Epithermal deposits of the Central Pilbara tectonic zone
Description and exploration significance

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Epithermal textures have recently been recognised in north-northwest-trending quartz veins hosted by Mesoarchaean rocks of the Central Pilbara tectonic zone. These veins occur near the inferred unconformity with the overlying Neoarchaean Fortescue Group. Geological relationships and Pb isotope model ages of possibly correlative mineralisation suggest that this epithermal mineralising event was associated with the opening and early development of the Hamersley Basin at around 2750 million years. These results have significance not only to the potential for the Pilbara Craton and overlying Fortescue Group, but also to other Archaean terranes; preservation, not age, is the determining factor for Archaean epithermal mineralisation.

In 1997, Resolute Ltd geologists recognised the presence of epithermal veins in the Indee district within the 3.1–2.95 million year old Central Pilbara tectonic zone of the Pilbara Craton. These veins are located just below the inferred position of the unconformity between the Central Pilbara tectonic zone and the overlying 2.78 million-year-old Fortescue Group. Elsewhere in the Pilbara, epithermal veins may be present in the basal units of the Fortescue Group.

The purposes of this communication are to:
1. describe the geology, vein textures and mineralogy of selected deposits;
2. document the trace element geochemistry of the veins;
3. provide preliminary constraints on the composition and temperature of the mineralising fluids; and
4. discuss the significance of these deposits to the Pilbara Craton and other Precambrian provinces.

Becher prospect (621500 mE, 7683700 mN)*
Epithermal textures are best developed at the Becher deposit, a zone of anastomosing quartz veins in sandstone of the Mallina Formation (figure 2). Although the vein system has an overall strike of 350º, it is comprised of two vein sets, with the more dominant set striking 310º and the subordinate set...
striking 350°. Wall rocks adjacent to the veins have been altered to a quartz–sericite–(ex)pyrite assemblage that can be traced at least 50 metres from the vein system, where it grades into a ‘background’, chloritic assemblage (figure 2). Kaolinitic zones locally occur within the quartz–sericite–(ex)pyrite assemblage.

The Becher vein system is dominated by massive chalcedony. Weakly banded chalcedony, also relatively abundant, is characterised by diffuse or vague colour banding, but no distinct crustiform banding is developed. Other habits of quartz include pseudoacicular quartz, quartz pseudomorphs replacing a coarsely bladed mineral (possibly carbonate) and colloform–crustiform quartz. Brecciation of these other textures is also present locally.

Radial, needle-like quartz (pseudoacicular or ‘mold’ textures) is present both at the hand specimen (figure 3a) and the microscopic scales (figure 3b). Both the pseudoacicular textures and quartz pseudomorphs in these zones are typically five to 20 centimetres in length and one to five millimetres in thickness.

Crustiform quartz (figure 3c), which has a very restricted distribution (figure 2), is characterised by two- to 20-millimetre bands with a colloform habit. Locally this banding has been brecciated, resulting in complex overprinting relationships both at the hand specimen and microscopic scales.

Bladed gossan (figure 3d) is characterised by iron oxides that have replaced massive zones of an unoriented bladed mineral (possibly Fe-rich carbonate). Bladed gossan, present only at the highest hill in the Becher vein system, appears to be paragenetically late as it fills the centre of individual veins and locally cross-cuts other quartz types. Zones of coarsely bladed quartz appear to occur lateral to this zone of bladed gossan.

Brecciated textures occur to varying degrees throughout the Becher vein system. These textures vary from wall rock breccias with chaledonic infill to breccias in which crustiform clasts are filled by later chaledonic quartz (figure 3e), and to breccias with complex clast and matrix types.

In thin section other textures are present, including cockade and plumose textures (figure 3f). The plumose quartz is associated with sericite that occurs both as seams and in a stubby mass, possibly pseudomorphic after a stubby mineral such as feldspar (possibly adularia).

The presence of abundant chalcedonic quartz and bladed quartz pseudomorphs—combined with the presence of limited crustiform–colloform quartz and the absence of crystalline quartz—suggests that the exposed Becher vein system is in the chalcedonic superzone or the upper part of the crustiform–colloform superzone of Morrison et al. These observations suggest that a boiling zone, if present, is at depth. The presence of multiple episodes of brecciation in some veins is also encouraging for mineral potential for the Becher vein system.

