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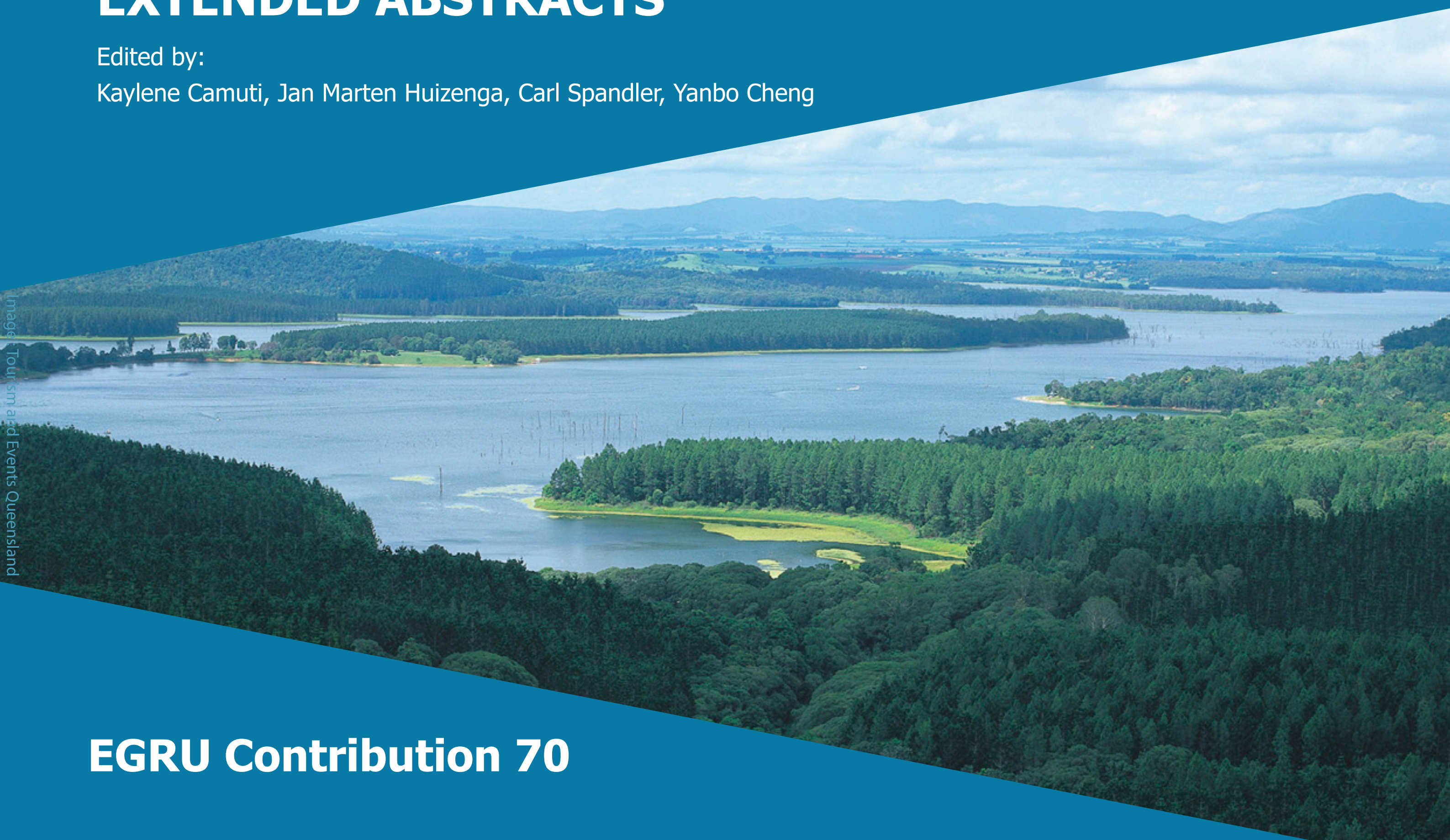
Sn-W-Critical Metals & Associated Magmatic Systems

An International Geological Conference

24th - 28th June 2019
Tinaroo Lake Resort
Atherton Tablelands
Queensland, Australia

EXTENDED ABSTRACTS

Edited by:
Kaylene Camuti, Jan Marten Huizenga, Carl Spandler, Yanbo Cheng



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The Watershed tungsten deposit, NE Queensland, Australia: An example of a Permian metamorphic tungsten upgrade after a Carboniferous magmatic-hydrothermal mineralisation event

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Tungsten is considered a strategic metal by various countries, including Australia. Between 1998 and 2016 Australia has been steadily increasing its tungsten production, but it is still far smaller than those of the main producers (e.g., China, Russia). Watershed with its current resources of 49.2 Mt averaging 0.14% WO_3 is considered one of the biggest undeveloped tungsten deposits outside of China, and if developed would boost Australia's tungsten production. We will be presenting the geological, geochemical and structural characteristics of the Watershed deposit, as well as the timing, mineral paragenesis and fluid characteristics of the mineralizing system; with the main goal of improving our understanding of the Watershed tungsten deposit and how to explore for similar deposits in northeast Queensland.

