

# Barium–gold mineralization at Quadrio Lake, Oldham Inlier, Little Sandy Desert, Western Australia

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## Abstract

Barite–hematite stockworks discovered near Quadrio Lake in the Oldham Inlier (northwestern Officer Basin) contain anomalous quantities of gold (up to 110 ppb), manganese, arsenic, and antimony. Regional geological and geophysical data suggest that this stockwork system may be part of a larger mineralized system. The mineralization is in the Quadrio Formation, a shale-dominated unit of probable Mesoproterozoic age in the Oldham Inlier, an unconformity-bounded inlier of older, deformed rocks surrounded by the virtually undeformed Officer Basin succession. This stockwork system resembles sedimentary exhalative-type deposits, where stratabound proximal sulfide and distal barite zones result from the uptake of hydrothermal fluids along fault structures. A sedimentary exhalative model is supported by Sr isotope ratios determined on samples of the Quadrio Lake barite.

**KEYWORDS:** Oldham Inlier, Quadrio Lake, Officer, Basin, barium, gold, sedimentary mineral deposits

## Introduction

Barite–hematite veins with anomalous gold, arsenic, and antimony values extend over an area of at least 500 m by 2000 m along the south side of Quadrio Lake, near the northern end of the 'Trainor track', the access road for the GSWA Trainor 1 drillhole (Fig. 1). The locality is 400 km northeast of Wiluna in the Little Sandy Desert, in the southeastern part of the TRAINOR\* 1:250 000 sheet (Williams, 1995). After the initial discovery (at MGA 465350E, 7282000N)<sup>†</sup>, barite–hematite

stockworks were traced northwest for a further 2 km, although the mineralized area could be more extensive, as the reconnaissance visit did not attempt to determine the extent of mineralization. Hairline barite veins associated with carbonate alteration in Trainor 1 (Fig. 1; Stevens and Adamides, 1998), 10 km to the northeast, suggest a northward-waning extension of the mineralized area. In a regional context, barite is known elsewhere in the Bangemall Supergroup, adjacent to the northwest

Officer Basin (Fig. 1). The Quadrio Lake vein system is probably the first indication of sedimentary exhalative (sedex) style mineralization in this area.

## Geology

Barite–hematite mineralization is hosted by rocks of the Oldham Inlier in the Savory region, a remote and poorly understood area (Fig. 1). The Oldham Inlier is overlain and onlapped by Neoproterozoic sedimentary rocks of the Sunbeam Group of the northwest Officer Basin (Fig. 1; Bagas et al., 1999). Rocks in the Oldham Inlier were previously mapped as one unit, the Cornelia Formation (Williams, 1990, 1995; Cornelia Sandstone of Brakel and Leech, 1980, and Muhling and Brakel, 1985). Recent reconnaissance work related to mapping on the NABBERU and STANLEY 1:250 000 sheets demonstrated the presence of three distinct lithologic units in the inlier (Table 1), and Hocking et al. (2000a) divided the Cornelia Sandstone into the Oldham Sandstone, the Quadrio Formation, and a redefined, more restricted Cornelia Sandstone. Barite–hematite mineralization is found in the Quadrio Formation. The ages of these units can only be inferred from regional correlations.

The Quadrio Formation is a dominantly fine grained shaly unit, with locally developed sandstone and chert intervals. Hocking et al. (2000b) extended the Quadrio Formation to the interval below 83 m in Trainor 1. However, a basal Phanerozoic age for the Trainor 1 interval (implied by U–Pb SHRIMP

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\* Capitalized names refer to standard 1:250 000 sheets.

<sup>†</sup> Locations mentioned in the text are referenced using Map Grid of Australia (MGA) coordinates, Zone 51. All locations are quoted to the nearest 100 m.

