GOSSAN HILL Cu-Zn-Au DEPOSIT, GOLDEN GROVE, WESTERN AUSTRALIA

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LOCATION

The Gossan Hill Cu-Zn-Au deposit at Golden Grove, 56 km SSW of Yalgoo, is 338 km NNE of Perth in the Murchison Province of the Archaean Yilgarn Craton at 28º45'S, 116º59'E; Yalgoo 1:250 000 map sheet (SH50-02).

DISCOVERY HISTORY

Outcropping gossans were recognized and sampled by Aztec Exploration Co. Pty Ltd in 1971 on what is now Gossan Hill. Five diamond drill holes tested the gossans in 1972 when Amax Exploration (Aust) Inc joined them in a joint venture. Four of the holes intersected significant base metal sulphides (about 1-3.5% Cu and Zn). In 1973 the Electrolytic Zinc Company of Australasia joined them and defined a resource of 15 Mt at 3.4% Cu. Difficulties in the geometry of the deposit were recognized. Exxon joined the joint venture in 1977 and continued exploration. The non-outcropping Scuddles deposit was discovered 4 km to the N of Gossan Hill in 1979. The geometry of the Scuddles deposit turned out to be relatively straightforward and much of the focus at Golden Grove then centred on delineation and development of Scuddles. The most intense exploration activity has been over the Gossan Hill to Scuddles area (Figure 1).

In the late 1980s, feasibility studies and further testing were conducted at Gossan Hill. A decline was commenced in 1994 for further exploration and possible mining. This was successful and underground development and mining commenced in 1997.

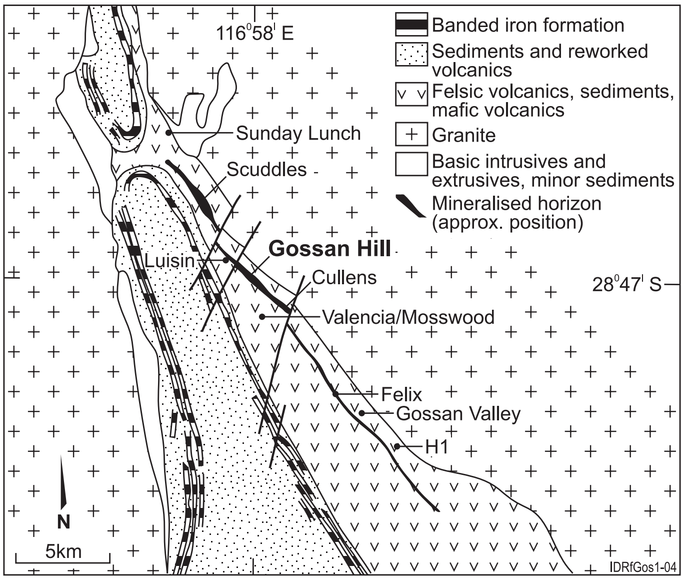

Figure 1. Regional geology of the Warriedar Fold Belt (after Mill et al., 1990).

PHYSICAL ENVIRONMENT

Base metal (Cu-Zn) exploration in the Golden Grove district has concentrated on a 30 x 2 km area of prospective felsic volcano-sedimentary rocks that have low relief, except where they locally rise some 80 m above the plains at Gossan Hill. A ridge of outcrops of the Thundelarra Group banded iron formation and basalt marks the boundary of a broad plain to the SW. This plain also continues S for some 20 km, extensively masking the prospective sequence with soil, sand and alluvium, commonly with lateritic gravel or duricrust at or beneath the surface.

The climate is semi-arid, with an erratic annual rainfall averaging 260 mm. The mean daily minimum and maximum temperatures are 22-38ºC in January, to 8-17ºC in July. Vegetation consists of a thick, low scrub of drought-resistant mulga (*Acacia* spp.) with an incomplete ground cover of shrubs and grasses. Historically, the district has been one of low-density sheep grazing.

GEOLOGICAL SETTING

The Gossan Hill and Scuddles VHMS deposits occur on the NE flank of the Warriedar Fold Belt (Figure 1), in the Golden Grove Domain, with an age of about 3.0 Ga. The Golden Grove Domain has a layered stratigraphy that is laterally continuous over some 30 km. Within this, the Golden Grove Formation is a layered rhyodacitic volcaniclastic succession that underlies and hosts the VHMS deposits. Dacitic and rhyodacitic volcanics of the Scuddles Formation are the main rock types of the hanging wall. Bedded tuffaceous volcaniclastic rocks of the Golden Grove Formation are subdivided into six members, based on facies, grain-size variation, abundance of volcanic quartz grains and bedding characteristics (Frater, 1983; Sharpe and Gemmell, 2001, 2002).

