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Angela and Pamela Uranium Deposits

by J. Borshoff[1] and I. Faris[2]

INTRODUCTION

The Angela and Pamela uranium deposits plus a number of smaller prospects occur within the Amadeus Basin, Northern Territory. Angela, the main deposit, lies at the eastern end of the Missionary Syncline, 25 km south of Alice Springs (Fig. 1), at lat. 23°55′S, long. 133°55′E, on the Alice Springs (SF 53–14) 1:250 000 and (5650) 1:100 000 scale map sheets. Pamela is a small occurrence 4 km north of Angela.

Exploration over a ten year period by Uranerz Australia Pty. Ltd. (UAL) and its joint venture partner, Carpentaria Exploration Company Pty. Ltd. (CEC), has delineated a measured resource of 4700 t equivalent (e)U_3O_8 in the Angela deposit and associated satellite bodies at an average grade of 0.13% eU_3O_8, to a depth of 650 m, using a cutoff of 0.05% eU_3O_8 over 2 m thickness. There is an additional indicated resource of 1950 t eU_3O_8 averaging about 0.1% eU_3O_8 at 0.05% cutoff. Wider spaced drilling in the deeper western extension of the Angela deposit area and the adjacent northern satellite orebodies gave an inferred resource of 3600 to 6000 t eU_3O_8 in the grade range 0.1 to 0.13% eU_3O_8.

EXPLORATION HISTORY

Exploration was initiated by UAL in 1972. The Amadeus Basin was targeted by analogy with sandstone-type uranium deposits of the western United States which are hosted by intermontane basins. Reconnaissance airborne spectrometry in 1972 located a small anomaly south of Alice Springs. Ground follow-up located three surface anomalies. Trenching and drilling of these anomalies in 1973–74 led to the recognition of the Angela and Pamela prospects and their association with complex redox boundaries within sandstone of the Undandita Member of the Brewer Conglomerate. Reconnaissance vacuum drilling and mapping indicated that anomalous uranium was associated regionally with gently north dipping redox boundaries which separate the reduced from the oxidised sandstone facies of the Undandita Member. Enrichment of uranium usually occurred where the normally planar redox boundary developed 'steps' locally to higher or lower stratigraphic levels. These steps can be remarkably consistent down plunge, and they became the principal exploration target from 1974 onwards.

Exploration was extended 80 km west of the Angela deposit in the Missionary Syncline and 50 km southwards into the adjacent Orange Creek Syncline. Activity included detailed ground scintillometry, radon surveys, shallow drilling and geochemistry. This work failed to locate any further significant prospects.

Detailed percussion and diamond drilling was carried out around the Angela and Pamela prospects during 1975–79. This located a number of satellite zones associated with the main Angela I orebody designated Angela III to V (Fig. 2), occurring immediately north and south of Angela I, but associated with smaller steps in the redox boundary. During the initial stages of exploring for satellite orebodies, Angela II was also defined. Later detailed drilling showed this mineralisation to be the northern margin of Angela I, and reference to Angela II has been discontinued. Results indicated that considerable further resources could occur in separate zones down dip. Follow-up deep drilling during 1980–81 confirmed that the Angela I deposit has a strike length in excess of 5700 m and is open down plunge to the west. The smaller Angela satellite bodies have similar potential but have yet to be tested. Mineralisation at Pamela is thinner, weaker and less continuous than at Angela.

The final measured, indicated and inferred resources were calculated using uranium assays derived from down hole radiometric logging and geostatistical estimations incorporating disjunctive kriging.

REGIONAL GEOLOGY

The Amadeus Basin, an east trending intracratonic basin, is bounded by the Lower Proterozoic Arunta Complex to the north and the Musgrave Block to the south (Wells et al., 1970). The basin sediments range in age from Late Proterozoic to Carboniferous.

