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THE GEOLOGY AND GEOCHRONOLOGY OF THE ARUNTA COMPLEX NORTH OF ORMISTON GORGE, CENTRAL AUSTRALIA

by

R.W. MARJORIBANKS AND L.P. BLACK

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SUMMARY

A major west-trending lineament marked by a wide belt of dynamically metamorphosed rocks lies in the Arunta Complex, north of the Amadeus Basin. Mapping across the zone indicates that the deformation occurred before a widespread migmatization event. Migmatization and associated granite intrusion are developed widely to the south of the deformed zone where they affect an older gneiss series. Rb-Sr isochrons yield dates of 1620 ± 70 m.y. for the metamorphism of the older gneiss, and 1076 ± 50 m.y. for the migmatization event. The migmatites are unconformably overlain by the basal unit of the Amadeus Basin sequence, the Heavitree Quartzite. The 1076 ± 50 m.y. date thus provides a maximum age for commencement of sedimentation along the northern margin of the Basin.

INTRODUCTION

The Arunta Complex, first defined by Mawson & Madigan (1930), is a series of metamorphic rocks that crop out north of the Amadeus Basin and south of the Georgina and Wiso Basins. It corresponds to the Arunta Block, shown on the Tectonic Map of Australia and New Guinea (Geol. Soc. Aust., 1971), and completely surrounds the Ngalia Basin. To the east of the area investigated, K-Ar dates by Stewart (1971), and Rb-Sr isochron dates by Bennett (in Cooper, Wells & Nicholas, 1971) and Riley (1968), indicate a widespread metamorphic event in the Arunta Block at about 1700 m.y. Various younger dates within the Arunta Block were obtained by these authors and also by Hurley, Fisher, Fairbairn & Pinson (1961), and Walpole & Smith (1961). Many of these dates were interpreted by Stewart (1971) and Shaw & Stewart (1973) as indicating a resetting of the isotopic ages during a Palaeozoic event, termed the Alice Springs Orogeny.

Shaw & Stewart (1973), in a review of the regional geology of the Arunta Block, divided the Block into three rock groups based on metamorphic facies, but emphasized that the ages and stratigraphic relations between and within the groups are largely unknown. The published evidence thus indicates only that the Arunta Block has been affected by at least one major Precambrian metamorphic event.

A Rb-Sr isochron date of 1280 m.y. has been determined by Cooper et al. (1971) for the Vaughan Springs Quartzite of the Ngalia Basin. As the Vaughan Springs Quartzite is generally correlated with the Heavitree Quartzite (Wells, Evans & Nicholas, 1968; Wells, Moss & Sabitay, 1972), Cooper et al. (1971) suggested that this date gives a minimum age of metamorphism in the Arunta Complex and of the commencement of sedimentation in the Ngalia and Amadeus Basins.

This paper describes the geology and presents new Rb-Sr age determinations from an area of the Arunta Block adjacent to the Amadeus

Basin about 120 km west of Alice Springs (Fig. 1). The area spans an extensive west-trending lineament, called here the Redbank Zone, which can be traced for about 500 km (Forman & Shaw, 1973). The Zone is marked by a break in outcrop within the Arunta Block, and by a strong gravity gradient across it; it is one of the dominant elements in the basement geology of central Australia. We believe that the area provides a representative cross-section across the Redbank Zone.

FIELD RELATIONS

The distribution of rock units is shown in Figure 1. Within the area the regional lineament is marked by a 5-10 km wide zone of flattened, mechanically-deformed rocks. They are pelitic, quartzitic, or quartzofeldspathic in composition, and posses a blastomylonitic, finely-foliated texture. Both the foliation and a strong mineral-streaking lineation within it dip at 40-60° to the north. Porphyroblasts of potash feldspar are common and increase in size and abundance towards the northern part of the zone. At Redbank Hill, large inclusion-filled feldspar prophyroblasts average 7-15 cm across, and over large areas constitute more than half the volume of the rock.