Regional deformation has resulted in EW compression, minor faulting, cleavage, schistosity and boudinageing of the rocks. Undulose cracking patterns are also common in the sulphide and magnetite bodies with fractures infilled by carbonate, chlorite and sulphides. A metamorphic assemblage typical of the biotite zone of the greenschist facies occurs throughout the Golden Grove Domain. However, there is no biotite at Gossan Hill. Its absence, together with the presence of andalusite and chloritoid, are thought to represent alkali depletion associated with intense hydrothermal alteration and mineralization. The Golden Grove Formation shows regionally extensive quartz, Fe-rich chlorite and lesser muscovite alteration. At Gossan Hill, alteration zones surround the deposit and are characterized by chlorite and ankerite-siderite (with FeO and MgO enrichment), grading stratigraphically upwards into intense silicification.

REGOLITH

The district has suffered prolonged deep weathering, resulting in a thick saprolite and oxidation of sulphides, commonly to 60-100 m. The top 0.5 m of saprolite is commonly mottled in which vermicular, ferruginous, nodular concretions are set in a clay matrix. Centimetre-sized lateritic pisoliths and nodules occur in the top 100 mm of the mottled zone. Accumulated lateritic nodules and pisoliths commonly overlie the mottled zone or the saprolite, forming a widespread lateritic gravel reaching 1-3 m thick, though not present everywhere. Where studied, at Gossan Hill, the lateritic nodules and pisoliths have a local origin, probably within 50-100 m of their source. More generally, the lateritic gravel is thought to have a variable residual to locally transported origin. In places, the lateritic gravel is cemented to a lateritic duricrust. In areas of low relief, the lateritic gravel is commonly overlain by >0.5 m of silty soil and aeolian sand and, in places, several metres of alluvium. Erosion of soil, lateritic gravel and duricrust has left windows of outcropping or subcropping saprolite. The border between erosional and relict regimes, in places, is marked by a subdued breakaway.

An area of outcrop and sub-crop, measuring some 500 x 600 m, forms the crest of Gossan Hill. Here, outcrops of ferruginous ironstone, after massive magnetite, are particularly prominent; somewhat less prominent gossans, formed from base metal sulphides, are associated with outcrops and subcrops of saprolitic volcano-sedimentary rocks.

MINERALIZATION

At the mine scale, a steep W-dipping horizon of thinly bedded chert and tuff, within the Golden Grove Formation, hosts the Zn mineralization at both Gossan Hill and Scuddles and is underlain by coarse felsic pyroclastic and epiclastic rocks. The Gossan Hill deposit consists of a number of lenses of Zn and Cu mineralization, extending over a strike of 400 m and a width of 20 m. The Cu ore occurs in magnetite-rich epiclastic rocks stratigraphically below the Zn ore. An oxidized near-surface Au-Ag resource overlies the Zn sulphide lenses and an oxide Cu resource overlies the Cu sulphide lenses (Normandy, 1999).

The Gossan Hill Deposit has the following resources: - (a) sulphide resources of 7 Mt at 3.4% Cu; 2.2 Mt at 11.3% Zn, 1.5 g/t Au, 102 g/t Ag; (b) supergene Cu, 5.3 Mt at 1.5% Cu; (c) oxide Au, 2 Mt at 2.2 g/t Au, 86 g/t Ag. The main ore minerals are sphalerite, chalcopyrite and lesser galena with a gangue of pyrite, pyrrhotite and magnetite. The ore shoots contain many chalcophile, or partly chalcophile elements namely Fe, S, Cu, Pb, Zn, Co, As, Sb, Bi, Cd, In, Mo, Ag, Sn, Ge, Se, Te, Hg and Au (Smith *et al.*, 1980; Smith and Perdrix, 1983).

