

extremely fine grained and fractures conchoidally. At first sight it appears siliceous, but the rock has a high specific gravity and commonly exhibits a fine spinifex texture. Other parts of the sequence include more coarsely spinifex-textured varieties, pillowed ultramafic flows and stratiform bodies (interpreted as sills) of gabbroic and ultramafic rocks. The rocks are typically massive, but pillowed units and spinifex zones show that dips are moderate south of Whim Creek and near the Sherlock River. The lithological differences between the variolitic basalt of Mount Negri and *Abu*, combined with the presence of consistently steeper dips in the latter, indicate that the two units are not conformable.

As can be seen from Figure 28, contacts between *Abu* and other rocks of the area are generally faulted. Near Sherlock River relations to *Ax* are uncertain because of incomplete exposure and a general absence of well-defined bedding planes. Approximately 20 km southwest of Roebourne rocks similar to *Abu* form part of the Teichmans Group, so that the unit may be older than the Whim Creek Group.

If *Abu* does not belong to the Negri Volcanics the relationship between the latter and the Fortescue Group cannot be directly demonstrated. Field evidence that the Whim Creek Group is Archaean rather than Proterozoic also becomes limited to an unconformable relationship between the Mount Roe Basalt and the Warambie Basalt near Warambie.

STRUCTURE

The Whim Creek Belt is bounded by major faults and, on the basis of stratigraphy, would appear to be a graben. Within the confines of these faults the Whim Creek Group is folded gently about northeast-trending axes. The folds plunge northeast and southwest, possibly because of open cross-folding, although this is uncertain. Miller and Gair (1975) recognize an east-trending anticline between Mons Cupri and Whim Creek.

A steep axial plane cleavage strikes northeast along the length of the belt, and affects all rocks, including the Negri Volcanics. At Whim Creek this cleavage is a true slaty cleavage inclined southeastwards at about 30° to 40° and is crenulated by a later nonpenetrative cleavage striking northwest. Kink bands which deform the slaty cleavage resemble D3 structures in the east Pilbara (Hickman, 1975).

CONCLUSIONS

The Whim Creek Group is a late Archaean volcanic sequence, relatively thin compared to the rest of the Archaean succession and of limited areal extent. The mid-Archaean regional unconformity recognized by Fitton and others (1975) has not been substantiated by regional geological mapping carried out by the Geological Survey of Western Australia. The Mallina Formation and Constantine Sandstone, placed by Fitton and others (1975) in the Whim Creek Group, belong to the Gorge Creek Group.

GEOCHRONOLOGICAL DATA CONCERNING THE EASTERN EXTENT OF THE PILBARA BLOCK

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ABSTRACT

The Pilbara Block, in the northwest part of Western Australia, is the smaller of the two major Archaean cratonic areas of the State. The bulk of its granitic rocks have Rb-Sr isochron ages of about 3.0 b.y., with initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratios (R_i) of about 0.702. In the eastern part of the block post-tectonic "younger" granites, 2.7-2.6 b.y. old with an R_i about 0.73, intrude the older granites and are thought to be derived anatectically from them. Rb-Sr data are reported from three rock bodies spaced along an east-west transect across the largely obscured eastern edge of the block. At the eastern end of the transect the Mount Crofton Granite, which intrudes folded Proterozoic sediments of the Yeneena Group, has a concordant total-rock and biotite age close to 600 m.y.; the R_i of about 0.71 indicates that it cannot have been derived by melting of underlying Archaean granitic

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- crust. At the western end of the transect the Cookes Creek Granite gives a broadly concordant total-rock and biotite age of 2.6 b.y. with an R_i of about 0.73; in both respects, and in other features, it belongs with other younger granites of the Pilbara Block. Between these, in the centre of the transect, granites with a pervasive cataclastic foliation in the southern part of the Gregory Granitic Complex, in the vicinity of Lookout Rocks, give a well-defined 2.65 b.y. total-rock isochron, with an R_i of about 0.71; discordant biotites give an age of 1.2 b.y. Geological and previous Rb-Sr evidence argue that the foliation cannot be older than 2.4-2.2 b.y., so that the total-rock age has survived its imposition. The biotite age may record either the age of the foliation or of a later event. The comparatively low R_i at Lookout Rocks suggests that between this area and the Cookes Creek Granite lies the eastern edge of the older granitic crust of the Pilbara Block.

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INTRODUCTION

The Pilbara Block is an area of Archaean rocks covering about 56 000 km² of the northwest part of Western Australia, between approximate latitudes 20° and 22°S and longitudes 116° and 121° E; it has a crudely triangular shape, with a short eastern side running north-south and longer north and south sides converging towards a western apex. The Archaean age of two generations of granite within it is established by Rb-Sr ages of 2 951 and 2 606 m.y., reported by de Laeter and others (1975) and by a similar range of Pb-Pb ages reported by Oversby (1976). Ages for the older granites, of 3 050 m.y. and 3 125 m.y., reported by Compston and Arriens (1968) and de Laeter and Blockley (1972) respectively, have wide uncertainty limits which include the more reliable ages already noted.

