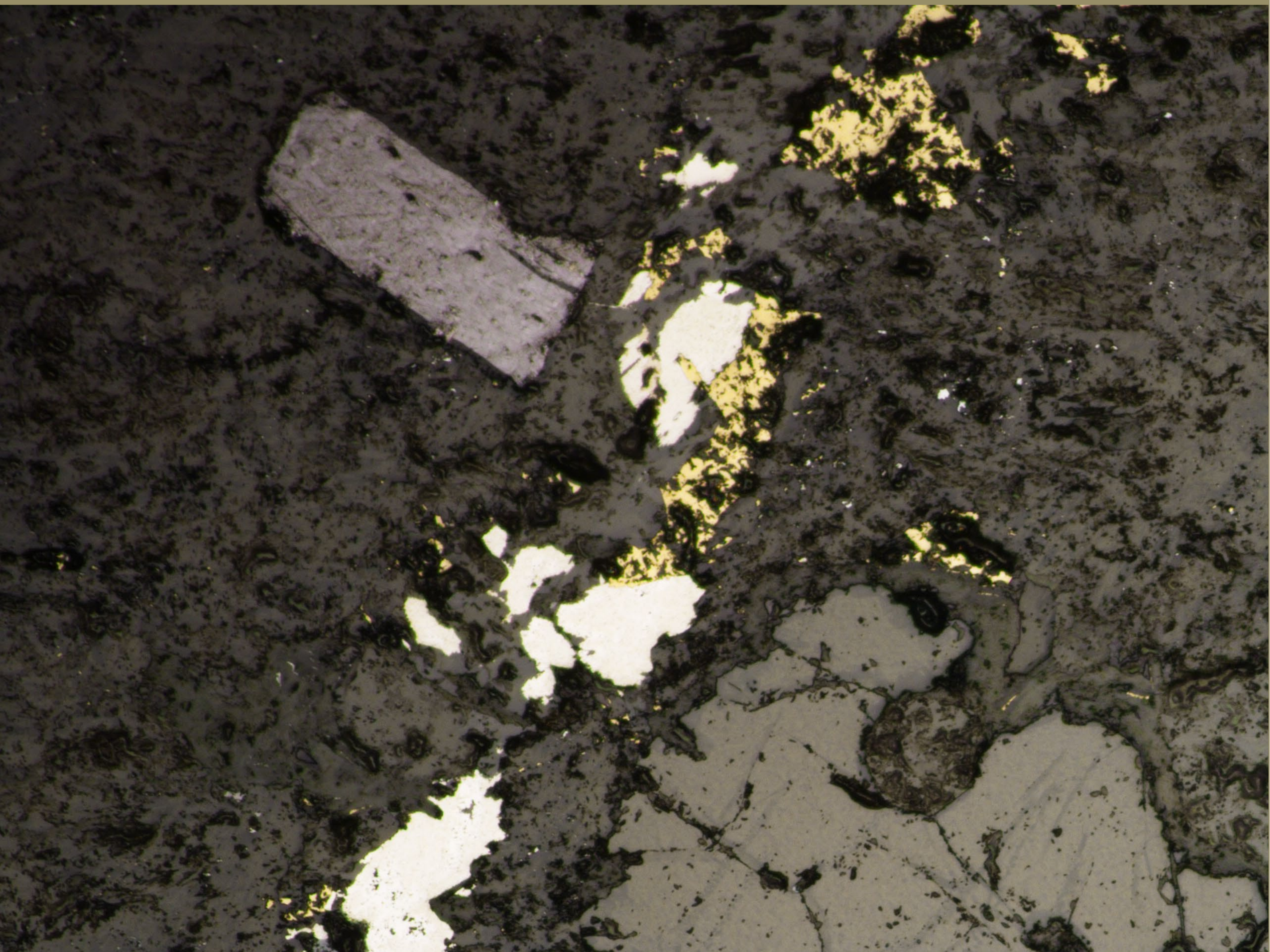
NORTHERN TERRITORY GEOLOGICAL SURVEY

RECORD 2017-010

Summary of results. Re–Os molybdenite dating of the Johnnies Reward prospect, Strangways Range, Aileron Province

MV McGloin and RA Creaser



NORTHERN TERRITORY GOVERNMENT

DEPARTMENT OF PRIMARY INDUSTRY AND RESOURCES
MINISTER: Hon. Ken Vowles, MLA
CHIEF EXECUTIVE: Alister Trier

NORTHERN TERRITORY GEOLOGICAL SURVEY
EXECUTIVE DIRECTOR: Ian Scrimgeour

BIBLIOGRAPHIC REFERENCE: McGloin MV and Creaser RA[1], 2017. Summary of results. Re–Os molybdenite dating of the Johnnies Reward prospect, Strangways Range, Aileron Province. *Northern Territory Geological Survey, Record* 2017-010.

(Record / Northern Territory Geological Survey ISSN 1443-1149)
Bibliography
ISBN: **978-0-7245-7320-2 (PDF)**

Keywords: geochronology, ID-TIMS, Re–Os, molybdenite, polymetallic, copper, lead, silver, zinc, gold, magnetite, mineralisation, Strangways Metamorphic Complex, Strangways Range.

EDITOR: GC MacDonald. Compiler: KJ Johnston.

Northern Territory Geological Survey
3rd floor Paspalis Centrepoint Building
Smith Street Mall, Darwin
GPO Box 4550
Darwin NT 0801, Australia

Arid Zone Research Institute
South Stuart Highway, Alice Springs
PO Box 8760
Alice Springs NT 0871, Australia

For further information contact:
Minerals and Energy InfoCentre
Phone +61 8 8999 6443
Website: www.minerals.nt.gov.au/ntgs
Email: geoscience.info@nt.gov.au

[1] Department of Earth & Atmospheric Sciences, University of Alberta, Edmonton, AB Canada T6G2R3

SUMMARY

This Record details new rhenium–osmium (Re–Os) geochronology from molybdenite associated with polymetallic Cu-Pb (Ag-Zn-Au) mineralisation at the Johnnies Reward prospect, ALICE SPRINGS[2], in the Aileron Province of the Arunta Region. Two molybdenite samples were collected from mineralised drill cores E058-003 and E058-005 from the prospect.

Molybdenite was dated to determine an absolute age for mineralisation. The Re–Os molybdenite model ages produced are 1396 ± 7 Ma and 1264 ± 7 Ma (repeat) for two aliquants from AS16MVM008, and 906 ± 4 Ma and 884 ± 4 Ma (repeat) for two aliquants from AS16MVM001. These resultant ages are inconclusive because repeated analyses failed to yield reproducible ages within uncertainty of the original samples. This irreproducibility is interpreted to result from closed-system decoupling of Re and ^{187}Os in the molybdenite grains analysed. Decoupling is most prevalent in samples that comprise smaller aliquants of coarser-grained and geologically older molybdenite. The molybdenite sampled from Johnnies Reward prospect is probably affected by decoupling due to its small volume, coarse-grained nature, and likely Precambrian age.

