DEPARTMENT OF NATIONAL RESOURCES

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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BMR's role in mineral exploration within the Pine Creek Geosyncline, 1949-1977

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The discovery of uranium minerals by prospector Jack White at Rum Jungle in 1949 sparked off a continuing exploration program in the Pine Creek Geosyncline; this led to the discovery of three uranium fields and several small base-metal and iron ore deposits with a total value (Today's prices) of nearly $17 000 million.

The BMR has been the most persistent of the explorers, and itself has discovered a significant proportion of these deposits. Its most important role has been the construction of basic geological and geophysical frameworks to aid metals search. In recent years, prompted by the vast mineral wealth in the most recently discovered deposits - those of the Alligator Rivers Uranium Field - a detailed review of these frameworks has been undertaken, and will eventually spread across the geosyncline.

The BMR role has been flexible, ranging from one of exploring and prospect evaluation, to technical assistance to prospectors, testing and development of various geophysical and geological equipment and methods, to regional geological and geophysical studies, and to studies in geochronology, rock and uranium lode geochemistry, and stable isotopes, largely as a support to the regional studies. Overall, this flexibility has matured over the years away from direct exploration involvement towards wide-ranging 'grass roots' studies more in keeping with the basic principles laid down for BMR in 1946 when the organisation was formed around the Mineral Resources Survey which was established in 1942. This change in role also reflects the ability of the larger companies, which have become involved in exploration in recent years, to undertake expensive operations such as airborne geophysical surveys, within their budgets, and the acceptance of airborne geophysics as the primary uranium exploration tool.

A chronological account of the exploration history of the region is given. An attempt is made to assess the success and cost-effectiveness of the Bureau's work. In view of the low order of duplication of BMR and company work, and the impact that the synthesis of the regional geology by the Bureau has had on exploration, it is reasonable to regard the expenditure by BMR as warranted in so far as it has furthered the orderly exploration of this hitherto remote and geologically poorly understood area, which is now a metalliferous province of world importance.

Introduction

Before the discovery of secondary uranium minerals at Rum Jungle in 1949 by prospector Jack White, mining activity within the Pine Creek Geosyncline involved the working of hundreds of small, shallow, gold and base-metal orebodies, mostly discovered in the 1872 Pine Creek and 1873 Grove Hill gold rushes by prospectors and small syndicates. The great strategic value of uranium in the late 1940s ensured prompt and extensive examination of White's find and surrounding areas by the Australian Government, and within a matter of months payable ore was discovered, and numerous other prospects located. In later years the restrictions on uranium mining were eased to allow private exploration for uranium. Government exploration and regional studies continued, and as a consequence of the combined effort of many private companies and the government two additional uranium fields and a few small base-metal and iron orebodies were discovered. The area of most interest at present is the Alligator Rivers Uranium Field in the extreme northeast of the geosyncline, which contains about one-quarter of the Western World's uranium. This uranium field, whose discovery was the climax to a chain of events sparked off by Jack White, has placed the Pine Creek Geosyncline amongst the greatest mineral fields of Australia, and as the most prominent of all the world's uranium provinces.

The agent of the Australian Government in the field of exploration and geological and geophysical regional studies has been the Bureau of Mineral Resources (BMR). Before 1953, when the management and development of the Rum Jungle field passed under government contract to Territory Enterprises Pty Ltd (TEP), and when the Australian Atomic Energy Commission (AAEC) was established, BMR managed exploration and mining activities, and stockpiled small quantities of ore won during exploratory underground excavation.

After the TEP takeover, BMR continued detailed geophysical and geochemical investigations at Rum Jungle, but the main exploratory role passed to TEP. The BMR program extended into other parts of the Pine Creek Geosyncline and special attention was paid to the Brocks Creek and South Alligator Valley areas where geological similarities with Rum Jungle had been noted. The ensuing systematic mapping program over the geosyncline was the first comprehensive geological study of the region. During this work the South Alligator Valley Uranium Field was discovered, and iron mineralisation recorded at Mount Bundey and Frances Creek. The results

of all the geological work done by BMR to 1958 were summarised in BMR Bulletin form by Walpole and others (1968); the accompanying 1:500 000 regional map emphasised geological similarities between the Rum Jungle and Alligator Rivers areas, and subsequently much interest developed in the northeastern part of the geosyncline. The year following publication of the map saw the delineation of airborne anomalies by several companies throughout the area, and in 1970 the discovery of the Ranger1, Koongarra, and Nabarlek orebodies established the area as a major uranium field.

These latest discoveries resulted in intensified activity by BMR in the Pine Creek Geosyncline once more, but with a markedly different approach to that of the 1948-1958 era. This paper examines the history of exploration within the Pine Creek Geosyncline since Jack White's discovery, and the varying role played by BMR during this time. The exercise is treated as far as possible as a 'case history', with the Pine Creek Geosyncline as the prospect and BMR as the operator. There are many obvious difficulties, the greatest of which is assessing the cost-effectiveness of BMR's work, which included testing and developing geophysical and geological equipment and techniques new to Australia, and other intangible contributions. However, the philosophy, methodology, successes, and failures of the BMR work can be assessed.

Geology

The Pine Creek Geosyncline is an inlier of Lower Proterozoic metasediments surrounded by the younger McArthur, Daly River, Victoria River, and Bathurst Terrace sedimentary basins on the east, south, and north (Fig. 1). The Litchfield Block, containing granite and metamorphic rocks of probable Archaean to Lower Proterozoic age, forms the western margin. The metasediments of the Pine Creek Geosyncline surround domes of Archaean-Lower Proterozoic granite, migmatite, and metasediment in the western and eastern parts, and are extensively intruded by late Lower Proterozoic basic and early Carpentarian acid igneous rocks throughout the whole of the region (Fig. 2). The mineral deposits are mostly within the Lower Proterozoic metasediments, either adjacent to the early Carpentarian granite (base metals, gold) or within carbonaceous or partly carbonaceous strata (uranium, gold). The mineral fields of the region are shown in Figure 3.