The Redbank Zone separates granulite-facies rocks of Mount Hay and Mount Chapple to the north from amphibolite-facies gneiss, metasediments, migmatites, and granites to the south. The field relations south of the deformed zone result from two distinct metamorphic events. The effects of the older event are preserved in the southeast of the area around the Chewings Range, where original sedimentary rocks (quartzite, pelite and probable arkose) have been syntectonically folded and metamorphosed to amphibolite-facies grade to yield strongly foliated and lineated quartzite, schist, and acid gneiss.

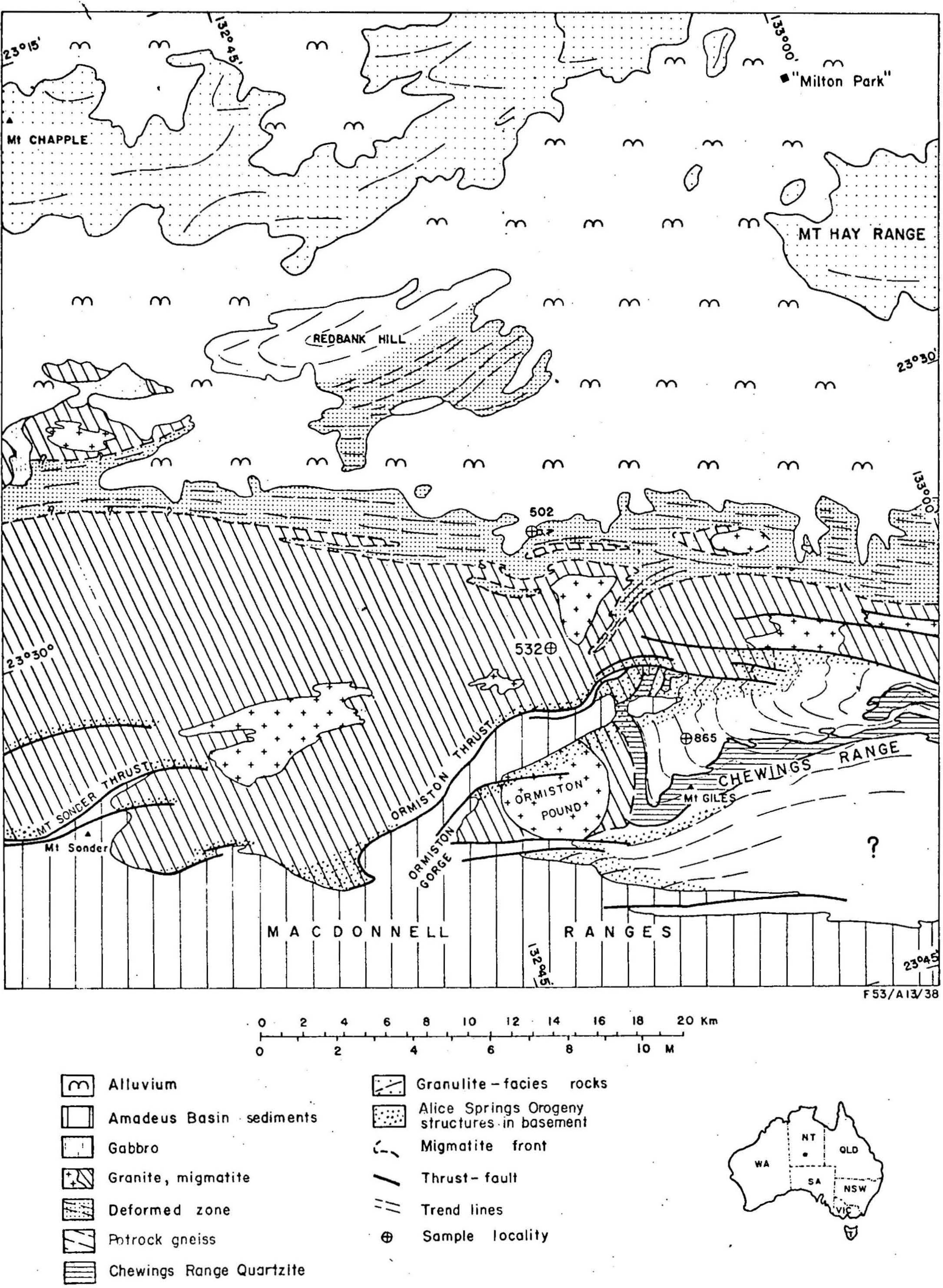

Figure 1. Simplified geological map of the area showing the main rock units and sample localities.

