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ISOTOPIC AGES OF ROCKS FROM THE GEORGETOWN/MOUNT GARNET/ HERBERTON AREA, NORTH QUEENSLAND

L.P. BLACK

DEPARTMENT OF NATIONAL DEVELOPMENT

Minister: The Hon. K.E. Newman, M.P.

Secretary: A.J. Woods

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Director: L.C. Noakes, O.B.E.

Assistant Director, Geological Branch: J.N. Casey

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SUMMARY

New isotopic ages indicate that Late Palaeozoic magmatism in the Georgetown/Mt Garnet/Herberton area extended over roughly 60 m.y. During this time there was at least an approximate correlation of volcanic with plutonic activity. Amongst the earliest dates are those determined for the Newcastle Range and Featherbed Volcanics (about 320 m.y.), the Nymbool Granite, and some areas of Elizabeth Creek Granite. A later period, between 314 and 300 m.y., saw the development of relatively basic magmatism (granodiorite to gabbro) in the area. Intrusion of the Mareeba Granite took place about 290 m.y. ago. The final stages of Late Palaeozoic magmatic activity were emplacement of the Trevethan and Finlayson Granites, near Cooktown, and some bodies of Mareeba Granite, and the extrusion of the northwestern segment of the Featherbed Volcanics.

Isotopic data for the Gurrumba Ring Complex show that the total-rock regression represents a mixing line rather than a true isochron. Those for the Featherbed Volcanics reveal a more complex geochronological history than previous isotopic data had suggested. Several analyses on the Hodgkinson Formation indicate possible derivation of these sediments from the Precambrian inlier. However, the initial ratios of the Upper Palaeozoic igneous rocks (mostly 0.707 to 0.717) are generally too low to allow their derivation from either the Hodgkinson Formation or rocks of the Precambrian inlier; a deeper source appears necessary.

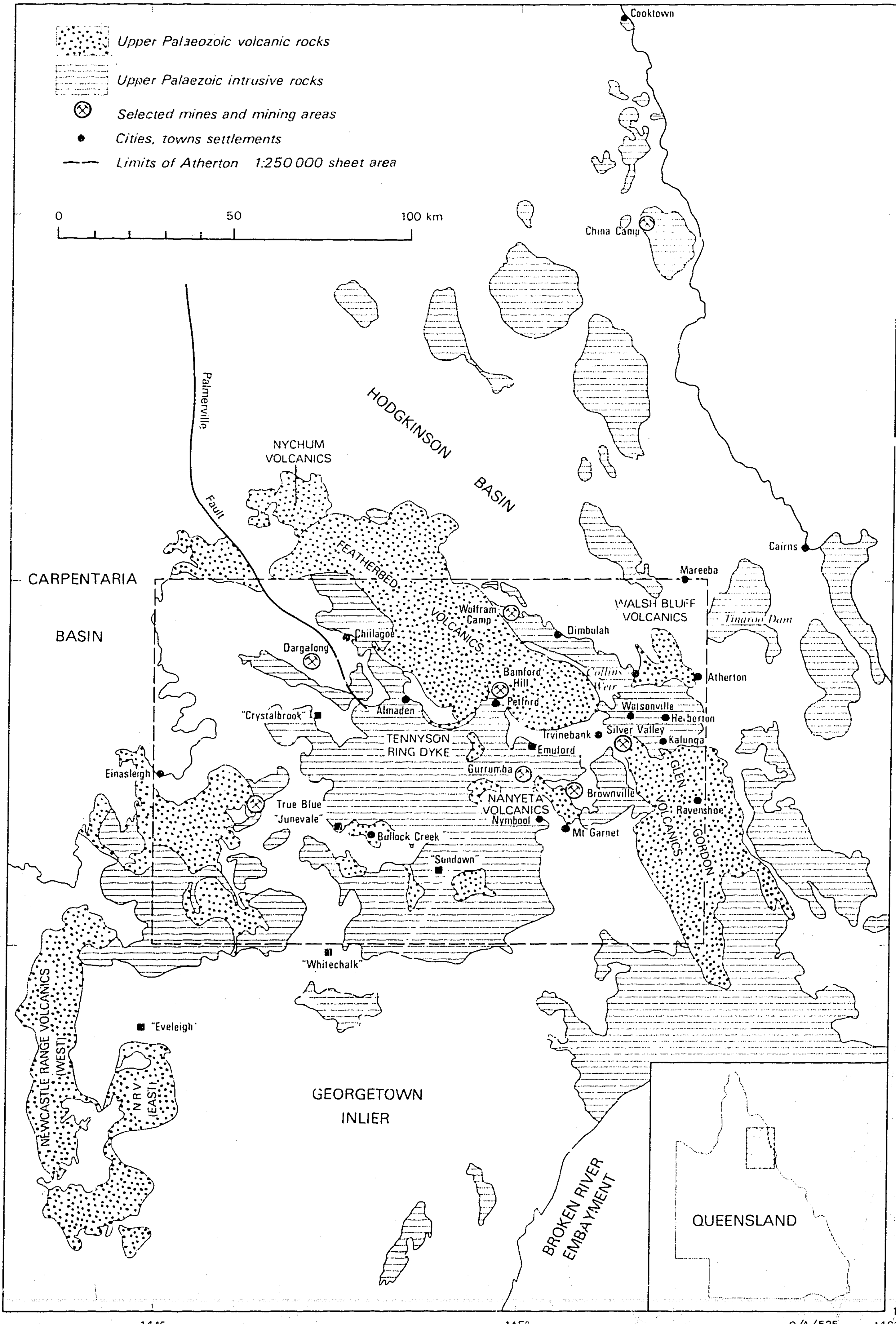

Fig I Locality Map Showing the Distribution of Upper Palaeozoic Igneous Rocks

INTRODUCTION

This study is part of a continuing interest by the Bureau of Mineral Resources in the Georgetown Inlier and its neighbouring rocks since regional mapping began in 1956 (Fig. 1). It represents work done between 1971 and 1974 on samples which were collected from 1961 to 1970. This study is not presented as a final geochronological statement on the Cairns hinterland; sampling and mapping programs are continuing.

In an earlier BMR Record, Black (1973) presented data from a large area of the Georgetown Inlier. With one exception, the Newcastle Range Volcanics, only pre-Carboniferous units were discussed. This paper complements the earlier one in that the analysed igneous units are exclusively Carboniferous or younger, and crop out almost entirely to the east of the inlier. Most sample localities occur in the area covered by the Atherton 1:250 000 Sheet.

In the tables, the names of homesteads are given in inverted commas, and sample numbers in the G.A. series are Australian National University registered numbers.

GEOLOGICAL SETTING

The general summary given here is based on studies by Best (1962), de Keyser & Wolff (1964), White (1965), Branch (1966), Richards et al. (1966), de Keyser & Lucas (1968), and Blake (1972).

The Precambrian Georgetown Inlier of northeast Queensland covers about 90 000 km^2 and is separated from the main Australian Shield 300 km farther west by Mesozoic sediments of the Great Artesian Basin. On its eastern flank is the Palaeozoic Tasman Geosyncline, a regional structure extending the whole length of eastern Australia. In northeast Queensland its width ranges from 80 to 240 km and it contains about 12 000 m of sediments.

Precambrian rock types of the Georgetown Inlier include micaceous schist, garnet-mica schist, andalusite schist, gneiss, migmatite, quartzite, augen gneiss, muscovite pegmatite, quartz amphibolite, and granitic rocks. The metamorphics are faulted and folded and are thought to have been derived from aluminous and siliceous rocks rich in potassium. All rock types except the amphibolites grade into each other.

Palaeozoic sediments are separated from these Precambrian rocks by large faults. The Chillagoe Formation abuts against the northeastern edge of the inlier. Its major component is 1500 to 3000 m of interbedded limestone and chert with minor quartz greywacke, siltstone, conglomerate, sedimentary breccia, and volcanics. The sediments indicate a near-shore, shallow-water, mixed clastic and reef environment. The thickest measured section is 10 000 m. Abundant fossils (particularly corals) indicate a Late Silurian to Early Devonian age.

The Hodgkinson Formation is for the most part stratigraphically younger than the Chillagoe Formation. It is confined to scattered outcrops in the northeastern part of the Atherton Sheet area but continues northwards, where it constitutes the Hodgkinson Basin, a major unit in the Tasman Geosynclinal zone. The Hodgkinson Formation is composed of highly folded beds of sandstone, siltstone, and shale, and minor conglomerate, chert, limestone, and basalt. Included fossils indicate a Silurian to Early Carboniferous age. The great thickness, the general uniformity of sediment type, and the presence of turbidity current structures probably indicate that the Hodgkinson Formation was deposited in a flysch type of environment. Sedimentary rocks in the Broken River Embayment to the south are generally similar in age and lithology.