Orange Rock deposit

The Orange Rock deposit is located 12 kilometres west-south-west of the Becher deposit within high-Mg granodiorite of the (~2950 Ma) Peawah Granodiorite. The Orange Rock vein system has an overall trend of 345°. Like the Becher vein system, it is segmented with two short segments in the northern and central parts of the vein system having trends in the range from 350 to 015° (figure 4).

Most of the Orange Rock vein system is characterised by well-developed vein breccias. These breccias typically contain one- to 20-centimetre clasts of silicified granodiorite and chaledonic quartz in a chaledonic matrix. Other textural types are much more restricted in their distribution. The
most abundant high-level textures in the Orange Rock vein system occur near the northern extremity. These vein textures occur in an approximately 50-metre-long, locally highly gossanous interval within a 345° trending segment just to the north of a jog from a 015° trending segment (figure 4).

Textures present in this gossanous interval include breccia, coarse bladed quartz pseudomorphs, and bladed gossan. The breccias contain silicified granodiorite clasts set within a gossanous matrix. The most unusual texture present in this zone is Fe-oxide pseudomorphs after a bladed mineral that has been folded (figure 3g). However, the lack of coherence within the folds and the lack of any other structural overprint suggest that the folds are not tectonic. Where the vein jogs to the south of this interval, the vein textures revert to the chalcedonic breccias characteristic of the vein system as a whole. This relationship implies that changes in vein trend have an important control on the development of epithermal textures in the Orange Rock vein system.

Bladed pseudomorphs of quartz are also present one kilometre to the south of the gossanous interval when the vein system bifurcates into a 350° trending main vein and a 530° trending branch. Chalcedonic quartz with disseminated pyrite is also locally present along the branch.

Veins in the Opaline Well Granite (575400 mE, 7679200 mN)
The 2765 million-year-old Opaline Well Granite is cut by a series of 0.2–3-metre quartz veins that trend north-west to north-north-west (320–345°) and have strike lengths up to several hundred metres. Although evidence of sulphide minerals (e.g. gossanous patches) is lacking, these veins typically have well-developed epithermal textures dominated by bladed pseudomorphs of quartz (figure 3h), with lesser, weakly banded chalcedonic quartz. An unusual characteristic of these bladed textures is that locally the blades are composed of fluorite and not quartz. In outcrop the fluorite weathers progressively, leaving residual silica ridges (figure 5a). In thin section, the selvages to some of the weakly banded chalcedonic veins are comprised of potassium feldspar (figure 5b). Marshall also reports the presence of epithermal textures in these veins, and notes the presence of colloform and crustiform textures.²

Sams Ridge deposit (590300 mE, 7707100 mN)
One of the more interesting prospects described by Marshall, the Sams Ridge deposit, is hosted by high-Mg basalt of the Louden Volcanics.² A brief visit was made to the Sams Ridge prospect at the location indicated by Smithies.³ This location is 2.3 kilometres north of the Sams Ridge prospect as identified by Marshall.²

The site visited is characterised mainly by grey-white chalcedonic quartz with minor gossanous zones and minor brecciated zones. Locally malachite and disseminated pyrite are present. The veins are generally narrow (<1 m) and strike due north. Marshall’s Sams Ridge prospect (590100 mN, 7704700 mE) consists of a north-trending 150-metre-wide zone of quartz veining and alteration along the same quartz vein system as the deposit visited by the authors. Marshall reports chalcedonic quartz, colloform banding, crack-seal textures and bladed pseudomorphs of quartz.² Gossanous zones, some of which contain oxide Cu minerals, occur along selvages of some of the chalcedonic veins.

Quartz Hill vein (5787000 mE, 7708000 mN)
The authors also visited a north-trending chalcedonic vein near Quartz Hill Well just to the north of the Sholl Shear Zone. This occurrence is characterised by a brecciated quartz vein up to 30 metres in width and three kilometres long. Other than the extensive brecciation, no epithermal textures were observed.

### References


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Figure 3. Photographs and photomicrographs showing textures in epithermal vein systems from the Central Pilbara tectonic zone.