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The effects of the younger event can be seen over a wide area of the Arunta Complex south of the Redbank Zone. Here, in a migmatite complex, all stages in the conversion of an older series of schist, amphibolite, and gneiss, to anatectic granite can be seen. The contact between the migmatite complex and the large palaeosome of unmigmatized rocks around the Chewings Range (the Chewings Range Palaeosome), which preserves the effects of the older metamorphic event, is marked in some places by the outcrop of the Chewings Range Quartzite, in other places by thrust faults of Alice Springs Orogeny age, and elsewhere by a narrow transitional zone. Across the transitional zone, or migmatite front, older metamorphic foliation is progressively affected by migmatization. Within the migmatite complex itself, large areas of the early foliation can still be distinguished, especially in amphibole-rich or biotite-rich units. The early foliation is, however, variously disrupted by contemporaneous folding and partial melting. Quartzofeldspathic segregations develop as streaks, patches, or veins, characteristically parallel or sub-parallel to the axial planes of the folds. Over large areas the older gneiss is converted in situ, by a gradual loss in definition of the older planar or linear structures, into nebulites or structureless granite.

The effects of migmatization die out northwards, but along the southern margin of the Redbank Zone the blastomylonites are disrupted, recrystallized, and reconstituted by progressive migmatization which was thus younger than the initiation of deformation in the Zone. Migmatization affects a considerable width of the southern margin of the deformed zone, and it is not possible to show on a small-scale map, other than in a generalized way, the contact between the migmatite complex and the rocks of the zone. The migmatite front shown in Figure 1 represents the approximate contact between areas where deformed rocks are dominantly preserved, and areas where migmatitic rocks predominate and older structures are obscured.

Within the Chewings Range Palaeosome, at least three phases of folding exist. The earliest phase produced isoclinal folds contemporaneous with the older metamorphic event. The dominant effect of the second phase is the large strike swing from east-west to north-south near Mount Giles. This large second-generation fold was probably associated with the intrusion of the Ormiston Pound granite. As the formation of the granite was intimately associated with the migmatization, the second-phase folds of the Chewings Range are thought to be coeval with the folds which accompany the granitization within the migmatite complex. The third phase produced localized open folds with no strong or widespread associated recrystallization.

In the Redbank Zone the mylonitic foliation is an axial-plane structure to reclined, rootless, intrafolial folds which are picked out by occasional quartzite or quartzofeldspathic bands. The strong mineral lineation is parallel to the axes of these folds. Both lineation and foliation in the southern margin of this zone are refolded by the folding associated with the migmatization.

Within the migmatite complex, granitization obscures the pre-migmatite structural history, but a least one phase of early intrafolial folds with associated strong axial lineation has been refolded by the folding that accompanied the migmatization. These tight early folds in the migmatite complex are probably equivalent to the first-phase folds seen in the Chewings Range and to the reclined folds seen in the Redbank Zone.

In the north-western part of Redbank Hill, north of the Redbank Zone, a small belt of synformally folded acid gneiss and amphibolite shares a common foliation with the deformed rocks to the south, and appears to grade into them. The gneiss and amphibolite are unmigmatized and may well be equivalent to the pre-migmatite gneiss to the south. The granulites of Mount Hay Range and Mount Chapple have along their southern margins a generally north-dipping banding and lineation, parallel to that of the deformed zone from which they are separated by areas of non-exposure; correlation of structures between the two areas is thus difficult.

