Proterozoic deposits in Australia and Greenland

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Proterozoic tectonic units in Australia

- Iron oxide, Cu, Au
- Sedimentary rock-hosted stratiform Zn, Pb, Ag
- Sedimentary rock-hosted Cu
- Layered mafic-ultramafic related stratabound PGE, Cr
- Mafic-ultramafic intrusive related Ni, Cu, PGE
- Fe–Ti–V in magnetite layers

- Diamond
- Felsic intrusion-related Sn, W
- Unconformity-related U
- Non-sulfide Pb
- Iron formation ore system
- Orogenic Au

Inferred craton margin
Inferred and approximate position of Proterozoic mantle plume head
Proterozoic tectonic units in Greenland

Kolb (2012)
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<th><strong>Australia</strong></th>
<th><strong>Greenland</strong></th>
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<td>1. Iron formations (e.g. Hamersley Basin, not discussed here)</td>
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<td>2. Orogenic and intrusion-related systems (e.g. in the Pine Creek)</td>
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2. Orogenic Au (ca. 1800 Ma)

Anorogenic and rift-related mineral systems
- Iron oxide, Cu, Au
- Sedimentary rock-hosted stratiform Zn, Pb, Ag
- Sedimentary rock-hosted Cu

Orthomagmatic mineral systems
- Layered mafic-ultramafic related stratabound PGE, Cr
- Mafic-ultramafic intrusive related Ni, Cu, PGE
- Fe–Ti–V in magnetite layers

Inferred craton margin

Inferred and approximate position of Proterozoic mantle plume head

Phanerozoic basin
Proterozoic orogen
Archean craton
Pine Creek Orogen, orogenic Au (ca. 1800 Ma)

- These are structurally controlled quartz-veined, greisens, and pegmatite-related or skarn deposits.

- SHRIMP U-Pb age of ca. 1800 Ma

- Mineralisation synchronous with granite emplacement and tectonic events (Shoobridge Tectonic Event).

- This type of deposit can found in Phanerozoic rocks
Many deposits are related to fluid moving through structurally prepared sites during greenschist/lower amphibolite facies metamorphism.

Zonation is common from base metals to gold.

Au-qtz veins with arsenopyrite, and lesser pyrite, marcasite, galena, chalcopyrite, sphalerite, covellite, bismuthinite, tetrahadrite, etc.
2. Orogenic Au (ca. 1800 Ma)

Kolb (2012)
Nalunaq, orogenic Au (ca. 1800 Ma)

- Deposits include structurally controlled quartz-veins or skarn deposits.

- Mineralisation ca. 1800-1770 Ma; partly synchronous with late-tectonic granite emplacement (Ketilidian Orogeny, 1850-1725 Ma)

- Nalunaq Gold Mine: 320 000 oz since 2004, that is >9 tonnes of gold
Orogenic Au (ca. 1800 Ma)

- **Metallogenic zoning:** W and base metal to Au deposits.
- **Saddle reefs,** fault-controlled concordant and discordant veins, and stockworks along anticline axes.

Hart (2007)
3. SEDEX deposits (ca. 1760-1620 Ma)

Back-arc rift system with development of basins (such as at Mount Isa and Broken Hill)
Tectonic activities during ca. 1760 - 1620 Ma were related to the collision of the Gawler Craton with the Central and North Australian cratons. During this period:

- Uranium was deposited in the Pine Creek Orogen.
- Orogenies resulted in inversion of the Leichhardt Superbasin in the Mount Isa Inlier.
- Magmatism in the Arunta Orogen
SEDEX deposits

- The McArthur River-Mount Isa, Broken Hill, Georgetown rift systems were developed as back-arc basins, accompanied by large-scale bimodal magmatism (e.g. Gawler Range Volcanics and Hiltaba Event in SAC)

- Crustal thinning, extension and bimodal magmatism

- Stratiform and stratabound ore systems

- Orebodies in the succession of quartz amphibolites
Pre-mining resource estimate of 300 Mt @ 20% combined Pb and Zn, and 80 ppm Ag
3. SEDEX deposits (ca. 1760-1620 Ma)

Kolb (2012)
• Shelf carbonates of the Karrat Group (1900-1870 Ma)
• Pyrite, sphalerite, galena, pyrrhotite, chalcopyrite, tennantite, arsenopyrite, fluorite, baryte.
• Deformed and metamorphosed massive sulfide lenses (< 30 m).
• > 11 million tons during 1973-90.

Thomassen (unpubl.)
- MVT Zn-Pb mineralization
- SEDEX and stratiform base metal mineralisation
Major stratabound U deposits are hosted by partly carbonaceous greenschist to amphibolite facies metasedimentary rocks, and all deposits are within 100 m of the unconformably overlying Kombolgie Formation (McArthur Basin).

