The mineral potential of the Arunta Block, central Australia

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The Arunta Block is the mass of Precambrian basement rocks in the southern part of the Northern Territory of Australia. It comprises an early Proterozoic (or older) discontinuous sequence of sedimentary and volcanic rocks that were multiply deformed and initially metamorphosed 1800-1700 m.y. ago, and numerous granite masses that intruded the metamorphic rocks from 1700 to 1000 m.y. The metavolcanic rocks are concentrated in the lower part of the sequence, and the sedimentary rocks become more mature and better differentiated towards the top of the sequence. One carbonatite and a mantle-derived intrusion of kimberlitic affinity are located near a major crustal lineament in the east of the Block.

Mineral occurrences as presently known are small and in general uneconomic; only one small mine was operating in 1976. The occurrences can be grouped into the following types: 1—Stratabound: copper-lead-zinc in metasediments in the lower and middle parts of the sequence; 2—Pegmatitic: mainly copper, tin, tungsten, and tantalum derived from granite, and mica in pegmatites formed by partial melting of metasediments; 3—Metasomatic: tungsten, molybdenum, and minor copper in calc-silicate rocks adjacent to granite; 4—Hydrothermal: gold in a zone of late Palaeozoic deformation and retrogressive metamorphism, and fluorite-barite veins in zones of late Palaeozoic warping; 5—Magmatic: very minor copper, nickel, and chromium, in mafic and ultramafic rocks; and 6—Weathering: manganese and uranium in superficial Phanerozoic rocks. The mineral occurrences are areally distributed in two zones which are directly related to the distribution of major rock-types in the Block. The stratabound occurrences in the lower part of the sequence, magmatic occurrences, mica pegmatites, and hydrothermal gold deposits are located in the southern part of the Block; the stratabound occurrences in the middle part of the sequence, metal-bearing pegmatites, metasomatic occurrences, and hydrothermal fluorite-barite veins are located in the north. In terms of future prospects, stratabound base-metal lodes in the lower part of the sequence, metasomatic tungsten, and superficial uranium are the most likely candidates for economic success. Diamonds, rare earth elements, and niobium, as yet undiscovered, are possibilities along or near the major lineament in the east of the Block.

The Arunta Block shows marked geological resemblances to The Granites-Tanami, Tennant Creek, and Willyama Blocks in Australia, and to the Precambrian rocks of the Baltic and East African regions. All these regions are economically mineralized to some degree, and this, together with its own mineralization, suggests that the Arunta Block holds some potential for economic deposits. How much is a matter for further exploration and assessment.

Introduction

The Arunta Block is the extensive region of igneous and metamorphic rocks in the southern part of the Northern Territory of Australia, between Barrow Creek in the north and Alice Springs in the south (Figure 1). This report is a review of available data on mineral occurrences of potentially economic value in the Arunta Block, apart from water resources, construction materials, and fuels, which are not considered. With the exception of the study by Warren (1974, 1975) on the Oonagalabi base-metal occurrence, there has been no detailed work on any mineral of economic interest in the Arunta Block. Accordingly, this report presents a synthesis of the presently available data in unpublished company reports, and in the reports of the Aerial Geological and Geophysical Survey of North Australia, the Bureau of Mineral Resources (BMR), and the Geological Survey of the Northern Territory (GSNT). This report also includes a summary of the geology of the Arunta Block (Shaw *et al.*, in prep., Stewart *et al.*, in prep.) and a review generalized from published literature on the geology of some other regions similar to the Arunta Block. Where the data warrant it, we have speculated on the origin and control of some of the mineral occurrences; such speculations are offered only as possible working hypotheses.

There are no major economic deposits yet known in the Arunta Block; tonnages of identified resources are shown in Table 1, but to date all are subeconomic. The total known tonnages of identified base-metal resources are about 330 000 t (tonnes) of copper (about two years' output from Mount Isa), 370 000 t of lead, and 7000 t of zinc. At the time of writing (October, 1976), only one small mine—Molyhil (tungsten and molybdenum)—is producing ore from the Arunta Block. A lone gouger is working at the Arltunga Goldfield. Three other ventures—Jervois and Home of Bullion (both copper) and Jericho (tungsten)—are under 'care and maintenance'. Until recently the Yuendumu Mining Company, operated by aboriginals, produced copper ore from one lode in the Mount Hardy field, but the operation is no longer economic. The Company is now quarrying road aggregate and facing stone from the Vaughan Springs Quartzite at the base of the Ngalia Basin sequence, 3 km south of Yuendumu. Uranium has recently been discovered in sedimentary rocks adjoining and overlying the Arunta Block, and is being evaluated. Sales of mineral specimens, gems, and ornamental rocks are an important part of the tourist trade in Alice Springs.

Geology

The Arunta Block measures about 1000 km east-west and 400 km north-south, and is basement to several basins of shallow-marine sediments of Late Proterozoic to Palaeozoic age (Figure 1). The Block is geologically very complex, because of its history of multiple deformation, episodic metamorphism, and widespread granitic intrusion, but essentially it consists of early Proterozoic or older sedimentary and volcanic rocks which were complexly deformed, metamorphosed, and intruded by granite during the mid-Proterozoic (Carpentarian). Later events include an episode of migmatization in the southern part of the Block during the late Proterozoic (Adelaidean), and widespread thrust-faulting and associated retrogressive metamorphism in the late Palaeozoic. For simplicity of presentation, the

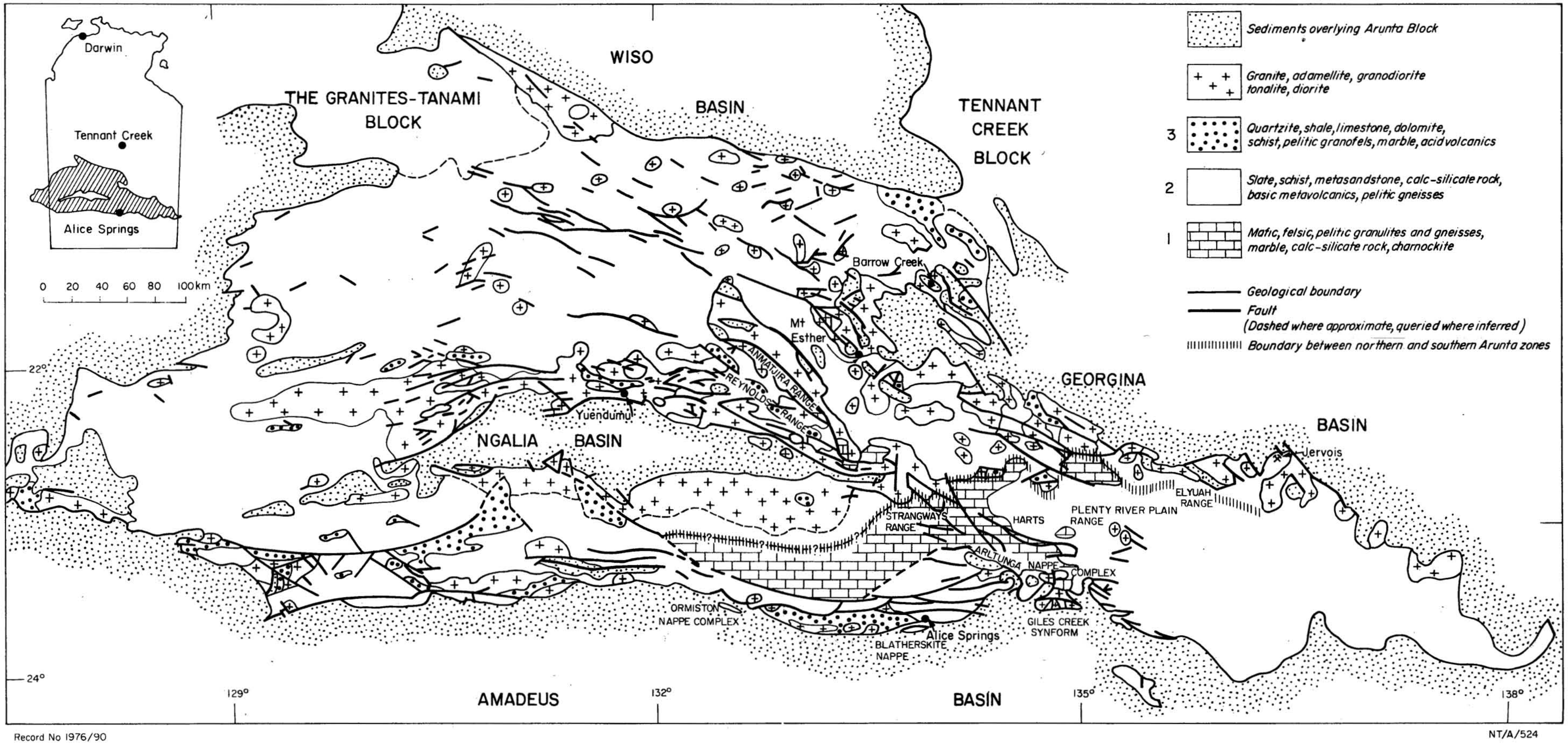

Figure 1. Generalized geological map of Arunta Block, showing major stratigraphic subdivisions and granite. Compiled from geological mapping, airphoto interpretation, and aeromagnetic interpretation by BMR, 1956-1976. Inset map shows location of Arunta Block in Southern part of Northern Territory.

