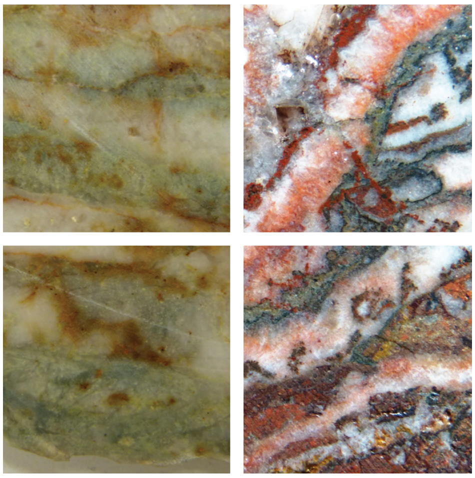
Fluid inclusion data from 23-Mile Quartz Quarry and Parkinson Dam, northern Eyre Peninsula

Ben E. Nicolson



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Geological Survey of South Australia, Resources and Energy Group

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Fluid inclusion data from 23-Mile Quartz Quarry and Parkinson Dam, northern Eyre Peninsula

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ABSTRACT

Seven samples of hydrothermal quartz displaying textures suggestive of vein formation in an epithermal environment were collected from quartz veins at two sites on the northeastern Eyre Peninsula. A combined fluid inclusion and oxygen-isotope study was initiated to determine fluid sources involved in vein formation. Five samples were collected from a quarry on the 23-Mile Quartz deposit, situated on the Pankalla Fault and two samples from vein material from the Parkinson Dam Au-Ag prospect. 100 µm thin-sections were prepared on four samples for fluid inclusion analysis to determine the temperature at which the veins formed; prior to proceeding to oxygen isotope analysis.

The data obtained from heating measurements showed fluid homogenisation temperatures have ranges in excess of 100 °C (collective Th = 148 to 308 °C). The wide range of temperatures indicates that the fluid inclusions have been modified since entrapment. As a result, further freezing measurements on these samples were not recommended. The inability to accurately determine the temperature of vein formation means that the appropriate fractionation factor, necessary to correct for the effect of mass dependent fractionation of the O-isotopic system, could not be determined and so any O-isotope measurements would be equally unreliable. As a result the anticipated oxygen isotope analyses did not proceed.

INTRODUCTION

During field mapping to update the ROOPENA 1:100 000 map sheet in 2014 multiple styles of hydrothermal veins were noted. Close examination identified a number of textures that suggest vein formation occurred at shallow depths, typical of an epithermal environment. These include colloform-crustiform banding, bladed carbonate replaced by quartz, or bladed carbonate replacement textures (BCRT) and cryptocrystalline (former chalcedony) silica. The most significant volume of veining occurs along the Pankalla Fault (McAvaney et al 2016) and is most clearly observed around the 23-Mile Quarry (Fig.1).

Epithermal textures were first recognised during mineral exploration programmes in the 1980s. The discovery of Menninnie Pb-Zn-Ag deposit and subsequent research by Roache (1996) confirmed many features of the deposit as epithermal. Colloform banded quartz veins with bladed carbonate, and banded sulfide veins were observed.

Subsequent mineral exploration led to the discovery of Au-Ag mineralisation at Parkinson Dam (Fig. 1) in 2007 (Smith 2008), and another Ag-Pb-rich mineral system with epithermal characteristics at Paris in 2011 (Anderson 2011). Parkinson Dam contains an abundance of epithermal textures including colloform-crustiform banding in some cases containing visible gold-silver alloys (electrum), BCRT, and amethystine quartz. In Paris, a more sulfide rich mineralised zone within a broad strong argillic alteration zone is encountered, with colloform-crustiform veins at the southern end of the deposit (Anderson pers. comm.). Growing acceptance that epithermal style mineralisation represents a valid exploration target on northern Eyre Peninsula has led to identification of additional veins with epithermal characteristics and research has been directed towards characterising these systems. Based of mineralogy, geochemistry, and vein textures the veins appear to conform to low-sulfidation to intermediate-sulfidation style epithermal deposits. A discovery in 1991 near Paris of an advanced-argillic alteration system at Nankivel Hill (Nicolson et al. in press) and associated anomalous As-dominated geochemistry are consistent with the high-sulfidation style end member of the epithermal group (Hedenquist 2000). A recent review (Wade and McAvaney 2015), documents many features of veins and breccias observed in additional sites on the northern Eyre Peninsula.