Characterised by chlorite alteration in breccia or fractured rocks in faults or shear zones.
Genetic model:

Mineralisation took place when highly oxidized and calcium-rich brines originating from the Kombolgie Formation reacted with feldspathic and reducing rocks and fluids in the basement at about 200°C.
4. Unconformity Greenland

Unconformities - conglomerates

No mineralisation explored

Kolb (2012)
5. Fe oxide-Cu-Au-U deposits

central Australia
Olympic Dam (ca. 1600-1580 Ma)

Olympic Dam, concealed under 100s of metres, is the world's largest U deposit, one of the largest Cu deposit, and contains significant reserves of Au, Ag, & REE.

Global resource of 31 810 Mt @ 1% Cu, 0.5 g/t Au, 3.6 g/t Ag, 400 g/t $U_3O_8$

Olympic Dam
Hydrothermal alteration assemblages grade from chlorite-hematite (after biotite-magnetite) in fractured granite, to sericite-chlorite-hematite, to sericite-hematite-only in the centre of the breccia bodies.

The extensive Fe-metasomatism was accompanied by F, Ba & REE, and the high-Fe content of the ore suggests that the mineralising fluid was saline. Collapse of upper parts of the breccia system was accompanied with deposition of sulfides.
Two sources of the mineralising fluids have been recognized:

1) An early fluid of magmatic origin produced the magnetite. The fluid had a high $\delta^{18}O$ of 10‰ and a high-$T$ of $\sim$400°C.

2) Later meteoric or seawater fluids deposited hematite, with $\delta^{18}O$ of $<9$‰, temperatures of 200° - 400° C and salinity 7 - 42 wt% NaCl equivalent.
Genetic model for Olympic Dam

Genetic model for Fe oxide Cu-Au-U-REE (IOCG) deposits at different crustal levels (adapted after Davidson, 2002, Ahmad et al., 1999 and Solomon et al., 2000)
5. Fe oxide-Cu-Au-U deposits

Kolb (2012)
Inglefield Land Cu-Au mineralisation

Dawes et al. (2000)
• **Cu-Au-magnetite/hematite mineralisation**
• Pyrite-barite-hematite±albite-magnetite alteration
• Associated with intermediate to mafic calc-alkaline intrusions
• Hosted in syn-magmatic shear zones and breccia (Ketilidian Orogen: ca. 1780 Ma; Inglefield Mobile Belt: ca. 1950-1915 Ma)
  • $H_2O-CO_2\pm CH_4$, 6-20 wt.% NaCl$_{eq}$.
  • 200-400° C, 0.5-1.5 kbar
• Definite classification and mineral system unclear!
6. Orthomagmatic deposits

Orogens

Inferred cratonic margin

- Phanerozoic
- Proterozoic basin
- Proterozoic orogen
- Archean craton
Nebo-Babel, Musgrave Complex

ca. 1080 Ma V-bearing titano-magnetite and ilmenite hosted by the Giles mafic-ultramafic intrusions at Jameson Range and Blackstone Range, and at Bell Rock, with a resource of >100 Mt @ 1% V$_2$O$_5$
3D view of the Nebo-Babel intrusion
(after Seat et al., 2007)
6. Orthomagmatic deposits

Kolb (2012)
Gardar Province rare metal deposits

Modified after Garde et al. (2002)
The alkaline intrusions of the Gardar Province rift system (1300-1120 Ma)

Ilímaussaq intrusion
- Layered alkaline complex
- 3 main pulses: augite syenite, peralkaline granite and syenite, peralkaline and Si-understurrated
- Bottom cummulates (kakortokite): Kringlerne Ta-Nb-REE-Zr
- Top cummulates (lujavrite): Kvanefjeld REE-U-Zn

Motzfeldt Centre ring complex
- Peralkaline syenite - nepheline syenite
- Motzfeldt Sø Formation: pyrochlore, thorite, zircon, bastnaesite (Ta-Nb-REE)
• Troctolite and gabbro
• Lopolithic bodies
• Very consistent mineral layering
• In graben structure
• Magnetite ore
Like Australia, Greenland has the potential for mineral systems formed in intraplate, plate margin, back-arc rift and collisional tectonic settings. These include:

- Iron formations or BIFs
- Orogenic and intrusion-related systems
- Orthomagmatic Ni-Cu-PGE, Fe-Ti-V, REE-Nb-Ta
- Anorogenic magmatism
- Rift-related sedimentary-hosted
- Uranium deposits

The major difference between Australia and Greenland is that Greenland is underexplored, as was Australia 200 years ago.