MULGA ROCK URANIUM AND MULTIELEMENT DEPOSITS, OFFICER BASIN, WA

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LOCATION

The Mulga Rock U and multi-element deposits are about 240 km NE of Kalgoorlie, on the SW margin of the Great Victoria Desert at 123°40'E 29°57'; Minigwal (SH 51-7) and Cundeelee (SH 51-11) 1:250 000 map sheets.

DISCOVERY HISTORY

The Mulga Rock deposits were discovered in 1979 by systematic exploration drilling for sedimentary U mineralization in an embayment in the SW margin of the Officer Basin. Drilling of over 200 holes (for 221 000 m) since 1978 has delineated three U bodies hosted by Eocene sediments in palaeochannels (Fulwood and Barwick, 1990).

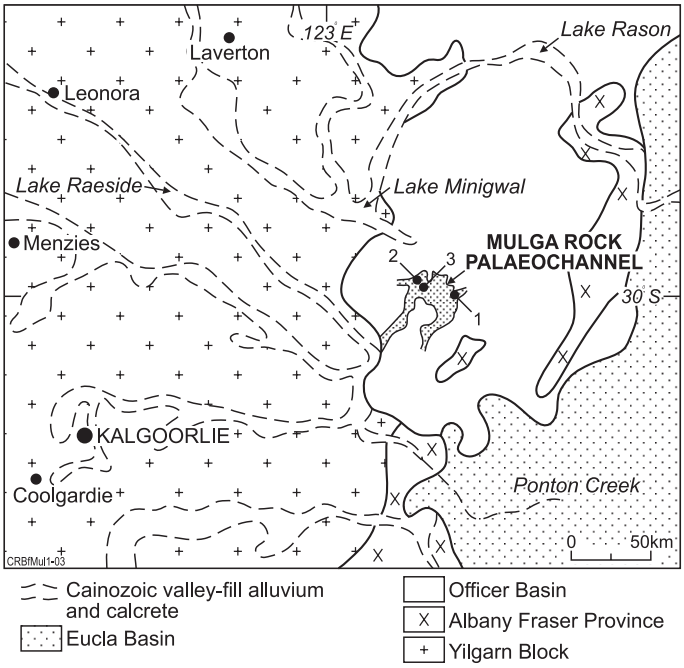

Figure 1. Regional geological setting of the Mulga Rock deposits (Ambassador (1), Emperor (2) and Shogun (3)).

PHYSICAL FEATURES AND ENVIRONMENT

The area surrounding Mulga Rock is an undulating sandy plain at an elevation of 325-400 m, crossed by ESE-trending sand dunes. The vegetation consists of an open spinifex-eucalypt association. The climate is semi-arid to arid, with an erratic annual rainfall of about. 220 mm, 70% falling February-August), with hot summers and mild winters. Mean daily maximum and minimum temperatures are about 34 and 18°C in January, 16 and 6°C in July.

GEOLOGICAL SETTING

Mulga Rock is on the SW extremity of the Officer Basin, and consists of three main deposits, Ambassador, Emperor and Shogun. Sediments of the Lower Permian Paterson Formation overlie the Precambrian basement, predominantly Archaean and Proterozoic granitoids of the Yilgarn Craton and Albany-Fraser Range Province, respectively (Figure 1). Permian rocks rarely outcrop, but are overlain by a variety of Mesozoic (Lower Cretaceous) and Cainozoic sediments. The region has been subjected to continental conditions since the Cretaceous, and planation and sedimentation have continued under humid and then arid conditions. The Mulga Rock lignites lie in a buried palaeochannel, 5-15 km wide, that has been traced for over 100 km (Fulwood and Barwick, 1990) and may have received input from drainage systems that extend for over 400 km NW across the Yilgarn Craton. The main channel is confined to a palaeovalley thought to have been eroded during the late Cretaceous/early Tertiary, underlain by Permian mudstones. In common with similar channels on the Yilgarn Craton, it may follow even earlier drainages that were widened and subsequently infilled during Permian glaciation. Some disturbance to the channel, due to the Lake Carey-Minigwal system being captured by the Lake Rason system may have been caused by crustal upwarping along the eastern margin of the Craton before the Late Eocene.