After the deposition of the first sediments of the Amadeus Basin, both basement and cover were affected by folding that culminated in the Alice Springs Orogeny (Forman, Milligan, & McCarthy, 1967). In the northern part of the Amadeus Basin immediately south of the area studied, these movements are marked by major unconformities and by the deposition in the Pertnjara Group of at least 3500 m of synorogenic molasse-type sediments (Jones, 1970, 1972). Jones (1970) estimated that to provide the sediments of the Pertnjara Group, a source area between the Amadeus and Ngalia Basins would have had to have been uplifted and eroded by at least 2.35 km. Thus during the Alice Springs Orogeny, considerable differential vertical movements of the order of 5-6 km or more between the basement underlying the northern part of the Amadeus Basin, and the basement to the north of the Basin, are indicated.

The visible effects of the Alice Springs Orogeny in the Arunta Complex are limited to the vicinity of discrete thrust-faults affecting both basement and cover. In the basement the faults are high-angle, and are controlled by the pre-existing trend of the Arunta Complex. Away from the thrust-faults there is no visible deformation resulting from the Alice Springs Orogeny, and no sign of any retrogression or refoliation. There is no direct evidence of any renewed deformation or movement within the Redbank Zone during the palaeozoic event. Within this Zone, lenticular outcrops of gabbro, which probably antedate the Alice Springs Orogeny, show no sign of deformation. However, movements along narrow portions of the Zone, perhaps in areas not now exposed, may have occurred. Considering the movements in the basement which can be deduced from the major synorogenic features of the basin sediments immediately to the south, it would be surprising if renewed movement along the deformed zone had not taken place during the Alice Springs Orogeny. The flattening to ellipsoidal shape of the large feldspar porphyroblasts within the Redbank Zone and the resetting of biotite ages south of the Zone (described below) may well reflect deformation during this later event.

SAMPLING AND ANLYTICAL PROCEDURES

Samples for dating were collected from Localities 502, 532, and 865 (Fig. 1). The sites were chosen to allow dating of the two metamorphic events described within the Arunta Block, and to determine to what extent the Alice Springs Orogeny affected the basement beyond the visible areas of deformation associated with this event.

Locality 502 consists of coarse banded migmatite from near the southern margin of the deformed zone. The rock has about equal parts of melanosome and leucosome and is composed principally of quartz, microcline, orthoclase, biotite, and muscovite.

Locality 532 is in a very similar rock type occurring within the migmatite complex.

Specimens from Locality 865 are of a leucocratic weakly-banded and lineated gneiss typical of the pre-migmatite gneiss of the Chewings Range Palaeosome. For convenience of description and to distinguish it from the migmatitic gneiss to the north, it will subsequently be referred to by its informal field name of Potrock gneiss. It is composed of quartz, microcline, oligoclase, orthoclase, biotite, and muscovite. Locality 865 was carefully chosen to lie outside the zone where deformation associated with the Alice Springs Orogeny could be detected in the field, and at the greatest distance possible from the migmatite front.

Gelignite was used at each locality to obtain several specimens of about 1 kg (designated by the symbols A-M in Table 1 and Fig. 2) from about one cubic metre of rock. Each fraction was reduced to less than 100 mesh. Analytical procedures for rubidium were based on the techniques of Compston, Lovering, & Vernon (1965). Those for strontium are described in Page & Johnson (in prep.). A mixed spike containing both Sr^{84} and Rb^{85} was used. Regression of the data on the isochron diagrams is based on the work of McIntyre, Brooks, Compston, & Turek (1966).

ISOTOPIC RESULTS

The isotopic data are given in Table I and on the conventional isochron presentation of Figure 2. The total-rock points for RWM 865 (the older gneiss) almost define a straight line within the limits of experimental error; the value of 3 for the mean square of weighted deviates (see McIntyre *et al.*, 1966) is only slightly significantly greater than unity for this number of analyses. For the migmatite samples (RWM 532 and RWM 502), however, the analytical points show considerable scatter about the regression lines, yielding a mean square of weighted deviates value of 92 for RWM 502 and 21 for RWM 532. As each migmatite sample group can be assumed to include only rocks of the same age, the scatter must result from either an original lack of isotopic equilibrium between phases (*i.e.*, incomplete isotopic homogenization during the metamorphism which gave the rock its present fabric) or from the effects of later geological events. We support the former alternative for the following reasons.

