Epithermal deposits of the Central Pilbara tectonic zone

Description and exploration significance

DL Huston, B Keillor, J Standing, R Blewett & TP Mernagh

Epthermal textures have recently been recognised in north-north-west-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.[1] 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.[2]

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

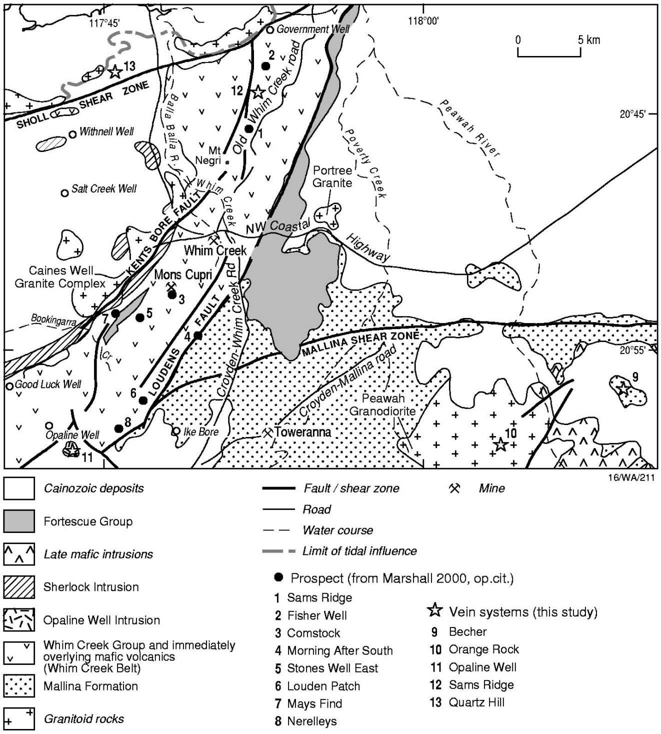

Figure 1. Location of epithermal deposits in the Central Pilbara tectonic zone (modified on Smithies, WA sheets 2456 & 2556—see references 5 & 13)

4. discuss the significance of these deposits to the Pilbara Craton and other Precambrian provinces.

Figure 1 shows the regional geology along with locations of epithermal deposits visited by the authors and described by Marshall.[2]

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 330°, it is comprised of two vein sets, with the more dominant set striking 310° and the subordinate set

* Zone 50 AMG locations using AGD66 datum

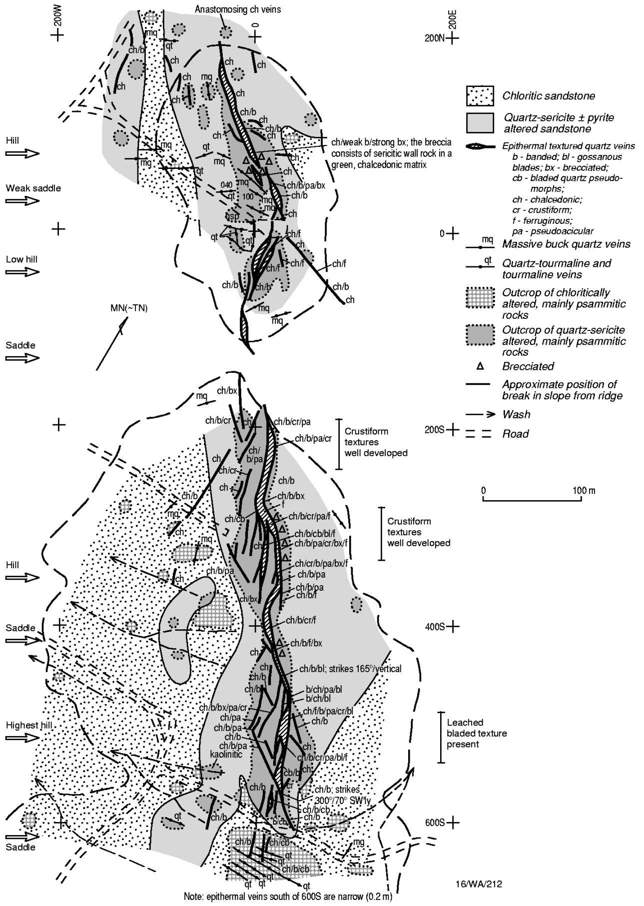

Figure 2. Surface geology of the Becher deposit

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 bladed minerals, and colloform–crustiform quartz. Brecciation of these other textures is also present locally.