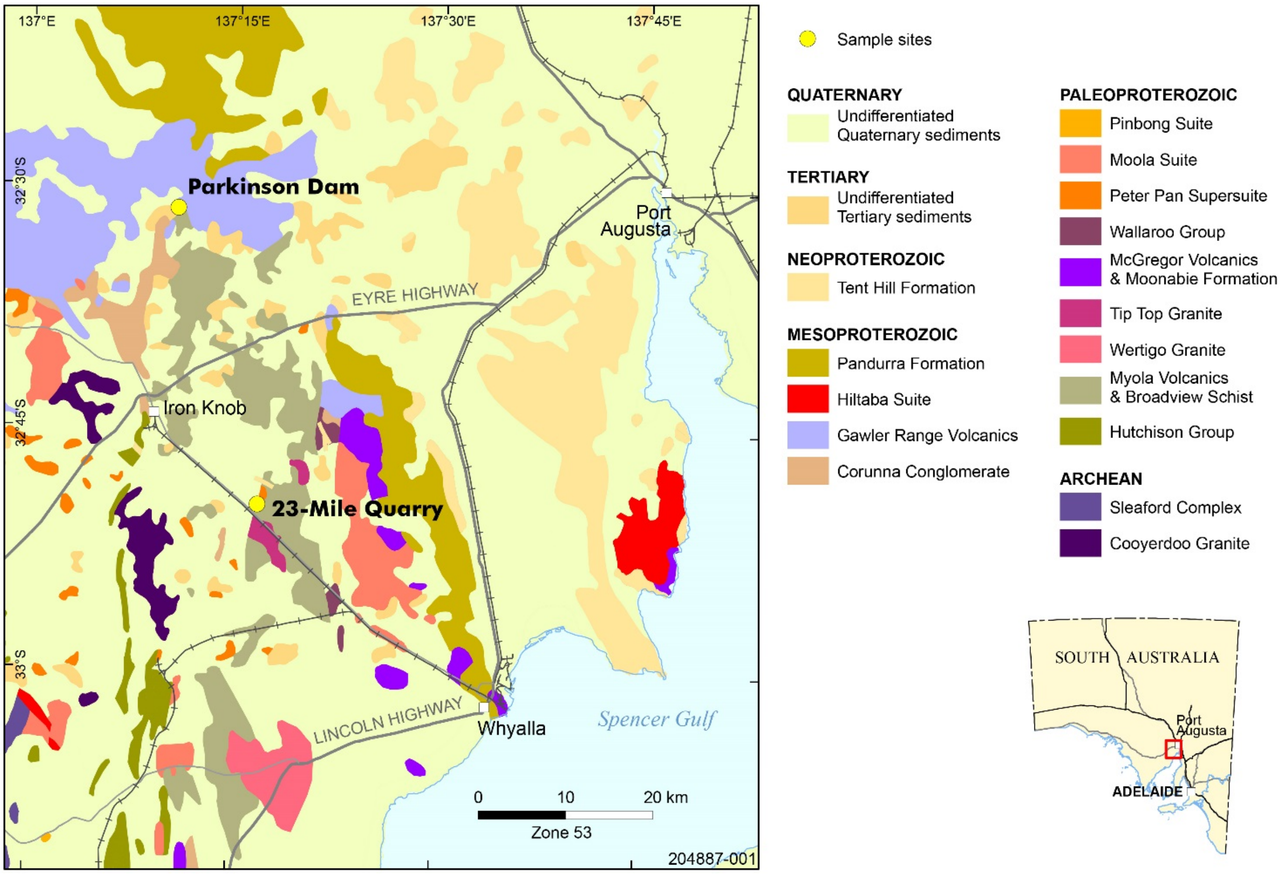

Figure 1. Regional and detailed location map showing the regional geology of the Parkinson Dam and 23-Mile Quarry locations sampled in this study.