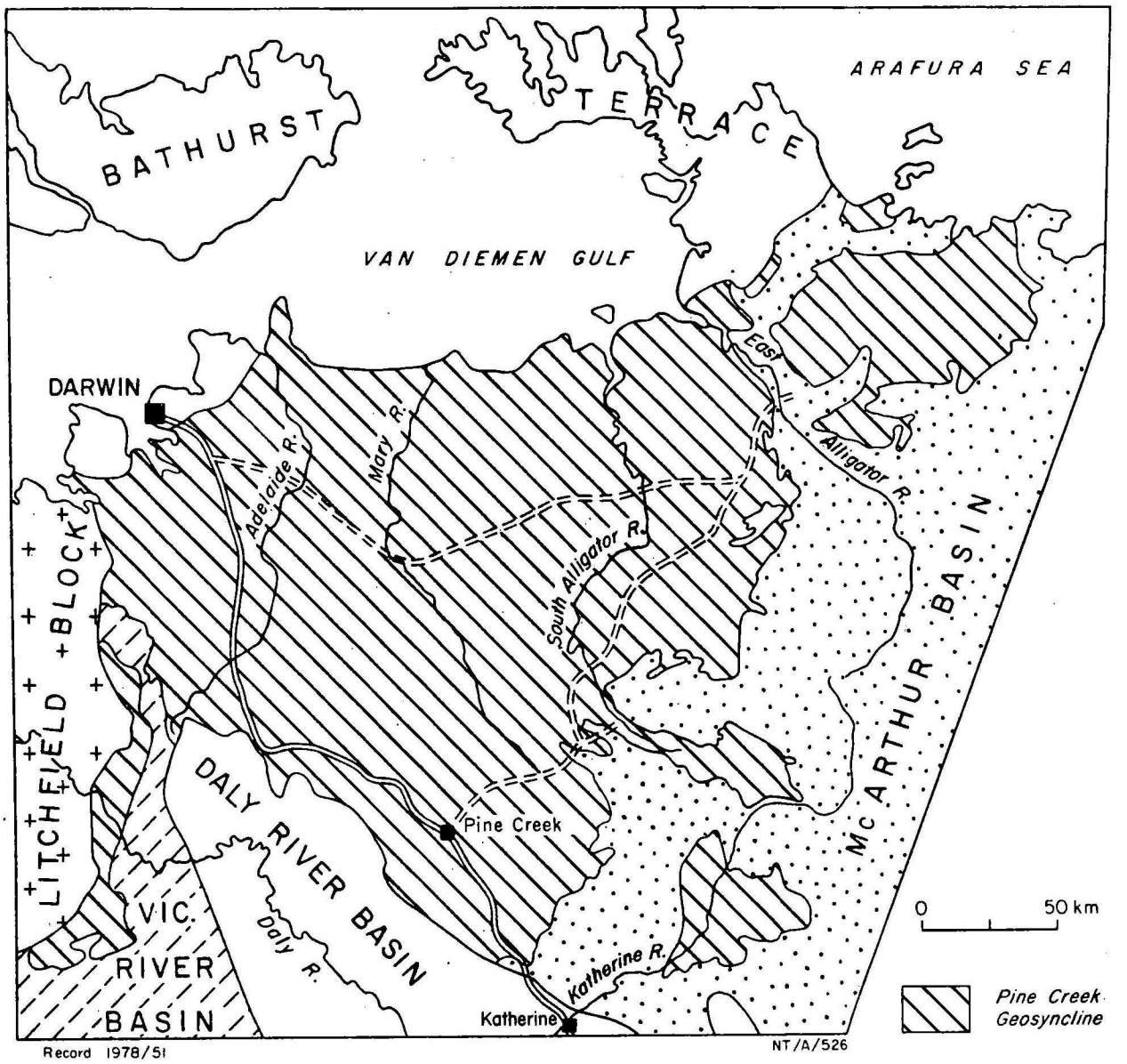


Fig. 1 Location and structural setting of the Pine Creek Geosyncline, N.T.

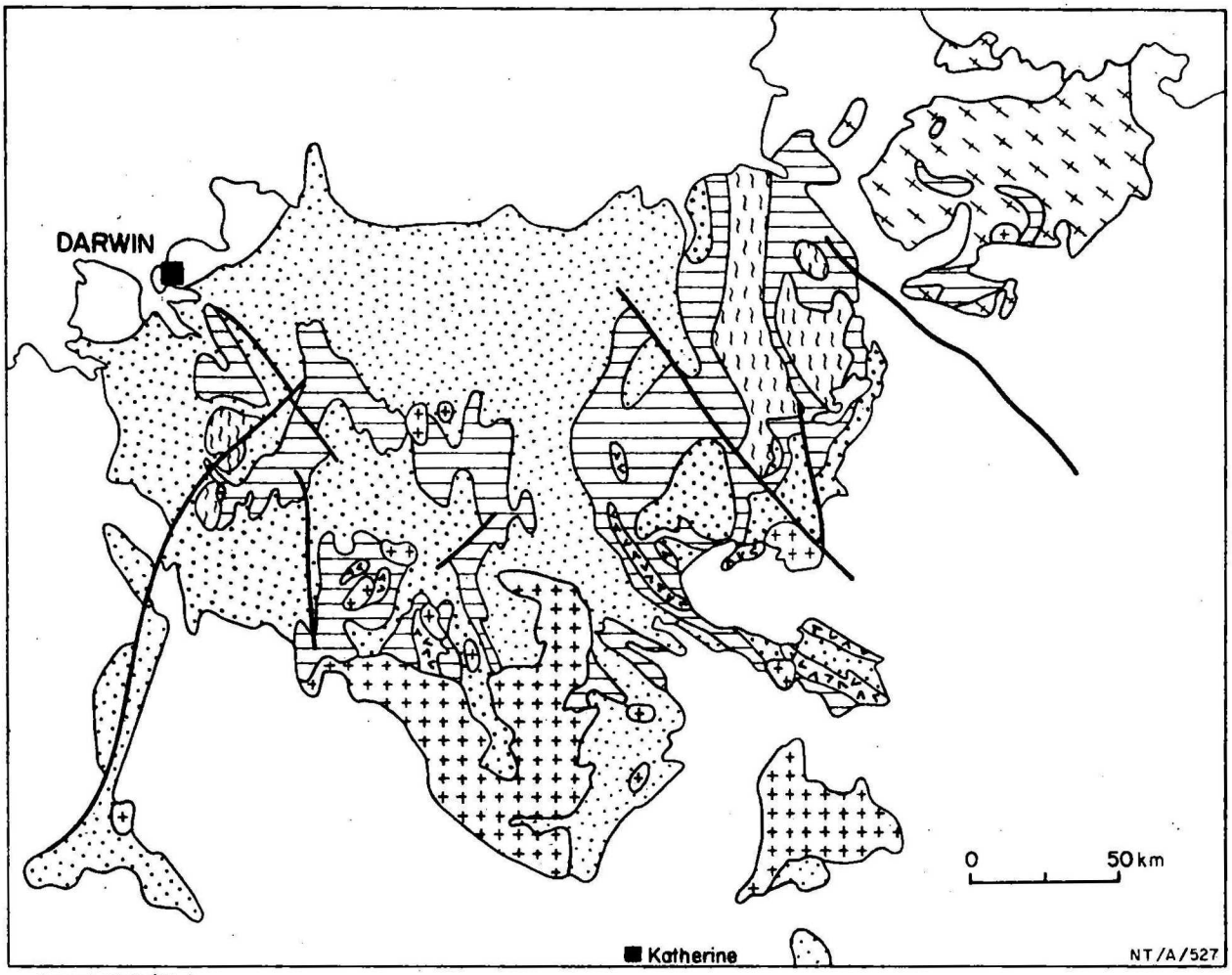


Fig. 2. Generalised geology, Pine Creek Geosyncline

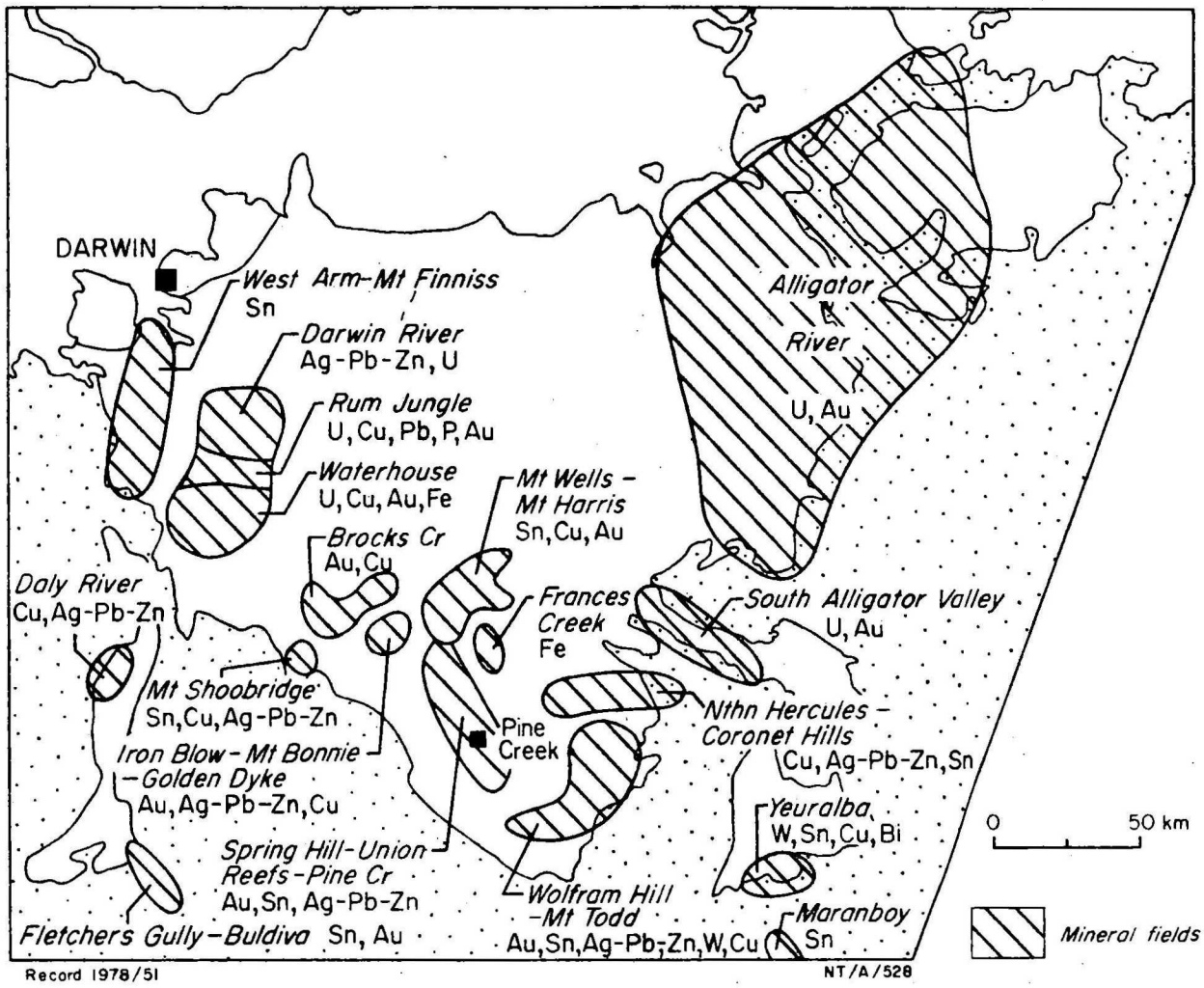


Fig. 3 Mineral fields, Pine Creek Geosyncline

Exploration history

The historical development of the Katherine-Darwin area as a metalliferous province can be divided into five chapters, which are chronologically described below.

