ALLIGATOR RIVERS URANIUM DEPOSITS (KOONGARRA, NABARLEK AND RANGER ONE), NORTHERN TERRITORY

Angela Giblin

CSIRO Exploration and Mining, P.O. Box 136, North Ryde, NSW 1670

LOCATION

Koongarra, Nabarlek and Ranger One are all within a radius of about 40 km in the Alligator Rivers region, NT. Koongarra is 225 km E of Darwin at 12º52'S, 132º50'E; Nabarlek is 270 km E of Darwin at 12º19'S, 133º19'E; Ranger One is 250 km E of Darwin at 12º43'S, 132ª55'E. Koongarra and Ranger One lie within the Kakadu National Park and Nabarlek within the Arnhem Land Aboriginal Reserve (Figure 1), Alligator River 1:250 000 map sheet (SD53-01).

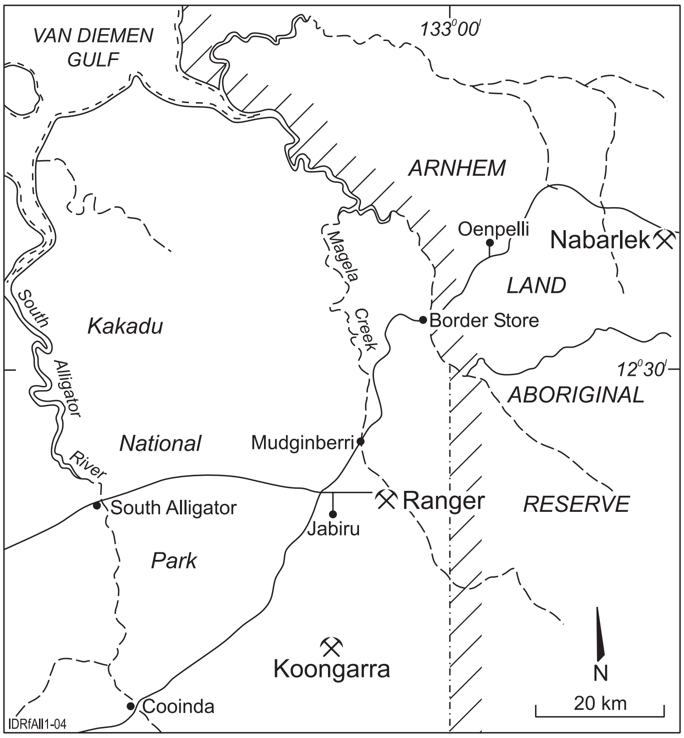

Figure 1. Location map of the Koongarra, Nabarlek and Ranger One U deposits (after Kendall 1990).

DISCOVERY HISTORY

Koongarra: airborne spectrometer surveys by Noranda Ltd in the Alligator Rivers area during 1969 identified a number of radiometric anomalies. Subsequent ground radiometric surveys confirmed one of these as a surface anomaly of 1300 cps that increased to 5300 cps, 3.4 m below the surface. The source of this anomaly was identified as secondary U minerals in weathered schist. Systematic fieldwork subsequently identified the Koongarra deposit as economically significant. The deposit of about 3.5 Mt contains approximately 13 000 t U.

Nabarlek: discovered by Queensland Mines in 1970 during ground follow-up of anomalies identified from airborne spectrometer and magnetometer surveys. Costeans at anomalous locations identified rich veins of pitchblende 1 m below the surface. The deposit of approximately 600 000 t contains approximately 9200 t U.

Ranger One: the airborne spectrometer survey by Noranda identified nine high intensity anomalies. In 1970, follow-up by ground geochemical and radiometric surveys, together with geological mapping, found substantial mineralized zones. Eventually, two viable ore-bodies, Numbers 1 and 3, were discovered by a consortium of Peko Mines NL and Electrolytic Zinc Co of Australasia by systematic percussion drilling on 100 m spacings to 100 m depth. The deposits, containing approximately 73 000 t U, were located in basin-shaped structures at and near the surface.