The northern boundary of the Pilbara Block is formed either by the Indian Ocean coastline or by overlying Phanerozoic sediments of the Canning Basin. The southern margin is defined by the unconformable base of the Proterozoic Fortescue Group, of the Hamersley Basin. On the most recent edition of the State geological map (G.S.W.A. 1973), and in a recent formal representation of Precambrian subdivisions (G.S.W.A., 1975, p. 29), the eastern edge of the Pilbara Block is shown as a continuation of the same unconformity, following an irregular north-south course within the rough longitude limits 120°20'-40'E. However, Hickman (1975a), after remapping of the Nullagine 1:250 000 Sheet area, which covers much of the relevant ground, shows a narrow north-south belt of Archaean and Proterozoic granitic rocks some 50-70 km farther east, and isolated from the main mass of the

Pilbara Block by Fortescue Group and younger rocks. This roughly 10-km wide belt of granitic and related rocks, called by Hickman (1975a, b) the Gregory Granitic Complex, extends for nearly 100 km from the Yarrle Sheet area in the north to the Balfour Downs Sheet area in the south. On the earlier edition of the Nullagine Sheet (Noldart and Wyatt, 1962) this belt was included within the "Gregory Range Granite", and was regarded as Proterozoic. It was also mapped as Proterozoic on the Balfour Downs Sheet (de la Hunty, 1964).

Remapping of the Nullagine Sheet revealed that a large part of the "Gregory Range Granite" was composed of felsic lava, now named the Koongaling Volcanics, apparently belonging to the Fortescue Group. The remainder was found to include granophyre and several different types of granitic rock. Each of these various types is broadly restricted to a particular part of the belt, suggesting that either they represent distinct zones within a heterogeneous intrusion or they form individual plutons. Because mapping did not establish which of these alternative explanations was correct Hickman (1975a) introduced the term Gregory Granitic Complex to include the granophyre and all the granitic rocks.

The map appearing as Figure 29 illustrates the disposition of the rock units referred to above, and includes further information, dealt with subsequently. Blockley and de la Hunty's (1975, p. 115-6) account of the components of the "Gregory Range Granite", was compiled from the best information available in 1971, and is superseded by later parts of this paper.