Pre-1949 - before White's discovery

The first recorded gold discovery was at Blackmore River 37 km south-southeast of Darwin in 1865, but it was the Pine Creek and Grove Hill strikes of the early 1870s which resulted in a rush of prospectors and miners to the Katherine-Darwin region. Although hundreds of prospects were located, most were worked to only shallow depths, and no workings reached any great depth. Many mines were abandoned or handed over to Chinese tributors originally brought to the area to work on the Darwin-Pine Creek railway. The discovery of tin at Maranboy in 1913 was the only other significant incident in this period, during which mine production steadily declined to a level of £3228 in 1946, which was 3% of the average annual value of production at the then current values during the boom years of the 1880s and 1890s (Noakes, 1949).

The first attempt at a systematic study of the area was begun in 1935 by the Aerial, Geological and Geophysical Survey of Northern Australia (jointly sponsored by the Commonwealth, Queensland, and Western Australian Governments), but the geological and geophysical surveys and limited regional mapping studies were confined generally to the known areas of mineralisation, and the work lapsed at the start of the Second World War. The first geological map of the region was compiled by Noakes (1949) following a regional survey in 1946 and review of previous work, in which the stratigraphy was rationalised and mineral resources were described. In the mid and late 1940s BMR examined some of the known deposits of the region with a view to stimulating exploration in the area, which was at its lowest ebb. These deposits included the Cosmopolitan Howley and Batchelor gold mines (Sullivan, 1946a, 1946b).

Several political decisions made during the 1940s were to have a marked effect on the Australian mining scene in general, and the Katherine-Darwin area in particular. Basically they were moves to stimulate the Australian mining industry which was ailing throughout the country, and were begun by the Chifley government in 1942 with the establishment of the Mineral Resources Survey (later (1946) the BMR). Two years later,

after approaches by the government of the United Kingdom, government encouragement specifically towards uranium exploration started. In 1947 the need for uranium for western defence purposes became urgent, and the Australian States and Federal Government cooperated to extend and intensify the search, and BMR became involved in uranium exploration. Finally, a scheme offering tax-free rewards of up to £25 000 for the discovery of new deposits was introduced in 1948, and in 1949 a guaranteed price schedule was introduced for uranium ores, and tax exemption measures were introduced for profits from uranium mining.

1949 - 1952; Rum Jungle Uranium Field

As part of the Federal Government's policy to stimulate uranium exploration, and following numerous requests for assistance from prospectors, BMR published a prospectors' guide to 'Radioactive Mineral Deposits' as a booklet in August 1948. During the following year prospector Jack White identified secondary uranium minerals near Rum Jungle Siding using the illustrations in the rear of the BMR booklet, and so sparked off a high level of activity throughout the Pine Creek Geosyncline which has persisted to the present.

Within one week of Mr White's visit to the NT Director of Mines on 7 September 1949, a BMR geologist visited the site of White's find; later that month a brief geological and geophysical study was made of the area, and more detailed work was recommended. A government mining reserve was placed over the area around the Rum Jungle Railway Siding, and was extended to cover the Hundred of Goyder in 1953. During October detailed geological investigations were made over an area 0.5 x 0.25 miles around White's find, a general reconnaissance of the district made, and a geiger survey commenced. The following dry season saw this style of work continuing, and during this work the Dyson's, White's Extended, Browns, Intermediate, and Mount Fitch uranium prospects were discovered. Testing of the prospects took the form of costeaning, shaft sinking, driving, and drilling. Initial investigation of White's prospect proved disappointing - an early assessment placed probable reserves at 10 tonnes U_3O_8, (Townley, 1950). However, drilling in 1951 intersected payable primary ore.

Following the intersection of high-grade ore at White's and Dyson's, and the discovery of additional prospects (White's South and Crater), the Federal Government discussed the development of the Rum Jungle Uranium

Field with the US and UK Atomic Energy Commissions. Subsequently developmental capital was provided by the Combined Development Agency - the joint Anglo-American uranium purchasing organisation - and tied to a 10-year contract for supply of uranium to US and UK.

In August 1952, the Federal Government made arrangements with Consolidated Zinc Pty Ltd to manage the development. A wholly-owned subsidiary company, Territory Enterprises Pty Ltd, was formed, and took over development of the uranium deposits of the Hundred of Goyder from BMR on 1 January 1953. The company was responsible to the Australian Atomic Energy Commission (established in April 1953); BMR's developmental responsibilities ceased and its initiatives in exploration programming within the Hundred of Goyder fell second to those of TEP and the AAEC.

By the close of 1952 the successful development of the Rum Jungle Uranium Field was assured. The BMR's role turned to exploration within and outside the Hundred of Goyder. During 1952 BMR conducted its first major airborne radiometric survey, which was the basis for the subsequent discovery of numerous additional prospects in and around the Rum Jungle district. By this time exploration activity for uranium by private individuals and companies was at a high level, and BMR played a vital role from its Darwin office as the identifier of mineral specimens and the fixer of broken-down geophysical instruments - in fact the BMR Darwin office was the only place in the Northern Territory for many years where maintenance of geophysical equipment was available.

1953 - 1958; South Alligator Valley Uranium Field

Virtually all the uranium prospects of the central and southern parts of the Pine Creek Geosyncline were discovered between late 1952 and the end of 1954, and during that time additional prospects were located near Rum Jungle. Whereas the prospects near Rum Jungle were mostly found as a result of ground follow-up of anomalies detected by the 1952 BMR airborne survey (including the Waterhouse, Brodribb, Frazer, and Ella Creek prospects), those elsewhere were located by the use of hand-held geiger counters. Notable discoveries included the Edith River group of prospects (unusual in their location within granite) where the initial finds were by the Young, Maslin, Cousins, and Andrew syndicate in October 1952; the Adelaide River lode discovered by prospector J. Lennox in March 1954; and the Coronation Hill **lode,** the ABC prospect, and the George Creek lode discovered

by BMR workers in June 1953, September 1953, and August 1954, respectively. Although minor amounts of uranium ore were produced from many of these finds during exploratory work, the Coronation Hill deposit was the only viable mine. Its discovery was of great significance as it focused the attention of prospectors on the surrounding area of the South Alligator Valley. Subsequently twelve more uranium or uranium/gold mines were established, and many more uneconomic prospects found.

Small government reserves were placed over BMR discoveries, unlike the larger reserve of the Hundred of Goyder at Rum Jungle. Consequently there was little restriction by government on private exploration during the 1953-1958 period. The government reserves were dropped after varying degrees of evaluation of the prospects by BMR, which in the case of the George Creek lode spanned several years, and involved sinking a shaft and making drives and cross-cuts.

The South Alligator Valley deposits were developed by two private mining companies, United Uranium N.L. and South Alligator Uranium N.L. Two of the deposits mined were BMR discoveries (Coronation Hill and Saddle Ridge) which accounted for about 17% of the total production of uranium oxide (874 tonnes) from the South Alligator Valley Field.