Siluro-Devonian granites crop out in the southern corner of the Georgetown Inlier. These include the biotite-granite, adamellite, and granodiorite of the Dumbano Granite and a biotite-hornblende tonalite (Sheraton and Labonne, in press) which has been called the Dido Granodiorite. A few small bodies of ultrabasic and basic rocks which occur along prominent faults in the east of the Atherton Sheet area are also thought to be Devonian.

Both the Precambrian inlier and the Palaeozoic geosyncline are covered by large areas of Upper Palaeozoic acid igneous rocks, which form the subject of this study. High-level plutons, ring complexes, and large cauldrons filled with ash flows are extensively developed. Most of the rocks are of a rather uniform acidic composition. Total outcrop area is about 25 000 km^2. These rocks have been interpreted by Branch (1966, 1967) as members of a well defined volcano-plutonic formation.

Most of the volcanic rocks are rhyodacite welded tuffs. Other rocks types, which are also calcalkaline, comprise rhyolite, trachyandesite, andesite, and basalt. The volcanics are almost exclusively confined to cauldron subsidence areas which range from 12 to 120 km long. Eleven of these, with an aggregate outcrop area of 10 000 km^2, have been recognized. Branch estimated the volume of the volcanic rocks at 4000 km^3. Maximum thickness of an individual ash flow is 450 m.

Seven ring complexes, which all contain both volcanic and plutonic members, occur on and to the east of the inlier. The complexes range in size from 400 m^2 to about 10 km^2. Branch considered that the location of both ring complexes and cauldrons is controlled by pre-existing fractures in the Precambrian basement.

Dykes and dyke-swarms are widespread and intrude the bulk of the pre-Mesozoic rocks. Most are rhyodacitic and porphyritic, but trachyandesite, andesite, and dolerite dykes also occur. The dykes are thought to be related to the Upper Palaeozoic volcanic rocks. Five major dyke swarms can be distinguished.

High-level Upper Palaeozoic granitic rocks crop out over a large proportion of the study area and probably underlie much of the remainder at shallow depth. Descriptions of the individual granite types are given in a later section.

Cainozoic basalt provinces cover approximately 15 000 km^2, both within the inlier and outside its eastern margin.

PREVIOUS GEOCHRONOLOGICAL WORK

The pioneering isotopic work on the Cairns Hinterland was presented by Richards et al. as recently as 1966. These authors analysed about 80 samples by the K-Ar method and 6 by Rb-Sr techniques. They demonstrated a long complex history extending back to at least 1460 m.y. The Croydon Volcanics, Esmeralda Granite, Forsayth Granite, and Robin Hood Granite were considered to be Precambrian. Their ages were often, however, influenced by argon loss during a Middle Palaeozoic event associated with the intrusion of the Dido Granodiorite and Dumbano Granite. Richards et al. were unable to demonstrate an age difference between the Elizabeth Creek and Herbert River Granites even though both were intruded over a long time period ($\pm$ 27 m.y.). However, the Mareeba Granite and Upper Permian granites near Cooktown were each formed during a well defined episode. The overall results showed a pattern of episodic igneous progression during the Palaeozoic from southwest to northeast.

Subsequently Black & Richards (1972a, b) presented $Rb^{87}Sr^{87}$, $Th^{232}Pb^{208}$, and $U^{238}Pb^{206}$ results which indicated that the Herbert River and Elizabeth Creek Granites not only were of similar age, but also of similar initial lead and strontium isotopic composition. Thus, it seemed most unlikely that the granites were of different origin as had been postulated by Branch (1966, 1967). In addition, Black & Richards derived an age of

327 ± 5 m.y. for much of the Elizabeth Creek Granite, a value approximately 30 m.y. older than the age they determined for the Featherbed Volcanics. This relation conflicted with the previous deductions by Blake (1968, 1972) from the mineral zonation about a mass of Elizabeth Creek Granite in the Emuford-Irvinebank area. Later, Black & Richards (1972b) discussed the mineralization more fully in the light of new evidence from ore-lead isotopes.

In another study Black et al. (1972) derived a Late Carboniferous age for the Nychum Volcanics. More recently, Black (1973) presented an article containing a series of exclusively pre-Carboniferous ages from the Georgetown Inlier itself. This article was later summarized by Oversby et al. (1973). This study indicated that Rb-Sr mineral ages, as well as the K-Ar dates, have been extensively reset over much of the inlier. Even so, there is compelling evidence for at least two distinct intrusive events during the Precambrian. One of these, the emplacement of the Esmeralda Granite (and formation of the associated Croydon Volcanics) occurred at about 1475 m.y. and most clearly antedated the extensive Upper Palaeozoic igneous rocks on the eastern margin of the inlier. These units were considered to be contemporaneous by some authors (e.g. Branch et al., 1960; White, 1962; Branch, 1966).

The regional isotopic resetting observed in the micas appears to become more pronounced in the east of the inlier, an effect which Black (1973) attributed to the orogenic phase of the adjacent Tasman Geosyncline.

Recently, Sheraton & Black (1973) attempted to relate the trace-element geochemistry of the various granite types with Sn, Pb, Zn, and Cu mineralization. Only generalized ages for the granites were given in that work. The present Report contains all the relevant data from which those generalizations were made. It also presents a series of hitherto unpublished ages on the Upper Palaeozoic volcanic rocks.

EXPERIMENTAL PROCEDURES

Samples used in this study were collected by D.H. Blake, J.W. Sheraton, W.B. Dallwitz, J.R. Richards, C.D. Branch, and the author; gelignite was used for sampling at about half the localities. Each sample was reduced to less than 100 mesh before analysis. Procedures for the separation of Rb are described in Compston et al. (1965); those for Sr are given in Page & Johnson (1974). A spike incorporating both Rb^{85} and Sr^{84} was used. The linear regressions on the isochron diagrams are based on the work of McIntyre et al. (1966). Uncertainties given for both ages and initial ratios are taken at the 95% confidence level. The value $1.39 \times 10^{-11} y^{-1}$ has been used for the Rb^{87} decay constant (Aldrich et al., 1956).

COMPARISON OF NEW Rb-Sr RESULTS WITH PREVIOUS ANALYSES

Thirteen samples, which were originally measured by Black & Richards (1972a), were re-analysed to provide a comparison between the new and previous data. The age calculated from an assumed initial ratio of 0.710 has been used as the comparative isotopic parameter. Table 1 contains those samples which were originally analysed in October 1967 (group 1) and those initially analysed in April 1968 (group 2). The Student's t test has been used to assess the data statistically with the t factor calculated according to the formula

$$t_{11} = \frac{X \quad n}{U}$$

where X = the mean of the percentage differences between the previous and new data for each grouping (each grouping is either those samples originally analysed in October 1967 or those originally analysed in April 1968),

n = the number of samples in each grouping,

TABLE 1. COMPARISON WITH PREVIOUSLY PUBLISHED Rb-Sr RESULTS

Sample No.		Rb	Sr	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age	% Difference
Group 1 (originally analysed in October 1967)							
G.A. 2952	New	230.1	47.03	0.77710	14.223	337.6	
"	Original	232.1	47.91	0.7757	14.08	333.9	+1.10
G.A. 2959	New	173.17	21.32	0.80719	23.68	294.1	
"	Original	173.1	21.44	0.8071	25.53	295.7	-0.54
G.A. 2960	New	513.9	19.973	1.05589	76.82	323.0	
"	Original	494.1	16.30	1.1163	90.93	320.1	+0.90
G.A. 2967	New	281.0	25.05	0.84986	32.84	305.3	
"	Original	298.1	24.77	0.8558	34.19	305.7	-0.13
G.A. 2969	New	436.1	21.25	0.98427	60.86	323.3	
"	Original	446.9	25.31	0.9480	52.18	327.1	-1.18
G.A. 2974	New	276.3	49.12	0.77925	16.357	303.1	
"	Original	260.7	47.07	0.7786	16.10	305.0	-0.63
G.A. series are A.N.U. registered numbers							
Group 2 (originally analysed in April 1968)							
67490001	New	1172.9	13.900	1.9619	273.5	326.1	
"	Original	1210.1	15.00	1.8911	259.9	328.5	+0.74
67490029	New	493.1	16.62	1.10883	89.05	321.3	
"	Original	518.3	16.33	1.1444	95.54	326.2	+1.52
67490097	New	485.3	22.33	1.00382	64.57	326.4	
"	Original	486.3	23.55	0.9898	61.26	327.6	+0.37
67490105	New	343.0	28.96	0.87009	34.74	330.4	
"	Original	343.8	29.94	0.8683	33.71	336.6	+1.88
67490128	New	549.0	20.75	1.06748	79.08	324.3	
"	Original	553.0	20.30	1.0826	81.55	324.5	+ .01
67490132	New	552.9	17.37	1.15401	95.93	332.1	
"	Original	558.2	17.06	1.1655	98.72	331.0	-0.33
67490155	New	507.7	15.25	1.17163	100.49	329.6	
"	Original	503.8	15.12	1.1800	100.7	334.9	+1.61

$$\text{and } U = \frac{7_i\ (x - \bar{x})^2 + 6_i\ (y - \bar{y})^2}{N - 2}$$

where x and x, and y and y refer to the mean and individual values of the percentage differences between the previous and new data for those samples originally analysed in April 1968 and October 1967, respectively, and N = the total number of samples, which is 13.