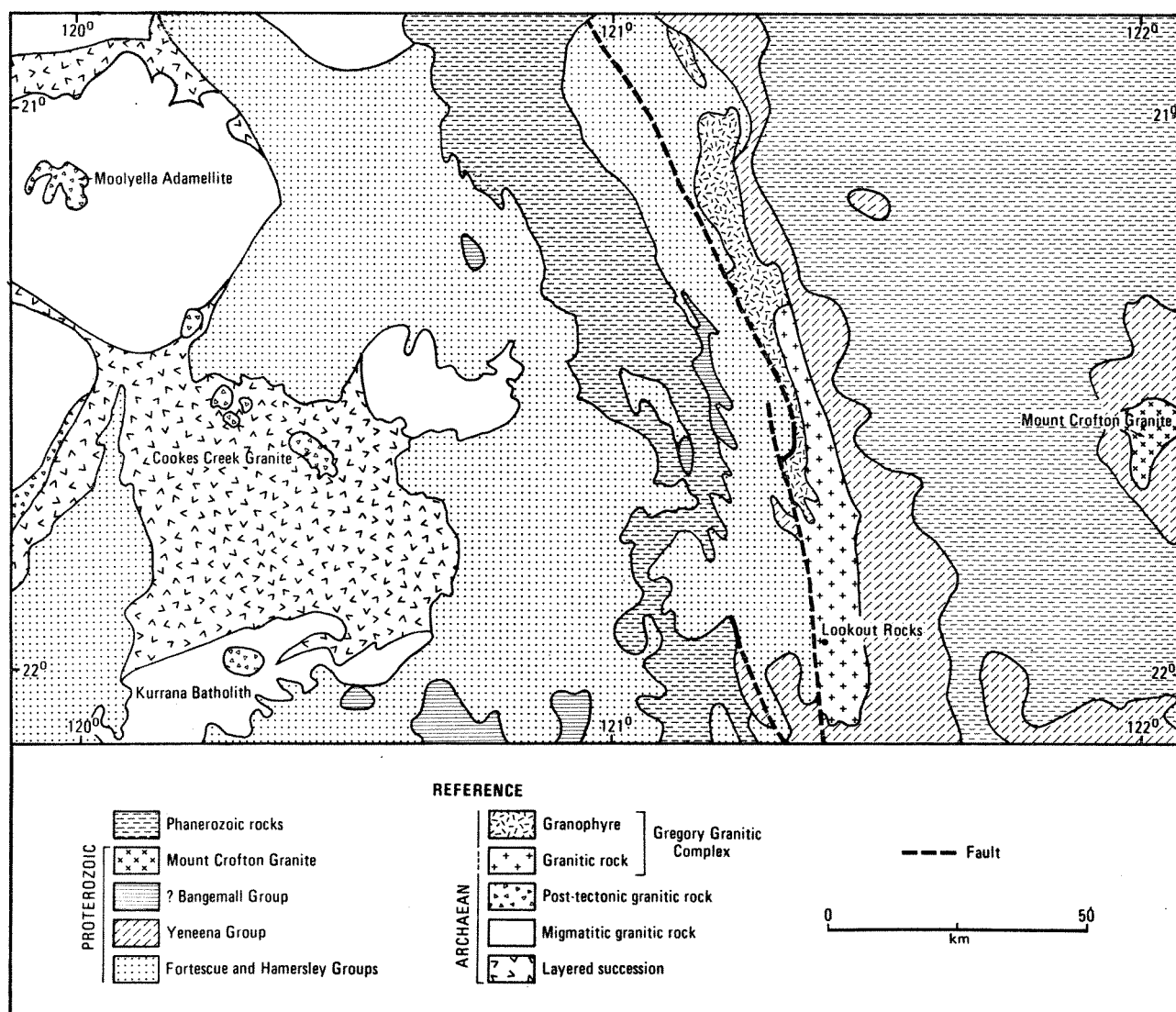


Figure 29. Simplified geological map of the eastern marginal area of the Pilbara Block.

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Hickman (1975a) did not provide explicit reasons for assigning an Archaean age to the granitic rocks of the complex, but gave the southern part the same lithological description as sheared granite and adamellite of the Kurrana Batholith (Fig. 29), a unit forming part of the Pilbara Block and known to be of Archaean age. Considerations not mentioned were the fact that the granophyre (regarded as a feeder of the Koongaling Volcanics) is generally far less deformed than the granitic rocks in the south, and also that the granitic rocks do not intrude or visibly metamorphose the Fortescue Group. He was also aware of the preliminary isotopic data mentioned by Blockley and de la Hunty (1975, p. 115) which, though of uncertain significance because of sampling problems, did indicate that at least part of the complex might be Archaean.

In 1975, as now, the only unequivocal geological evidence for the age of the rocks was that on the eastern side they are unconformably overlain by gently dipping sandstone of Lower or Middle Proterozoic age (Yeneena Group, Williams and others, 1976). On the western side, the contact between the complex and the Fortescue Group is tectonic in the south and tectonic or gradational (granophyre-Koongaling Volcanics contact) in the north.

The purposes of this paper are to record Rb-Sr whole-rock and mineral analyses of rocks from the southern part of the Gregory Granitic Complex which confirm their age as Archaean, to report additional Rb-Sr data from other rock units to the east and west, and to discuss the implications of all the data for regional geological history.

EXPERIMENTAL PROCEDURE

The experimental procedure for Rb-Sr analyses used in this laboratory are essentially the same as those described by Lewis and others (1975) and de Laeter and Abercrombie (1970).

The value of ⁸⁷Sr/⁸⁶Sr for the NBS 967 standard measure during this project was 0.710 2 ± 0.000 1, normalised to a ⁸⁸Sr/⁸⁶Sr value of 8.375 2. The value of 1.39 x 10⁻¹¹ yr⁻¹ was used for the decay constant of ⁸⁷Rb. The measured Rb/Sr and ⁸⁷Sr/⁸⁶Sr ratios, as well as the calculated ⁸⁷Rb/⁸⁶Sr ratios are given in Tables 12-14. Errors accompanying the data are at the 95 per cent confidence level. Regression analyses of the data were carried out using the least squares programme of McIntyre and others (1966).

COOKES CREEK GRANITE

GEOLOGICAL RELATIONSHIPS

The position of the Cookes Creek Granite (Noldart, 1960, p. 141) is shown on Figure 29. It crops out over 40 km² at the junction of Cookes Creek with the Nullagine River, about 45 km northeast of Nullagine.

The granite is a stock intruded into Archaean basaltic rocks of the Warrawoona Group (Hickman, 1975a). Its margins are irregular and discordant to the bedding of the greenstones, and appear to be intrusive on all sides. The enveloping greenstones are not visibly disrupted by the intrusion, indicating that emplacement was passive. At the southeastern contact of the mass, dykes of granitic rock intrude adjacent sandstone, gabbro and ultramafic rock. Sandstone near the contact is spotted and extensively recrystallized, apparently due to contact metamorphism. Granitic rock next to the contact contains about 70 per cent quartz and is rich in aluminous minerals. The main body of the stock is a poorly foliated or nonfoliated, coarse to medium-grained granite or adamellite. In places it is porphyritic and a cataclastic foliation is developed near minor faults. Faults and joints are a conspicuous feature of the stock, and, because the topography is rugged and the exposure good, these appear as well-defined lineaments on aerial photographs. Faults and joints trending north are offset by faults striking at 100°. Another set of lineaments, commonly intruded by quartz, trends north-northwest. Some of the quartz veins contain fluorite and barite, and at the Cookes Creek mining centre others have been worked for wolframite and scheelite.

Hickman (1975b) notes that the Cookes Creek Granite intrudes the core of a syncline, and interprets it as a post-tectonic intrusion, similar in many respects to the "tin granites" of the Pilbara Block. One of these, the Moolyella Adamellite (shown on Fig. 29), was dated by de Laeter and Blockley (1972) at 2 670 ± 95 m.y.

