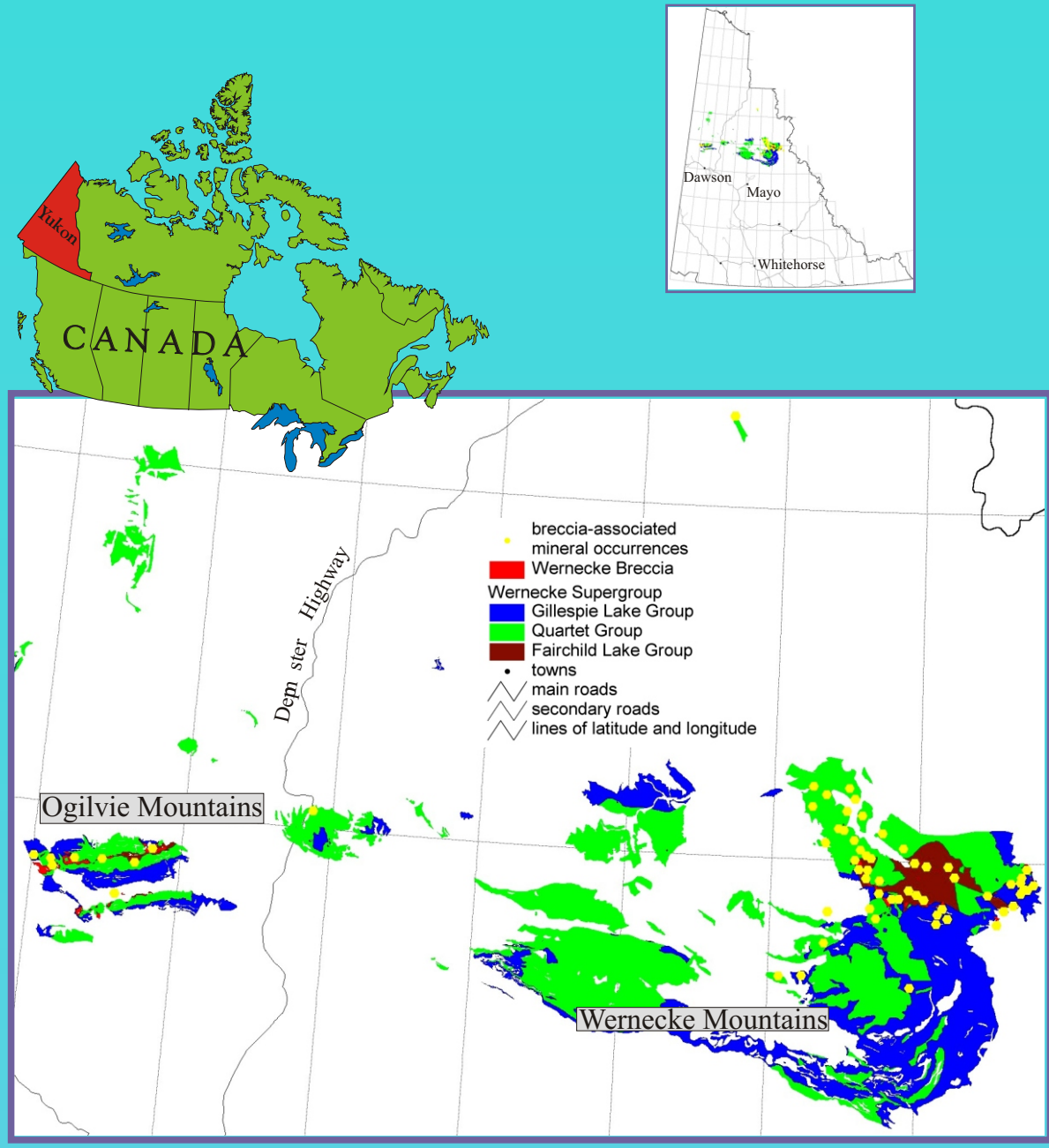


by

Julie Hunt, Geordie Mark, Tim Baker and Derek Thorkelson



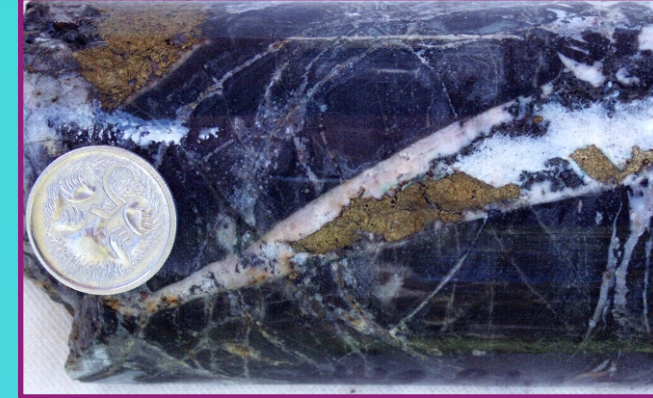
## Mineralization



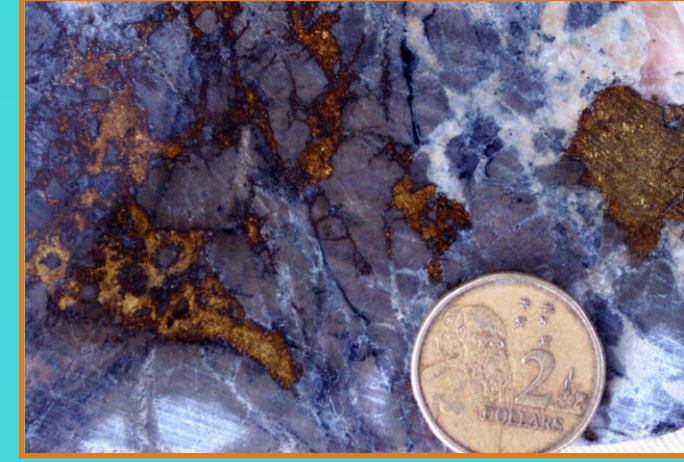
Distribution of Wernecke Supergroup rocks and Wernecke Breccia occurrences in the Yukon. Data from Gordley and Makepeace (2000).



Malachite stained Fairchild Lake Group sedimentary rocks.



Carbonate-chalcopryrite vein cutting Fairchild Lake Group sediments.



Calcite-chalcopryrite-pyrite forming the matrix to Wernecke Breccia.



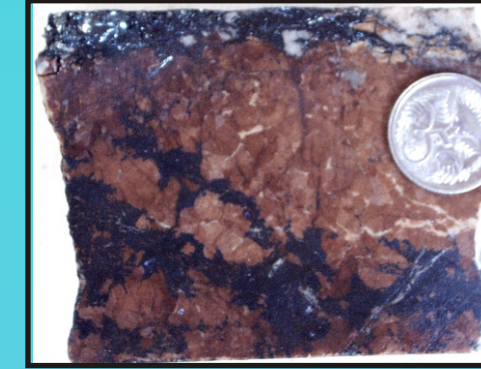
Disseminated hematite locally forms the matrix to Wernecke Breccia.



10 cm thick pyrite-chalcopryrite-quartz-muscovite vein cutting carbonate-magnetite altered sedimentary rocks.



Sulphide clast in Wernecke Breccia.



Early carbonate-magnetite veins cut Wernecke Supergroup sediments

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Thorkelson, D.J., Mortensen, J.K., Davidson, G.J., Creaser, R.A., Perez, W.A. and Abbott, J.G., 2001. Early Mesoproterozoic intrusive breccias in Yukon, Canada: the role of hydrothermal systems in reconstructions of North America and Australia. Precambrian Research, vol. 111, p. 31-55.