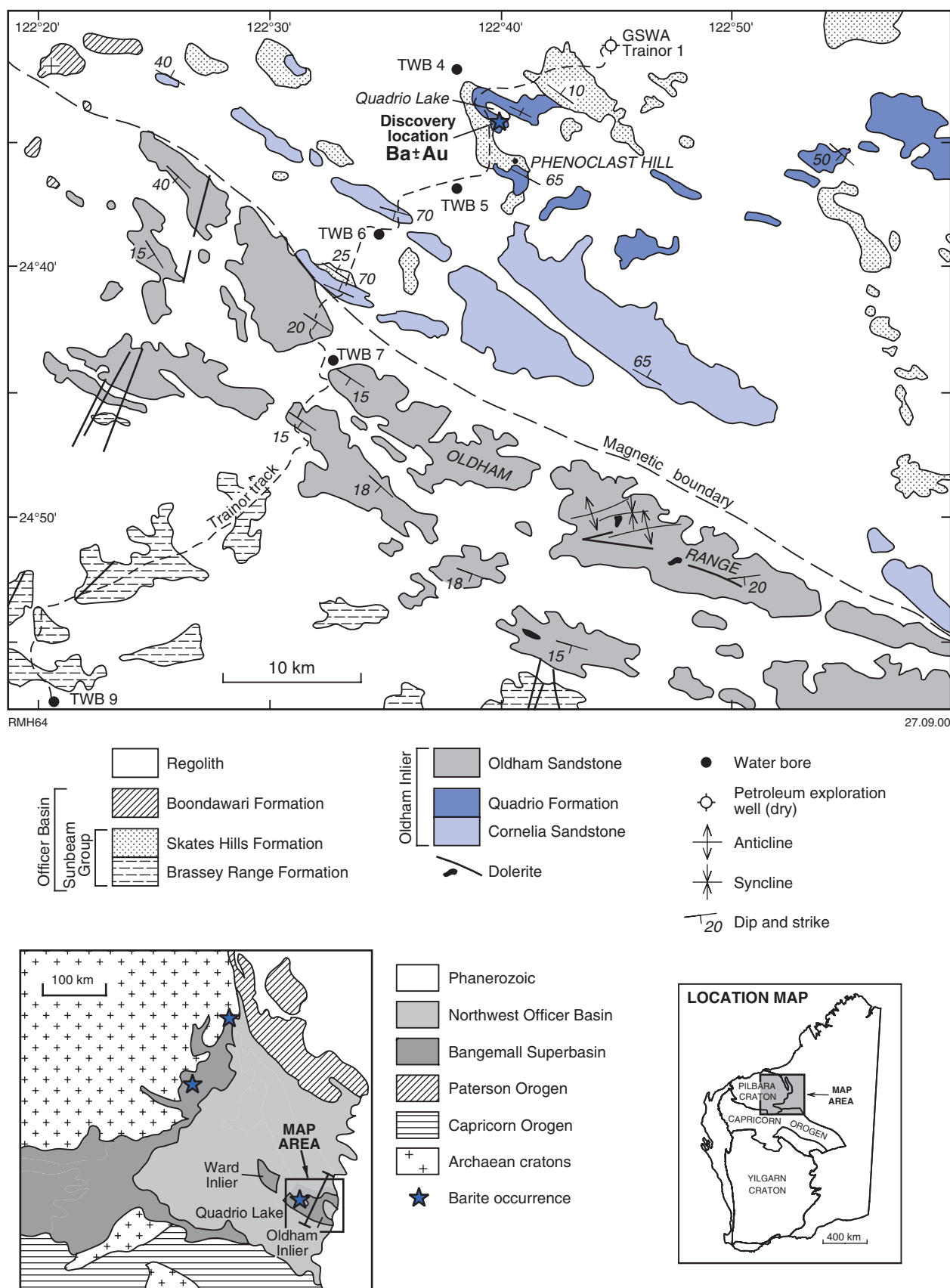


Figure 1. Geological map of the area around Quadrio Lake (based on Williams, 1995). Inset shows simplified geology of the northwestern Officer Basin (modified from Bagas et al., 1999)

Table 1. Stratigraphy of the Oldham Inlier

<i>Williams (1990, 1995), Muhling and Brakel (1985) stratigraphy</i>	<i>Hocking et al. (2000a,b) stratigraphy</i>	<i>Lithology</i>	<i>Age, correlation</i>
Cornelia Formation	Oldham Sandstone	Silicified sandstone; moderately dipping	?>1 – 1.2 Ga, ?Collier Group
	Quadrio Formation	Shale, minor sandstone; subvertical	?1.6 Ga, ?Edmund Group
	Cornelia Sandstone	Intensely silicified sandstone; steeply dipping	?1.6 Ga, ?Edmund Group

zircon ages of Nelson (1997)) is not accepted, as this would require an unreasonably complex structural model to be valid (Hocking et al., 2000b).