FLUID SOURCES AND OXYGEN ISOTOPES

Research into oxygen (and hydrogen) isotopes has shown that major fluid source areas have distinct ranges in $\delta^{18}O$ values. A summary of the fluid source regions and expected $\delta^{18}O$ values are shown in Figure 2. Determining the isotopic composition of fluids from quartz samples is a useful aid in determining the origin of hydrothermal fluids responsible for the formation of veins and mineralisation. The veins in the study area are assumed to be of two major styles with strongly contrasting isotopic signatures. Hence, determination of their isotopic ratio would provide a useful indicator of fluid origin. Fluid sources are often a strong indicator of the types of mineralisation that is likely to be found associated with the hydrothermal activity that produced the veins and as such, the study of vein isotopic signatures is a useful tool in assessing mineral potential of an area.

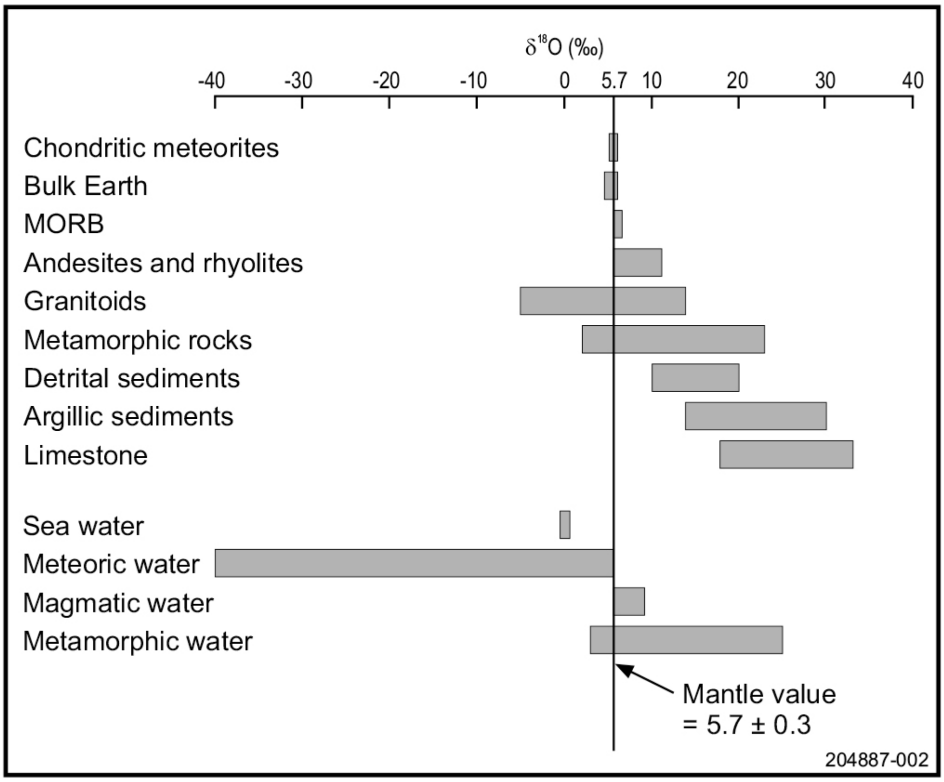

Figure 2. Natural oxygen isotope reservoirs. Taken from Rollinson (1993); data from Taylor (1974), Onuma et al. (1972), Sheppard (1977), Graham and Harmon (1983) and Hoefs (1987).

RATIONALE

Hydrothermal systems dominated by meteoric water that form at shallow depths, (typically ≤1000 m depth below surface are referred to as epithermal systems. Typically veins of this type form in a volcanic environment proximal to a heat source such as a subvolcanic intrusive that drives the system. The ascending hot fluids are subject to rapidly changing conditions that can induce boiling. Such changes destabilise the fluids causing rapid precipitation of minerals including metalliferous minerals in fertile systems, however fluid inclusions that form in quartz in epithermal vein systems are often very small due to the rapid precipitation of the gangue minerals.