Status	Tonnes of ore (x10³)	Grade of ore (%)	Tonnes of metal	Mine*	Reference**
Copper					
Measured	1753	0.3—4.1	5 260—71 870	J	A
Measured	3085	3.07	94 710	J	B
Measured	3.05	12—24	370—730	H	C
			100 340—167 310		
Indicated	635	3.07	19 500	J	B
Indicated	ca 30	6	ca 1 800	H	C
			ca 21 300		
Inferred	420	2.56—3.42	11 000—14 400	J	B
Inferred	4 170	3.1	129 270	J	B
Inferred	12.2	15	1 830	H	C
Inferred	30.5	4	1 220	H	C
			143 320—146 720		
Total identified copper resources = 264 960—335 330 tonnes of metal					
Lead					
Measured	3.05	2—3	60—90	H	C
Indicated	ca 30	2	ca 600	H	C
Inferred	30.5	2—3	610—920	H	C
Inferred	12.2	Not stated	Unknown	H	C
Inferred	3350	8—11	286 000—368 500	J	D
Total identified lead resources = 287 270—370 110 tonnes of metal					
Zinc					
Measured	12	5.7	680	J	E
Measured	3.05	1	30	H	C
			710		
Indicated	204	?2	?4080	J	E
Indicated	3.05	5—10	150—300	H	C
			4230—4380		
Inferred	87	2	1740	J	E
Total identified zinc resources = 6680—6830 tonnes of metal					
Bismuth					
Inferred	3350	0.054—0.073	1800—2400	J	D
Gold					
?Inferred	7.4	0.00023	0.017	W	F
Silver					
Inferred	3350	0.0052—0.033	170—1100	J	D

Table 1. Known tonnages of identified subeconomic resources of base and noble metals in some deposits in Arunta Block.

*** J—Jervois; H—Home of Bullion; W—White Range**

**** A—Sydney Stock Exchange, 1973; B—Goldner *et al.*, 1974; C—Sullivan, 1953; D—Elliott, 1974; E—Holmes, 1972; F—Hossfeld, 1937a.**

metamorphic rocks are grouped into three divisions (Figures 1 and 2). The rocks assigned to each division are tentatively regarded as chronological or stratigraphic correlatives.

The first division (Figure 2) consists essentially of granulites of mafic, felsic, and pelitic compositions; the first two types include chemical equivalents of basic and acid volcanics (Shaw *et al.*, in prep.). In the Harts and Strangways Ranges, the granulites are succeeded by metapelitic and cordierite-rich gneisses, marble, and calc-silicate rock of the amphibolite facies. These rocks are separated from the granulites by a major stratigraphic break.

The second division consists of greenschist facies slate, schist, and metasandstone (including Lander Rock Beds and Mount Stafford Beds; Shaw & Stewart, 1975), calc-silicate rock, and associated intermediate and basic flows or sills. In the Harts Range, these rocks pass into amphibolite-facies equivalents (including Irindina Gneiss and Harts Range Group of Joklik, 1955), and to granulite-facies equivalents in the Reynolds Range. As a whole, the metasediments of the second division show a higher degree of sedimentary maturity than those of the first, and there is a smaller proportion of meta-igneous rock. The two divisions are everywhere in discordant contact, but whether the discordance is a metamorphosed fault or a metamorphosed unconformity has not yet been determined.

The third division lies with angular unconformity on the second, and shows an even greater degree of sedimentary maturity; it consists of weakly metamorphosed sedimentary rocks, including orthoquartzite with a basal conglomerate, shale, lenses of limestone and dolomite, and sills and a lopolith of granitic porphyry. It is almost everywhere at greenschist facies, but in the eastern part of the Arunta Block, both the second and third divisions are generally at amphibolite grade. In the Reynolds Range, in the northwest of the Block, the second and third divisions can be traced southeastwards from low-greenschist metasediments through a retrograde zone to granulite-facies rocks.

Large elongate syntectonic granite batholiths and smaller equant post-tectonic plutons intrude the three metamorphic divisions. Granitic rocks are uncommon in the southeastern part of the Block; a few small syntectonic intrusions are present, and a diorite-tonalite-granite complex with associated ultramafic hypabyssal intrusions has also been recognized (Shaw *et al.*, in prep.). Smaller plutons unrelated to the granites include a late Proterozoic basic intrusive complex (the Mordor Complex) with ultramafic differentiates of kimberlitic affinity, and a carbonatite (the Mud Tank Carbonatite) of similar age. Dolerite dykes and plugs cut all the units except some post-tectonic plutons; some dolerites are progressively metamorphosed to granulite-facies assemblages, some are retrogressively metamorphosed to greenschist facies, and still others are unmetamorphosed.

The Arunta Block is cut by numerous major faults which trend mainly west-northwest in the east of the Block, and west-southwest in the west, forming an arc convex to the north (Figure 1). Also prominent in the east is a major gravity lineament—the Woolanga Lineament—which trends north-northwest for 300 km (Anfiloff & Shaw, 1973). Many major faults coincide with or diverge from this Lineament, and the Mordor Igneous Complex and Mud Tank Carbonite are located near it (Figure 1).

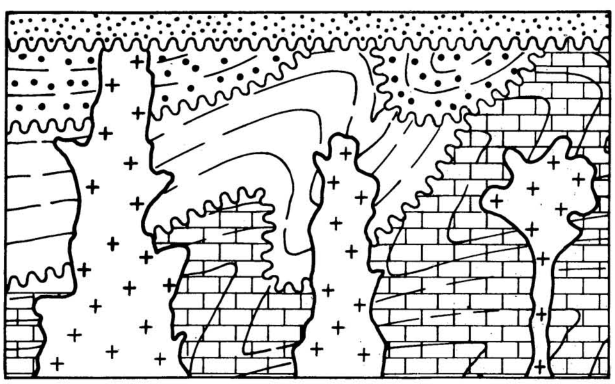

Figure 2. Schematic diagram of relationships between major stratigraphic divisions of Arunta Block; reference as for Figure 1.

Shortly after the episode of migmatization in the south of the Arunta Block, Late Proterozoic shallow-marine sediments were laid down near and over much of the Block.

Deposition began with the Heavitree Quartzite of the Amadeus Basin to the south of the Block (Wells *et al.*, 1970), and its correlative the Vaughan Springs Quartzite of the Ngalia Basin, which overlies the central part of the Block. The Heavitree Quartzite was conformably succeeded by dolomite, limestone, shale, and evaporites of the Late Proterozoic Bitter Springs Formation, and this was followed by tilloid, shale, red-beds, orthoquartzite, carbonates, and evaporites during the remainder of the Proterozoic and early Palaeozoic. Deposition in the Amadeus Basin finished with molasse conglomerate and sandstone of the Devonian Pertnjara Group. The sequence in the Ngalia Basin is in general sandier and thinner than that in the Amadeus Basin (Wells *et al.*, 1972).

The northern margins of both Basins became the site of major overthrust faulting during the Late Devonian and/or Early Carboniferous Alice Springs Orogeny. At Arltunga, in the southeast of the Arunta Block (Figure 1), several nappes—the Arltunga Nappe Complex—comprising cores of Arunta basement rock and envelopes of Heavitree Quartzite and Bitter Springs Formation were transported southwards for some tens of kilometres, mainly by low-angle thrust-faulting and sliding; ductile deformation took place under conditions of increased metamorphic grade in the root zone of the nappes (Stewart, 1971a; Shaw *et al.*, 1971; Stewart *et al.*, 1976). Other thrust nappes formed in the Ormiston and Alice Springs areas (Figure 1—Marjoribanks, 1975; Stewart, 1967). Along the northern margin of the Ngalia Basin, the late Palaeozoic movements took place along north-dipping thrust-faults (Wells *et al.*, 1972).

