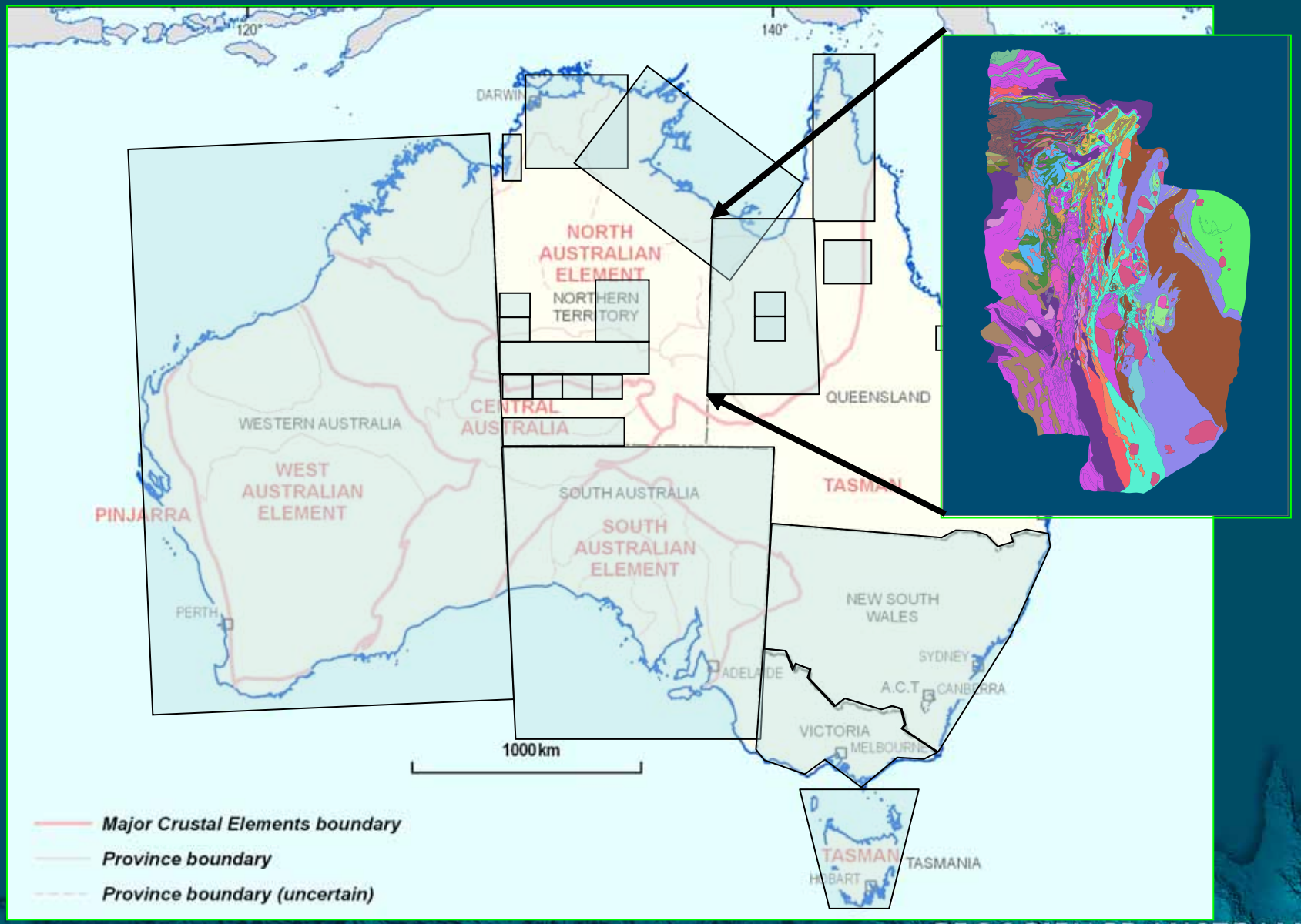
- **Inputs 2 & 3: Major Crustal Elements and Solid Geology Base Maps.** Economic potential → important to assess total areal extent/volume of magmatic system

Input 1: Geochronology



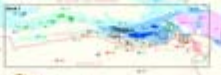


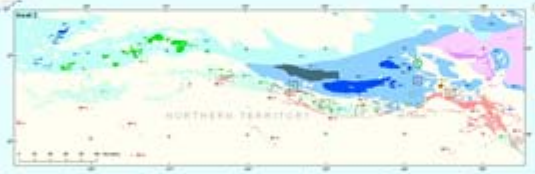
Inputs 2 & 3: Crustal Elements and Solid Geology Maps



Shaw et al. (1995)

AUSTRALIAN PROTEROZOIC MAFIC-ULTRAMAFIC MAGMATIC EVENTS (Sheet 1 of 2)





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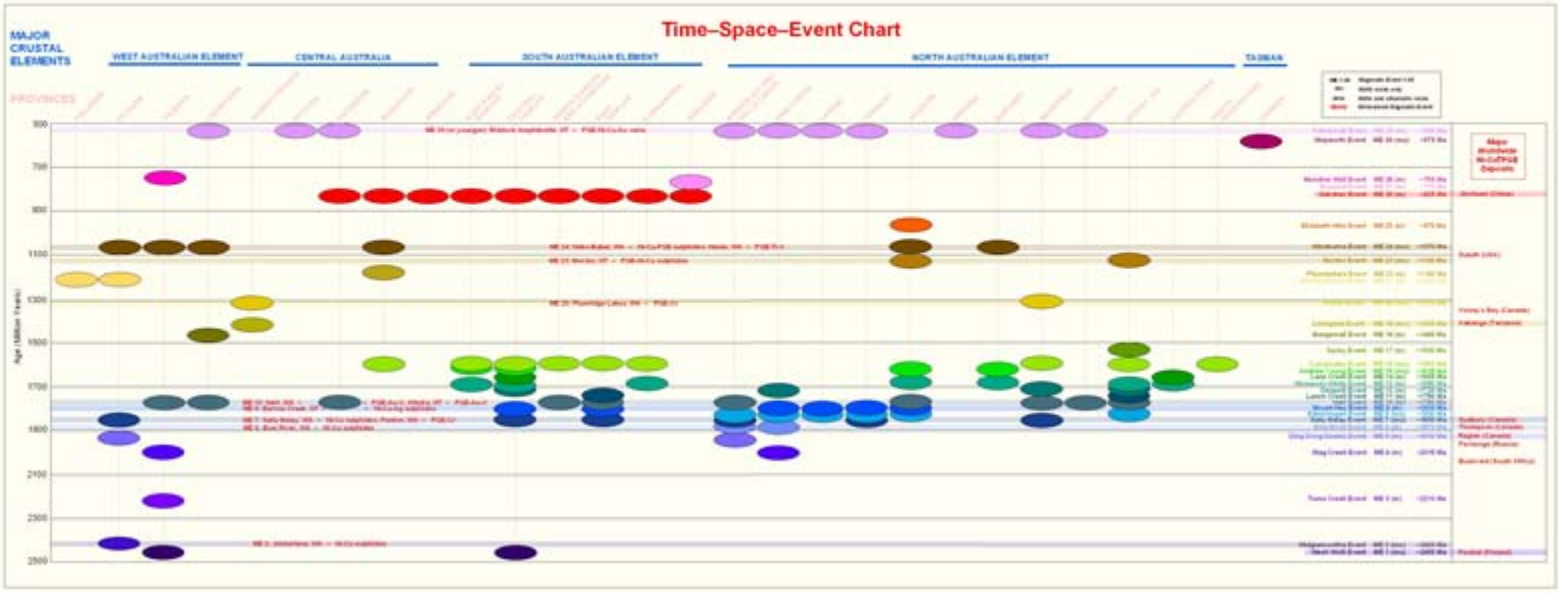
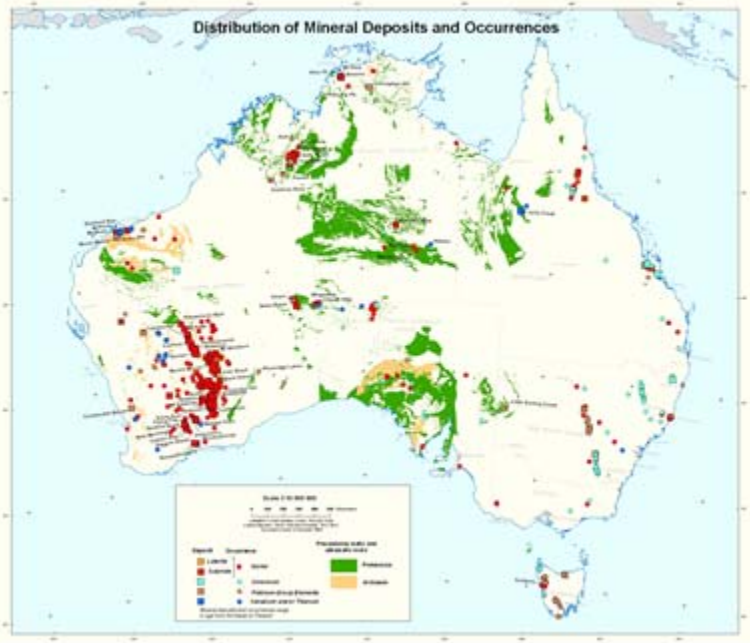
AUSTRALIAN PROTEROZOIC MAFIC-ULTRAMAFIC MAGMATIC EVENTS (Sheet 2 of 2)

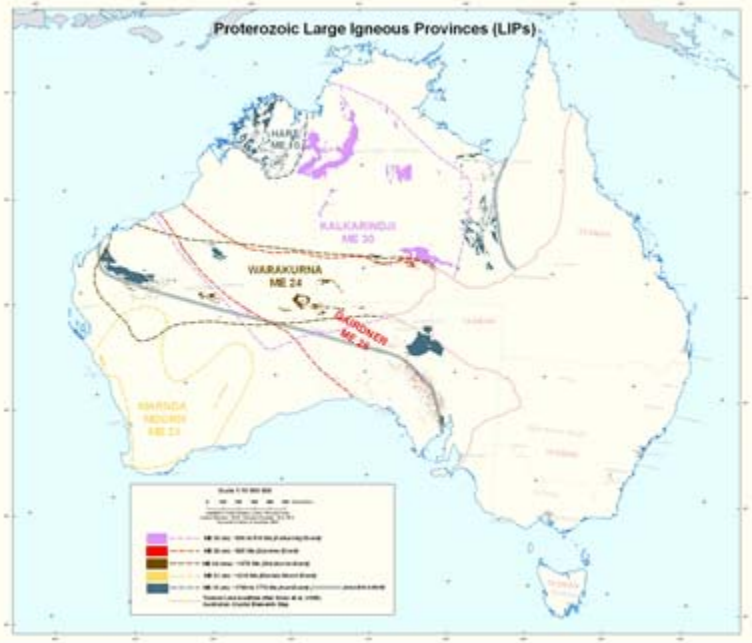
Time–Space–Event Chart



Distribution of Mineral Deposits and Occurrences



Proterozoic Large Igneous Provinces (LIPs)



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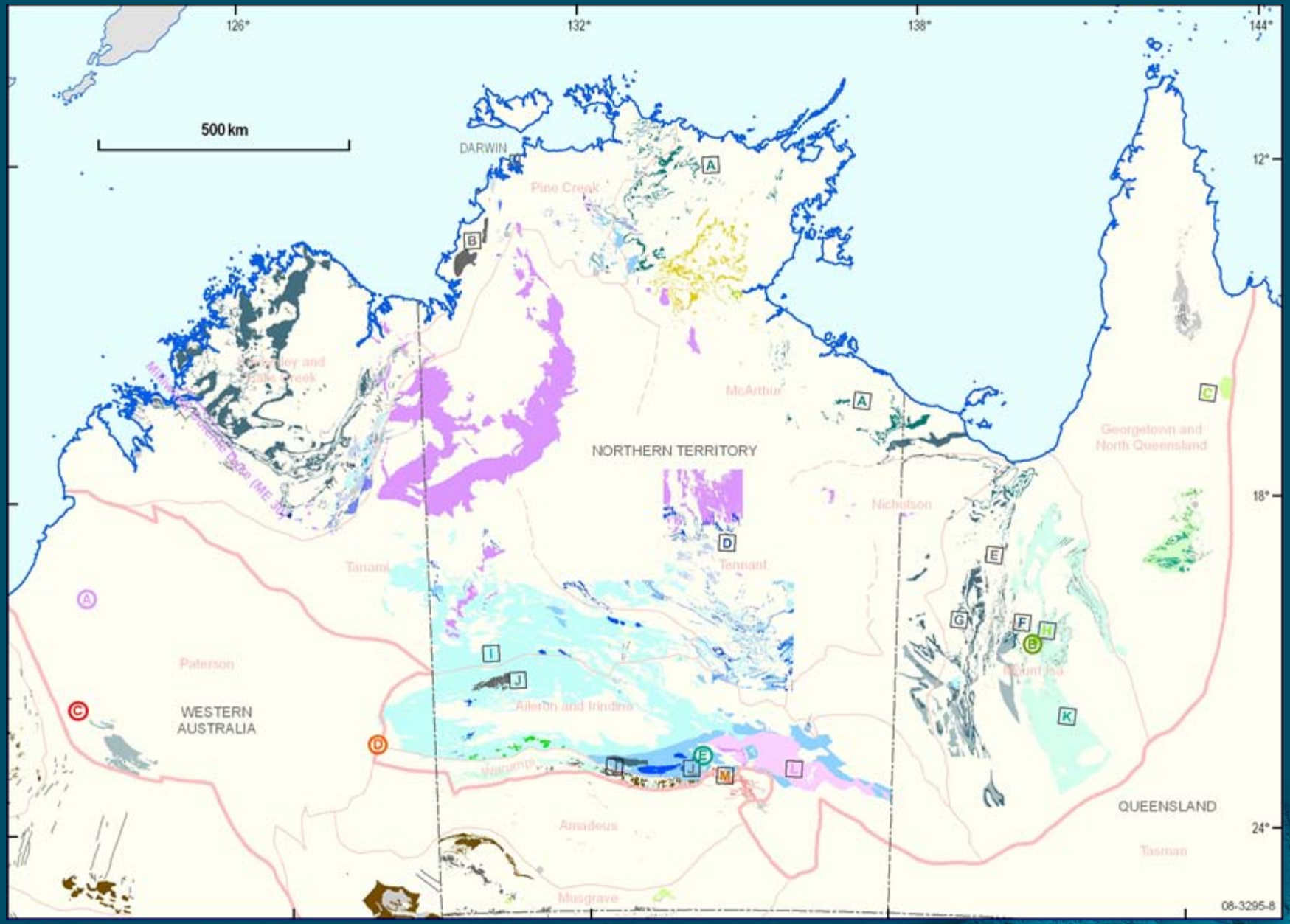
126°
132°
138°
144°
12°
18°
24°
500 km
DARWIN
Pine Creek
McArthur
Georgetown and North Queensland
Nicholson
Tennant
Tanami
Paterson
Ailerón and Irindina
Amadeus
Musgrave
Tasman
NORTHERN TERRITORY
WESTERN AUSTRALIA
QUEENSLAND
A
B
C
D
E
F
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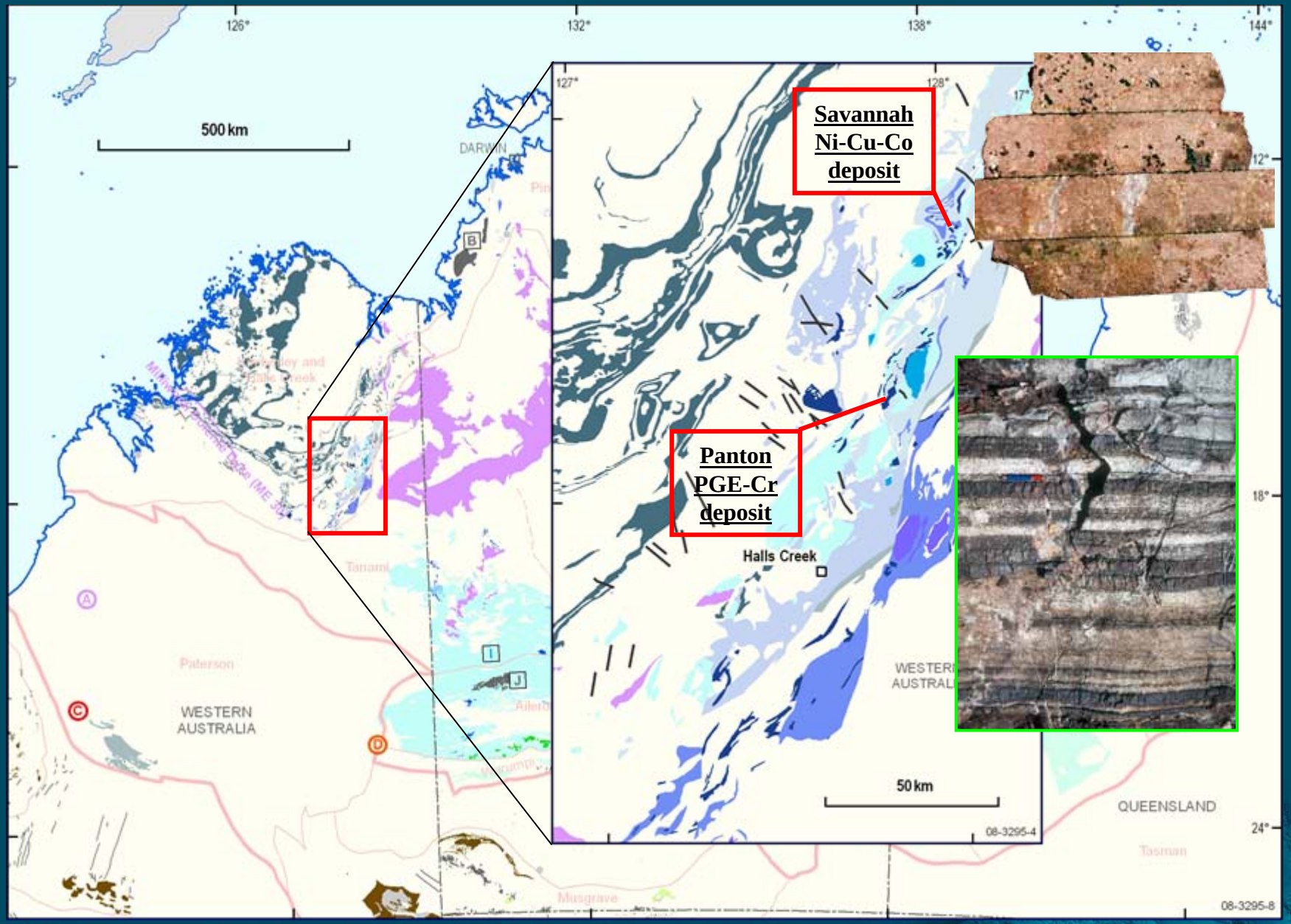
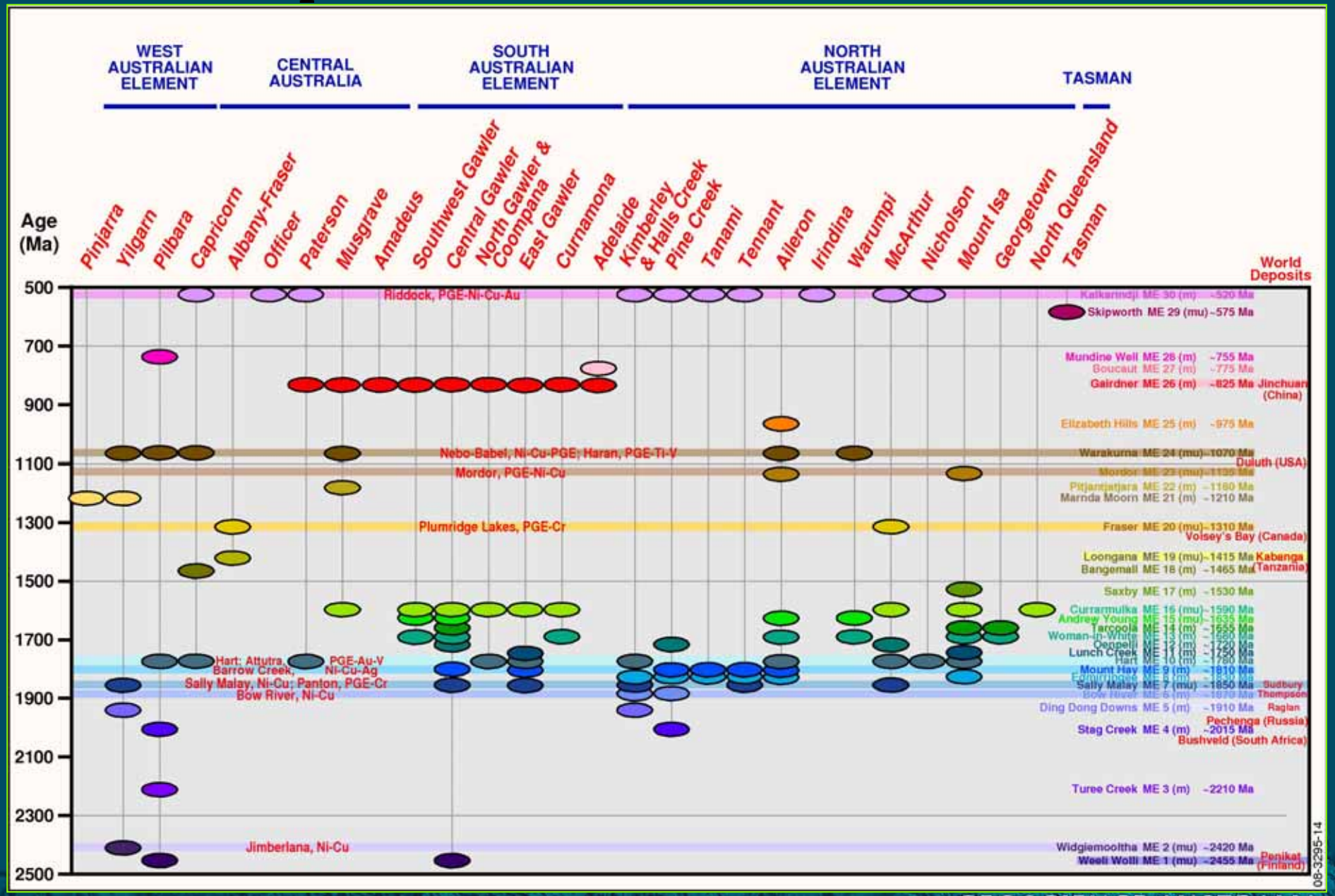
M
08-3295-8