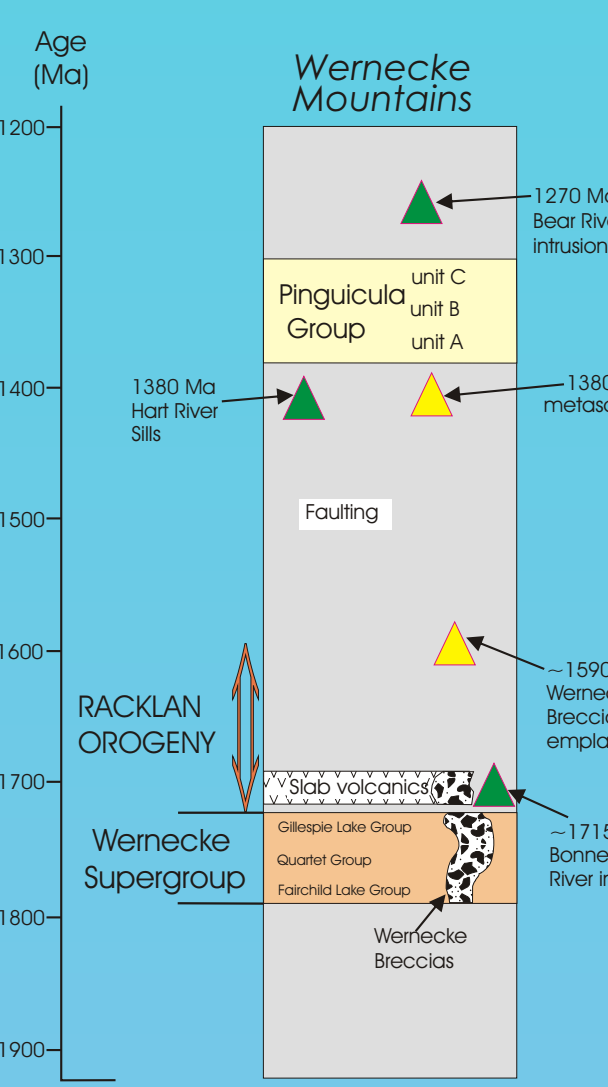
Yukon MINFILE, 2001. Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada.

Proterozoic breccia bodies, from 0.1 to 10 km<sup>2</sup>, occur in curvilinear arrays over large areas (3500 km<sup>2</sup>) in the Wernecke and Ogilvie Mountains of the Yukon (cf. Bell, 1986; Thorkelson, 2000). The breccias, collectively known as Wernecke Breccia, cut Early Proterozoic Wernecke Supergroup sedimentary rocks, Bonnet Plume River Intrusions and Slab volcanics and are associated with iron oxide-copper-gold mineralization. Crystalline basement to the sedimentary successions is not exposed. However, the combination of thick sedimentary successions and an overall continental setting suggest that the region is underlain by attenuated continental crust (Thorkelson, 2000).

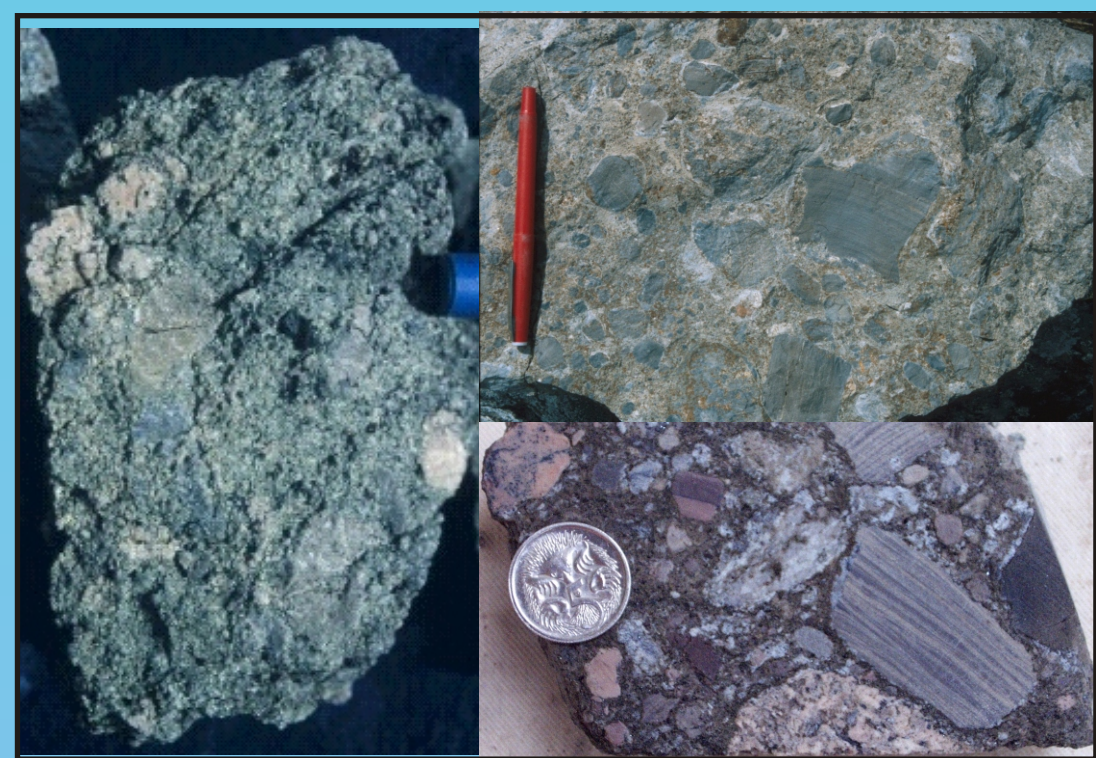
Multiple phases of brecciation and hydrothermal activity are evident and large metasomatic aureoles are typically present in breccia zones and surrounding country rock (cf. Thorkelson *et al.*, 2001). The main phase of brecciation occurred at ca. 1.6 Ga and is associated with extensive metasomatic effects that include the precipitation of hematite, magnetite, calcite, albite, microcline, muscovite/sericite, chalcopryrite and pyrite (Thorkelson, 2000). Metasomatism began before and ended after brecciation. Clasts within the breccia are dominantly sedimentary rocks of the Wernecke Supergroup; clasts of Slab Volcanics and Bonnet Plume River Intrusions are abundant locally as are clasts of earlier breccia and mineralization. Clasts are generally sub-angular to sub-rounded and range from < 1 cm to several hundred metres across.