The Undandita Member (sandstone) of the Brewer Conglomerate, the youngest unit in the Amadeus Basin, hosts the Angela and Pamela deposits. It is the uppermost unit of the Pertnjara Group, a 7000 m thick pile of terrigenous Upper Devonian–Lower Carboniferous sediments, which marks the end of sedimentation in the Amadeus Basin. The Undandita Member interfingers with the Brewer Conglomerate south of the MacDonnell Ranges and reaches a maximum thickness of about 3000 m in the middle of the Missionary Syncline 15 km SW of Alice Springs. The member is a sequence of generally oxidised sediments, but contains a wedge of reduced sediments between regionally planar upper and lower redox boundaries. The Undandita Member ranges from fine to coarse grained lithic arenite to medium to coarse grained lithic arkose intermixed with thin mudstone units.

Further aspects of the regional geology are covered by Freeman et al. (this publication).

THE ANGELA DEPOSITS

Most of the mineralisation at Angela is hosted by medium to coarse grained feldspathic lithic arenite. Calcite as coarse spar is the dominant cement with trace to minor authigenic quartz. Most grains exhibit moderate rounding with no marked variation with grain size. Lithic fragments, which constitute an average of 22%, indicate two distinct sedimentary provenances. Metaquartzite, schist, gneiss and granite fragments are derived from the Arunta Complex, and silt-

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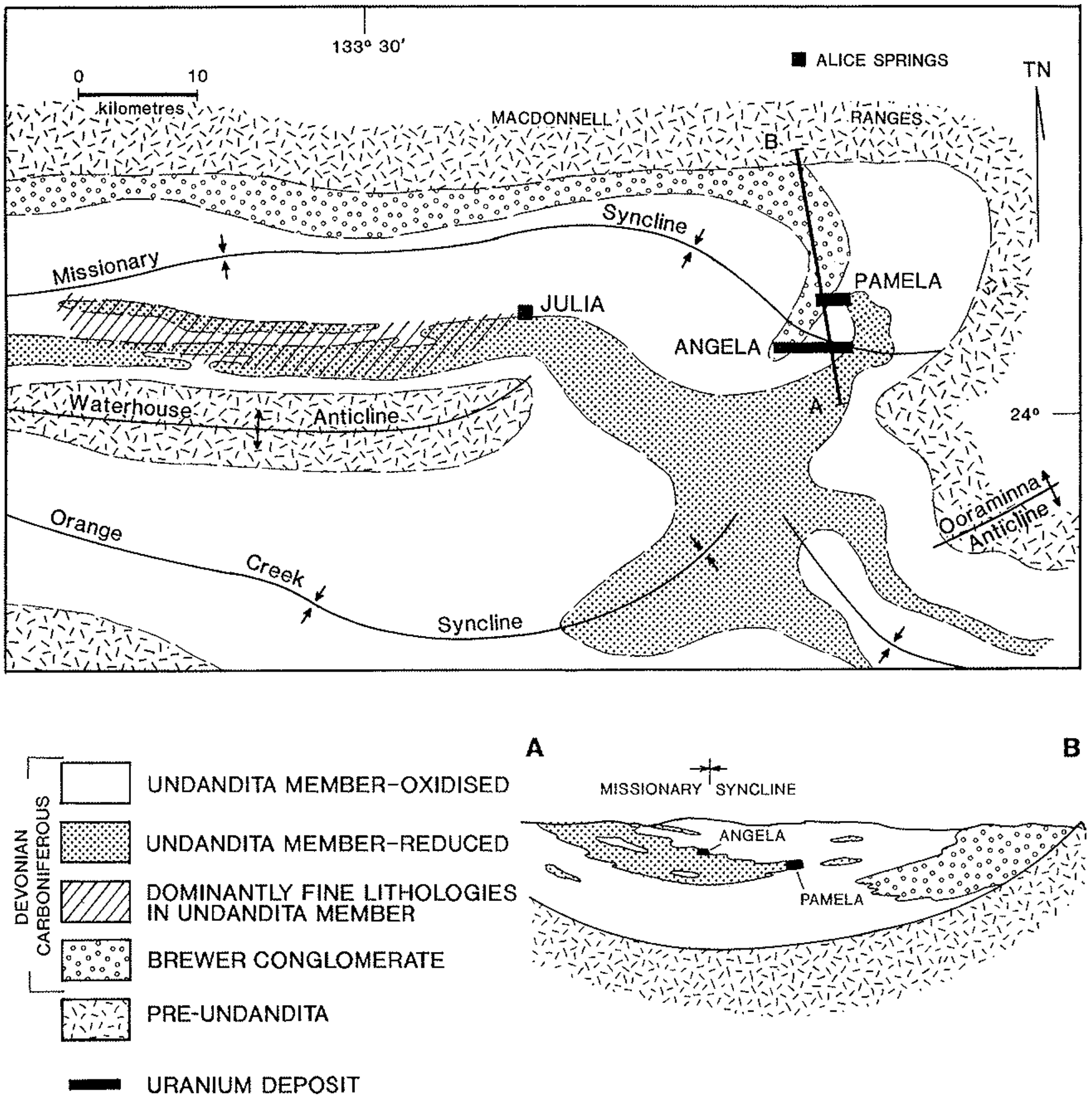