REGOLITH

The palaeovalley hosting the Mulga Rock deposits contains up to 100 m of non-marine, Tertiary sediments overlying remnant Cretaceous units and glacial sediments of the Permian Paterson Formation. The Tertiary sediments form three broad units: (i) fluviatile sands and interbedded lacustrine sediments; (ii) lacustrine to paludal sediments, including lignite (peat), clay-rich lignite and carbonaceous sands and clays, and (iii) basal fluviatile sands and gravels. The whole sequence is covered by 2-10 m of aeolian sand. The lignite is of middle Eocene age (Islam, 1983). Maceral analysis suggests the organic matter was derived from a wetland environment devoid of large trees, with abundant algal biomass (Douglas *et al*., 1993). The upper sedimentary units have been weathered and are variably ferruginized and silicified; intense silicification to silcrete is locally intense in some sandy units, commonly within 10 m of the surface. The depth of weathering mostly exceeds 20 m, with a sharp weathering front at a redox boundary at the contact between kaolinitic paludal clay and the lignite, commonly close to the water-table. The weathering is presumably equivalent to that which affected the Yilgarn Craton during the Oligocene to mid-Miocene during humid, possibly tropical, climatic episodes. Some of the sediments, e.g., some kaolinitic and quartz units, could themselves be eroded products of such weathering. The sequence has undoubtedly been affected by later weathering under the more arid environment that has prevailed since the mid-Miocene.

MINERALIZATION

The total resource at Mulga Rock is estimated to be 13 000 t of contained U in 10.8 Mt of ore with a mean grade of 0.12% U (Fulwood *et al.,* 1990). The maximum grade is 8.2% U over a 200 mm interval at the Ambassador deposit. The total areal extent of mineralization of the Ambassador, Emperor and Shogun deposits is 7 km^2 at cut-off grades of 0.03% U and 0.1m% U. The organic-rich ore contains up to 45% water and 60% organic matter (Fulwood and Barwick, 1990). Mineralization within the Mulga Rock deposits occurs in the top 1-2 m of lignite in the palaeochannel sediment sequence. Mineralization has been concentrated by the oxidation and precipitation of mobile trace elements from reduced groundwaters at a redox interface between the top of the lignite and the overlying clay (Figure 2). Uranium decay elements in the clay mark previous redox front positions (Fulwood and Barwick, 1990; Douglas *et al*., 1993). Analysis of U-Th disequilibrium in the Ambassador deposit indicates a predominant pattern of U-excess and/or daughter radionuclide deficiency developed in the past 300 000 years (Douglas *et al*., 1993).

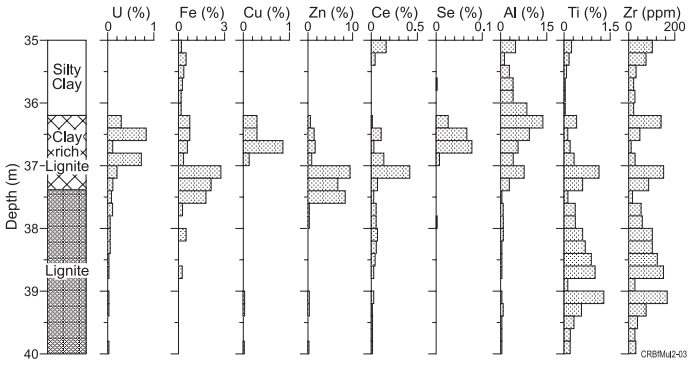

Figure 2. Representative downhole geochemical profile, Ambassador Deposit. The redox front is within the clay-rich lignite. Materials above 35 m are barren.