Hydrothermal systems dominated by metamorphic fluids are formed at depths of typically >1000 m, and most often at depths of >3 km to ~15 km depth, in a mesothermal environment. Resultant veins are termed mesothermal or orogenic vein systems. Mesothermal veins are generally formed under uniform conditions that can remain stable for long periods of time. Fluid inclusions formed in mesothermal systems tend to be larger than their counterparts from epithermal vein systems.

The 23-Mile Quarry is located 25 km south of Parkinson Dam and the southern margin of the Gawler Range Volcanics (GRV). Without any obvious proximal volcanic heat source, the origin of the epithermal textures evident in veins in outcrops at the quarry is somewhat enigmatic.

An alternative hypothesis is that an unusually high geothermal gradient may have existed without the presence of proximal subvolcanic intrusives. If the geothermal gradient, or permeability was sufficient to maintain a high fluid temperature such that ascending metamorphic fluids boiled and deposited quartz, identical epithermal textures would form, but from fluids of a very different source.

The textures present in epithermal veins are therefore useful indicators of depth of formation in a particular vein system however, are not diagnostic of the type of fluids involved. A possible heat source in this sense is the South Australian heat flow anomaly (SAHFA), Neumann et al. (2000). Mass dependent fractionation affects the stable isotopes of the lighter elements including oxygen (Faure and Mensing 2005). Fractionation factors decrease with increasing temperature of the fluid between 1 °C and 350 °C (Faure 2009; Horita and Wesolowski 1994) however, effects are most pronounced at low to mid-range temperatures. The effect can be significant, therefore a well constrained entrapment temperature is required to provide meaningful basis for oxygen isotope ratio calculations that are necessary to interpret the source of fluids.

23-MILE QUARTZ DEPOSIT

Large outcrops and quartz blows consisting of white quartz occur along the Pankalla Fault (McAvaney et al. 2016). Composite veins, consisting of multiple overprinting vein sets attain a maximum thickness of 30–40 m in the 23-Mile Quartz Quarry, situated at 32.8293 °S 137.28067 °E, close to the Iron Knob–Whyalla Road (Fig. 1).

The quarry faces provide excellent exposures of the vein where textural relationships can be observed (Fig. 3). Vein textures include massive crystalline quartz ('buck' quartz), cut by anastomosing vein networks containing comb-texture crystalline quartz, colloform and colloform-crustiform banded quartz, bladed carbonate replacement textures, which attain an extremely coarse size of several centimetres, carbonate molds and geopetal features. Textures indicative of repeated brecciation are observed at intervals along the vein and include cockade and hydrothermal mill breccias composed of rounded to sub-angular quartz fragments cemented within later hydrothermal quartz. Textures are summarised in Figure 3.

Figure 3 (next page). Vein textures from the 23-Mile Quarry. (a) Batter face exposures at the north end of the 23-Mile Quarry. Quartz veining occupies the entire 25 metre field of view. **(b)** Quartz pyrite veins in silicified and sericite altered wall rock (Broadview schist). Sample contains 2–5% disseminated pyrite and minor green alteration sulfates containing anomalous Cu ~200 ppm. Sample number R2079425. **(c)** Crystalline quartz, appearance is more typical of mesothermal vein quartz. Sample number R2079427. **(d)** Pale grey, sericite included quartz or intensely silicified zone, cut by weakly banded quartz veinlets. Sample number R2079429. **(e)** Parallel banded late stage veins containing comb-ectureds coarsely crystalline ingrowths. Sample number R2079430. **(f)** Extremely coarse bladed carbonate replacement texture. Early formed coarse carbonate wafers have been replaced by quartz, pseudomorphing and preserving the original texture. Sample number R2079431.

Figure 3. Vein textures from the 23-Mile Quarry.

PARKINSON DAM

Veins at Parkinson Dam Au-Ag prospect, situated at 32.52415 °S 137.17782 °E are typically narrow and range from a few millimetres to 30 centimetres thickness. The veins are composed entirely of texture styles indicative of formation in an epithermal environment; fine grained chalcedonic to saccharoidal quartz, banded colloform veins, comb-textured veins, often composed of amethyst, and BCRT (Fig. 4). Sulfide is present in veins comprising up to 5% of the vein, and contains pyrite, galena, sphalerite and chalcopyrite. Gold-silver alloy (electrum) is visible in high-grade veins that include individual assays up to 106 g/t Au (Smith 2008).