REGOLITH EXPRESSION

Gossans

Massive Fe-rich gossans occur over the sulphide shoots and massive ironstones over the magnetite bodies. Frater (1983) recognized and mapped several gossan and ironstone types at Gossan Hill, based on their mesoscopic fabrics, partly inherited from the parent mineralogy, their position within the mapped sequence and their geochemistry. These were i) base-metal sulphide (Cu) gossan, ii) base-metal sulphide (Zn/Pb) gossan, iii) base-metal sulphide/magnetite gossan, iv) iron sulphide gossan, and v) massive magnetite ironstone (Smith *et al.*, 1980, 1992; Anand *et al.*, 1993). The base-metal sulphide gossans tend to have cellular fabrics with a crumbly, porous and knobbly surface.

Of the 36 gossan samples taken in the original exploration, 23 were deemed to be anomalous (thresholds shown in brackets) in Cu (1000 ppm), Pb (200 ppm), Zn (500 ppm) or Ag (4 ppm). The most strongly anomalous sample contained 1800 ppm Cu, 1850 ppm Pb, 3400 ppm Zn and 4 ppm Ag (Josh Pitt personal communication, 1979). All were low in Ni, mostly in the range 10-15 ppm, discriminating them from nickel sulphide gossans, which were the focus of much mineral exploration in the early 1970s.

Smith and Perdrix (1983) showed that the gossans and ironstones are all anomalous in As, Sb, Bi, Sn and Se, with Cu and Au anomalous in some. From a total of 103 gossan and ironstone samples from Gossan Hill, 95% are anomalous in chalcophile indicator elements, 90% strongly so. Although approximately 60% of gossans over the main Cu ore shoots are anomalous in Cu (using a revised threshold of 400 ppm) more than 90% are anomalous in chalcophile elements. Only a minority of the Cu and Zn gossans are anomalous in Zn, due to leaching. These findings indicate the importance of multi-element geochemistry for successful gossan identification in exploration of weathered terrain. Of the total gossan and ironstone samples at Gossan Hill, 52% are anomalous in Au (threshold 23 ppb). Furthermore, the base metal gossans (with a median of 251 ppb Au) and iron sulphide gossans (with a median of 464 ppb Au) are generally substantially richer in Au than the ironstones after magnetite (median <2 ppb).

Lateritic nodules and duricrust

Gossan Hill was the test area for initial CSIRO research on geochemical dispersion into laterite, which commenced in 1979, which had the objective of determining whether the multi-element signature seen in gossans could be recognised in lateritic gravel and duricrust. This was found to be the case. The dispersion anomaly is approximately 1.5 x 2 km, forming a target far greater in area than the surface projection of the ore deposits (Figures 2 and 3). The dispersion halo in laterite has a Cu, Zn, As, Sb, Bi, Sn, In and Au association. The largest dispersion haloes are for Bi, Sn and As, followed, in decreasing order, by Sb, Mo, Se, Cu, Zn, Ag, and Au. The strike of the anomaly can be increased with using multi-element chalcophile indices (Smith and Perdrix, 1983) to some 6 km, linking Gossan Hill and Scuddles. Multivariate statistical methods can improve anomaly recognition and ranking (Smith *et al.*, 1984). The anomaly in the lateritic mantle is asymmetric, with the strongest multi-element association on the SW of Gossan Hill (Figure 2). This is partly because many of the gossans are SW of the hill crest but also partly because lateritic gravel or duricrust are missing from the local erosional window (Smith and Perdrix, 1983). The Au anomaly is localized in comparison with the other elements. It closely indicated the locality where Au was most strongly anomalous in the gossans.

Gossan fragments have contributed to the dispersion halo in laterite through mechanical dispersion and residual accumulation as lateritic nodules and pisoliths. In addition, hydromorphic dispersion of Cu, As and Zn has taken place, with these elements being incorporated into the concretionary skins (cutans) of nodules and pisoliths. Fine grains of cassiterite (typically 5-10 µm) have also dispersed mechanically and have been incorporated into cutans of nodules and pisoliths. Cassiterite also occurs within gossan fragments, which are common as cores to lateritic nodules.