The averaged ca 1330 Ma and 895 Ma model ages are younger than previous estimates for the timing of mineralisation at the Johnnies Reward prospect (ca 1.80–1.77 Ga). Although epigenetic models for mineralisation consistent with these younger ages are plausible, the geological significance of these new molybdenite ages remains unclear. Both older Paleoproterozoic and younger timings for mineralisation remain possible.

[2] Names of 1:250 000 and 1:100 000 scale mapsheets are shown in all capitals and small capital letters respectively, eg ALICE SPRINGS, LAUGHLEN.

TABLE OF CONTENTS

FIGURES

TABLES

INTRODUCTION

The Johnnies Reward prospect is located 1.3 km north-northwest of Southern Cross Bore on The Gardens cattle station, about 1.5 km west of a station track that connects the Plenty Highway to the north with the Arltunga Tourist Drive to the south (**Figure 1**). Molybdenite samples were obtained during regional mapping and mineral systems prospectivity analysis by the Northern Territory Geological Survey (NTGS) in 2016. Re–Os molybdenite dating was completed in June of the same year at the University of Alberta, Canada.

The Johnnies Reward prospect is one example of several polymetallic base metal prospects in the Strangways Metamorphic Complex. These prospects host a variety of base metal assemblages and associated alteration styles. In most cases, the prospects were metamorphosed to granulite-facies conditions during the Paleoproterozoic (Hussey *et al* 2006). The apparent syngenetic and epigenetic mineralisation styles are generally considered to represent a spectrum of metamorphosed volcanic-associated massive sulfide (VAMS), carbonate-replacement, and iron oxide copper gold (IOCG) type deposits (eg Warren *et al* 1974, Warren and Shaw 1985, Skidmore 1996, Hussey *et al* 2006, Scrimgeour 2013). The different mineralisation styles have been interpreted by these authors to have a variety of mineralisation ages ranging from the Palaeoproterozoic into the Palaeozoic.

Given that many deposits and prospects in the Strangways Metamorphic Complex lack reliable absolute ages for mineralisation, determining precise genetic models for mineralisation is difficult. This problem is exacerbated by a lack of robust timing constraints on host rock maximum depositional ages and on the age and nature of deformation and regional magmatism (see Scrimgeour 2013). This lack of understanding of mineralisation processes and timing is the result of the complicating effects of high-grade granulite facies metamorphism, and multiple episodes of deformation and fluid flow over a protracted period from the Proterozoic to the Palaeozoic. This includes localised amphibolite and greenschist facies retrogression and fluid flow along shear zones. All these events obscure evidence of the timing and nature of mineralisation, making it particularly difficult to differentiate between epigenetic and syngenetic mineralisation processes.

Johnnies Reward is a prospect-scale exemplification of the difficulties in understanding the genetic model for ore formation in the polymetallic base metal prospects throughout the Aileron Province. Here we use the Re–Os system in molybdenite to test the timing of mineralisation and to develop a genetic model for mineralisation processes at Johnnies Reward.

Base metal mineralisation at Johnnies Reward is hosted within altered metafelsic, metamafic and metapelitic granulite, and marble of the lower Cadney Metamorphics (Shaw *et al* 1979, Warren 1980, Hussey *et al* 2006). The protoliths to the host succession are interpreted as dominantly sedimentary mudstone and carbonate rocks, and possibly bimodal volcanic rocks, that are all intruded by bimodal igneous rocks, represented locally by unnamed mafic sills (Hussey *et al* 2006). Precise SHRIMP U–Pb zircon maximum depositional or igneous crystallisation ages for host rocks at the Johnnies Reward prospect are not known. Protolith ages for the Strangways Metamorphic Complex are interpreted to range from ca 1815–1780 Ma based on zircon dating of probable volcaniclastic rocks (Hussey *et al* 2006, Scrimgeour 2013).

Mineralisation occurs within a stratiform magnetite–diopside–tremolite–chlorite–quartz skarn[3] assemblage up to 50 m wide and 200 m along strike. This mineralised zone is surrounded by an asymmetrically altered quartz–biotite–garnet±feldspar orthogneiss (Chuck 1984, 1985; Hussey *et al* 2006). The diamond drill cores E058-003 and E058-005 sampled for molybdenite were part of a drilling campaign by Alcoa Australia Limited in 1983 and 1984. Drilling intersections up to 25 m length yielded > 0.9 % combined Cu, Pb and Zn with appreciable Ag and Au credits (Chuck 1984, 1985).

Relatively high iron and manganese concentrations, high Pb>Zn ratios and elevated Au values distinguish the Johnnies Reward prospect from other examples of mineralisation in the Strangways Range (eg Edwards Creek prospect, Oonagalabi prospect). Hussey *et al* (2006) interpreted the Fe-rich alteration at Johnnies Reward to represent pre-existing chlorite alteration of host rocks that were subsequently metamorphosed to the granulite facies. Galena from the prospect yields Pb isotope model ages of 1.8 to 1.7 Ga (Hussey *et al* 2006). Theses ages are younger than Pb model ages for nearby VAMS mineralisation (eg Edwards Creek, Harry Creek, Coles Hill prospects) although galena from all these prospects have similar Pb isotope compositions (see Warren *et al* 1995, Hussey *et al* 2006).

Both syngenetic (eg metamorphosed VAMS; Warren and Shaw 1985) and epigenetic (metamorphosed IOCG; Hussey *et al* 2006, Corriveau and Spry 2014) models have been proposed for the mineralisation at Johnnies Reward. However, recent observations indicate that the prospect may be the result of more than one mineralising episode (McGloin 2017). Epigenetic magnetite–chlorite–copper assemblages overprint earlier stratiform Fe- and Mn-rich alteration assemblages; this suggests retrograde fluid-assisted alteration of silicate minerals like garnet and biotite, which break down to form magnetite and chlorite, are subsequently overprinted by chalcopyrite and pyrite (McGloin 2017). This interpretation implies that early syn-sedimentary hydrothermal processes may provide a fundamental control on the alteration associated with later epigenetic copper mineralisation. It remains unclear whether the later copper is remobilised locally from pre-existing sulfide mineralisation, is leached from the host succession, or is introduced from more exotic sources such as magmatic-hydrothermal fluids.

Re–Os dating of molybdenite at Johnnies Reward prospect provides an opportunity to constrain the timing of mineralisation and thus reassess genetic models for mineralisation. This Record documents the sample locations (**Figure 1**), geological context, descriptions of the target mineral and the relevant analytical data. A summary

[3] Note that the term skarn is descriptive and does not have a genetic implication.