The results of the t test indicate agreement within the group 1 results. However, the original measurements and re-analysis of group 2 are significantly different from each other at the 95% confidence level. It seems most likely that this 0.9% discrepancy, which arose between October 1967 and April 1968, results from contamination of the isotopic spike which was in use at that time. Analyses determined before November 1967 appear to be directly comparable with the new data presented here. Those analysed in April 1968, which are not, have all been re-analysed.

ISOTOPIC RESULTS

Elizabeth Creek Granite

The most comprehensive descriptions of the Elizabeth Creek Granite are to be found in White (1961), Branch (1966), and Blake (1972). It occurs mainly in the area covered by the Atherton 1:250 000 Sheet, and crops out over a total area of 5000 km^2 at and near the northeastern margin of the Georgetown Inlier. Typically the Elizabeth Creek Granite is a leucocratic biotite adamellite, but grades into alkali granite in places. Salmon to pale pink, orange, white, and grey varieties occur. It is generally medium and even-grained, though porphyritic modifications are also common. The Elizabeth Creek Granite is the most acidic granitic rock in the area, generally containing from 76 to 78% SiO_2. It is essentially free of xenoliths and pegmatitic phases, but is notable for a widely associated greisen, especially in mineralized areas. Aplites are common in some localities.

The Elizabeth Creek Granite intrudes sediments of the Silurian to possibly Lower Carboniferous Hodgkinson Formation, and is overlain by flat-lying Lower Cretaceous sedimentary rocks. It was originally regarded as Carboniferous by Jensen (1923) and Permian by Ball (1923). Later White (1961) and Best (1962) stated that the granite was Upper Permian to Triassic. This estimate was based on palaeobotanical and stratigraphical evidence from the Nychum and Agate Creek Volcanics coupled with the rather insecure grounds of lithological correlation. The K-Ar work of Richards et al. (1966), however, indicated that the Elizabeth Creek Granite is about 282 m.y. old, either latest Carboniferous or earliest Permian. De Keyser & Wolff (1964), Branch (1966), and Blake (1968) have all mentioned the possibility of two slightly different ages for this granite, as stratigraphical relations are not always consistent. For example, the Tennyson Ring Dyke (continuous at least with part of the Featherbed Volcanics) contains boulders of Elizabeth Creek Granite which must antedate the volcanics. In the Bamford Hill and Wolfram Camp area, however, stocks of Elizabeth Creek Granite intrude the Featherbed Volcanics. The reconnaissance dating survey of Richards et al. (1966) may also be interpreted as suggesting two distinct periods of intrusion.

More recent isotopic work using the Rb-Sr (Black & Richards, 1972a) and U-Pb and Th-Pb systems (Black & Richards, 1972b) indicated an age of about 327 $\pm$ 5 m.y. for much of the Elizabeth Creek Granite, in particular the large mass that crops out in the Emuford/Mt Garnet/Ravenshoe area. These authors also acknowledged the presence of Elizabeth Creek Granite of a substantially younger age (e.g. masses at Wolfram Camp and Bamford Hill).

New isotopic data

The new isotopic data for the Elizabeth Creek Granite are presented in Table 2. They show clearly that the term 'Elizabeth Creek Granite' encompasses rocks of various ages. Thus, in this text, the granite has been subdivided into nine groups on a broadly areal basis to facilitate discussion.

TABLE 2. ISOTOPIC DATA FOR THE ELIZABETH CREEK GRANITE

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
68590058	3 km S of Herberton	434.6	48.20	0.83326	26.35		This work
68590068) Biotite)	19 km E of "Sundown"	1281.6	5.410	5.1039	978.2	322	"
68590069	8 km E of Mt Garnet	333.7	12.740	1.05360	78.23	316	"
68590071) Biotite)	5 km SW of "Crystal-brook"	2461	7.385	8.4368	1689.8	328	"
68590080	3 km SE of Herberton	410.1	30.54	0.89152	39.48		"
67490001	10 km SSE of Irvinebank	1172.9	13.900	1.96189	273.5	328	"
67490028	3 km N of Brownville	538.4	23.02	1.02253	69.63	322	"
67490029	1 km S of Emuford	493.1	16.616	1.10883	89.05	321	"
67490029) Biotite)	"	2034	5.361	9.955	2087	319	"
67490039R1*	9 km WSW of Watsonville	678.6	9.125	1.7648	236.9	320	"
67490045R	13 km SE of Dimbulah	496.1	22.13	1.01030	66.66	323	"
67490046R*	"	595.9	4.896	2.5352	414.2	316	"
67490052	18 km W of Atherton	421.9	9.929	1.26818	129.62	309	"
67490054	1 km N of Herberton	420.3	43.75	0.83953	28.09		"
67490070*	5 km SSW of Emuford	445.5	16.157	1.07951	82.51	322	"
67490070R1*	"	633.1	3.636	3.5429	642.3	317	"
67490089	4.5 km W of Nymbool	463.6	20.93	1.00435	65.81	322	"
67490089R1*	"	541.4	6.947	1.8142	249.4	319	"
67490097	13 km NW of Mt Garnet	485.3	22.33	1.00382	64.57	326	

TABLE 2 (Continued)

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
67490098R1	5 km NNW of Nymbool	612.9	3.631	3.4690	619.1	321	"
67490105	8 km W of Mt Garnet	343.0	28.96	0.87009	34.74	330	"
67490111	8 km E of Mt Garnet	334.5	4.070	1.8852	264.6	319	"
67490119	3 km WNW of Brownville	390.7	34.83	0.85741	32.86	323	"
67490120	5 km NW of Brownville	491.0	23.30	0.98980	62.54	322	"
67490121	6 km NW of Brownville	548.6	18.781	1.10854	87.67	326	"
67490121R2*	"	564.6	7.445	1.7686	241.7	315	"
67490128	8 km NNW of Brownville	549.0	20.75	1.06748	79.08	324	"
67490128) Biotite)	"	2624	5.864	13.707	2935	319	"
67490128R1*	"	628.4	4.283	3.0198	519.4	320	"
67490132	8 km N of Brownville	552.9	17.367	1.15401	95.93	332	"
67490132) Biotite)	"	3251	7.933	12.023	2493	326	"
67490155	8.5 km E of Brownville	507.7	15.250	1.17163	100.49	330	"
67490155) Biotite)	"	511.2	5.272	2.1260	318.8	320	"
G.A. 2957) Biotite)	1 km NNW of "Junevale"	1069.2	3.839	6.2197	1238.3	319	"
G.A. 2960) Biotite)	3 km SSW of Emuford	2104	4.643	14.413	3063	321	"
68490014G	10 km WSW of Mt Garnet	315.0	32.50	0.84357	28.36	339**	"
68490022G	14 km SW of Mt Garnet	307.2	16.877	0.95988	53.85	333	"
68490025G	10 km SE of Brownville	482.3	19.343	1.04682	74.44	325	"
68490026G	11 km SE of Brownville	384.5	28.63	0.89233	39.49	331	"

TABLE 2 (Continued)

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
68490027G	4 km NNW of Brownville	489.0	32.05	0.90923	44.92	319	"
68490028G	"	476.9	63.62	0.80461	21.18	322	"
70571002	1 km E of Wolfram Camp	467.2	17.315	1.04934	80.60		"
70571003	1 km S of Wolfram Camp	321.5	23.66	0.88103	39.86		"
70571004	2 km SSW of Wolfram Camp	347.7	28.11	0.86625	36.31		"
70571009	6.5 km N of Bamford Hill	142.07	218.1	0.71764	1.8826		"
70571010	"	284.2	52.17	0.77810	15.837		"
70571011	5.5 km NNE of Bamford Hill	176.22	158.81	0.72272	3.209		"
70571012	"			0.89320	44.20		"
70571016	Bamford Hill	181.27	148.89	0.72411	3.521		"
70571017	"	356.2	20.09	0.92672	52.30		"
70571022	5 km SSE of Petford	250.1	98.17	0.74167	7.380		"
70571041	4.5 km WSW of Petford	137.43	149.67	0.72162	2.655		"
70571042	"	187.98	131.32	0.72879	4.142		"
70571286	"	239.1	114.17	0.73529	6.065		"
70571287	3.5 km W of Petford	214.4	127.99	0.73082	4.848		"
70571289	3 km SE of Petford	240.4	95.52	0.74080	7.291		This work
G.A. 2967	6 km SW of Petford	298.1	24.77	0.85581	34.19		Black & Richards (1972a)