The major host to veining is the Corunna Conglomerate which overlies Broadview Schist. Veining outcrop across a peneplained synclinal fold hinge within the Corunna Conglomerate. The structural control on the veins is poorly understood. Veins have a sporadic distribution over the prospect area, and mostly appear as a series of discontinuous veins with limited strike and dip extent. The presence of extremely high grade gold intersections (>100 g/t Au) makes the system a highly attractive gold exploration target, despite the difficulties such a system presents in regards to defining ore reserves.

The GRV unconformably overlie the Broadview schist to the east and wrap around, and may overlie portions of the northerly expression of the Corunna Conglomerate (Fig. 1). Veining does not appear to be developed within the GRV, though float trains containing vein quartz derived from the Corunna Conglomerate spread across some areas of GRV outcrops.

All of the veins observed display low- to intermediate-style epithermal textures. The association of precious metal mineralisation attaining exceptionally high grades is typical of a depth of formation within the precious metal zone as described by Buchanan (1981). The simple mineralogy of gangue and low percentage of sulfide ore/gangue minerals is also characteristic of low-sulfidation epithermal vein systems.

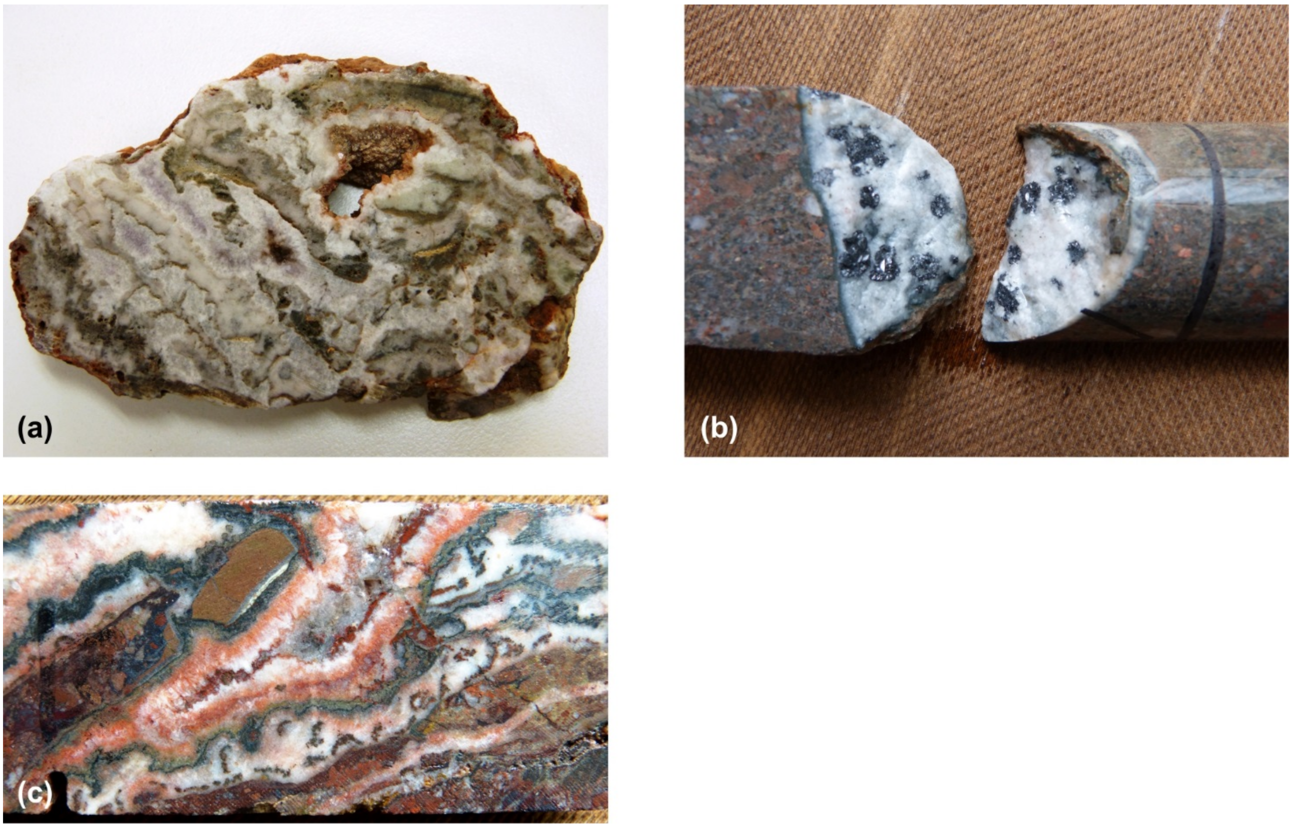

Figure 4. Vein textures from the Parkinson Dam low-sulfidation epithermal Au-Ag prospect. (a) Banded colloform to crustiform quartz veins. Colloform bands consist of fine-grained quartz (originally chalcedony?) alternate with comb textured bands and amethyst bands. Sample is anomalous in gold (~1 ppm Au). Sample number

R2079433. **(b)** Quartz-galena vein sampled for fluid inclusion analysis. Sample from RCDD07PD63, 383.55–383.61 m. Sample number R2079791. **(c)** Complex vein and cemented wall rock fragments. Colloform-crustiform features are present and contained visible Au. RCDD07PD63, 199.0–199.1 m. Sample number R2079796. Sample is typical of banding and grade commonly seen in the mineralised zones of epithermal gold deposits.

METHODOLOGY

A necessary component of any study of oxygen isotopes is to firstly determine the temperature of the fluids at the time of quartz precipitation and is best done by a fluid inclusion study. This data enables a correction factor to be applied to compensate for mass-dependent fractionation of the isotopic system (Faure and Mensing 2005). The results can be used to indicate the environment from which the fluid was sourced. In the study case, the purpose was to determine whether the veins were from fluids dominated by meteoric water or metamorphic water.

