The OLYMPIC DAM Cu-U-Au-Ag-REE deposit,
Australia

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Abstract. The giant Olympic Dam iron oxide deposit is one of the world’s greatest amounts of copper, uranium, silver and gold. Located in the centre of the province South Australia, it belongs to the units of the Archaen Gawler Craton. The Burgoyne batholite, member of Middle Proterozoic granites called Hiltaba Suit, hosted the deposit where a long and repeated process of brecciation and magnetite-hematite alteration took place. Hence the deposit is located within a huge complex of irregularly shaped and variably mineralised breccia bodies which is known as the Olympic Dam Breccia Complex. Furthermore, a great number of veins and dykes cross the deposit. Today BHP Billiton runs the Olympic Dam mine and produces approximately 200,000 t of copper and 3,500 t of uranium oxide each year. An increase in capacity to a considerable degree is planned and shows the importance of Olympic Dam.

Introduction

The Olympic Dam mining complex, one of the biggest producers of copper, uranium, gold and silver on the Australian continent, is located in the centre of the province South Australia, approximately 520 km NNW of Adelaide and east of Lake Torrens. The nearest town is Roxby Downs, where most of its inhabitants are employed at the Olympic Dam mine.

The deposit which is formed by a huge Breccia Complex and primarily consisting of iron oxide contains a huge association of copper, gold, silver and rare earth materials (REE). Current calculations suggest ore reserves of more than 600 Mt with a content of average 1.8 wt.% Cu, 0.5 kg/t uranium oxide, 3.6 g/t silver and 0.5 g/t gold. On this premise a total production of up to 30 Mt Cu, 930 Kt of $\text{U}_3\text{O}_8$, 6,700 t of silver and 1,200 t of gold seems to be possible. Furthermore a variable REE mineralization of mostly cerium and lanthanum is disseminated across the deposit.
Today the Olympic Dam mining complex annually produces around 9 million tonnes of ore and recovers approximately 200,000 tonnes of refined copper, 3,500 tonnes of uranium oxide, 820,000 ounces of silver and 90,000 ounces of gold (state of 2007). Rare earth materials are not extracted because it is uneconomic with current technologies. To handle that amount of material, the ore body is exploited by a highly mechanised underground mining operation. This is connected with an on-site processing autogenous mill, a concentrator as well as a hydrometallurgical plant, a smelter and a refinery.

Of course this highly developed and highly effective mining process requires a long period of exploration. The discovery of the deposit was already made in 1975 by Western Mining Corporation (WMC) in association with a multi-disciplinary exploration effort to find sediment hosted copper deposits. The studies integrated geology as well as geophysics and tectonic analysis, which can be detailed fathomed in Laylor (1984 & 1986), Reeve et al (1990) and Roberts & Hudson (1983). Opened in 1988, the mine was completely owned and operated by WMC. To raise the capacity to 200,000 tonnes copper and nearly 4,000 kg of \( \text{U}_3\text{O}_8 \) an AU$ 1.9 billion expansion programme was realized until 1999. In 2005 BHP Billiton gained control of WMC and also the Olympic Dam mine in an AU$ 9.2 billion takeover. Actually the increase of the production capacity up to 500,000 tonnes of refined copper and the potential for open pit mining is proved by an AU$ 145 million study.

**Regional geological settings**

**Geological affiliation**

The Olympic Dam Breccia Complex (ODBC) is part of the Gawler craton (Fig.1.), which accounts for 440,000 square kilometres of South Australia. The oldest known rocks of this geologic unit were formed in the late Archaen and consist of ortho- and paragneiss, variably metamorphosed to granulit facies. They are summarizing to the Mulgathing Complex in the western and northern Cawler Craton and the Sleaford Complex, exposed in the south.

In the region of Olympic Dam the most common formations of the early Proterozoic are made up by a huge span of metasediments and deformed granites, correlated with the Hutchison Group with an age of 2000 to 1850 million years and the Lincoln Complex granitoids.

These rocks were intruded by the extensive Hiltaba Suite, dominated by felsic granite plutons and with a Middle Proterozoic age of 1600 to 1585 million years. The characteristic color is pink due to an intensive hematite alteration. The Gawler Range Volcanics are comagmatic with the Hiltaba Suite and form a huge felsic volcanic province with a preserved outcrop of 25,000 square kilometres in the central Gawler Craton. The age of these units were dated to 1590 million years.
Both, the Gawler Range Volcanics and a part of the Hiltaba Suite, the so-called Burgoyne batholith hosted the ODBC and are covered by approximately 300 meters of flat-lying sedimentary rocks, which belong to the Stuart Shelf and have a Late Proterozoic to Cambrian age.