RWM 532 with its wide scatter of total-rock points appears to have been only slightly affected by later events, as shown by its concordant muscovite age, 1076 m.y. (see below). On the other hand, the Potrock gneiss, which has been affected by later events (it contains isotopically reset

TABLE I

Rb-Sr ISOTOPIC ANALYSES

Sample No.	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}
RWM 865 (equivalent to BMR sample 72933002)				
865 A	300.9	43.25	1.20852	21.07
B	282.8	48.43	1.12493	17.548
C	293.7	41.39	1.21892	21.51
D	266.4	50.45	1.08739	15.815
E	256.7	48.43	1.09624	15.883
H	288.4	39.36	1.24415	22.22
I	289.6	46.13	1.15659	18.924
J	296.1	43.19	1.19609	20.74
K	303.7	39.72	1.26016	23.27
L	273.0	49.26	1.10879	16.628
M	292.3	45.94	1.16115	19.185
Plagioclase	26.85	47.71	0.96413	1.6660
K-Feldspar	842.8	81.90	1.34241	31.56
Muscovite	1283.7	9.729	15.2893	924.5
Biotite	2159	12.463	25.441	1709.3
RWM 502 (equivalent to BMR sample 72933000)				
502 A	147.18	271.1	.74744	1.5734
B	189.16	258.2	.75580	2.125
C	142.12	291.3	.74083	1.4131
D	205.3	256.9	.75614	2.3178
E	246.9	260.6	.76380	2.7501
F	171.97	289.4	.74565	1.7221
G	205.7	297.8	.75001	2.002
H	181.68	290.81	.74698	1.7656
I	171.61	315.7	.74179	1.5747
J	202.1	324.0	.74580	1.8077
K	188.27	271.3	.75063	2.012
L	204.7	299.1	.75029	1.9840
Biotite	760.6	9.389	2.2544	269.3
RWM 532 (equivalent to BMR sample 72933001)				
532 A	178.70	182.49	.77650	2.847
B	206.0	209.8	.77545	2.854
C	200.2	180.54	.78220	3.225
D	234.2	188.75	.78829	3.610
E	213.5	187.20	.78582	3.319
F	216.6	194.97	.78278	3.232
G	292.3	208.3	.79496	4.086
H	284.7	188.00	.79947	4.412
I	302.8	192.01	.80392	4.595
J	284.2	192.50	.79885	4.301
K	333.1	194.96	.80729	4.982
L	312.3	195.28	.80267	4.660
M	271.3	195.40	.79823	4.056
Muscovite	732.1	19.312	2.7071	130.87
Biotite	1182.4	6.809	14.019	1154.3

(The letters A to M represent individual specimens from each single sampling site)