A. Complex vein characterised by multiple generations of banded, pseudoacicular quartz
B. Banded clast with pseudoacicular quartz overgrowths (plane light)
C. Crustiform clast overgrown by crustiform quartz
D. Bladed gossan
E. Vein breccia, with crustiform quartz clasts in a chalcedonic quartz matrix
F. Plumose to subhedral quartz grains growing perpendicular to elongate seams of sericite. (Note the presence of a stubby shape of sericite mat in the centre of the frame and the fluid inclusions that decorate growth zones just above this sericite mat; crossed polars.)
G. Fe oxides, pseudomorphous after a bladed and folded mineral
H. Bladed pseudomorphs of quartz

Geochemical studies

Twenty-four grab samples were analyzed at Analabs’ Welshpool laboratory for a suite of elements (Au, Ag, Hg, As, Bi, Sb, Te, Ti, W, U, Cu, Pb and Zn) considered characteristic of the epithermal environment using a combination of AAS (atomic absorption spectrometry) and ICP-MS (induction coupled plasma-mass spectrometry) techniques. The samples were selected to be representative of the vein textures present at each deposit. Table 1 summarises the results.

The most anomalous samples were from the Becher prospect, where Au assays ranged upwards to 0.22 ppm. Arsenic, Bi, Sb, Te, W, Cu and Zn were also anomalous. Arsenic, Sb and Te were most elevated, with values to 6610 ppm, 178 ppm and 3.3 ppm, respectively. Analyses from the Orange Rock prospect, although lower than Becher, are still anomalous. The maximum assay for Au was 0.06 ppm, but As (to 208 ppm), Sb (to 14 ppm) and Te (to 0.6 ppm) were significantly elevated relative to average crustal abundances.

With the exception of weak Sb and Te anomalous, the results from the Opaline Well and Quartz Hill Well veins are uniformly low. Marshall, however, reported anomalous Au, Sb and Cu in streams draining the contact between the Opaline Well Granite and surrounding turbidites. In contrast, results from Sams Ridge are enriched in Ag, Hg, Au, Bi, Sb, Te and Cu, but Au assays are low (Table 1). Marshall reported highly anomalous assays from his Sams Ridge prospect, with values up to 0.44 ppm Au, 15 ppm Ag, 90 ppm As, 8100 ppm Sb and 9860 ppm Cu. These latter results are the most significant reported for an epithermal prospect from the Central Pilbara tectonic zone.

Fluid inclusion studies

Preliminary fluid inclusion studies were undertaken on two samples from the Becher deposit. In the first sample, equant fluid inclusions that decorate growth banding in plumose quartz yielded eutectic temperatures of -50 to -46ºC, indicating the presence of other salts (e.g. KCl, CaCl₂, MgCl₂, FeCl₂) besides NaCl. Salinities ranged between 9.2 and 17.8 wt % NaCl equivalent with a mode around 15.5 wt % NaCl equivalent. The inclusions homogenised over the range from 92 to 161ºC with a mode at 146ºC.

In the second sample, characterised by rhythmically banded chalcedonic quartz, primary inclusions decorate growth bands in euhedral quartz crystals that occur on the boundary of the chalcedonic quartz. These primary fluid inclusions are rounded to irregular in shape. Eutectic melting could not always be observed. When it was it ranged from -16.4 to -12.5ºC. Salinities of inclusion fluids were all less than 3 wt % NaCl equivalent. Homogenisation occurred over a range of temperatures from 130 to 299ºC with the majority of inclusions homogenising below 210ºC.

No definitive evidence for boiling was found in either sample, but the vapour phase is commonly not trapped in epithermal systems. The large scatter in homogenisation temperatures in the second sample may be the result of necking down or other post-entrapment modifications. Temperatures near the minimum homogenisation temperature (i.e.
130–150°C) most likely represent trapping temperatures as post-entrapment modifications commonly increase observed homogenisation temperatures. The salinity of the fluid in the first sample is clearly higher than that reported for most epithermal systems. Although early high-salinity fluids have been previously reported from the Creede and Summitville deposits (Colorado, USA),8 the significance of these high-salinity fluids at Becher is not understood. The lower fluid salinities (reported from sample 98044088A) are more akin to those from typical epithermal systems.7

**Discussion**

Vein textures, trace element associations and the preliminary fluid inclusion data are all consistent with an epithermal origin for the Becher, Orange Rock, Opaline Well and Sams Ridge vein systems. The combination of chaledonic, pseudoacicular, crustiform and bladed pseudomorphs is diagnostic of the epithermal environment,9 and the trace element assemblage As–Sb–Te±Bi±W is also consistent with such an environment.10 Moreover, the presence of potassium feldspar at the Opaline Well veins suggests a low sulphidation character to some of the deposits. The fluid inclusion characteristics of the Becher system are also consistent with an epithermal origin.