A program of isotopic dating of rocks of the Arunta Block began in 1972. Preliminary results (Black, 1975) suggest two widespread episodes of regional metamorphism throughout the Block; the first, of granulite grade, at about 1800 m.y., and the second, generally of amphibolite grade but reaching granulite in the centre, at about 1700 m.y. Woodford *et al.* (1975) have recognized a third episode, also of granulite grade, at about 1400 m.y. in the Strangways Range. Most granites date at about 1700 m.y., but intermittent granitic intrusion continued to about 1000 m.y. The Mordor Complex is dated at 1210 m.y. (Langworthy &

No	Name	Lat (S) Deg. min.	Long (E) Deg. min.	Element(s)	Type*	Notes
1	Jervois	22 40	136 16	Cu, Pb, Zn	Str	Estimated production 500-1000 t Cu, Bi, W associated.
2a	Bonya	22 44	136 03	Cu	Peg	Estimated production 50-100 t Cu.
2b	Jericho	22 42	136 06	W	Met	Production several tonnes W.
2c	Samarkand	22 44	136 04	W	Met	
2d	Marrakesh	22 41	136 05	W	Met	
2e	Tashkent	22 41	136 09	W	Met	Stockpiled ore being milled at Molyhil (3) (1976).
2f	City of Medina	22 41	136 06	W	Met	
2g	White Violet	22 44	136 05	W	Met	
3	Molyhil	22 44	135 45	W, Mo	Met	Operating (1976). Grade estimated from production figures 0.6% W.
4	Jinka district	22 43	135 47	F, Ba	Hyd	Estimated resources 370 000 t ore at 39.6% CaF_2 (Gourlay, 1974)
5	Perenti	22 31	135 02	Cu	Hyd	
6	Delmore Downs	22 30	134 53	W	Peg	
7	Delny	22 34	134 53	W	Peg	
8	Bundey River	22 25	134 48	Ta, Bi	Peg	Bismuthinite assays 0.005% U, greisen 0.022% U (Daly & Dyson, 1963).
9	Utopia	22 12	134 26	Ta, Bi	Peg	Weakly radioactive.
10	Home of Bullion	22 31	134 10	Cu, Pb, Zn	Hyd	Production ca 1000 t Cu. Galena contains Ag.
11	Home of Bullion district	21 30	134 04	Cu	?	No details known.
12	Barrow Creek district	21 28	133 47	Sn, Ta, W	Peg	Several small occurrences.
13	Anningie	21 41	133 06	Sn, Ta	Peg	Production ca 27 t concentrate. Greisen assays 0.024% U_3O_8 (Daly & Dyson, 1963).
14	Mount Peake	21 31	133 05	Pb	Peg	Quartz vein in amphibolite. Galena assays 279 g/t Ag.
15	Waldron's Hill	20 45	132 29	Au	Hyd	Quartz-carbonate in metadolerite and hornfels; assays 5g/t Au (Anon., 1941).
16a	Reward	22 11	132 49	Cu, Pb, Zn	Str	Estimated production 8 t Cu. Max. assays: 0.016% Cu, 0.03% Zn (Anon., 1967).
16b	—	22 13	132 47	Cu, Pb, Zn	Str	Max. assays 0.009% Cu over 1.5 m, 0.046% Pb and 0.072% Zn over 0.6 m (Anon., 1967).
17	Mount Allan	22 13	132 10	Sn	Peg	Estimated production 1 t Sn. Ta associated.
18	Aileron	22 39	133 17	Au	Hyd	Quartz veins in retrograde schist. Production 0.03 kg Au.
19	Mount Boothby	22 37	133 20	W	Peg	Production 0.4 t W.
20	Brookes Soak	22 07	132 10	W	Peg	Position approximate. Production ca 0.5 t concentrate.
21	Coniston	22 07	132 34	Sn	Peg	Greisen in albite-quartz rock.
22a	Mount Stafford	22 02	132 34	Sn	Peg	
22b	Mount Stafford	22 03	132 36	Sn	Peg	
23	Double Dams	22 07	132 16	Ta	Peg	
24	Double Dams	22 07	132 13	W	Peg	Production 0.05 t W.
25	Patty Well/Stuart Bluff +	22 47	132 51	Fe	Hyd	Hematite-quartz veins in granite and Vaughan Springs Qtzt. F. assoc.
26	Pine Hill	22 11	132 47	Au, Cu	Hyd	Quartz vein in schist. Assays: 6.14 g/t Au, 4.91 g/t Au.
27	Ingellina Gap	22 09	132 49	W	Peg	No details known: position approximate.
28	Barney's +	22 19	132 46	Fe	?	Earthy limonite lenses in schist.
29	Woodforde River +	22 33	133 06	Fe	?	Limonite lens in marble. Assays 0.0375% Zn.
30	White Hill Yard	22 29	133 07	Cu	Hyd	One grab sample assayed 5% Cu.
31	Lander	22 09	132 48	Cu	Hyd	Estimated production 10 t Cu.
32	Wolfram Hill	22 03	131 19	W	Peg	Production 90 t wolframite.
33	Mount Hardy district	22 07	131 33	Cu	Peg	Estimated resources 12 200 t ore at 3-4% Cu, 56 g/t Ag (Grainger, 1968).
34	Rock Hill	22 11	131 46	Cu	Peg	Estimated production 5 t Cu.
35	Jubilee Silver King	22 07	131 11	Cu, Pb	Peg	Bi associated. Assays: 11-14% Cu, 16-55% Pb, 140-1490 g/t Ag.
36	Vaughan Springs	22 11	131 19	F, Ba	Hyd	Cu, Pb associated.
37	Clark	22 02	131 01	Cu	Peg	Estimated production 10 t Cu.
38	Buger Creek	22 07	130 40	Cu	Hyd	
39	Djagamara +	22 12	131 17	Fe	Str	Banded iron formation.
40	Patmungala	22 13	131 12	Cu	Hyd	Estimated production 1 t Cu.
41	Wilson's Find	21 59	130 41	W	Peg	Production 2 t concentrate. Also called Mt Singleton Wolfram Mine.
42	Tom Braun's	23 05	133 52	Cu	Mag	
43	Mueller Creek	23 01	134 04	Cu	Mag	
44	Copper Queen	23 09	134 40	Cu	Met	
45	Selin's	23 05	134 42	Cu	Mag	
46	Virginia	23 04	134 40	Cu	Mag	
47	Arthur Pope's	24 05	135 27	Cu	Mag	
48	The Pinnacles	23 09	134 14	Cu	Met	Estimated production 20 t Cu. Au, Ag, Bi associated.

No	Name	Lat (S) Deg. min.	Long (E) Deg. min.	Element(s)	Type*	Notes
49	Sliding Rock	23 19	134 12	Cu	Str	
50	Turner's	23 19	134 13	Cu	Mag	Au associated.
51	Paddy's Jump-Up	23 32	134 37	Cu	Mag	
52	Gecko	23 18	134 09	Cu, Pb, Zn	Str	Ag associated.
53	Rankin's	23 17	134 07	Cu, Pb, Zn	Str	Assays 4-16% Cu.
54a	Glen Helen	23 26	132 15	Cu	Peg	
54b	Glen Helen	23 27	132 17	Cu	Peg	
55	Stokes Yard	23 27	132 06	Cu, Pb, Zn	Peg	Ag associated. Assays on core: 0.85% Cu, 0.08% Pb, 0.22% Zn.
56	Oonagalabi	23 07	134 52	Cu, Pb, Zn	Str	Assays: 1% Cu and 1.6% Zn over 40 m.
57	Johnnie's Reward	23 08	134 13	Cu, Pb, Zn	Str	
58	Edwards Creek	23 01	134 01	Cu, Pb, Zn	Str	Assays at surface: up to 3.6% Cu, 4.7% Pb, 4.5% Zn.
59	Harry Bore	23 12	133 56	Cu, Pb, Zn	Str	Assays: Cu and Pb very low, up to 9.5% Zn (surface and core).
60	Red Rock	23 03	133 46	Cu, Pb, Zn	Str	Assays of core: 0.25% Cu, 0.69% Pb, 1.62% Zn over 16.5 m.
61	Woolanga Bore	23 07	134 13	Pb	Str	Galena in forsterite marble.
62	Johannsen's Mine	23 14	134 05	Cu, Pb, Zn	Str	Production 3.57 t phlogopite. Core assays up to 3.3% Zn.
63	Winnecke goldfield	23 19	134 17	Au	Hyd	Production 37.5 kg Au recorded, 375 kg estimated.
64	Glankroil	23 18	134 21	Pb	Peg	Estimated production 10 t Pb, 50-100 kg Ag. Galena assays 5000 g/t Ag.
65	White Range	23 28	134 46	Au	Hyd	Production 363 kg Au. Cu associated.
66a	Wheal Fortune	23 25	134 48	Au	Hyd	
66b	Wheal Mundi	23 24	134 47	Au	Hyd	Production 10.8 kg Au.
67a	Wipe Out	23 24	134 45	Au	Hyd	Production ca 6 kg Au.
67b	Jenkins	23 23	134 45	Au	Hyd	
68	—	23 24	134 44	Au	Hyd	Minor workings west of Wipe Out. Pyrite absent.
69	Round Hill	23 25	134 45	Au	Hyd	
70	Claraville	23 25	134 43	Au	Hyd	Production 0.7 kg Au.
71	Arltunga	23 26	134 42	Pb	Peg	Ag and Bi associated.
72	Hale River +	23 26	135 01	Cu	?	Au associated.
73	Tommys Gap	23 37	134 38	Cu	?Peg	Production ca 1 t Cu, 0.3 kg Ag (Shaw, 1967). Hydrothermal?
74a	Inkamulla Dome	23 05	135 12	Mo	?Met	No details known.
74b	Inkamulla Dome +	23 03	135 09	W	?Met	In calc-silicate rock; no details known.
75+	—	22 29	131 01	Fe	Wea	Ironstone capping on marble.
76+	—	23 02	133 47	Cu	?	
77+	—	23 03	134 24	Cu	?	
78+	—	23 04	134 26	Cu	?	
79	Arltunga goldfield	23 27	134 39	Au	Hyd	Production 2 kg Au recorded, much more estimated.
80	Yarraman	22 39	135 58	Cu	Mag	
81	King's Legend	22 47	136 06	Cu	Mag	Estimated production 5-10 t Cu.
82	Ivy	21 24	133 57	Sn	Peg	
83	Watt Range	21 26	133 55	W	Peg	Bi associated.
84	Neutral Junction	21 31	133 58	W	Peg	
85	Haasts Bluff	23 26	131 57	Cu	Mag	
86	—	22 33	134 57	Cr	Mag	Talc schist; assays up to 0.6% Cr.
87	Xanten	22 41	136 04	Cu	Mag	Estimated production 5-10 t Cu.
88	—	22 13	132 44	Mn	Wea	Laterite. Cu, Pb, Zn also present.
89	Mordor Complex	23 27	134 27	Cu, Ni, Cr, U, Th	Mag	Ultramafite assays 0.3% Cr. Albitite assays 2.88% U, 0.98% Th (Kostlin, 1971).
90	—	23 12	134 13	Diamond	Mag	One diamond (0.0002 carat = 0.00004 g) in stream sediment.