Both the Cornelia Sandstone and Quadrio Formation are steeply dipping, folded along west-northwest axes, and have a similar subdued magnetic character. In contrast, the Oldham Sandstone dips uniformly at about 20° southwest and has a more varied magnetic character. The Quadrio Formation and Cornelia Sandstone are tentatively considered to be of similar age, and the Oldham Sandstone is thought to be younger. The Cornelia Sandstone and Quadrio Formation probably correlate with the c. 1.6 Ga Edmund Group in the Bangemall Basin, 300 km to the west, but could also correlate with the ?c. 1.0 Ga Throssell Group, 150 km to the north (Hocking et al., 2000b). The Oldham Sandstone may correlate with the c. 1.2 Ga Collier Group in the Bangemall Basin.

There is a major change in magnetic character and structural orientation within the Oldham Inlier along the northern margin of the Oldham Range, about 15 km southwest of Quadrio Lake. This coincides with a fault northwest of the Trainor track, which marks the boundary between the Oldham and Cornelia Sandstones. Stratigraphic relationships suggest that it may be a south-directed reverse fault. No other major change in magnetic character is present between the fault and Trainor 1. On a gravity image (Geological Survey of Western Australia, 1996a), the Cornelia Sandstone occupies an intermediate 'terrace' (Hocking, 1994) between the higher density Oldham Sandstone to

the south and the lower density Quadrio Formation to the north. The first vertical derivative Bouguer gravity image (Geological Survey of Western Australia, 1996b) shows a well-defined, northwesterly trending ridge coincident with the northern side of the 'terrace'. One interpretation is that a fault separates the Quadrio Formation and Cornelia Sandstone, although none is apparent on aerial photographs. A local circular gravity low immediately south of Phenoclast Hill may represent a basement feature, or buried Mesoproterozoic-sourced salt diapirism.

Aeromagnetic imagery, Landsat/SPOT images, and mapping by

Williams (1995) of the Ward Inlier to the northwest (Fig. 1) show that its southern part appears to be Oldham Sandstone, and the northern third, Quadrio Formation. The Cornelia Sandstone may be present, but if so is less extensive than in the Oldham Inlier.

### *The barite-hematite vein system*

The vein material is composed of barite and iron oxides (mostly hematite) that form a stockwork system trending at about 270°. The veins cut siliciclastic sedimentary rocks (mainly brown shale and siltstone), which have been



Figure 2. Barite-hematite vein system in outcrop (MGA 465350E, 782000N)

Table 2. Selected trace element abundances of barite vein material

Sample no.	161270A	161270A (repeat)	161270B	161270C	Trainor 1 maxima
<b>Parts per million<sup>(a)</sup></b>					
Au (ppb)	<b>90<sup>(b)</sup></b>	<b>110</b>	<b>40</b>	<b>80</b>	<b>33</b>
V	24	—	26	42	385
Mn	200	—	125	120	na
Ni	50	—	6	9	167
Cu	64	—	82	44	402
Zn	11	—	19	12	313
As	<b>70</b>	—	42	<b>80</b>	<b>132</b>
Mo	2.2	—	0.9	2.6	8.4
Ag	<0.1	—	<0.1	<0.1	0.86
Sn	<0.1	—	0.1	0.2	2.8
Sb	<b>19.0</b>	—	8.6	<b>27.5</b>	<0.1
Ba (%)	<b>27.5</b>	—	<b>39.0</b>	<b>26.0</b>	29
W	0.7	—	0.5	1.1	7.1
Pb	24	—	10	16	79

NOTES: (a) Unless otherwise indicated  
(b) Abundances considered anomalous are shown in bold italics

Analyses performed by Genalysis, Perth  
na not analysed

deformed into a local northwesterly plunging, upright anticline. The host rocks near the veins are silicified and contain multiple, silica-filled hairline fractures, indicative of hydraulic fracturing by high-pressure fluids. Scattered barite-

hematite veins, up to 30 cm across (Fig. 2), are present for at least 2 km to the northwest, along the margins of Quadrio Lake.

Core from the Trainor 1 drillhole, about 10 km northeast of Quadrio

Lake, contains thin barite-hematite veinlets, locally associated with pyrite, in hydrothermally altered dark-grey mudstone (Stevens and Adamides, 1998) lithologically similar to the Quadrio Formation. Hydrothermal alteration in the core predominantly consists of disseminated carbonate porphyroblasts. Maximum element abundances, using all analyses, are shown in Table 2.