126°
132°
138°
144°
500 km
DARWIN
127°
128°
17°
12°
Savannah
Ni-Cu-Co
deposit
Panton
PGE-Cr
deposit
Halls Creek
18°
WESTERN
AUSTRALIA
50 km
QUEENSLAND
24°
08-3295-4
08-3295-8

Magmatic Events

Major mafic-ultramafic rocks = bold colours
Minor mafic-ultramafic rocks with other rocks = pale colours

Time–Space–Event Chart: 30 Proterozoic Events



Time-Slice Maps of 30 Proterozoic Magmatic Events

ME 1 (mu) ~2455 Ma *Weeli Wolli Event*

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ME 2 (mu) ~2420 Ma *Widgiemooltha Event*

ME 3 (m) ~2210 Ma *Turee Creek Event*

ME 4 (m) ~2015 Ma *Stag Creek Event*

ME 5 (m) ~1910 Ma *Ding Dong Downs Event*

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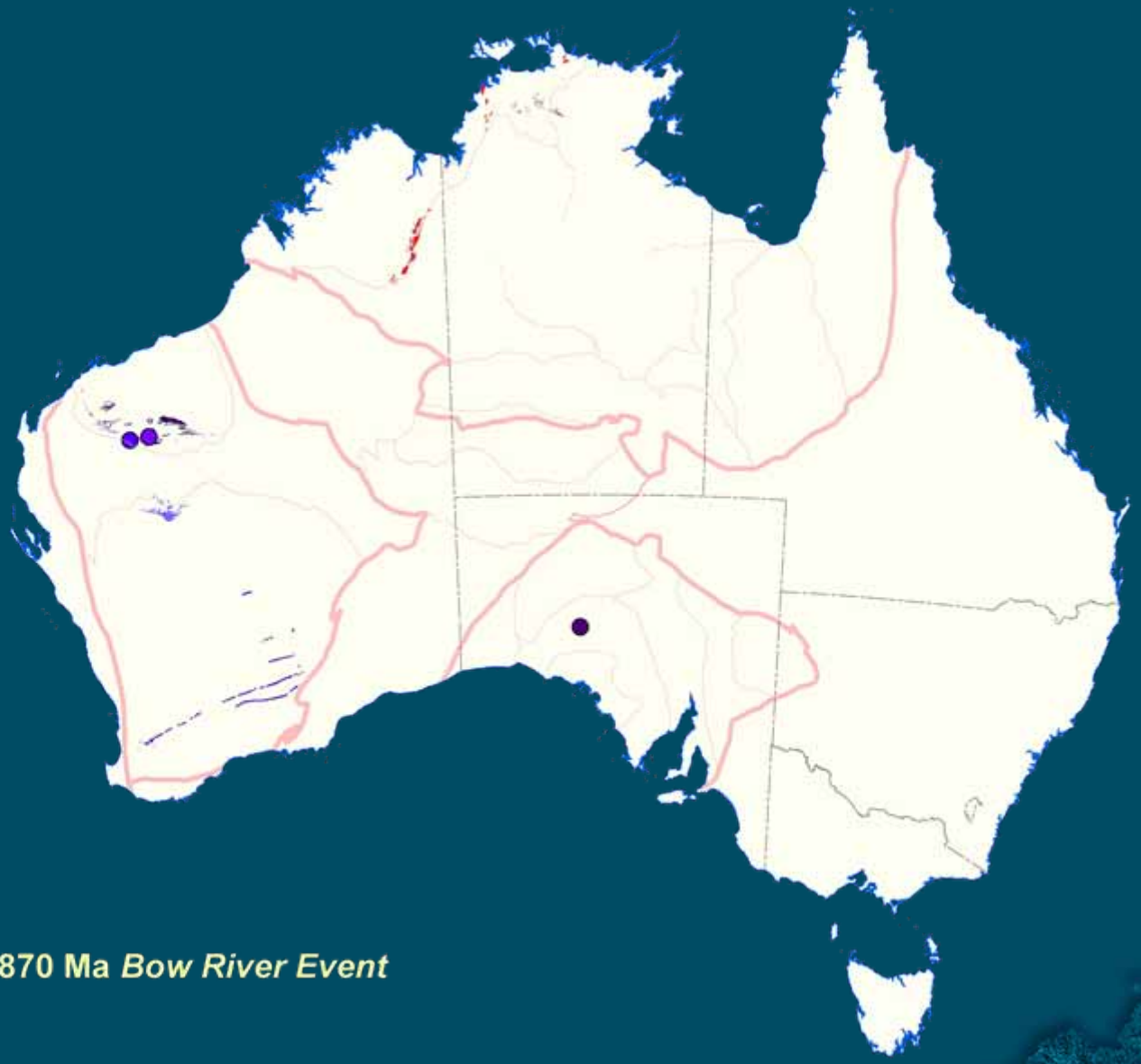
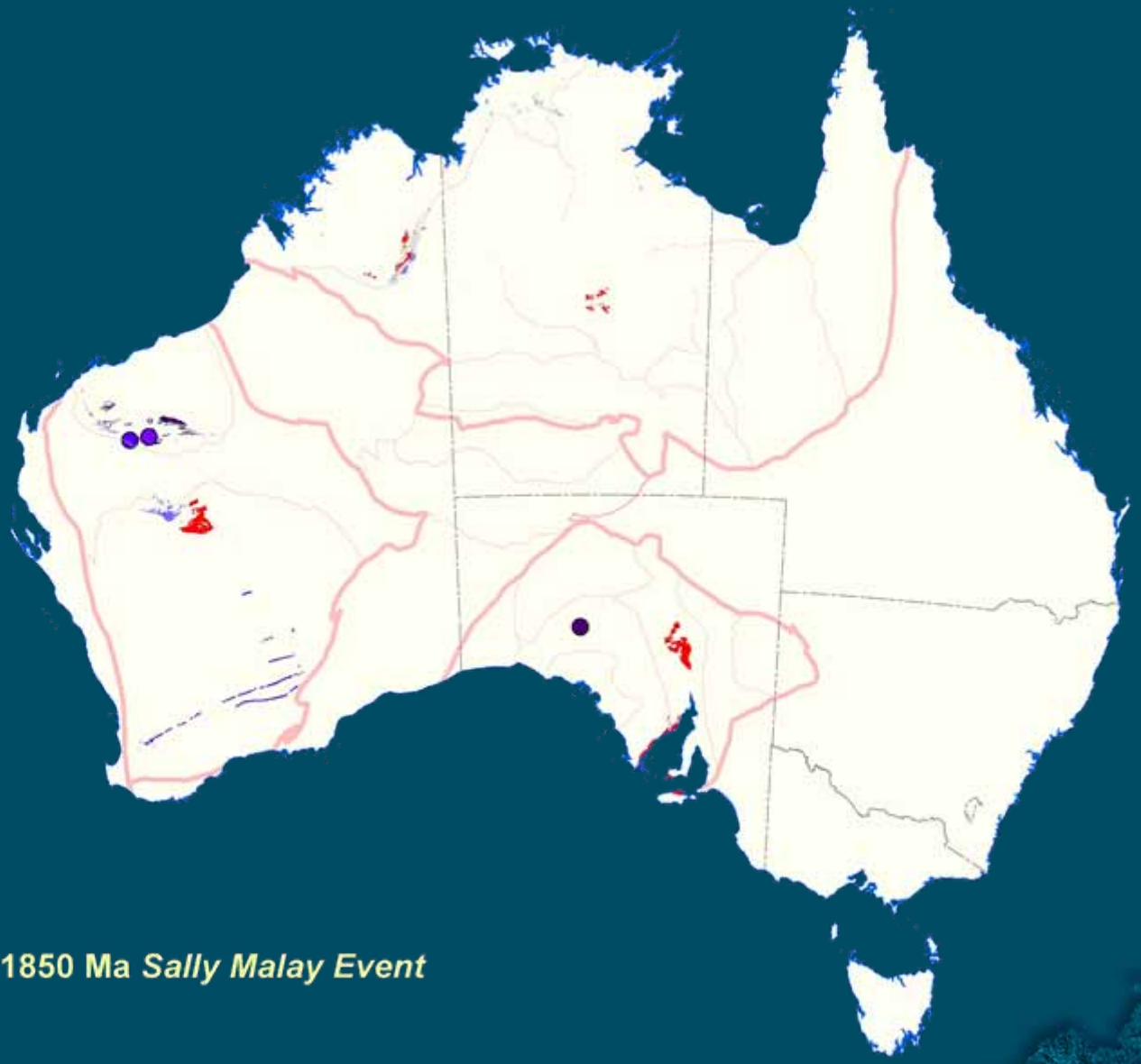
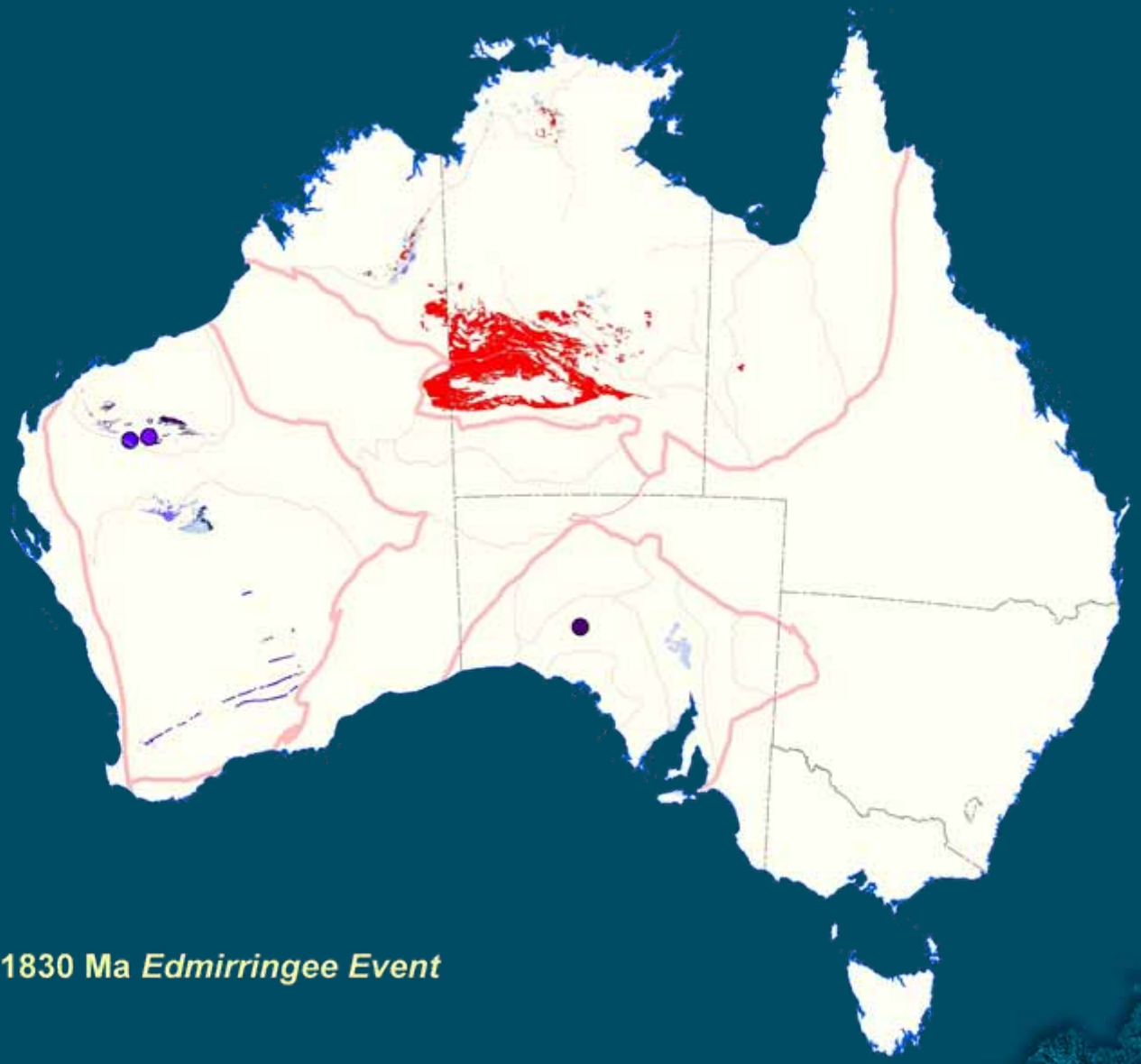