During this period the activities of BMR diversified. Direct exploration work continued at Rum Jungle largely dictated by programming initiatives of TEP and the AAEC. However, exploration continued at a high level outside the Hundred of Goyder, where BMR exploration for uranium was partly funded by the AAEC within a 100-mile radius of Rum Jungle. This activity was tied closely either to follow-up of airborne anomalies detected by BMR surveys (during which BMR developed a carborne system of radiometric traversing) or to follow-up of finds by the regional mapping parties. This period also saw new exploration initiatives into geochemical and geobotanical studies and gravity surveys, as well as essentially continuous work in the field of regional and detailed airborne radiometric and magnetic surveys, in other geophysical studies, and in rock and ore petrology.

The most significant diversification was into regional mapping. Sparked by the knowledge of high-grade mineralisation at Rum Jungle, the need for a basic geological framework for the whole of the Pine Creek Geosyncline became apparent. Also by this time the association of uranium with copper had been recognised at Rum Jungle in White's deposit and at the Intermediate prospect (later Intermediate mine), and so emphasis was

placed on areas of known copper mineralisation, essentially the belt of country extending from the Brocks Creek Mineral Field to the Coronet Hill group of mines (Fig. 3). The interest in the uranium-copper association was vital in the discovery of the South Alligator Valley Uranium Field. Following this theory a BMR geologist accompanied prospector Joe Callanan to inspect a copper prospect. Nearby, secondary uranium minerals were identified by the BMR man, and so, on Coronation Day, 1953, the Coronation Hill uranium deposit was discovered.

Between 1953 and 1958 several tin, lead, and iron prospects were located by private prospectors, or by the BMR regional mapping team. The tin and lead finds resulted from a re-evaluation of areas of known mineralisation, the more significant of several small mines being Jessops and Mavis (tin, Mount Wells/Mount Harris Mineral Field, discovered in 1957 and 1958, respectively), and Osman, where a shaft sunk in 1958 intersected deeper mineralisation in a previously worked stanniferous lode in the Maranboy Tinfield. The most **significant discoveries were the** iron ore deposits of Frances Creek and Mount Bundey. Both were discovered early in the regional mapping program of BMR. Interest in iron ore was low at the time, and the only work done was to test the Mount Bundey (Pritchard's Lode) prospect as a possible ferruginous gossan over a copper lode. The one drill hole passed under the near-surface iron orebody, and failed to intersect any lode material. However, the iron potential was recognised, and when interest in iron was stimulated by the partial lifting of the iron-ore export embargo in 1959, the NT Mines Branch investigated the deposit, and outlined the orebody which was later mined out by Morgan Mining and Industrial Co. Pty Ltd. The Frances Creek deposit was delineated and mined out by Frances Creek Iron Mining Co. Ltd.

By 1958, exploration activity had slowed down, especially in the search for uranium. Many companies were attracted to the Mount Isa region in 1954 following the discovery of Mary Kathleen. Airborne surveys north of the South Alligator River Valley (Livingstone, 1958) did not extend north of Spring Peak and Mount Basedow, where radioactive pebble beds had been detected during regional mapping. In 1957 minor radiometric surveys were made of two small areas in the Myra Falls Inlier southwest of Nabarlek during airborne checking of granite outcrops, over rocks believed to be similar to uranium host rocks at Rum Jungle and on the South Alligator Valley. However, no anomalous values were recorded (P.R. Dunn, personal communication).

1959 - 1968; base metals, iron, and phosphate.

This period saw a change in emphasis away from uranium search. Although exploration had been intense, no notable deposit had been discovered since 1954 other than the Rum Jungle Creek South uranium orebody (discovered by an extensive drilling program by TEP following up airborne anomalies detected by BMR). The partial lifting of the embargo on the export of iron ore by the Federal Government in December 1959 stimulated the search for new deposits and the testing of previously known deposits, principally in Western Australia. Likewise, the knowledge of iron ore formations in the Pine Creek Geosyncline led to the testing and eventual development of these occurrences, and prospecting - mostly by individuals - for additional deposits. This search yielded only numerous very small occurrences of no economic significance.

The BMR, on behalf of the Australian and New Zealand governments, made a survey for phosphate on the Pacific Islands, but only small reserves were indicated (Kalix, 1960). Since then, BMR has made an assessment of Australia's phosphate potential. As part of that assessment the phosphate deposits of the Pine Creek Geosyncline were studied. The presence of phosphate was first noticed in geochemical analysis of lilac 'shale' from Castlemain Hill near Rum Jungle Creek during investigations which eventually led to the discovery of the Rum Jungle Creek South uranium deposit. Siltstone and hematite-quartz breccia found during the regional mapping program elsewhere in the Rum Jungle and South Alligator Valley districts were examined during a phosphate survey of the Katherine-Darwin area during 1961-1962. All deposits were found unsuitable for the manufacture of fertilizer and for beneficiation, although there is some possibility of production of finely ground calcined ore for local use (Kalix, 1964).

Meanwhile, routine geochemical and radiometric investigations continued in and around the Hundred of Goyder. The significance of a carbonate/graphite lithological association (Coomalie Dolomite/Golden Dyke Formation contact) had been recognised since initial detailed investigations near White's deposit in 1950-1951. Poor exposure led to the introduction of shallow drilling to locate and test this contact. Systematic auger gridding with associated geological logging of cuttings, radiometric probing of holes, and geochemical assay (generally only bottom-

hole samples) was introduced in the early 1960s when suitable drilling equipment became available. The first extensive use of this system by BMR was in 1964 (Dodson & Shatwell, 1965) east of Rum Jungle, during which the Woodcutters linear zone of geochemical and radiometric anomalies was outlined whilst following up airborne radiometric anomalies detected by BMR in 1957. Subsequent deeper drilling up to 1967 intersected high-grade lead-zinc mineralisation. The deposit then passed to the successful tenderers, Geopeko Ltd., who were unable to prove sufficient ore to bring the deposit to production (approx. 600 000 tonnes averaging 8% lead, 16% zinc, and 214g/tonne silver). The discovery of Woodcutters intensified base-metal search throughout the geosyncline, which coincided with the beginnings of the great Australian mineral boom of the late 1960s and early 1970s. By this time, BMR was largely inactive in the Katherine-Darwin region other than for completion of low-order recommendations made during earlier base-metal and uranium search in the Rum Jungle district. Its major contribution during this time, and arguably its greatest part in the history of exploration in the Pine Creek Geosyncline, was a sedentary one. Recommendations were made to companies and individuals that the Pine Creek Geosyncline was an area of interest for exploration for base metals and uranium . One of the first approaches for uranium was made by Agip Nucleare in 1966, but no ground was taken up by them. Noranda was recommended five areas in the Northern Territory for uranium search (Arnhem, Roper River, Nabarlek, Jim Jim area, and Tanami-Killi Killi). The company took up ground in the Arnhem and Roper River areas, and awaited relinquishment of the Jim Jim area by Macmine, who were searching for Woodcutters-type base metals there. Geopeko was also looking for base metals in the belief that a second Woodcutters-sized orebody would justify mine development in tandem. Geopeko took up areas south and west of Mudginberri homestead in the East Alligator area, but were unable to take out the Oenpelli region, which at the time was already held by Queensland Mines. Queensland Mines Ltd took out this area to test the Carpentarian sandstone for Westmoreland-type uranium deposits, which had just been discovered by them whilst following up airborne radiometric anomalies delineated by a 1957 BMR survey along the Queensland/Northern Territory border.

In spite of recommendations put to some of these companies and others by BMR, based on the geological framework built up largely by the regional geological mapping program of the mid 1950s, it was a Mrs Stevens, an Adelaide intrepreneur, who took out authorities to prospect over much of the Alligator Rivers region. She first approached P.R. Dunn (at the time BMR's Northern Territory minerals man) for advice on areas in which to explore for manganese and nickel within the Katherine-Darwin area. He agreed there was some potential for these metals (Union Carbide was already searching for manganese and bauxite in parts of Cobourg Peninsula to the north). She was told that the area was 'really a uranium area', and so with this combination of potential minerals she approached several companies. Some had recognised obvious geological parallels between Rum Jungle and the Alligator Rivers area following publication of a ½-million-scale regional map of the geosyncline by BMR, on which the granites in these areas were assigned to the Archaean, and so interest in the uranium potential of the area grew.

The scene was set for the discovery of one of Australia's great mineral fields.