Geological context

The Watershed tungsten deposit lies within the Mossman Orogen (Fig. 1A), which comprises multiply deformed Silurian-Ordovician metasedimentary rocks of the Hodgkinson Formation intruded by Carboniferous-Permian granites of the Kennedy Igneous Association (Fig. 1B) (Champion and Bultitude, 2013; Henderson et al., 2013). The Hodgkinson Formation is host to tungsten, tin, copper and gold deposits (Fig. 1B). The Hodgkinson Formation in the Watershed area comprises skarn-altered conglomerate, psammite and slate units, which record at least four deformation events including early ductile folding and shearing events (D_1 to D_3) and later brittle-ductile shear zones (D_4) associated with mineralisation and the emplacement of scheelite-bearing tension veins, which record four separate stages of retrograde metamorphism/alteration (Retrograde Stages 1 to 4). Peak metamorphic assemblages (garnet, actinolite, quartz, clinopyroxene, titanite) in the host rocks to mineralisation formed during D_{1-2}. Multiple felsic dykes intruded the metasedimentary rocks at Watershed and include: (a) Carboniferous, monzonite dykes (zircon U/Pb age of 350±3 Ma) emplaced during D_{1-2}; and (b) Permian granite plutons and dykes (zircon U/Pb ages of 276±2 Ma, 275±2 Ma and 273±1 Ma), and diorite (zircon U/Pb age of 281±1 Ma) emplaced during D_4.

Mineralisation events and paragenesis

An early (syn-D_{1-2}) mineralisation event involved the syn-tectonic growth of disseminated scheelite in monzonite dykes and adjacent skarn-altered conglomerate, and was associated with the emplacement of the monzonite, which appears to have enriched the Hodgkinson Formation in W-Be-B-Sc-Cu-Mo-Re. The bulk of the economic scheelite mineralisation formed in syn-D_4 shear-related, quartz-oligoclase veins and associated vein haloes (with a muscovite Ar-Ar age of 276±6 Ma). The veins developed preferentially in skarn-altered conglomerate, and they terminate abruptly where they encounter slate. Vein opening involved four stages, each associated with a characteristic retrograde alteration assemblage. The margins of the D_4 veins contain feldspar, scheelite and quartz, which represent Retrograde Stages 1 and 2. During Retrograde Stage 1 early sanidine (overgrown by plagioclase, An_{15-55}) formed with minor quartz. Retrograde Stage 2 is characterised by intergrown scheelite and plagioclase (An_{3-43}) overgrowing early plagioclase, phlogopite and trace apatite. Further vein opening during Retrograde Stage 3 infilled the central part of the vein with quartz, which is intergrown with muscovite, calcite and minor chlorite, tourmaline and fluorite. Fractures that formed during Retrograde Stage 4 cut textures belonging to the previous stages and contain pyrrhotite, arsenopyrite with lesser pyrite, chalcopyrite, and sphalerite.

Scheelite trace element characteristics

Scheelite can incorporate small amounts of REE, and the origin of the scheelite grains (i.e. intrusion-related vs metamorphic) has been investigated using the relative abundance of contained LREE, MREE and HREE. Using ternary REE plots, early D_{1-2} scheelite in monzonite coincides with the compositional field for scheelite that forms during magmatic-hydrothermal processes, whereas late D_4 vein-hosted scheelite is compositionally similar to pure hydrothermal scheelite. The Eu and Mo contents of scheelite, coupled with graphite inclusions in scheelite and the presence of pyrrhotite and arsenopyrite in scheelite-bearing veins, show that D_{1-2} scheelite precipitated from a relatively oxidized fluid, while vein-hosted D_4 scheelite records a shift to more