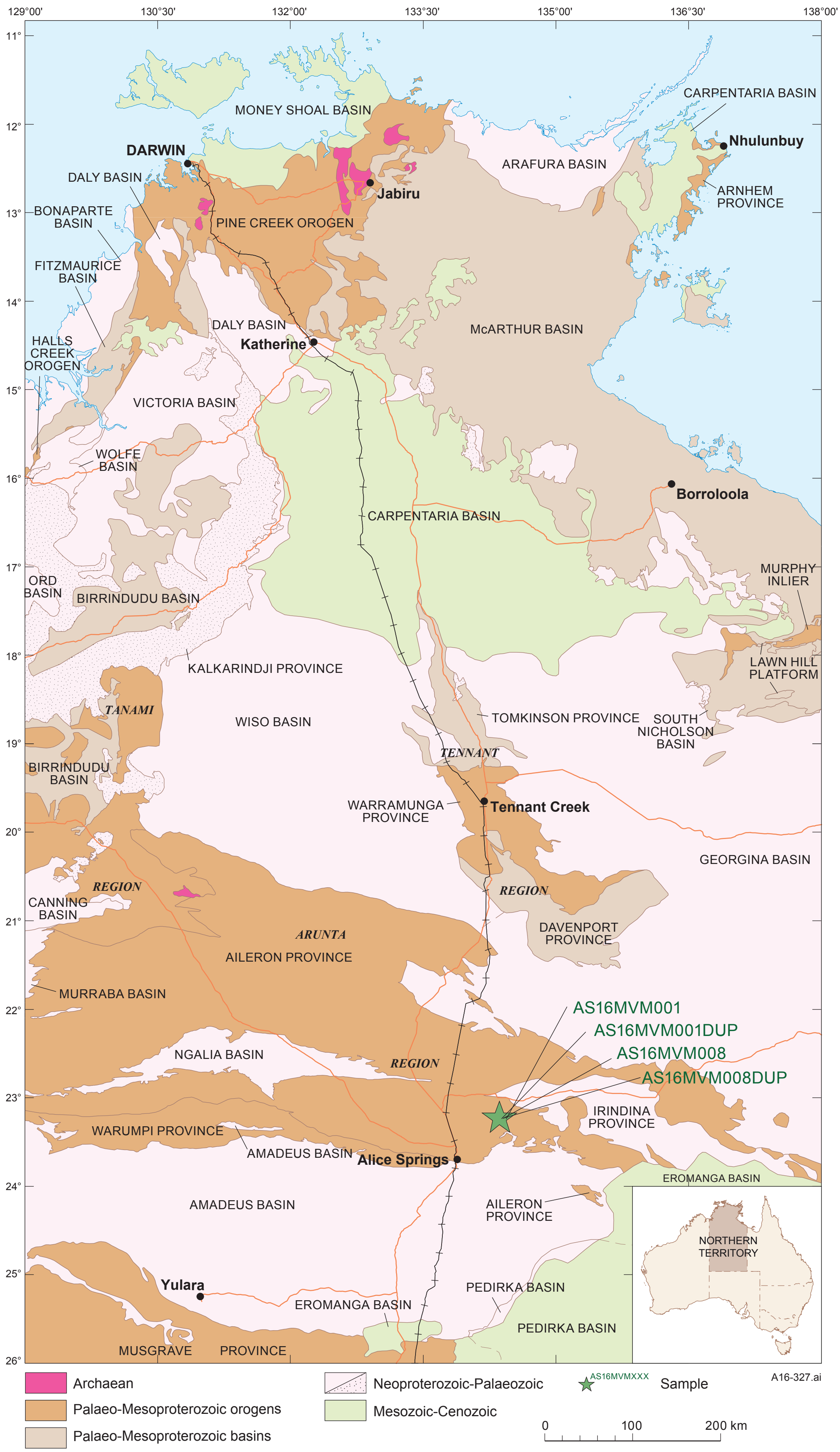


Figure 1. Location of the Johnnies Reward prospect and drillholes (E058-003 and E058-005), source of molybdenite from rock samples AS16MVM001 and AS16MVM008.

Table 1. Summary of molybdenite Re–Os model ages from AS16MVM001, AS16MVM001DUP, AS16MVM008 and AS16MVM008DUP.

Stratigraphic Unit	Sample No	Target mineral	MGA94 zone	Easting (mE)	Northing (mN)	Interpreted mineralisation model age (Ma)
Mineralised gneiss, lower Cadney Metamorphics	AS16MVM001	molybdenite	53K	419685	7440644	905.9 ± 4.4
Mineralised gneiss, lower Cadney Metamorphics	AS16MVM001 (DUP)	molybdenite	53K	419685	7440644	883.5 ± 4.2
Mineralised gneiss, lower Cadney Metamorphics	AS16MVM008	molybdenite	53K	419678	7440467	1396 ± 7
Mineralised gneiss, lower Cadney Metamorphics	AS16MVM008 (DUP)	molybdenite	53K	419678	7440467	1264 ± 7

of the results is listed in **Table 1**. A brief discussion and interpretation of the isotopic data is presented for each sample.

ANALYTICAL PROCEDURES

Re–Os Molybdenite dating

The Re–Os chronometer for dating molybdenite is a robust and reliable chronological tool (Stein *et al* 2001 and references therein). Re–Os is a closed isotopic system in molybdenite during high-grade metamorphism and deformation, even under granulite facies conditions (Bingen and Stein 2003). The Re–Os system seems particularly useful in terranes that have experienced multiple hydrothermal, magmatic and metamorphic episodes. The Re–Os molybdenite system has reportedly lower closure temperatures in some examples (at least ~550°C; eg Suzuki *et al* 2001) compared to more traditional U–Pb mineral chronometers (~800–600°C; eg zircon, monazite, titanite, baddeleyite; Schaefer 2016). However, more recent studies have demonstrated that closure temperatures for the molybdenite Re–Os system are likely to be higher (~800 °C; Bingen and Stein 2003, Selby *et al* 2004). In addition, unlike commonly dated minerals, molybdenite can be a useful chronometer in polymetamorphosed and deformed terranes. This is because molybdenite is not complicated by overgrowths that are common in minerals like zircon, monazite and xenotime (Stein *et al* 2001). In addition, the Re–Os system in molybdenite is not commonly susceptible to chemical and thermal disturbances, providing an advantage over the Rb–Sr, K–Ar and ^{40}Ar–^{39}Ar isotopic systems (Stein *et al* 2001).

Sample preparation and analysis

Molybdenite was separated by metal-free crushing, followed by gravity and magnetic concentration methods as described in detail by Selby and Creaser (2004). Samples AS16MVM001 and AS16MVM008 used aliquants containing 20 mg and 15 mg of molybdenite respectively. Analyses of both samples were repeated (AS16MVM001DUP and AS16MVM008DUP) using further aliquants of 11 mg and 10 mg of molybdenite respectively. The ^{187}Re and ^{187}Os concentrations in molybdenite were determined by isotope dilution mass spectrometry using Carius tube, solvent extraction, anion chromatography, and negative thermal ionisation mass spectrometry techniques (ID–NTIMS). A mixed double spike containing known amounts of isotopically enriched ^{185}Re, ^{190}Os, and ^{188}Os was used (Markey *et al* 2007). Isotopic analysis was carried out on a ThermoScientific Triton mass spectrometer by Faraday collector.

