Oxidized Magmas and Skarn-Porphyry Mineralisation in the Chillagoe Mining District, Northeast Queensland, Australia

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The Chillagoe District is ~200km west of Cairns and ~550 km northwest of Townsville in north Queensland, Australia. The NW-trending ~60 x 10 km district along the district-scale Palmerville Fault contains many Zn-Pb-Ag-Cu-Au deposits and prospects in several mineral centres including the Mungana-Red Dome area, the Red Cap area (Queenslander, Morrison, Victoria, Penzance and other prospects), the Red Hill area, the King Vol area and the Shannons – Zillmanton area. The Chillagoe district has a long mining history starting from late 1800's. The historical production includes:

- Red Dome (1986 – 1996): 15 Mt @ 2.0 g/t gold, 0.5% copper, 15 g/t silver
- Mungana (2008 – 2012): 0.7 Mt @ 11.1% zinc, 1.8% copper, 1.0% lead, 1.0 g/t gold, 80 g/t silver
- Lady Jane & Girofla (1896 – 1926): 0.3 Mt @3.5% copper, 14% lead, 250 g/t silver
- Red Cap area (pre 1930): 300 t copper, 525 t lead, 24 koz silver (http://athertonresources.com.au/chillagoe-project/; accessed on 10 August 2015)

The current resources include:

- Mungana-Red Dome: 131 Mt @ 0.65 g/t Au, 0.21% Cu, and 8.1 g/t Ag (ASX: 29 October 2013, Annual Report).
- King Vol: 2.99 Mt @ 11.9% Zn, 0.8% Cu, 0.6% Pb, and 29.9g /t Ag (ASX: 28 Jan 2015)
- Red Cap: 3.8 Mt @ 4.8% Zn, 0.7% Cu, 0.2% Pb, 0.1 g/t Au and 19 g/t Ag, (ASX:27 Apr 2015)

These deposits have been described as skarn, porphyry and reduced intrusion related gold deposits.

The numerous deposits and prospects in this district indicates that it is a fertile district. However no giant deposits have been found so far, despite > 100 years of mining and exploration activities. In this study we investigate the timing framework of and relationship among the regional structures, magmas and mineralisation to improve the metallogenic understanding and to help further exploration.

The Chillagoe District is at the western margin of the Siluro-Devonian Mossman Orogen, and is in the Chillagoe Subprovince of the Hodgkinson Province. Within the district the Chillagoe Formation is approximately 7.5 km wide and is bound to the southwest by the Palmerville fault, a major northeast dipping suture zone separating Precambrian schistose rocks of the Northern

Australia Craton to the southwest from the Hodgkinson Province in the northeast. To the northeast the Chillagoe District is bound by the Redcap Fault where the Chillagoe block has been thrusted on top of Late Carboniferous Redcap Dacite Group volcanic rocks.

The stratigraphy in the Chillagoe District consists of the Chillagoe Formation that is comprised of variably fossiliferous lime mudstone, chert, sandstone, basalt and conglomerate. The Chillagoe Formation sedimentary rocks have been overturned 50 degrees to near vertical. Based on new geologic mapping district scale northeast- and northwest-trending faults are predominant and are likely related to rotation of the Chillagoe Formation. The strike of the northwest fault sets are nearly parallel to the strike of the bedding of the Chillagoe Formation and the Palmerville Fault whereas the northeast fault set is perpendicular. With the exception of the Palmerville and Redcap Faults the dip of these faults are currently unknown. With the exception of the Redcap Fault the displacement directions are unknown. The majority of the northeast-trending faults are cut by the northwest fault set. Only one example has been found of northeast faulting cutting a northwesterly fault. The Red Dome porphyry cuts and is not displaced by one of the northeast tending faults which demonstrates that one of the northeast-trending faults pre-date Carboniferous magmatism. One of the northwest trending faults are cut by the early Permian Ruddygore pluton. Since the porphyries and plutons in the district are vertical we interpret the Carboniferous magmatism and the related skarn-porphyry mineralization to postdate rotation of the Chillagoe Formation.

Carboniferous to Permian magmas intruded the overturned Chillagoe Formation and caused the Chillagoe skarns and porphyry deposits. Based on molybdenite Re-Os and zircon U-Pb age analysis three general age populations of magmatism and associated skarn occur within the Chillagoe district: ~335 Ma, 322-307 Ma and 301-297 Ma. The oldest recorded age of mineralization in the Chillagoe district is 334.8 $\pm$ 3.3 Ma (molybdenite Re-Os age; 2 sigma uncertainty) at the Mungana Zn-Pb-Cu distal skarn. The causative intrusion for the zinc resource remains at depth below drilling limits. A separate porphyry gold resource at Mungana and Au-Cu skarn mineralization at Red Dome are hosted by thin (35-200 meters wide) rhyolite porphyry intrusions and their associated breccia systems. The porphyries have been dated between 322-312 Ma by zircon U-Pb method. These intrusions have a CIPW normative compositions of granite.

At both Red Dome and Mungana, the largest deposits in the Chillagoe district, hydrothermal breccias immediately above the rhyolite porphyries host significant amount of mineralisation with relatively higher grades. The formation of the hydrothermal breccias is believed to be related to the texture of the intrusive rocks. The porphyries contain 10% or less phenocrysts including vermicular quartz with lesser euhedral feldspar. The vermicular quartz indicate a high fluorine activity and low magma viscosity. The scarcity of phenocrysts is favorable for water bubbles rising through the melt. Water bubbles in silicate melt tend to attach to existing crystals therefore abundant crystals may slow down the rising of aqueous phases to the top of a magma chamber. It is speculated that coupled magmas low viscosity and low phenocryst abundance could allow large amounts of water to rise through the melt quickly which may result in large amount of magmatic water escaping the magma chamber violently, causing hydrothermal explosions and the formation of their associated hydrothermal breccia systems.

The formation of the Mungana and Red Dome deposits (322-312 Ma) was followed by the eruption of the Redcap Dacite Group rocks and emplacement of a mediumgrained granite below Mungana (310-307 Ma). The Chillagoe Formation was then thrust on top of the ~308 Ma Redcap Dacite Group. This northwest-dipping thrust contact is cut by later Belgravia and Ruddygore plutons (301-297 Ma), thus the timing of this fault is between 308-301 Ma.

Emplacement of the large volume (>2 km wide), medium-grained Belgravia and Ruddygore plutons (301-297 Ma) followed the thrusting of the Chillagoe Formation. These plutons cut both the Chillagoe Formation and the Redcap Dacite Group. The intrusive rocks have CIPW normative compositions of granodiorite to tonalite. Where the large plutons intersect limestone, thin and discontinuous garnet-bearing skarns occur locally. Subsequent erosion has exposed large portions of the plutons.

All Carboniferous to Permian igneous rocks in the district have Fe_2O_3/FeO ratios (1.3-1.6) typical of oxidized magmas and magnetite series granitoids. Coupled with the relatively oxidized mineralogy of the skarns (andraditic garnet; abundant magnetite and the lack of pyrrhotite) we conclude that the skarn and porphyries of the Chillagoe district formed from oxidized magmas. The deposits are not reduced intrusion related gold systems as described by previous authors.