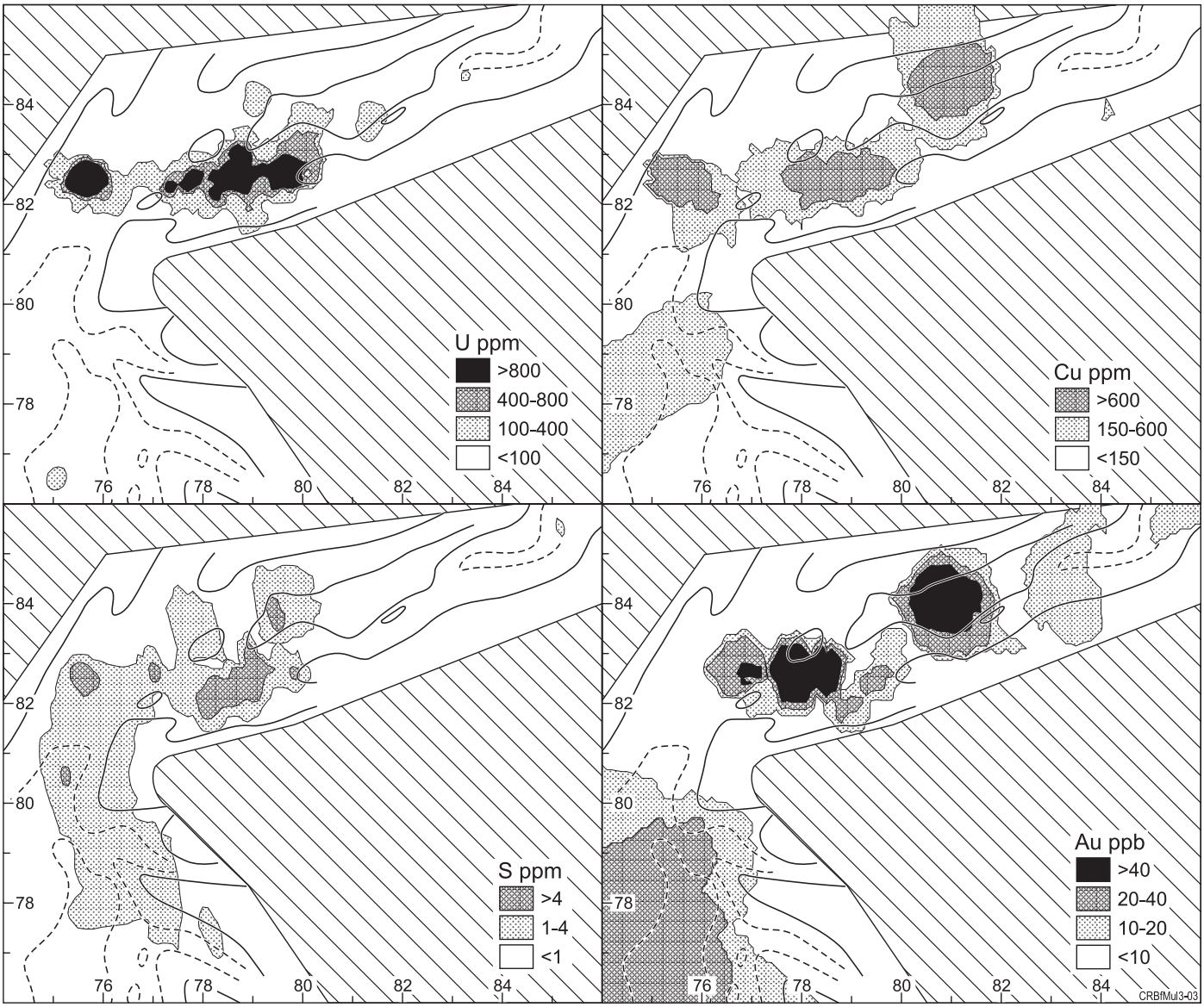

Figure 3. Maps of U, Cu, Se, Au distributions in the redox front in the lignite, Ambassador deposit.

TABLE 1

MAJOR MINERAL GROUPINGS IN THE MINERALIZED REDOX FRONT

Mineral grouping	Minerals	Morphology
Authigenic		
Organo-complexed trace elements and radionuclides	None, but probable precursor to discrete mineral phases	Ion-exchangeable, diffuse impregnation in organic matter
Sulphides, sulphates	Pyrite, galena and sphalerite, with other transition metals (*e.g.* Co, Ni, Cd, Mo, REE) and U sulphides and sulphates (gypsum, barite) commonly present	As discrete crystalline grains or spherules, irregular masses in matrix or infilling voids
Silicate, oxide and native elements	U- and Ti-bearing silicate and oxide minerals: coffinite ($USiO_4$), brannerite ($UTiO_6$), Fe-Ti and Ti oxides: ilmenite, rutile/anatase. Native elements: Se needles, gold, sulphur. Complex REE phases	A close spatial association of secondary U-Ti minerals suggests common origin. Coffinite may form by co-precipitation from supersaturated Si, U-solution
Detrital		
Silicates	Quartz, kaolinite	Act as substrate for organic matter adsorption, major matrix constituent
Heavy minerals	Predominantly zircon, rutile, ilmenite, anatase, cassiterite, monazite and xenotime	Many heavy minerals are etched or show evidence of partial dissolution, indicating they could be a partial source of the REE

Although the mineralogy of the Mulga Rock deposits is complex, with >50 minerals recognized in addition to common rock-forming minerals at Shogun (Just, 1988), the minerals may be grouped into three authigenic and two detrital groups (Table 1).