Total blanks for Re and Os are less than 3 picograms and 2 picograms respectively, which are insignificant for the Re and Os concentrations in molybdenite. The molybdenite powder HLP-5 (Markey *et al* 1998), was analysed as a standard; an average Re–Os date of 221.1 ± 1.0 Ma (1SD uncertainty, n=12) was obtained over a period of two years. This Re–Os age date is identical to that reported by Markey *et al* (1998) of 221.0 ± 1.0 Ma. All uncertainties are quoted at 2σ level, and include all known analytical uncertainty, including uncertainty in the decay constant of ^{187}Re. Because of the irreproducibility in both samples, very approximate interpreted model ages were calculated by averaging the results of the original analyses and duplicate analyses.

SAMPLES ANALYSED

Weakly mineralised quartz–garnet–biotite (chlorite)–diopside–tremolite paragneiss, Johnnies Reward prospect (AS15MVM001 and AS15MVM001DUP)

Sample information

NTGS Sample ID: AS16MVM001
Collector: Matt McGloin
1:250 000 mapsheet: ALICE SPRINGS (SF53-14)
1:100 000 mapsheet: LAUGHLEN (5751)
Region/Province: Aileron Province, Arunta Region
Grid Reference: MGA94 Zone 53, 419685mE 7440644mN
Drill hole: E058-005 (Alcoa Australia Limited)
Azimuth: 270°
Declination: -70°
Depth: 163.9 m
Formal Name: lower Cadney Metamorphics
Lithology: weakly mineralised quartz–garnet–biotite (chlorite)–diopside–tremolite paragneiss
Geochronology target: molybdenite

Interpreted model age summary

ca 895 Ma

Sample details and lithological characteristics

Molybdenite was sampled from ¼ diamond drill core E058-005 at the 163.9 m depth interval. **Figure 2** shows a geological summary of this drillhole. Most mineralisation occurs within magnetite–pyroxene-bearing rocks up to 50 m thick with highest Cu, Pb, Ag and Au grades intercepted between 126 and 171 m (Chuck 1985). The molybdenite sample was taken from the footwall below the main mineralised zone within a weakly mineralised quartz–garnet–biotite (chlorite)–diopside–tremolite paragneiss. The molybdenite is associated with chalcopyrite, pyrite and minor magnetite, all of which occur as disseminations that are associated with fine quartz veins that cross-cut and overprint the host assemblage (**Figure 3**). **Figure 4** shows photomicrographs of AS16MVM001. The groundmass consists of diopside, tremolite, garnet, quartz and minor calcite. The margins of garnet porphyroblasts show

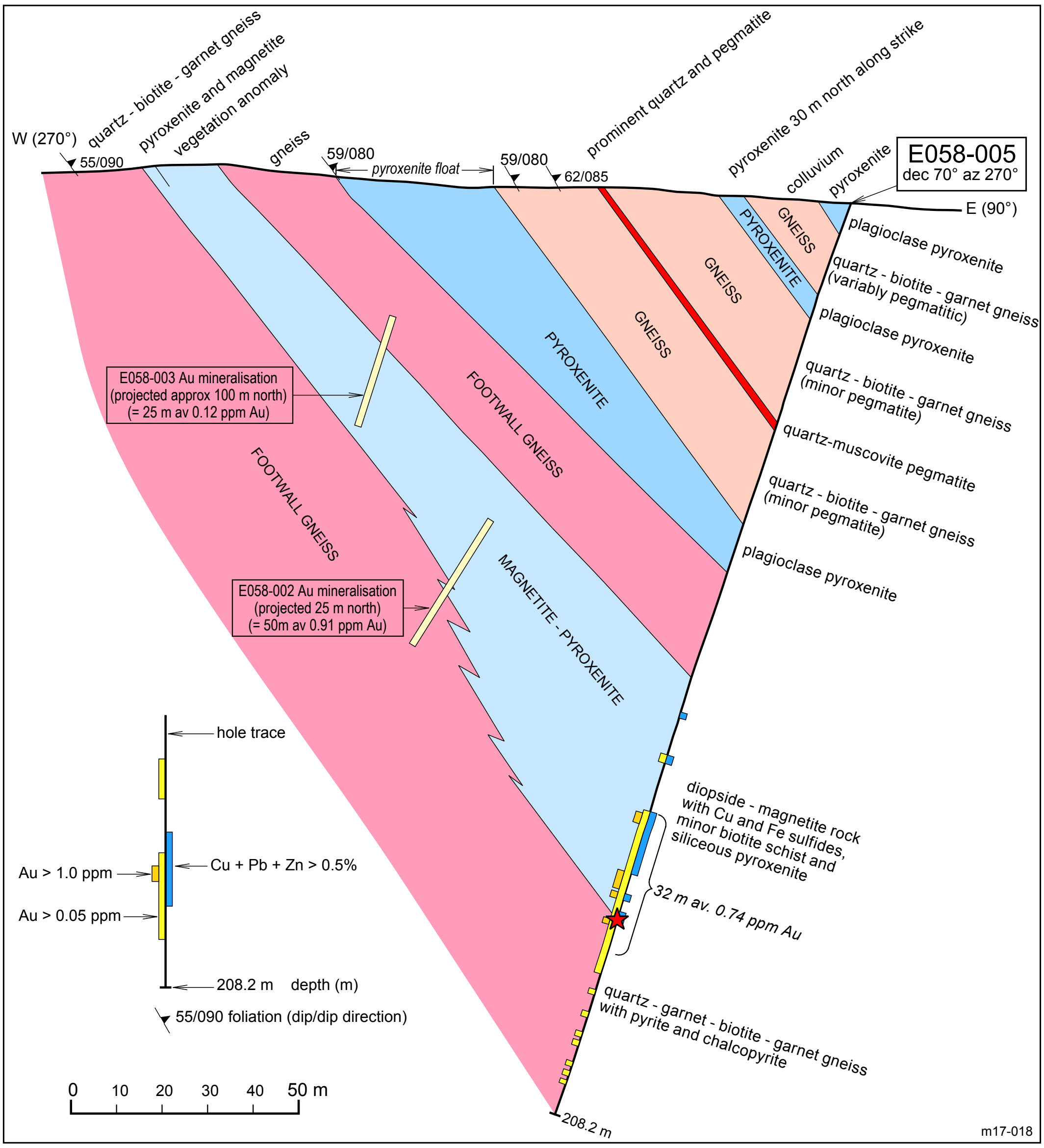


Figure 2. Geological cross section including drillhole E058-005, Johnnies Reward prospect, showing interpreted lithology and mineralisation. Red star indicates approximate position of molybdenite sampled in this study (adapted from Chuck 1985).

chloritisation on the contact with the cross-cutting quartz vein (**Figure 4b)**.