Analyses of three random samples of barite-rich vein material are also shown in Table 2. These samples were taken randomly, from barite-rich material. In addition to barium, there are anomalous abundances of gold (up to 110 ppb), arsenic, and antimony.

### Regional overview of stratigraphy, orogenies, and associated mineralizing events

In order to constrain an ore deposit model for the auriferous barite-hematite veins, the tectono-stratigraphic context of the region must be considered. Figure 3 shows a schematic southwest-

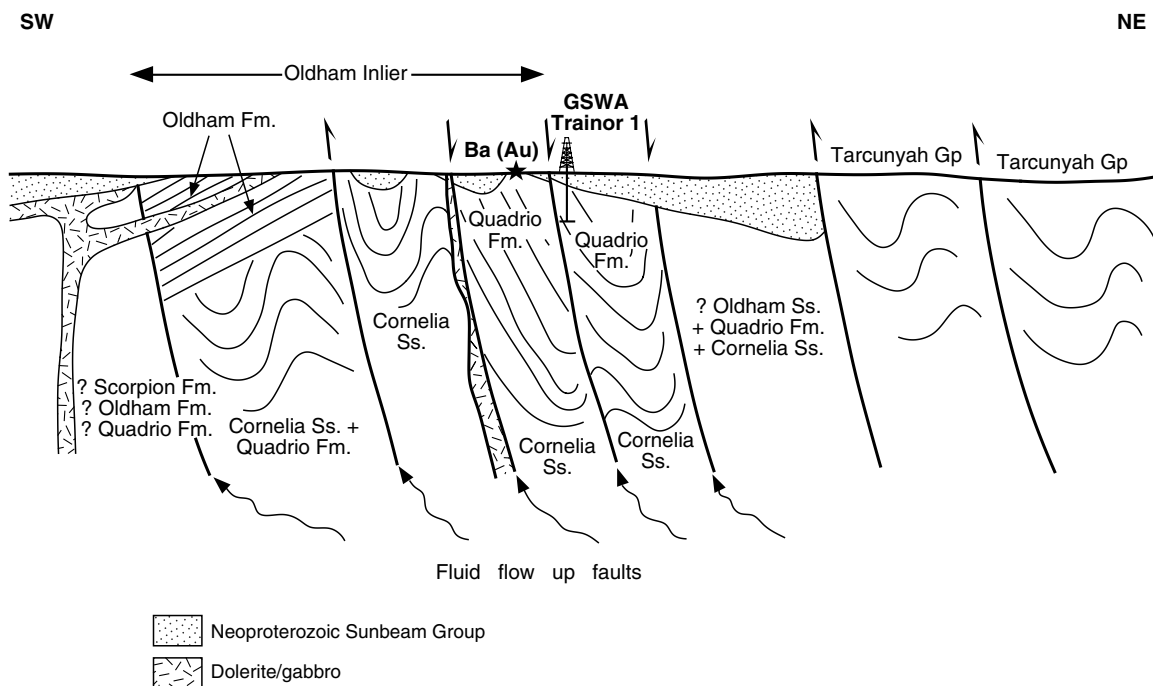


Figure 3. Schematic cross section, oriented north-northeast, across the Quadrio Lake area (not to scale; see Fig. 1 for position of section)