Cu, Co, Au, Ag, U, and locally Mo mineralization occurs within breccia zones and in adjacent metasomatized country rock. Several authors (cf. Bell, 1989; Gandhi and Bell, 1990; Hitzman *et al.*, 1992; Thorkelson *et al.*, 2001) have drawn a connection with breccias in Australia based on similar physical and mineralogical characteristics and suggest that Wernecke Breccias have the potential to host deposits similar to the world class Olympic Dam and Ernest Henry deposits (see over).

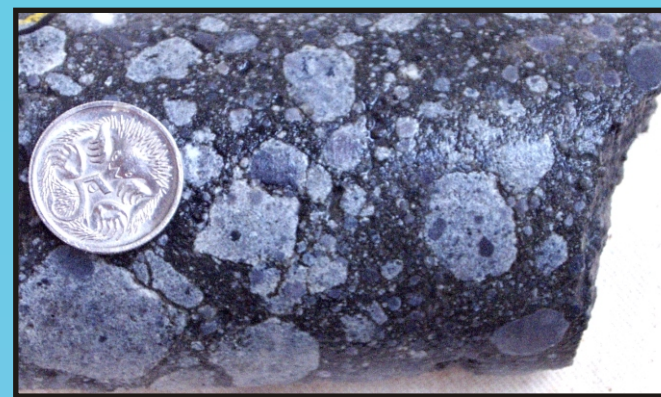
## Wernecke Breccia



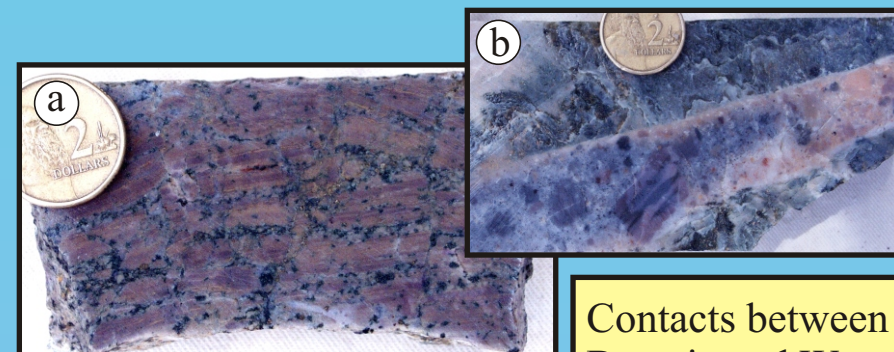
Generalized stratigraphic column for the Wernecke Mountains. Modified from Thorkelson (2000).