MATERIAL ANALYSED

Five samples (18415, 16, 17A, 17B, 18) collected from a restricted area near where the track from Mosquito Creek crosses Cookes Creek (lat. 21°37'52"S, long. 120°26'17"E) were analysed. Samples 18417A, 17B, and 18 were collected from the creek bed, no more than 30 m apart; 18415 and 16 come from an excavation close to the track about 150 m south of the crossing. They include equigranular and porphyritic varieties.

Sample 18417A is an equigranular coarse-grained adamellite containing masses of anhedral quartz up to 6 mm across, smaller subhedral to anhedral prisms of albite (An₃) and plentiful interstitial microcline. Minor biotite has been entirely chloritized and the albite is slightly sericitized. The chlorite is associated with accessory zircon and secondary sphene and fluorite. Fluorite also occurs, with a little carbonate, in minor fractures and shears within the rock. Specimen 18415 is a leucocratic variety with prominent mylonitic zones, apparent only in thin section, in which small masses of fluorite are developed. Sample 18417B is a medium-grained, leucocratic aplite similar in mineralogy to 18417A.

Sample 18418 is a porphyritic adamellite containing subhedral phenocrysts of perthitic microcline up to 2 cm long, subhedral to anhedral oligoclase (An₂₅) prisms, interstitial quartz and minor green biotite. Accessory apatite, zircon, sphene, epidote, and metamict allanite are present. The sphene contains metamict zones and is a pale brown low birefringence variety. Minor secondary fluorite is associated with the biotite.

Specimen 18416 was collected from a dyke-like pod and consists of a mass of pale bleached biotite with lesser microcline and fluorite. A little quartz is present, along with accessory zircon and secondary rutile.

Chemical compositions of the two main granite types are given in Table 11.

TABLE 11. CHEMICAL COMPOSITION OF THE COOKES CREEK GRANITE

	18417A	18418
SiO ₂	76.3	71.2
Al ₂ O ₃	12.1	13.9
Fe ₂ O ₃	0.4	1.0
FeO	1.51	2.75
MgO	0.00	0.5
CaO	0.51	1.79
Na ₂ O	3.72	3.88
K ₂ O	4.3	4.4
H ₂ O ⁺	0.77	0.80
H ₂ O ⁻	0.10	0.13
CO ₂	0.19	0.07
TiO ₂	0.17	0.49
P ₂ O ₅	0.02	0.11
MnO	0.04	0.06
Total	100.1	101.0

Trace elements (ppm)

Li	50	170
Ba	170	580
Rb	420	355
Sr	40	120
Sn	10	5
Zr	130	190
U	3	4
F	2 240	1 880

Analyst: N. Marsh, West. Australia Government Chemical Laboratories

TABLE 12. ANALYTICAL DATA FOR FIVE TOTAL-ROCK SAMPLES AND TWO BIOTITE CONCENTRATES FROM THE COOKES CREEK GRANITE

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	⁸⁷ Rb/ ⁸⁶ Sr	Sr ⁸⁷ / ⁸⁶ Sr
Total rocks					
18418	360	110	3.25 ± 0.03	9.7 ± 0.1	1.084 1 ± 0.001 1
18417A	418	31	13.5 ± 0.1	45.2 ± 0.5	2.341 1 ± 0.002 3
18415	495	23	21.1 ± 0.2	74.8 ± 0.7	3.017 2 ± 0.001 0
18417B	490	14	35.1 ± 0.3	161 ± 1	6.768 ± 0.008
18416	2 600	40	65.6 ± 0.6	561 ± 5	20.78 ± 0.04
Biotites					
18418	1 650	21	78 ± 2	526 ± 8	14.380 ± 0.014
18416	3 000	37	81 ± 2	1 640 ± 20	62.051 ± 0.062

RESULTS

The data from the five total rocks and from biotite fractions separated from two of them appear in Table 12, and are displayed in Figure 30. It is clear from inspection that 18415 falls below a line well defined by the remaining four total-rock samples. These yield a Model 1 isochron of $2\,568 \pm 37$ m.y. with an initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (R_i) of $0.730\,7 \pm 0.009\,7$. This age and R_i are closely controlled by samples 18416 and 18418 respectively.

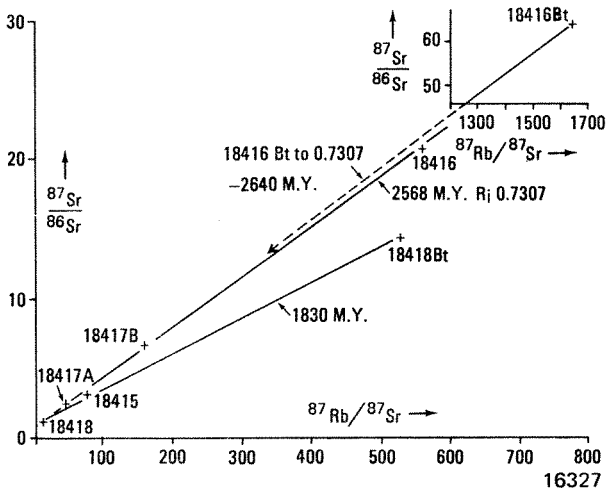


Figure 30. Isochron diagram of five total-rock samples from the Cookes Creek Granite and of biotites concentrated from two of them. The 1 830 m.y. line joins total rock 18418 with its separated biotite. The crosses marking analyses are symbolic only, and do not represent error limits.