The age of the mineral deposits has not been established directly. However, inferences can be made based on geological relationships, particularly from the Opaline Well occurrences. The veins at Opaline Well cut 2765 million-year granite set a maximum age of the mineralisation. Fluorite in these veins is found elsewhere in the Pilbara, in veins that have model Pb isotope ages of 2700–2750 million years.11 Moreover, all Pilbara veins occupy north-west- to north-trending structures associated with the opening of the Fortescue basin (at ~2780 Ma).12 These geological data are most consistent with, although not definitive of, an age of around 2700–2750 million years for the epithermal veins. If true, this suggests that Precambrian terranes, generally not considered prospective for these deposits, may contain epithermal deposits if a high crustal level has been preserved.

Finally, figure 1 shows that many of the veins, although north-north-west-trending, are located near north-east-trending structures such as the Kents Bore and Loudens Faults.
Conclusion
Quartz veins containing textures typical of epithermal vein deposits are present in a number of locations in the Central Pilbara tectonic zone. These veins cut a variety of host rocks including turbiditic sandstone, granite, high-Mg basalt, and high-Mg granodiorite. Elsewhere in the Pilbara, these veins cut basal units of the overlying Fortescue Group. These veins appear to be related geologically to the opening of the Fortescue Basin, with a probable age of approximately 2700–2750 million years. The presence of epithermal veins in the Pilbara indicates the possibility of epithermal deposits in other Precambrian terranes—provided that high-level environments have been preserved and not eroded.

Table 1. Range in trace element analyses from epithermal deposits of the Central Pilbara tectonic zone (all in ppm).

<table>
<thead>
<tr>
<th>Deposit</th>
<th>No</th>
<th>Au</th>
<th>Ag</th>
<th>Hg</th>
<th>As</th>
<th>Bi</th>
<th>Sb</th>
<th>Te</th>
<th>Th</th>
<th>W</th>
<th>U</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
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<td>Becher</td>
<td>12</td>
<td>&lt;0.01–0.22</td>
<td>&lt;0.1–1.8</td>
<td>&lt;0.005–0.36</td>
<td>0.2–3.5</td>
<td>2.6–178</td>
<td>0.2–3.5</td>
<td>&lt;0.5&lt;0.6</td>
<td>1.6–349</td>
<td>&lt;0.05&lt;0.119</td>
<td>4–740</td>
<td>&lt;5–170</td>
<td>&lt;4–409</td>
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<tr>
<td>Orange Rock</td>
<td>7</td>
<td>&lt;0.01–0.06</td>
<td>&lt;0.1–0.2</td>
<td>0.024–0.1</td>
<td>0.2–1.1</td>
<td>5.7–13</td>
<td>0.5–0.6</td>
<td>&lt;0.5–1.1</td>
<td>1.0–2.4</td>
<td>0.08–0.5</td>
<td>5–29</td>
<td>&lt;5–15</td>
<td>2–22</td>
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<td>Opaline Well</td>
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<td>&lt;0.1–0.012</td>
<td>0.024–0.024</td>
<td>0.2–0.5</td>
<td>8.4–3</td>
<td>0.8–1.3</td>
<td>&lt;0.5–1.3</td>
<td>1.6–1.6</td>
<td>0.07–0.07</td>
<td>5–5</td>
<td>23–5</td>
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<td>&lt;0.01</td>
<td>&lt;0.1–0.015</td>
<td>0.05–0.05</td>
<td>15–0.5</td>
<td>14.3–0.7</td>
<td>0.7–0.5</td>
<td>0.8–0.05</td>
<td>6–5</td>
<td>5–5</td>
<td></td>
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<tr>
<td>Sams Ridge</td>
<td>2</td>
<td>&lt;0.01&lt;0.02</td>
<td>2.3–4.5</td>
<td>1.64</td>
<td>73–868</td>
<td>0.5–7.9</td>
<td>60–131</td>
<td>0.6–0.8</td>
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<td>1.6–1.6</td>
<td>385</td>
<td>105–187</td>
<td>50–40</td>
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References

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