Model results

ID–TIMS analysis of molybdenite from sample AS16MVM001 yielded a model age of 905.9 ± 4.4 Ma (2σ), whereas a repeat analysis of this sample (AS16MVM001DUP) yielded an age of 883.5 ± 4.2 Ma (2σ). The two model ages are similar but not within uncertainty of each other, indicating the model ages are not reproducible within analytical uncertainty. The Re–Os isotopic data for these samples are reported in **Table 2**. The average age of these results is ca 895 Ma.

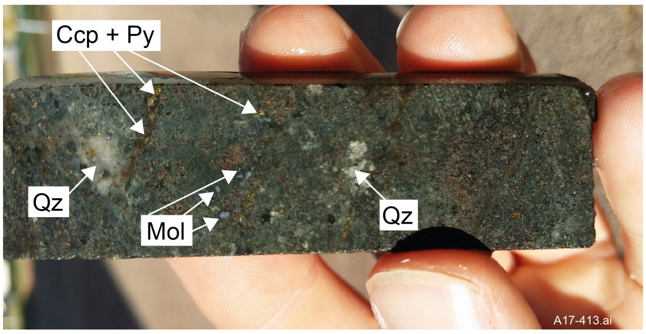


Figure 3. Photo of wet ¼ diamond drill core from E058-005, Johnnies Reward prospect. Minor disseminated, coarse-grained purple-blue-coloured molybdenite (Mol) sampled for AS16MVM001 can be seen in the centre of the drill core associated with chalcopyrite (Ccp) and pyrite (Py) and minor quartz (Qz) veining that overprints the host rock assemblage. Width of drill core is approximately 3 cm.

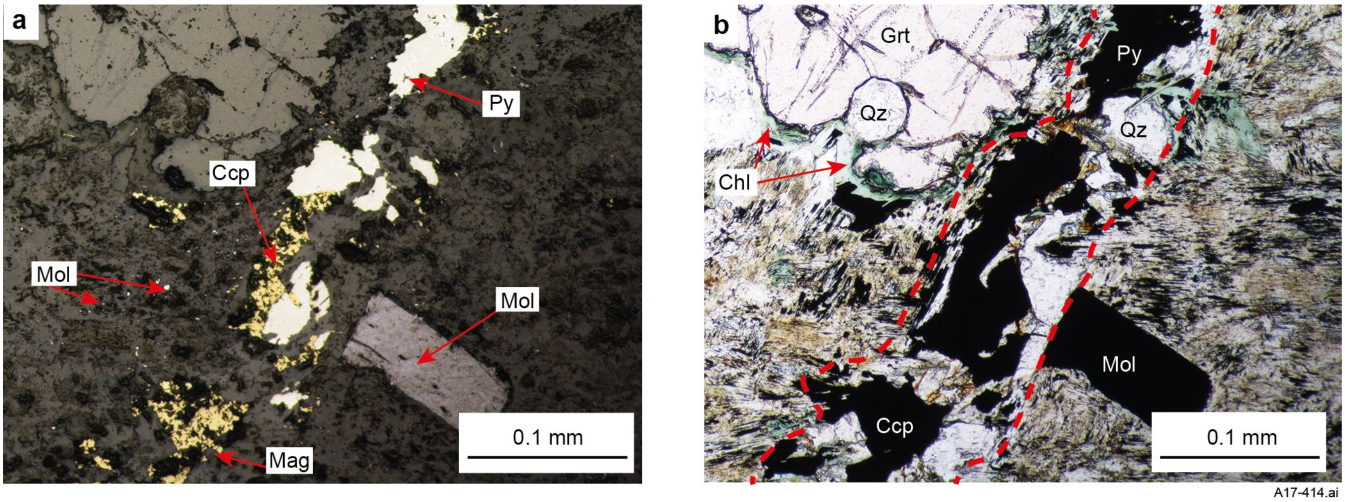


Figure 4. Photomicrographs of sample AS16MVM001. (**a**) Reflected plane-polarised light: molybdenite (Mol) associated with chalcopyrite (Ccp), pyrite (Py) and minor magnetite (Mag) in a quartz (Qz) vein that cross-cuts the host assemblage. (**b**) Plane-polarised light: the cross-cutting sulfide-bearing quartz vein that runs from upper mid-right to lower mid-left in the image is associated with chloritisation (Chl) of garnet (Grt) and other host minerals on vein margins. The red dashed lines represent the approximate margins of the quartz vein.

Table 2. Summary of Re–Os isotopic data and model age determinations; ppb = parts per billion, ppm = parts per million.

Sample	Re (ppm)	± 2σ	^{187}Re (ppm)	± 2σ	^{187}Os (ppb)	± 2σ	Model age (Ma)	± 2σ (Ma)
AS16MVM001	66.17	0.22	41.59	0.14	632.5	1.0	905.9	4.4
AS16MVM001(DUP)	104.0	0.30	65.36	0.21	969.1	1.7	883.5	4.2
AS16MVM008	5.210	0.01	3.28	0.01	77.1	0.2	1396	7
AS16MVM008(DUP)	3.850	0.06	2.42	0.01	51.5	0.2	1264	7

Mineralised quartz–biotite (chlorite)–garnet–feldspar paragneiss, Johnnies Reward prospect (AS15MVM008 and AS15MVM008DUP)

Sample information

NTGS Sample ID: AS16MVM008
Collector: Matt McGloin
1:250 000 mapsheet: ALICE SPRINGS (SF53-14)
1:100 000 mapsheet: LAUGHLEN (5751)
Region/Province: Aileron Province, Arunta Region
Grid Reference: MGA94 Zone 53, 419678mE 7440467mN
Drill hole: E058-003 (Alcoa Australia Limited)
Depth: 81.4 m
Azimuth: 240°
Declination: -50°
Formal name: lower Cadney Metamorphics
Lithology: mineralised quartz vein in foliated quartz–biotite (chlorite)–garnet–feldspar gneiss
Geochronology target: molybdenite

Interpreted model age summary

ca 1330 Ma

Sample details and lithological characteristics

Molybdenite was sampled from ¼ diamond drill core E058-003 at the 81.4m depth interval. **Figure 5** shows a geological summary for this drillhole. The majority of mineralisation occurs within magnetite–pyroxene-bearing rocks that contain the highest Cu, Pb, Ag and Au grades intercepted between 29 and 54 m (Chuck 1984). The molybdenite sample was taken from the footwall below the main mineralised zone within a weakly mineralised zone of foliated quartz–biotite (chlorite)–garnet–plagioclase–K-feldspar gneiss. The foliation is defined by aligned biotite (commonly chloritised) and augen-shaped garnet porphyroclasts. Several disseminations of molybdenite are associated with chalcopyrite and pyrite and occur on the edges of thin quartz veinlets (**Figure 6**). These veins overprint the host assemblage. **Figure 7** shows photomicrographs of molybdenite and associated sulfides on the margin of a quartz vein; the margins of the quartz veins are associated with chloritised biotite. Elsewhere in the thin section, molybdenite and associated sulfides can be seen invading the cleavage in biotite and chlorite, indicating that this phase of sulfide mineralisation occurred syn- or post-formation of the