PHYSICAL FEATURES AND ENVIRONMENT

The *Koongarra* deposit is located on gently sloping ground in a valley between escarpments of the Middle Proterozoic Kombolgie Sandstone of the Brockman Outlier, which rises 200-300 m above the plain. The *Nabarlek* deposit is on a gently undulating erosional plain in an embayment between dissected low plateaux of the Kombolgie Sandstone. The *Ranger One* deposits lie in gently undulating erosional plains from which the Kombolgie Sandstone has been eroded. The present escarpment of Kombolgie Sandstone occurs N, S and E of the Number 1 orebody and W of the Number 3 orebody.

The Alligator Rivers Region has a strongly seasonal tropical savanna climate. Virtually the entire annual rainfall (mean 1485 mm) falls during the summer wet season in November to March. The local water table is within 2-3 m of the surface in summer but falls several metres in winter at Koongarra and has a low salinity (<200 mg/l; Giblin and Snelling, 1983). Mean daily temperatures range from 25 to 34ºC in January and 18-32ºC in July. Vegetation is mostly open woodland of *Eucalyptus* with patches of open grassland and small shrubs, changing to paperbark forests (*Melaleuca* spp.) and *Pandanus* palms adjacent to watercourses. Traditional land use was hunting and gathering by local indigenous people. Current use includes these traditional activities, tourism, U mining, research and conservation of natural ecological systems.

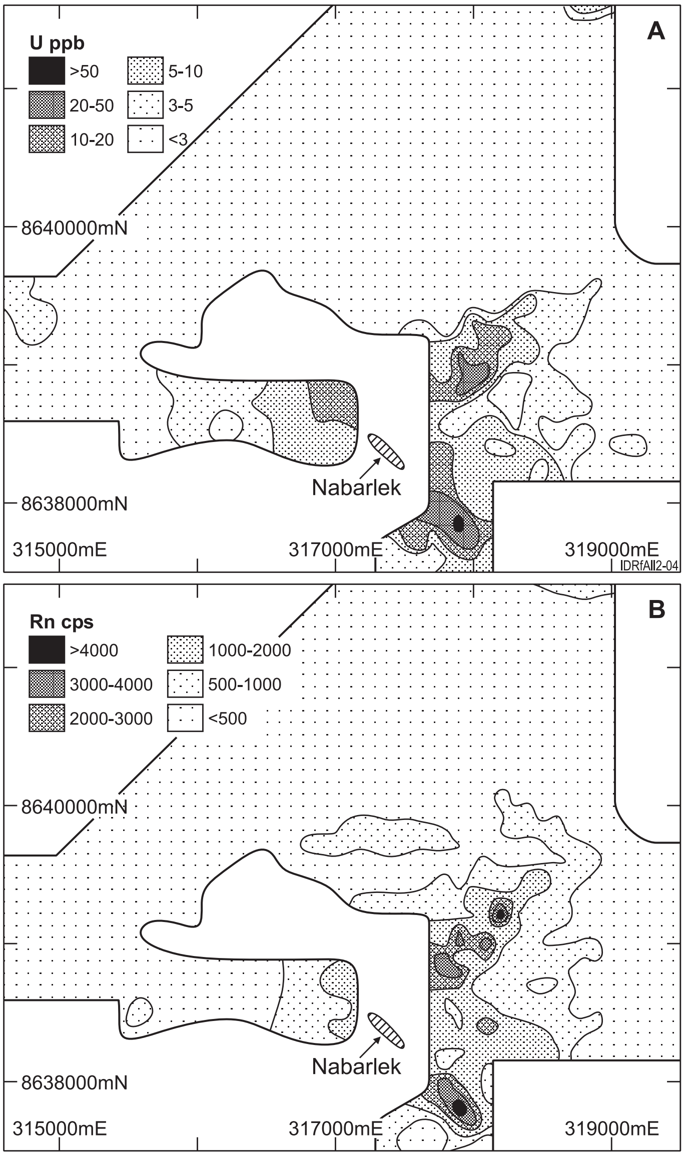

Figure 2. Distribution of U in <180 µm soil around Nabarlek (A). Distribution of Rn measured by alpha-track film around Nabarlek (B). Locations affected by mining excluded. Data from 689 sites.