Double-polished 100 micron thin sections were prepared by Adelaide Petrographic Laboratories and forwarded to GNS Science, New Zealand for investigation. Fluid inclusions in four sections were examined in a heating stage to obtain data on the temperature of vein formation.

Samples were selected with the aim of determining the oxygen isotope composition of the quartz (SiO_2) in order to gain insights into the fluid chemistry and source regions of fluids.

A suite of 25 samples of hydrothermal quartz veins were collected from two locations on the northeastern Eyre Peninsula. Nine samples were collected from the 23-Mile Quartz Quarry and four samples were collected from the Parkinson Dam Au-Ag prospect (Fig. 1), in addition to nine samples of drill core from Parkinson Dam. Seven of these samples were selected for follow-up petrology, fluid inclusion and oxygen isotope work Details of the shortlisted samples are shown in Table 1.

Table 1. Table of sample data for prospective fluid inclusion and stable isotope study.

Sample number	Site	Class	Anomalism	Description	Latitude (WGS84)	Longitude (WGS84)
R2079425 Outcrop	23-Mile Quarry	Mineralised vein	Cu	Pyrite with anomalous Cu in chalcedonic to crystalline quartz	-32.82871	137.28003
R2079427 Outcrop	23-Mile Quarry	Crystalline quartz		Massive crystalline quartz outbound from other sample sites	-32.82824	137.27997
R2079429 Outcrop	23-Mile Quarry	Crystalline Quartz		Massive crystalline quartz	-32.82812	137.27996
R2079430 Outcrop	23-Mile Quarry	Epithermal		Multistage banded comb veins – late stage epithermal	-32.82813	137.28000
R2079431 Outcrop	23-Mile Quarry	Epithermal		Epithermal textures dominated by coarse BCRT, chalcedony	-32.82868	137.28007
R2079433 Outcrop	Parkinson Dam	Mineralised vein	Ag-Au	Ag-Au bearing brecciated chalcedony with later comb crystalline clear to amethystine quartz infill	-32.53811	137.17082
R2079791 RCDD07PD 63 384.13 – 384.22 m	Parkinson Dam	Mineralised vein	Pb	Saccharoidal moderately crystalline, weakly banded quartz vein with galena. Some growth zoning in comb quartz.	-32.53527	137.17149

RESULTS

Fluid inclusion heating studies were completed on four samples provided to GNS Science. In all cases fluid inclusion geometry suggests post entrapment modification and that the inclusions are not primary. Results are detailed in Table 2.