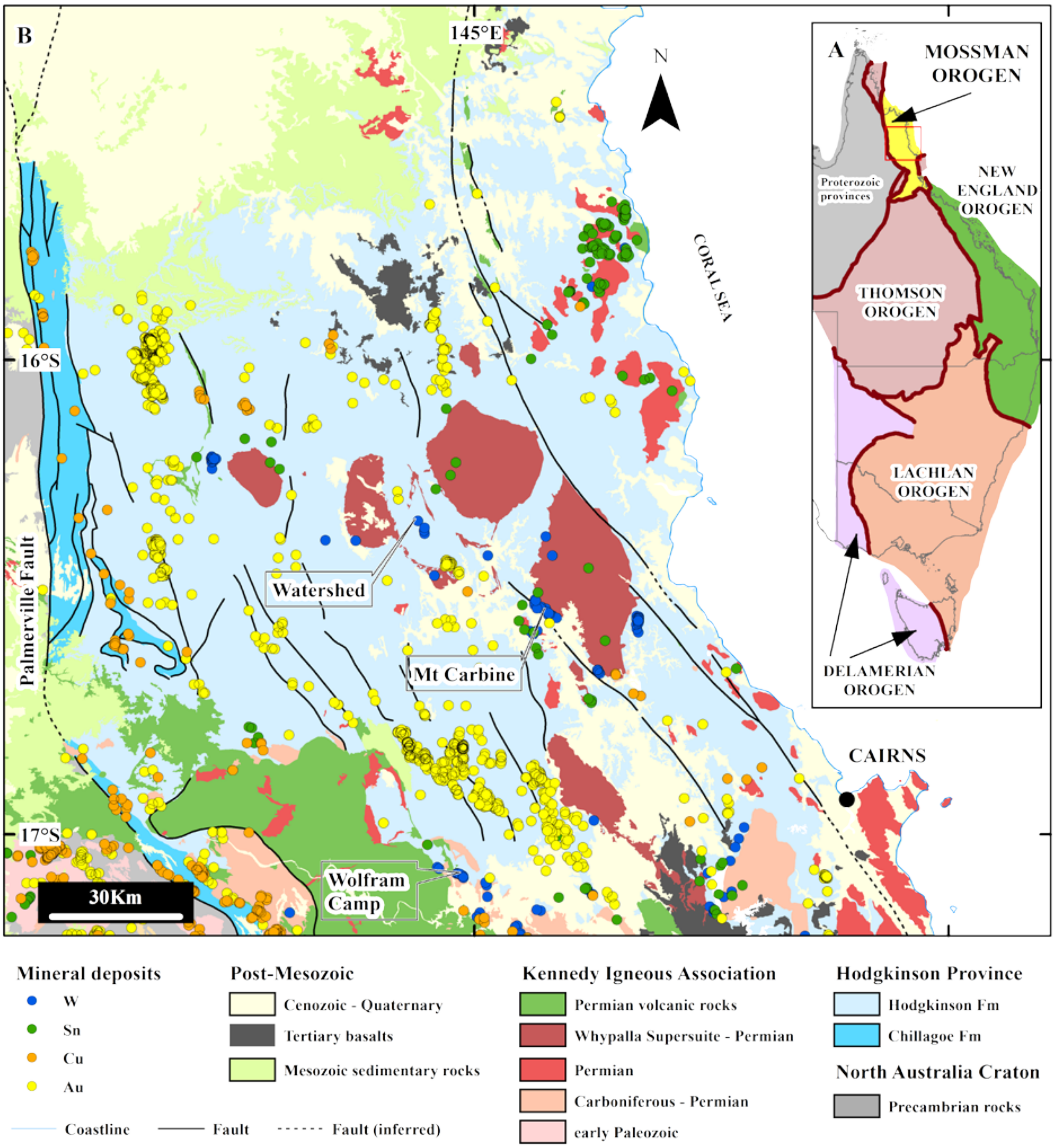

Fig 1. Regional geological setting of the Watershed tungsten deposit in northeast Queensland, Australia. The three largest tungsten deposits of the area are labelled: Mt Carbine (83,706 t WO_3), Watershed (70,400 t WO_3) and Wolfram Camp (12,260 t WO_3). Other tungsten deposits are much smaller (Chang et al., 2017). Also gold, copper and tin deposits hosted in hard rock are shown in the map. Note the higher density of mineral occurrences in the Hodgkinson Formation compared with the rocks of the Kennedy Igneous Association. Mineral occurrences are those compiled by the Geological Survey of Queensland (2017).

reduced conditions as a result of fluid interaction with carbonaceous shale.