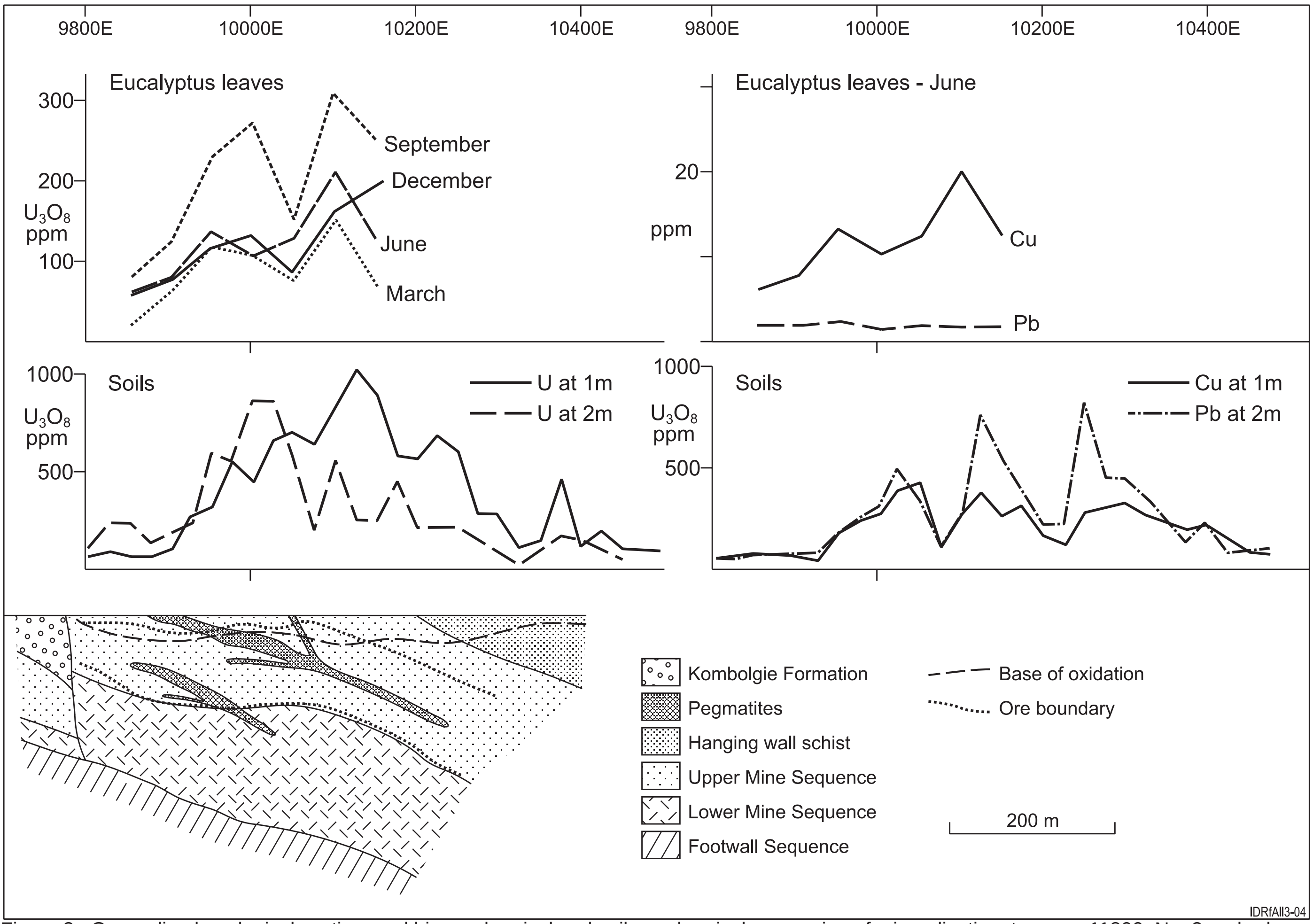

Figure 3. Generalized geological section, and biogeochemical and soil geochemical expression of mineralization, traverse 11800, No. 3 orebody, Ranger One (after Eupene and Williams, 1980).

