BODDINGTON GOLD DEPOSIT, WESTERN AUSTRALIA

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LOCATION

The Boddington Au deposit (Figure 1) is in the Darling Range, approximately 100 km SSE of Perth, at 32º44'S, 116º22'E; Pinjarra 1:250 000 map sheet (SI50-02).

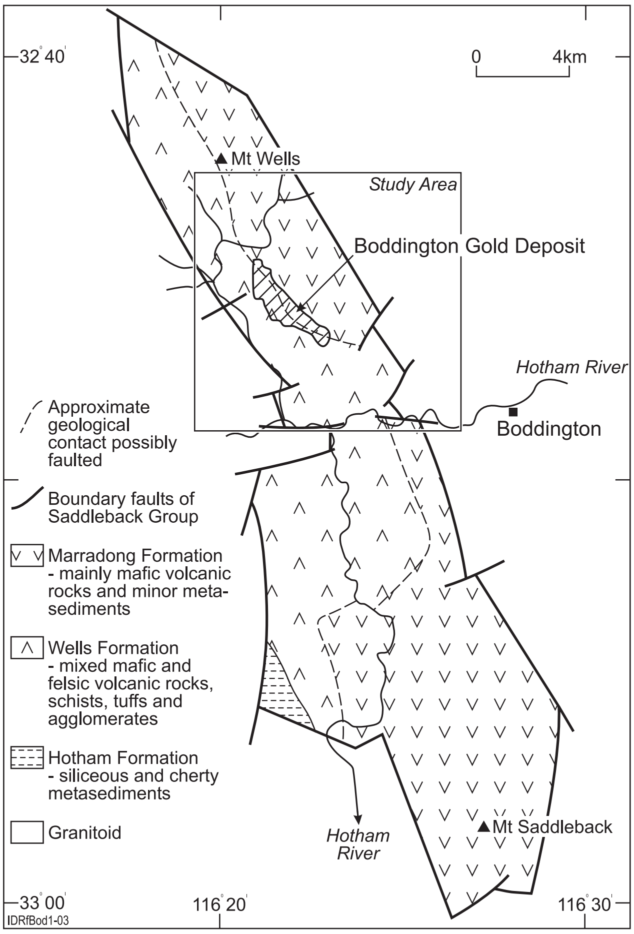

Figure 1. Generalized geological map of the Saddleback Greenstrone Belt (after Wilde and Low, 1980).

DISCOVERY HISTORY

In 1979, a geochemical prospecting program (stream sediments, soil and rock) by the Geological Survey of Western Australia discovered anomalous Au (max 1.6 ppm), As, Cu, Pb, Mo and Zn in an area 5 km long by 500 m wide in the Saddleback Greenstone Belt (Davy, 1979). In 1980, Reynolds Mines Pty Ltd commenced Au exploration of this area, which had previously been explored for bauxite, by sampling laterite. Promising areas were followed up by reassaying bauxite drill samples and led to the discovery of the Boddington Au deposit.

PHYSICAL FEATURES AND ENVIRONMENT

The deposit is situated towards the eastern edge of the Darling Plateau, beneath a deeply weathered, undulating landscape (Figure 2) varying from 250 to 400 m asl. Local relief is about 50 m, with shallow valley floors adjacent to smooth, broadly convex crests. Inselbergs, such as Mt Wells, project above the plateau to >500 m. The climate is Mediterranean with an average annual rainfall of 800 mm; mean temperature ranges are 14-32ºC (January) and 4-15ºC (July). The dominant vegetation is eucalptus forest.