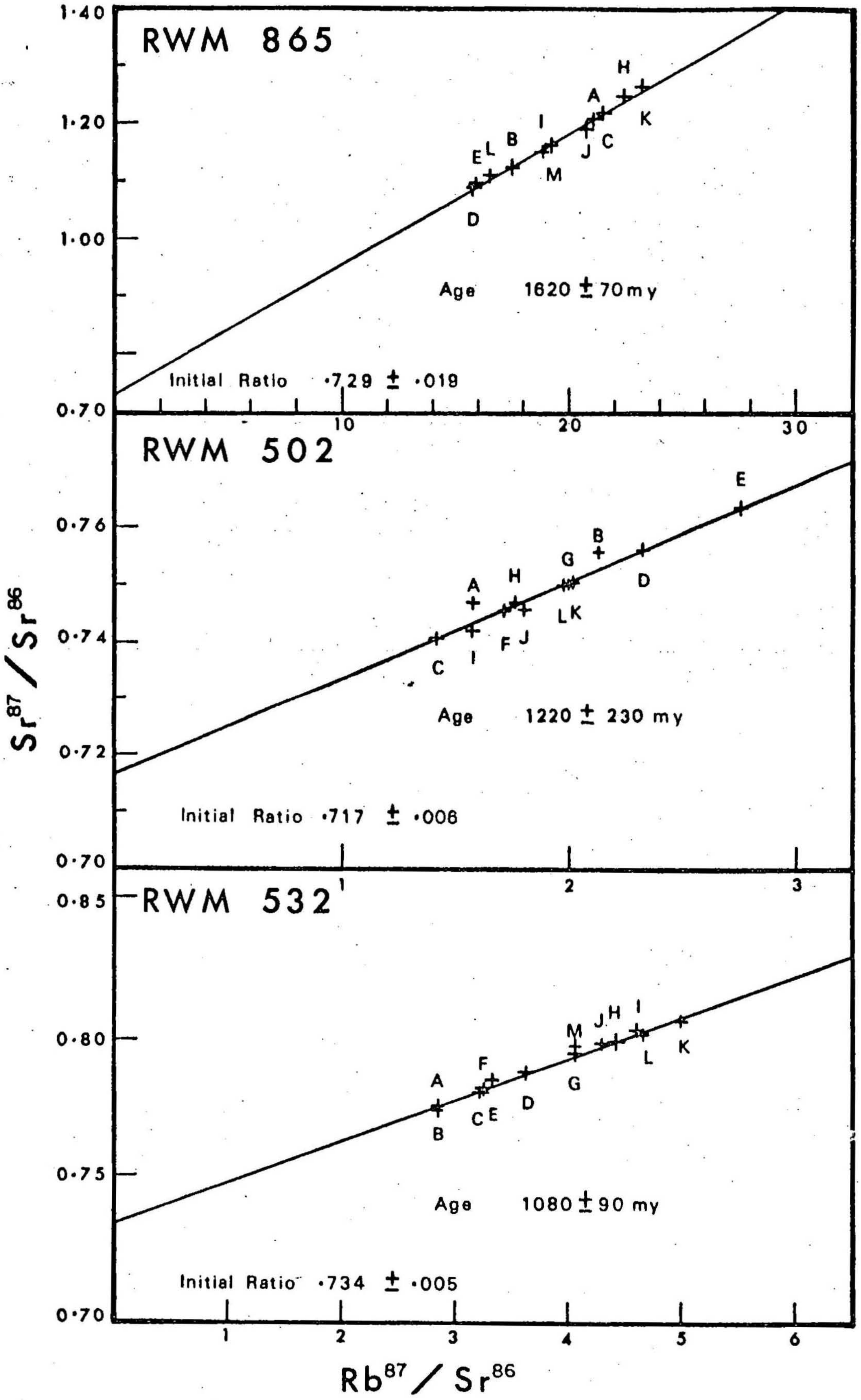

Figure 2. Isochron diagrams for the Potrock gneiss (RWM 865) and migmatite (RWM 532 and 502) samples. RWM 865, 532, and 502 are equivalent to BMR sample numbers 72933002, 72933001, and 72933000 respectively.

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muscovite) still preserves a well defined total-rock isochron. Hence it seems likely that the dispersion about the migmatite isochron results from an original lack of isotopic equilibrium between phases. An additional argument is presented by the computer-selected regression models: in three out of the four total-rock and total-rock muscovite isochrons (see below; note the total-rock muscovite isochron is not included in Figure 2), the nature of the analytical dispersion is best described as resulting from slightly differing initial isotopic ratios for the individual samples (see McIntyre _et al._, 1966, for the theory behind these models).

In the Potrock gneiss (Locality 865) the structural and textural effects of only one metamorphic event are visible, and it is probable that the 1620 ± 70 m.y. total-rock date defines this event. In addition, the indicated age agrees reasonably well with a general value of about 1700 m.y. found in other areas of the Arunta Complex, and interpreted by other authors as defining a metamorphic event (Stewart, 1971; Shaw & Stewart, 1973).

The regression for the total-rock points of RWM 502 (migmatite within the Redbank Zone) yields an age of 1220 ± 230 m.y. with an initial ratio of 0.717 ± 0.006; that for RWM 532 (migmatite within the migmatite complex) gives parameters of 1080 ± 90 m.y. and 0.734 ± 0.005. These ages are mutually indistinguishable and are significantly younger than that of the Potrock gneiss. They thus confirm the relative ages that were deduced from the field relations of the two metamorphic events to the south of the deformed zone. The younger age clearly defines a metamorphic event, probably the time of migmatization, as the remnant structures in the migmatite zone indicate a history stretching back at least to the time of older gneiss formation.