GEOLOGICAL SETTING

The *Koongarra* deposit is hosted by the Lower Proterozoic Cahill Formation in layered sequences of quartz-Mg-chlorite schist. Layers of dolomite and metamorphosed limestone of the same unit underlie the mineralization. Crystalline granitic rocks of the Archaean Nanambu Complex form a dome that is flanked by rocks of the U-mineralized Cahill Formation. The Middle Proterozoic Kombolgie Sandstone unconformably overlies the Cahill Formation. However, it is absent over the Koongarra deposit, having been reverse faulted to a position dipping at 55º SE beneath the deposit, and weathered from the surface back to escarpment outcrops immediately N of and 20 km E of the deposit.

The *Nabarlek* deposit is hosted by structurally prepared porous zones in the Early Proterozoic Myra Falls Metamorphics, part of the Archaean to Early Proterozoic granites, granitic gneisses and biotite schists of the Nimbuwah Complex.

The *Ranger One* orebodies are hosted in structurally-controlled locations within the Cahill Formation chlorite schists that overlie Archaean granite, granitic gneiss and migmatitic schist of the Nanambu Complex. Dykes, up to 70 m thick, of pegmatite and dolerite are common, but rarely host U mineralization. Unmineralized cherts, dipping 55ºE, outcrop W of both orebodies.

REGOLITH

In the *Koongarra* area, soils consist of sandy loams, white sands and fragmented sandstone derived from weathered Kombolgie Sandstone. Locally, extensive lateritic ferricretes have formed from secondary cementation of transported pisolitic gravels, and overlie soils that cover weathered schists. At *Nabarlek*, soils are sandy loams, white sands and red-yellow clays, covered by surface layers of coarse, siliceous sand and ironstone gravel. In the *Ranger One* area, soils typically have a sandy, grey, slightly organic surface horizon, 10-45 cm thick with quartz pebbles and ferruginous pisoliths, overlying a red-brown ferruginous zone 0.5-4.0 m thick, pisolitic in its upper part. This is underlain by mottled (to 8 m thick), bleached (to 7 m thick) and grey-brown (to 20 m thick) saprolite.

MINERALIZATION

Koongarra: Uranium mineralization occurs in two distinct but clearly related orebodies, separated by 100 m of barren schist along strike and parallel to a reverse faulted contact with the Kombolgie Sandstone. The zone comprising both orebodies is 650 m long, strikes NE and dips 55º SE. Each orebody has an average width of 30 m tapering out at 100 m down dip in the SW section and at 250 m in the NE section. The primary ore mineral, pitchblende (UO_2), occurs in veins 1-10 mm thick intimately intergrown and probably formed together with the Mg-chlorite. Minor quantities of Au and sulphides (galena > Cu sulphides) are disseminated in the ore. Abundant secondary U minerals, predominantly within a 100 m dispersion fan of weathering above the SW zone of the deposit, include uranyl phosphates, particularly saleeite ($Mg(UO_2)_2(PO_4)_2.10H_2O$), metatorbenite ($Cu(UO_2)_2(PO_4)_2.8H_2O$) and renardite ($Pb(UO_2)_4(PO_4)_2(OH)_4.7H_2O$). Within the primary ore zone, uraninite has been oxidized and altered to the uranyl silicates, kasolite ($Pb(UO_2)SiO_4.H_2O$), sklodowskite ($(H_2O)_2Mg(UO_2)_2(SiO_4).4H_2O$) and uranophane ($Ca(UO_2)_2(SiO_3OH)_2.5H_2O$).