Heating data revealed a large range in homogenisation temperatures, such that no distinct statistically viable population could be determined (Figs 5 and 6). Such tight constraints upon temperature, as previously mentioned are necessary for an accurate correction factor to be applied to the $^{16}O/^{18}O$-isotopic ratios. As a result no definitive conclusions could be drawn from any O-isotope analyses that were conducted on the samples.

Table 2. Fluid inclusion heating study results.

Sample	Mineral	Inclusion type	Th range (°C)	n	Average
2079425 (23-Mile Quarry)	Quartz	secondary	168 to 272	19	200
2079425 (23-Mile Quarry)	Quartz	pseudosecondary?	148 to 286	19	199
2079433 (Parkinson Dam)	Quartz	secondary / (pseudosecondary?)	151 to 273	7	198
2079791 (Parkinson Dam)	Quartz	secondary	163 to 308	15	218

Without the possibility of a clear outcome, proceeding with oxygen isotope analysis on these samples was deemed to have no merit and the program was terminated.

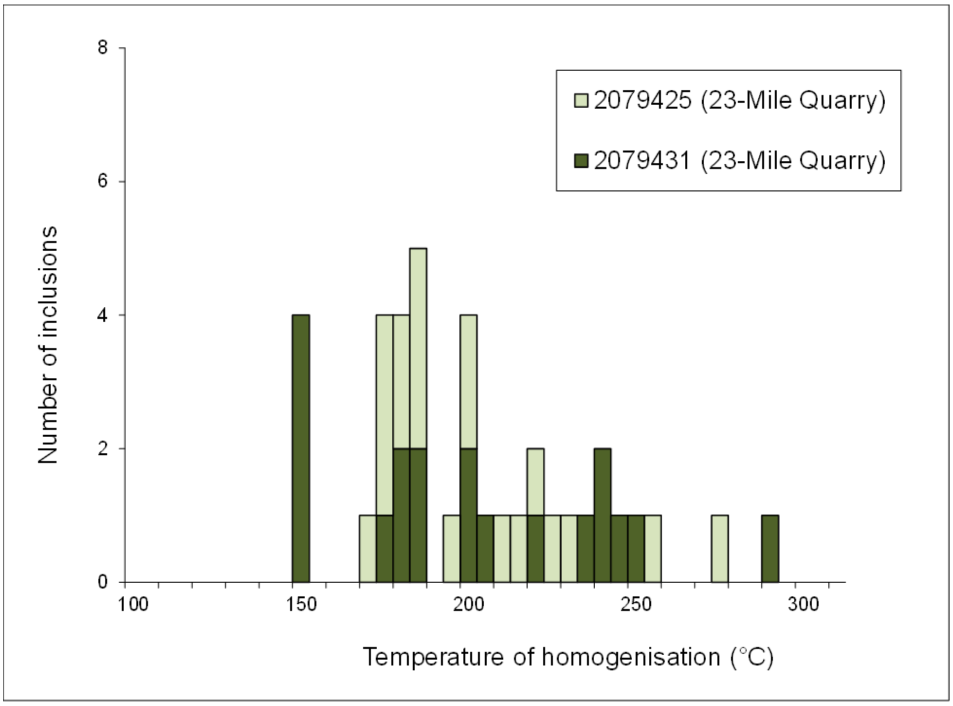

Figure 5. Fluid inclusion temperature and population distribution graph, 23-Mile Quarry samples.