The separated biotite 18416 yields an age of 2 700 m.y. when joined to its total-rock point, but this figure implies an impossible, negative, R_i . The biotite was separated from a different part of the sample from that used for the total-rock analysis, and this anomalous result can only be accounted for by slight inhomogeneity within the sample. We know of no mechanism whereby granite biotite can acquire an anomalously high Rb-Sr age, and conclude that the real age of the granite probably lies within both the error limits of the total-rock age and those of a model age for the biotite which accepts the computed R_i . These limits, an upper of 2 605 m.y. for the total-rock isochron, and a lower of 2 607 m.y. for the biotite, marginally fail to overlap, but this margin is trivial, and for purposes of later discussion we refer to this granite as showing a concordant total-rock and biotite age of about 2 600 m.y.

The green biotite in sample 18418 clearly records a discordant age of 1 830 m.y., and it may be that the position of the mylonitic rock 18415, which records a model age (R_i 0.73) of 2 170 m.y. reflects a partial response to this event.

GREGORY GRANITIC COMPLEX

GEOLOGICAL RELATIONSHIPS

The background to the introduction of the name Gregory Granitic Complex by Hickman (1975a) has already been given above; the complex includes both granophyre and granitic rocks and is shown in Figure 29. We are concerned here with the geological relationships only of that part of the complex in the Lookout Rocks area, from which the analysed samples were collected.

This part of the complex contains schistose to well-foliated granite and adamellite. On the west side these granitic rocks are separated from lava and sedimentary rocks of the Fortescue Group by a major north-striking fault filled with quartz. On the east side they are unconformably overlain by gently east-dipping sandstone of the Yeneena Group, and to the north a foliated hornblende granite is exposed. In the field this rock is distinct from the foliated granite of the Lookout Rocks area; it is finer grained, more massive, and spotted with hornblende. The granite and adamellite of the Lookout Rocks area is locally flaggy, and in such cases primary igneous textures have been destroyed by shear. This tectonic foliation (S5) strikes north-northwest, and dips steeply south-westwards or north-eastwards in the western part of the complex and gently westwards or sub-horizontally in the eastern part. A structural interpretation (Hickman, 1975a, Fig. 3) equates a north-northwest-trending anticlinal fold of S5 with folds of similar orientation which affect rocks of the Yeneena Group to the east. The S5 foliation in the granitic rocks is also correlated with an axial plane cleavage related to upright tight-to-isoclinal folds in the Fortescue Group immediately west of the complex. This correlation is based on similarity of orientation and on photo-interpretation. No locality affords a well-exposed, non-tectonic contact between the Fortescue Group and the granitic rocks.

The lithological similarity between the granite at Lookout Rocks and the granite and adamellite of the Kurrana Batholith has already been noted. Bouguer anomaly patterns (Hickman, 1975a, Fig. 6) do not rule out the possibility that the two masses are continuous at depth beneath the Fortescue Group. The strong tectonic foliation of the Kurrana Batholith is clearly Archaean in age, however; since it is unconformably overlain by the Fortescue Group.

MATERIAL ANALYSED

Twelve total-rock samples were analysed, together with separated biotites from two of these. Nine of these samples, collected by two of us in 1976 specifically for geochronology, came from two sampling points, situated respectively 1.8 km on a bearing of 328° from Lookout Rocks (45756A-E) and 1.6 km on a bearing of 342° from Lookout Rocks (45757A-D). The remaining three samples include one (13891) collected by H.W.B. Talbot (1920, pp. 129 and 187) in 1914 about 1 km due north of Lookout Rocks and two samples (16446, 7) collected by J. G. Blockley in 1969, respectively 9.0 and 10.6 km from Lookout Rocks on a bearing of 170° .

Samples 45756A-E were spaced at roughly equal intervals over an east-west distance of about 150 m along the crest of a low ridge. A, B, D, and E have an identical macroscopic appearance; they are fresh, coarse, pink, gneissic granites in which the thin dark streaks of biotite and hornblende which define the foliation enclose feldspars

about 1 cm in diameter. Sample 45756C is a finer-grained and more massive, darker pink, rock in which the feldspars do not exceed a diameter of 2-3 mm. Samples 45757A-D come from about 1 km farther east, at the south foot of the same ridge, and have a maximum separation of 50 m. A and B are almost identical in appearance to 45756A, B, D and E, but more strongly foliated. Sample 45757C was taken from a very strongly sheared band about a metre wide within this granite, in which its components have apparently been ground to form a black streaky mylonite. Sample 45757D forms a halfway stage between C and the gneissic granite of A and B; it is an augen gneiss in which the dark streaks of mylonitised material enclose remnants of granitic material.

Along the whole ridge including the 45756 and 45757 sampling points, the foliation of the gneissic granite and of its mylonitic derivatives maintains a very consistent direction, striking 320-325° and dipping at about 80° eastwards.

In thin section this foliation, the S5 of Hickman (1975a, b), dominates the general appearance of the rocks. Mineralogically, and in initial texture, all these rocks were clearly granites, with patches of coarse quartz mosaic, and anhedral potassic feldspars and sodic plagioclases about 5 mm across forming the main components; less abundant biotite and hornblende were supplemented by accessory sphene, apatite, zircon, fluorite and opaques.