GEOLOGICAL SETTING

The Boddington deposit lies within the N part of the Archaean Saddleback greenstone belt, a steeply-dipping and extensively faulted sequence of greenschist to lower amphibolite metamorphosed sedimentary, felsic, and mafic volcanic and pyroclastic rocks, which have been extensively faulted. The deposit is adjacent to a NW-trending lineament that, at mine-scale, forms a shear zone along the western margin

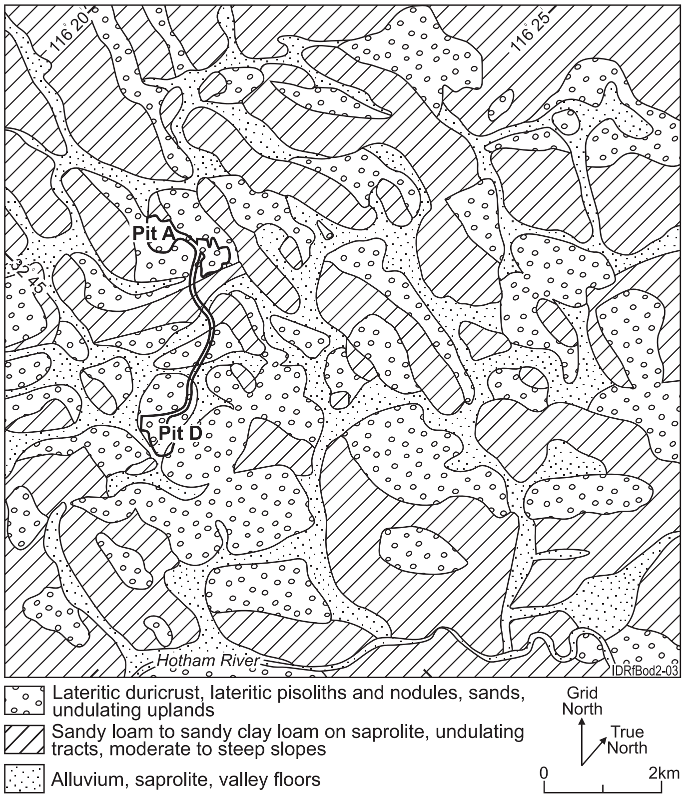

Figure 2. Simplified regolith-landform for the Boddington area.

of the mineralization. Bedrock near the mine is felsic and mafic andesite to the E and schists to the W.

REGOLITH

The regolith consists of saprock, saprolite, ferruginous saprolite, a bauxite zone, ferruginous duricrust and loose nodules and pisoliths. The saprolite is clay-rich, 25-70 m thick, and ranges from white to multi-coloured and ferruginous. The gibbsitic bauxite zone, about 4 m thick, contains fragments of saprolite, incipient nodules and is mottled in places. Ferruginous duricrust forms an almost continuous blanket over large areas. Its thickness, facies and origin vary with topographic position. It is better developed and/or better preserved on mid slopes than on crests or lower slopes. The mid-slopes are typically dominated by 1-2 m of fragmental duricrust overlain by 0.5-1.0 m of pisolitic duricrust. Fragmental duricrust has subangular to angular, dark brown to red, hematite-rich fragments, that range from a few mm to more than 30 mm, in a matrix of gibbsite and goethite. Pseudomorphs after primary minerals are common. The transition from fragmental to pisolitic duricrust is sharp in some places and gradational in others. The pisolitic duricrust is darker and more Fe-rich than the fragmental duricrust. It contains red to black, simple or compound, generally transported pisoliths that are either hematite or maghemite-rich (Anand, 1994), cemented by goethite and gibbsite. Fragmental duricrust is generally related to the underlying lithologies, whereas the pisolitic duricrust has suffered limited colluvial transport that is still continuing. The loose hematite- and maghemite-rich gravels are shallow (0.2-0.5 m) on crests and upper slopes and increase in thickness (2-4 m) down slope. The nodular and pisolitic surface lag on this gravelly material is dark red-brown to black, highly magnetic, and dominated by hematite, maghemite and poorly crystalline alumina.

MINERALIZATION

The primary Au mineralization is hosted in intermediate to felsic volcanic rocks. It is a low-sulphide system with intense silicification, potassic and calc-silicate alteration, and a Au-Cu-Mo-W-(Bi) association (Symmons *et al.*, 1988). In the regolith, Au is concentrated in the lower part of the bauxite zone, the middle of the clay saprolite and the base of the saprolite. Mineable lateritic reserves of 60 Mt at 1.6 g/t occur over 4.5 km^2 (Symons *et al.*, 1990).