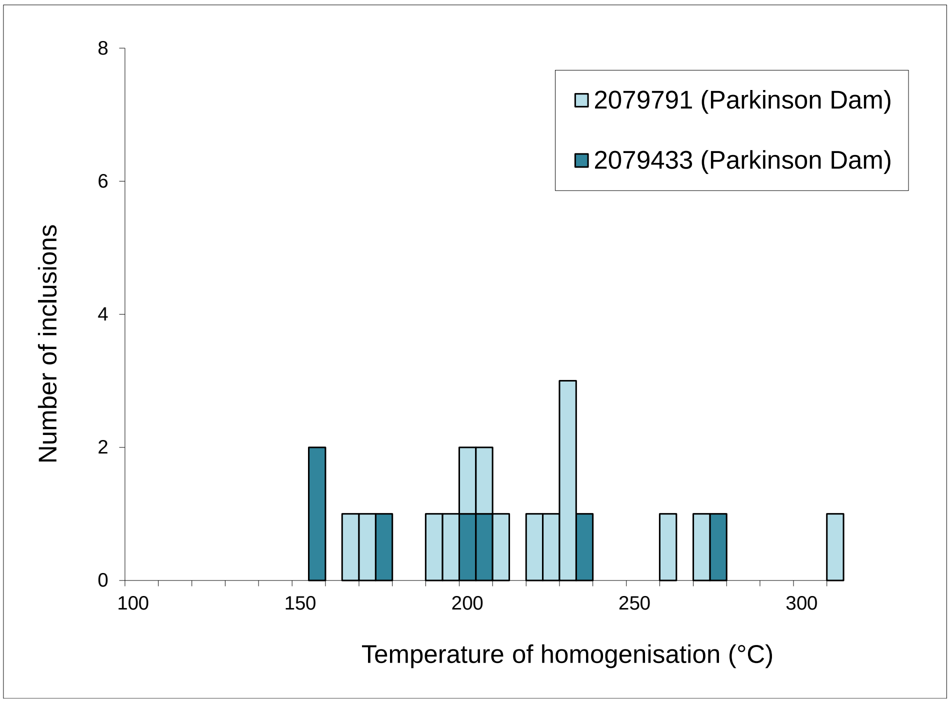

Figure 6. Fluid inclusion temperature and population distribution graph, Parkinson Dam samples.

RECOMMENDATIONS

Three further samples remained prepared to be tested by fluid inclusion data, though the results to date indicated that these additional samples were anticipated to contain modified fluid inclusions (more of the same).

A further targeted approach to sampling additional material is also a possibility. However, such a program would be time consuming and using professional laboratory services to complete the analyses adds significantly to costs. An alternative to reduce costs would be to incorporate further fluid inclusion studies from the vein deposits into a university research thesis with the aim of conducting a stable isotope assessment of hydrothermal fluid sources in the region. This has implications for mineral prospectivity in an area subject to ongoing mineral exploration.

ACKNOWLEDGEMENTS

Thanks to Rob Smith, Tasman Resources for permission to review drill hole data from the Parkinson Dam Au-Ag prospect, and to undertake sampling and publish the results of this project. Thanks to Kevin Faure, Andrew Rae, and Mark Simpson of GNS Science, New Zealand for discussions on procedures and results of the fluid inclusion study.

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APPENDIX

REPORT ON FLUID INCLUSION STUDY BY GNS SCIENCE, NEW ZEALAND

Hello Ben,

We have completed the fluid inclusion heating measurements on the 4 samples. The results are summarised in the attached document (table / plots).

Homogenisation temperatures for each of the 4 samples have ranges in excess of 100 C (collective Th = 148 to 308 C). The wide range indicates that the fluid inclusions have been modified since entrapment and are unreliable. Due to the wide range, further freezing measurements on these inclusions is no recommended (unless you would like otherwise).

There are several options on how to advance;

1) Despite the wide ranges, proceed with sending these samples for stable isotope analyses.
2) Attempt to measure more inclusions in the remaining samples. Although visual examination of inclusions seen to date suggest these too have been modified and thus anticipate similar wide ranging results (that will not be meaningful).
3) Do no further work. Complete the report on the results obtained thus far and return the samples.

Best regards,

Mark Simpson
GNS Science