Fig. 1—Regional geology of the eastern Missionary Syncline.

stone, sandstone, chert and limestone fragments are from older formations within the Amadeus Basin. Mapping evidence and sedimentary features in diamond drill core are indicative of a braided stream environment.

Both the upper and lower redox surfaces bounding the reduced sediments of the Undandita Member have associated uranium mineralisation but concentrations are generally higher on the upper redox boundary (Fig. 2). The boundary does not necessarily have uranium mineralisation throughout. The reduced sediments show little post-depositional weathering as evidenced by the abundance of fresh, unaltered feldspar grains and the occurrence of rare, detrital glauconite indicative of rapid deposition. Primary calcite cement was precipitated from pore water as conditions became more reducing during burial followed by some later in situ dissolution of the calcite cement. The oxidised sediments display a similar paragenetic history to the reduced sediments. Flushing of the partially cemented sediments by oxidising ground waters initiated a period of calcite dissolution and hematite precipitation with cyclical alternation. Uranium precipitation and remobilisation is associated with this phase of cementation.

In cross section (Fig. 3) the higher grade mineralisation at Angela I coincides with a complex 30 to 40 m high step zone on the upper regional redox boundary. The step zone when projected to surface displays a remarkably linear E-W trend over at least 5700 m, plunging to the west at about 9°, with the main mineralisation varying in width from 70 to 250 m (Fig. 2). This step zone on the upper redox boundary is subparallel to the axis of the Missionary Syncline. Its position may be related to an east trending fault or structural break, as irregularities in dip and lithology occur across it, and a seismic reflection survey delineated distinct reflectors with a change in dip and disappearance of coherent reflectors across the step zone. Correlation of down hole electrical logs suggests a displacement of about 5 m, north block down, but other firm evidence is lacking. In the less well mineralised Angela III to V deposits these step zones are not as well developed.

In detail the Angela I deposit consists of a series of stacked mineralised horizons each made up of one or more small uranium roll front occurrences (inset, Fig. 3). Together they have the configuration, in section, of a flattened 'Z' coinciding with a step on the upper redox boundary. The most continuous mineralised horizon defines the base of the 'Z'. It