Table 2: List of mineral occurrences in Arunta Block

* Str = stratabound, Peg = pegmatitic, Met = metasomatic, Hyd = hydrothermal, Mag = magmatic, Wea = weathering.
+ Not mentioned in text; described in Warren *et al.* (1974).

Black, in prep.), and dating of the Mud Tank Carbonatite is in progress. The late Proterozoic migmatization in the southern part of the Block has been dated at 1076 m.y. (Marjoribanks & Black, 1974), and this date sets an older time limit for the beginning of subsequent deposition in the Amadeus Basin. The retrogressive metamorphism that accompanied the late Palaeozoic Alice Springs Orogeny has been dated at 342 and 319 m.y. (Carboniferous) at Arltunga (Armstrong & Stewart, 1975). The Alice Springs Orogeny was also accompanied by local melting and pegmatite emplacement in the eastern part of the Harts Range (Black, *op. cit.*).

Mineral occurrences

Introduction

The Arunta Block has produced mainly copper, gold, tin, and tungsten, small amounts of other metals, and mica, in total worth about $10 million (total production at early 1976 prices). Mineral occurrences in the Block, together with their locations, elements present, genetic type in the classification of Lindgren (1933) as modified by Park & MacDiarmid (1964), and notes on production, etc., are listed in Table 2. The mineral occurrences are plotted in Figure 3, and have been assigned to the following genetic categories: 1—stratabound (and/or stratiform), 2—pegmatitic, 3—metasomatic, 4—hydrothermal, 5—magmatic, 6—weathering.

Stratabound (Figure 3-1)

These are base-metal occurrences containing copper, lead, zinc, and in some cases small amounts of bismuth, gold, and silver. The content of zinc equals or exceeds that of copper. They can be grouped into two types—the Jervois type and the Oonagalabi type.

The **Jervois type** (1, 16a-b)* are located in the northern part of the Arunta Block (henceforth referred to as the northern zone) in dominantly pelitic metasediments of Division 2. The Jervois lodes themselves (1) are the largest in the Arunta Block, and contain copper, lead, zinc, silver, and minor bismuth; tungsten is present in the hanging wall

***Number in parenthesis refer to locations of occurrences in Figure 3 and entries in Table 2.**

above the base-metal lodes (Watson, 1975). The lodes are lenticular (Holmes, 1972), and lie along a synform in metapelitic and calc-silicate rocks. Fluorite and scheelite occur in a small intrusive plug in the axial zone of the synform. Metamorphic facies of the country rocks is high greenschist or low amphibolite (Robertson, 1959; Morgan, 1959). Ore grades are listed in Table 1. Watson (1975) suggested a two-stage process for the genesis of the Jervois lodes: syngenetic deposition of sulphides in reef carbonates (or in sabkha carbonate ooze—Warren, 1974), followed by migration of the base metals in brine along faults to the lode positions.

The Reward prospect (16a) is a small subsurface group of three steeply dipping weakly mineralized zones in sericite schist, biotite-sericite schist and sericite quartzite of Division 2 (Anon., 1967). The sulphides present are pyrite, chalcopyrite, and sphalerite. At the surface, the prospect is marked by a hydrothermal quartzose lode containing pyrite, chalcopyrite, galena, and their oxidation products in a sericitic shear zone (Warren *et al.*, 1974).

Weakly mineralized carbonaceous schistose meta-siltstone (16b) is present in the subsurface 5 km southwest of the Reward prospect. Intermittent films and fractures in the rock are filled with pyrite, chalcopyrite, and sphalerite over a width of about 36 m. The longitudinal extents of both subsurface prospects are not known. They are currently (October 1976) under investigation by GSNT.

The **Oonagalabi type** occurrences (56, 57, 58, 59, 60, 61, 62; probably also 49, 52, 53) are all located in the southern part of the Block (henceforth, the southern zone) in rocks of Division 1. They are characterized by a distinctive lithological assemblage of three adjoining rock-types, all of them mineralized. They are: (i) forsterite marble, accompanied by calcium minerals such as diopside; (ii) gneisses containing abundant magnesium and aluminium, and characterized by anthophyllite, cummingtonite-gedrite, Mg-Al spinel, enstatite, and sapphirine; and (iii) quartz-magnetite rock, which occurs everywhere except at Oonagalabi itself (Warren *et al.*, 1974; 1975). A fourth rock-type, para-amphibolite, is also present in the mineralized zone in some occurrences. The mineralized rocks lie at the stratigraphic break (possible unconformity) between the two subdivisions of Division 1 of the Arunta Block. Primary economic minerals present in the occurrences are chalcopyrite, sphalerite, and galena (generally confined to the marble).

Fine to coarse-grained phlogopite is a characteristic constituent of the mineralized rocks of the Oonagalabi type, and at Johannsen's Phlogopite Mine (62) this mineral occurs as very coarse books in cordierite-feldspar gneiss and forsterite marble. The phlogopite was mined during World War II.

Small amounts of native gold occur with the sulphides at Oonagalabi (Warren *et al.*, 1975) and Johannsen's Phlogopite Mine (Stillwell, 1943).

The origin of the Oonagalabi type of deposits is not known. They resemble the Orijärvi and Lampinsaari deposits of Finland, and these are both regarded as having been formed by metasomatism, namely, of felsic and aluminous granulites and marble by igneous solutions at Orijärvi (Eskola, 1914; 1950), and of dolomite and basic volcanics by igneous or syngenetic (connate) solutions at Lampinsaari (Kahma, 1973). However, the stratabound nature of the Oonagalabi occurrences and the absence of igneous rocks in their vicinity suggests a sedimentary origin, possibly as a marine sequence of shale overlain by bituminous (and metalliferous) evaporitic dolomite and chert, the whole subsequently metamorphosed. Warren (1974) suggested a syngenetic origin by weathering of pre-existing rock together with simultaneous precipitation of base-metals from groundwater in the weathering profile. Weathering of a mixed terrain of silicate and carbonate rocks by nearly stagnant groundwater of neutral to slightly alkaline pH and reducing Eh could produce an assemblage of magnesium and aluminium clay minerals such as montmorillonite, palygorskite, and possibly also kaolinite and magnesite (Lukashev, 1958 translated 1970, p. 155; Deer, Howie & Zussman, 1962, p. 241) whereas potassium, most of the sodium, calcium, iron, and silicon would be taken into solution. Evaporation of the groundwater would precipitate the calcium, iron, and silicon as calcrete and a ferruginous silica pan above the water-table, whereas the soluble alkalies would remain in solution and eventually be removed by groundwater flow. In this way, the three contrasting rock-types characteristic of the Oonagalabi deposits could be formed. The conditions for such a weathering profile to develop would need to be: a fairly average overall rainfall to decompose the rocks, a low floral content in the soil to prevent the groundwater from being too acid, a landscape of low relief and poor drainage to hinder removal of cations produced by decomposition of the rocks (except alkalies), and to allow formation of clays, and seasonality of the rainfall to allow evaporation of the groundwater and deposition of calcium, iron, and silicon. Such conditions would not have been dissimilar from those that prevailed during mid-Tertiary time in inland Australia, where long-continued weathering of an old landsurface approaching a peneplain produced vast tracts of calcrete, silcrete, and laterite over a kaolinitic leached zone. The main difference would have been the paucity of plant life during the early Proterozoic, resulting in nearly neutral groundwater that enabled Mg-clay to precipitate, as well as kaolinite.

Pegmatitic (Figure 3-2)

Minerals of economic interest are present in granitic pegmatite or quartz veins—mostly in the northern zone—where they contain copper, lead, tin, tantalum, tungsten, bismuth, uranium, and lithium. In the southern zone, the pegmatites contain beryllium, uranium, thorium, rare earth elements, and mica. Many of the pegmatites have been mined by small syndicates in the past, but none is currently being worked.