Radial, needle-like quartz (pseudoacicular[3] or 'mold' textures[4]) is present both at the hand specimen (figure 3a) and the microscopic scales (figure 3b). Both the pseudoacicular textures and quartz pseudomorphs replacing a coarsely bladed mineral (possibly carbonate) are restricted in distribution (figure 2). Where present, bladed textures tend to occur along the hanging wall (e.g. western) side of the vein. Within these zones, the blades 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 banding 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 chalcedonic infill to breccias in which crustiform clasts are infilled by later chalcedonic 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 pseudomorphous after a stubby mineral such as feldspar (possibly adularia).

The presence of abundant chacedonic 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.[4] 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 (610250 mE, 7678900 mN)

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.[5] 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 chalcedonic quartz in a chalcedonic 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 psuedomorphs, 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 where the vein system bifurcates into a 350° trending main vein and a 330° 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[6] 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 recessively, leaving residual silica ridges (figure 5a). In thin section, the selvedges 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 mN) 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 selvedges of some of the chalcedonic veins.

Quartz Hill vein (578700 mE, 7708000mN)

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.

➥ *From page 33* **Standard database entry of sequence stratigraphic units in AGSO**

References:

Jones WH. 1985. A sequence framework for the Cretaceous of the Wildcat Basin. Drill Here Journal; 63:119–137.

Re-naming sequences

The naming of sequences in AGSO and elsewhere has been based on a number of methods in the past—most of which are inappropriate to the standards set out here. Names typically are not unique and are commonly based on alphanumeric codes or age-specific names. Use of the geographic parts of formally defined lithostratigraphic names is also widespread, even though the units often are not identical. Ideally, only where there is an exact vertical correspondence between a sequence stratigraphic unit and a lithostratigraphic unit should the geographic name also be adopted.

An example of how current *might* be revised is set out below, using the AGSO guidelines. Alongside the published version is a possible revised scheme, based on carriage names.

Published scheme	Possible revised scheme
BB12	Chariot Sequence
BB12C	Chariot 3 Subsequence
BB12B	Chariot 2 Subsequence
BB12A	Chariot 1 Subsequence
BB11	Coach Sequence
BB10	Phaeton Sequence
BB9	Brougham Sequence
BB8	Wagon Sequence
BB7	Rickshaw Sequence

References

1. Brakel AT. 1999. Avoiding stratigraphic confusion in exploration: The need for standards in sequence stratigraphy. APPEA Journal; 39(1):485–493.
2. Brakel AT & Passlow V. 1999. Preliminary AGSO scheme for standard database entry of sequence stratigraphic units. AGSO Research Newsletter, Nov; 31:20–21.

Acknowledgments: This scheme was developed from the preliminary scheme[2] by a forum of AGSO staff, who are thanked for their input.

➤ Dr Albert Brakel, Minerals Division, AGSO, phone +61 2 6249 9697 or e-mail albert.brakel@agso.gov.au