But the post-crystallization imposition of the strong foliation has been accompanied in all these rocks, including the more massive 45756C, by strong cataclastic deformation of all the major minerals. The quartz is streaked out into complex wisps and ribbons, and the feldspars are broken down into smaller grains, in which the twin laminae are kinked or bent. Even the biotite is strongly broken and twisted, and has not since recrystallized. It is clear that the development of the foliation has been associated with an intense and penetrative late cataclasis.

Samples 13891, 16446, and 16447 are coarse pink foliated granites closely similar to the 45756-7 samples in macroscopic appearance, mineralogy, and in the association, beneath the microscope, of the foliation with pervasive cataclasis.

RESULTS

The data from the 12 total-rock samples analysed, and from biotite fractions separated from two of them, appear in Table 13 and are also displayed in Figure 31. The total-rock data are well aligned on a Model 3 isochron of 2 651 ± 60 m.y.; the two biotites, when joined with their parent rocks, give closely similar ages with a mean near 1 200 m.y.

TABLE 13. ANALYTICAL DATA FOR TWELVE TOTAL-ROCK SAMPLES AND TWO BIOTITE CONCENTRATES FROM GRANITIC ROCKS OF THE LOOKOUT ROCKS AREA

Sample	Rb (ppm)	Sr (ppm)	Rb/Sr	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr
Total rocks					
45757C	115	176	0.65 ± 0.01	1.89 ± 0.03	0.774 31 ± 0.000 71
45757D	116	170	0.68 ± 0.01	1.97 ± 0.04	0.784 01 ± 0.000 74
45757B	111	105	1.06 ± 0.01	3.11 ± 0.04	0.821 45 ± 0.000 79
45757A	126	91	1.39 ± 0.02	4.08 ± 0.07	0.865 17 ± 0.000 64
45756B	172	71	2.41 ± 0.04	7.15 ± 0.08	0.984 14 ± 0.000 76
45756E	166	68	2.45 ± 0.04	7.30 ± 0.08	0.984 90 ± 0.000 83
45756A	168	66	2.54 ± 0.04	7.60 ± 0.09	0.991 71 ± 0.000 89
45756D	171	66	2.60 ± 0.04	7.69 ± 0.09	0.993 67 ± 0.000 83
45756C	171	40	4.28 ± 0.06	12.93 ± 0.15	1.191 5 ± 0.000 94
13891	.....	.....	0.70 ± 0.01	2.03 ± 0.02	0.788 51 ± 0.000 81
16447	.....	.....	0.96 ± 0.01	2.79 ± 0.03	0.810 52 ± 0.000 73
16446	.....	.....	1.13 ± 0.01	3.30 ± 0.03	0.834 32 ± 0.000 81
Biotites					
45756E	700	40	17.6 ± 0.4	56 ± 1.0	1.805 02 ± 0.001 2
45756D	615	42	14.6 ± 0.3	46 ± 1.0	1.653 61 ± 0.001 1

Note: In Tables 11, 12, and 13 the Rb and Sr concentrations have been determined by X-ray fluorescence spectrometry. We believe the values are accurate to ± 7 per cent. The Rb/Sr values do not correspond exactly with the ratios that would be derived from the separate Rb and Sr values listed.

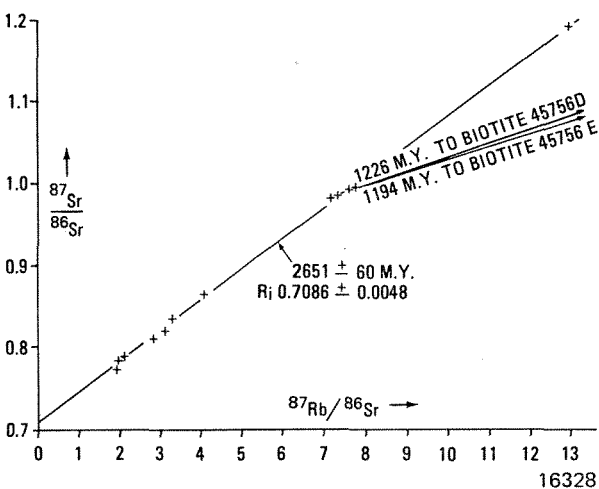


Figure 31. Isochron line of twelve total-rock samples from the southern (Lookout Rocks) area of the Gregory Granitic Complex and of biotites concentrated from two of them. Crosses marking analyses are symbolic only, and do not represent error limits.

MOUNT CROFTON GRANITE

GEOLOGICAL RELATIONSHIPS

The Mount Crofton Granite (Chin and Hickman, in prep.) underlies an area of approximately 150 km² in the Paterson Range 1:250 000 Sheet area (Fig. 29). The pluton is composed of medium to coarse-grained, unfoliated biotite granite with marginal pegmatitic and late aplitic phases. Its intrusive relationship to the Yeneena Group is visible 100 m south of the road linking Port Hedland and Telfer, about 15 km northwest of Mount Crofton. On a regional scale its contacts cut sharply across pre-existing fold structures in the neighbouring Proterozoic sedimentary rocks. Thus, the Mount Crofton Granite postdates the Yeneena Group and the main episode of deformation in the Paterson Province.

