Mineral prospectivity and $^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology of Proterozoic mobile belts: an example from the Gawler Craton

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Geological Survey of South Australia
UNCOVER Themes

4D Geodynamics and Metallogeny

Lithospheric Architecture

Activities in AMIRA Roadmap:

• Detect exposure levels of mineral systems
• Vector to *upper levels* of mineral systems
• Activity of large fault zones: lithospheric architecture

Role for thermochronology in mineral systems evaluation
**K-bearing minerals**

Step heating analysis of irradiated mineral separates

Laser or furnace technique

Closure temperature ranges: ± 50 °C

- Hornblende ~550 °C
- Muscovite ~350 °C
- Biotite ~300 °C
- *K-feldspar* >300 - 150 °C
- Sericite ~200 °C

For details see McDougall and Harrison (1999), Snee (2002)
Thermochronology – a record of thermal history

e.g. c. 1670 Ma Sybella Batholith, Mt Isa

Sprinks et al., 2002. *Tectonophysics*, v349
Dating mineralisation

e.g. Buffalo Hump district, Idaho

- Country rocks had cooled to <280 °C by 78.2 Ma

- Implies the muscovite ages are very close to formation age

- Heat associated with intrusion & mineralisation rapidly dissipated

Interpretation requires knowledge of regional thermal evolution

\[ {^{40} \text{Ar}}/{^{39} \text{Ar}} \text{ thermochronology} \]

Lund et al. 1986, Economic Geology, v81, 990-996.
**$^{40}\text{Ar}/^{39}\text{Ar}$ thermochronology**

Thermochronology – a record of thermal history

Closure temperature as a broad proxy for depth
Closure temperature, proxy for depth

Central Gneiss Belt, Grenville Province
(Cosca et al. 1991)

- Initial cooling from gt-opx composition 15 bars/°C; project this rate through ‘realistic’ geotherm: 30 °C/km
- Cooling rate: 2 – 4 °C/myr
- Isotherm relaxation, erosion driven cooling

40Ar/39Ar thermochronology

Peak P-T ~1160 Ma

Temperature (°C)

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Age Range (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-feldspar</td>
<td>870–700</td>
</tr>
<tr>
<td>Biotite</td>
<td>950–840</td>
</tr>
<tr>
<td>Muscovite</td>
<td>950–870</td>
</tr>
<tr>
<td>Hornblende</td>
<td>1025–930</td>
</tr>
</tbody>
</table>
Closure temperature, proxy for depth

Northern Gawler Craton (Forbes et al. 2012)
  • Higher T geotherm, possibly indicates depth

Limitation: no ‘universal geotherm’
Mineral system

- Crustal level – *style of deposit*
- Erosion depth – *preservation*

Image adapted from Graham Begg, 2015, cited in AMIRA P1162 Report, Unlocking Australia’s hidden potential. An Industry Roadmap – Stage 1
Iron oxide-copper-gold mineral systems

- Fe-rich hydrothermal systems related to igneous intrusions
- 1590 Ma metallogenic event

Key ingredients:
1. Regional magnetite- and hematite-rich alteration
2. Tholeiitic basalts
3. Movement of trans-lithospheric shear zones
4. Preserved subvolcanic depths (preferably <5 km)
5. Oxidised upper crustal packages

(Hayward & Skirrow, 2010)
Iron oxide-copper-gold mineral systems

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Key ingredients:
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(Hayward & Skirrow, 2010)
Gawler Craton
Age (Ma)
Reworking
c. 1450 Ma

Large igneous province
& mineralisation
1600 – 1575 Ma

Tectono-metamorphic event; “orogeny”
1730 – 1690 Ma

Cover
1900 – 1730 Ma

Basement
3150 – 2000 Ma
$^{40}\text{Ar}/^{39}\text{Ar}$ data

Gawler Craton
- 117 data points

Data sources for this and subsequent figures:
- Foster and Ehlers, 1998
- Forbes et al., 2012
- Tomkins et al. 2004
- Fraser and Lyons 2006
- Skirrow et al. 2007
- Fraser et al. 2007
- Fraser et al. 2012
- Reid and Jourdan, unpub.data
40Ar/39Ar data

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Neoarchean basement
Mesoproterozoic volcanics & intrusives
Paleoproterozoic cover sequences
Prominent Hill
Olympic Dam
Carrapateena

Paleoproterozoic cover sequences
Biotite and sericite $^{40}$Ar/$^{39}$Ar data

Old ages in Neoarchean basement

Prominent Hill

Carrapateena

Olympic Dam
Biotite and sericite $^{40}\text{Ar}/^{39}\text{Ar}$ data

Drill hole SH 7

Prominent Hill

Olympic Dam

Carrapateena
SH 7: new $^{40}\text{Ar}/^{39}\text{Ar}$ results

- **Muscovite**: ~2000 Ma
- **Biotite**: ~2000 Ma
- **K-feldspar**: ~1800 Ma
- **Sericite**: ~1590 Ma

Reid, Jourdan and Jagodzinski, *in review*
SH 7: new $^{40}\text{Ar}/^{39}\text{Ar}$ results

Emplacement ~2535 Ma

Gawler Craton IOCG mineralisation “window”

Temperature ($^\circ$C)