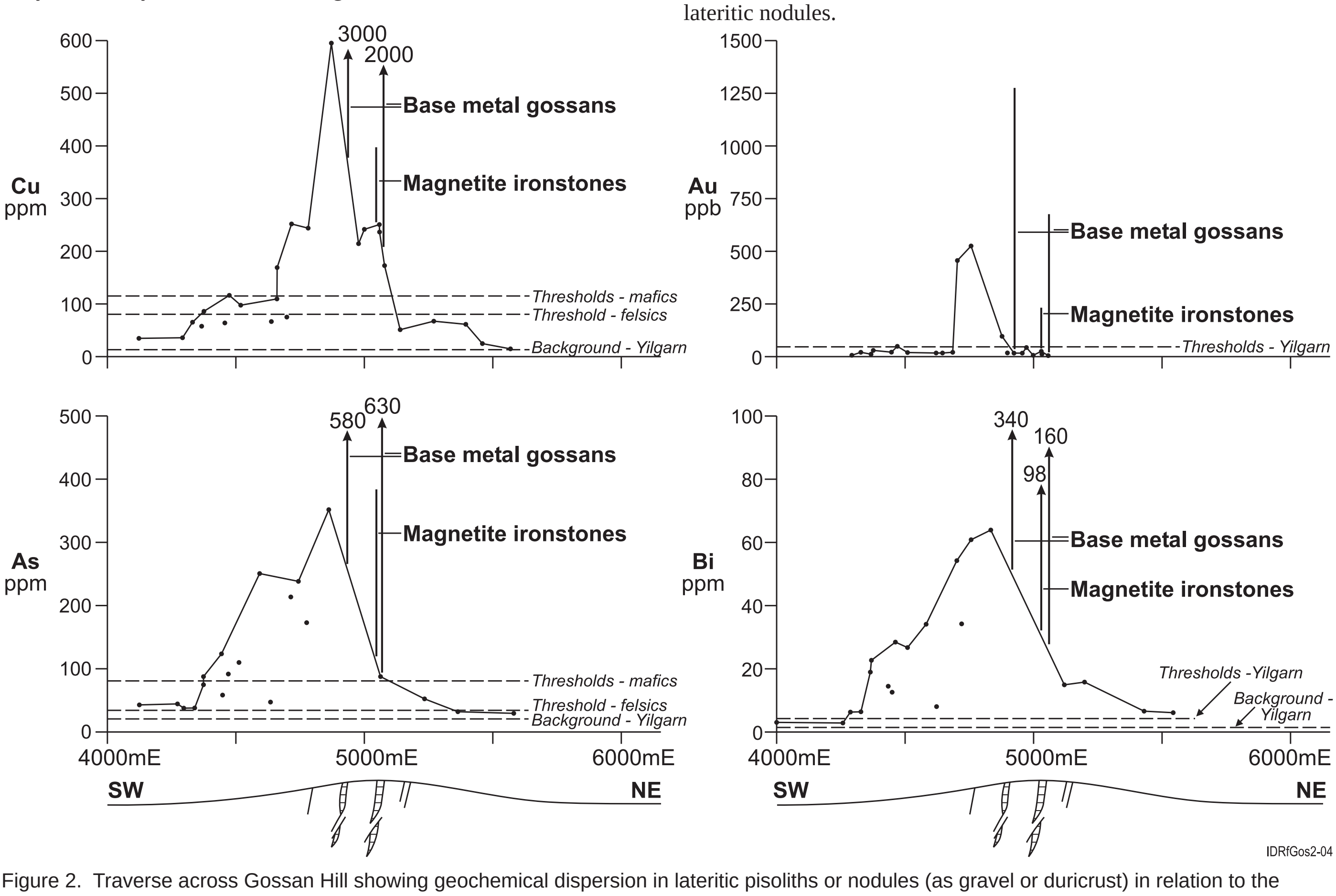

Figure 2. Traverse across Gossan Hill showing geochemical dispersion in lateritic pisoliths or nodules (as gravel or duricrust) in relation to the position and strength of likely source gossans. Data, shown as an envelope enclosing high values, are compiled between 18250N and 18500N (mine grid) for Cu Au and Bi, and between 18100N and 18500N for As. Modified after Anand et al., 1993.