MATERIAL ANALYSED

The exact locations, and petrographic descriptions, of eight total-rock samples of the Mount Crofton Granite used for Rb-Sr isotopic analysis were given by Trendall (1974) and are not repeated here. Biotites were separated from four of the coarse granites among Trendall's samples.

RESULTS

Analytical results for the four biotite samples are given in Table 14. The ages given by projecting each biotite analysis to its parent total rock are, in the numerical order of the table, 568, 580, 592 and 580 m.y., so that there is little scatter about the mean of 580 m.y.

TABLE 14. ANALYTICAL DATA FOR FOUR BIOTITE CONCENTRATES FROM THE MOUNT CROFTON GRANITE

Sample	Rb/Sr	⁸⁷ Rb/ ⁸⁶ Sr	⁸⁷ Sr/ ⁸⁶ Sr
30555	111 ± 2	427 ± 9	4.101 1 ± 0.005 1
30558	188 ± 4	953 ± 20	8.433 9 ± 0.008 4
30559	140 ± 3	601 ± 12	5.678 0 ± 0.004 8
30562	179 ± 4	876 ± 18	7.809 5 ± 0.007 3

DISCUSSION

The three rock bodies from which we report data are about equally spaced along a roughly east-west transect across the eastern margin of the Pilbara Block, and their Rb-Sr systematics thus have an important bearing on its history. The mean biotite age of 580 m.y. from the Mount Crofton Granite, the easternmost of the three, is slightly younger than the two alternative ages, 612 and 594 m.y., suggested by Trendall (1974) to be interpretable from his total-rock analyses from this body. The new data lend greater support to the second of these, with an interpretation of the younger biotite age as an expression of the delay in cooling to the biotite blocking temperature. However, the implied interval of 14 m.y. for this is notably longer than estimates for some eastern Australian granites with more precise Rb-Sr control (Williams and others, 1975; Roddick and Compston, 1976).

The intervals between all these interpretable ages are trivial within the broader time scale of this discussion, and Trendall's (1974) earlier conclusion that the Mount Crofton Granite is a diapiric granite emplaced about 600 m.y. ago, and that it had a prior crustal history no longer than 30-60 m.y., remains valid. This granite cannot have been anatectically derived from an underlying extension of the granitic crust of the Pilbara Block, if this bore any resemblance in Rb-Sr chemistry to Pilbara Block granites studied by de Laeter and Blockley (1972), de Laeter and others (1975), Oversby (1976), or by us in this paper. If the rising diapir penetrated such material it must have done so with minimal contamination by radiogenic strontium.

At the western end of the transect, the data from the Cookes Creek Granite indicate similar general concordance between total-rock and mineral ages; apart from biotite 18416 and total-rock 18415, to which this discussion returns later, the body has an undisturbed age of about 2 600 m.y. This is close to the previously reported ages of other "younger" granites from the eastern Pilbara Block, at Moolyella (de Laeter and Blockley, 1972) and Cooglegong (de Laeter and others, 1975). It is consistent also with Hickman's (1975b) designation of the Cookes Creek Granite, from field evidence, as an Archaean "post-tectonic granite". Like the other younger granites its R_i of 0.7307 is also consistent with a derivation from older granitic crust by partial melting.

With these two very different situations, both in age and origin, at each end of the transect the position in the centre is of critical significance. Here, in the Lookout Rocks area of the Gregory Granitic Complex, the total-rock isochron gives an age closely similar to that of the Cookes Creek Granite. There are, however, two important differences. Firstly, the R_i of 0.7086 is substantially lower than that of the Cookes Creek Granite or the other younger granites; this point is taken up in later discussion.

Secondly, the two Lookout Rocks biotites both give a much younger age, of 1 200 m.y., than the total rock isochron; the significance of these two ages needs assessment in the light of both the geological and other isotopic evidence.

The S5 foliation in the Lookout Rocks area equally affects both the granitic rocks and the adjacent Fortescue Group, the age of which thus sets an upper limit on the age of the granitic rocks. The lowermost lavas of the Fortescue Group were probably erupted about 2 330 m.y. ago (Lewis and others, 1975), although Trendall (1976), in a review of the evidence, has pointed out that the possible age limits imposed by the available data are about 2 700-2 200 m.y. Hickman and de Laeter (1977) have sub-

sequently presented new evidence which can be interpreted as indicating deposition of the Fortescue Group at 2 650 m.y. However, if the Fortescue Group is younger than this, the age recorded by the total-rock samples from the Lookout Rocks area must be interpreted as a real emplacement age which has survived the imposition of the younger S5 foliation. The relative immobility of Rb and Sr during the presumably low-temperature development of this foliation appears consistent with its strongly cataclastic petrographic expression.