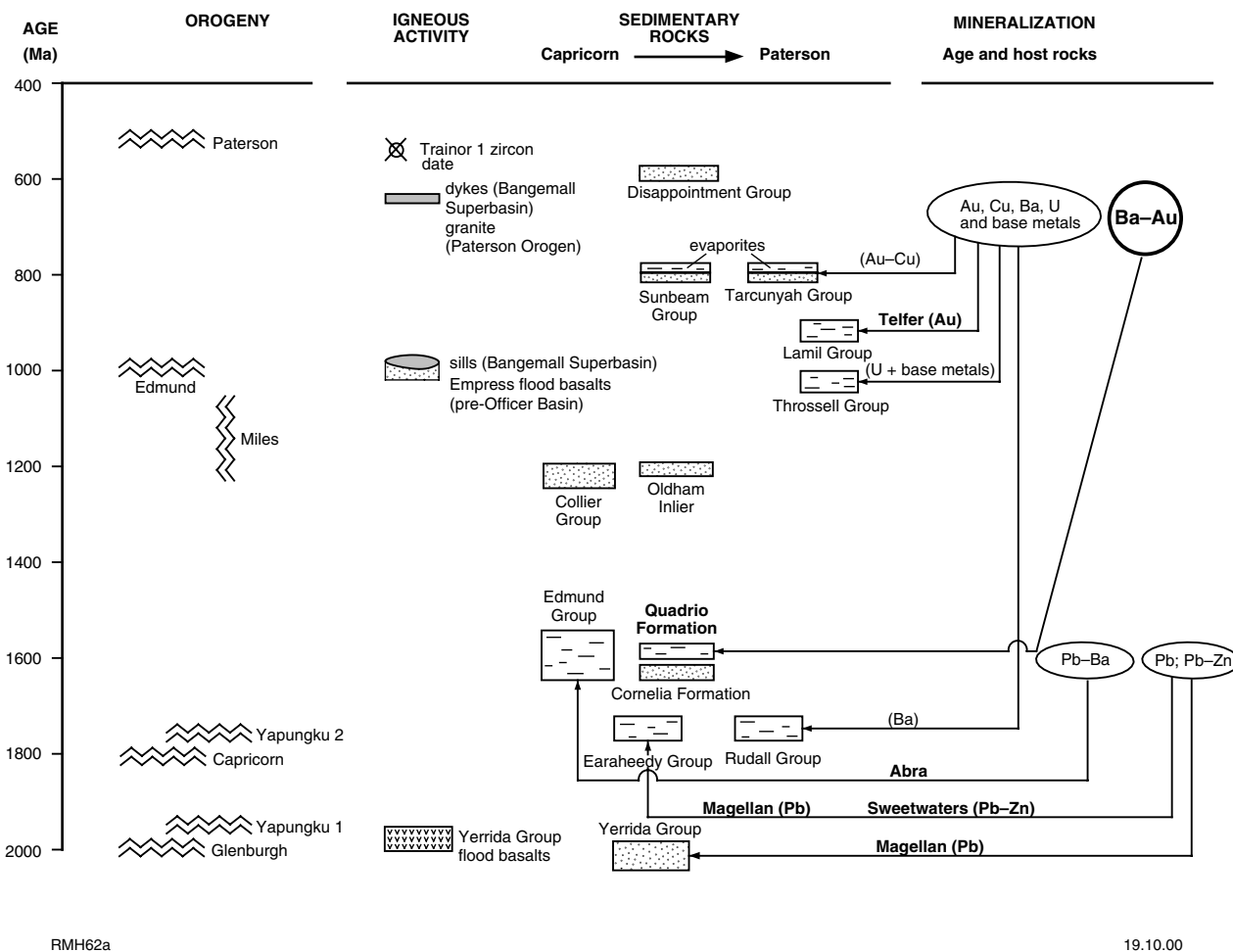


Figure 4. Chronostratigraphic correlation of Proterozoic orogenic, igneous, and mineralizing events

northeast section across the Quadrio Lake area, based on field observations, and aeromagnetic and gravity data. A series of faults that cut the folded rocks of the Oldham Inlier could have acted as conduits for mineralizing fluids.

The age of the barium mineralization (with or without gold) around Quadrio Lake is not known, but since this mineralization crosscuts deformed sedimentary rocks, it must be epigenetic. The ages of mineralizing events and orogenies in the region are shown in Figure 4. There are several groups of events, including the latest Palaeoproterozoic event (c. 1.65 Ga; e.g. Abra lead-barium, Sweetwaters lead-zinc, Magellan lead; Jones et al., 2000), and a much younger event at c. 700–600 Ma that is bracketed between the Miles and Paterson Orogenies (Tyler et al., 1998). The Telfer gold mineralization is

associated with this younger event (Rowins et al., 1997; Bagas and Lubieniecki, 2000). As the Quadrio Lake mineralization post-dates deformation of the Quadrio Formation, it is unlikely to be part of the older event (Fig. 4). Since there is no recorded mineralizing event between 1650 and 800 Ma, it is likely that the Quadrio Lake barite is part of the same event that produced the Telfer gold mineralization and other metalliferous occurrences in the Throssell and Lamil Groups (Fig. 4).