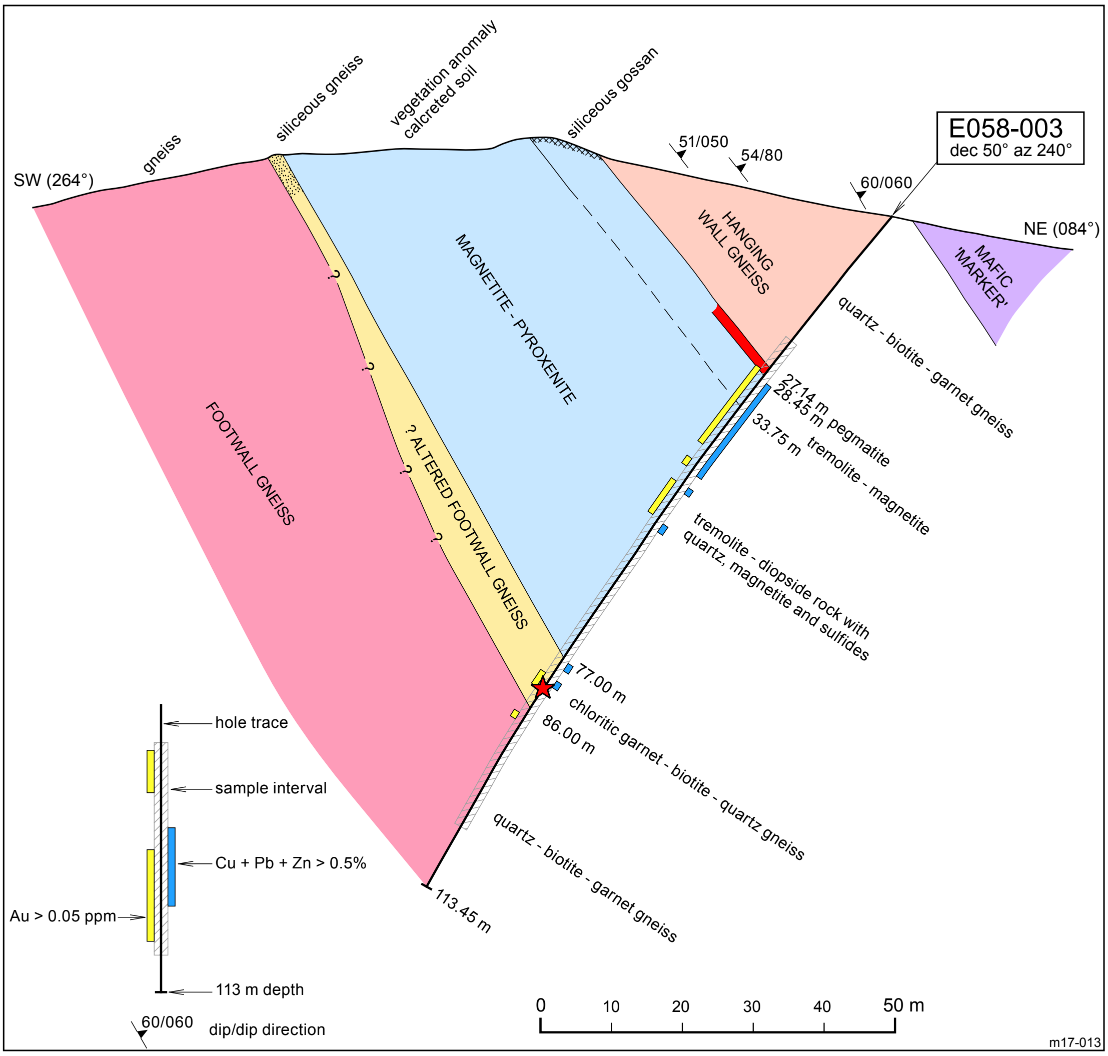


Figure 5. Geological cross section including drillhole E058-003, Johnnies Reward prospect, showing interpreted lithology and mineralisation. Red star indicates approximate position of molybdenite sampled in this study (adapted from Chuck 1984).

main foliation in the host rock. Some sulfides are included in garnet, indicating that sulfides also precipitated syn- or post-garnet crystallisation.

Model results

ID–TIMS analysis of molybdenite from sample AS16MVM008 yielded a model age of 1396 ± 7 Ma (2σ), whereas a repeat analysis for this sample (AS16MVM008DUP) yielded an age of 1264 ± 7 Ma (2σ). The two model ages are similar but not within uncertainty of each other, indicating the model ages are not reproducible within analytical uncertainty. The Re–Os isotopic data for these samples are reported in **Table 2**. The average age of these results is ca 1330 Ma.

Interpretation of results from Johnnies Reward

The molybdenite from samples AS16MVM001 and AS16MVM008 both yielded Re–Os model ages that were not reproducible within analytical uncertainty when duplicate analyses of these two samples were conducted. This irreproducibility in the data dictates that the numerical ages yielded cannot be considered robust for dating purposes.

The failure to generate reproducible ages in both samples is likely the result of the coarse grain size and small overall quantities of molybdenite available for sampling. Several studies have noted that the accuracy and reproducibility of Re–Os molybdenite ages can be affected by the geological age and natural grain size of the molybdenite sampled (eg Stein *et al* 2003, Selby and Creaser 2004). These studies demonstrated that molybdenite Re–Os ages are more likely to be accurate and reproducible if the molybdenite analysed is geologically younger (eg Palaeozoic compared to Precambrian) and finer-grained; these criteria appear to limit the effect of internal Re and ^{187}Os decoupling in individual molybdenite grains.