Copper occurrences (2a, 33, 34, 35, 37, 54, 55, 73) are generally near granite in metapelitic schist or phyllite of Division 2. The country rocks, however, also include calc-silicate rock, granitic gneiss, amphibolite, and basic metavolcanics. The lodes are small, and consist of assemblages of chalcopyrite, pyrite, and galena—and their corresponding secondary and oxidized equivalents—in pegmatite or quartz veins which are commonly slightly discordant to the foliation of the country rock. The absence of mica in the veins indicates that they are not metamorphic segregations from the micaceous country rock schist or gneiss. The common occurrence of granite near the pegmatite and quartz vein coppers suggest that the veins and the copper in them originated from the granites.

Lead (14, 35, 55, 64, 71) occurs as galena in small quartz or pegmatite veins in both the northern and southern zones of the Arunta Block. The veins are emplaced in a variety of country rocks, including biotite gneiss, felsic schist, sericite schist, granitic gneiss, amphibolite, and calc-silicate rock. The galena in all the deposits is argentiferous. At Jubilee Silver King, the galena is largely replaced by chalcocite, and what remained of the galena has altered to anglesite and a small amount of native silver (CSIRO, 1957).

The tin prospects in the Arunta Block are situated in the northern zone (Figure 3), and consist of cassiterite in pegmatite and greisen. Six small prospects (12, 13, 17, 21, 22, 82) are known; all lie in an east-northeast-trending zone of small faults of various orientations which crosses the west-northwest trend of the major faults in the Arunta Block (Figure 1). The tin-bearing pegmatites intrude metapelitic schist of Division 2, and in all cases granite crops out a few kilometres nearby. Calc-silicate rock and quartzite accompany the schist at the Mount Allan Tin Mine (17); the tin-bearing pegmatite at this locality is heavily kaolinized.

Tantalum (8, 9, 12, 13, 23) is found only in the northern zone, and occurs as tantalite in pegmatites intruded into metapelitic schist and gneiss of Division 2. Some of the tantalum occurs with tin in the tin zone that extends from Yuendumu to Barrow Creek, but it also forms small concentrations away from this zone, and in these it is accompanied by bismuth. The tantalite is commonly weakly radioactive (8, 9, 13) (Daly & Dyson, 1963).

Tungsten (7, 12, 19, 20, 24, 27, 32, 41, 83, 84) generally occurs as wolframite in pegmatitic segregations or quartz veins in the border zones of granites in the northern zone of the Arunta Block; some are known in granite well away from its margins. At all these occurrences the wolframite-bearing granite is surrounded by metapelitic schist and sandstone of Division 2. The occurrence at Delmore Downs (6) consists of wolframite disseminated in metapelitic gneiss near granite. The wolframite-bearing granites themselves include representatives of both the earlier syntectonic batholiths and the later porphyritic plutons.

Small quantities of bismuth minerals are known in some pegmatites in the northern zone (8, 9, 35, 83), where they accompany tantalum, copper, lead, and tungsten. A small amount of bismuthinite occurs with galena and pyrite in vein quartz (71) in the southern zone.

The lithium minerals elbaite, spodumene, and lepidolite occur in pegmatite a few kilometres east of the Anningie tin field (13) (Pontifex, 1965). Beryl is present in several pegmatites in the Harts Range (Joklik, 1955).

Grains of a uraniferous silicate are present in radioactive gossan (36) on strike with a quartz vein that cuts granite 55 km west of Yuendumu (Warren *et al.*, 1974; Ivanac & Spark, 1976). Uranium, thorium, and rare earth elements are present in monazite, samarskite, and betafite in several pegmatites in the Harts Range (Joklik, *op. cit.*). Biotite gneiss of Division 1 north of the Plenty River Plain contains up to 0.016 percent Th (Mannoni *et al.*, 1971).

Muscovite was mined from 1888 to 1961 from numerous pegmatites in the Harts Range and Plenty River Plain (Figure 3) (Joklik, 1955). A total of 1660 t was produced (Gourlay, 1965). The mica-rich pegmatites fill cross-cutting fractures in mica-rich metapelitic gneisses of the middle-amphibolite metamorphic facies. The gneisses form the outer part of a large dome of metamorphic rocks—the Harts Range Group—and are assigned to Division 2. The inner part of the dome consists of non or poorly micaceous felsic gneisses, and pegmatites cutting these rocks are poor in mica (Joklik, *op. cit.*). Hence the pegmatites are regarded as partial melts originating in the nearby country rocks. The best muscovite came from zoned pegmatites containing oligoclase. The last mines could not compete with imported mica, and were abandoned in 1961 when the Commonwealth Mica Pool ceased operation.

Metasomatic (Figure 3-3)

Metasomatic tungsten occurrences (1, 2b-g, 3) are in general larger than those of the pegmatite type described above. One—Molyhil (3)—is currently being worked (1976), but it has not been drilled and reserves are unknown. The tungsten occurs as scheelite in layers in calc-silicate rock of Division 2. Bowen *et al.* (1972) found that the scheelite in the Bonya Mineral District (2b-g, immediately east of the Jinka Granite) is generally restricted to within 400 m of granitic pegmatites that cut the calc-silicate rocks, and Molyhil is situated in a roof pendant of calc-silicate rock in the west of the Jinka Granite. It seems that the tungsten has been metasomatically introduced from this granite, and when we recall that the pegmatitic tungsten lodes all occur in or near granites that are surrounded by schist and sandstone—but not by calc-silicate rock, it appears that the calc-silicates have acted as a sink for tungsten that became concentrated in the late magmatic fraction of the granite. Where the tungsten-bearing granites were surrounded by non-calcareous schist and sandstone, the tungsten remained in the residual part of the magma, and crystallized as wolframite.

Molybdenite occurs with the scheelite at Molyhil (3), and is being stockpiled in mill tailings. Molybdenite (74a) occurs in felsic gneiss in the eastern part of the Harts Range (Warren *et al.*, 1974), but details of the occurrence are not known.

The two copper occurrences classed as metasomatic consist of copper sulphides in calc-silicate rock (44) or in quartz veins in calc-silicate marble (48) of Division 1 in the southern zone (Shaw, 1970; Warren *et al.*, 1974). Both deposits have been worked by small syndicates, but are now abandoned.

Hydrothermal (Figure 3-4)

Gold produced in the Arunta Block came from the White Range goldfield (65) in the eastern part of the southern zone; smaller amounts came from the nearby Arltunga goldfield (79), from the Wheal Fortune (66a) and adjacent mines north of the White Range, and from the Winnecke goldfield (63) 40 km west of White Range.

The White Range, Arltunga, and Winnecke goldfields are situated in the central and western parts of the Arltunga Nappe Complex. At White Range, the lodes were quartz-pyrite-chalcopyrite bodies that filled tension joints and fissures in the metamorphosed Heavitree Quartzite; the gold was contained in the pyrite, or in limonite near the surface, where oxidation had taken place (Hossfeld, 1937a). At Winnecke the gold was mined from similar oxidized quartz-pyrite veins in Heavitree Quartzite and schist of the Bitter Springs Formation, but chalcopyrite was generally absent (Hossfeld, 1940). The nature of the gold lodes west of Arltunga is not known with certainty; veins observed during geological mapping of the area by BMR in 1971 are similar to those in the Winnecke goldfield. The auriferous lodes in the Arunta basement rocks north of the White Range (66a-b, 67a-b, 68, 69, 70) were generally quartz-pyrite veins, but some also carried abundant calcite and/or siderite, and some were composed of quartz and calcite without pyrite (Hossfeld, 1937b).

The time of formation of the auriferous lodes in the metamorphosed Heavitree Quartzite is indirectly dated at 322 m.y. (Carboniferous) on muscovite of sample 206 in Stewart (1971b), which comes from one of many quartz 'blows' that fill irregular fissures in the metamorphosed Heavitree Quartzite of the White Range-Arltunga area. Warren *et al.* (1974) suggested that the gold in the White Range lodes may have been introduced by mobilization during Devonian-Carboniferous time of older lodes in the adjoining Arunta basement rocks to the north. However, the basement rocks of the Arunta Block north of White Range are known to have undergone substantial retrogressive metamorphism during the Carboniferous (Stewart, 1971a, 1971b; Shaw *et al.*, 1971; Armstrong & Stewart, 1975)—calcic plagioclase altered to epidote, white mica (muscovite and paragonite) and calcite, hornblende altered to epidote and calcite, biotite altered to chlorite, and quartz