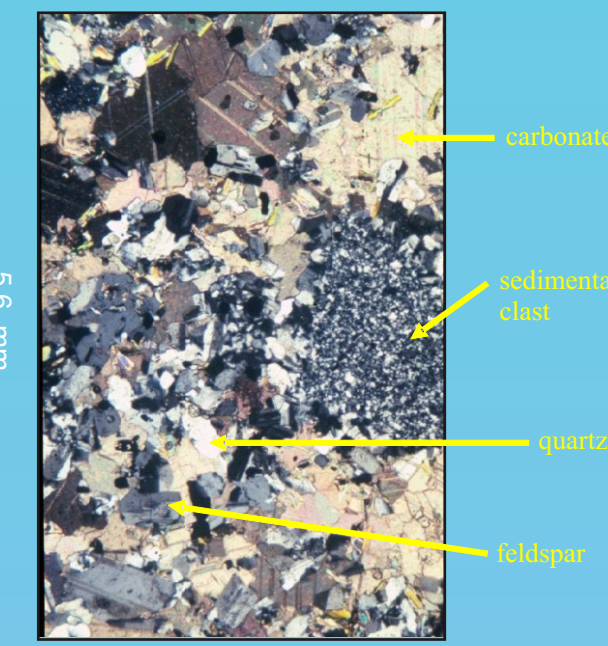
Typical examples of Wernecke Breccia.



Wernecke Breccia displaying multiple brecciation events.



Contacts between Wernecke Breccia and Wernecke Group sedimentary rocks vary from gradational to sharp. a) crackle brecciated gradational contact. b) sharp contact.

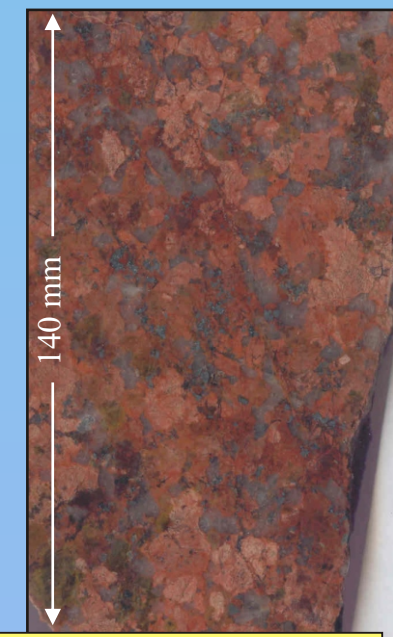


Thin section (crossed polars) of Wernecke Breccia matrix made up dominantly of sedimentary clasts, carbonate, feldspar and quartz.