REGOLITH EXPRESSION

A stream sediment orientation survey in 1983, prior to mining, showed maximum concentrations of Au (>1 ppm) and As (80-350 ppm) in all size fractions (Table 1) occurring directly over mineralization, decreasing progressively down drainage (Beeson, 1995). The greatest dispersion of Au was in the <75 µm fraction, with anomalous concentrations (0.06 ppm Au) extending 8 km down drainage. Visible Au in panned concentrates, bulk cyanide leach Au and As (>10 ppm) all remain anomalous for over 12 km. Copper, Ni and Zn abundances in stream sediments appear to reflect the greenstone belt, rather than the deposit itself. A pre-mining survey using lateritic pisoliths and nodules at approximately 1 km intervals (Smith, 1989) shows a 3x1 km anomaly at >40 ppb Au, but much larger anomalies are shown by several pathfinder elements. These are summarized by a chalcophile index (As, Sb, Bi, Mo, Ag, W, Se), which is anomalous over 30x4 km (Figure 3).

TABLE 1 - STREAM SEDIMENTS

Elements	Size fraction (µm)	Threshold (ppm)	Maximum anomaly (ppm)	Dispersion (km)
Au	400-1700	0.02	>1	3
	200-400	0.02	>1	3
	75-200	0.02	>1	3
	<75	0.02	>1	8
As	400-1700	10	350	>12
	200-400	10	80-100	>12
	75-200	10	80-100	>12
	<75	10	80-100	>12

In a more detailed survey (Table 2), lag samples (nodules and pisoliths) were collected over a radius of 5-10 m at 100 m intervals close to the mine. Over Pit A (Figure 4) and Pit D, the Au pattern shows small, erratic anomalies (<0.1 ppm) with some higher concentrations (to 1.15 ppm) at the S end of Pit A. Gold is more abundant in the underlying lateritic residuum (mean 0.25 ppm) and the bauxite zone (0.61 ppm; Figure 5). There is a strong relationship between the Au distribution in the bauxite zone and the overlying fragmental duricrust but no direct relationship between the Au distribution in fragmental duricrust and the overlying pisolitic duricrust (Anand, 1994). This suggests precipitation of Au at the bauxite zone and fragmental duricrust with subsequent leaching or modification of the Au distribution during formation of the pisoliths. High rainfall and soil waters rich in organic ligands from the abundant vegetation may have leached Au from the surface pisoliths to precipitate it at the base of the bauxite zone.

Although Au contents in lag and colluvial gravel at or near the surface are relatively low, As, W, Sn, Mo and Bi are strongly anomalous. The As concentrations are high and widespread over Pit A (maximum 350 ppm) but is weaker (maximum 58 ppm) over Pit D. The As anomaly is some 400x300 m over Pit A and shows a more consistent and widespread distribution than Au (Figure 4). High concentrations of As reflect arsenopyrite bedrock mineralization. Electron microprobe data of selected ferruginous pisoliths indicate a moderate association of As with Fe oxides (Figure 6). However, the As abundance varies with the