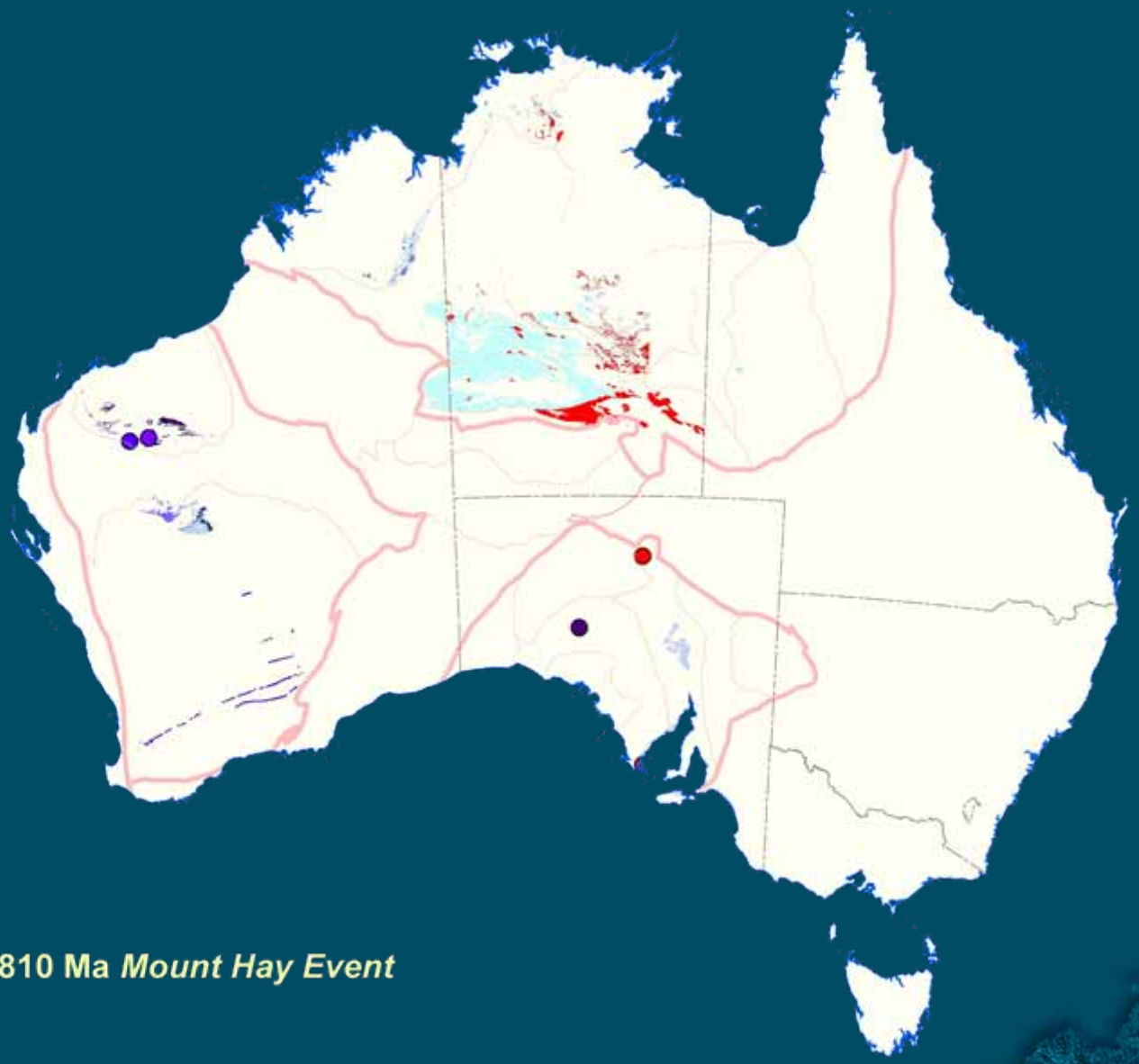
ME 6 (m) ~1870 Ma *Bow River Event*



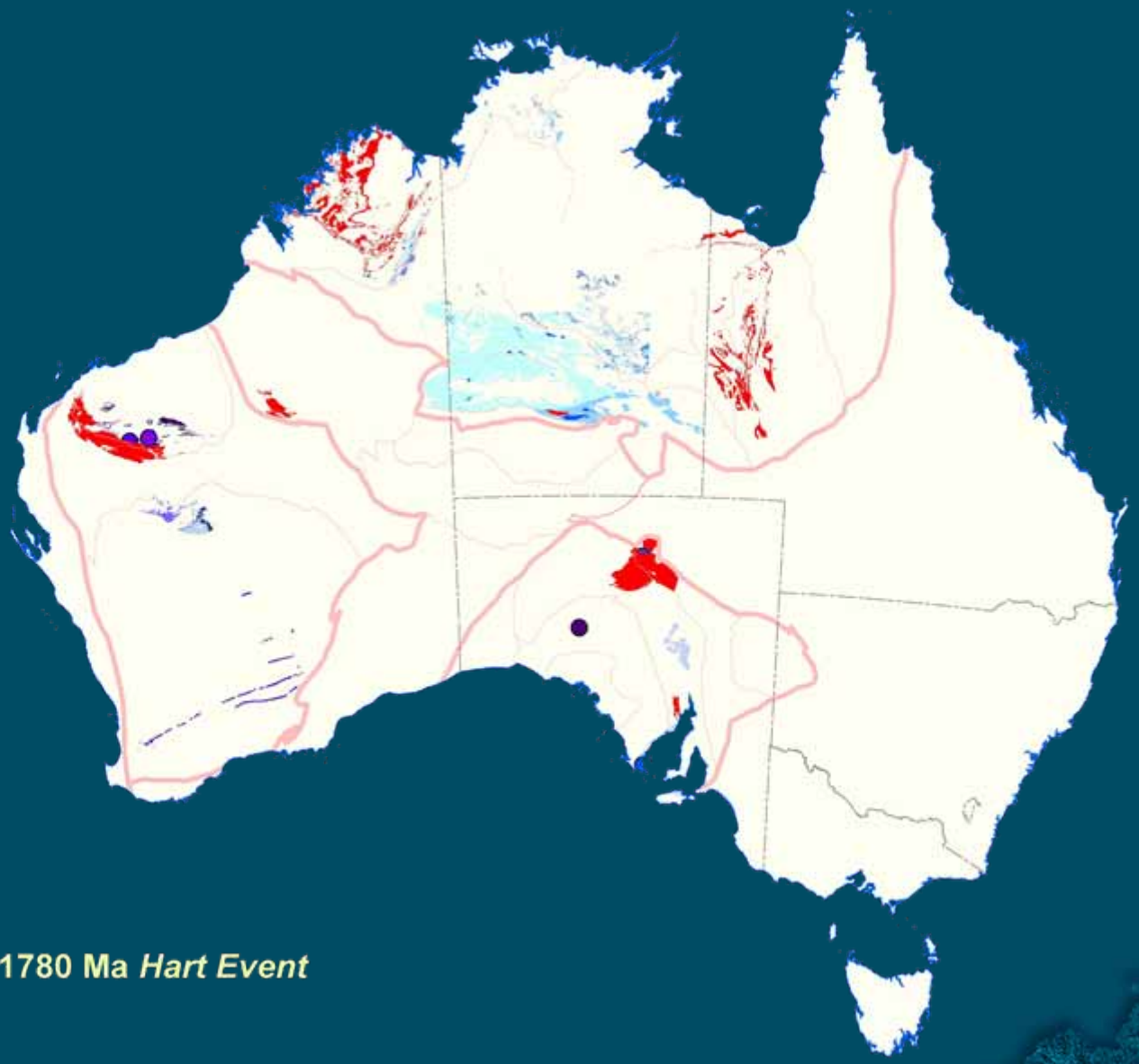
ME 7 (mu) ~1850 Ma *Sally Malay Event*



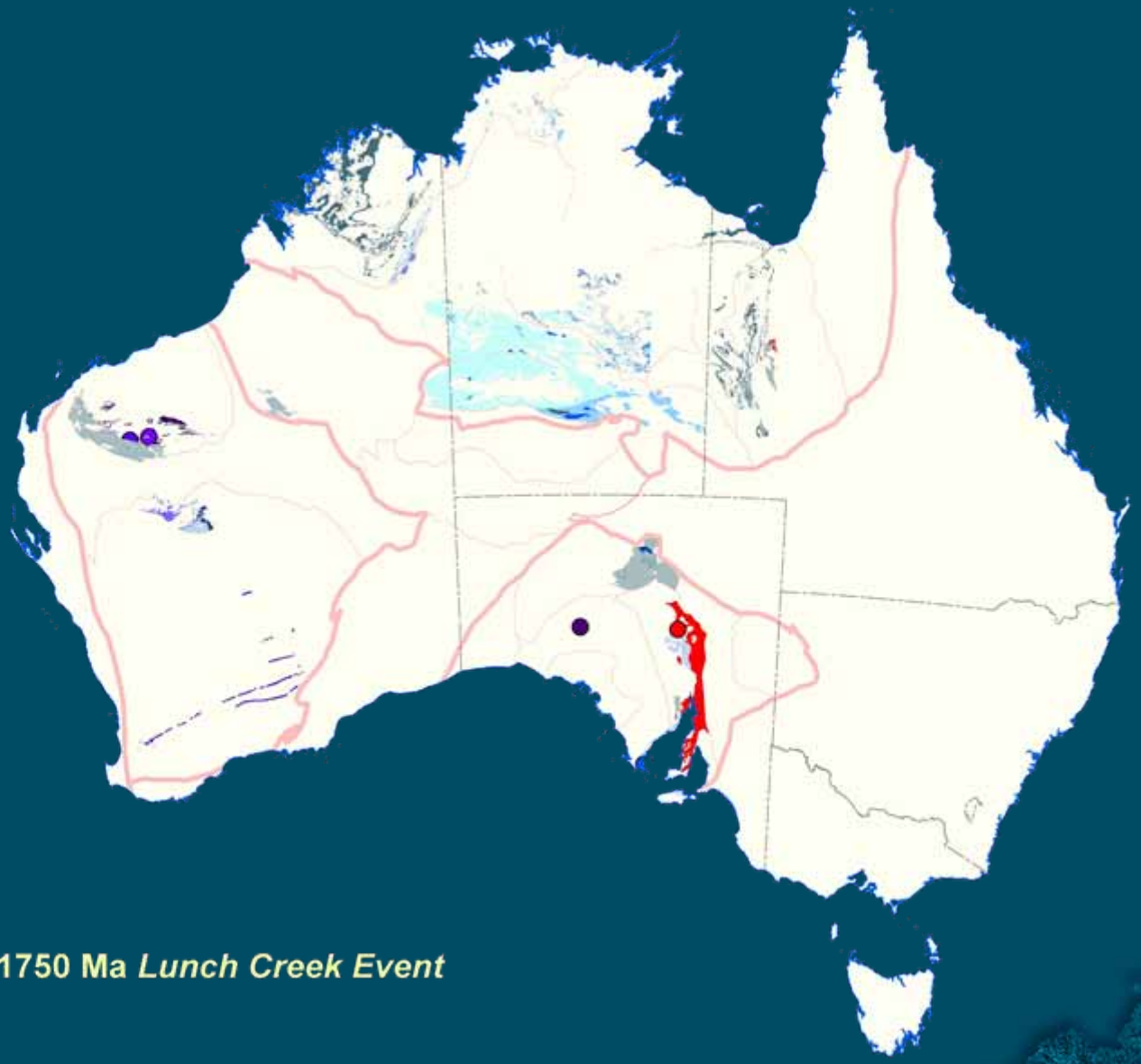
ME 8 (mu) ~1830 Ma *Edmirringee Event*



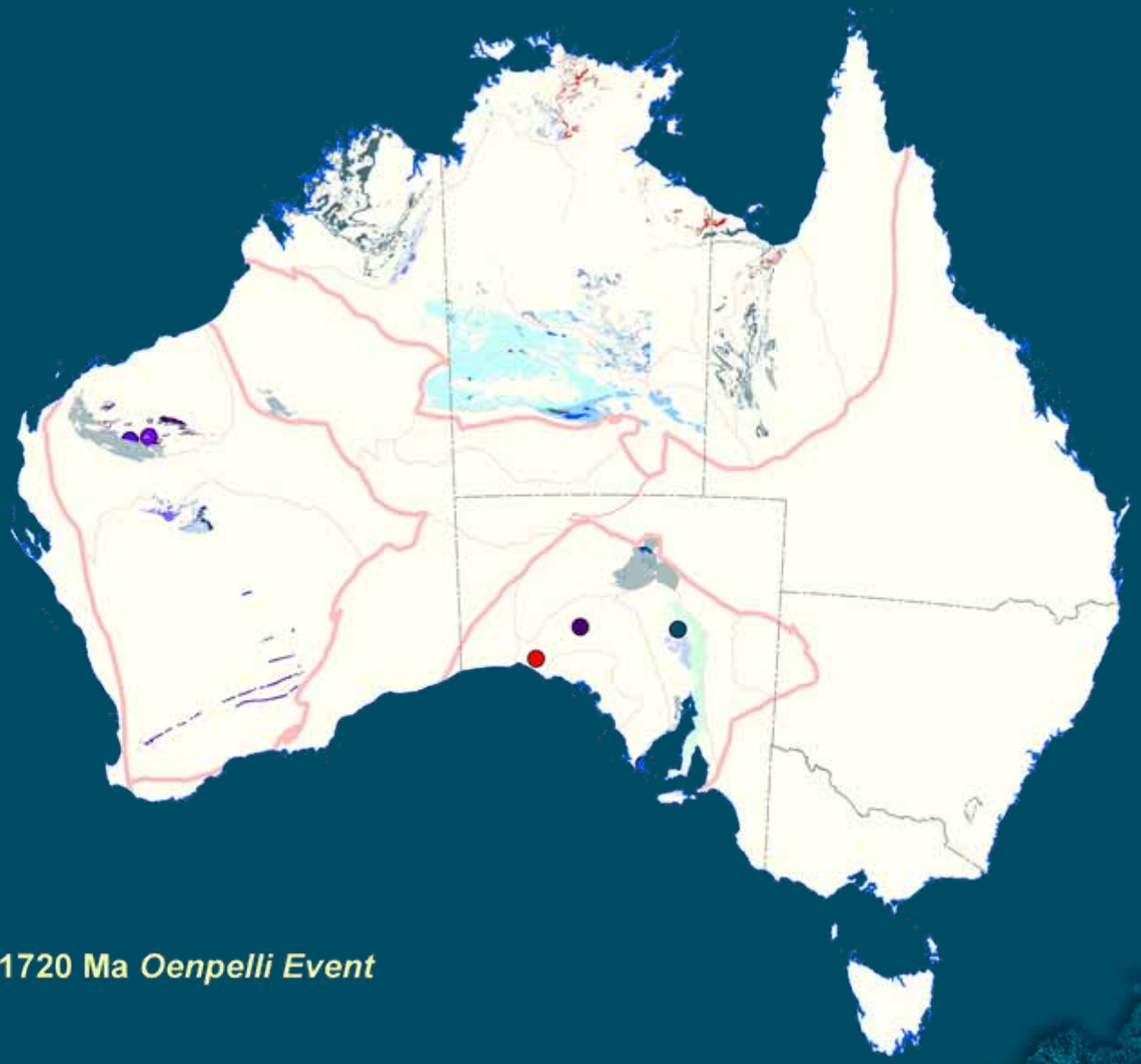
ME 9 (m) ~1810 Ma *Mount Hay Event*



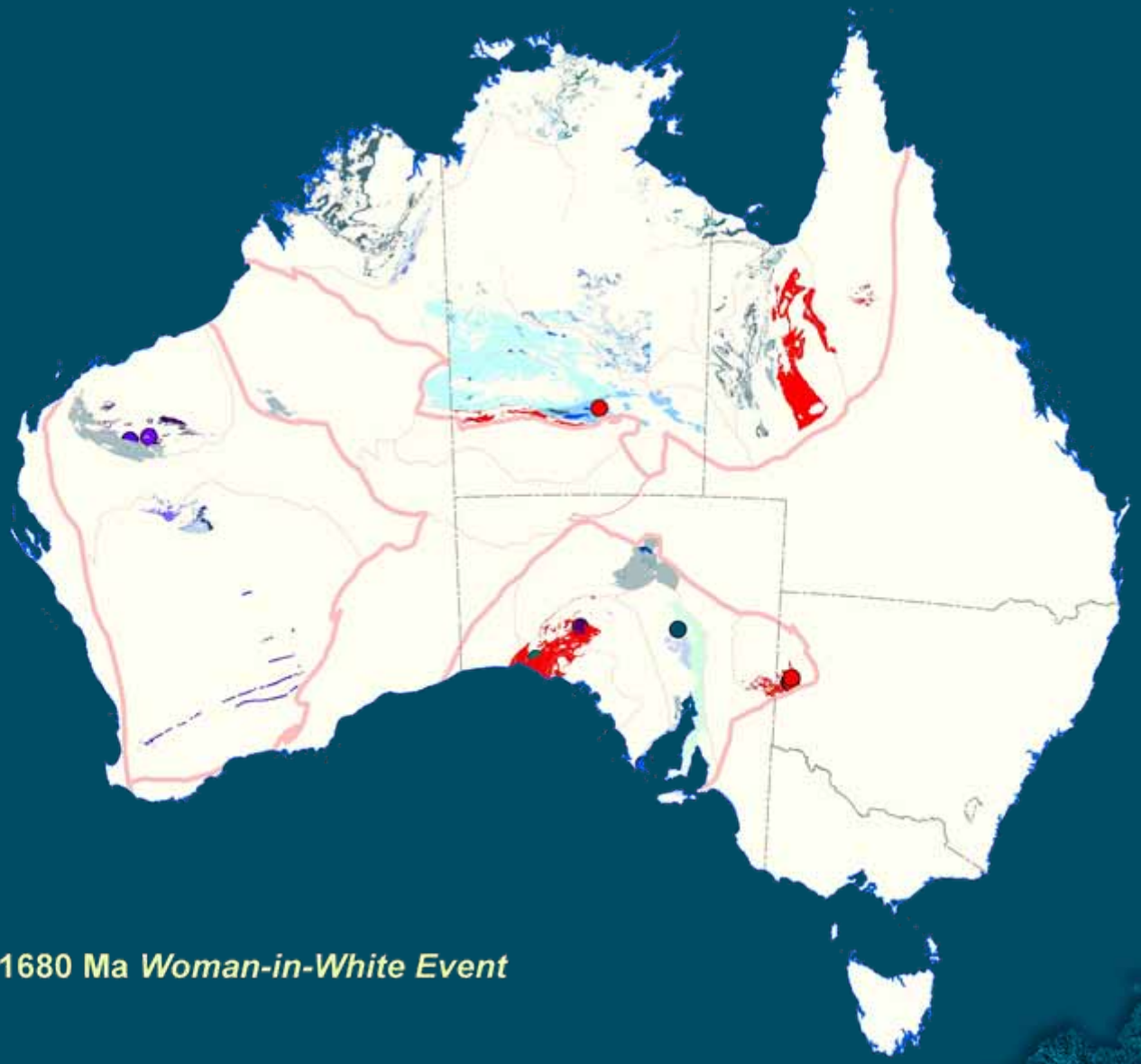