TABLE 2 (Continued)

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
68590067	24 km S of Sundown Turnoff on Hann Highway	1302.5	6.610	3.6507	732.7	288	This work
68590107) Biotite)	8 km NE of "Whitechalk"	750.2	8.822	1.8231	272.3	293	"
G.A. 542) Biotite)	"	1423.1	4.361	6.9375	1516.6	295	"
68590108) Biotite)	"	2356	6.064	9.0710	2040	294	"

* denotes aplitic sample

**This age is probably too old, owing to contamination by country rock as evidenced by included xenoliths.

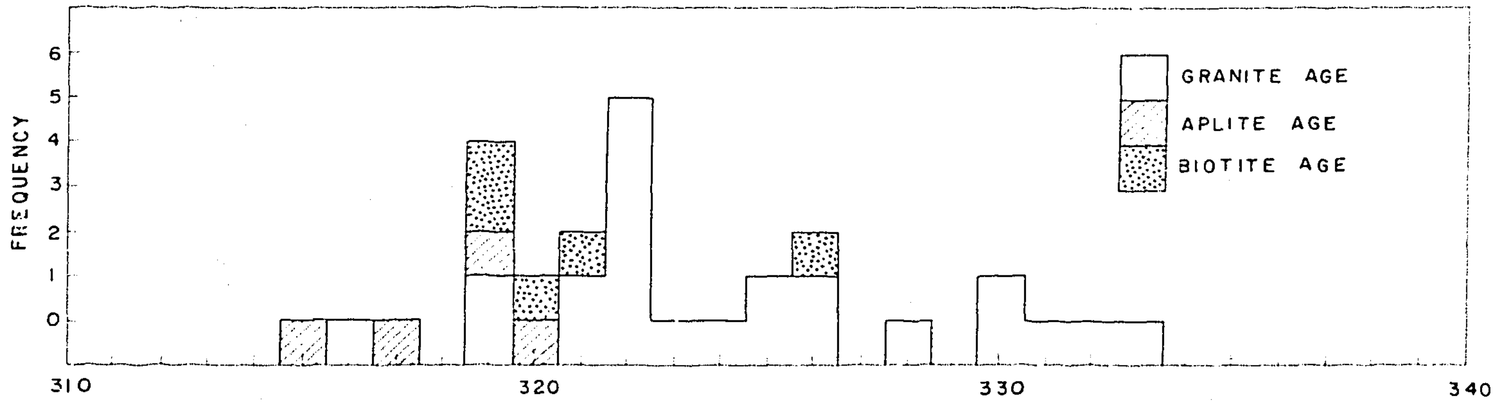

FIG 2 HISTOGRAM OF AGES FOR THE ELIZABETH CREEK GRANITE IN THE EMUFORD/IRVINEBANK/MT GARNET AREA

Emuford/Irvinebank/Mt Garnet area This grouping incorporates two large and several smaller granite masses in the Herberton and Mt Garnet 1:63 360 Sheet areas, with boundaries at Emuford in the north, Gurrumba in the west, and 7-mile Hill and the Wild River in the south and east. This is the Elizabeth Creek Granite which Blake & Smith (1970) considered to be associated with the metalliferous zoning in the Emuford-Irvinebank area.

The granite is enriched in Rb with respect to Sr to such an extent that it is possible to estimate ages from individual analyses. Errors arising from initial ratio assumptions are for the most part less than 5 m.y., and almost always less than 10 m.y. for each change of 0.005 in estimated initial ratio. Ages quoted in Table 2 and shown in Figure 2 have been calculated using an initial Sr^{87}/Sr^{86} ratio of 0.710, a value determined previously (Black & Richards, 1972a) to be broadly representative of both the Herbert River and Elizabeth Creek Granites. A total of 32 ages are plotted in the figure. Those representing biotite separates are more precisely defined than the total-rock ages; any change in assumed initial Sr^{87}/Sr^{86} ratio of 0.005 alters the calculated age by less than 1 m.y. The mean age of the 32 results is 323 $\pm$ 2 m.y. This compares with an isochron age of 320 $\pm$ 2 m.y. (initial ratio = 0.714 $\pm$ 0.004 when regressed according to the method of McIntyre et al., 1966). The high precision relates only to the certainty to which the mean age is known, for, if the initial ratio assumptions are correct, there is an indicated age range of 18 m.y. It seems unlikely that the derived ages could be influenced by any inter-rock redistribution of isotopes after original closure of the isotopic system at this high crustal level. However, it is conceivable that samples that fall in the upper part of the range (i.e. with indicated ages of 330 m.y. and older) could yield slightly old age estimates through erroneous initial ratio assumptions. Indeed, initial ratios ranging up to 0.722 have been found for the Upper Palaeozoic rock units. Table 3 indicates that if initial ratios of up to 0.725 should apply, then all these 'old' granites would have ages no greater than 321 m.y. Even though these 'old' indicated ages may be treated with caution, there seems little doubt that there is a real spread of ages for the Elizabeth Creek Granite in this area. Sample 67490001 is sufficiently enriched in Rb with respect to Sr to require an initial ratio in excess of 0.74 before an age as young as 322 m.y. could be derived. Biotite sample 67490121 (with an indicated age of 326 m.y.) would require the substantially higher initial ratio of 0.83 to fulfil this requirement. Thus, it seems as if the small peak on the histogram at about 326 m.y., which agrees with the age derived for much of the Elizabeth Creek Granite by Black & Richards (1972a), may be significant. However, Figure 2 clearly indicates a dominant period of intrusion between 319 and 322 m.y. The effects of this event have, in places, been sufficiently marked to reset the biotite ages of previously intruded Elizabeth Creek Granite (e.g. samples 67490128 and 67490155). The possibility of intrusion at about 320 m.y. was previously alluded to by Black (1969).

TABLE 3. AGES OF ELIZABETH CREEK GRANITE FOR DIFFERENT ASSUMED INITIAL Sr^{87}/Sr^{86} RATIOS

Sample No.	Initial Ratio used for Age Calculation .710	.715	.720	.725	.73	.74
			Age (m.y.)			
67490001	328	327	326	325	324	323
67490097	326	321	315			
67490121	326	325	324	323		
67490128	324	320	315			
67490132	326		325			325
Biotite						
68490025 G	325	320	315			
67490105	330	320	310			
67490132	332	328	325	321		
67490155	330	327	323	319		
67490022 G	333	326	319			
67490026 G	331	322	313			

The four aplite samples (67490070 R1, 67490089 R1, 67490121 R2, and 67490128 R1) appear to yield reliable ages for they are highly enriched in Rb with respect to Sr (values greater