REGOLITH EXPRESSION

Mineralization at the Mulga Rock deposits is contained entirely within the palaeochannel sediments and has no surface expression. There is no wider geochemical halo or local or regional surface radiometric expression, other than the Rn response (Figure 4). The mineralization is hosted exclusively by a narrow band associated with both the present water-table and recent redox front, which may be colocated. Uranium is the best indicator of mineralization, but numerous other trace elements are strongly enriched, particularly those that form hydrous oxyanions (e.g., As, Mo, Se, P, S, V), many transition metals (including Co, Cu, Ni, Pb, Zn), REE and Y (Douglas *et al*., 1993). Concentrations of Co, Cu, Pb, Zn and total REE exceed 1% in one or more (commonly different) samples; three samples contain >400 ppb Au. Palaeochannel groundwater compositions differ substantially between each mineralized zone, but commonly have a low Eh. Groundwaters from the Ambassador deposit are substantially enriched in HCO_3, PO_4, Ba and W, enriched in K, Ca and Sr, but depleted in Si, relative to those in the Yilgarn Craton (Gray, 2001).

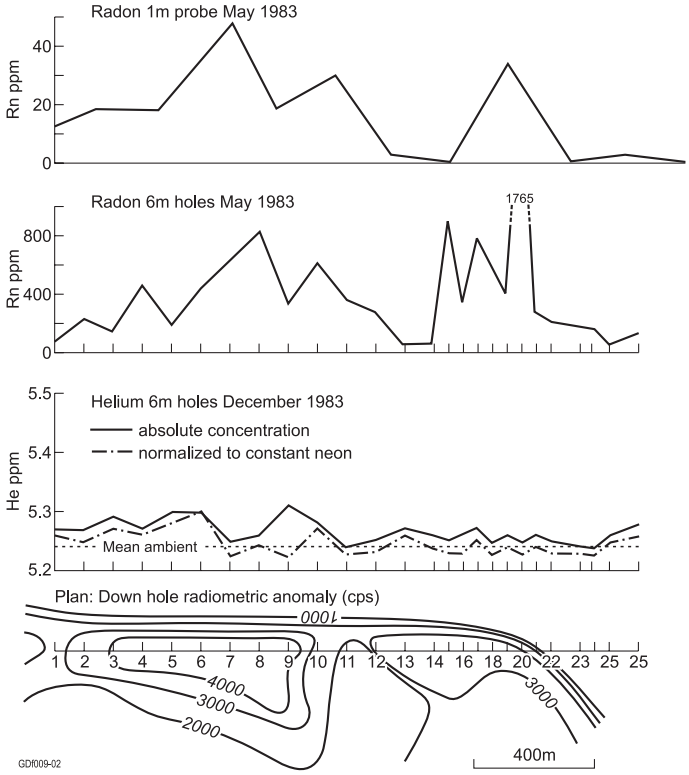

Figure 4. Concentrations in overburden gas of helium (6 m depth) and radon (1 m and 6 m depth), Mulga Rock deposit (from Butt and Gole, 1985).