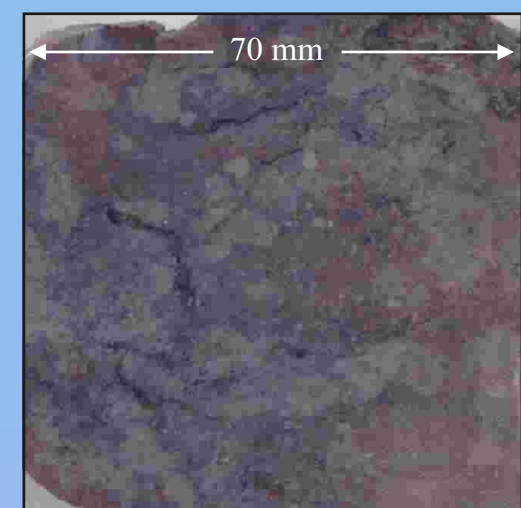
## Olympic Dam

## The North American-Australian Connection

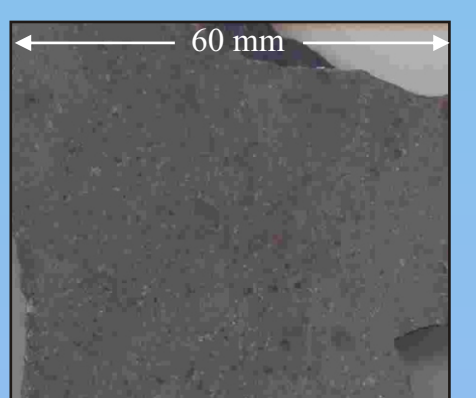
## Ernest Henry



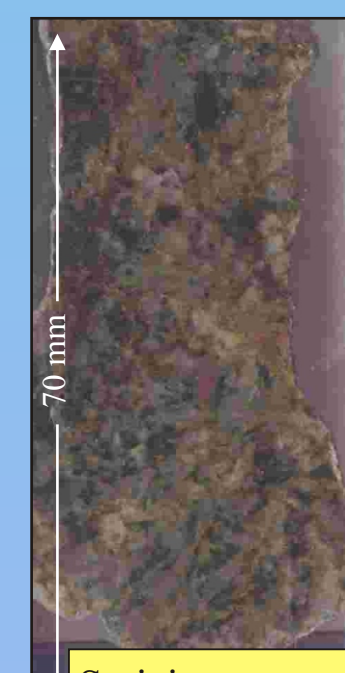
Coarse-grained, magnetite-bearing Roxby Downs Granite. Photo from G. Mark.



Hematite-rich matrix-supported ore (bornite, chalcocite) breccia. Photo from G. Mark.



Barren quartz-hematite hydrothermal breccia from the core of the Olympic Dam deposit. Photo from G. Mark.



Sericite-muscovite-altered and brecciated Roxby Downs Granite. Photo from G. Mark.

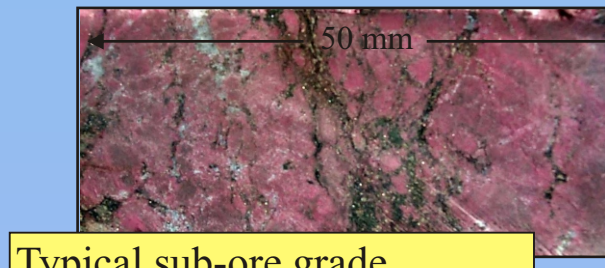
Several authors have drawn connections between Wernecke Breccia and breccia-associated deposits in Australia including Olympic Dam and Ernest Henry. These ties are based on similar ages and physical characteristics of the breccias and the probable proximity of ancestral North America with Australia in Proterozoic time (see Thorkelson 2000 for a review, and Thorkelson *et al.* 2001 for a comparison).



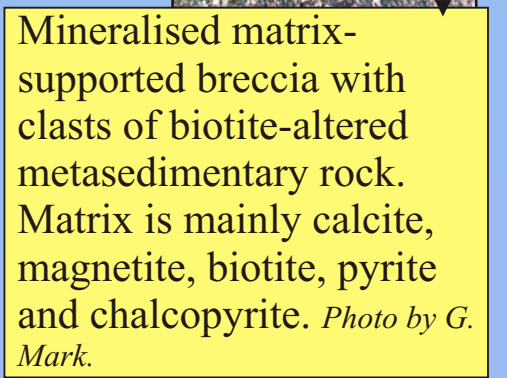
Main ore type: mineralised matrix-supported breccia with clasts of hematitic K-feldspar-altered metavolcanic rock. Matrix is composed of finely disseminated magnetite, pyrite, chalcopryrite and biotite. Photo by G. Mark.



Mineralised matrix-supported breccia cut by carbonate-chalcopryrite veins. Photo by G. Mark.



Typical sub-ore grade mineralization: K-feldspar-altered metavolcanic rock cut by biotite-rich and sulphide-bearing veins. Photo by G. Mark.