Nabarlek: Mineralization is hosted by altered Fe-rich metapelites comprising complexly folded Mg-chlorite- and sericite-schists and amphibolites. It is concentrated in a brecciated part of the Nabarlek Shear, where it forms veins, stringers, massive pods and encrustations of pitchblende that contain 72% U_3O_8. The orebody is 250 m long, has an average thickness of 7 m, strikes 330º and dips 30-45ºE. A central high-grade zone of >1% U_3O_8 is surrounded by a low-grade zone of disseminated ore at 0.1% U_3O_8. In the upper part of the orebody, the primary ore includes coffinite ($U[SiO_4,(OH)_4]$). Secondary ore minerals in weathered zones close to the present surface include sklodowskite $(H_3O)_2Mg(UO_2)_2(SiO_4)_2.2H_2O$, rutherfordine $(UO_2)CO_3$, kasolite $Pb(UO_2)SiO_4.H_2O$, curite $(Pb_{6.5}(UO_2)_{16}O_{16}(OH)_{12}(H_2O,OH)_4)$, torbernite $Cu(UO_2)_2(PO_4)_2.10H_2O)$

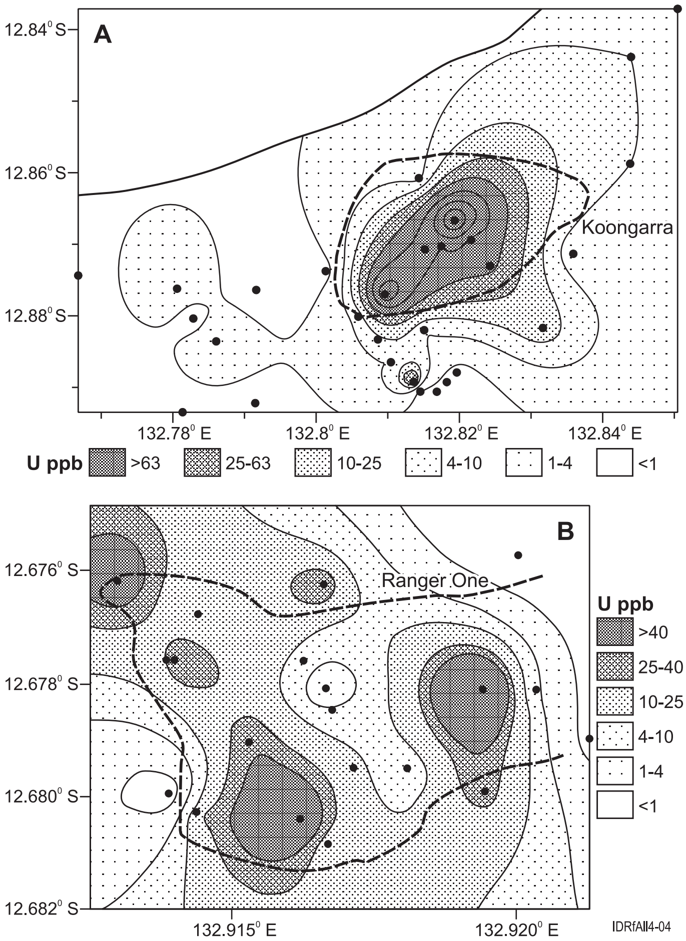

Figure 4. Contoured distribution of U in groundwaters around the Koongarra Number 1 orebody (A) and Ranger One Number 3 orebody (B). Sample locations shown with symbols.

and autunite ($Ca(UO_2)_2(PO_4)_2.10H_2O$).