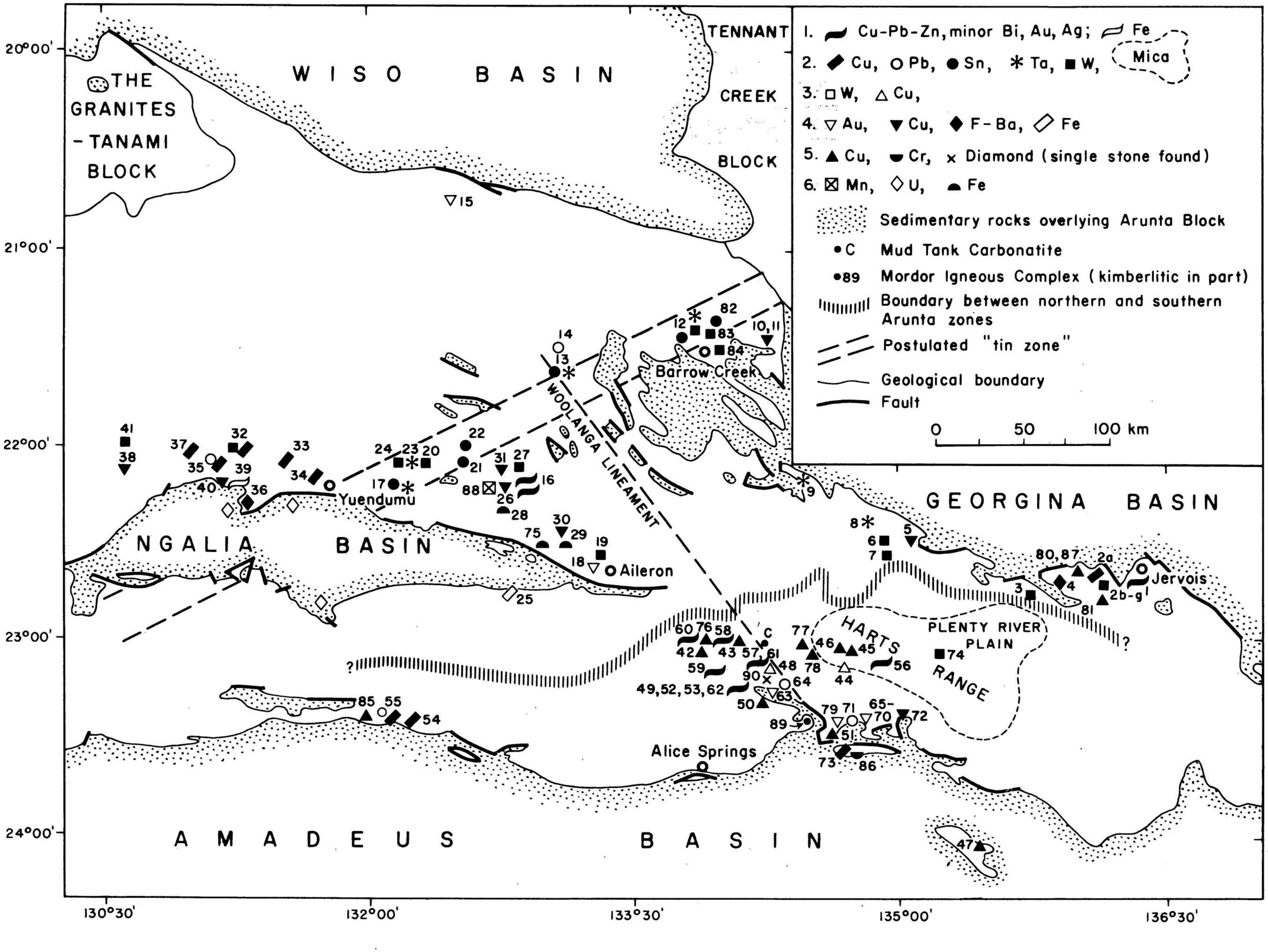

Figure 3. Distribution of mineral occurrences in Arunta Block; categories 1 to 6 explained in text. Orientation of elongate metallogenic symbols has no structural significance.

was extensively recrystallized. Hence, we now believe that the abundance of carbonates in the auriferous lodes in the Arunta basement rocks north of White Range indicates that these lodes are hydrothermal concentrations, in fissures, of silica and carbonate that were mobilized during the retrogressive metamorphism, and hence are also of Devonian to Carboniferous age. The origin of the lodes by retrogressive metamorphism is also supported by the existence of several veins of pyrite epidosite (pyrite-epidote-quartz rock) noted during mapping of the region by BMR in 1968.

Gold (15, 18, 26) also occurs in the northern zone in fault zones which cut a variety of rocks, including metapelitic schist and gneiss, metasandstone, metadolerite, hornfels, and granite.

Seven hydrothermal copper occurrences (5, 10, 16a, 30, 31, 38, 40) are located in fault or shear zones generally in metapelitic schist of Division 2; at White Hill Yard (30) the metapelitic country rocks are at high amphibolite or low granulite facies. All the occurrences are in the northern zone. Copper minerals present include chalcopyrite, bornite, pyrite, galena, and chalcocite, and are commonly accompanied by vein quartz or quartz stringers. At Home of Bullion (10), sphalerite is a major constituent and the lodes occupy parallel shear zones (Hossfeld, 1937c; Sullivan, 1953) which are one half of a complementary set of shear planes symmetrically disposed about the axial planes of the macroscopic folds in the area. Presumably the lodes formed by mobilization and deposition of ore shortly after folding. Both in metal content and nature of surrounding country rocks the Home of Bullion lodes resemble the stratabound lodes of the Jervois type described above, and so may be derived from such an orebody at depth.

Fluorite and smaller amounts of barite are major constituents of certain hydrothermal veins which cut some of the granites in the northern zone. The largest veins—in the Jinka mineral district (4)—cut the Jinka Granite east and west of the Elyuah Range in the east of the Arunta Block (Figure 1), and consist of quartz-fluorite-barite and minor hematite, malachite, azurite, and galena. Hill (1972) regarded the veins as telethermal to epithermal. Some of the Jinka veins also cut the lowest unit of the Proterozoic sequence in the Elyuah Range (Hill, *op. cit.*), and so are considerably younger than the Jinka Granite. The mineralogically similar Vaughan Springs fluorite prospect (36) cuts granite 55 km west of Yuendumu, and is on strike with a fault in the lower part of the nearby late Proterozoic sequence of the Ngalia Basin. The prospect is currently (October 1976) being assessed by GSNT. Small quartz-fluorite veins (not plotted in Figure 3) cut granite in the Anmatjira Range (Stewart *et al.*, in prep.) and porphyritic granite immediately south of Mount Esther (Offe, in prep.).

Magmatic (Figure 3-5)

Numerous small occurrences (42, 43, 45, 46, 47, 50, 51, 80, 81, 85, 87) of copper sulphides or their oxidized equivalents are disseminated in lenses or layers or concentrated in shears or joints in metamorphosed basic rock. All but two (81, 87) are in the southern Arunta zone, and few have been mined. They are probably small concentrations localized during initial crystallization of the rock, or during later recrystallization and deformation. Traces of copper and nickel sulphides are present in monzonite and melamonzonite of the Mordor Igneous Complex (89) (Kostlin, 1971), and are currently (1976) being investigated by GSNT (Barraclough, 1975). The Mordor Complex also contains uranium and thorium silicates (including brannerite and uranophane) in various plagioclase-rich rock-types (Kostlin, *op. cit.*). Chromium occurs in ultramafic differentiates of the Mordor Complex (Langworthy & Black, in prep.), and in two small exposures of talc schist (86) at the western end of the Giles Creek Synform (Shaw *et al.*, in prep.). The schist forms part of a unit of basic metavolcanics, and is considered to be metamorphosed ultramafic igneous rock.

Weathering (Figure 3-6)

Manganiferous laterite has formed on carbonate rocks at a number of localities in the Arunta Block, particularly in the northwest, where laterite (88) on limestone and dolomite of Division 3 contains up to 58 percent Mn (Stewart *et al.*, in prep.).

Uraninite and carnotite occur in several areas in Devonian and Carboniferous lacustrine sandstones of the Ngalia Basin (Ivanac & Spark, 1976) and Amadeus Basin, and in Quaternary calcrete overlying or flanking the Arunta Block. The discoveries are currently (1976) being prospected and evaluated. A BMR survey of part of the northwestern Arunta Block in 1958 found that the granites in this area are notably radioactive (Carter, 1960), and prospecting of some of these granites has shown that in places they have up to 10 times the average uranium content for granite, and in faults and shear zones up to 150 times the average for granite (Davies, 1973; Paltridge, 1973). An airborne survey over the Alcoota 1:250 000 Sheet area (north of the Harts and Strangways Ranges—Figure 1) detected anomalous uranium radiation from two areas of granite (Wyatt, 1974). These data, and the occurrence of uranium in pegmatites at several localities in the Arunta Block (described above), indicate that the Arunta rocks are the likely source of much of the uranium in the over-lying sediments.

Gemstones and mineral specimens

Coarsely crystalline mineral specimens are obtained from the pegmatites and metamorphic rocks of the Harts Range, and faceted gemstones of zircon, garnet, cordierite, and smoky quartz have been cut from material from the Mud Tank Carbonatite, the Harts Range, and elsewhere. A single small diamond (90) was found 10 km southwest of the Woolanga Lineament (Figure 3) in 1973 (Stracke, 1974).