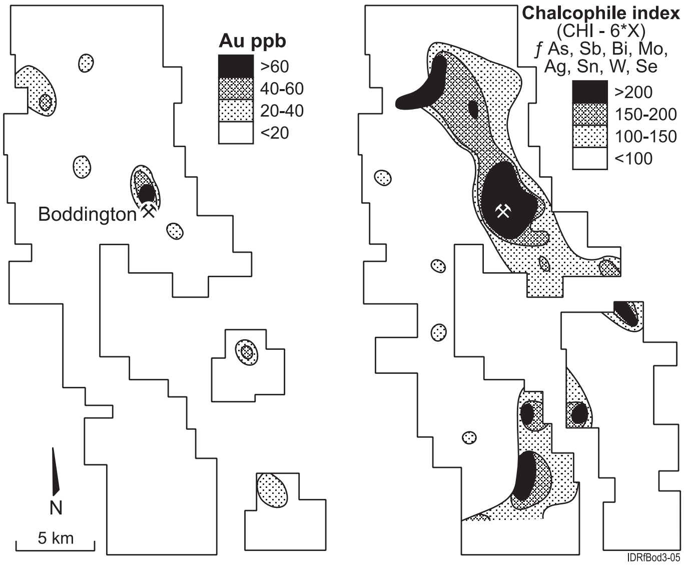

Figure 3. Regional laterite survey, Saddleback Greenstone Belt, WA, showing multi-element dispersion patterns around the Boddington gold mine (after Smith, 1989).

Fe oxide species, despite similar Fe contents. Areas very rich in Fe (>70% Fe_2O_3) have a wide range of As (200-1500 ppm). Hematite-maghemite-rich areas are poor in As relative to goethite-rich areas, suggesting that As, originally present in goethite, was probably ejected during dehydration to maghemite (see below) and carried away in solution.

The W anomaly (max 130 ppm) in gravelly lag, in the SE of Pit A and in Pit D, is 500x400 m. The Sn anomaly (max 48 ppm) is similar to W in strike continuity and breadth but less strong. It is relatively more abundant in Pit D. The Sn and W occur mainly as cassiterite and scheelite, respectively. Molybdenum is anomalous both over Pit A and Pit D, reaching a maximum of 130 ppm. Copper and Zn are weak and do not appear to be particularly useful in defining mineralization. Bismuth (max 50 ppm) is unevenly distributed and strongest and most widespread in the SW corner of Pit A.

The non-magnetic fractions of gravelly lag and pisolitic duricrust are enriched in Au, As, Mo, Cu and Bi relative to the magnetic fractions, probably due to their ejection during transformation from goethite to maghemite (Sidhu et al., 1980). The non-magnetic fractions of gravelly lag and pisolitic duricrust are rich in Au, As, Mo, Cu and Bi relative to the magnetic fractions. The non-magnetic lag consists mainly of hematite and goethite, whereas the magnetic lag contains maghemite, which has formed from heating of goethite and hematite during bushfires (Anand and Gilkes, 1987), causing the loss of these elements (Sidhu *et al.*, 1980) during the transformation.

The major components of the bauxite zone, fragmental duricrust, pisolitic duricrust and gravelly lag were separated and analysed (Figure 7). In the bauxite zone, the hematite- and gibbsite-rich fragments have