Ranger One: Mineralization occurs as fine-grained (about 5 µm) pitchblende in veins <10 mm wide and as disseminations, with erratic variations in grade, throughout coexisting massive and schistose Mg-chlorite rocks. The average grade is 0.3-0.4% U_3O_8. Primary ore minerals include minor brannerite ($(U,Ca,Y,Ce)(Ti,Fe)_2O_6$) and other U minerals containing Ti and P. The primary ore also contains sub-economic concentrations of Cu, Pb and Au. The Number 1 orebody is 250 m long, occurs as a discrete basin about 120 m deep in the centre, and comprises two ore-grade zones. One is a highly brecciated zone that averages 1% U_3O_8 and the other, smaller zone averages 0.15% U_3O_8. The Number 3 orebody is 160 m long, contains an intensely brecciated, 2-3 m thick zone of ore that grades up to 8% U_3O_8. Above this, a wider, weakly brecciated zone of chloritized schist contains 0.15% U_3O_8. Secondary ore minerals in weathered zones close to the present surface include urano-phosphates, principally saleeite, with lesser sklodowskite, metatorbernite and "gummite" (poorly characterized U oxides).

REGOLITH EXPRESSION

γ-radiometric surveys

All three deposits have strong airborne- and ground radiometric responses, which were the basis for their discovery.

Soil geochemistry

Soil sampling detects near surface U mineralization at all three deposits. At *Nabarlek*, a U soil survey using the <180 µm soil fraction (Figure 2A) and α-radioactivity sourced from Rn and Ra (using α-track film; Figure 2B) detected an anomalous region NE to SE of the deposit. Sample sites for these surveys avoided all locations affected by mining activities. At *Ranger*, orientation studies (Eupene and Williams, 1980; Cruikshank and Pyke, 1986; Watters, 1988) showed strong responses to mineralization in soil and saprolite. In profiles above the orebody and downslope (E), for over 100 m, U, Cu and Pb are leached from the surface horizon, but are concentrated in the ferruginous zone and mottled saprolite, with the U peak (mostly 800-1000 ppm) generally at 0.5-4.0 m and Cu (1000 ppm) and Pb (800 ppm) have accumulated a little deeper, at 1.5-5.0 m. Iron, P and V are also leached from the surface, but accumulate towards the top of the ferruginous zone, above 2 m depth. In the saprolite, U contents show an overall enrichment of about 20% over primary grade, with some depletion in the bleached saprolite and supergene enrichment to 1.5 times the primary grade below. Copper and Pb are depleted overall by 50% and 70%, respectively. Uranium and Cu contents of samples from 2 m depth delineate the sub-crop of the mineralization quite accurately, with some dispersion down slope (Figure 3). Dispersion is greater in 1 m deep samples, extending 300 m E; data for shallower samples are not reported.

Biogeochemistry

Biogeochemical studies at Ranger One (Eupene and Williams, 1980) showed that the U and Cu content of leaves from *Eucalyptus* spp. discriminated the mineralization; U contents are highest in September, in the mid to late dry season (Figure 3), whereas Cu (and Zn) maxima are in June. Other species and plant organs were tested, but generally gave poorer responses (Cruikshank and Pyke, 1986).

Groundwater

Uranium anomalies in groundwater are present around the Koongarra deposit (Figure 4A) and Ranger One Number 3 orebody (Figure 4B). At Koongarra, groundwaters from aquifers within No 1 orebody contain 80-4100 ppb U. However, although base metal sulphides occur at Koongarra, there is no significant response in groundwater.

High concentrations (>0.8) of normalized Mg (NMg) in the groundwater (where NMg = Mg / (Mg + Na + Ca + K)) provide a geochemical indicator to the Koongarra (Figure 5A), Nabarlek (Figure 5B) and Ranger One (Figure 5C) deposits. Contoured NMg steadily increases towards the deposits, due to the intimate association of U minerals with Mg-chlorite in the mineralization. High NMg (>0.8) coincide with high U concentrations (>20 ppb U) in groundwaters near Nabarlek and Ranger. Conversely, NMg <0.8 occurs in groundwaters from unmineralized rocks, even though such waters (e.g., from aquifers in felsic rocks) may contain >50 ppb U.