ME 10 (m) ~1780 Ma *Hart Event*



ME 11 (m) ~1750 Ma *Lunch Creek Event*



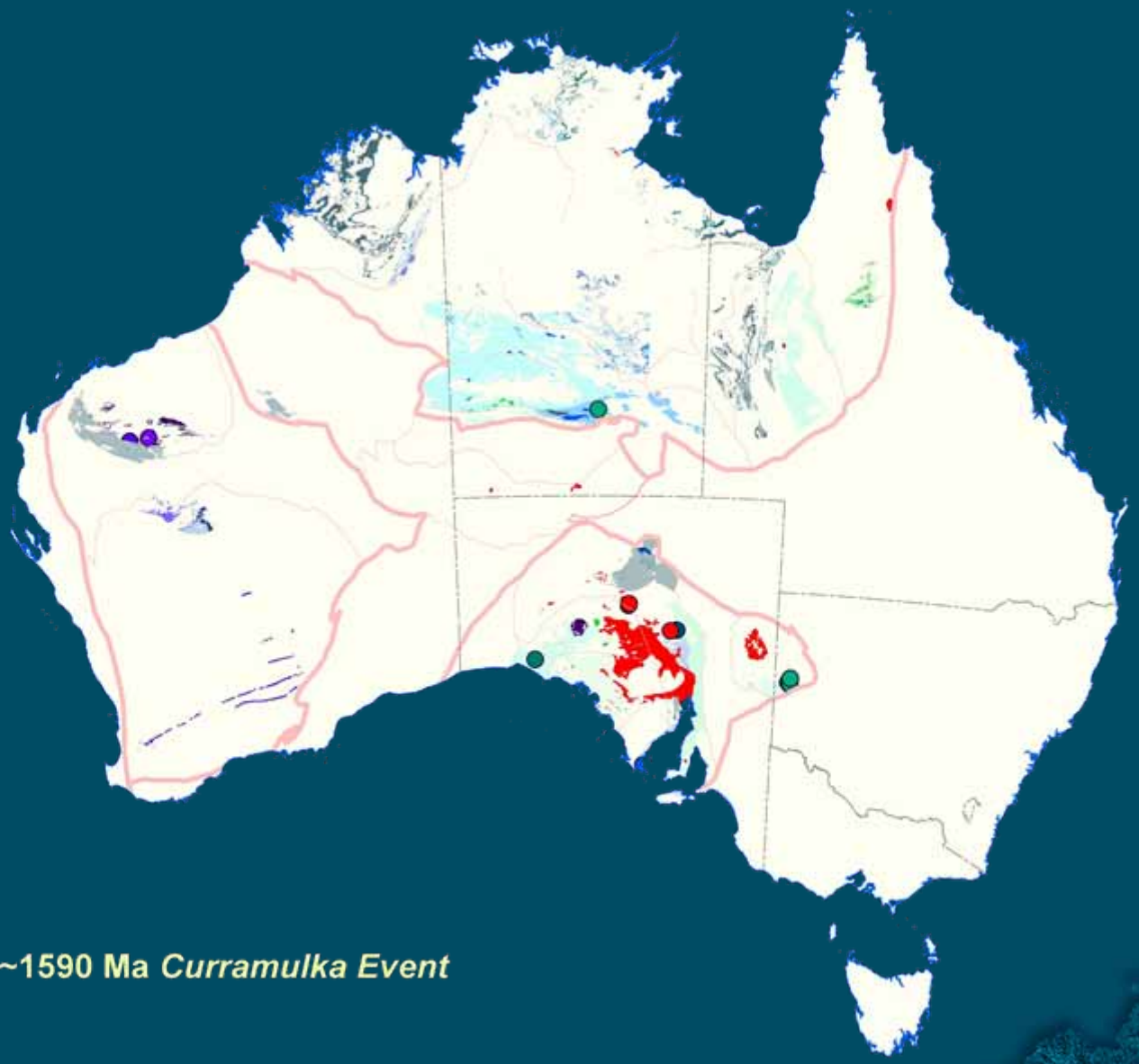
ME 12 (m) ~1720 Ma *Oenpelli Event*



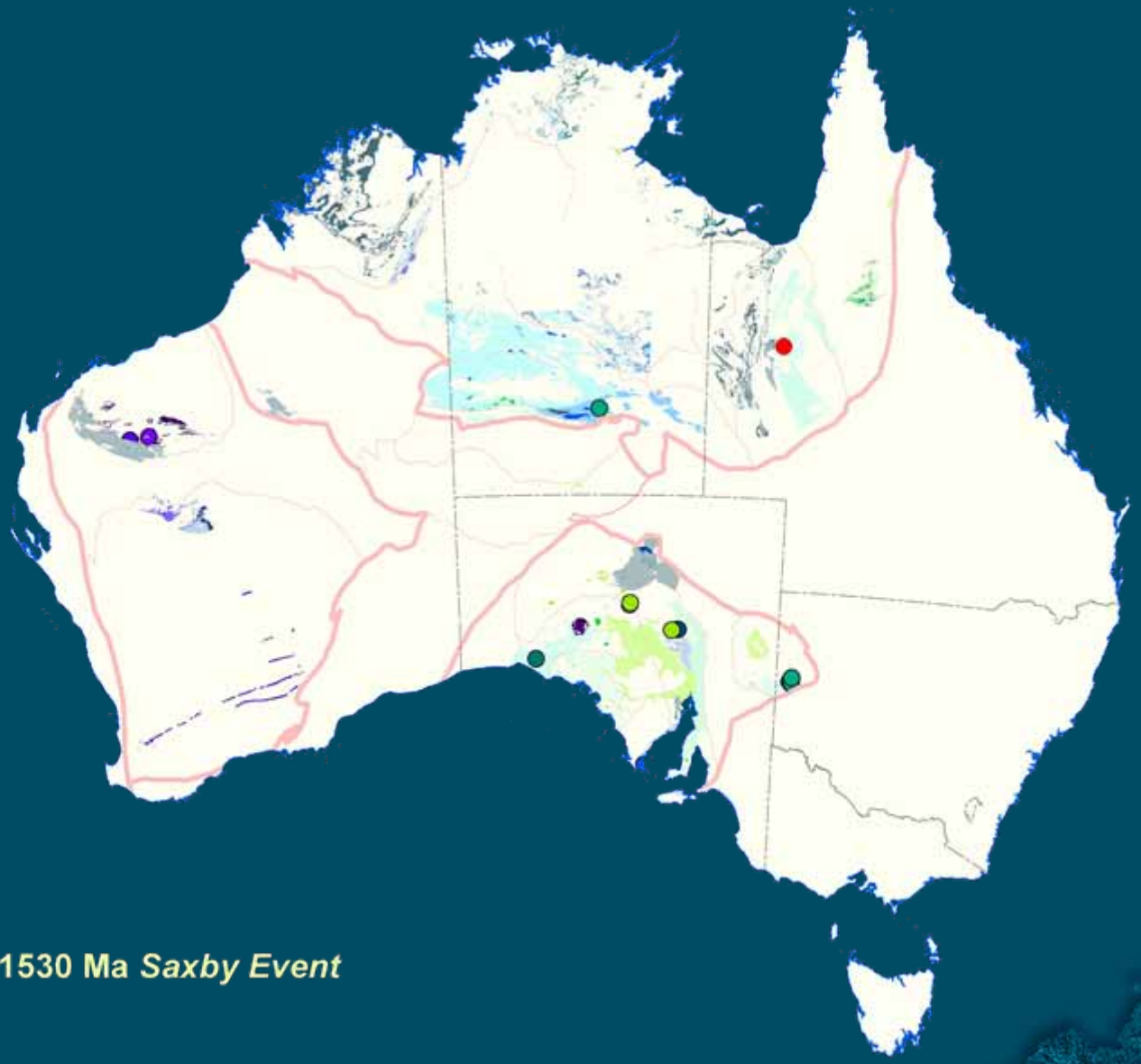
ME 13 (m) ~1680 Ma *Woman-in-White Event*

ME 14 (m) ~1655 Ma *Lane Creek Event*

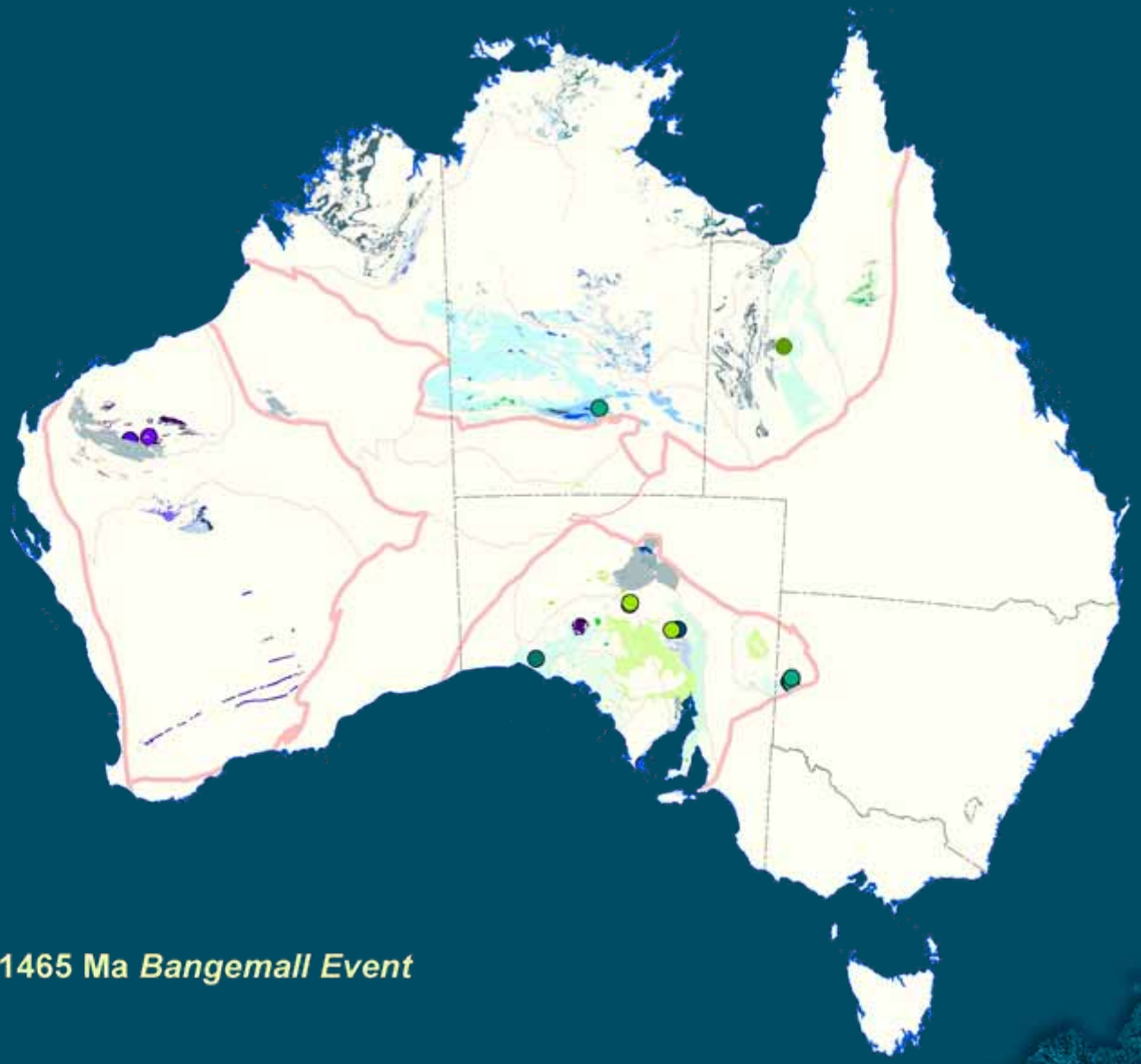
ME 15 (mu) ~1635 Ma *Andrew Young Event*