### An ore deposit model

Barite deposits are commonly associated with either continental margins in foreland basins, or with intracratonic rifts (Maynard et al., 1995). The former forms barite-only deposits, with no associated lead-zinc deposits,

whereas the latter commonly represents a distal facies to stratiform lead and zinc deposits, such as those of Rammelsberg in Germany. Maynard et al. (1995) convincingly demonstrated that the use of Sr isotopes can discriminate between barite associated with stratiform–stratabound sulfide deposits in rift environments, and barren barite. They showed that  $^{87}\text{Sr}/^{86}\text{Sr}$  values greater than 0.710 are only recorded from barite associated with sulfide deposits in intracratonic rift settings (e.g. Rammelsberg in Germany, Hilton in Australia). Strontium isotope ratios for the Quadrio Lake barite are presented in Table 3. Initial ratios have been calculated at 487 and 610 Ma. For both ages,  $^{87}\text{Sr}/^{86}\text{Sr}$  values are greater than 0.710 and therefore we suggest that the Quadrio Lake barite belongs to an intracratonic environment. This is consistent with the recognized

Table 3. Sr isotope ratios

Sample	$^{87}\text{Sr}/^{86}\text{Sr}$	$\pm 2 \text{ SD}^{(a)}$	Rb (ppm)	Sr (ppm)	487 Ma	610 Ma
161270A	0.713844	0.000008	2.14	2 730	0.713824	0.713819
161270B-1	0.716063	0.000008	3.4	3 369	0.716043	0.716038
161270B-2	0.716067	0.000008	3.4	3 369	0.716047	0.716042

NOTES: (a) Standard deviation

Sr isotope analysis carried out at Shimane University, Matsue, Japan, following procedures discussed by Iizumi et al. (1994). Rb and Sr concentrations determined by ICP-MS at Genalysis Laboratory Services (Perth), following procedures discussed in Morris (2000)

intracratonic setting of the region since the Mesoproterozoic, and with the anoxic depositional setting implied by the host rocks (shale and siltstone). An anoxic depositional environment in parts of the host intracratonic basin is

conductive to the later deposition of sulfides.

The tectonic setting of the area (an intracontinental basin) is conducive to sedex deposits. A proposed ore deposit model is presented in

Figure 5, based on the sedex-style sulfide deposits described by Goodfellow et al. (1993). In our model, the mineralization can extend for hundreds of metres to tens of kilometres from feeder channels. The three main facies comprise a vent complex, proximal stratabound sulfide ore, and distal stratabound sulfate and oxide ore (Fig. 5). A halo of hydrothermal alteration (albite, chlorite, carbonate, and silica) surrounds the feeder channel. The sulfide, oxide, and sulfate mineralization replaced the pre-existing lithologies on a 'lit-par-lit' style.

The feeder channels are probably controlled by structural breaks, such as fault or shear zones. The major fault 15 km south of Quadrio Lake could be one of these structures. Alternatively, if the gravity 'terrace'