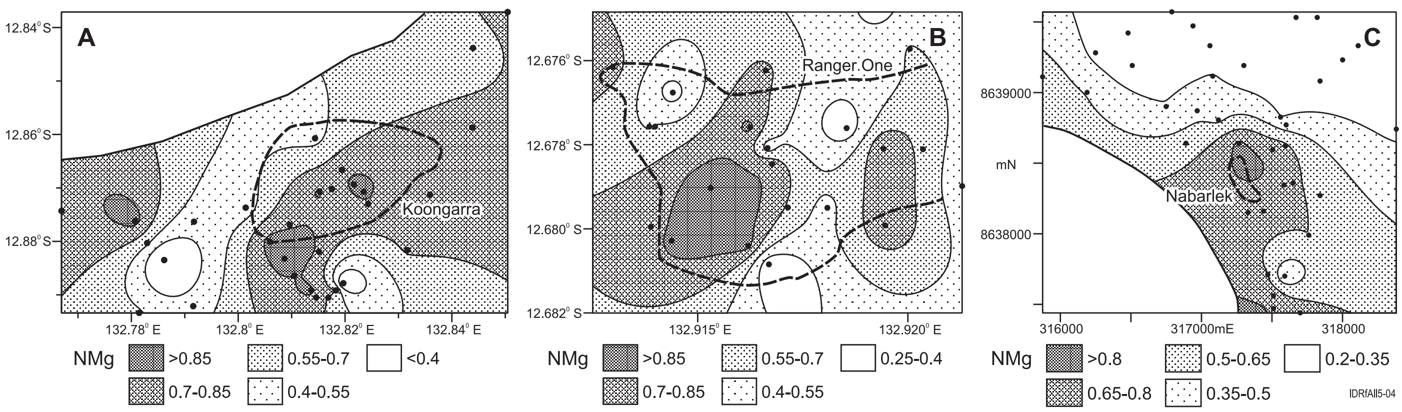

Figure 5. Contoured distribution of NMg (see text) in groundwaters at the Koongarra No 1 orebody (A), Ranger One No 3 orebody (B) and Nabarlek deposit (C).