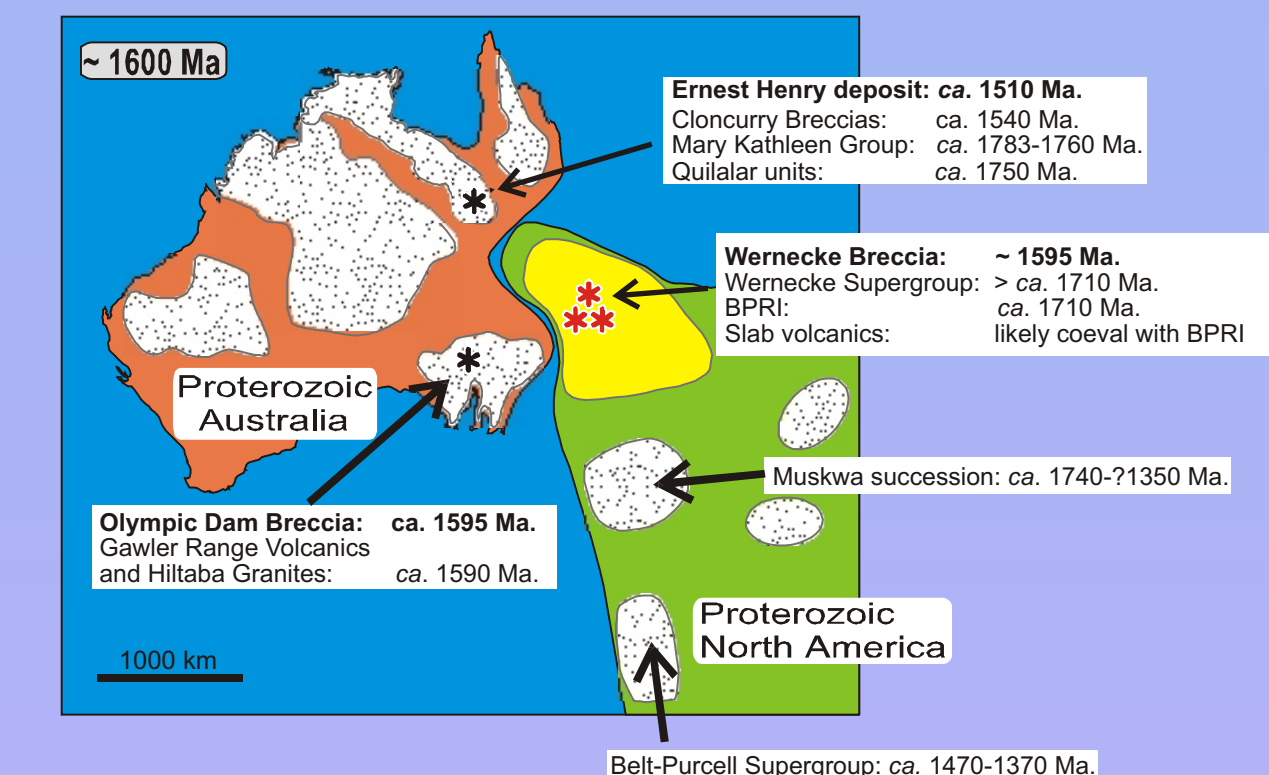
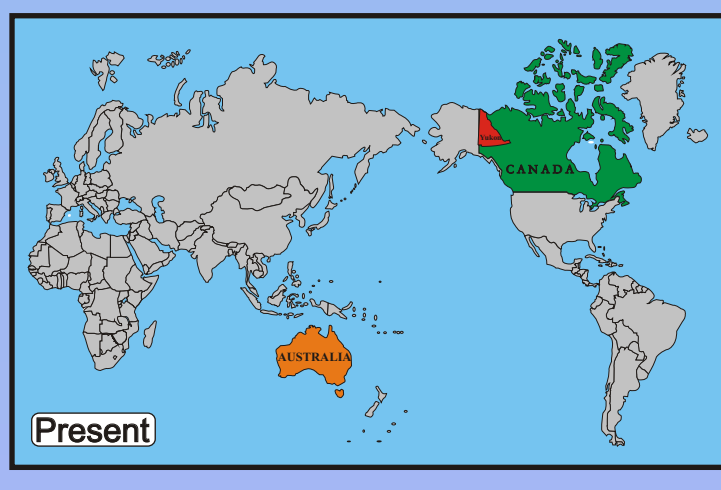


Mineralised matrix-supported breccia with clasts of biotite-altered metavolcanic rock. Matrix is mainly calcite, magnetite, biotite, pyrite and chalcopryrite. Photo by G. Mark.

\*\*The following summary of the Olympic Dam deposit is from Reynolds (2000) unless otherwise noted.