If this interpretation is correct, it is not at present possible to assign a definite geological significance to the 1 200 m.y. biotite age, but some limitations can be suggested. The S5 foliation is truncated by, and is therefore older than, the Yeneena Group; it is also deformed by folding correlated with that of the Yeneena Group in the Paterson Province (Hickman, 1975a). Folds in the Yeneena Group are known to pre-date the Bangemall Group (Williams and others, 1976) which is dated at about 1 100 m.y. (Compston and Arriens, 1968; Gee and others, 1976). The Yeneena Group unconformably overlies the Rudall Metamorphic Complex (Williams and others, 1976; Chin and others, in prep.), provisionally dated by one of us (JRdeL) at about 1 500 m.y. (noted in Blockley, 1974). This figure must be treated with caution pending the results of further work in progress, but it suggests, in conjunction with the points already given, that deposition and deformation of the Yeneena Group occurred between 1 500 and 1 100 m.y.

Thus if the 1 200 m.y. biotite be assumed to be the age of the S5 foliation, which is the most immediately attractive hypothesis, it follows that both the deposition and folding of the Yeneena Group took place in a comparatively short, but not impossible, period between 1 200 and 1 100 m.y. Alternatively, our 1 200 m.y. age from Lookout Rocks may be related to the concurrent folding of S5 and the Yeneena Group. If this is so, there is no sign, in our data from the Lookout Rocks area, of any isotopic effect of S5 earlier than 1 200 m.y. but younger than the Fortescue Group.

The 18418 biotite age of 1 800 m.y. from the Cookes Creek Granite falls in this expected interval, but without further work we cannot do more than indicate the possibility of a relationship. Both that age, and the updating of the mylonitic total rock 18415 are clearly related to unknown regional events that only slightly affected this granite.

We return finally to the significance of the low R_i of the 2 650 m.y.-old granitic rocks of the Lookout Rocks area, which we see as an important result of this study. Arriens (1971) first focussed attention on the statistically sharp contrast between periods of largescale granite generation in the two major Archaean areas of Western Australia, the Pilbara and Yilgarn Blocks. In the Pilbara Block the greatest volume of granite is of approximately 3 000 m.y. age, with R_i of about 0.702. In the Yilgarn Block the greatest volume of granite has an age range about 2 700-2 600 m.y., with a similar R_i . In the eastern part of the Pilbara Block the post-tectonic younger granites have the same age, but have R_i s close to 0.73, and occur in relatively small stocks cutting the older granites, from which they are presumed to be anatectically derived.

We suggest the possibility that this later granite-forming event was of vast extent and applied equally to areas of earlier-formed thick granitic crust, and to areas not so covered. In the latter, large volumes of low- R_i granites were generated, but in the former the main effects were the generation of high- R_i material by partial crustal melting at low levels and its upward diapiric penetration in small volumes. In this concept the presence of a low- R_i granite with a 2 650 m.y. age in the Gregory Granitic Complex shows the real existence, between it and Cookes Creek, of an "edge" to the older granitic material of the Pilbara Block. In a petrogenetic, but not necessarily tectonic, sense we picture the granitic rocks in the Lookout Rocks area as more closely related to the Yilgarn Block than the Pilbara Block.

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THE DEPOSITIONAL ENVIRONMENT AND AGE OF A SHALE WITHIN THE HARDEY SANDSTONE OF THE FORTESCUE GROUP

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ABSTRACT

Boron, gallium and rubidium analyses support lithological and stratigraphic evidence that shale collected from the Hardey Sandstone, a formation of the Fortescue Group, was deposited in a fresh-water environment. Rb-Sr isotope analysis indicates that the age of the shale may be between 2 700 and 2 600 m.y., but whether or not this date is a true reflection of the unit's depositional age is uncertain. The possibility that the Hardey Sandstone is 2 600 m.y. old has important implications as to the age of the Proterozoic/Archaean unconformity in the Pilbara Block.

INTRODUCTION

The Hardey Sandstone (MacLeod and others, 1963) conformably overlies the oldest formation of the Lower Proterozoic Fortescue Group in the Pilbara, the Mount Roe Basalt (Kriewaldt, 1964). In many areas this basalt is absent and the sandstone rests directly on steeply inclined Archaean rock. The age of the formation therefore approximates to the age of the Proterozoic/Archaean unconformity, currently the subject of a regional investigation programme.

PREVIOUS GEOCHRONOLOGY

Previous geochronological work relevant to the age of the Hardey Sandstone indicates that it exceeds 2 200 m.y., the reported age of the Weeli Wolli Formation in the Hamersley Group (de Laeter and others, 1974), and that it is close to $2\,329 \pm 89$ m.y., the age of the Black Range Dyke (Lewis and others, 1975), which may be a feeder to the Mount Roe Basalt. The younger age limit for the Hardey Sandstone is firmly established by the age of a major dacite sill which intrudes it. This sill, the Spinaway Porphyry, was dated by Trendall (1975) at $2\,124 \pm 195$ m.y. The older age limit for the formation is far less well defined. South of Nullagine the Cajuput Dyke, a dolerite of the same orientation, composition and size as the Black Range Dyke, is unconformably overlain by shale, pisolitic tuff, sandstone and conglomerate of the Hardey Sandstone. The two dykes probably belong to the same intrusive suite; B. J. J. Embleton (pers. comm.) states that the two dykes are palaeomagnetically indistinguishable.

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