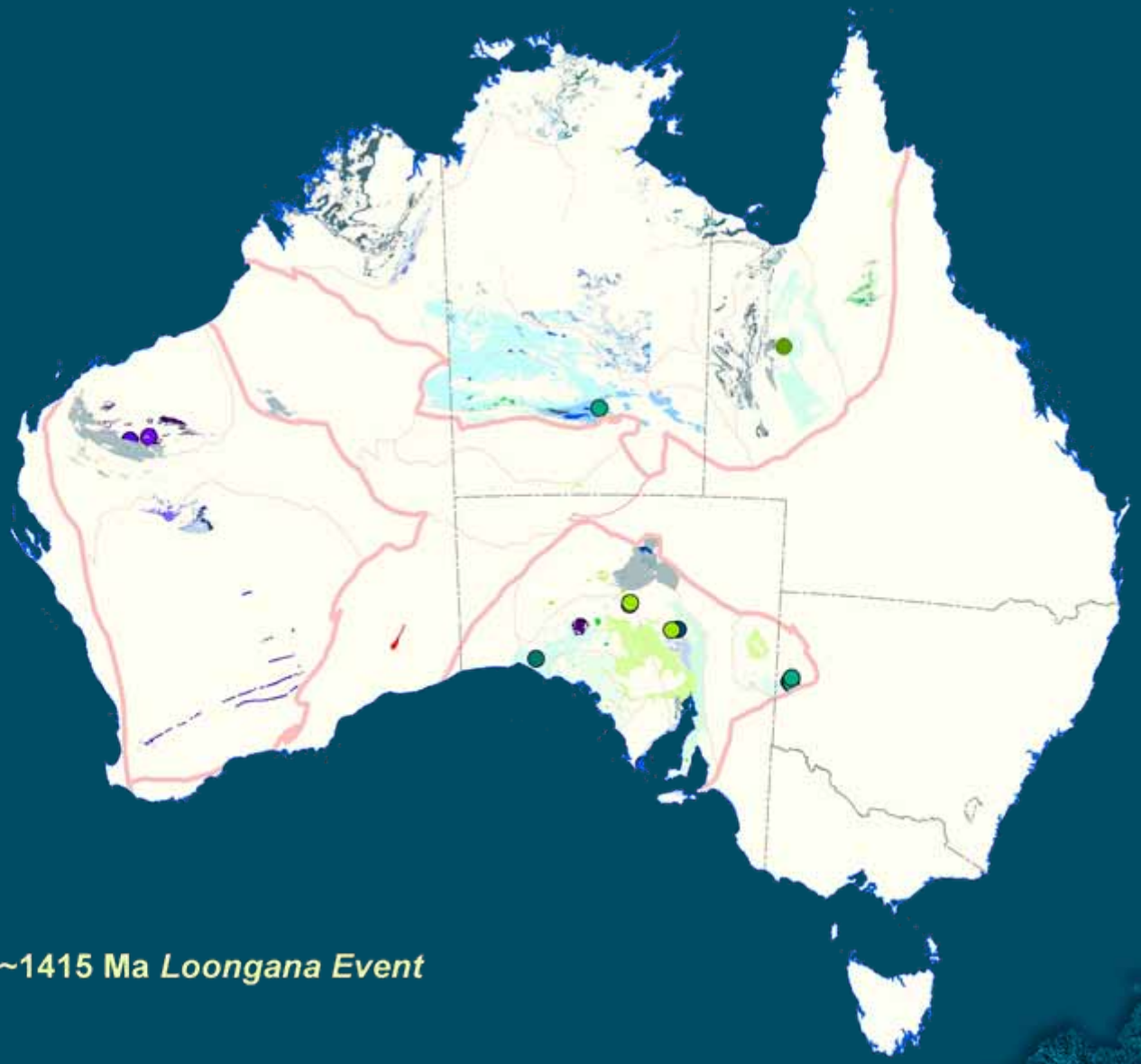
ME 16 (mu) ~1590 Ma *Curramulka Event*



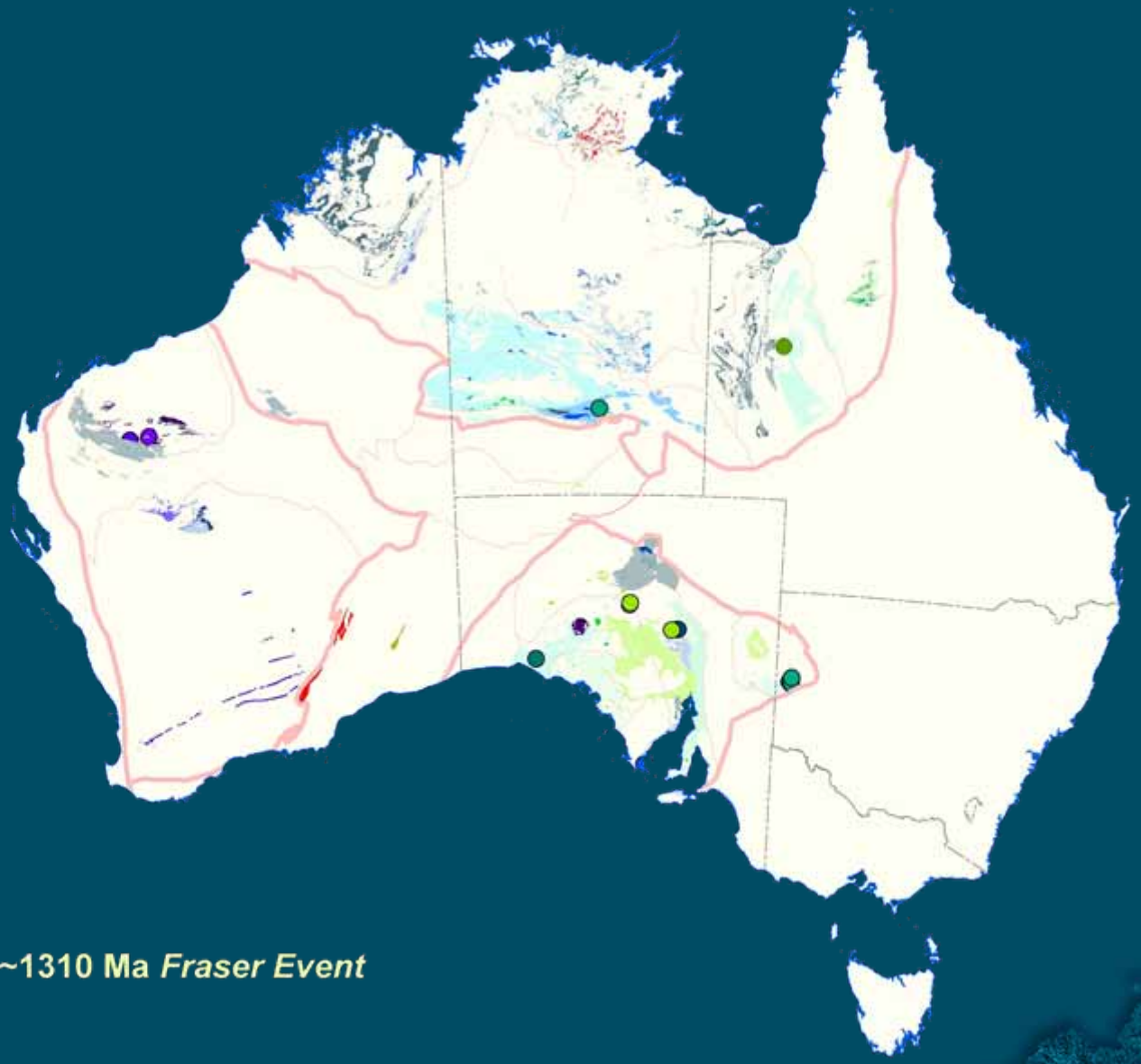
ME 17 (m) ~1530 Ma *Saxby Event*



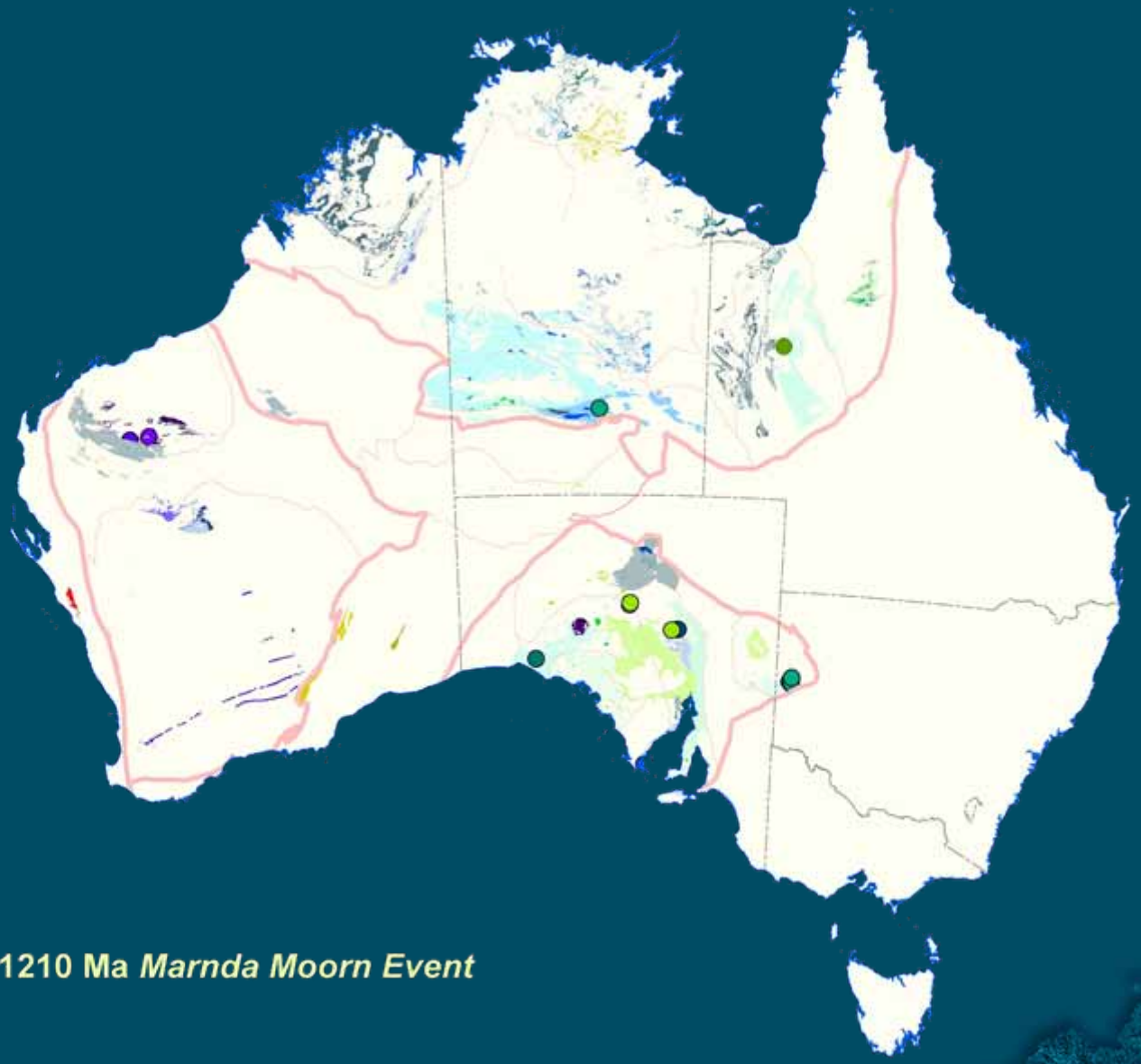
ME 18 (m) ~1465 Ma *Bangemall Event*



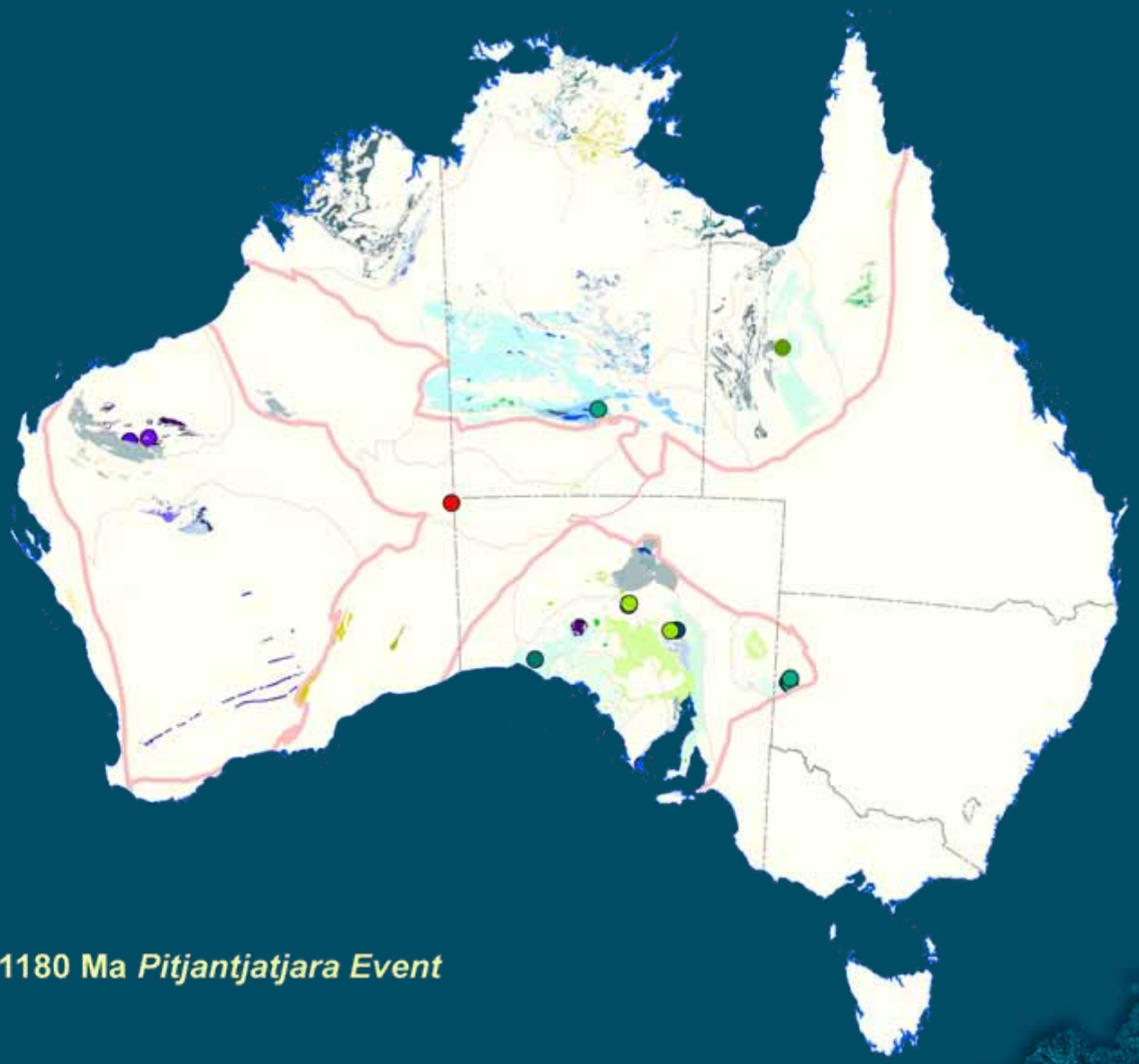
ME 19 (mu) ~1415 Ma *Loongana Event*



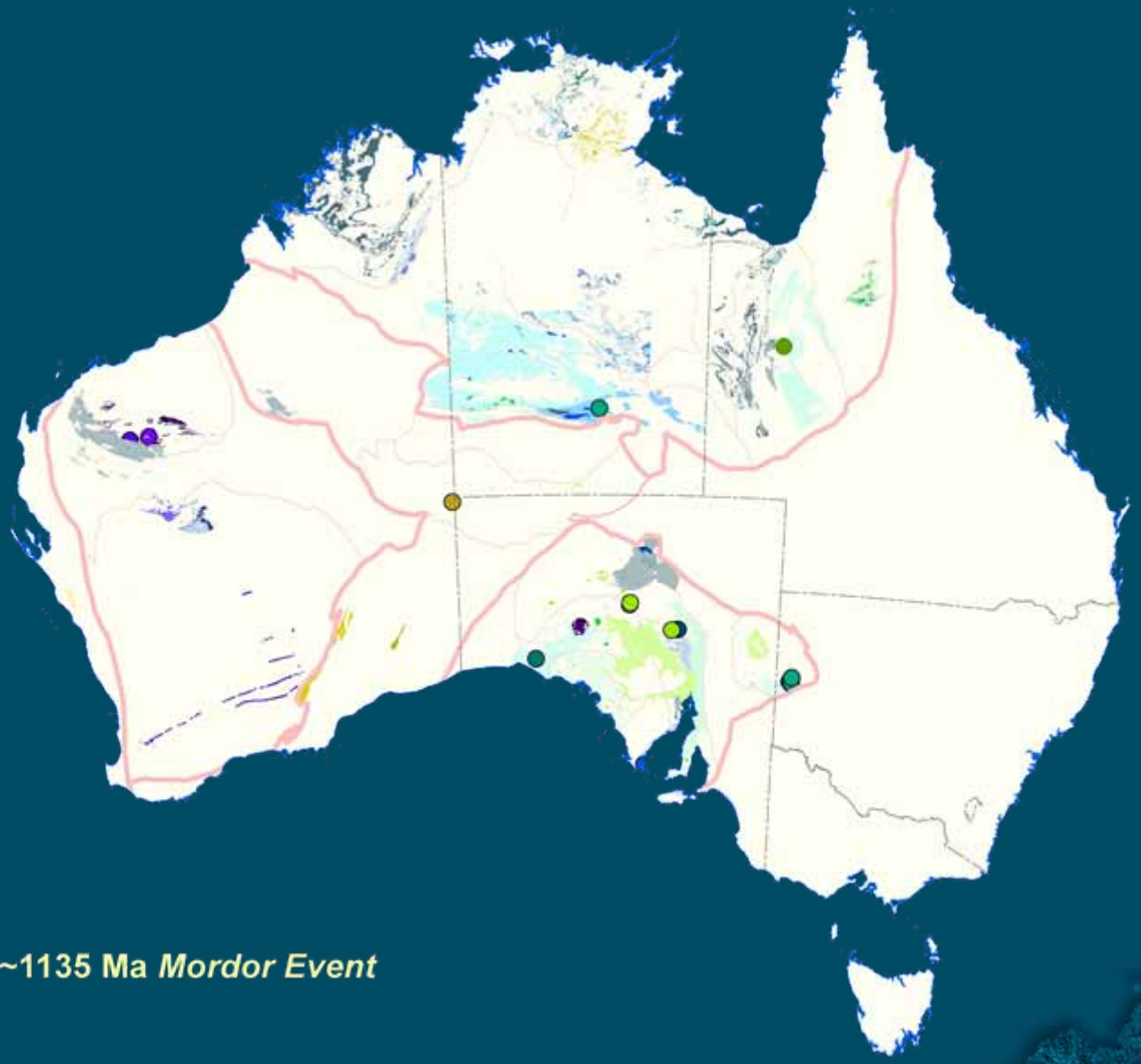
ME 20 (mu) ~1310 Ma *Fraser Event*



ME 21 (m) ~1210 Ma *Marnda Moorn Event*

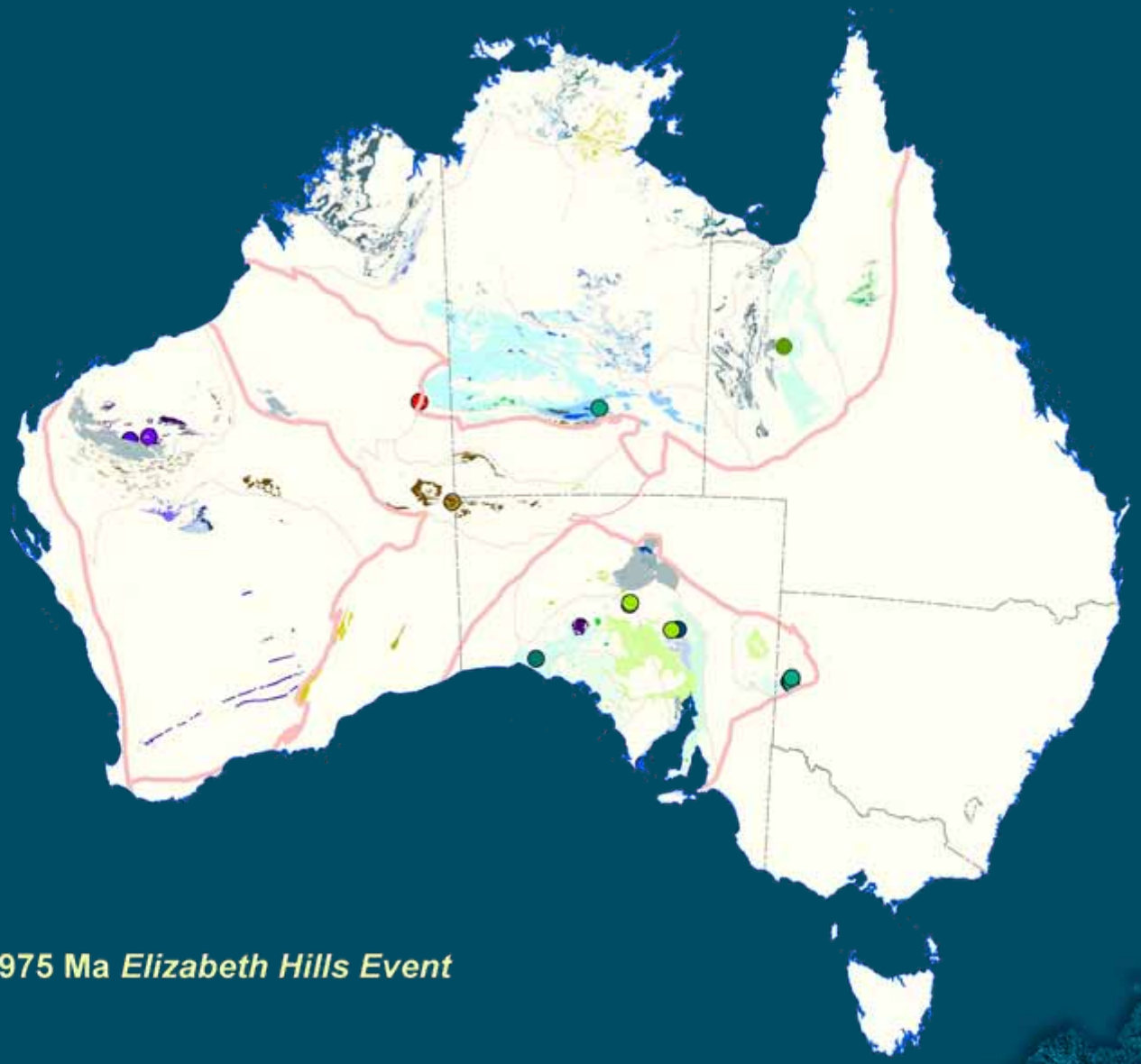


ME 22 (m) ~1180 Ma *Pitjantjatjara Event*



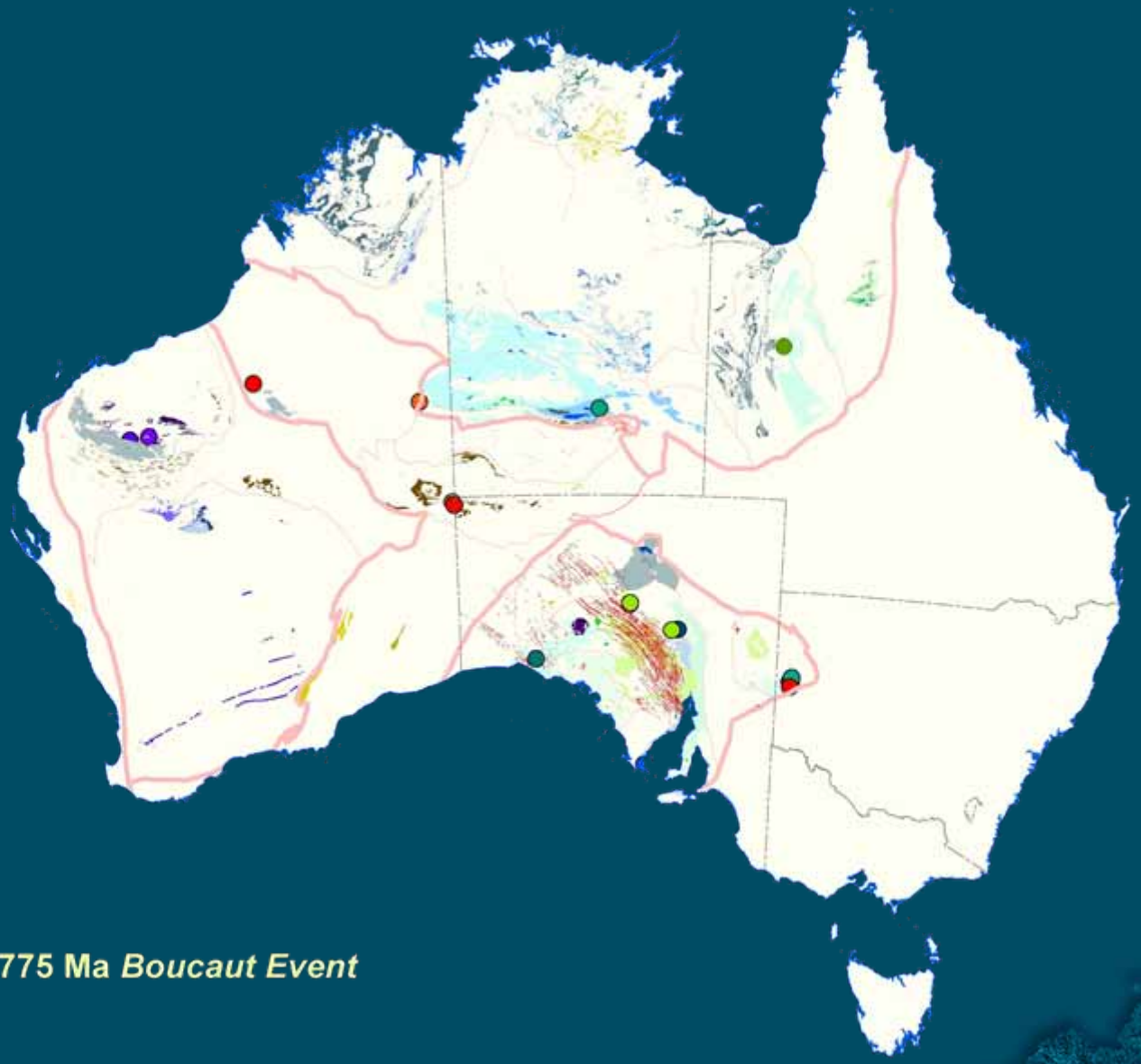