75 km east of the deposit passes the NNW trending Torrens Hinge Zone which separates the undeformed sedimentary rocks of the Stuart Shelf from their non deformed and even thicker equivalents within the Adelaide Fold Belt.

Fig.1. Simplified subsurface geology of the Gawler Craton (modified from Daly et al., 1998)
Tectonic settings

A sufficient understanding of the tectonic settings of the Olympic Dam Breccia Complex is impeded by the thick cover of Proterozoic to Phanerozoic sedimentary successions. Recent geophysical studies use seismic reflection profiles to have a look at the depth. They sounded the Burgoyne batholite beneath the ODBC, a high temperature (approximately 1000°C) granitic intrusion. This is located at the edge between an Archean to Proterozoic core and a younger Meso- to Neoproterozoic mobile belt and above a zone of weak reflectivity. Perhaps this is the source-region of the batholiths. The interpretation of the seismic data suggests that both neither mantle underplating nor lithospheric extension can be responsible for such a heat source. Furthermore, a mantle plume is not very probable either (Drummond et al., 2005). Maybe radiogenic heating in the lower crust is an alternative to these hypotheses.

The Moho was detected at a depth of 40 to 42 km with crystalline basement dominated by thrusts above (Fig.2.).

![Fig.2.](image)

(a) Seismic data from a north-south seismic line through the ODBC. (b) Interpretation of the seismic data. T: thrust, BT: back-thrust, B1 and B2: duplexes in the mid crust reflective layer, OD: Olympic Dam, hosted by the Burgoyne batholit of the Hiltaba Suite. The thick black line in the lower part shows the Moho, interrupted by a bland zone. (after Drummond et al., 2005)
Olympic Dam Breccia Complex

Structure

The Olympic Dam breccia complex is irregular in shape with a long and narrow extension to the northwest (Fig.3.). The individual breccias are very different in size and shape but mostly steeply dipping to sub-vertical (Oreskes & Einaudi, 1990). They also have a NW to NNW trend. Although the breccia complex extends to depths of more than 1.4 km, the area below 800 m is poorly explored by current drilling. Unfortunately early structures within the complex have been destroyed during the repeated processes of brecciation and alteration. However, an en-echelon fault network can be suggested by the pattern of the individual breccias. Furthermore it is possible that the fault network was situated within a dextral dilatational jog zone even though there is no evidence of major bounding faults which belong to such a jog (Reynolds, 2000).

Minor brittle faults are more visible. They are irregular and discontinuous with different movement histories. Most of them activated ore-existing anisotropies like intrusive or lithological contacts. The displacement is less than 10 meters and can be observed only in the way of mine development. Larger faults with a displacement of approximately 100 m, a strike continuity of nearly 2 km and cataclastic zones up to 1 m are also known but only a few of them reach the surface (Reynolds, 2000).

Fig.3. Geological plan of the ODBC and the general distribution of the deposit.
and major breccias types. Shows the zonation from the host granite to hematite-quartz rich breccias in the centre (after Reynolds, 2000)

Hematite-Granite Breccias

The Breccias are a result of a permanent and repeated process of hydraulic fracturing, chemical erosion, tectonic faulting, gravity collapse and phreatomagmatism (Reeve et al., 1990). Depending on the degree of brecciation and alteration they show a high variation of mineralization which tends to a stepwise zonation between hematite-quartz breccias in the core and weakly sericitised and fractured granite in the outer range of the complex (Fig.4.).

The core contains quartz and hematite clasts in a hematite and barite dominated matrix. These breccias are the end-member of the above-mentioned processes and show in contrast to other breccias in the complex a distinct lack of sulfide mineralization.

Outside the core there is a belt with hematite-rich breccias, which are also matrix supported, pore sorted and with fragments of intensely altered derives from the host granite. The clasts are generally angular with a size of less than 20 cm.

Heterolithic breccias are the most common within the complex. They are characterized by a huge array and proportion of altered granite and hematite clasts. Moreover, they contain clasts from porphyritic volcanics, correlating with the Gawler Range Volcanics, laminated fine-grained sediments, extremely altered ultramafic to felsic intrusives and vain fragments with copper sulfides, siderite or barite (Reeve et al., 1990).

Granite-rich breccias are located at the margin of the ODBC. They are clast supported, fractured and often show a sericitic alteration as well as widespread veining. The Roxby Downs Granite surrounds the breccia complex and is similar o the Hiltaba Suite.

Alteration

The alteration mineralogy within the ODBC is characterized by sericite-hematite with less abundant magnetite, chlorite, silica and siderite. The composition of these minerals varies varied through the deposit because the degree of alteration depends on the amount of brecciation (Reeve et al., 1990). Highest grades of alteration can be found on the margins of and within the several hematite-granite brecciation bodies and especially the core (Fig.4.).