Comparisons with other areas

Shaw & Stewart (1975) have drawn attention to the marked lithological similarities of the Arunta Block to its two tectonic neighbours, The Granites-Tanami Block (Blake & Hodgson, 1975; Blake *et al.*, in prep.) and the Tennant Creek Block (Crohn, 1975; Le Messurier, 1976; Mendum & Tonkin, in prep.). In both these regions there is a lower pelitic sequence (Tanami complex and Warramunga Group, respectively) of siltstone, shale, micaceous quartz sandstone, greywacke, and minor basic volcanic rocks, all metamorphosed to lower greenschist facies, which correlate with Division 2 of the Arunta Block. These rocks are unconformably overlain by cleaner sedimentary rocks (Pargee Sandstone and Hatches Creek Group respectively) comprising quartzite, sandstone, conglomerate, and acid volcanics, correlated with Division 3. The sequences in both regions are intruded by granites dated at between 1800 and 1700 m.y. (Page *et al.*, 1976; Riley, 1968; Crohn, *op. cit.*). Hematite quartzite, garnet-mica gneiss, grunerite-garnet gneiss, and plagioclase gneiss intruded by acid to basic igneous rocks 30 km west-southwest of Tennant Creek may be basement to the Warramunga Group (Mendum & Tonkin, *op. cit.*; Crohn, *op. cit.*), and hence may be correlated with Division 1 of the Arunta Block. An equivalent of Division 1 is not known in The Granites-Tanami Block. The Warramunga Group at

Tennant Creek is host to high-grade gold deposits in conformable lenticular ironstone bodies, and to copper-gold-bismuth lodes in steeply plunging ironstone bodies in the cores of zoned pipes of hydrothermally altered and metasomatized metapelite (Le Messurier, 1976; Large, 1975). Quartz veins in metapelitic rocks of the Tanami complex were worked for gold from 1900 to 1960.

The Arunta Block also shows similarities to the Willyama Block, around Broken Hill. The succession in the Willyama Block comprises phyllite, slate, metapelitic schist and gneiss, calc-silicate rock, banded iron formation, quartz-feldspar gneiss, feldspathic gneiss, and amphibolite, formed by the metamorphism of siltstone, shale, sandstone, impure dolomite, and basic sills (Thomson, 1975). The assemblage resembles Division 2 of the Arunta Block, and, as in the Arunta, the metamorphism and accompanying synorogenic granites are dated at 1700 m.y., followed in this area by emplacement of pegmatite at 1560 m.y. and post-orogenic granite at 1520 m.y. (Thomson, *op. cit.*). The sequence at Broken Hill itself—the Mine Sequence—is interpreted as a conformable assemblage of basic and acid volcanics, shale, and quartzite metamorphosed to high amphibolite-low granulite facies (Johnson & Klingner, 1975). Several of the rock-types in the Mine Sequence, particularly the sillimanite gneiss and Potosi Gneiss, show marked resemblances to the Lander Rock Beds and Mount Stafford Beds, and the Irindina Gneiss (respectively) of the Arunta Block. The Broken Hill area is Australia's major producer of silver, lead, and zinc; the metals occur in tightly folded sulphide orebodies in the Mine Sequence, and are now generally regarded as syngenetic in origin (Johnson & Klingner, *op. cit.*).

Outside Australia, the Arunta Block is similar lithologically, stratigraphically, and temporally to parts of the Precambrian of the Baltic region (notably Sweden and Finland) and East Africa.

The oldest rocks in Sweden are gneisses of Archaean age, and these are basement to the unconformably overlying Svecofennian rocks (Magnusson, 1960). The latter is a thick sequence of basic to acid volcanics, detrital sediments, and calc-silicate rocks which were folded and metamorphosed at about 1950 m.y. (Geijer, 1963), and which are similar to those of Division 1 of the Arunta Block. Unconformably overlying the Svecofennian rocks are phyllite, greywacke, and slate of the Elvaberg Series and Upper Phyllite Series (Geijer, *op. cit.*), and these correspond lithogically to Division 2. Unconformably above these rocks are conglomerate, quartzite, slate, limestone, dolomite, and basic volcanics of the Karelian (Magnusson, *op. cit.*; Geijer, *op. cit.*), which corresponds lithologically to Division 3. The Svecofennian, Upper Phyllite Series, and Karelian rocks are all intruded by granites dated at 1850-1750 m.y. (Magnusson *et al.*, 1960), which is the same age as the early granites of the Arunta Block. The Svecofennian volcanics are host to numerous stratabound base-metal deposits, such as those in the Skellefte region (Rickard & Sweifel, 1975), which are similar to the Oonagalabi type of the Arunta Block.

Similar rocks to the Swedish sequence are present in Finland, but here the Svecofennian and Karelian are considered to be equivalents (termed Svecokarelide), because they both overlie basement of Archaean age, and proof of unconformity between the two is lacking (Simonen, 1960; Eskola, 1963; Kahma, 1973). Almost all the economic ores in Finland are in the Svecokarelide rocks, and include numerous stratiform base-metal deposits in the 'Main Sulphide Ore Belt' (Kahma, *op. cit.*), some of which are similar to the Oonagalabi type in the Arunta.

In East Africa, Archaean rocks of the Nyanza-Tanganyika Shield are unconformably overlain to the southwest by the Proterozoic Ubendian Belt of metapelite, basic metavolcanics, calcic granulite, migmatite, anorthosite, and charnockite, intruded by large synorogenic to post-orogenic granites (Pallister, 1971); the Ubendian rocks are dated at about 1800 m.y. (Pallister, *op. cit.*), and correspond lithogically in a general way to Divisions 1 and 2 of the Arunta Block. These rocks are unconformably overlain in the east by undeformed sandstone, dolomite, and basalt (the Abercorn Sandstone and Plateau Series of Zambia), and in the northeast by sediments of the Kibaran-Burundian-Karagwe-Ankolean belt, comprising metapelite and quartzite of low metamorphic grade; these sediments correspond lithologically to Division 3. The Abercorn Sandstone and Plateau Series are intruded and metamorphosed by granite dated at 1725 m.y.; the metasediments of the Kibaran-Burundian-Karagwe-Ankolean belt have yielded a single isotopic date of 1185 m.y. (Pallister, *op. cit.*), and are intruded by granites which are mined for beryllium, and are the source of alluvial tin and tungsten (Saggerson, 1962). The late Proterozoic episodes of metamorphism and granitic intrusion have their counterparts in the southern part of the Arunta Block (Marjoribanks & Black, 1974), described above in the section on Geology. The Proterozoic rocks of East Africa produce small amounts of copper, cobalt, tin, tungsten, and 15 percent of the world's beryllium (Unesco/ASGA, 1969). Carbonatites related to the East African Rift System have been worked for niobium. The major economic mineral of the region as a whole is diamond, which occurs in many kimberlite pipes of Mesozoic age in Tanzania, but in economic amount in only one, the Mwadui pipe (Edwards & Howkins, 1966), which produces 3 percent of the world's diamonds (Unesco/ASGA, *op. cit.*).

Discussion

Metallogenesis

As noted by Warren *et al.* (1974), the various types of mineral occurrences in the Arunta Block are distributed in two distinct geographic zones (Figure 3), which also differ geologically. The southern zone includes almost all the rocks of Division 1; rocks of Divisions 2 and 3 are generally metamorphosed to middle amphibolite facies; and granites are few and small. Metallogenically, the southern zone includes the stratabound base-metal occurrences of the Oonagalabi type, which are found only in rocks of Division 1; pegmatites are characterized by beryllium, uranium, thorium, rare earth elements, and abundant mica, and originated by partial melting of amphibolite-facies metasediments of Division 2; numerous magmatic occurrences of copper are located in metabasic rocks of Division 2, which are relatively more abundant in the southern zone; and hydrothermal gold lodes are restricted to the southern zone, where late Palaeozoic reactivation of the Arunta Block was most intense and penetrative. The northern zone, in contrast, is characterized by an almost total absence of rocks of Division 1; rocks of Divisions 2 and 3 are generally metamorphosed only to greenschist or low-amphibolite facies; and granites are large and numerous. Metallogenically, the northern zone includes a different type of stratabound base-metal occurrence, the Jervois type, which is found in rocks of Division 2, accompanied in a few places by compositionally similar hydrothermal derivatives (Home of Bullion, Reward); the pegmatites are characterized by the presence of copper, tin, tungsten, tantalum, and bismuth, and originated from the abundant granite masses; metasomatic deposits of tungsten are located near granite in this zone; and hydrothermal veins of fluorite and barite are present only in this zone. Occurrences formed by weathering—uranium and manganese—are found in superficial rocks of both zones. It thus appears that, in general, metal occurrence in the Arunta Block is closely related to rock-type, although other factors, such as faulting, deformation, and weathering, are also involved. These processes, following on from sedimentation and granite emplacement, allowed movement and concentration of some of the economically desirable elements.

The metallogenic history of the Arunta Block began during the accumulation of basic and acid volcanics and generally immature sediments of Division 1, when base metals were concentrated in the Oonagalabi stratabound occurrences, possibly during a time of still-stand and emergence. After more mature sediments of Divisions 2 and 3 had accumulated, folding, regional metamorphism, and partial melting led to the concentration of mica, uranium, and thorium in complex pegmatites and copper in ortho-amphibolite. Subsequent emplacement of large granite masses in the northern zone was accompanied by injection of simple pegmatites containing copper, tungsten, tantalum, and bismuth, presumably the residual elements from the granite magmas (cf. Tauson, 1974), and by metasomatism of calcareous country rocks to scheelite-bearing calc-silicate assemblages. The granites also brought with them uranium and tin, and epeirogenic movements that occurred towards the end of granite emplacement facilitated the concentration of these elements into fault zones. Further faulting led to the formation of small hydrothermal lodes of gold and copper.