Although the migmatization event is better delineated by the total-rock age for sample RWM 532 than by that for RWM 502, it is still not well defined. A more precise estimate can be made when the analyses of the included muscovite in RWM 532 is regressed with the total-rock points. This yields parameters (age, 1076 ± 12 m.y.; initial ratio, 0.734 ± 0.001) which are not significantly different from those of the total-rock isochron. The error limits for this regression can be strictly regared only as estimates of technical precision. We believe that a more conservative estimate of 1076 ± 50 m.y. should be used to allow for the added probability of slight geological perturbations.

Unlike the analysed muscovite, biotite concentrates from the two migmatite samples have definitely been affected by subsequent geological events. Biotite concentrate from RWM 532 gives an age of approximately 830 m.y.; that from RWM 502 gives an age of about 400 m.y. The Alice Springs Orogeny, which is interpreted as resetting many mica ages elsewhere in the Arunta Complex (Stewart, 1971; Black, unpublished analyses), is probably responsible for the younger ages yielded by the biotites. The biotite from Locality 502, which lies within the deformed zone, has almost completely responded to the Alice Springs Orogeny, in contrast to that from Locality 532 which has been only partly reset.

SUMMARY OF METAMORPHIC HISTORY

The following tentative geological history is proposed for the area studied:

1. Granulite-facies metamorphism. This event produced the rocks now exposed in Mount Hay Range and Mount Chapple. The granulite has not yet been dated, but it may be of the same age as widely separated occurrences of granulite-facies rocks in the Harts and Reynolds Ranges of the Arunta Complex, which have yielded Rb-Sr total-rock isochron dates of between 1700 and 1800 m.y. (Black, unpublished analyses).

2. Formation of Redbank Zone. The exact age and nature of this zone are not known, but the evidence indicates that it represents a major north-dipping dislocation zone which penetrates deep into the crust and was initiated before 1076 m.y. (cf. Forman & Shaw, 1973). Comparison of structures suggests that the formation of the zone may be syntectonic with the 1620 m.y. metamorphic event to the south.

3. Widespread regional metamorphism. This event reached amphibolite-facies grade and is the only major metamorphism preserved in the Chewings Range Palaeosome. It is dated at 1620 ± 70 m.y.

4. Migmatization. This event was accompanied by partial melting of the older gneisses and by the intrusion of granite magma. It is therefore thought to have taken place under upper amphibolite-facies conditions (Winkler, 1967). The migmatization is dated at 1076 ± 50 m.y.

5. Intrusion of small bodies of gabbro. The gabbro is intruded into the deformed zone and is possibly of the same age as swarms of dolerite dykes which cut the migmatite farther south. The dykes are truncated by, and hence are older than, the Heavitree Quartzite.

6. The Alice Springs Orogeny. Only small areas of the exposed Arunta rocks show any retrogression or refoliation caused by this event. However, biotite concentrates from the migmatite samples (RWM 502 and RWM 532) show isotopic resetting and probably indicate a rise in geothermal gradient (with a maximum value towards the Redbank Zone) within the basement during the Alice Springs Orogeny. This supports the possibility of renewed movement along narrow portions of the deformed zone at this time. It is probable that the existence of this zone exercised a major control on the Alice Springs Orogeny.

DISCUSSION

Field and isotopic evidence from a small area of the Arunta Complex prove at least two Precambrian metamorphic events. The age of the older event (1620 ± 70 m.y.) is similar to dates around 1700 m.y. obtained from other areas in the Arunta Complex (see Shaw & Stewart, 1973). Meramorphism was thus widespread within the complex at this time.