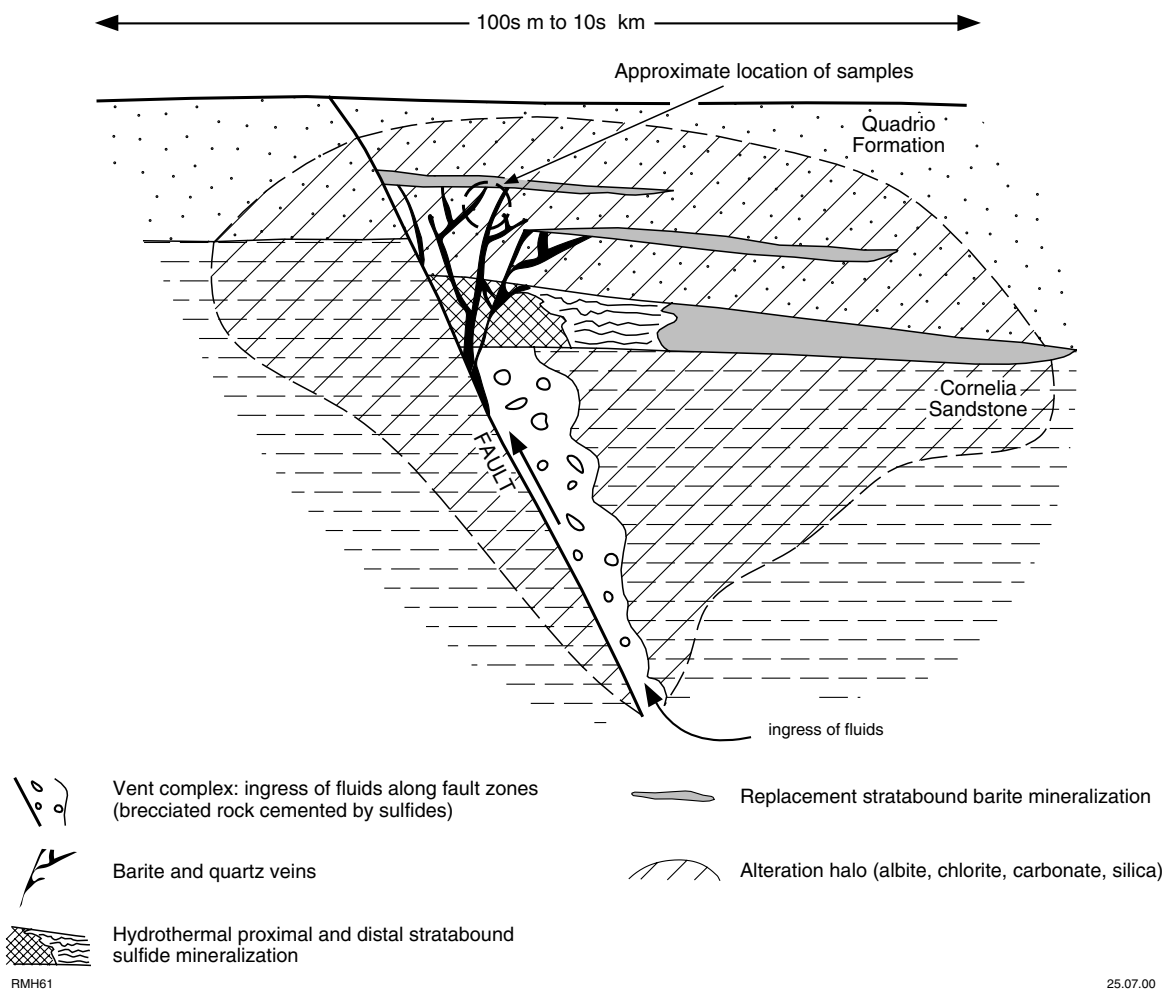


Figure 5. Ore deposit model, showing vent, replacement-style proximal sulfide, and distal oxide-sulfate facies

on which the Cornelia Sandstone lies is also a fault terrace, then the northern edge (immediately south of Phenoclast Hill) could be the controlling structure. A typical feeder channel is a vent complex, characterized by brecciated material cemented by sulfides. Sedimentary rocks lie above the feeder and form a stratabound–stratiform massive sulfide zone. In the general model, layers and stockworks of barite are present distal to the sulfide zone. The Quadrio Lake stockwork may be in this distal zone. It may be significant that silica alteration is present around the barite veins, whereas carbonate alteration is present in the barite–sulfide mineralization detected in the Trainor core (Stevens and Adamides, 1998).

The model is simplistic because of the poor knowledge of the geology, stratigraphy, and structure of the

region. Other possible models include a mineralized system centred on a buried intrusion, which is possible because of the gravity low immediately south of Phenoclast Hill. Such options can only be assessed when more is known about the geology of the Oldham Inlier and adjacent areas.

Further exploration should be directed towards sedimentary horizons that are indicative of an anoxic environment, particularly at their intersection with major structures.

### Conclusions

The Quadrio Lake area and surrounding region has potential for sedex-type base metal mineralization. The discovery of barite with anomalous gold in the Oldham Inlier raises the

prospectivity of these other occurrences. The challenge for the explorationist is to be able to locate sulfide mineralization that may be linked to the barite–hematite vein system. The presence of anomalous amounts of gold, arsenic, and antimony in barite suggests that hydrothermal fluids carried gold and other metals in solution, which precipitated primarily in sites closer to the venting structures. The ‘spent’ solutions always carry trace amounts of the main solutes, which in this case probably included gold, arsenic, and antimony.