1969-1977; Alligator Rivers Uranium Field

The airborne radiometric technique had been gradually perfected during the Rum Jungle and South Alligator Valley years. Its contribution towards locating most of the uranium prospects in the Pine Creek Geosyncline was without parallel. In even remoter areas, such as the Alligator Rivers region, especially those parts within the Arnhem Land Plateau (a deeply dissected sandstone plateau) it was the obvious method by which to cover difficult country quickly and thoroughly at reasonable cost. Queensland Mines and Noranda flew their areas in 1969, and Geopeko in 1970 (postponed owing to technical and weather problems - Eupene and others, 1976). The Nabarlek and Ranger 1 orebodies were detected as priority anomalies (the Ranger 1 anomaly was first detected by Noranda in 1969 whilst flying their adjacent area to the south), and Koongarra as a low-order anomaly.

Subsequent events are recent history extensively recorded in the press. Highlights include the downgrading of Nabarlek reserves from 55 000 tonnes U_3O_8 to 9500 tonnes in September 1971; the discovery of the Jabiluka 1 deposit by ground reconnaissance spectrometer surveys in 1971; and the discovery of the Jabiluka 2 deposit in 1973 by exploratory drilling along strike from Jabiluka 1 (Rowntree & Mosher, 1976). Numerous additional prospects have been discovered, but few have been fully investigated following complications deriving from the establishment of the Kakadu National Park in the area, and the Ranger Uranium Environmental Inquiry. Changes in the Northern Territory Mining Ordinance made in 1971 stipulated gradual relinquishment of exploration licences and transfer to mineral leases for remaining areas. Relinquished areas are held under government reserve pending the outcome of the Inquiry. The only activity outside MLs and restricted ELs at present is by the exploration division of the Australian Atomic Energy Commission. The most recent discovery is the Austatom 1 prospect announced by AAEC in December 1976.*

As on similar occasions, BMR was quick to begin working in this new area of uranium discoveries. However, this time the Bureau's approach was markedly different, not only as a result of its not being directly involved in the discovery of these new uranium deposits, but also because since 1955 there had been a gradual change in its philosophy of involvement in minerals exploration away from direct exploratory participation towards a role perhaps more befitting a national geological survey.

In the dry season following the Nabarlek, Ranger 1, and Koongarra announcements, a small field party began semi-detailed mapping of the uranium field. Close liaison with companies contributed to the progress of work in this relatively poorly known undeveloped region, and contrasted with the air of rivalry which existed at times in earlier days. Subsequently small teams in the fields of regional and detailed airborne and ground geophysics, rock and ore genesis geochemistry, and geochronology became involved in the area mainly to establish a sound geological base for further exploration and to formulate concepts of ore controls and genesis. Palaeomagnetic and regional geophysical interpretation studies began in 1977.

In the same vein, ore genesis studies in the Rum Jungle and Brocks Creek/Mount Bonnie areas recommenced in 1970, and semi-detailed remapping of the Rum Jungle district began in 1971.

* Since the time of writing, Geopeko have announced the discovery of high-grade mineralisation at Ranger 68, 4.5 km west-south of Jabiluka 1.

The remapping program will eventually cover the whole of the geosyncline, and together with geochemical and geophysical studies, will provide a sound base for more detailed scientific studies and exploratory work throughout this metalliferous province.

Mines and as yet unworked orebodies discovered since 1948 are shown in Figure 4. Production from or reasonably assured resources within these are listed in Table 1.

BMR Involvement

As can be seen in the account of the exploration history of the Pine Creek Geosyncline, BMR has played a continuous and major role since Jack White's discovery, and even before that it contributed in the form of regional geological and detailed mine investigations, although it was the publication of the uranium prospectors' guide pamphlet which led to the initial discovery of uranium which in turn was the stimulus for all subsequent work.

The Bureau has been involved in five main ways :

1. Stimulation by detailed investigation of areas of known mineralisation
2. Exploration activities
3. Regional studies
4. Specialist research studies
5. Dissemination of information

Figure 5 shows the fields in which the BMR has been involved since 1948, and the manpower commitment. Stimulation by examination of areas of known mineralisation began before White's discovery, when several abandoned gold mines were investigated. This work also included investigations in the West Arm/Mount Finnis Tinfield (including assessment of tin, tantalum, and niobium deposits) in 1955 and 1956, the Maranboy Tinfield (1958-1959), and later, the Union Reefs Goldfield (1963-1964).

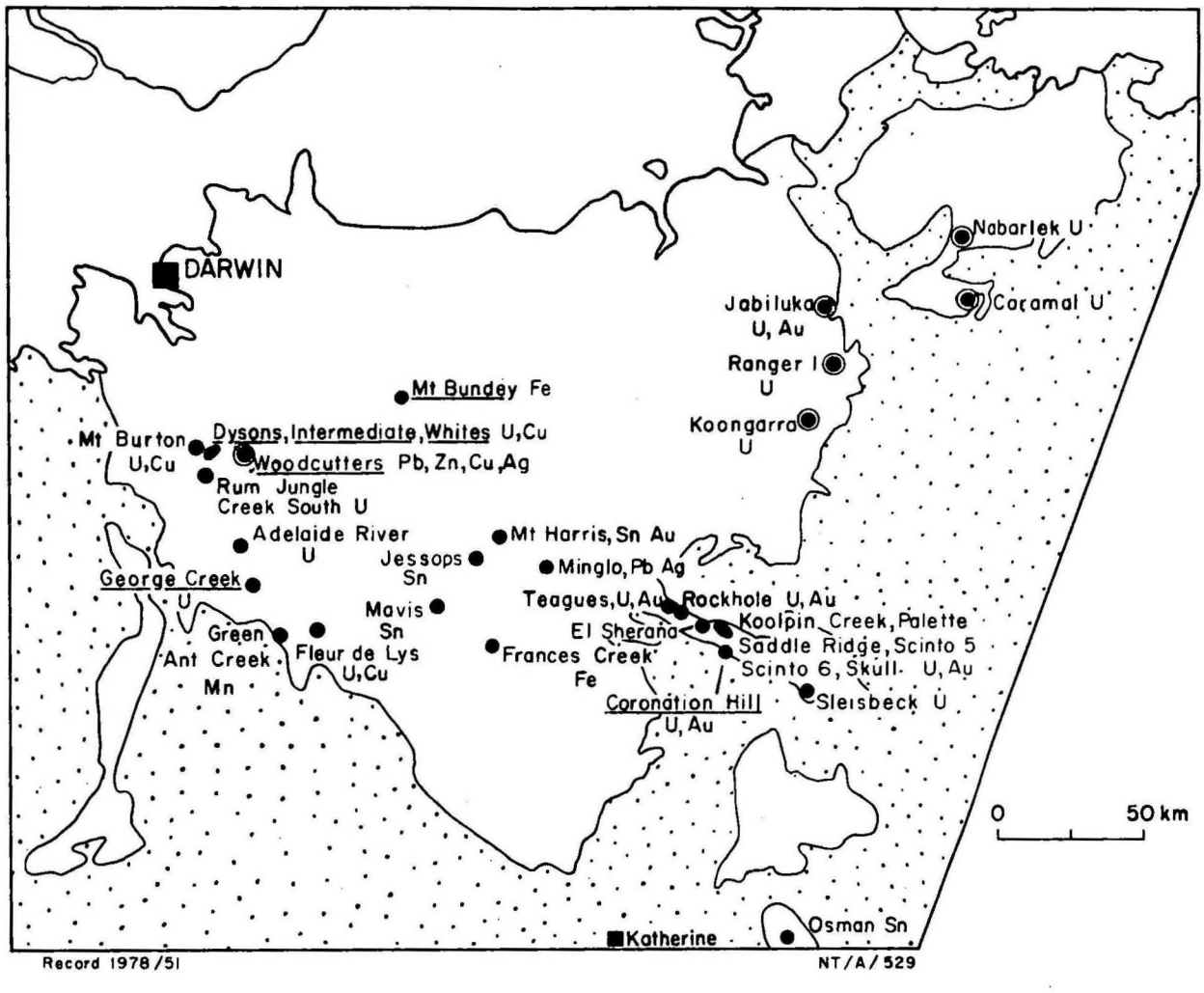


Fig. 4 Mines and unworked orebodies discovered since 1948 – underlining indicates BMR find