The earliest phase of alteration was associated with magnetite. This can be assumed because of magnetite cores inside hematite grains. Responsible for this alteration event was a high temperature fluid showing an isotopic equilibrium with the Roxby Downs Granite (Johnson & McCulloch, 1995).

A later fluid overprinted the primary magnetite mineralization. After Oreskes & Einaudi (1992) this fluid had a lower temperature and maybe was of surficial ori-
gin. Contrary to this Johnson & McCulloch (1995) proposed a fluid influenced by mafic to ultramafic, mantle derived magma. However, it is relatively ensured that the ore mineralization was connected with this late hematite alteration.

![Vein arrays and dyke swarms](image)

**Vein arrays and dyke swarms**

Veins, veinlets and vein fragments are very common within the breccia complex. They are mono- or polymineralic and consist of mineral assemblages which also dominate the alteration and mineralization associations of the breccias. Those are sericite, barite, siderite, chlorite, fluorite, sulfides, quartz or pitchblende. A second, late stage array of veins contains a laminated barite-siderite-flourite-sulfide mineralization and extends into the sedimentary cover.

The ODBC was also intruded by several ultramafic, mafic and felsic dykes with irregular wispy or tentacular shapes (Reynolds, 2000). At the top of the deposit they are less than 1 meter thick but thicker and more abundant at the depth. Associated with the regional Gairdner Dyke Swarm, a post-mineralization dolerite dyke intruded the deposit in the southeast (Fig.4.).
Mineralization

Economic ore minerals

Principal copper-bearing minerals are chalcopyrite, bornite and chalcocite, which precipitated co-genetically. There also is a small amount of native copper and other copper-bearing minerals. The copper sulfides form disseminated grains, fragments and veinlets. Massive ore is rare within the breccia zones.

Uranium occurs in form of uraninite, with lesser brannerite and coffinite. They are disseminated as fine grains inside the hematitic breccias and intergrown with hematite and sulfides.

Silver and gold are associated with copper-bearing minerals. The first one forms solid solutions while gold occurs as extremely fine particles. Bastnaesite is the main REE-bearing mineral.

Fig.5. Distribution of ore zones (after Reynolds, 2000)
Ore zones and mineralization patterns

Although the ore zones account for only a small part of the whole volume of the breccia complex Cu, U, Ag and Au minerals are widespread within the deposit (Fig. 5.). There are background levels of around 0.5 wt. % copper, 0.2 kg/t uranium oxide, 1 g/t silver and 0.5 g/t gold. The highest grade of copper and uranium mineralization is associated with more hematite altered rocks even though the hematite-quartz core is barren of copper and uranium minerals.

The copper content inside the ore zones amounts between 1 wt. % and 6 wt. %. Higher grades are achieved in bornite-chalcocite rich ore (up to 35%) which can be found in the upper part of the deposit. Chalcopyrite dominated the remainder and is common at the periphery and in the depth of the deposit. The edge between bornite and chalcopyrite dominated ore is generally sharp and mappable. Higher amounts of uranium, silver and gold are also associated with bornite-chalcocite mineralization. The highest gold contents occur around the margin of the hematite-quartz core.

Maybe the sulfide pattern is based on a hypogene origin. This suggests a multi-stage input of hydrothermal fluids and various ore precipitation mechanisms. The pattern also represents sulfide stability fields which were controlled by temperature, oxidation and depletion of reduced sulfur and shifting Fe/Cu ratios (Eldridge & Danti, 1994). The influence of supergene weathering processes on the mineralization patterns is less significant.

Geochronology

The age of the Roxby Downs Granite was determinate to 1588±4 Ma by U-Pb zircon dating. This is also the maximum age of the mineralization and brecciation at the ODBC. Another data, indicating an age of approximately 1590 Ma, was specified by SHRIMP U-Pb zircon samples collected from three dykes within the breccias. This suggests that the processes of brecciation closely followed emplacement and cooling of the Roxby Downs Granite (Johnson & Cross, 1995).

Conclusions

Although the ODBC was already discovered in 1975 there are still questions about the geological evolution of the deposit because of its structural complexity. Which source do the hydrothermal fluids and metals have? What system was responsible for the process of brecciation? Which type of heat source do the intrusive host rocks have? To answer this, more studies about the genetic models are necessary. Over and above that, the importance of the Olympic Dam deposit with regard to the increasing demand for resources is proven. Olympic Dam is not a unique type
of deposit. Furthermore, it describes a genetic model which can be applied for many deposits all over the world.

References


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