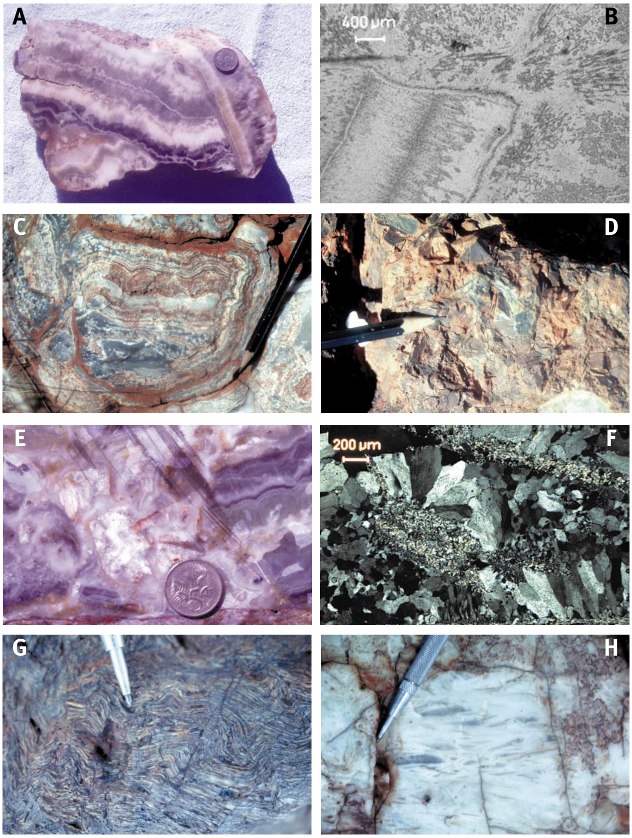

Figure 3. Photographs and photomicrographs showing textures in epithermal vein systems from the Central Pilbara tectonic zone.

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 a 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, Tl, 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 anomalism, 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.[2] In contrast, results from Sams Ridge are enriched in Ag, Hg, As, 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 9800 ppm Cu.[2] 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 -46°C, indicating the presence of other salts (e.g. KCl, $CaCl_2$, $MgCl_2$, $FeCl_2$) 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 161°C with a mode at 146°C.

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 -12.5°C. Salinities of inclusion fluids were all less than 3 wt % NaCl equivalent. Homogenisation occurred over a range of temperatures from 130 to 299°C with the majority of inclusions homogenising below 210°C.

No definitive evidence for boiling was found in either sample, but the vapour phase is commonly not trapped in epithermal systems.[7] 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.

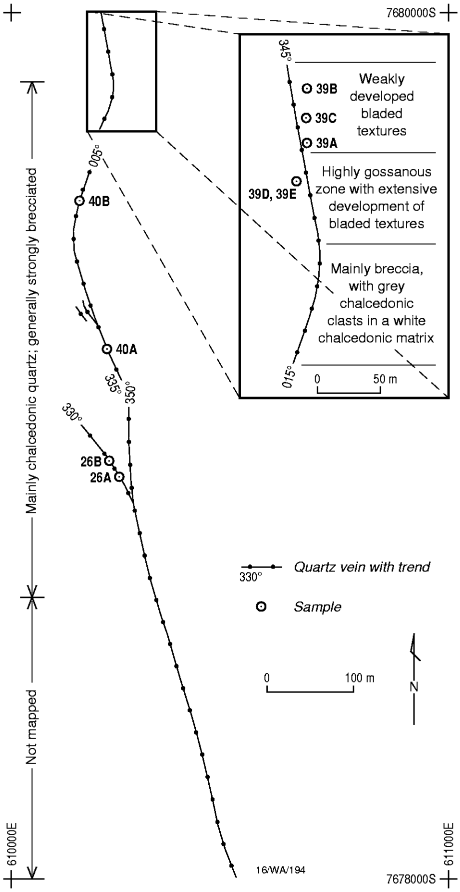

Figure 4. Geology of the Orange Rock vein system

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 (Colarado, 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 chalcedonic, 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.[7]

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.

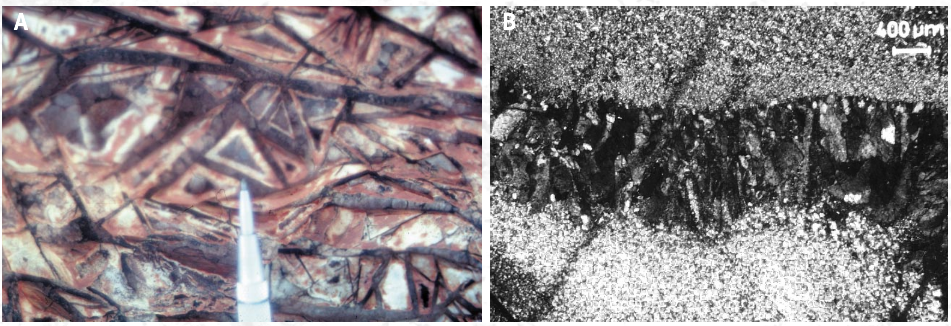

Figure 5. Photographs and photomicrographs showing textures in epithermal vein systems from the Central Pilbara tectonic zone. **A.** Fluorite pseudomorphs after a bladed mineral (recessively weathered) **B.** Low-temperature potassium feldspar forming selvedges to chalcedonic quartz vein

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).