● Mine

◉ Unworked orebody

Table 1. Production and reasonably assured resources* of ore deposits discovered since 1948 in Pine Creek Geosyncline.

world metal prices as at 31/12/76; uranium at $25/lb - current mean long term contract price 31/12/76

Deposit	Mineral(s)	Tonnes metal (U.as U_3O_8)	Value today's prices $000	Discoverer/year
Whites	U, Cu, Ag	2 Ag 15,000 Cu 1,069 U	77,354	prospector White/BMR 1949
Dysons	U	534	29,370	BMR 1950
Mt Burton	U, Cu	100 Cu 12.6 U	815	BMR 1950
Intermediate	Cu	9,140	11,151	TEP (CRA Expl)
Rum Jungle Creek South	U	2,612	143,660	TEP (CRA Expl) 1959
Browns	Pb	unpublished		CRA Expl
Woodcutters	Pb,Zn,Ag	48,000 Pb* 96,000 Zn* 128 Ag*	111,060	BMR 1964
Coronation Hill	U	75	4,125	BMR 1953
Saddle Ridge	U	78	4,290	BMR 1953
El Sherana	U,Au	226 U	12,430	United Uranium 1954
El Sherana West	U,Au	185 U Total Au 0.3	10,175 1.4	BMR/United Uranium 1960
Rockhole (incl. O'Dwyers Teagues & Sterrits)	U, Au	152 U	8,360	Various prospectors mostly 1954
Palette	U, Au	124 U	6,820	United Uranium 1955
Scinto 5	U	22	1,210	United Uranium 1954
Scinto 6	U	3	165	United Uranium 1954
Koolpin Creek	U	3	165	prospector 1954
Skull	U	3	165	prospector 1954
Sleisbeck	U	3	165	Nth Aust. Uranium Corp. 1954
George Ck	U	1 mine production plus	55	BMR 1954
Adelaide River	U	45 'probable reserves'	2,475	prospector Lennox 1954
Fleus de Lys	U	0.15	8.25	prospector McDonald 195
Nabarlek	U	9,550*	525,250	Queensland Mines 196
Caramal	U	unpublished		Queensland Mines 197
Ranger 1	U	100,700*	5,538,500	Geopeko

Deposit	Mineral(s)	Tonnes metal (U. as U_3O_8)	Value today's prices $000's	Discoverer/year
Jabiluka 1 & 2	U, Au	(8 Au* (207,400 U*	11,407,000	Pancontinental
Koongarra	U	15,920*	875,600	Noranda (Aust)
Green Ant Ck	Mn	540 tonnes ore	16.2	
Jessops/Billy Can	Sn	100	836.7	prospector Jessop 1957
Mavis	Sn	2	16.7	1958
Minglo	Pb, Ag			1954
Osman	Sn			United Uranium 1958
Mt Bundey	Fe	600,000	9,600	BMR 1956
Frances Ck	Fe	3,300,000	52,800	BMR 1954
		TOTAL	18,833.7	MILLION DOLLARS

(ALLIGATOR RIVERS URANIUM FIELD COMPONENT
18,346.4 MILLION DOLLARS)

TABLE 2. Cost of BMR program in Pine Creek Geosyncline, 1973/4 to 1975/6
(at prices current at the end of each period)

	1973/4	1974/5	1975/6
Ground geophysics	$68 800	$91 100	$60 700
Airborne geophysics	$11 700	$59 300	$76 350
Geological mapping	$130 900	$162 300	$173 400
Drilling	$68 300	$104 000	$58 600
	$279 700	$416 700	$369 100
Overheads (20%) (admin, general stores, leave, etc.)	$55 900	$83 300	$73 800
	$335 600	$500 000	$442 900

Exploration activity began immediately following the assessment of White's find, in October 1949, and continued in the area until 1970 when the Rum Jungle plant ceased operation, and recommendations for further exploratory work by previous workers had been completed with negative results. Bursts of exploration activity in other areas followed discoveries made during regional mapping, and spanned the years 1953 to 1960 (South Alligator Valley, George Creek, and Adelaide River uranium; Namoona lead; Mount Bundey iron); and 1962 to 1963 (phosphate at Rum Jungle and South Alligator Valley); and also 1965-1968 (Woodcutters lead-zinc-silver discovered during systematic search for uranium east of Rum Jungle).

Regional studies began in 1953, and were the single most labour-intensive part of the Bureau's work in the area (fifteen geologists in 1955). Map production, field checking, and report writing continued to 1965, when the summary Bulletin on the work was completed (Walpole and others, 1968). Following the discovery of the Alligator Rivers Field, the main emphasis has been on regional studies, which have been carried out in conjunction with a variety of specialist research programs, unlike the projects of the 1950s and 1960s which (apart from the regional mapping) were generally narrow in scope and short in duration.

Dissemination of information is the final aspect of the Bureau's work. Information produced has taken the form of commodity reviews pertinent to minerals contained in the Katherine-Darwin region (the latest being uranium-Ingram, 1974), review papers on regional geology, progress and end-of-survey reports (generally unpublished), summary and conceptual papers, and geological and geophysical maps. The prospectors' guide to uranium exploration, which proved so valuable in the early days, appeared in three editions between 1948 and 1957. Its usefulness is hinted at in Ross Annabell's account of the early 'uranium fever' years (Annabell, 1971).

The professional manpower commitment towards all Pine Creek Geosyncline activity (excluding supervisory and other staff with no field input) is shown in Figure 5. The manpower bulge in the 1950s reflects not only the high degree of activity in several fields of work, but also the labour-intensive nature of early airborne surveys (seven geophysicists were involved in the 1952 survey in contrast to only two in recent surveys) and the great degree of effort to complete the regional mapping program quickly - a massive task considering the remoteness of the area and poor geological knowledge (guides were required to locate some of the 'main' tracks away