TABLE 2

SAMPLE MEDIA SUMMARY TABLE

Mineralized lignite

	Method	Detection limit (ppm)	Mean (ppm)	Min (ppm)	Max (ppm)	Standard Deviation
U	INAA	2	473	1	5870	1035
Th	INAA	0.5	23	0.3	190	27
Co	INAA	1	219	1	9740	860
Cu	XRF	5	483	3	8459	1071
Pb	XRF	5	88	3	1025	144
Zn	XRF	5	1157	3	29408	3015
Ce	INAA	2	325	1	4060	507
La	XRF	0.5	123	4	1410	183
Y	XRF	5	102	3	1162	148
As	INAA	1	12	1	100	16
Sc	XRF	0.1	54	1	1090	126
W	INAA	2	12	1	359	31
Sb	XRF	0.2	1	0.3	16	2
Au	INAA	0.005	0.022	0.003	0.555	0.073
Cr	INAA	5	131	11	1610	187
Zr	XRF	5	525	11	2765	511

Gas samples at 5-8 m depth

He*	MS	0.01	5.25	5.22	5.30	0.02
Rn (cpm)	ZnS scintillometer	~10	384	55	1765	371

* normalized to constant ^{20}Ne

Helium and Rn were determined across the Shogun deposit by sampling soil/overburden gas using fixed collectors at 5-8 m depth at 50-100 m intervals (Figure 4). There was no significant difference in He content between mineralized (mean 5.248 ppm He) and unmineralized areas (5.240 ppm He). In contrast, Rn analyses showed a marked anomaly which was duplicated, at much reduced contrast and intensity, even in 1 m probe samples (Butt and Gole, 1985).

ORIGIN OF URANIUM AND TRACE ELEMENT ENRICHMENTS

Radiogenic isotope (Pb-Pb, Rb-Sr and Sm-Nd) signatures and U-Th disequilibria studies (Douglas *et al.,* 1993) tightly constrain the potential sources of the mineralization of the Mulga Rock deposit. There has been substantial homogenization of the radiogenic isotopic systems, consistent with the precipitation of a range of elements at the redox front. However, the Pb-Pb isotope system, in particular, suggests a high Th/U ratio source of Archaean or Proterozoic age. Individual Sr and Nd isotopic signatures are typical of many Yilgarn granitoids, but the combination of these two isotopic systems precludes a significant granitic contribution to mineralization. The highly variable ^{230}Th/^{232}Th ratio in the Ambassador deposit, as well as other U-Th data (Douglas *et al.,* 1993), indicate that monazite, sourced from Yilgarn granitoids or from other sources, cannot explain the observed distribution of Th and LRRE. Deep intrusives such as lamproites, kimberlites or carbonatites can satisfy these radiogenic isotopic constraints. Lamproites and kimberlites, known from Western Australia, satisfy both Pb-Pb and Nd-Sr isotopic signatures (Douglas *et al.,* 1993). In addition, lamproites may have wide ranges of Th/U ratios, some of which may be compatible with those in the mineralization at Mulga Rock, and contain a wide suite of trace elements. Such deep intrusives occur in the region: the Mt. Weld carbonatite is about 175 km NW, and the Cundeelee carbonatite is about 75 km SW. Neither is strongly enriched in U, but Cundeelee has high Zn contents (R. Duncan, personal communication, 1992). There is potential for other, yet undiscovered, intrusives in the vicinity which could be the source of the metals at Mulga Rock.

REFERENCES

Butt, C.R.M. and Gole, M.J., 1985. Helium in soil and overburden gas as an exploration pathfinder – an assessment. Journal of Geochemical Exploration 24: 141-173.

Douglas, G.B., Gray, D.J. and Butt, C.R.M., 1993. Geochemistry, Mineralogy and Hydrogeochemistry of the Ambassador Multi Element Lignite Deposit, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 337R. 63 pp + Appendix. (Revised and re-issued April 1996 with additional investigations on the characterization of organic matter. CRC LEME Restricted Report 2R, CRC for Landscape Evolution and Mineral Exploration, Perth. 121 pp + Appendix.

Fulwood, K. E. and Barwick, R. E., 1990. Mulga Rock Uranium deposits, Officer Basin. In F. E. Hughes (Editor) Geology of the Mineral Deposits of Australia and Papua New Guinea. The Australasian Institute of Mining and Metallurgy, Melbourne, pp 1621-1623.

Gray, D.J., 2001. Hydrogeochemistry in the Yilgarn Craton. Geochemistry: Exploration, Environment, Analysis, 1: 253-264.

Islam, M.A., 1983. Palynological report on samples from the western Eucla basin. Report R12/83/1. ECL Australia Pty. Ltd. (unpublished).

Just, J., 1988. Report on mineralogical investigation of samples from drill holes CD-795, CD-1101 and CD-1406, prepared for PNC Exploration (Australia) Pty. Ltd. (unpublished).