Deposit	No	Au	Ag	Hg	As	Bi	Sb	Te	Tl	W	U	Cu	Pb	Zn
Becher	12	<0.01–0.22	<0.1–1.8	<0.005–0.36	15–6610	0.2–3.3	2.6–178	0.2–3.3	<0.5–0.6	1.6–34.9	<0.05–11.9	4–740	<5–170	<4–409
Orange Rock	7	<0.01–0.06	<0.1–0.3	0.012–0.024	6–208	0.2–1.1	5.7–13.5	0.5–0.6	<0.5	1.1–2.4	0.08–2.9	5–13	<5–22	5–26
Opaline Well	2	<0.01	<0.1–0.2	0.012	8–27	0.4–0.5	6.2–8.4	0.5 0.8	<0.5	1.3–1.6	<0.05–0.07	4–5	16–23	4–5
Quartz Hill	1	<0.01	<0.1	0.035	13	0.5	14.3	0.7	<0.5	0.8	0.05	6	5	5
Sams Ridge	2	<0.01–0.02	2.3–4.5	1.64	73–868	0.3–7.9	69–131	0.6–0.8	<0.5	1.0–1.3	0.16–4.3	1135 2820	<5–187	39–40

References

1. Hickman AH. 1999. New tectono-stratigraqphic interpretations of the Pilbara Craton, Western Australia. In: GSWA '99 extended abstracts: New geological data for WA explorers. Perth: Geological Survey of Western Australia, record 1999/6:4–6.
2. Marshall AM. 2000. Low temperature-low pressure ('epithermal') vein deposits of the North Pilbara granite-greenstone terrane, Western Australia. Canberra: AGSO, record 2000/1.
3. Dong G, Morrison G & Jaireth S. 1995. Quartz textures in epithermal veins, Queensland: Classification, origin, and implication. Economic Geology; 90:1841–1856.
4. Morrison G, Dong G & Jaireth S. 1990. Textural zoning in epithermal quartz veins. Townsville: James Cook University; unpublished AMIRA report.
5. Smithies RH. 1999. Yule (WA) sheet 2556. 1:100 000 geological series explanatory notes. Perth: Geological Survey of Western Australia.
6. Nelson DR. 1997. Compilation of SHRIMP U–Pb zircon geochronology data, 1996. Perth: Geological Survey of Western Australia, record 1997/2.
7. Bodnar RJ, Reynolds TJ & Kuehn CA. 1985. Fluid inclusion systematics in epithermal systems. Reviews in Economic Geology; 2:73–97.
8. Hayba DO, Bethke PM, Heald P & Foley NK. 1985. Geologic, mineralogic and geochemical characteristics of volcanic-hosted epithermal precious-metal deposits. Reviews in Economic Geology; 2:129–167.
9. Dowling K & Morrison GW. 1989. Application of quartz textures to the classification of gold deposits using North Queensland examples. Economic Geology; monograph 6:342–355.
10. Silberman ML & Berger BR. 1985. Relationship of trace-element patterns to alteration and morphology in epithermal precious-metal deposits. Reviews in Economic Geology; 2:203–232.
11. Huston D. 1999. Unpublished data.
12. Blake T. 1993. Late Archaean crustal extension, sedimentary basin formation, flood basalt volcanism and continental rifting: The Nullagine and Mount Jope supersequences, Western Australia. Precambrian Research; 60:185–241.
13. Smithies RH. 1997. Sherlock (WA) sheet 2456. 1:100 000 geological series explanatory notes. Perth: Geological Survey of Western Australia.

Acknowledgments: This contribution benefited from discussions with Subhash Jarieth, Hugh Smithies and Ken Lawrie. Subhash Jarieth and David Champion provided comments on an earlier version of this contribution.

- Dr David Huston, Minerals Division, AGSO, phone +61 2 6249 9577 or e-mail david.huston@agso.gov.au
- Brett Keillor, Resolute Ltd, phone +61 8 9261 6100 or e-mail bkeillor@resolute-ltd.com.au
- Jon Standing, Fluid Focus, phone +61 8 9474 5855 or e-mail jstanding@ozemail.com.au
- Dr Richard Blewett, Minerals Division, AGSO, phone +61 2 6249 9713 or e-mail richard.blewett@agso.gov.au
- Dr Terry Mernagh, Minerals Division, AGSO, phone +61 2 6249 9640 or e-mail terry.mernagh@agso.gov.au