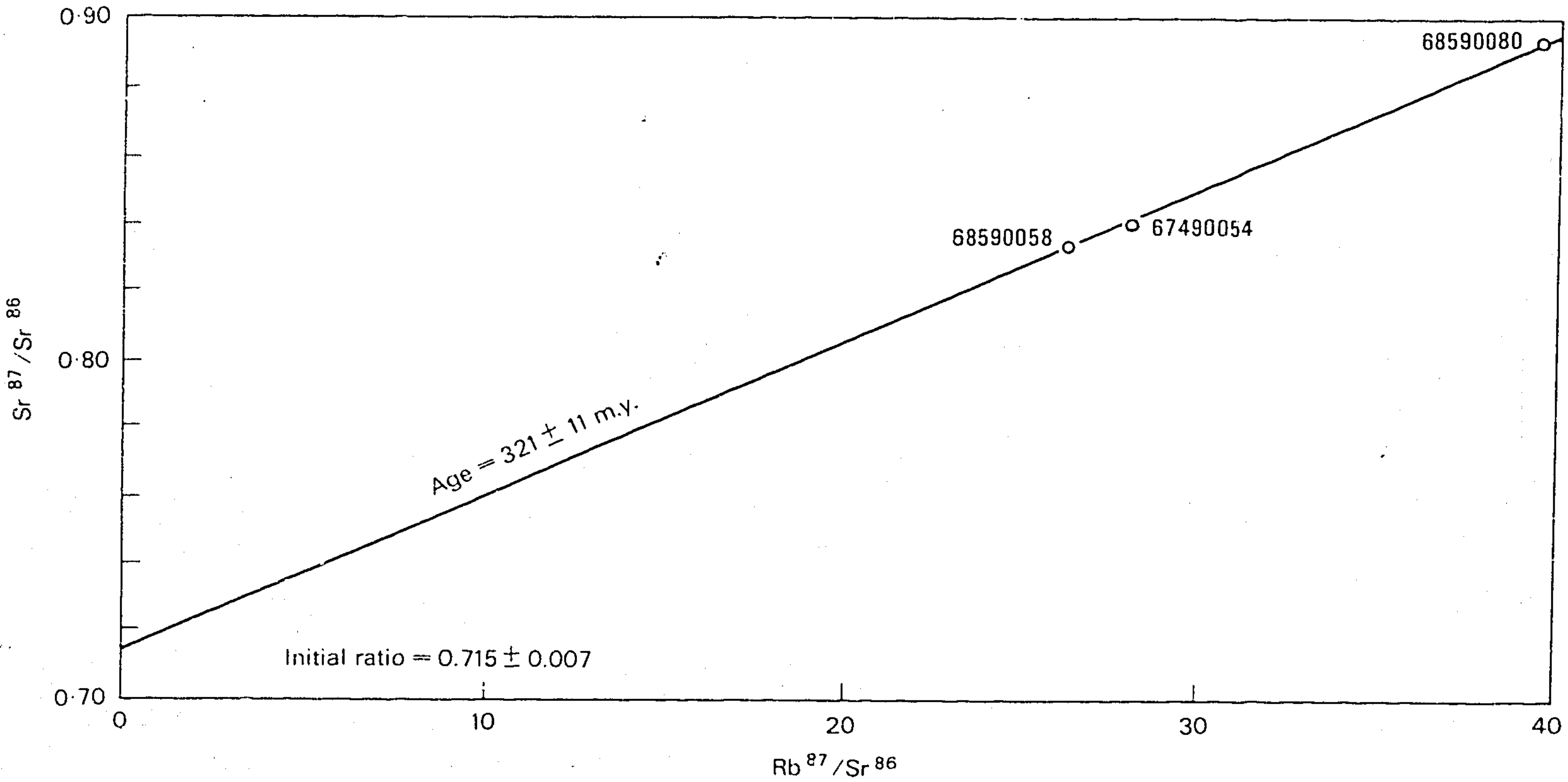

Fig 3 Isochron Diagram for the Elizabeth Creek Granite in the Herberton Area

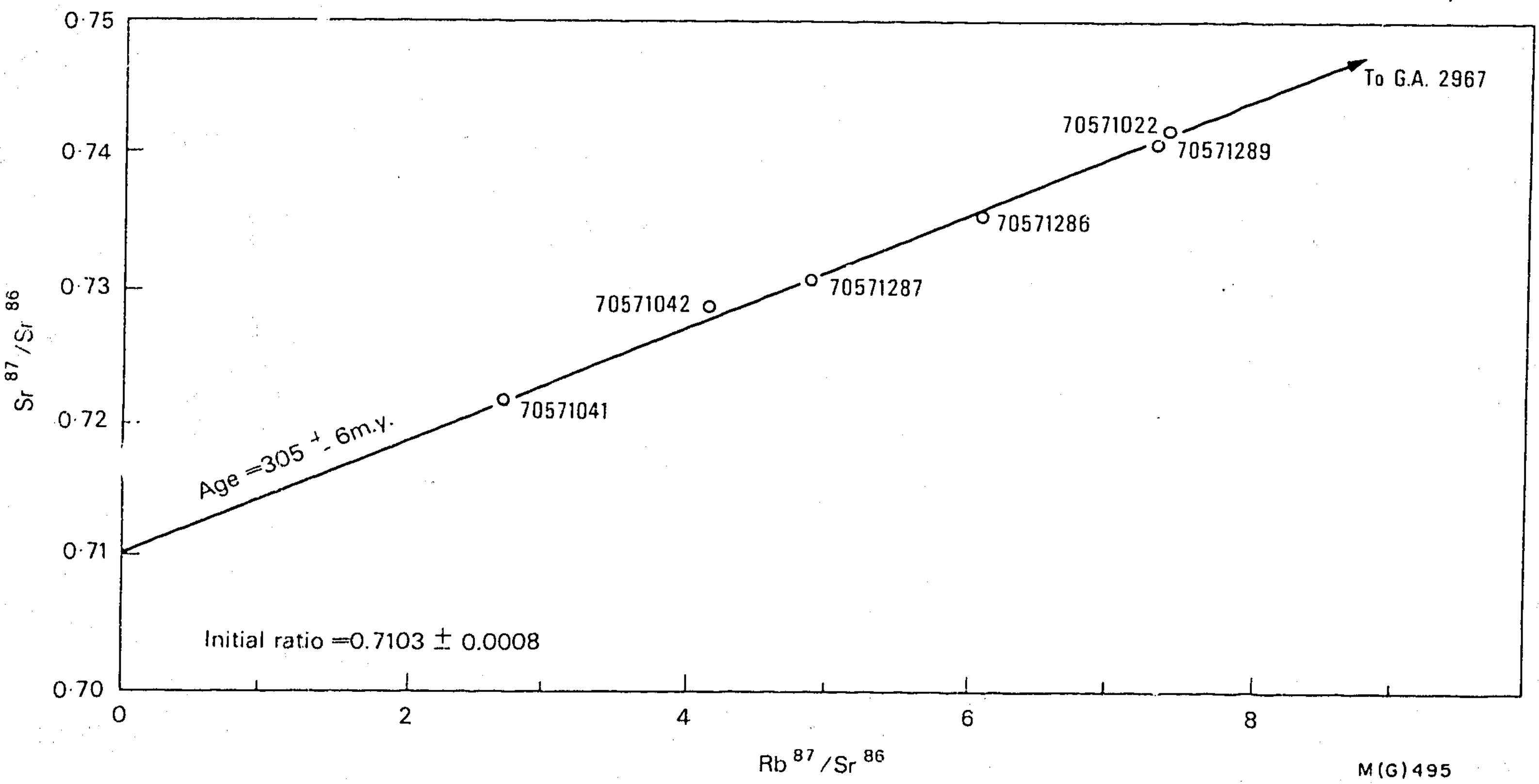

Fig 4 Isochron Diagram for the Elizabeth Creek Granite in the Petford Area

than 240). Student's _t_ test indicates that the 6 m.y. age difference from the host granitic rock (67490070, 67490089, 67490121 and 67490128) is significant at the 99% confidence level.

In summary, the isotopic information indicates possible granite intrusion at 326 m.y. and a definite event at about 320 m.y. The possibility of intrusion extending back to 330 m.y. must be considered with caution at the moment, for an explanation involving high initial Sr^{87}/Sr^{86} ratios may be applicable. Aplite formation at about 318 m.y. was significantly later than these granitic events.

Herberton area (Fig. 3) An isotopic age of 321 $\pm$ 73 m.y. has been determined for the mass of Elizabeth Creek Granite which crops out around the township of Herberton. The large uncertainty reflects only the small number of samples (68590058, 68590080, and 67490054) rather than isotopic scatter, for the analytical points fit the isochron within the limits of experimental uncertainty (mean square of weighted deviates (MSWD = 3.1). If we are prepared to assume an original isotopic equilibrium between the whole-rock samples, and subsequent chemical closure (such assumptions can only be made when the regressed points fulfil Model 1 requirements - see McIntyre et al., 1966), we obtain two more degrees of freedom, thereby reducing the age uncertainty limits to $\pm$ 11 m.y. (initial ratio = 0.715 $\pm$ .007).

The body of Elizabeth Creek Granite at Herberton, then, is indistinguishable in age from that in the Emuford/Irvinebank/Mt Garnet area.

Watsonville area Sample 67490039 R1, from 9 km WSW of Watsonville township, provides the only age estimate of the Elizabeth Creek Granite in this area. As it is highly enriched in Sr^{87} it yields an age (320 m.y.) which is virtually independent of initial ratio assumptions. This age is effectively the same as those for the aplites to the southwest (discussed above). Thus it appears that the Elizabeth Creek Granite in the Watsonville area may correlate, in broad terms at least, with the Elizabeth Creek Granite in the Emuford - Irvinebank area.

Dimbulah area Two samples have been taken, about 1 km apart, from the elongate mass of Elizabeth Creek Granite that crops out to the southeast of Dimbulah. Both are sufficiently enriched in Sr^{87} to allow independent age estimates; the value 0.71 has been used for the initial Sr^{87}/Sr^{86} ratio in these calculations. The porphyritic granite (67490045 R) yields an age of 323 m.y. This estimate will change by 5 m.y. for any change of 0.005 in assumed initial ratio. The age of the aplite (67490046 R) is more precisely determined at 316 m.y. Possible errors resulting from initial ratio assumptions amount to 1 m.y. for each change of 0.005 in initial ratio.