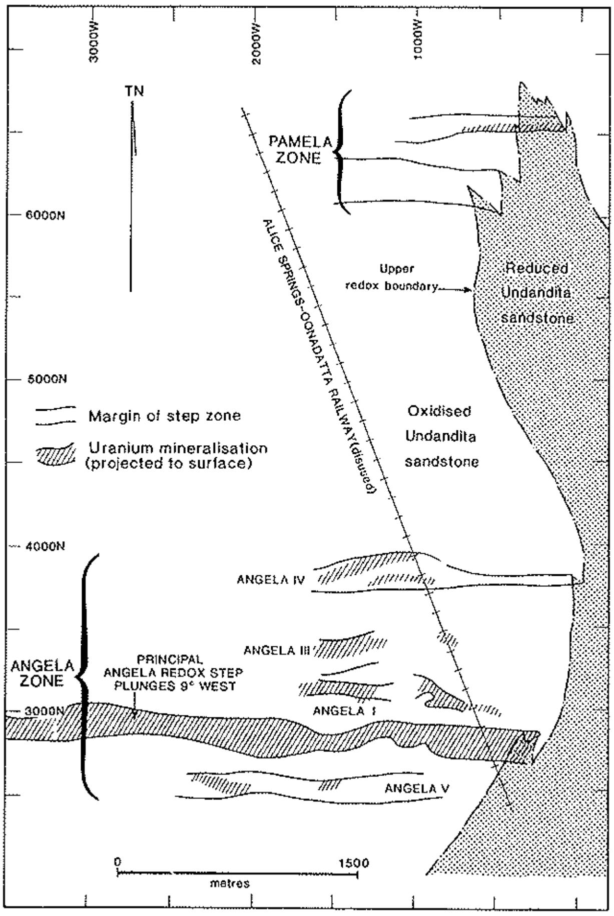

Fig. 2—Plan projection of the Angela and Pamela deposits.

contains 60 to 75% of the resource. The second zone of uranium concentration is just below the top of the 'Z' on the oblique connection where minor roll fronts extend into the reduced sediments. Although the individual rolls are not laterally continuous, the zone itself is persistently mineralised down plunge. The third zone of higher grade mineralisation on the top of the 'Z' coincides with the relatively planar upper redox boundary.

Although this simplified view of distribution of the mineralisation has been developed from work in the shallow eastern portion of the deposit where drill hole density is highest, more widely spaced drilling further west does not suggest any significant variation from this configuration.

The primary uranium mineralisation consists of poorly crystalline uraninite and pitchblende with minor coffinite occurring as grain coatings, void linings and blebs. The bulk of the mineralisation is fine grained to amorphous. Secondary uranium minerals occur in both the zone of weathering and at depth, probably as a result of the decomposition of primary uranium minerals. The secondary minerals identified include carnotite, autunite, tyuyamunite and metatyuyamunite. The secondary uranium mineralisation at depth appears to have formed during a late diagenetic event and occurs as very fine grained coatings, disseminations in the matrix and fracture fillings within some detrital grains. In many samples carnotite appears to be closely associated with the deposition of fine calcite spar cement and hematite. Vanadium is present at approximately half the grade of uranium, and anomalous copper, lead, selenium, arsenic and yttrium have been recorded. The mineralisation is now generally in radiometric equilibrium except where affected by near surface weathering. Gangue mineralogy is principally fine grained to amorphous hematitic cement occurring as black grain coatings and matrix fillings. Pyrite and organic material are negligible.

Redox-related changes, signified particularly by the presence of the iron oxide-hydroxide species, are the principal alteration features associated with the uranium mineralisation. Hematite has resulted from the oxidation of magnetite and iron bearing silicates particularly biotite. Four distinct zones characterise the redox boundary. From the oxidised to the reduced side of the boundary they are: a red hematite zone; a patchy and mottled hematite zone; a bleached zone; and a grey-green reduced zone. The bleached zones exhibit the strongest control over mineralised lenses and appear to be associated with the more permeable coarser layers.

PAMELA DEPOSIT

The Pamela deposit is at the NE end of the reduced sandstone facies wedge where the steps and irregularities on the upper and lower boundaries meet to form a sequence of alternating oxidised and reduced sandstone. Although multiple redox boundaries and step zones up to 50 m thick are present, mineralisation is thinner, weaker and less continuous than at Angela with no zone of enrichment being recognised that is continuous down dip.