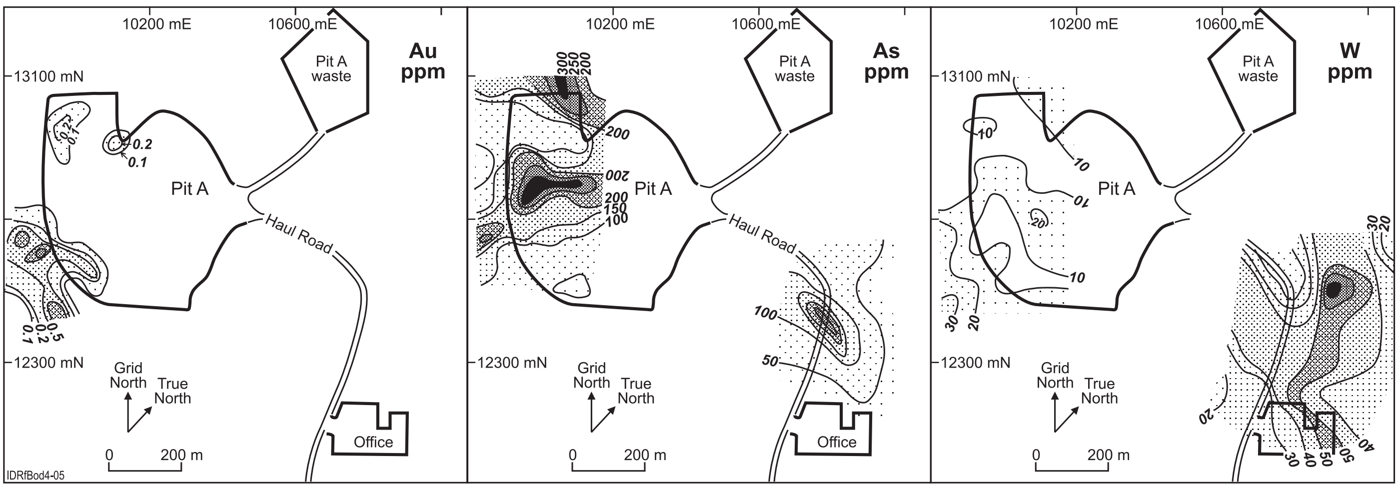

Figure 4. Geochemical dispersion maps of the distribution of Au, As, and W in nodular and pisolitic lag in the Boddington Au deposit (N=73).

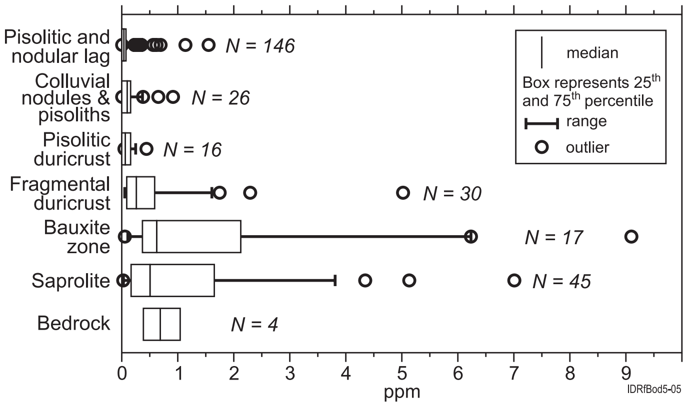

Figure 5. Box plots of the Au distribution in regolith materials arranged in vertical order of regolith occurrence.

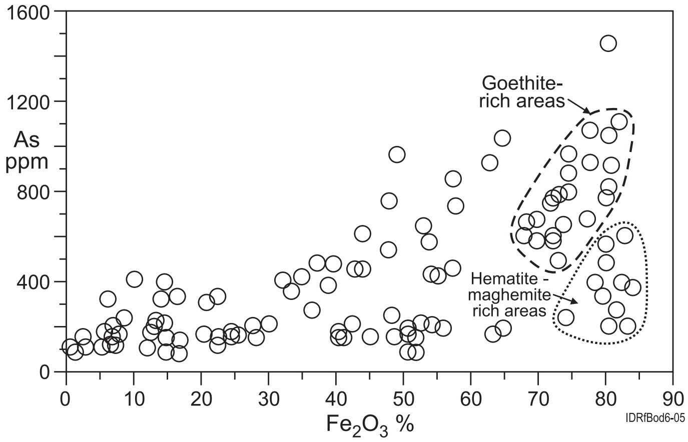

Figure 6. Scatterplot of electron microprobe As and Fe analyses of nodules and pisoliths.

more Au than the corresponding gibbsite-rich matrix. In the overlying fragmental duricrust, there is no systematic Au distribution between fragments and matrix. In the pisolitic duricrust, the goethite- and gibbsite-rich cutans are the main host of Au. At surface, Au is more abundant in nodules than pisoliths and this may reflect the greater abundance of Au in fragmental duricrust. There are small (<5 µm) droplike Au grains in Au-rich material in the bauxite zone. No microscopically visible Au occurs in pisolitic duricrust or gravelly lag, suggesting that the Au is sub-microscopic.