Thus, even though the data from this mass are sparse, they nevertheless suggest a conformity with the Elizabeth Creek Granite groups already discussed.

Collins Weir area Sample 67490052 was collected 2 km northeast of Collins Weir. The granite at this locality was originally mapped as Herbert River type (see Atherton 1:250 000 Sheet area), but has since been redefined by Blake (1972) as Elizabeth Creek type. The age estimate for this sample of 309 m.y. is altered by 2 m.y. for any change of 0.005 in assumed initial ratio. It would appear, then, that this phase of the Elizabeth Creek Granite is slightly younger than those discussed in the sections above.

Petford area (Fig. 4) De Keyser & Wolff (1964) subdivided the granitoid rocks of the Chillagoe district into six groups. In the Petford area they distinguished both fine and coarse-grained varieties of Elizabeth Creek Granite, and a pink or grey fine-grained hornblende-bearing biotite granite which was tentatively also ascribed to this granite-type. De Keyser & Wolff considered the latter, which is the subject of this section, to possibly represent the youngest intrusion in the area. It crops out over about 80 km^2 to the south of Petford.

Samples were taken from seven sites around the southern margin of the intrusion. These yield an age of 305 $\pm$ 6 m.y. and initial ratio of 0.7103 $\pm$ .0008. The analytical points do not fit the regression within the limits of experimental error, but appear to fulfil model III conditions (see McIntyre et al., 1966), suggesting a common age but slightly different initial ratio for the suite.

Thus, this intrusion is slightly younger than the Elizabeth Creek Granite to the south and east but possibly contemporaneous with that near Collins Weir.

Wolfram Camp area (Fig. 5) De Keyser & Wolff (1964) identified an intrusion of Elizabeth Creek Granite in the Wolfram Camp area which, on the basis of apparent marginal chilling, they considered to postdate the adjacent Featherbed Volcanics. Three samples (70571002, 70571003, and 70571004) with moderate enrichment in Sr^{87} yield an age of 297 $\pm$ 37 m.y. and initial ratio of 0.716 $\pm$ .023. Since the points fulfil model 1 conditions (MSWD = 0.01), it may be justifiable to assume isotopic equilibration and subsequent chemical closure between samples, thereby reducing the uncertainty limits. The new isotopic parameters then become 297 $\pm$ 6 m.y. and 0.716 $\pm$ .004. Application of the Student's t test reveals that this age is not significantly different (at the 95% confidence level) from that of the Elizabeth Creek Granite in the Petford area (discussed above). However, the t test does show that the initial Sr^{87}/Sr^{86} ratios are indeed significantly different at the 95% confidence level. Hence, these two granites appear to have been formed at about the same time from source regions with different isotopic characteristics. Alternatively, the original magmas could have been related, with subsequent isotopic contamination in the case of the Wolfram Camp mass.

Bamford Hill area (Fig. 6) Several small stocks of Elizabeth Creek Granite intrude the Featherbed Volcanics along a lineament extending northwards from Bamford Hill. Six samples from three of these intrusions were selected for analysis. When regressed, these yield a model III isochron with age 298 $\pm$ 6 m.y. and initial ratio 0.710 $\pm$ .002. If sample 70571010 is omitted the MSWD for the regression is reduced from 14.6 to 2.5, a value indistinguishable from unity for this number of samples. It is felt that the attainment of this low MSWD is sufficient justification for the