ME 23 (mu) ~1135 Ma *Mordor Event*

ME 24 (mu) ~1070 Ma *Warakurna Event*

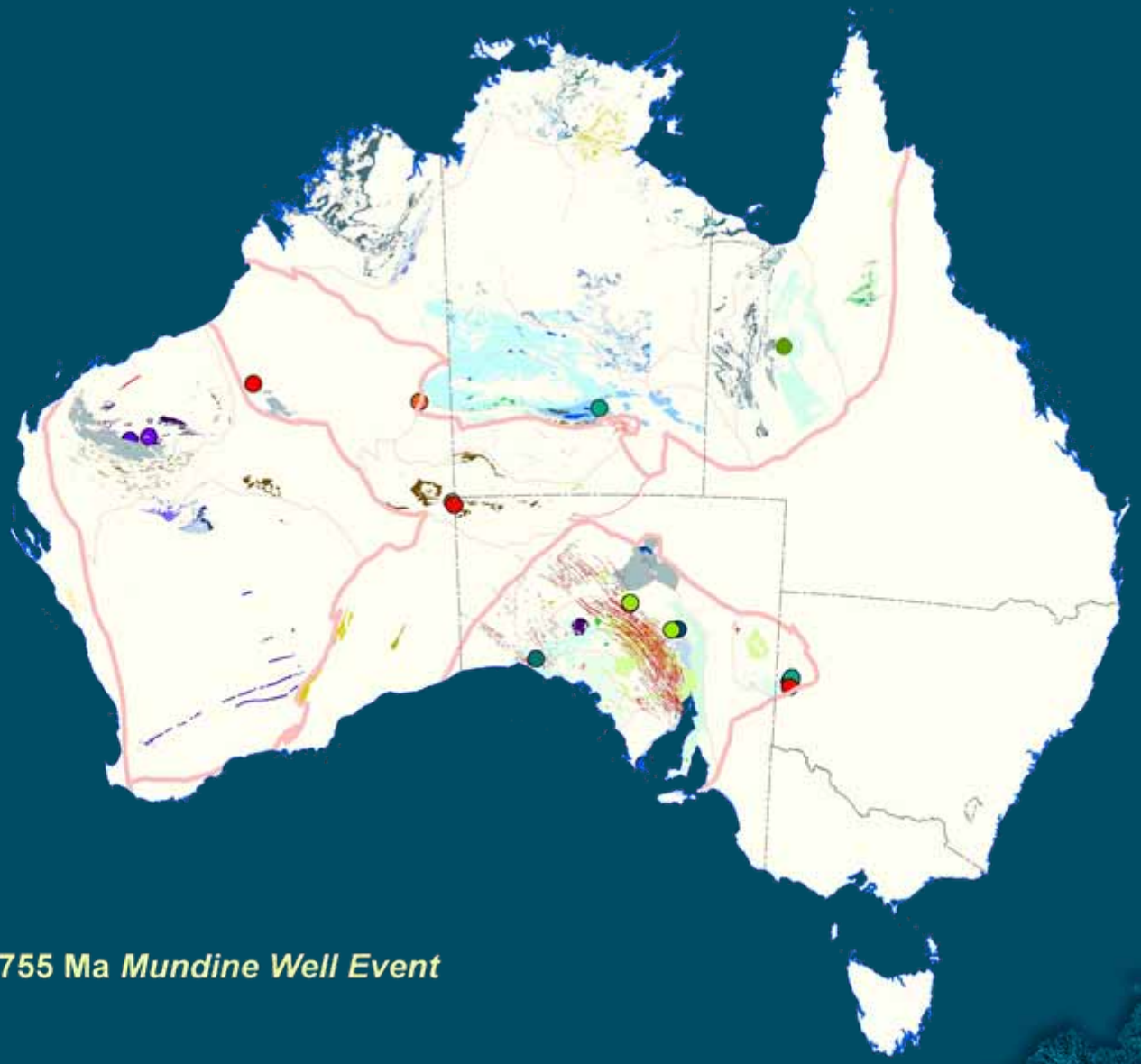


ME 25 (m) ~975 Ma *Elizabeth Hills Event*

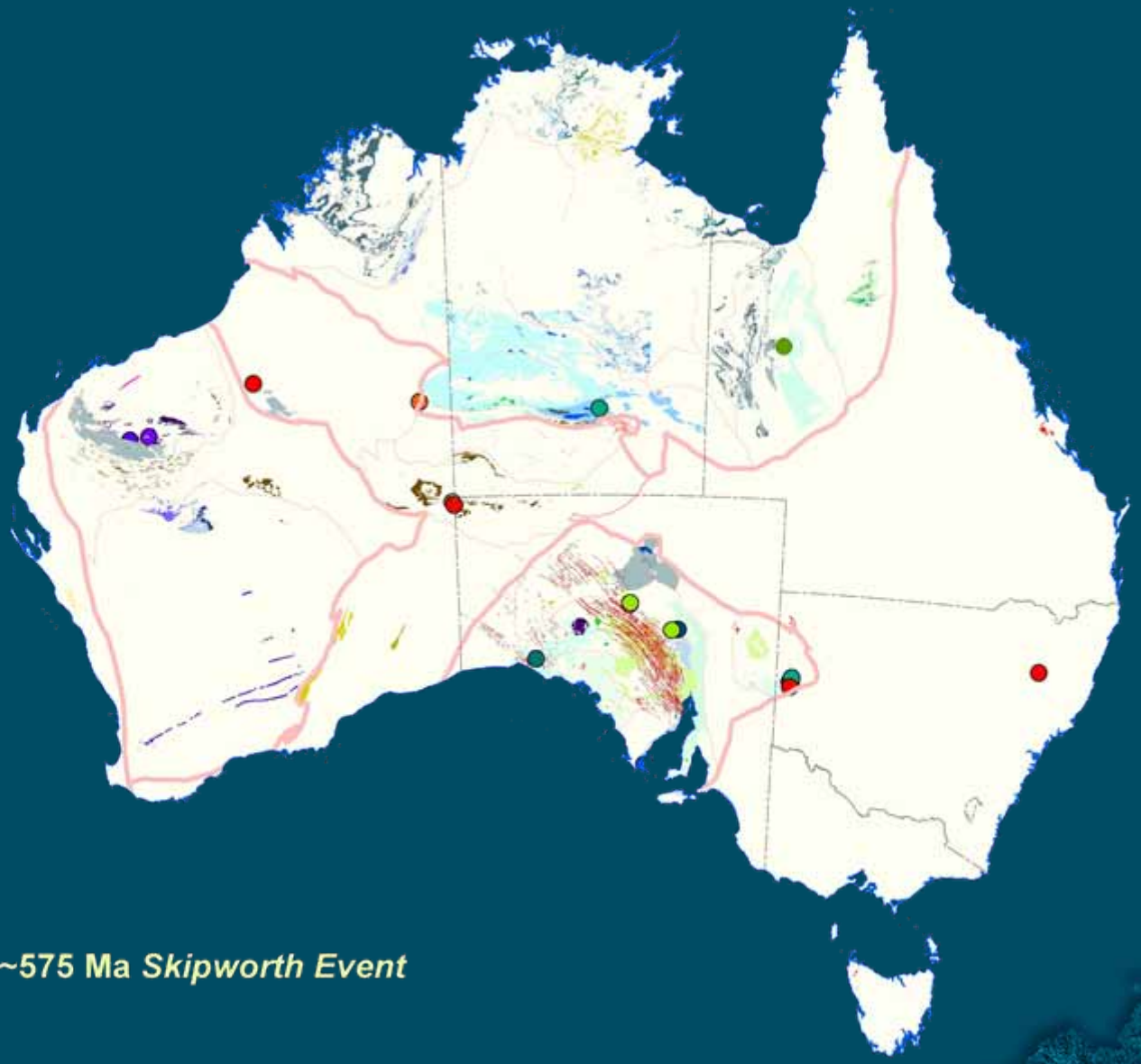
ME 26 (m) ~825 Ma *Gairdner Event*



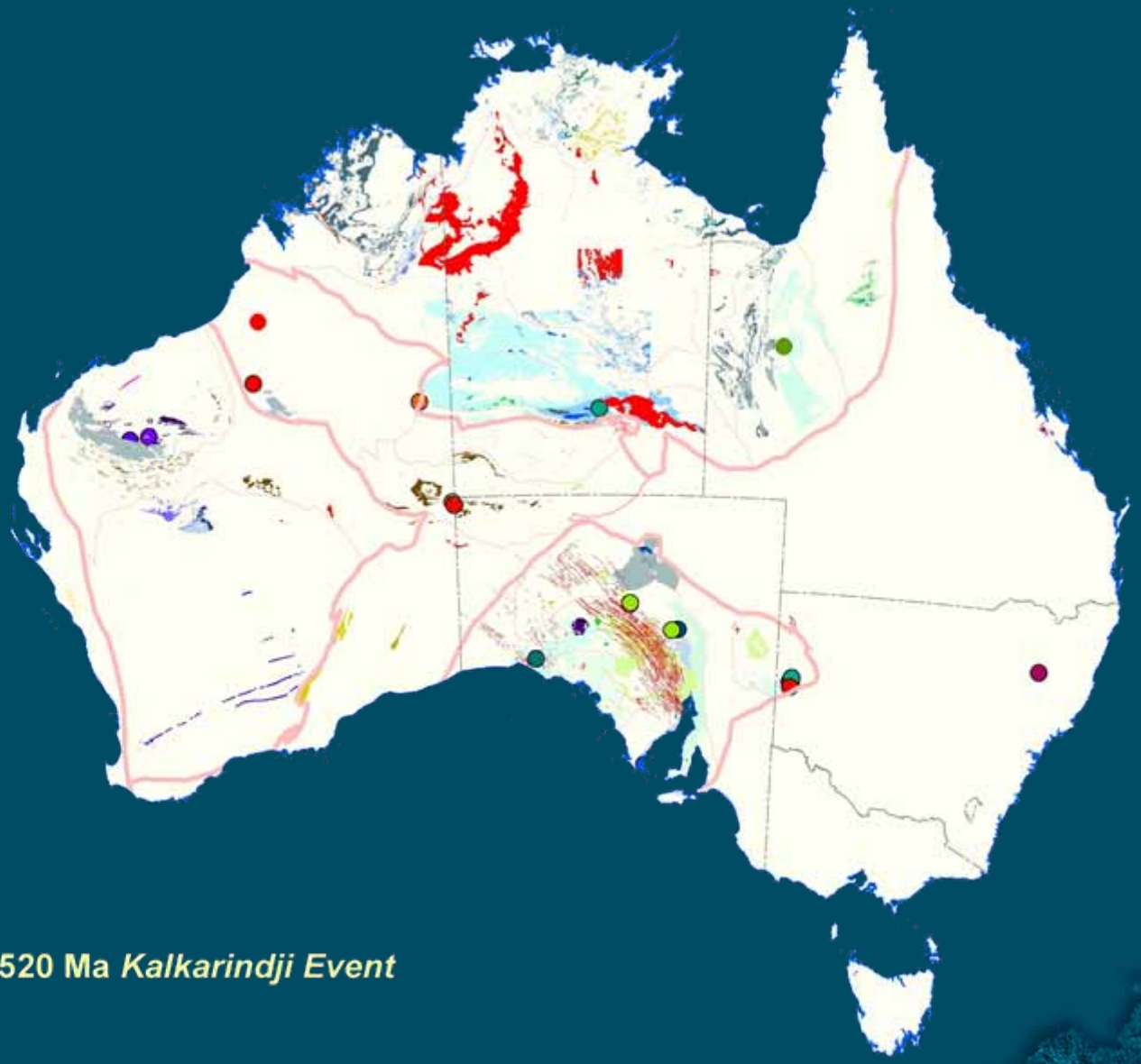
ME 27 (m) ~775 Ma *Boucaut Event*



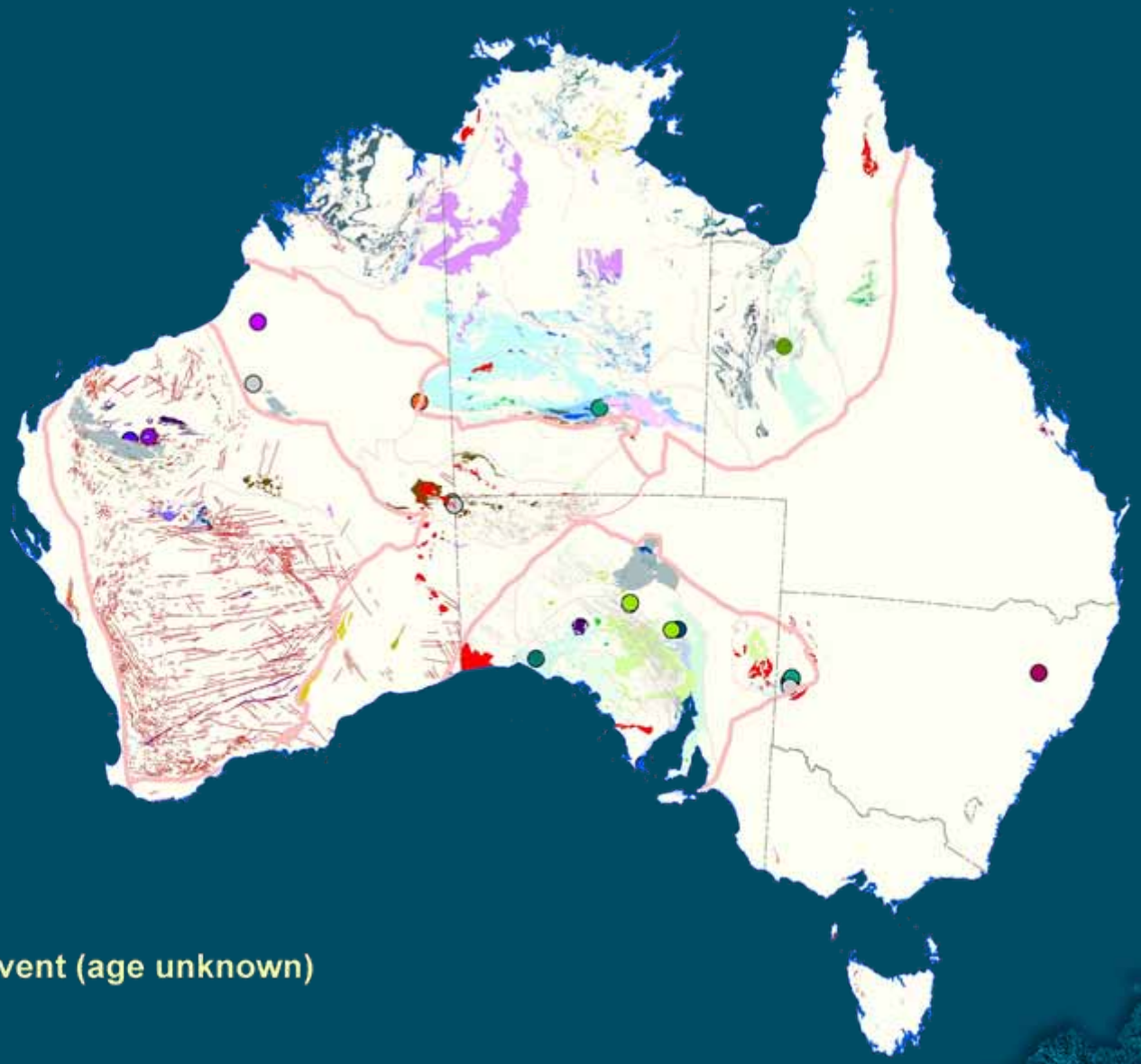
ME 28 (m) ~755 Ma *Mundine Well Event*



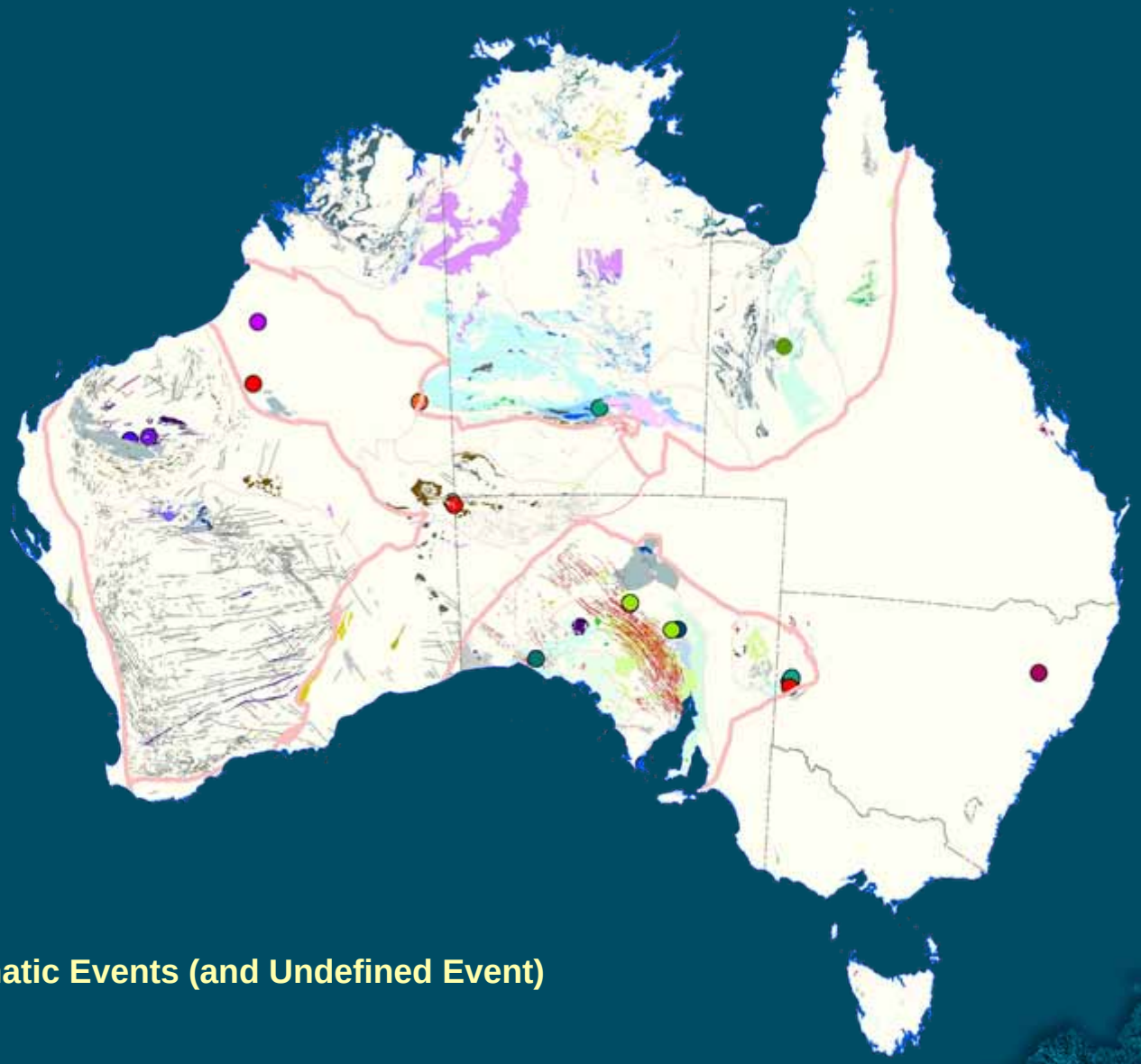
ME 29 (mu) ~575 Ma *Skipworth Event*



ME 30 (m) ~520 Ma *Kalkarindji Event*

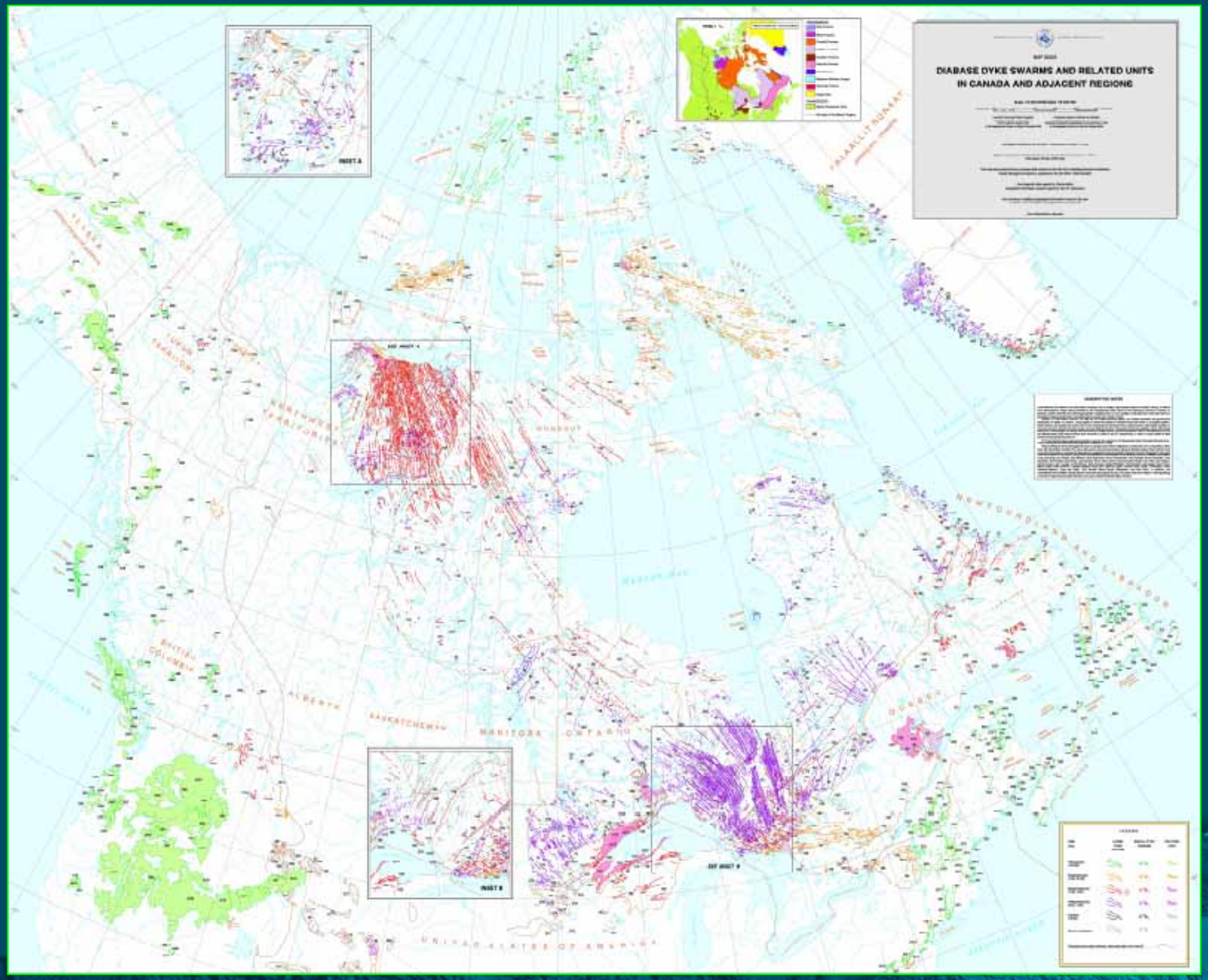