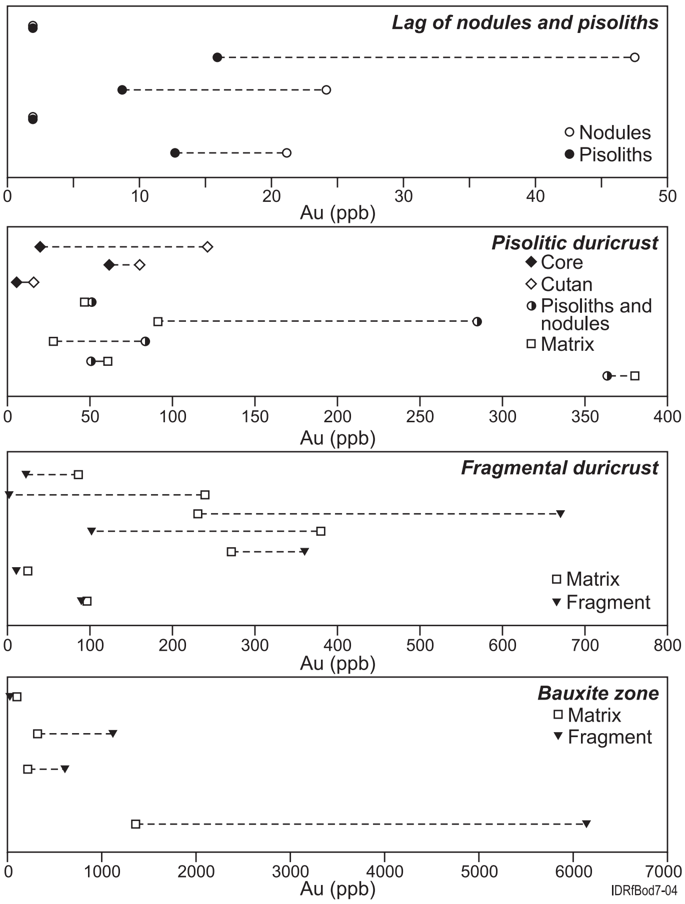

Figure 7. Gold distribution in the different micro-morphological facies of the bauxite zone, fragmental duricrust, pisolitic duricrust and gravelly lag of nodules and pisoliths using a small number of samples (N). The pecked line joins each sample pair.

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TABLE 2 - COMPARISON OF SAMPLE MEDIA

	Saprolite N=45					Bauxite Zone N=17				
ppm	Mean	SD	Min	Max	Median	Mean	SD	Min	Max	Median
Cu	1070	2120	10	10000	199	69	39	17	134	61
As	55	101	1	564	19	70	93	5	304	34
Bi	4.9	6.5	1	26	2	9.2	7.9	2	25	5.5
Mo	18.5	22.3	0.33	113	11	26	30	1	120	14.5
W	30.4	52.6	1.3	322	15	61	63	4	185	25
Au	1.519	2.305	0.01	12	0.505	1.954	2.66	0.05	9.1	0.605

	Fragmental duricrust N=30					Pisolitic duricrust N=16				
ppm	Mean	SD	Min	Max	Median	Mean	SD	Min	Max	Median
Cu	51	69	8	308	30	34	39	3	130	18
As	83	105	7	370	26	132	159	13	460	47
Bi	4.6	2.9	1	14	4	5.7	8.2	1	35	3
Mo	41	25	3	130	38	40	20	6	74	36
W	81	69	1	195	57	93	78	16	230	31
Au	0.612	0.991	0.001	5.02	0.25	0.109	0.116	0.001	0.46	0.07

	Loose pisoliths N=26					Pisolitic and nodular lag N=146				
ppm	Mean	SD	Min	Max	Median	Mean	SD	Min	Max	Median
Cu	22	36	2	178	11	20	17	1	120	15
As	121	129	6	521	75	64	74	8	350	32
Bi	4	3	1	12	4	4.2	6.3	1	52	2
Mo	36	15	1	62	36	24	15	5	125	24
W	54	64	1	200	24	39	27	1	130	36
Au	0.152	0.212	0.01	0.92	0.08	0.081	1.191	0.001	1.58	0.02