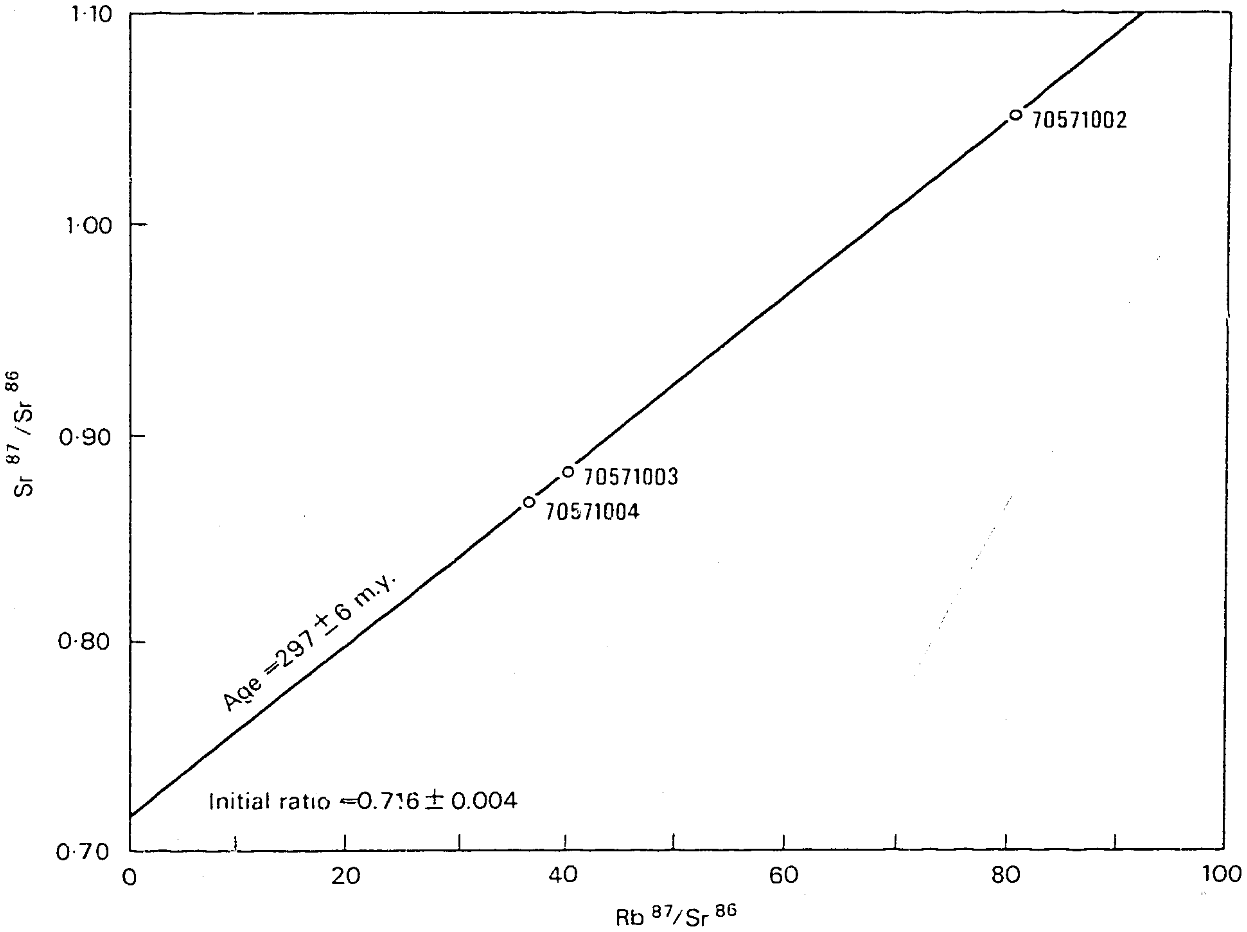

Fig 5 Isochron Diagram for the Elizabeth Creek Granite in the Wolfram Camp Area

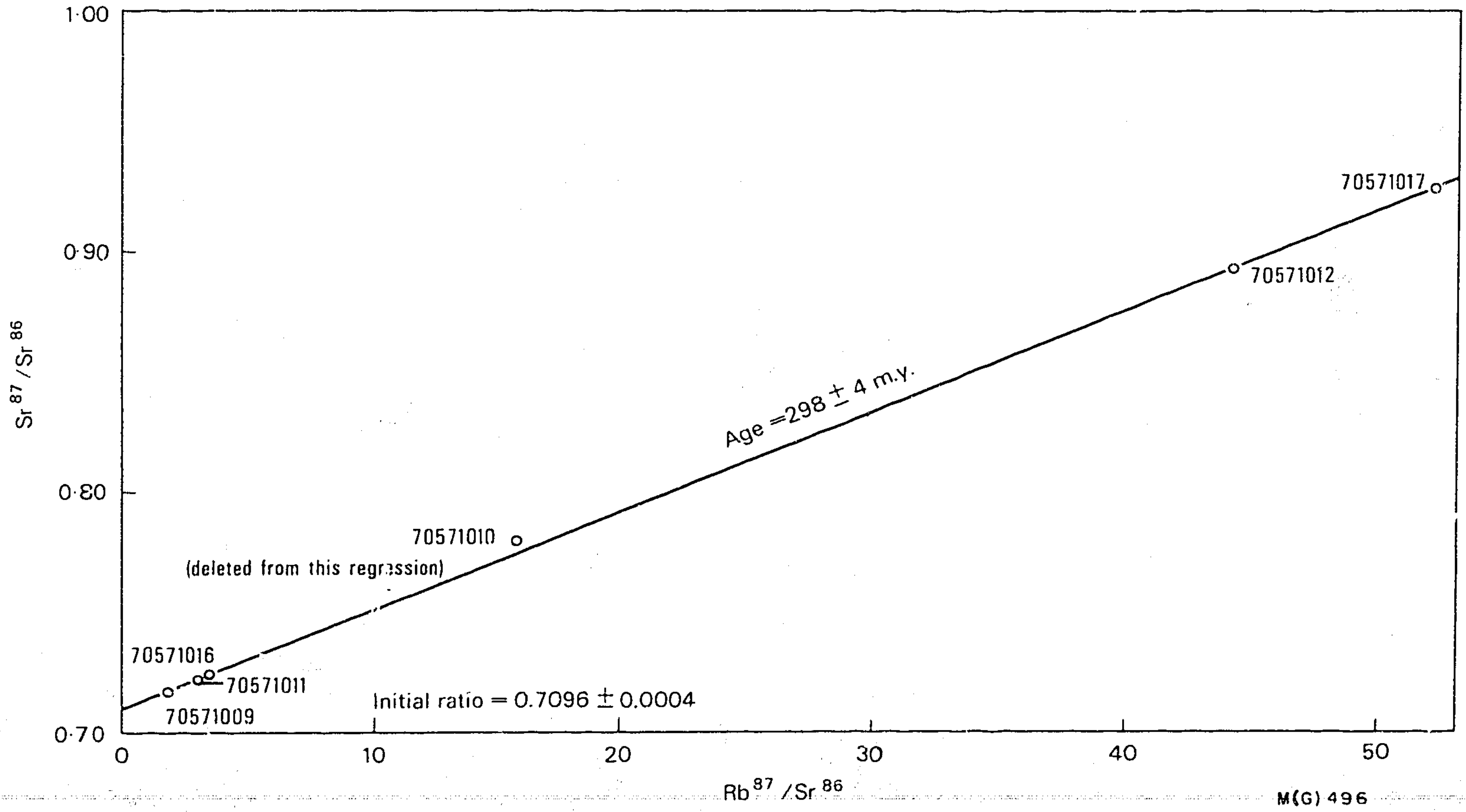

Fig 6 Isochron Diagram for the Elizabeth Creek Granite in the Bamford Hill Area

alternative regression, even in the absence of supporting geological criteria to justify the omission of sample 70571010. An age of 298 ± 4 m.y. and initial ratio 0.7096 ± .0004 are deduced from the regression through samples 70571009, 70571011, 70571012, 70571016, and 70571017 alone. If this regression is indeed valid it can be said that the Elizabeth Creek Granite around Bamford Hill cannot be distinguished in age from the granite at Wolfram Camp. However, their initial Sr^{87}/Sr^{86} ratios are clearly different. On the other hand, the 8 m.y. age difference between the Bamford Hill and the Petford intrusions appears to be significant at the 95% confidence level; the initial ratios of these granites, however, are mutually indistinguishable.

The results show, then, that even over the relatively restricted distance of 40 km southwards from Wolfram Camp there are three varieties of Elizabeth Creek Granite distinguishable by either initial ratio or age differences.

'<u>Western area</u>' Seven analyses have been made on isolated samples of Elizabeth Creek Granite from the southern and western parts of the Atherton 1:250 000 Sheet area. As each age has been determined on a mica concentrate it is virtually independent of initial ratio assumptions, and the maximum age shift resulting from a possible error of 0.005 in initial ratio is less than 2 m.y. Samples 68590068, 68590071, and G.A. 2957 (designated by Richards et al. (1966) as a 'hybrid' granite), from 20 km east of Sundown homestead, 5 km southeast of Crystalbrook homestead, and 1 km north of Junevale homestead, respectively, yield ages of 322, 328, and 319 m.y. Thus, they would appear to correlate with the large mass of Elizabeth Creek Granite in the Emuford-Irvinebank area.

Samples from two localities farther south yield ages which are at least as young as the Elizabeth Creek Granite in the Bamford Hill and Wolfram Camp areas. The age of sample 68590067, from the Hann Highway at the southern extremity of the Atherton Sheet area, is about 288 m.y. Those derived for samples 68590107, G.A. 542, and 68590108, all collected 8 km northeast of Whitechalk homestead, are 293, 295, and 294 m.y. This locality is 36 km from that for sample site 68590067, suggesting a fairly extensive outcrop of this young phase of the Elizabeth Creek Granite at the southern margin of the Atherton Sheet area.

Summary The overall evidence indicates that the Elizabeth Creek Granite was intruded over at least a 30 m.y. period. The granite at the eastern end of the Featherbed Volcanics near the towns of Dimbulah, Emuford, Mount Garnet, Irvinebank, and Herberton, at about 320 to 325 m.y., is oldest. Associated aplite formed at about 317 m.y. To the west of this area, in a north-south lineament running 40 km southwards from Wolfram Camp, is an area containing younger Elizabeth Creek Granite. Even within this restricted area there appear to be two intrusive periods (at 297 ± 4 and 305 ± 6 m.y.). Preliminary data indicate that Elizabeth Creek Granite of the same age as that in the Emuford-Irvinebank mass occurs as far west as Crystal Brook and Junevale homesteads. Elizabeth Creek Granite of the same age or possibly even slightly younger than that in the Wolfram Camp/Bamford Hill lineament occurs in at least two locations in the extreme south of the Atherton Sheet area. Indicated initial Sr^{87}/Sr^{86} ratios for the Elizabeth Creek Granite range from 0.710 to 0.716.

Herbert River Granite

A broad twofold classification of Upper Palaeozoic granite in the Chillagoe/Herberton/Mt Garnet area into Elizabeth Creek and Herbert River types was used by BMR officers during regional mapping. Both terms have continued to be used by most workers, e.g. de Keyser & Wolff (1964), White (1965), Branch (1966), and de Keyser & Lucas (1968). However, Blake (1972) in subsequent work in the Herberton and Mt Garnet 1:63 360 Sheet areas has subdivided the Herbert River Granite into six granite types and discontinued use of the term altogether. He considered that it was originally a 'hold-all' name to include all those granites not classed as Elizabeth Creek Granite, and as such had little meaning. Thus, in this work, the term Herbert River Granite will be used in most cases to refer to rocks cropping out to the south and west of the Featherbed Volcanics. It does not include rocks from the Herberton and Mt Garnet Sheet areas. No samples from the type location at the Herbert River Falls have been dated.

The most comprehensive descriptions of the Herbert River Granite are given in White (1961), Best (1962), de Keyser & Wolff (1964), Branch (1966), and de Keyser & Lucas (1968). The granite crops out over 2000 to 3000 km^2 of the Einasleigh and Atherton Sheet areas, along the southern border of the Hodgkinson Basin and in the adjoining inlier. It is predominantly a medium-grained grey biotite adamellite with porphyritic pink alkali feldspar; in places it grades into hornblende-biotite granodiorite. Branch (1966) has determined a SiO_2 range for this rock type of 65-77%. No greisen has been found associated with this granite. Branch reported that aplite, pegmatite, xenoliths (generally basic and small), flow foliation, and lineation are uncommon.

The Herbert River Granite intrudes the Hodgkinson Formation and is reputed by field workers to be intruded by the Elizabeth Creek Granite. Early age estimates (e.g. White, 1961; Best, 1962) range from Carboniferous to Early Triassic.

A series of K-Ar analyses by Richards et al. (1966) indicated a mean age (286 m.y.) statistically indistinguishable from the Elizabeth Creek Granite, even though both were intruded over a long time period ($\pm$ 27 m.y.). Black & Richards (1972a) were likewise unable to demonstrate a significant Rb-Sr age difference between the two granite types. These authors were, however, only able to derive a relatively imprecise age (318 $\pm$ 56 m.y.) for the Herbert River Granite.