The ~ 1590 Ma Olympic Dam Cu-U-Au-Ag-REE deposit contains reserves in excess of 600 Mt averaging 1.8% Cu, 0.5 kg/t U<sub>3</sub>O<sub>8</sub>, 0.5 g/t Au and 3.6 g/t Ag (Reynolds, 2000). The deposit is hosted by a large breccia system that is contained within the Roxby Downs Granite, a Proterozoic age granitoid. Basement to the deposit is Early Proterozoic sedimentary rocks and granitoids. Locally the host Middle Proterozoic granitoids are overlain by bimodal volcanics.

- The breccia complex forms a local basement high on a regional basement uplift and lies at the intersection of two gravity lineaments.
- Regional geophysical data sets indicate that Olympic Dam is one of numerous coincident magnetic-gravity anomalies. Drilling has shown that many of these anomalies are caused by hydrothermal iron oxide alteration in the basement associated with granite
- Breccia zones are associated with a complex pattern of alteration, dominated by hematite and sericite, with lesser chlorite, siderite and quartz
- Mineralization in the deposit is associated with iron oxide alteration of the granitoid which dominantly occurs as hematite, with lesser magnetite at depth and on the periphery of the breccia complex
- Principal copper minerals in the deposit show a broad lateral and vertical zonation pattern grading from chalcopryrite on the margins to bornite, then chalcocite adjacent to a central barren core
- Gold and silver are mainly associated with copper sulphides
- Uranium dominantly occurs in pitchblende disseminated throughout the hematitic breccia zone
- Overall, mineralization grade generally correlates with the degree of hematite alteration and is largely dependent on the copper sulphide tenor
- The deposit formed in a high level volcanic environment, venting to surface
- The Olympic Dam breccia complex can be considered as having formed by the progressive hydrothermal brecciation and iron metasomatism of the host granite (Oreskes and Einaudi, 1990). Breccias formed by repeated and combined: 1) hydraulic fracturing, 2) tectonic faulting, 3) chemical corrosion, 4) phreatomagmatism and 5) gravity collapse
- Mafic and felsic dykes intrude the breccia complex
- Tectonism, hydrothermal activity, dyke intrusion, brecciation, alteration and mineralization were broadly concurrent and interdependent
- Hydrothermal fluids and metals have a dominantly magmatic source



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\*\*The following summary of the Ernest Henry deposit is from Geordie Mark (pers comm. 2002) or Mark (2000) unless otherwise noted.

The ca 1510 Ma Ernest Henry Fe oxide-Cu-Au deposit contains a resource of 167 Mt averaging 1.1% Cu and 0.54 g/t Au (Mark *et al.* 2000). The deposit is hosted by a large breccia system within felspar phyric igneous rock (ca 1740 Ma)

- The ore body is 250 m thick, 300 m wide, at least 1000 m long and forms a pipe-like body that dips moderately to the SE
- Brecciation and ore deposition occurred in a dilational zone between deposit-bounding shear zones.
- Mineralization occurred @ ca 1510 Ma after peak metamorphism (ca 1590 Ma) and synchronous with batholith emplacement (1550-1500 Ma)
- Economic mineralization occurs in matrix-supported breccia with a matrix of hydrothermal infill made up dominantly of magnetite, calcite, pyrite, biotite, chalcopryrite, potassium feldspar, quartz and barite and minor molybdenite, garnet, amphibole and fluorite
- Economic mineralization typically grades to uneconomic peripheral crackle-veined K-feldspar-altered metavolcanic rocks
- Hydrothermally altered rocks enriched in K, Ba, As, Mn, U, REE and F extend for up to a kilometre beyond the ore and can be used as exploration vectors
- The Ernest Henry deposit has a positive airborne magnetic geophysical response
- Mineralization likely formed from high temperature (350-450°C) relatively oxidized saline fluids with a significant magmatic component
- All deposits in the Cloncurry district record early, pre-mineralization alkali metasomatism. Generally, albitization is dominant, however, at Ernest Henry K-feldspathization is dominant around the ore.
- Rheological heterogeneities were important in controlling the location of mineralization at most deposits in the Cloncurry district