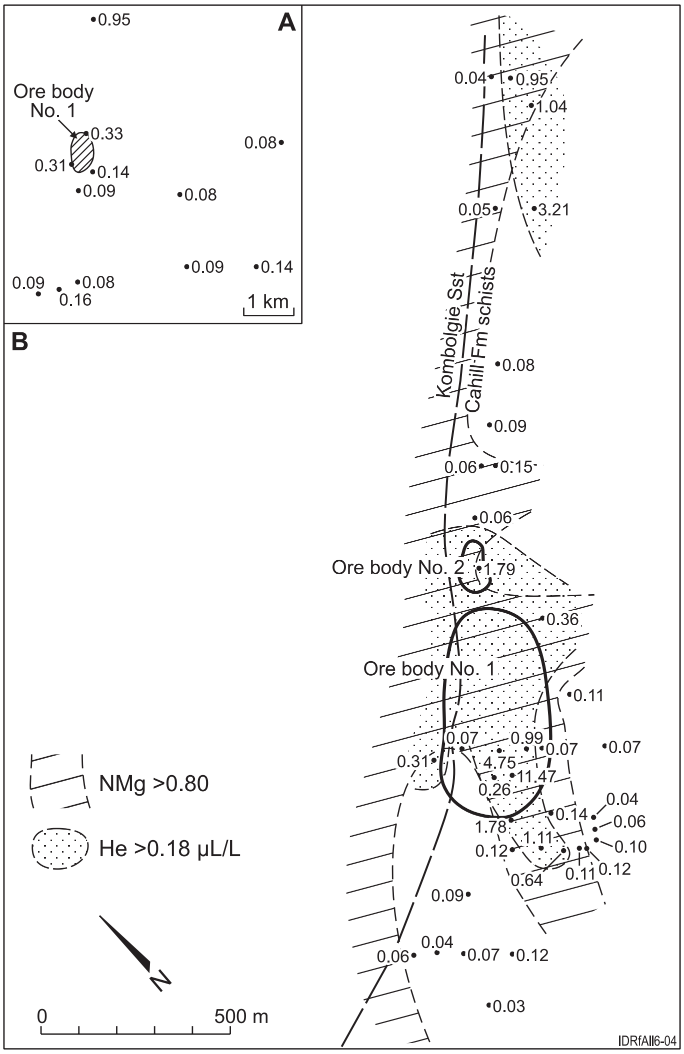

Figure 6. Helium contents (µL/L) in groundwater at Koongarra at semi-regional scale (A) and at detailed scale compared to NMg (B).

Helium

The distribution of He, a stable daughter product of the radioactive decay of U, was investigated in groundwater at Koongarra (Gole *et al.*, 1986). Water samples from 44 drill holes were collected from 10 m below the water-table. Anomalous He concentrations (threshold 0.18 µL/L, approximately 4 times the atmospheric equilibrium value) occur within, or close to, the margins of the orebodies and in a separate group 1.5 km NE (Figure 6), although not all groundwaters over the deposit are anomalous. Rapid degassing of He prevents a significant halo, with groundwaters >150 m from the main ore having background He contents. As all holes were cased, the data represent dispersion at the base of weathering, uninfluenced by secondary mineralization and the free-flowing near-surface aquifer. The He anomaly has a closer spatial correlation with the known distribution of mineralization than the zone of anomalous NMg.

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SAMPLE MEDIA - SUMMARY TABLE

				Koongarra			
Sample	*Element*	*Analytical methods*	*Detection limit*	*Background*	*Threshold*	*Maximum*	*Dispersion distance (m)*
Primary mineralization	Ra. Rn	Spectrometer					
Supergene mineralization	Ra Rn	Spectrometer					
Soil	U	ICP-MS	0.100				
Groundwater	U ppm NMg He _L/Ll	ICP-MS ICP-AES Mass Spec	0.001 0.001 <0.001	<0.001 <0.2 0.044	0.004 0.4 0.18	4 0.8 11.47	About 2000 About 2000 150
				Nabarlek			
Primary mineralization	U	ICP-MS	0.001				
Soil (<180 µm)	U Rn, Ra	ICP-AES α-track film	0.100	<1 40 cps	20 2900 cps	76 5600 cps	1000 1000
Groundwater	NMg	ICP-AES	0.000001	<0.2	0.4	0.8	1000
				Ranger One			
				Mean (ppm)	*Minimum (ppm)*	*Maximum (ppm)*	*Dispersion distance (m)*
Primary mineralization	U_3O_8	Acid digest; AAS	na	3250	40	2700	na
	Cu	as above	na	325	10	1800	na
	Pb	as above	na	850	10	2000	na
Soil: 1-5 m	U_3O_8	as above	na	3500	10	16000	100
	Cu	as above	na	450	10	3800	100
	Pb	as above	na	600	10	2000	100
Eucalyptus leaves (Sept)	U_3O_8	ash; acid digest; AAS	na	74	3	290	na
	Cu	as above	na	6.2	4	8	na
	Pb	as above	na	<1	<1	2	na
				Background (ppm)	*Threshold (ppm)*	*Maximum anomaly (ppm)*	*Dispersion distance (m)*
Soil: 2 m	U_3O_8	Acid digest; AAS	na	10-60	190	1000	300
	Cu	as above	na	10-150	300	1000	300
	Pb	as above	na	10-150	500	950	300
Groundwater	NMg U	ICP-AES ICP-MS	0.000001 0.001	<0.0001 <0.001	0.0004 0.004	0.0008 0.16	1000 600

na: not available

ICP-MS and ICP-AAS analysis after acid digest.