Age (Ma)
Post-emplacement cooling ages in Hiltaba Suite granites
Biotite \( \approx 1580 \text{ Ma} \)
Sericite alteration in gold deposit:
1582 ± 8 Ma
Fraser et al. 2007, sample 2003369004
Deformed granite, Coorabie Shear Zone, Fraser and Lyons, 2006; Biotite age, 1452 Ma
- 1580 Ma metamorphism adjacent shear zone
- Near isobaric cooling

Halpin, Reid, Jagodzinski unpub data
Biotite Age (Ma)
- 1250 - 1350
- 1420 - 1490
- 1490 - 1570
- 1570 - 1600
- 1600 - 1730
- 1730 - 2155

Sericite Age (Ma)
- 1420 - 1450
- 1490 - 1570
- 1570 - 1600
- 1560 - 1595

Hornblende Age (Ma)
- 1500 Ma

Fowler Domain
Nuyts Domain

Reid and Jourdan, unpubdata
Variable cooling rates:
~3 °C/Myr then ~6 °C/Myr
Increased rate – phase of exhumation at ~1500 Ma

How do these cooling histories compare with other orogens?
Cooling rates and exhumation

- Bodorkos and Reddy, 2004; Cosca et al., 1991; Dahl et al., 2004; Flowers et al., 2006; Forbes et al., 2012; Fraser et al., 2012; Kamber et al., 2002; Mahan et al., 2011; Mezger et al., 1990; Rivers, 2012; Schneider et al., 2007; Sciborski et al., 2015; Tomkins et al., 2004; Willigers et al., 2002;

Neoarchean basement, northern Gawler Craton
Cooling rates and exhumation

- Upper crust at 1590 Ma, during the metallogenic event
Cooling rates and exhumation

Slow – <4 °C/Myr – Erosion controlled exhumation, e.g. Limpopo Belt (Mahan et al., 2011); Superior Province (Mezger et al. 1990)
Cooling rates and exhumation

Western and Northern Gawler Craton
- Moderate cooling rates: ~2 – 6 °C/Myr
Cooling rates and exhumation

Cooling rates:

- **Moderate** – 4 - 10 °C/Myr – Structural control on exhumation & cooling; settings include late orogenic crustal extrusion along major fault zones, e.g. Trans Hudson (Schneider et al., 2007); post-orogenic collapse, e.g. Grenville Province (Rivers, 2012)
- **Fast** – >10 °C/Myr – Active thrusting; e.g. Albany Fraser Orogen (Scibiorski et al. 2015)
- Phanerozoic orogens typically show even faster cooling
Cooling rates and exhumation

- Archean – slow, erosion dominated cooling
- Proterozoic – faster cooling; tectonic control
- Reflects secular change in tectonic style and crustal level exposed: deeper levels generally exposed in large Archean orogens
- Mixed levels exposed in Proterozoic (and Phanerozoic) consequently faster cooling rates are preserved (see also Willigers et al. 2002. *J. Geology*, 110, 503-517)
Cooling rates and exhumation

- Western and Northern Gawler Craton
- Moderate cooling rates: ~4 – 6 °C/Myr
- Post-1590 Ma exhumation; likely active control on cooling
- Mineralisation – either deep crustal at 1590 Ma, or post-1590 Ma upper crustal mineral systems.
Mid crust at 1590 Ma

Active shear zone at ~1450 Ma

Exhumation focused adjacent shear zone in Fowler Domain

Thrust vergence towards craton

- Active shear zone at ~1500 Ma
- Exhumation focused adjacent shear zone in Fowler Domain

Mid crust at 1590 Ma

Upper crust at 1590 Ma

Post 1450 Ma exhumation

Mid crust at 1590 Ma
~1460 Ma exhumation

13GA-EG1 Dutch et al. 2015
Broad crustal level at 1590 Ma

- Upper crust
- Mid-Upper crust
- Lower-Mid crust
- Mid crust
- Differential exhumation

Prominent Hill

Olympic Dam

Carrapateena

Biotite Age (Ma)

- 1250 - 1350
- 1420 - 1490
- 1490 - 1570
- 1570 - 1600
- 1600 - 1730
- 1730 - 2155

Sericite Age (Ma)

- 1420 - 1450
- 1560 - 1595

Kilometers
Lithospheric structure

- Reactivated major structures – potential sites for fluid flow, mineralisation
Lithospheric structure

- Reactivated major structures – potential sites for fluid flow, mineralisation
Lithospheric structure

- Structures expressed in potential field data, magnetotellurics, and thermochronology
- Time-temperature history – compare to regional tectonic evolution
Role for thermochronology in mineral systems evaluation

4D geodynamic evolution
- Crustal level through time
- Erosion depth
  - Inform predictions of likely styles of mineralisation

Lithospheric architecture
- Major fault zones
Regional “crustal level” through time

UNCOVER: An Australia-wide thermal evolution project?

Add in other thermochronology systems:
e.g. U-Pb apatite, AFT (zircon, apatite), aHe, zHe

Gleadow et al. 2002; Tectonophysics v 349
Scopus search – “Argon Australia”
75 papers
- Mostly regional cooling studies & dating mineralization
- Dating deformation

UNCOVER: An Australia-wide thermal evolution project?
References

Gawler Craton thermochronology and geology


Fraser, G., Skirrow, R. G., and Holm, O., 2007, Mesoproterozoic gold prospects in the central Gawler Craton, South Australia: geology, alteration, fluids and timing: Economic Geology, no. 102, p. 1511-1539.


Geophysical data


Regional cooling paths


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