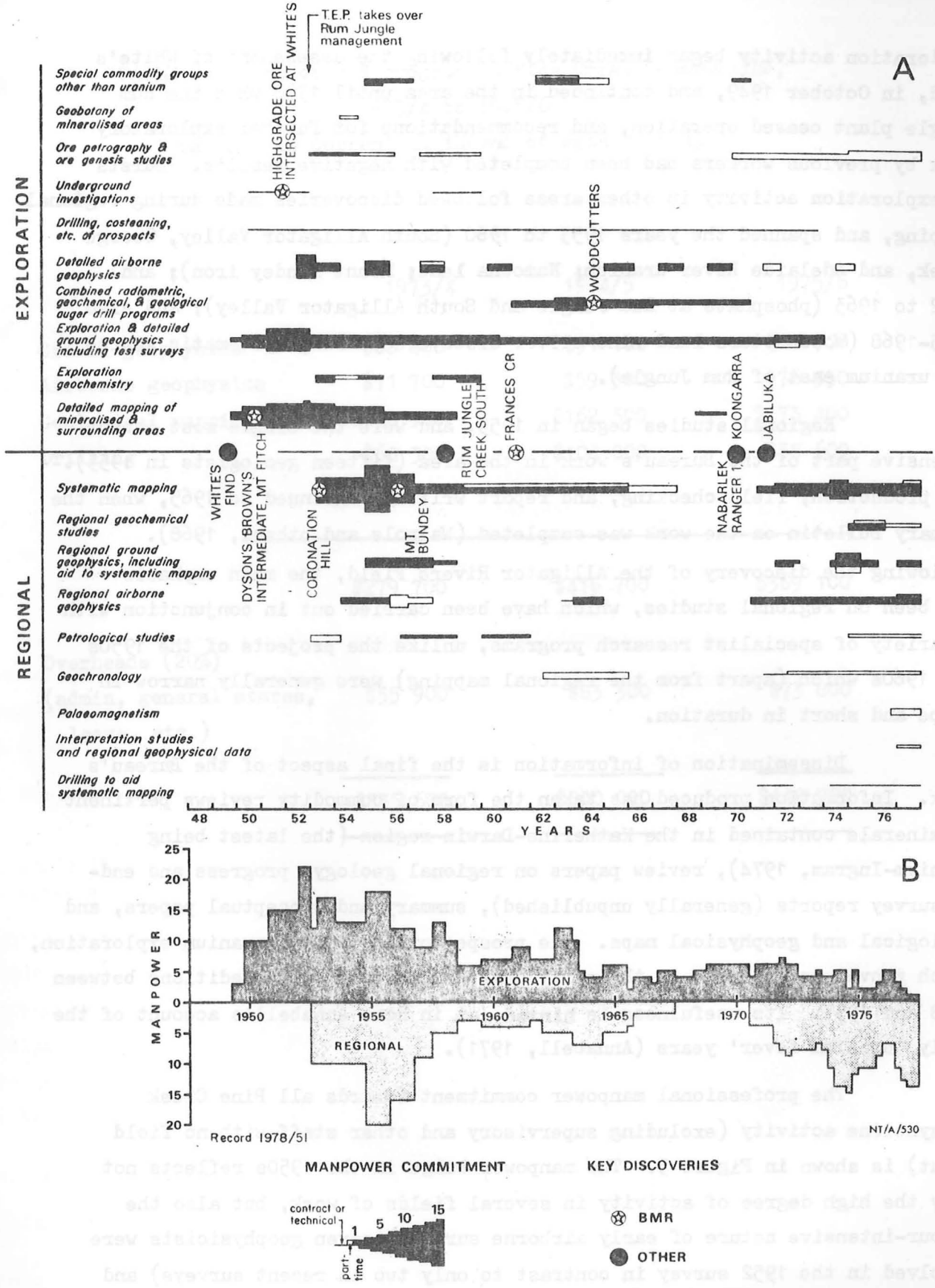


Fig 5 BMR COMMITMENT IN THE PINE CREEK GEOSYNCLINE, 1948-77 METHODOLOGY & MANPOWER

from the Stuart Highway as late as 1953). The histogram in Figure 5 highlights the emphasis away from exploration towards regional and related studies since 1970. Improved technology has resulted in fewer people being involved in many of the fields of work, and indeed some continuing studies, such as geochronology, involve only one professional person on a part-time basis. Therefore, for less manpower commitment, a wider range of studies is currently being undertaken than by larger numbers of people in earlier periods.

There is a group of activities which cannot be expressed in terms of manpower commitment, as they are not programmed or recorded as individual projects, but are a part of continuing services; these include the development of techniques and field testing of equipment manned partly by professional and partly be technical staff. Examples are developmental work in airborne and other geophysical surveys, introduction of systematic shallow drilling when suitable equipment became available, maintenance and repair of geophysical equipment for individuals and organisations, advice in all respects to prospectors, and perfection of field mapping techniques (from oblique photography in the 1940s to vertical colour photography in the 1970s).

At times, up to 20% of all BMR professional staff were involved in fieldwork in the Pine Creek Geosyncline (1955), reflecting the great strategic importance placed upon uranium by the government at that time. Currently, manning runs at about 6% of professional staff, and compares with similar commitments in other 'semi-detailed' projects in the Mount Isa Block, the Georgetown Inlier, and Central Australia.

Philosophy

Before examining the philosophy behind the Bureau's involvement in the Pine Creek Geosyncline, the influences exerted by political and economic pressures, changing concepts of ore controls, and advances in exploration technology must be considered.

Political and economic influences

The overriding politico-economic pressures which were present during much of the 1948-1970 period gave little room for conceptual programming by BMR, only one of several government agencies and interests active in the area at the time.

Pressures were both national and international, and are discussed at length by Raggatt (1968). The Mineral Resources Survey (later the BMR) was formed in 1942, following recommendations made to the government

of the day by the Mining Industry Advisory Panel set up to investigate the depressed state of the Australian mining industry. At the same time tax reform recommendations were accepted, and were extended in later years. Following the request of the UK Government, the Australian Federal and State Governments began searching for uranium in 1944; before 1949 the search was centred on the Mount Painter and Radium Hill deposits in South Australia. In 1947 the Federal Government sought the cooperation of the State Governments in intensifying uranium search, and in the following year private searchers were stimulated by the offer of direct rewards for uranium discovery. The pressure for uranium was on, being applied primarily by the Federal Government on behalf of the UK Government, so it was only natural that the recently-formed BMR would have a large part to play.

There being no other suitable government agent, the role of explorer fell to BMR in the early years of Rum Jungle. During this period it was free to direct all aspects of its work from programming to investigation of prospects. Following the establishment of the AAEC in 1953, the BMR's initiatives were confined to areas outside the Hundred of Goyder, where programming was largely dictated by the desires of AAEC and TEP.

The strategic and political importance of uranium influenced much of the work in the Pine Creek Geosyncline until the mid 1950s, when demand for the metal declined. The end of this period of influence is marked by a trend back to programs to stimulate interest in certain other areas and commodities by reinvestigation of known mineral fields (especially tin and gold, in the West Arm-Mount Finnis and Maranboy Tinfields, and in the Union Reefs Goldfield, between 1955 and 1964). Subsequent work has been influenced largely by the need for more precise scientific information on known mineralisation, and although some of these recent studies were instigated purely on this basis (e.g., ore genesis investigations at Woodcutters, Mount Bonnie, etc., and remapping of the Rum Jungle district), most were prompted by the tremendous economic importance of the uranium discoveries of the Alligator Rivers region, where the geology was less known than in any other part of the geosyncline.

Concepts of ore control

Proximity to granite margins is an age-old exploration guide to hydrothermal deposits. The first-discovered uranium prospects at Rum Jungle were thus thought to be hydrothermal in origin, and attention was focussed on areas close to the granite. Later, when detailed investigations showed that the granite was older than the sediments, and the association of metals

with the contact between graphitic rocks and carbonate rocks was conceptualised, emphasis shifted to tracing and exploration of this type of contact in the sedimentary succession around the granite - the systematic auger drill programs were essential tools for this work. Apparently BMR work took greater account of this association than did similar work by TEP, and eventually led to the discovery of Woodcutters.

The uranium/copper association evident at Rum Jungle, and noted by BMR, influenced the direction of exploration in other areas, and led to the discovery of the South Alligator Uranium Field. Later, a uranium/carbon association became evident in this area, and was one of the main factors considered in concepts of ore genesis by BMR (Condon & Walpole, 1955) although it did little to affect the philosophical approach of the rush of geiger-clutching prospectors that followed. The philosophy that led to the interest in the Alligator Rivers area was one of geological similarity with the Rum Jungle district as portrayed on the 1:500 000-scale BMR map of the Katherine-Darwin area.

Development of exploration technology

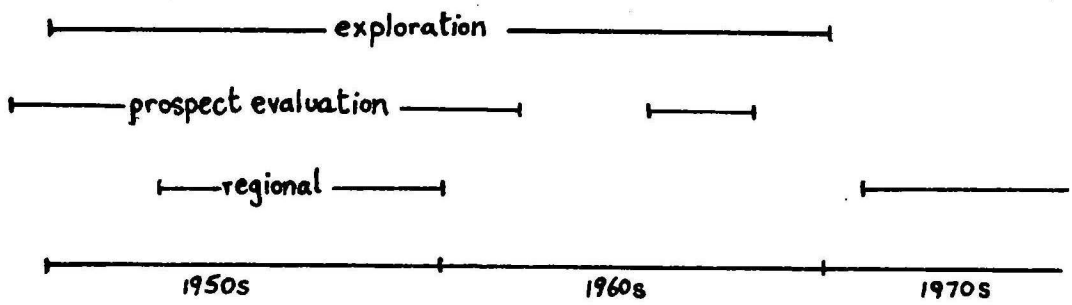
Exploration technique has varied according to the available technology of the day. Where surface indications were rare and in places absent, even to the eyes of the experienced geologist, the geiger counter was the invaluable prospector's tool of the 1950s. Airborne scintillometer surveys have out-dated much of the old-style ground work in uranium search, and are the primary tool in all present - day exploration. But now it appears that all the easily detected orebodies have been found, and this is resulting in a profound change in exploration philosophy. Factors emerging in current studies in the Alligator Rivers Uranium Field suggest that stratigraphic, alteration, and structural controls apparent in the location of known orebodies will greatly influence the style of future search programs. Several techniques to detect hidden uranium deposits, mostly involving the detection of radon gas, are being tested, and if found successful can be expected to figure **prominently in future exploration.**

BMR's philosophy

In 1946 BMR was set up to help revitalise the Australian mining industry, and was stated to have three main functions: systematic geological mapping of Australia and an assessment of its mineral resources and potential; basic geophysical surveys of Australia, and development and use of methods of geophysical prospecting; and gathering and publishing

statistics and other information about the mineral industry (Raggatt, 1968). In recent years the Bureau's work in the Pine Creek Geosyncline has conformed to these guidelines, but earlier work was subject to politico-economic pressures which made it impossible to conform to these basic objectives.