Undefined Event (age unknown)



All 30 Magmatic Events (and Undefined Event)

Five-Event Dyke Chronology: Canada



Buchan & Ernst (2004)

Large Igneous Provinces: Potential for 'Noril'sk-type' Ni-Cu-PGE Deposits

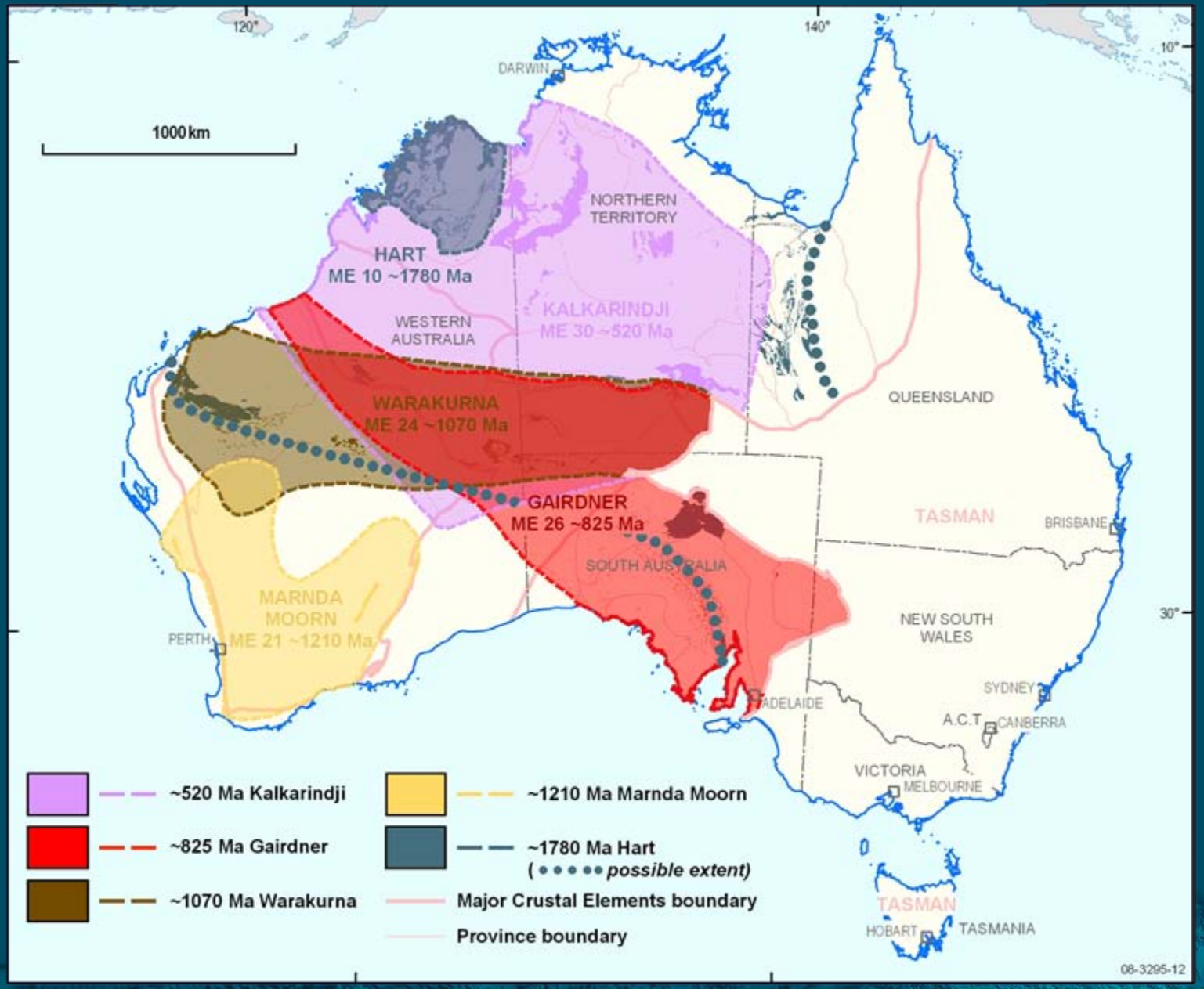
Large Igneous Provinces (LIPS):

- Large volumes of coeval mafic-dominated magmas (flood basalts, dyke swarms & sills, intrusions)
- Indicators of: thermal mantle plumes, rift environments regional-scale uplift, continental breakup, Ni-Cu-PGE mineralisation events

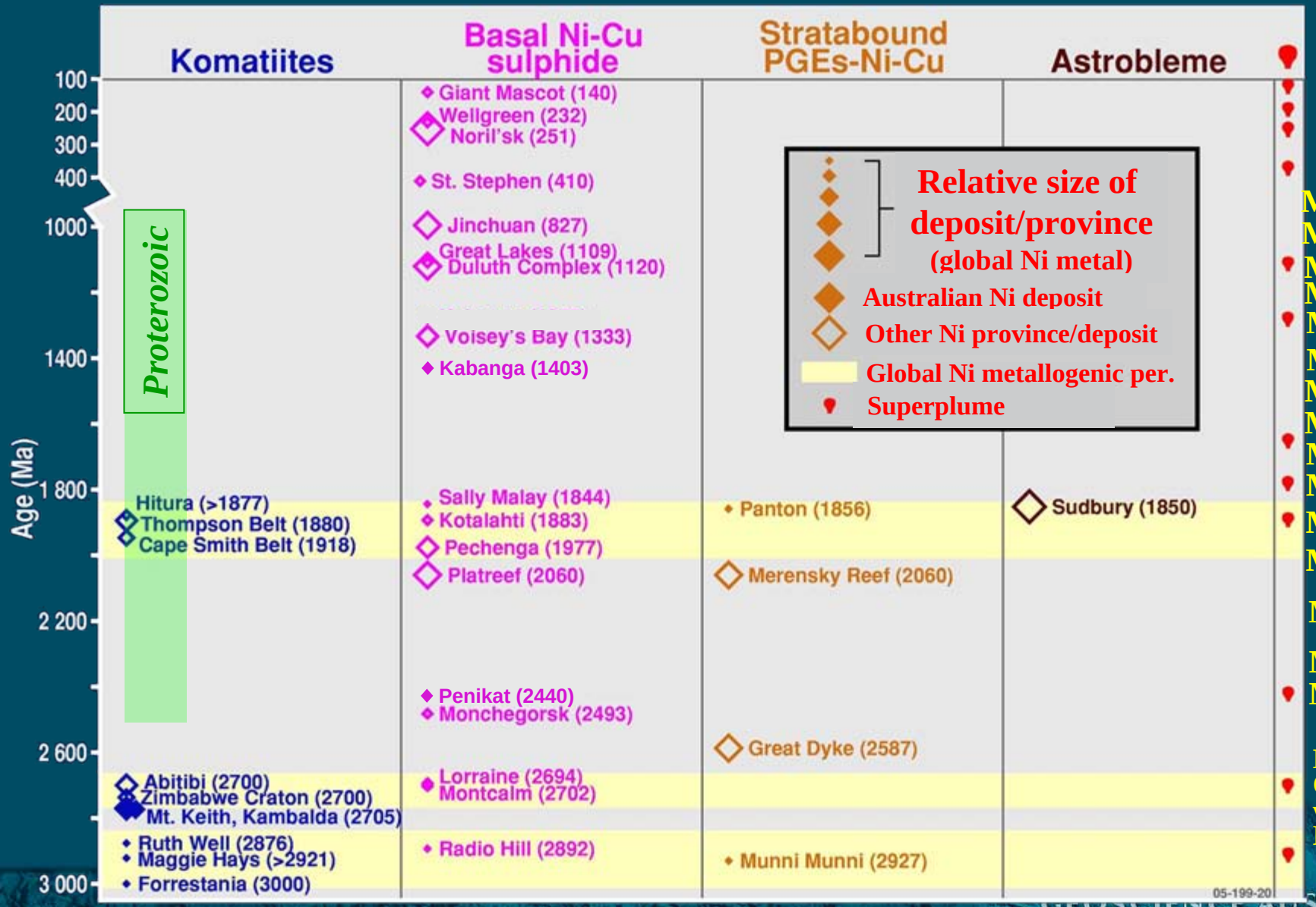
Exploration Criteria:

- Continental-scale flood basalt provinces
- Controlling faults, magma plumbing systems, feeder conduits
- Depletion of chalcophile metal elements coincident with geochemical signatures (Th/Nb, La/Sm) of crustal contamination

Large Igneous Provinces



Correlation of Proterozoic Magmatic Events



Proterozoic Magmatic Ni-Cu-PGEs: Exploration

NICKEL:

- focus: mafic intrusions
- small to large tholeiitic bodies
- massive sulphides
- basal contacts, feeder conduits
- high-magma flux zones

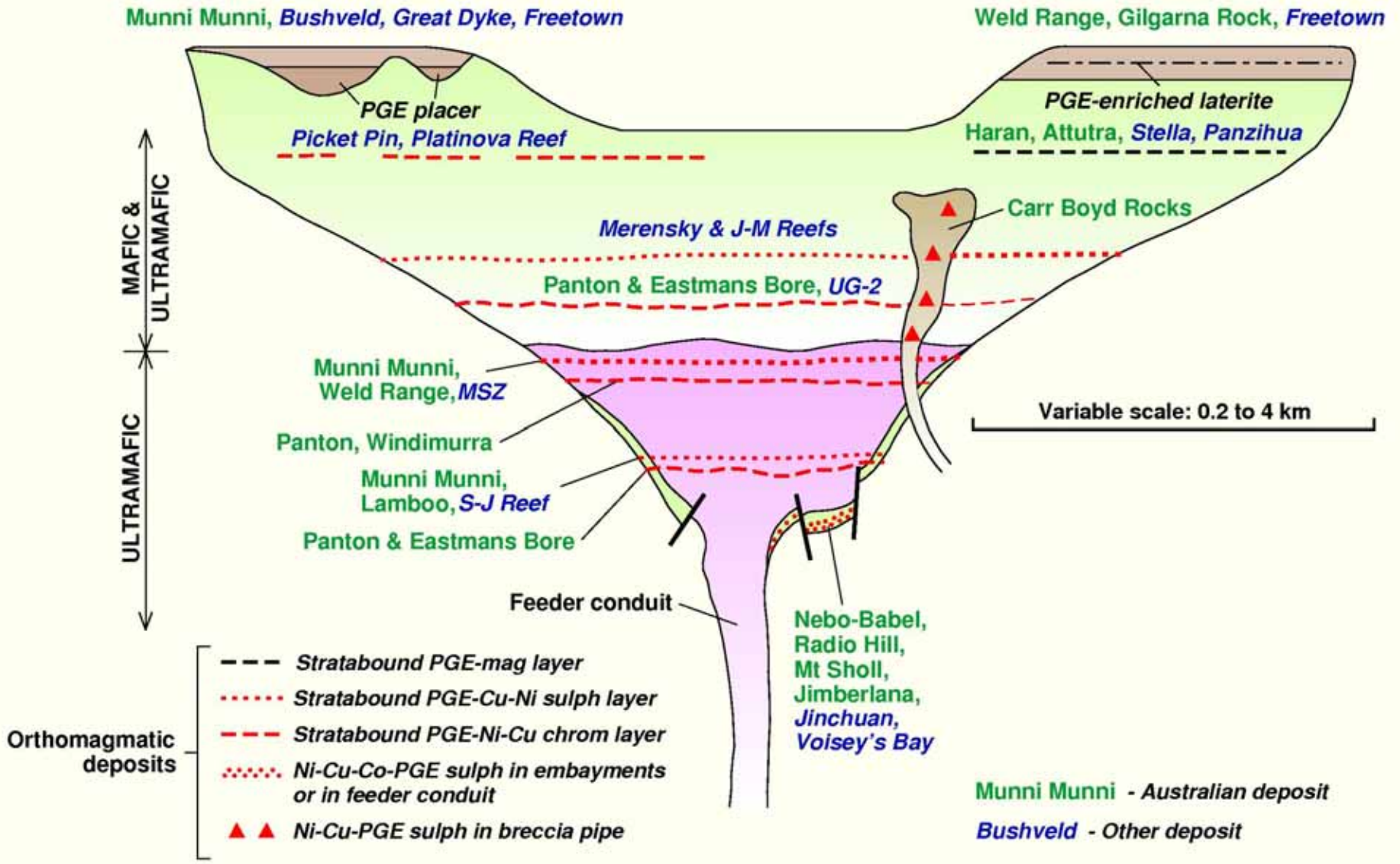
PGEs:

- focus: ultramafic-mafic intrusions
- >1000 concentration factor
- giant magmatic systems
- high-Mg primitive magmas
- late S saturation
- crustal contamination, magma mixing

Outcropping massive Ni-Cu sulphides, Voisey's Bay (Burrows: Vale-Inco)

Nickel and PGE Deposits: Mafic-Ultramafic Intrusion

Note: Schematic Spatial Distribution Only



Preliminary Findings from National Study

- **Thirty major Proterozoic magmatic events:** tholeiitic mafic>>>ultramafic; komatiitic systems not identified; protracted tholeiitic magmatism 1870 to 1590 Ma (35% of all events)
- **Nine Magmatic Events are mineralised:** six are coeval with major overseas deposits (~827 Ma Jinchuan, 1850 Ma Sudbury)
- **Apparent deficit of significant Proterozoic mineralisation discovered,** but Magmatic Events have mineralised correlatives elsewhere in the continent (1070 Ma Giles Event in WA & SA-NT) & high % of Prot intrusions under shallow cover & untested
- **Large volume, continent-wide igneous provinces** (>1 x 10^6 km^2) ~1790 Hart; ~1210 Marnda Moorn; ~1070 Ma Warakurna; ~825 Ma Gairdner; ~520 Ma Kalkarindji

Critical Questions for Explorers… Revisited

Where are the mafic-ultramafic magma systems?

- continent-wide spatial & temporal correlations
- potential under cover

Which Magmatic Events are the big ones?

- Large Igneous Provinces
- several Magmatic Events correlate continent-wide

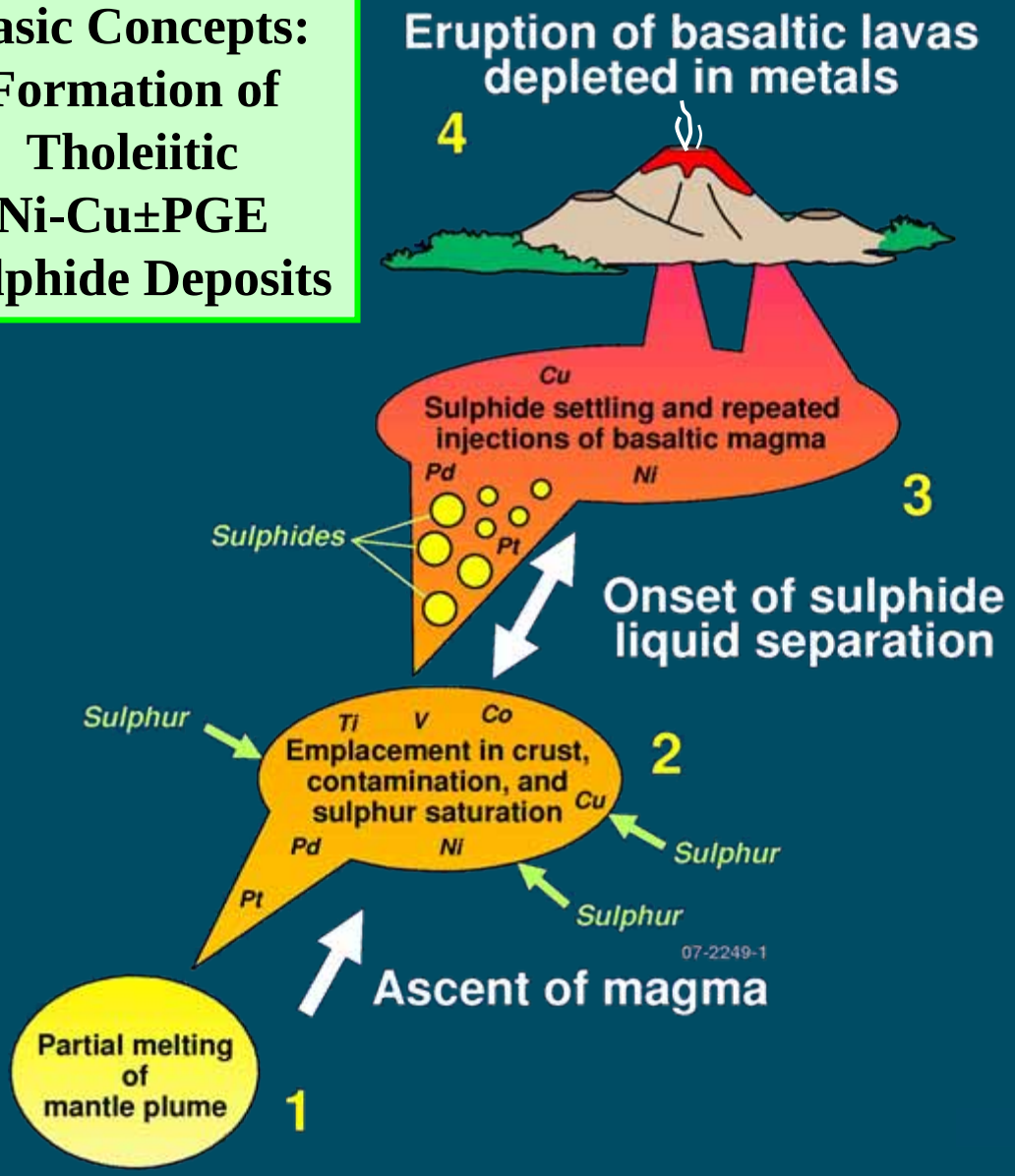
Which Magmatic Events have ultramafic magmas?

- 11 Magmatic Events have an ultramafic component

Can crustal structure narrow the exploration focus?

- clear relationships with Major Crustal Elements
- LIPs feeder focus in Central-Western Australia

Basic Concepts: Formation of Tholeiitic Ni-Cu±PGE Sulphide Deposits



4. Surface Setting:
Depleted basalts → vectors for sulphide separation at depth

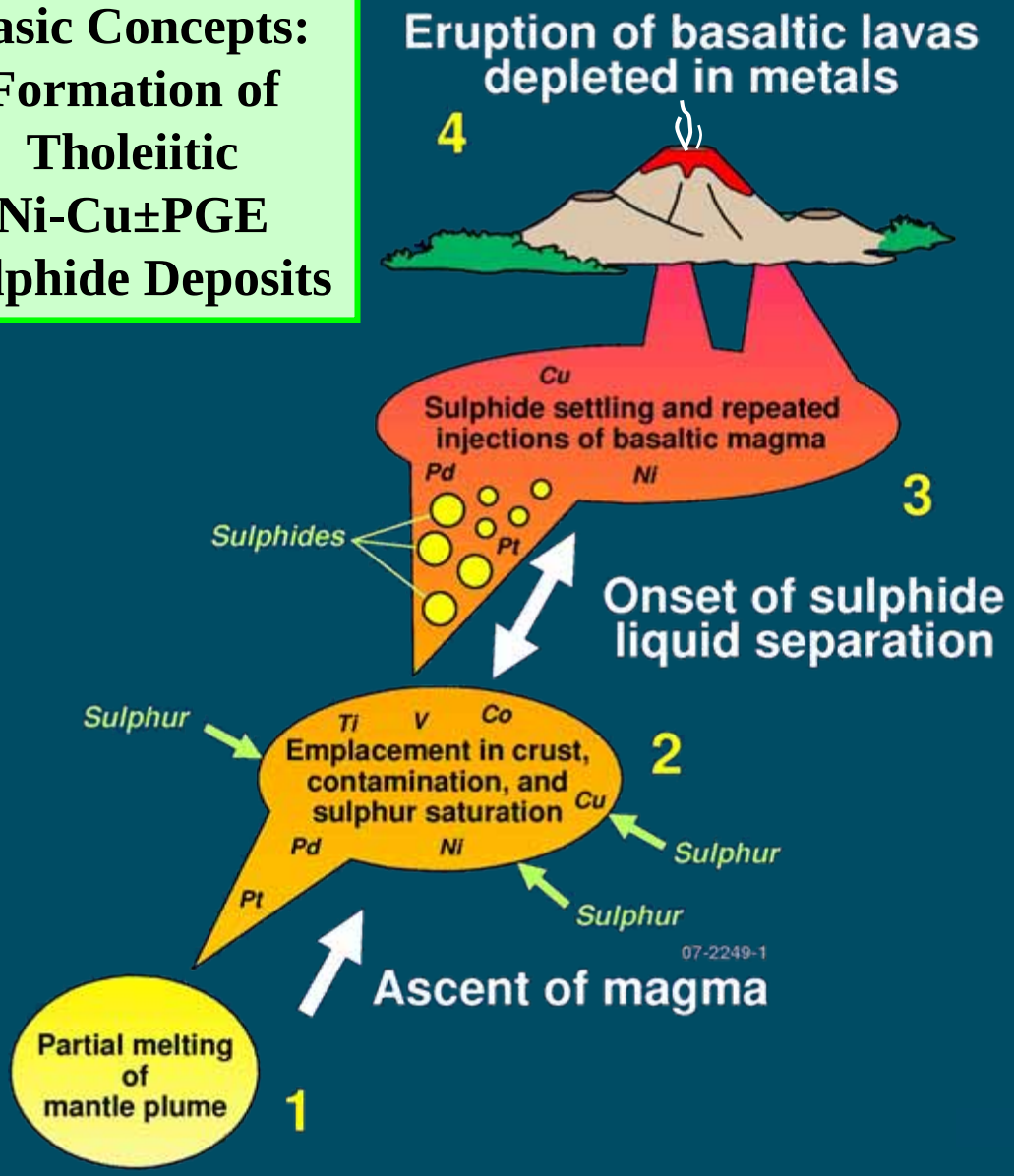
3. Sub-Volcanic Setting:
Suphides scavenge Ni, Cu, PGEs in high-level contaminated sills (Noril'sk)

2. Intrusive Setting: **Late S saturation of magma in chamber → stratabound PGE layer (Merensky Reef, Munni Munni); early S saturation → massive Ni-Cu sulphides at basal contact & feeder conduit (Voisey's Bay, Sally Malay)**

1. Mantle Setting:
Fertile magmas derived from melting of mantle plume

Modified after Schulz & Cannon (1997)

Basic Concepts: Formation of Tholeiitic Ni-Cu±PGE Sulphide Deposits



4. Surface Setting:

Kalkarindji ME 30

Hart ME 10

3. Sub-Volcanic Setting:

Gairdner ME 26

Warakurna ME 24

Bangemall ME 18

2. Intrusive Setting:

Mordor ME 23

Fraser ME 20

Loongana ME 19

Andrew Young ME 15

Lunch Creek ME 11

Mount Hay ME 9

Edmirringee ME 8

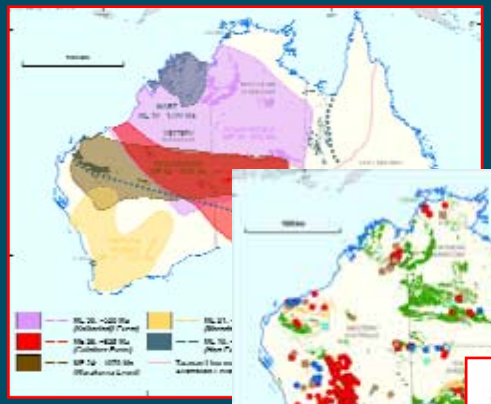
Sally Malay ME 7

Widgiemooltha ME 2

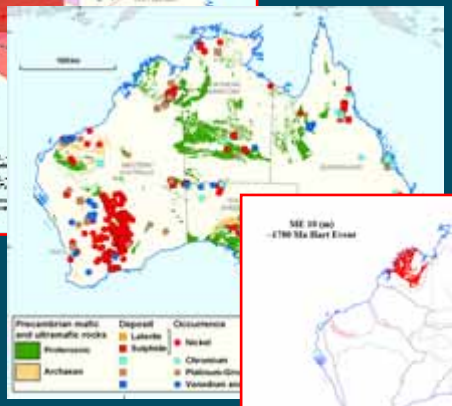
Modified after Schulz & Cannon (1997)

Free GA products: download at www.ga.gov.au

National Map



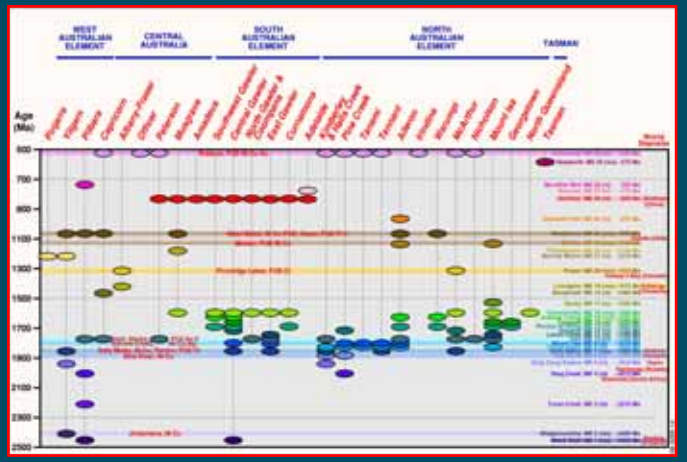
LIPs



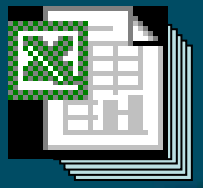
Mineral Deposits

Time-Slice Maps

Time-Space-Event Chart



140-page GA Record 2008/15



State/Territory Data Tables

Visit Geoscience Australia's booth #27 and website* for:

- Magmatic Events & nickel exploration maps, reports
- Comprehensive review of Australia's nickel sulphide deposits (Ore Geology Reviews v 29)
- Other products to assist explorers

Thank you

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*www.ga.gov.au/minerals/research/pubspres.jsp