Decoupling is the process whereby Re and ^{187}Os become physically redistributed or separated within an individual molybdenite grain after formation (Selby and Creaser 2004). This decoupling is problematic because it can affect Re–Os systematics in molybdenite that correspond directly to any Re–Os model ages calculated. The decoupling effect is generally more pronounced in geologically older or coarser grained molybdenite samples because increased time and distance are favourable to closed-system primary diffusion which is suggested to control this decoupling behaviour (Selby and Creaser 2004). The decoupling effect is not the

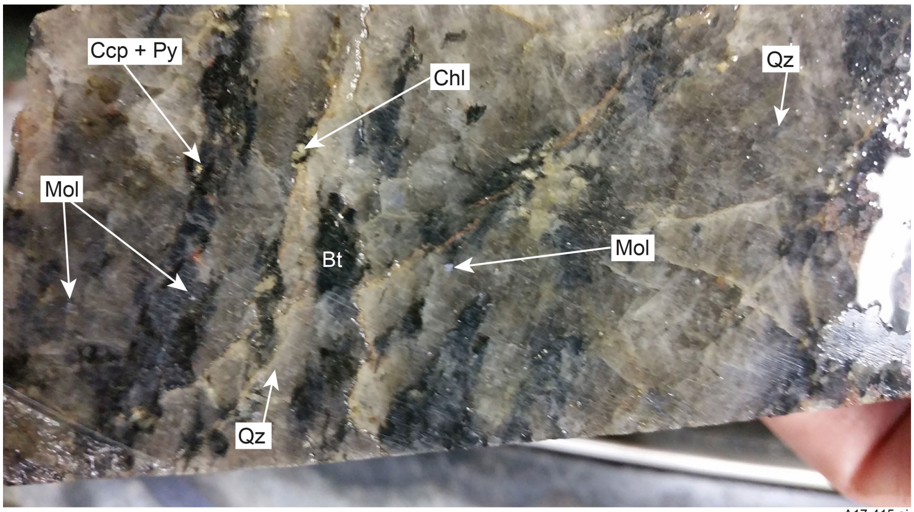


Figure 6. Photo of wet ½ diamond drill core from E058-003, Johnnies Reward prospect. Very minor disseminated, coarse-grained purple-blue-coloured molybdenite (Mol) sampled for AS16MVM008 can be seen in the top centre of the drill core associated with quartz (Qz) veining and very minor chalcopyrite (Ccp) and pyrite (Py) blebs that all overprint the host rock assemblage. Bt = Biotite, Chl = chlorite. Width of drill core is approximately 6 cm.

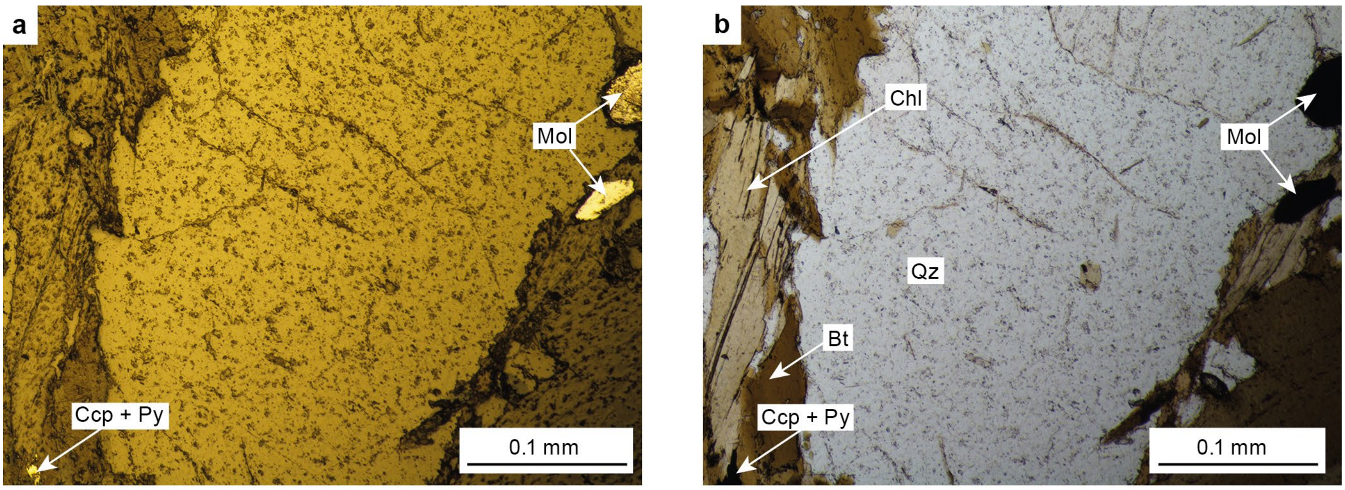


Figure 7. Photomicrographs of sample AS16MVM008. (**a**) Molybdenite (Mol), chalcopyrite (Ccp) and pyrite (Py) associated with a quartz (Qz) vein that intrudes the host rock assemblage (in reflected plane-polarised light). (**b**) Same image in plane-polarised light indicating that quartz vein margins are associated with chloritisation (Chl) of biotite (Bt) in the host assemblage.

result of open system behaviour due to isotopic disturbance because there is no evidence for net loss or gain of Re nor ^{187}Os in molybdenite during such processes.

The small sample aliquants and coarse-grained nature of the molybdenite analysed from the Johnnies Reward prospect is interpreted to have adversely affected the Re–Os systematics in these samples. The collection of larger amounts of molybdenite from each sample location would have minimised the potential effects of decoupling. However, in our work there was not enough molybdenite in the two samples to yield the recommended minimum sample size for analyses (~ 40 mg).

Although the sample irreproducibility means that the absolute Re–Os model ages yielded should be treated with a very high degree of caution, the approximate ages may have some geological significance. In both samples, molybdenite is intimately associated with chalcopyrite and pyrite, and all these sulfide minerals are hosted in or on the margins of quartz veins that overprint the host assemblage (**Figures 4** and **7**). These sulfide minerals must be syn- to post-metamorphic in timing because they are found as inclusions within prograde metamorphic minerals like garnet, or within the cleavage or foliation that is best developed in biotite and chlorite. Where quartz veins intrude the host assemblage, metamorphic minerals are commonly chloritised, indicating retrograde fluid assisted processes were involved in chloritising these minerals and depositing the molybdenite-associated sulfide assemblages.

The sample and duplicate average ages (ca 1330 Ma and ca 895 Ma) from the 2 samples of molybdenite are appreciably younger than previous estimates for the age of the host succession and the timing of mineralisation at Johnnies Reward. There is no well-constrained chronologic data for the lower Cadney Metamorphics that may assist in determining the age of the host rock succession, intrusive magmatic units, mineralising or deformation events. The host succession is suggested to have a ca 1800–1780 Ma age based on maximum depositional and magmatic crystallisation ages for host rocks in other parts of the Strangways Range (Hussey *et al* 2006; Scrimgeour 2013). Previous ages for the apparently stratiform mineralisation at Johnnies Reward based on galena lead model data indicate mineralisation occurred between ca 1795–1770 Ma (Hussey *et al* 2006).

Although epigenetic models for mineralisation at the Johnnies Reward prospect remain plausible (from petrographic evidence for sulfides that overprint foliated rocks in the host succession), we cautiously interpret the molybdenite ages to reflect the approximate timing of two different episodes of hydrothermal fluid flow that affected pre-existing and likely syngenetic mineralisation and alteration at the deposit. If the molybdenite ages are geologically significant, they are considerably younger than the estimated host succession ages for the prospect. In this case, these episodes of fluid flow either remobilised pre-existing copper mineralisation or introduced new copper mineralisation from a more exotic source. However, it cannot be precluded that the Re–Os model ages may have no geological meaning because of Re–Os decoupling, and consequently the significance of the ages remains to be tested.