The Arunta Block than became tectonically less active for about 800 m.y., although it was never quiescent in the classical sense of a stable craton, and at the end of this period downwarping initiated shallow-marine sedimentation in late Proterozoic basins around and over much of the Block. By Devonian-Carboniferous time, orogenic uplift halted marine deposition, and led to rapid erosion of the uplifted area and deposition of thick non-marine sandstone and conglomerate above the marine sequence. Eventually the erosion reached Arunta basement rocks, and allowed transport and deposition of uranium in the non-marine sediments. The late Palaeozoic orogeny culminated in thrust-faulting and folding of both basement and sedimentary cover, and the basement rocks were sufficiently heated to reset isotopic mineral dates throughout much of the Block (Black, 1975), mobilize fluorite and barite into fissures in basement and cover rocks of the northern zone, and metamorphose basement and the lowermost cover rocks to greenschist facies assemblages in the southeast of the Block, thereby mobilizing and concentrating gold into hydrothermal fissure fillings. In the Harts Range, the late Palaeozoic heating was sufficiently intense to form pegmatitic partial melts (Black, *op. cit.*). Finally, long-continued weathering and erosion during much of the Mesozoic and Cainozoic enabled further movement and concentration of uranium to take place in the late Palaeozoic non-marine sediments and in late Cainozoic superficial calcrete.

Future prospects

The mineral commodities of greatest potential value in the Arunta Block are base metals (copper, lead, and zinc), gold, and tungsten. Economic base-metal deposits of the Oonagalabi type may yet be discovered in Division 1 of the Arunta Block, and if so will probably contain small amounts of bismuth, gold, and silver as well. However, there is no evidence at present that any further occurrences will be larger than those already known. The rocks of Division 2, in which the economically paramarginal base-metal lodes at Jervois and Home of Bullion are situated, crop out across the whole northern zone of the Arunta Block, and the presence of three small prospects of the same type within 5 km of one another between the Reynolds and Anmatjira Ranges may signify the existence of further deposits there. The same rocks are also host to two other common types of copper occurrence, namely hydrothermal and pegmatitic. However, the latter are derived from granitic source rocks, and so further occurrences of this type are unlikely to be large. Basic igneous rocks are not a likely source of large magmatic copper deposits, unless a very large basic rock mass is found in which extensive segregation has taken place; the Riddoch Amphibolite in the Harts Range Group is very large, but has only a few small copper concentrations in it. Diorite and tonalite in the Giles Creek Synform in the southeast of the Block may warrant examination for low-grade copper deposits, and in fact two very small copper occurrences are known here, consisting of partly oxidized chalcopyrite in quartz and quartz-calcite veins (Shaw *et al.*, in prep.). Both veins cut metamorphosed basic volcanic rocks which are intruded by the diorite-tonalite-granite complex, but copper minerals are not known in the plutonic rocks themselves.

The easily mined gold deposits in the White Range, Arltunga, and Winnecke areas have been exhausted, and the other areas affected by Devonian-Carboniferous tectonism and metamorphism along the southern margin of the Arunta Block are not known to contain gold. Detailed investigations in these areas, namely, the eastern part of the Arltunga Nappe Complex by Khan (1972) and Shaw *et al.* (1971), and of the Ormiston Nappe Complex by Marjoribanks (1975), have shown that, in contrast to the central and western parts of the Arltunga Nappe Complex (Stewart, 1971a; Shaw *et al.*, 1971), penetrative deformation and greenschist metamorphism were restricted to the immediate vicinity of thrust faults, whereas the bulk of the rock between the faults was largely unaffected by penetrative processes. A similar situation prevails at Alice Springs itself, where movement of the Blatherskite Nappe took place along a single thrust fault (Stewart, 1967). As gold has never been discovered in these particular areas it appears that the formation of the gold deposits at White Range, Arltunga, and Winnecke was the result of the penetrative nature of the deformation and greenschist facies metamorphism in the latter areas. If this is so, it seems unlikely that gold is present in the Ormiston Nappe Complex, the Blatherskite Nappe, the eastern part of the Arltunga Nappe Complex, or in the area of extensive thrust-faulted Arunta basement and Heavitree Quartzite southeast of the Arltunga Nappe Complex (Figure 1). However, the large area of infolded Arunta basement and Heavitree Quartzite 50 km west of the Ormiston Nappe Complex has not yet been studied in detail, and if extensive penetrative deformation and low-grade metamorphism have taken place there, this area may be prospective for small gold lodes. In the other main area of Carboniferous tectonism—the northern margin of the Ngalia Basin—the movement took place along discrete thrust faults, and associated low-grade metamorphism was restricted in extent; the probability of discovering gold there is low. The area of Tertiary sediments north of the Winnecke and White Range goldfields, between the Arltunga Nappe Complex and Harts Range (Figure 1), may warrant prospecting for alluvial gold. Mapping of the biotite isograd in the large areas of greenschist facies rocks of Divisions 2 and 3 of the northern Arunta Zone may lead to additional discoveries also, as gold is localized along the biotite isograd in some other areas—e.g., the Lachlan Geosyncline of New South Wales (Warren, 1972).

After the base and noble metals, tungsten is the most likely metal to be present in significant quantity in the Arunta Block. Calc-silicate host rocks and granitic source rocks of the types known at the Molyhil mine are common throughout the northern zone of the Block, and so further economic deposits of tungsten may be present in that region. Molybdenum may also be present in any further discovery of this type.

Tin exhibits some degree of structural control, although this is only an empirical observation as yet. If the tin zone is a real tectonic lineament, other tin deposits may be located along it, but they will probably be similar in size to the presently known uneconomic occurrences. Tantalum and tungsten may be associated with any further tin occurrences.

Economic amounts of fluorite and barite may be present in veins around the margins of the Georgina and Ngalia Basins, which overlie the Arunta Block, or in veins intruding the base of the basin sequences themselves.

The entire Pertnjara Group (Devonian) of the Amadeus Basin, and its lithological counterpart in the Ngalia Basin—the Mount Eclipse Sandstone (Carboniferous)—are prospective for uranium. In addition to these formations, basins of Tertiary 'deep alluvium' in the northern Arunta zone contain up to 250 m of unconsolidated gravel, sand, clay, and coal seams (Morton, 1965; O'Sullivan, 1973; Shaw & Warren, 1975; Stewart, in press; Offe, in prep.), derived from the radioactive granites and surrounding country rocks, and so these basins may be prospective for stratiform uranium deposits.

In addition to those commodities that have been obtained from the Arunta Block in the past, other commodities may prove to be present in economic amounts. Chief among these are diamond from kimberlite, and niobium and rare earth elements from carbonatite. The proximity of the Woolanga Lineament (Figure 3) to both the Mud Tank Carbonatite and the Mordor Igneous Complex, which has chemical similarities to kimberlite, indicates the deep-seated nature of the Lineament, and suggests the possibility that true kimberlites and other carbonatites containing niobium and rare earth elements may have been emplaced elsewhere along or near the Lineament. The occurrence of a single diamond in the vicinity of the Lineament strengthens this possibility.

Conclusions

The Arunta Block, on present evidence, is a region of small uneconomic lodes of copper, lead, zinc, gold, tin, tungsten, bismuth, mica, fluorite, and a few rarer metals such as tantalum and molybdenum. In the northern part of the Block, most of the lodes, including copper, tin, tungsten, bismuth, tantalum, and molybdenum, are derived from granites, and so further occurrences are unlikely to be large. Sedimentary uranium derived from the granites is currently being evaluated, but whatever the results of the present assessments are, the predicted increase in demand (Hanrahan, 1975) will enhance the value of the occurrences in the future. In the southern part of the Block, the potentially most valuable lodes are the stratabound base-metal occurrences of the Oonagalabi type. Little exploration has been done to test the subsurface extensions of any lodes in the Arunta Block.

Geological mapping of the Arunta Block to date has shown it to be lithogically, stratigraphically, and temporally similar to a number of other Precambrian shield areas. In Australia, it closely resembles the Tennant Creek Block, which until 1975 produced 8000 t of copper, 6 t of gold, and 350 t of bismuth each year (Large, 1975), although copper production is now halted (October, 1976). The Arunta Block also resembles The Granites-Tanami Block, which produced about 550 kg of gold between 1900 and 1960 (Blake *et al.*, in prep.). The Willyama Block (Broken Hill area) is similar to the rocks of Division 2 of the Arunta Block; the Broken Hill area itself has produced 30 million t of combined silver, lead, and zinc, and a further 15 million t remain to be extracted (Johnson & Klingner, 1975). Outside Australia, the Arunta Block markedly resembles the Precambrian rocks of the Baltic region, where stratabound base metals are mined from rocks corresponding to Division 1 of the Arunta Block, and also the East African region, where tin, tungsten and beryllium are produced from granites which are geochemically similar to those in the Arunta Block. While recognizing that lithological character is only one of many factors that control the economic concentration of minerals, it does appear on present evidence that the Arunta Block holds some potential for economic deposits of these commodities. How much can be determined only by further exploration in the region.

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