The effects of a late migmatization event have been observed on several reconnaissance traverses across the Arunta Complex as far east as Alice Springs. Farther east again, in the Arltunga and Harts Range regions of the Arunta Complex, mica ages of 1000 - 1200 m.y. (Hurley et al., 1961; Riley, 1968; Stewart, 1971) may also relate to this event. To the west of the area, geological mapping by the Bureau of Mineral Resources in the Mount Liebig and Mount Rennie 1:250 000 Sheet areas indicates large areas of intrusive granite within the Arunta Complex immediately to the south of the Redbank Zone. These granites occur in a similar structural position to the granites within the area studied, and may well be of the same age. Along the southern edge of the Amadeus Basin, intrusive granites of an approximately comparable age to the migmatite event cut the basement gneiss. In the Musgrave Ranges these late granites yield Rb-Sr isochron ages of 1100 - 1200 m.y., and are referred to as the Kulgeran phase of metamorphism (Compston & Arriens, 1968; Parkin, 1969): they have been correlated (Compston & Nesbitt, 1967; Thomson, 1970) with the Pottoyu Granite Complex (southwest of the Amadeus Basin), which is dated at 1150 - 1190 m.y. (Rb-Sr total-rock ages by P.J. Leggo, quoted in Forman, 1966), and with the Tollu Volcanics. The migmatization in the area may thus be part of a very widespread granitization event occurring within the Arunta Block and the northern part of the Musgrave Block.

The 1076 m.y. date from the Arunta Complex imposes a maximum age for the deposition of the unconformably overlying Heavitree Quartzite. If the

Heavitree and Vaughan Springs Quartzites are equivalent, then this maximum age is in conflict with the 1280 m.y. date for the Vaughan Springs Quartzite given by Cooper et al. (1971). Likewise, the 1076 m.y. Arunta date is not consistent with a Rb-Sr estimated age of 1170 m.y. (V.M. Bofinger, written comm. in Wells, Ranford, Stewart, Cook, & Shaw, 1967) obtained on a single specimen of shale from the Bitter Springs Formation, which overlies the Heavitree Quartzite.

The younger date for the commencement of deposition in the Amadeus Basin is supported by palaeontological evidence, based on stromatolite fossils, which suggests a 950 - 650 m.y. date for the Bitter Springs Formation (Glaessner, Priess, & Walter, 1969; Priess, 1972). In addition, Compston & Nesbitt (1967) argued that the correlation of the Dean and Heavitree Quartzites within the Amadeus Basin suggests a younger date than 1190 m.y. for the commencement of deposition in the Basin, since the Dean Quartzite rests unconformably (Wells et al., 1970) on the 1150 - 1190 m.y. Pottoyu granite.

If the late migmatization and granite intrusion in the Arunta Complex are correctly dated, then either the Vaughan Springs Quartzite is at least 200 m.y. older than the Heavitree Quartzite or the 1280 m.y. date quoted by Cooper et al., (1971) for the Vaughan Springs Quartzite is too old. The latter alternative could possibly be explained if the glauconite analysed by these authors were of detrital or partly detrital origin.

ACKNOWLEDGMENTS

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APPENDIX

Several arguments can be advanced against the possibility that the regression lines for both migmatites represent mixing lines (rather than true isochrons) between rocks of different age or different initial Sr^{87}/Sr^{86} (see Black, Morgan, & White, 1970) with no direct chronological significance. The arguments are as follows:

1. The total-rock ages for the migmatite samples RWM 502 and RWM 532 are in accordance with each other but the indicated values for initial Sr^{87}/Sr^{86} of the two rocks are quite different. This means that quite different end members for the hypothetical mixing would have to be involved, and it is most improbable that the slopes (ages) of the two mixing lines would be the same.

2. It would be a curious coincidence if the regression line yielding a mineral age (1060 ± 170 m.y.) for the Potrock gneiss (RWM 865) were the same as the slope of the hypothetical mixing lines of the two migmatite total-rock samples.

3. Even if a mixing model applies, internal mineral isochrons should yield the correct age of the system, unless affected by a later event (see Black et al., 1972). In the present case, a coincidental combination of circumstances would have to occur in which perturbations resulting from mixing in the total-rock system were quantitatively matched by offsetting of the muscovite age, presumably as the result of a later event.

The evidence is thus heavily in favour of 1076 ± 50 m.y. representing the age of migmatization.

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