### References

- BAGAS, L., GREY, K., HOCKING, R. M., and WILLIAMS, I. R., 1999, Neoproterozoic successions of the northwest Officer Basin: a re-appraisal: Western Australia Geological Survey, Annual Review 1998–99, p. 39–44.
- BAGAS, L., and LUBIENIECKI, Z., 2000, Copper and associated polymetallic mineralization along the Camel–Tabletop Fault Zone in the Paterson Orogen, Western Australia: Western Australia Geological Survey, Annual Review 1999–2000, p. 36–41.
- BRAKEL, A. T., and LEECH, R. E. J., 1980, Trainor, W.A.: Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 13p.
- GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 1996a, Savory Basin Bouger gravity image, 1:250 000: Western Australia Geological Survey.
- GEOLOGICAL SURVEY OF WESTERN AUSTRALIA, 1996b, Savory Basin First vertical derivative of Bouger gravity image, 1:250 000: Western Australia Geological Survey.
- GOODFELLOW, W. D., LYDON, J. W., and TURNER, R. J. W., 1993, Geology and genesis of stratiform sediment-hosted (SEDEX) zinc–lead–silver sulphide deposits: Geological Association of Canada, Special Paper 40, p. 201–252.
- HOCKING, R. M., 1994, Subdivisions of Western Australian Neoproterozoic and Phanerozoic sedimentary basins: Western Australia Geological Survey, Record 1994/4, 83p.
- HOCKING, R. M., JONES, J. A., PIRAJNO, F., and GREY, K., 2000a, Revised lithostratigraphy for Proterozoic rocks in the Earaheedy Basin and nearby areas: Western Australia Geological Survey, Record 2000/16, 22p.
- HOCKING, R. M., GREY, K., BAGAS, L., and STEVENS, M. K., 2000b, Mesoproterozoic stratigraphy in the Oldham Inlier, Little Sandy Desert, central Western Australia: Western Australia Geological Survey, Annual Review 1999–2000, p. 49–56.
- IIZUMI, S., MAEHARA, K., MORRIS, P. A., and SAWADA, Y., 1994, Sr isotope data of some CSJ rock reference samples: Matsue, Japan, Shimane University, Memoirs of the Faculty of Science, v. 28, p. 83–86.
- JONES, J. A., PIRAJNO, F., HOCKING, R. M., and GREY, K., 2000, Revised stratigraphy for the Earaheedy Group: implications for the tectonic evolution and mineral potential of the Earaheedy Basin: Western Australia Geological Survey, Annual Review 1999–2000, p. 57–64.
- MAYNARD, J. B., MORTON, J., VALDES-NODARSE, E. L., and DIAZ-CARMONA, A., 1995, Sr isotopes of bedded barites: guides to distinguishing basins with Pb–Zn mineralization: Economic Geology, v. 90, p. 2058–2064.

- MORRIS, P. A., 2000, Composition of Geological Survey of Western Australia geochemical reference materials: Western Australia Geological Survey, Record, 2000/11, 33p.
- MUHLING, P. C., and BRAKEL, A. T., 1985, Geology of the Bangemall Group — evolution of an intracratonic Proterozoic basin: Western Australia Geological Survey, Bulletin 128, 266p.
- NELSON, D. R., 1997, Compilation of SHRIMP U–Pb zircon geochronology data, 1996: Western Australia Geological Survey, Record 1997/2, 189p.
- ROWINS, S. M., GROVES, D. I., McNAUGHTON, N. J., PALMER, M. R., and ELDRIDGE, C. S., 1997, A reinterpretation of the role of granitoids in the genesis of Neoproterozoic gold mineralization in the Telfer Dome, Western Australia: *Economic Geology*, v. 92, p. 133–172.
- STEVENS, M. K., and ADAMIDES, N. G., 1998, GSWA Trainor 1 well completion report, Savory Sub-basin, Western Australia, with notes on petroleum and mineral potential: Western Australia Geological Survey, Record 1996/12, 69p.
- TYLER, I. M., PIRAJNO, F., BAGAS, L., MYERS, J. S., and PRESTON, W. A., 1998, The geology and mineral deposits of the Proterozoic in Western Australia: Australian Geological Survey Organisation, *Journal of Australian Geology and Geophysics*, v. 17, p. 223–244.
- WILLIAMS, I. R., 1990, Savory Basin, *in* Geology and mineral resources of Western Australia: Western Australia Geological Survey, Memoir 3, p. 329–335.
- WILLIAMS, I. R., 1995, Trainor, W.A. (2nd edition): Western Australia Geological Survey, 1:250 000 Geological Series Explanatory Notes, 31p.