CONTROLS OF MINERALISATION

The location of the Angela and Pamela mineralisation is related to the early tectonic evolution of the Amadeus Basin, and the control it exerted on palaeoenvironments and ground water flows as has been discussed by Jones, Ferguson and Wygrala (1981). The source of the uranium is ultimately the granitic units within the Arunta Complex, but the uranium bearing solutions were generated within the sedimentary pile by leaching by low temperature oxidising ground waters. These fertile oxidising ground waters deposited uranium regionally at the redox boundary with particular uranium concentrations controlled locally by lithology and permeability contrasts.

At Angela I the richer mineralisation is generally associated with stronger permeability contrasts, such as the contact between medium grained sandstone and coarse pebbly sandstone horizons, particularly if associated with the redox boundary. Regionally the planar upper redox boundary intersects the bedding at angles of up to 5°. On the local scale, where the oxidising fluids encountered a zone of increased permeability associated with the more porous units within the reduced zone, higher grades of uranium mineralisation developed because of a more efficient focusing and throughput of the uranium rich ground waters. As the more permeable horizons are at a slight angle to the regional redox boundary, steps develop at this boundary as the redox front progresses. Detailed core logging has shown that, in the Angela area, several 30 to 40 m thick sedimentary cycles are prevalent with cementation concentrated at the base. Four sedimentary cycles have been identified in the Angela area. These have been termed AI, AIII, AIV and AV, reflecting the mineralisation they host. These cycles provided a significant control on the localisation of the mineralisation at Angela I and its adjacent satellite orebodies. Thin section study suggests that pedogenic calcrete, deposited during the sedimentary hiatus which occurred between each cycle, formed a permeability barrier. The calcrete horizon is often observed to be reworked by the subsequent cycle forming permeability breaks along these barriers. In the Angela area the barriers and the breaks along them strongly influenced subsequent ground water movement. At Angela I the well cemented base of a single sedimentary cycle 35 m thick, with a coarse to very coarse sand fraction immediately above, prevented oxidising ground waters from breaking through to the lower cycle and focused the mineralising fluids into the coarse permeable sands (Fig. 3).

The principal reductants included lithic fragments and clay minerals with only a minor contribution from pyrite and organic material.