Whole-rock geochemical pathfinders

Whole-rock geochemistry of the various rock types within the deposit indicates that the Watershed deposit is characterised by an enrichment of W-Be-B-Sc-Cu-Mo-Re. These elements were probably remobilised from the Hodgkinson Formation and introduced by hydrothermal fluids during D_4 veining. The fluid interacted with the skarn-altered conglomerate to leach REE, Y and Nb plus skarn-related elements (i.e., Ca-F-P-Fe-Sr), and add Rb, Cs and Li in vein haloes. Whole-rock geochemistry of psammite units along a 2 km transect north of the deposit shows a regional footprint that is characterised by enrichment in W-Cu-Mo-Ca-Fe-Mn-Li.

Fluid inclusions and stable isotope characteristics

Fluid inclusions in D_4 vein scheelite and quartz from Retrograde Stage 2 constrain *P-T* conditions during mineralisation to ca. 300°C and 1-1.5 kbar (i.e. depths of 3.5-6 km) indicating a high geothermal gradient, which has been linked to the emplacement of Permian granites.

The *P-T* conditions are similar to those recorded in lode-gold deposits in the Hodgkinson Gold Field and elsewhere (Peters et al., 1990; Groves et al., 1998; Vos and Bierlein, 2006). The fluid inclusions preserve a low salinity H_2O-NaCl-CH_4 fluid (XCH4 < 0.01) with evidence for fluid-fluid mixing between low- (close to 0 wt.% NaCl) and medium-salinity (< 8 wt.% NaCl) fluids. The oxygen fugacity was calculated at 0.6 to 0.8 $\log_{10}$ values below the FMQ buffer, consistent with the reduced mineralogy and geochemical signatures. $\delta^{18}O_{VSMOW}$ values obtained for scheelite (+3.4 to +7.3‰), plagioclase (+7.0 to +11.8‰) and quartz (+12.6 to +15.5‰), which formed during Retrograde Stage 2, and δD_{VSMOW} (-73.4 to -62.7‰) and $\delta^{18}O_{VSMOW}$ (+11.5 to +13.2‰) values for muscovite that formed during Retrograde Stage 3 are indicative of a metamorphic origin for the mineralising fluids, with a possible magmatic component. Sulphur isotope ($\delta^{34}S_{CDT}$) values for sulphides formed during Retrograde Stage 4 in veins are consistent with the presence of seawater sulphate (i.e. basinal brine) in the system. Metamorphic fluids probably originated from prograde devolatilisation reactions during metamorphism of the Hodgkinson Formation.

Main findings

Our findings indicate that tungsten was sourced from Carboniferous monzonite, which enriched the metasedimentary rock units of the Hodgkinson Formation during the early stages of deformation/ metamorphism. Continued ductile deformation and associated metamorphism during D_{1-3} caused devolatilisation reactions in the host rocks and remobilisation of tungsten. Permian scheelite mineralisation during D_4 involved a metamorphic-hydrothermal fluid with minor magmatic input that deposited tungsten at 300°C and 1-1.5 kbar (<6 km depth). This tungsten was transported as $NaWO_4^-$, HWO_4^- and WO_4^{2-} complexes (Wood and Samson, 2000) along extensional shear zones. Calcium was supplied by the skarn-altered conglomerate that hosts the scheelite-bearing veins. It is proposed that the precipitation of scheelite was promoted by the interaction between the relatively acidic hydrothermal fluids and the alkaline, carbonate-rich, skarn-altered conglomerate host rock, lowering the solubility of the tungsten complexes and co-precipitating scheelite and Na-rich plagioclase during Retrograde Stage 2.

The main controls on economic scheelite mineralisation at Watershed include: (a) D_4 shear-zones that formed in response to N-S extension; (b) D_4 tension veins (commonly E-W trending), that opened up in association with the shear-zones; (c) skarn-altered conglomerate units that supplied Ca as well as chemical (pH) and physical (localisation of tension veins) controls on mineralisation; (d) an extensional setting to allow fluid penetration; (e) high geothermal gradients driving fluid flow; and (f) the presence of ~350 Ma, scheelite-enriched monzonite dykes that appear to have prepared the ground. Thus, exploration should focus on the identification of ~350 Ma intrusions in association with skarn-altered units, and younger (i.e. D_4) shear-zones that formed in an extensional regime. Considering a continuum model for this deposit type (i.e. mineralisation could form between 2-20 km depth) there is potential for mineralisation at depth.

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