Hydrothermal fluid flow events related to the new molybdenite ages are not known in the Aileron Province. Similarly the timing of deformational events in the Strangways Metamorphic Complex are widely disparate. Most data suggest that metamorphism and deformation in the Paleoproterozoic occurred between ca 1.78 to 1.69 Ga although there is no well-established consensus on the nature, extent and periodicity of this deformation (see Collins and Shaw 1995, Maidment *et al* 2005, Hussey *et al* 2006, Claoue-Long *et al* 2008; Scrimgeour 2013). The Alice Springs Orogeny between ca 450–300 Ma also affected the area locally (Collins and Teyssier 1989, Collins and Shaw 1995). The existence of deformation, magmatism and metamorphism younger than the Palaeoproterozoic but older than the Palaeozoic is not well constrained in the Strangways Range. The new molybdenite ages obtained from the Johnnies Reward prospect do not correspond to any known geological event.

ACKNOWLEDGMENTS

Thanks to Barry Reno and Jo Whelan for reviewing this Record, Jay Carter and Max Heckenberg for assistance at the NTGS Alice Springs Core Facility. Thanks to Ian Burgan and Kathy Johnston for figure preparation and formatting.

REFERENCES

Bigden B and Stein S, 2003. Molybdenite Re–Os dating of biotite dehydration melting in the Rogaland high-temperature granulites, S Norway. *Earth and Planetary Science Letters* 208, 181–195.

Chuck RG, 1984. Diamond drilling at Johnnies Reward gold and base metal prospect. Strangways Range, Central Australia. *Northern Territory Geological Survey, Open File Company Report* CR1984-0054.

Chuck RG, 1985. Annual and Final Report for the project, period ending 24-5-85, Alcoa Australia. *Northern Territory Geological Survey, Open File Company Report* CR1985/253.

Claoue-Long J, Maidment D, Hussey K and Huston D, 2008. The duration of the Strangways Event in central Australia: evidence for prolonged deep crustal processes. *Precambrian Research* 166, 246–262.

Collins WJ and Shaw RD, 1995. Geochronological constraints on orogenic events in the Arunta Inlier: a review. *Precambrian Research* 71, 315–346.

Collins WJ and Teyssier C 1989. Crustal scale ductile fault systems in the Arunta Inlier, central Australia. *Tectonophysics* 158, 49–66.

Corriveau L and Spry P, 2014. Metamorphosed hydrothermal ore deposits: in Scott SD (editor).'*Treatise on geochemistry. Second Edition'*. Elsevier, 175–194.

Hussey KJ, Huston DL and Claoue-Long JC, 2006. Geology and origin of some Cu-Pb-Zn (Au-Ag) deposits in the Strangways Metamorphic Complex, Arunta Region, Northern Territory. *Northern Territory Geological Survey, Report* 17.

Maidment DW, Hand M and Williams IS, 2005. Tectonic cycles in the Strangways Metamorphic Complex, Arunta Inlier, central Australia: geochronological evidence for exhumation and basin formation between two high-grade metamorphic events. *Australian Journal of Earth Sciences* 52, 205–215.

Markey RJ, Stein HJ and Morgan JW, 1998. Highly precise Re–Os dating for molybdenite using alkaline fusion and NTIMS. *Talanta* 45, 935–946.

Markey RJ, Stein HJ, Hannah JL, Selby D and Creaser RA, 2007. Standardizing Re–Os geochronology: A new molybdenite Reference Material (Henderson, USA) and the stoichiometry of Os salts. *Chemical Geology* 244, 74–87.

McGloin MV, 2017. The significance of metaexhalites, seafloor alteration and retrograde processes for metamorphosed mineral deposits: examples of distinct alteration styles from the Aileron Province in: '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory, 28–29 March 2017*'. Northern Territory Geological Survey, Darwin.

Selby D, Creaser RA and Feely M, 2004. Accurate and precise Re–Os molybdenite dates from the Galway Granite, Ireland. Critical comment on 'Disturbance of the Re–Os chronometer of molybdenites from the late-Caledonian Galway Granite, Ireland, by hydrothermal fluid circulation' by Suzuki *et al*, Geochemical Journal 35, 29–35, 2001. *Geochemical Journal* 38, 291–294.

Selby D and Creaser RA, 2004. Macroscale NTIMS and microscale LA–MC–ICP–MS Re–Os isotopic analysis of molybdenite: Testing spatial restrictions for reliable Re–Os age determinations, and implications for the decoupling of Re and Os within molybdenite. *Geochimica et Cosmochimica Acta* 68, 3897–3908.

Schaefer BF, 2016. *Radiogenic Isotope geochemistry: a guide for industry professionals.* Macquarie University, Sydney, Australia, Cambridge University Press, 196pp.

Scrimgeour IR, 2013. The Aileron Province: in Ahmad M and Munson TJ (compilers). 'Geology and mineral resources of the Northern Territory.' *Northern Territory Geological Survey, Special Publication* 5.

Shaw RD, Langworthy AP, Offe LA, Stewart AJ, Allen AR and Senior BR, 1979. Geological report on 1:100 000-scale mapping of the southeastern Arunta Block, Northern Territory. *Bureau of Mineral Resources, Australia*, *Record* 1979/47.

Skidmore CP, 1996. *An investigation into the origin and timing of the Oonagalabi Cu-Zn deposit, Harts Range, Central Australia*. Honours Thesis, University of Adelaide.

Stein HJ, Markey RJ, Morgan JW, Hannah JL and Schersten A, 2001. The remarkable Re–Os chronometer in molybdenite: how and why it works. *Terra Nova* 13, 479–486.

Stein H, Scherstén A, Hannah J and Markey R, 2003. Subgrain scale decoupling of Re and ^{187}Os and assessment of laser ablation ICP–MS spot dating in molybdenite. *Geochimica et Cosmochimica Acta* 67, 3673–3686.

Suzuki K, Feely M and O'Reilly C, 2001. Disturbance of the Re–Os chronometer of molybdenites from the late Caledonian Galway Granite, Ireland, by hydrothermal fluid circulation. *Geochemical Journal* 35, 29–35.

Warren RG, 1980. Summary of the mineral deposits in the Alice Springs 1:250 000 sheet area. *Bureau of Mineral Resources, Australia*, *Record* 44.

Warren RG, Stewart AJ and Shaw RD, 1974. Summary of information on mineral deposits of the Arunta Complex, Alice Springs Area, NT. *Bureau of Mineral Resources, Australia, Record* 1974/117.

Warren RG, Thorpe RI, Dean JA and Mortensen JK, 1995. Pb-isotope data from base-metal deposits in central Australia: implications for Proterozoic stratigraphic correlations, Australian Geological Survey Organisation. *Journal of Australian Geology and Geophysics* 15, 501–509.

Warren RG and Shaw RD, 1985. Volcanogenic Cu-Pb–Zn bodies in granulites of the central Arunta Block, central Australia. *Journal of Metamorphic Geology* 3, 481–499.