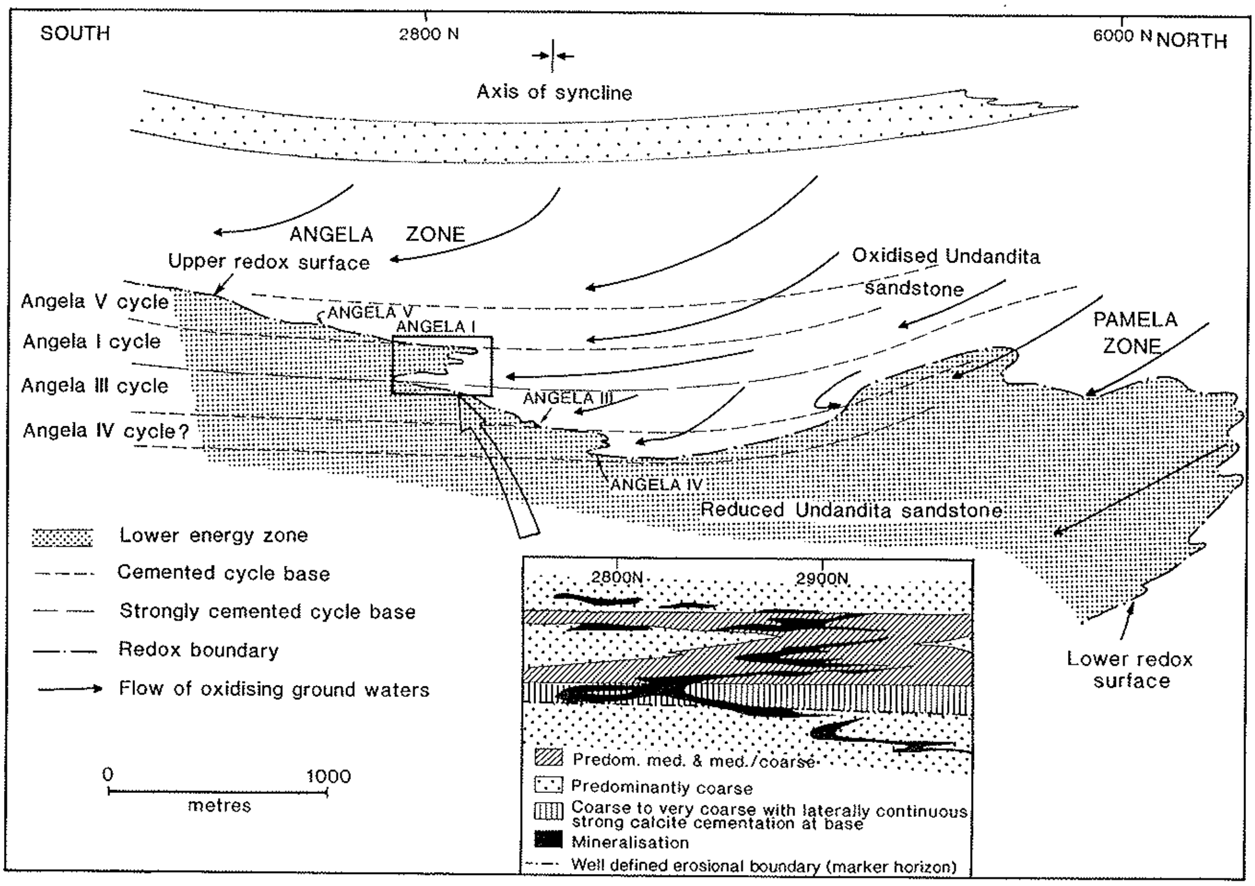

Fig. 3—Schematic section of the Angela and Pamela deposits showing the relation between lithology, oxidation and mineralisation.

ORE GENESIS

Evidence clearly shows that uranium was introduced by an oxidising uranium rich ground water system and deposited along a near horizontal regional redox boundary. The evidence suggests a southerly ground water flow with reduced lithologies therefore preserved only in the southern part of the Missionary Syncline and Orange Creek Syncline. The development of the redox boundary probably stopped at its present position in late Carboniferous time in response to a major change in the prevailing ground water hydrological regime. This cessation of mineralising activity was related to tectonic influences and a deepening of the syncline. The redox boundary was controlled ultimately by permeability created either by regional lateral grain size variations and/or regional variation in the degree of cementation in the sandstone. Aberrations on this planar boundary reflect local lateral and vertical grain size variations, and impermeable layers marked by accumulation of pedogenic calcrete at the base of sedimentary cycles associated with long breaks in sedimentation.

This sequence allowed ground waters to migrate near horizontally, and hence oxidation to develop, in selected beds as a relatively planar redox feature. Breaks in the aquicludes related to incomplete calcification, facies changes or erosion by subsequent sedimentary cycles, allowed irregularities and steps to develop along the regionally planar redox boundary by migration of oxidising ground water to lower stratigraphic levels. Thus, although the redox boundary is regionally a relatively regular feature, often conformable with bedding over a number of kilometres, in detail it is irregular with the degree of irregularity depending on local grain size and cementation controls.

Conditions for the accumulation of economic quantities of uranium appear to have been most favourable in the eastern Missionary Syncline, where the regional redox boundary coincides with the coarser lithologies. In the Julia area (Fig. 1) the dominantly finer lithology and consequential lower permeability and fluid flow are reflected by multiple redox boundaries having only weakly anomalous uranium.

The regionally conformable nature of the upper redox boundary to the bedding implies that it formed prior to the major downwarping of the sediments. The oxidation with its associated uranium mineralisation was probably a diagenetic event.

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