This change has resulted in an overall development from an earlier competitive and support role to one of 'grass roots' work and fundamental studies in the fields of regional geology and geophysics, geochemistry, geochronology, etc, and can be summarised thus:



Even though the regional program of the 1950s was relatively shortlived, its labour-intensive nature reveals the importance placed upon establishing a sound geological framework, and reflects a change in the Bureau's overall program away from assessment of known resources and mineralised areas which had been its main role until the early 1950s. Because of the depth of its involvement in exploration at Rum Jungle, however, the drive towards exploration during the regional mapping was strong, and served to influence the direction of that program, and prolong prospect assessment studies. This strong exploration drive was lost in about 1955 (P. R. Dunn, pers. comm.).

The Bureau's work spearheaded all exploration work up to the late 1960s. Since then, large national and international companies have been active, and able to afford the extensive airborne scintillometer surveys which were beyond the reach of earlier individuals and small companies. These surveys started the exploration boom of the early 1970s, and proved the economic worth of the Alligator Rivers region. Companies have given less attention to regional geological mapping as an exploration tool, and BMR has taken up this avenue as its principal support role, coordinated with wide-ranging airborne scintillometer and magnetometer surveys (1-mile spacing compared to $\frac{1}{4}$-mile spacing of the company surveys), which now cover the entire geosyncline, and with other fundamental framework studies

including geochronology, magnetostratography, regional geochemistry and regional geophysical interpretation.

Assessment of BMR work

BMR's contribution has ranged from providing basic geological and geophysical frameworks, to testing and development of novel geophysical and geological techniques, most of which today are accepted methodology, to advice to prospectors and maintenance of their equipment, and to the discovery of several orebodies.

Because of this multifarious involvement it is an unrealistic exercise to calculate the 'cost effectiveness' of the Bureau's work. The Bureau can be credited with the discvoery of Dysons, Mount Bundey, Coronation Hill, and other deposits, but its contribution to the discovery of White's, El Sherana, Ranger 1, and Nabarlek, for example, would be impossible to assess. Nor is it possible to calculate the actual cost of its program from 1949 to the present, as detailed costing has been introduced only in recent years. However, expenditure on the Pine Creek Geosyncline work over the last three years averages about $425,000 per annum, and a total cost of the entire BMR program since 1949 could be something like $15 million at current values. Bearing in mind that there have been few instances of work duplication between BMR and companies over the years, it is reasonable to regard this as a necessary contribution to effective exploration.

This expenditure is 5% of the value (at today's prices) of those deposits discovered by BMR (see Table 1), and 0.07% of the total value of all mineral discoveries since 1949 - and it is not unreasonable to suggest that BMR contributed to the discovery of each to some extent.

The 1950s regional mapping has been the most valuable contribution, and the method of work resulted in many Bureau and other discoveries. The present mapping program is of value in current exploration thinking (exploration at the moment is at a virtual standstill in the Alligator Rivers Uranium Field; applications for ELs are not being processed pending decisions on government philosophy towards exploration in proposed National Park areas) and may well prove fundamental in future exploration philosophy. The programmed remapping of the entire geosyncline would appear warranted in view of the proven economic value of the region as a uranium province of world significance.

The current remapping is modifying the earlier concept of extensively interfingering sedimentary units; this concept has, if anything, served to complicate a relatively simple stratigraphic order, and thus hamper stratigraphy-orientated exploration. The complex picture that emerged could well have resulted from a confusing interaction of the ideas of such a large number of workers, a high turnover rate in experience (most of the 1954 mapping staff were new recruits), and concentrated effort over a short period (most of the fieldwork was completed in three seasons); furthermore, the work was done under the guidance of one supervising geologist who was largely responsible for the eventual synthesis of all the data. This situation appears undesirable in future programs.

In retrospect it is hard not to criticise the Bureau for not following up its own recommendations to explore in the Alligator Rivers area for uranium, either as an extension of the South Alligator airborne survey by Livingstone (1958) in 1957, or when the future demand for uranium became apparent in the late 1960s. Although no written record of the past philosophical attitude of the Bureau is available, it is easy to assume that the law of probabilities established for the geosyncline by 1957 was one of small deposits, and thus it would have appeared prohibitively expensive to extend an airborne survey from the South Alligator Valley to the East Alligator River for what seemed to be such a small potential reward. Further, it has never been BMR's function to gamble at exploration. Rather, exploratory work has been generally directed to areas of **known mineralisation.** However, regional investigations to follow up the inference of uranium potential in the Alligator Rivers region made in the summary Bulletin would appear to have been warranted.

The production of the 1:500 000-scale geological map of the Katherine-Darwin area was timely in that it provided a synthesis of one of Australia's few uraniferous areas just as interest was reviving in that metal. The importance of this map has been alluded to already but the criticism must be made that the map appeared ten years after the main period of field mapping ended. A similar time lag with no coincident drop in exploration interest for uranium in the interim may have resulted in companies needing to do their own regional mapping. Notwithstanding, base-metal exploration for Woodcutters-type mineralisation would have benefited by earlier publication of the Bulletin and map.

A point not often remembered is that the Rum Jungle discovery

was the first significant find in northern Australia since Mount Isa in 1923, and did much to stimulate private company search in the remoter northern parts of our country, which had been regarded a 'poor prospect' (Raggatt, 1968). The continuing presence of BMR in the Pine Creek Geosyncline has done much to stimulate interest in the area, both by the discovery of deposits and the provision of basic data on which exploration targets of companies have been largely based. Flexibility in the Bureau's role over the years has been a highly desirable feature, but it appears unlikely that the Bureau's present philosophy of regional and fundamental studies will alter in the future, given the large budgets available to the present explorers allowing comprehensive geophysical and geological exploration activities once carried out in the geosyncline largely by the Bureau.

REFERENCES

Annabell, R., 1971 - THE URANIUM HUNTERS. Rigby, Adelaide.

Bureau of Mineral Resources, 1948 - Radioactive mineral deposits, Notes for Guidance of Prospectors in Australia. Pamphlet No. 3.

Condon, M.A. & Walpole, B.P., 1955 - Sedimentary environment as a control of uranium mineralization in the Katherine-Darwin region, Northern Territory Bureau of Mineral Resources Australia, Report 24.

Dodson, R.G., & Shatwell, D.O., 1965 - Geochemical and radiometric surveys, Rum Jungle, NT, 1964. Bureau of Mineral Resources Australia, Record 1965/254 (unpublished).

Eupene, G.S., Fee, P.H., & Colville, R.G., 1976 - Ranger 1 uranium deposits. In Economic Geology of Australia and Papua-New Guinea, Vol. 1: Metals, Australasian Institute of Mining and Metallurgy, Melbourne.

Ingram, J.A., 1974 - Uranium deposits. Bureau of Mineral Resources. Australia, Mineral Resources Report 6.

Kalix, Z., 1960 - The Australian Mineral Industry, Annual Review. Bureau of Mineral Resources, Australia.

Kalix, Z., 1964 - The Australian Mineral Industry, Annual Review. Bureau of Mineral Resources, Australia.

Livingstone, D.F., 1958 - Airborne radiometric survey of the South Alligator River region, Northern Territory. Bureau of Mineral Resources, Australia, 1958/70 (unpublished).

Noakes, L.C., 1949 - A geological reconnaissance of the Katherine-Darwin region, Northern Territory. Bureau of Mineral Resources, Australia, Bulletin 16.

Raggatt, H.G., 1968 - MOUNTAINS OF ORE Lansdowne Press, Melbourne.

Rowntree, J.C., & Mosher, D.V., 1976 - Jabiluka uranium deposits. In Economic Geology of Australia and Papua-New Guinea, Vol. 1 Metals, Australasian Institute of Mining and Metallurgy, Melbourne.

Townley, K.A., 1950 - Report on the Rum Jungle Uranium deposits. Bureau of Mineral Resources, Australia, Record 1950/23 (unpublished).

Walpole, B.P., Crohn, P.W., Dunn, P.R., & Randal, M.A., 1968 - Geology of the Katherine-Darwin Region, Northern Territory Bureau of Mineral Resources Australia, Bulletin 82.