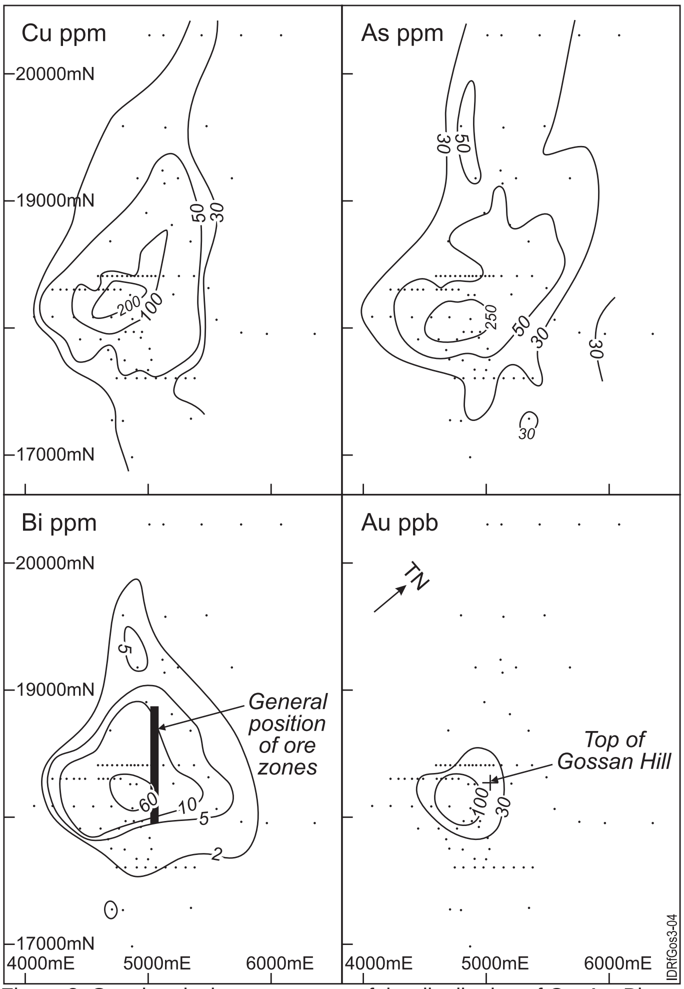

Figure 3. Geochemical contour maps of the distribution of Cu, As, Bi and Au in pisolitic or nodular laterite (sampled as gravel or duricrust) at Gossan Hill, modified from Smith and Perdrix (1983). Sample sites are shown as dots.

Soil

An orientation survey over Gossan Hill (Tetley *et al.*, 1973), using Cu, Pb and Zn, showed that the best contrast was in the 350-700 µm fraction, the Cu anomaly being a peak of 200 ppm against a background of 15-135 ppm.

Saprolite

Geochemical orientation information for saprolite has not been assembled at this stage.

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SAMPLE MEDIA - SUMMARY TABLE

Sample medium	Indicator elements	Analytical methods	Detection limits (ppm)	Background (ppm)	Maximum anomaly (ppm)	Dispersion distance (m)
Gossan	Cu	XRF	5	175	10 000	Not applicable to gossans
	Pb	XRF	5	15	1700	
	Zn	XRF	5	160	1400	
	Au	INAA	0.005	0.003	5	
	Ni	XRF	5	130	15	
	Co	INAA	1	45	46	
	As	INAA	1	20	3840	
	Sb	INAA	0.2	2	816	
	Bi	XRF	1	1	665	
	Cd	XRF	1	<1	2	
	In	XRF	1	<1	66	
	Mo	XRF	1	1	292	
	Ag	OES	0.1	0.3	15	
	Sn	XRF	2	3	3800	
	Ge	OES	1	<1	30	
	W	INAA	2	3	280	
	Ba	XRF	10	300	836	
	Se	XRF	2	2	300	
	Te	XRF	1	<1	32	
	Tl	OES	1	<1	<1	
Lateritic nodules, pisoliths or duricrust	Cu	XRF	5	40	663	800
	Pb	XRF	5	28	185	50
	Zn	XRF	5	11	140	600
	Au	INAA	0.005	0.005	5	250
	Ni	XRF	5	19	35	NA
	Co	INAA	1	8	65	NA
	As	INAA	1	6	450	1000
	Sb	INAA	0.2	1	215	1000
	Bi	XRF	1	0.3	90	1000
	Cd	XRF	1	0.3	3	<10
	In	XRF	1	<1	36	700
	Mo	XRF	1	1	105	NA
	Ag	OES	0.1	0.2	4.0	<10
	Sn	XRF	2	<1	95	900
	Ge	OES	1	0.3	3	NA
	W	INAA	2	3	60	NA
	Ba	XRF	10	80	1350	NA
	Se	XRF	2	2	35	<10
	Tl	OES	1	<1	<1	<10
Soil	Cu	Not known	Not known	15-135	200	

Notes

1. Gossan background is median of Yilgarn ferricretes (Smith *et al.*,1992), n = 500.
2. Lateritic nodule background etc, from Golden Grove background group (Smith *et al.*, 1984), n = 35.