TABLE 4. ISOTOPIC DATA FOR THE HERBERT RIVER GRANITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
G.A. 505 Biotite	2 km NE of "Mt Cardwell"	393.0	7.396	1.38389	163.56	296	This work
68590074 Biotite	3 km E of True Blue mine	1298.5	6.696	4.1296	747.3	328	"
68590078 Biotite	8 km W of Dimbulah	1591.2	6.308	5.2410	1051.2	309	"
70571279	3 km SW of Ootann	264.9	67.41	0.77008	11.415		"
70571280	2 km W of Ootann	159.49	166.75	0.72386	2.766		"
70571281	3.5 km N of Ootann	261.3	84.50	0.74724	8.963		"
70571282	6 km NNE of Ootann	225.9	157.52	0.7271	4.149		"
70571284	3 km N of Almaden	265.9	64.15	0.76010	12.028		"
G.A. 2955	6 km SW of Dargalong	169.50	133.01	0.72810	3.688		Black & Richards (1972a)
G.A. 2955 Biotite	"	494.4	3.955	2.5091	424.5	305	This work
G.A. 2965	6 km ESE of Almaden	220.6	162.82	0.72639	3.920		Black & Richards (1972a)
G.A. 2965 Biotite	"	553.2	17.394	1.11358	95.48	304	This work
G.A. 2968	2 km E of "Mt Cardwell"	63.32	378.5	0.71231	0.4828		Black & Richards (1972a)
G.A. 2977	6 km ESE of Almaden	241.6	121.30	0.73462	5.769		"
G.A. 2978	6 km SE of Almaden	221.5	158.89	0.72950	4.032		"
G.A. 2979	9 km SSW of Almaden	155.01	154.42	0.72488	2.902		"

<u>New isotopic data</u> (Table 4)

Ten total-rock samples are included in the regression for the Herbert River Granite. A further sample, 70571279, does not fall near the isochron and has been discarded. Eight samples come from a 20-km long intrusion to the south of Almaden. A ninth comes from an adjoining west-northwest trending intrusion to the west of Dargalong. A previously analysed sample (Black & Richards, 1972a) of reputed Herbert River Granite type from Mount Cardwell homestead (G.A. 2968), has also been included. In all, an additional four analyses over those reported in Black & Richards (op. cit.) are reported here.

The large MSWD for the regression of 22.6 probably results mainly from initial ratio differences, as is indicated by the computer-selected model III interpretation. An age of 288 $\pm$ 18 m.y. and initial ratio of 0.7115 $\pm$ .0017 are obtained. If the analyses of the supposedly related Almaden Granite reported in the following section are included, an age of 298 $\pm$ 15 m.y. and initial ratio of 0.7104 $\pm$ .0011 are obtained according to the assumptions of model II fit. The first age would appear preferable, as the Almaden Granite may not have been subjected to complete isotopic homogenization (see Black & Richards, 1972a)

Five new biotite analyses are now available to complement the total-rock data (Fig. 7). One of these (G.A. 2965), which was collected from the main intrusion to the south of Almaden, yields an age of 304 m.y. Another biotite sample (G.A. 2955), from the west-northwest trending intrusion to the west of Dargalong, gives an age of 305 m.y. This is almost certainly the time of emplacement of the Herbert River Granite in the Almaden-Dargalong region, for not only are the two biotite ages concordant with each other, but they also agree with those of the adjoining Almaden Granite (see next section). The fact that both biotite ages plot at the upper limit of the indicated isochron age probably reflects a slight under-estimation of the mean age or uncertainty limits, for it is difficult to envisage a mechanism whereby these biotite concentrates could yield too old an age.

Sample 68590074, from 3 km east of the True Blue fluorite mine, was originally identified as Herbert River Granite by Richards et al. (1966) during collection. On the basis of its petrology, however, it may well represent Elizabeth Creek Granite type. Its age of 328 m.y. is similar to many Elizabeth Creek Granite ages in the east, but older than any Herbert River Granite or Almaden Granite ages found to date.

A sample (68590078) collected 8 km west of Dimbulah yields a biotite age of 309 m.y. This is only slightly older than the nearby Elizabeth Creek Granite at Wolfram Camp (10 km distant) and similar in age to the large mass of Herbert River Granite near Almaden.

A biotite age of 296 m.y. has been obtained for sample G.A. 505, classed as Herbert River Granite type by Best (1962) and Branch (1966), which come from the central unit of the Claret Creek Ring Complex. This age is remarkably similar to those of the granites in the Wolfram Camp/Bamford Hill lineament. Furthermore, this Herbert River Granite stock appears to lie on a southern extension of the lineament, suggesting a distinct zone of relatively young (309 to 296 m.y.) ages.

The indicated age of the Herbert River Granite broadly coincides with some Elizabeth Creek Granite intrusions. Currently, however, there are no examples of undisputed Herbert River Granite samples as old as the oldest Elizabeth Creek Granite (i.e. the 320 and possibly 326 m.y. events indicated in the Emuford - Irvinebank mass).

Almaden Granite

Descriptions of the Almaden Granite are given in de Keyser & Wolff (1964), Branch (1966), Richards et al. (1966), and de Keyser & Lucas (1968). Branch considered that it is derived from the assimilation of basic material by Herbert River Granite magma. The granite crops out over 500 km^2 in a north-northwest-

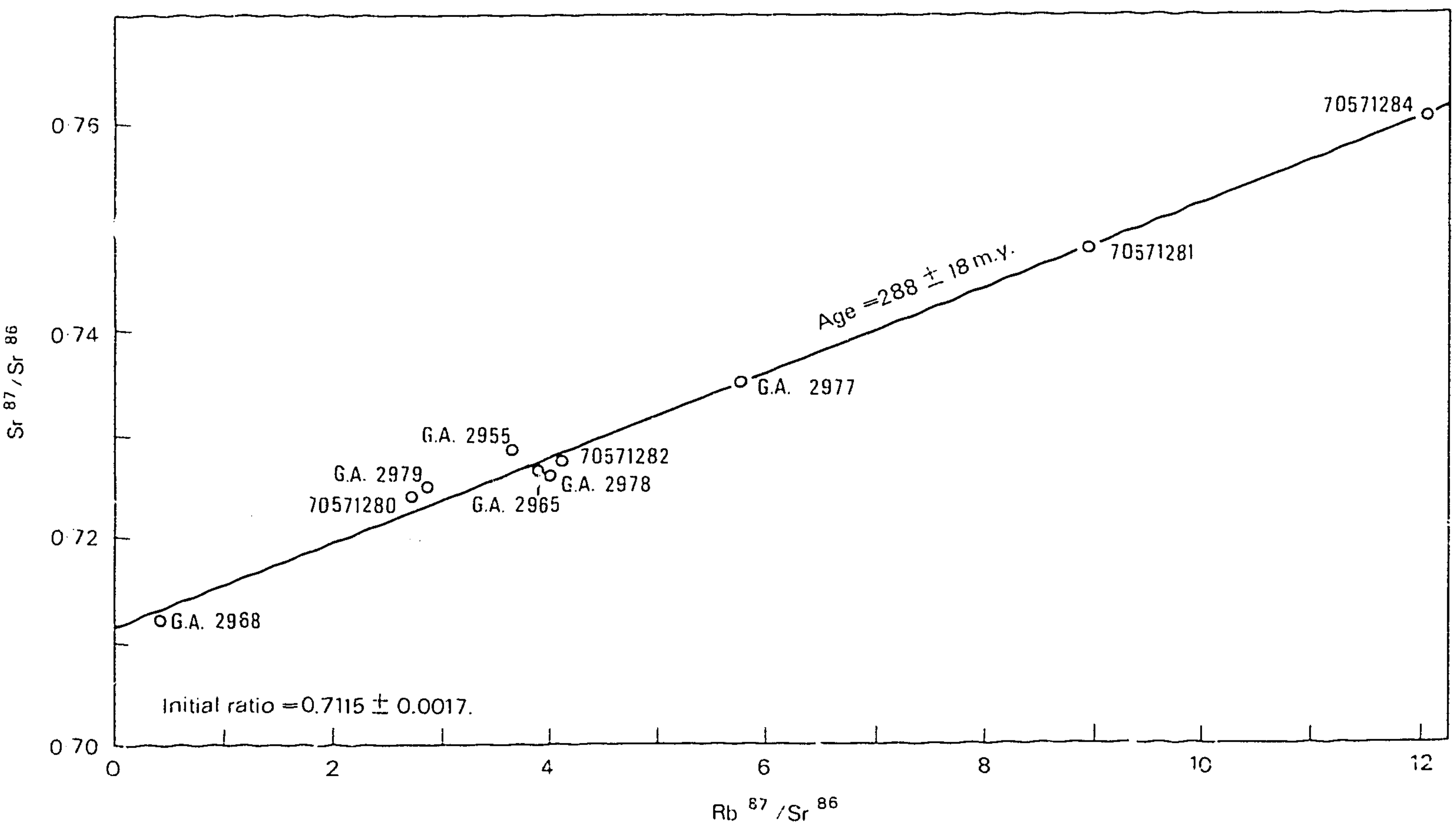

Fig 7 Isochron Diagram for the Herbert River Granite

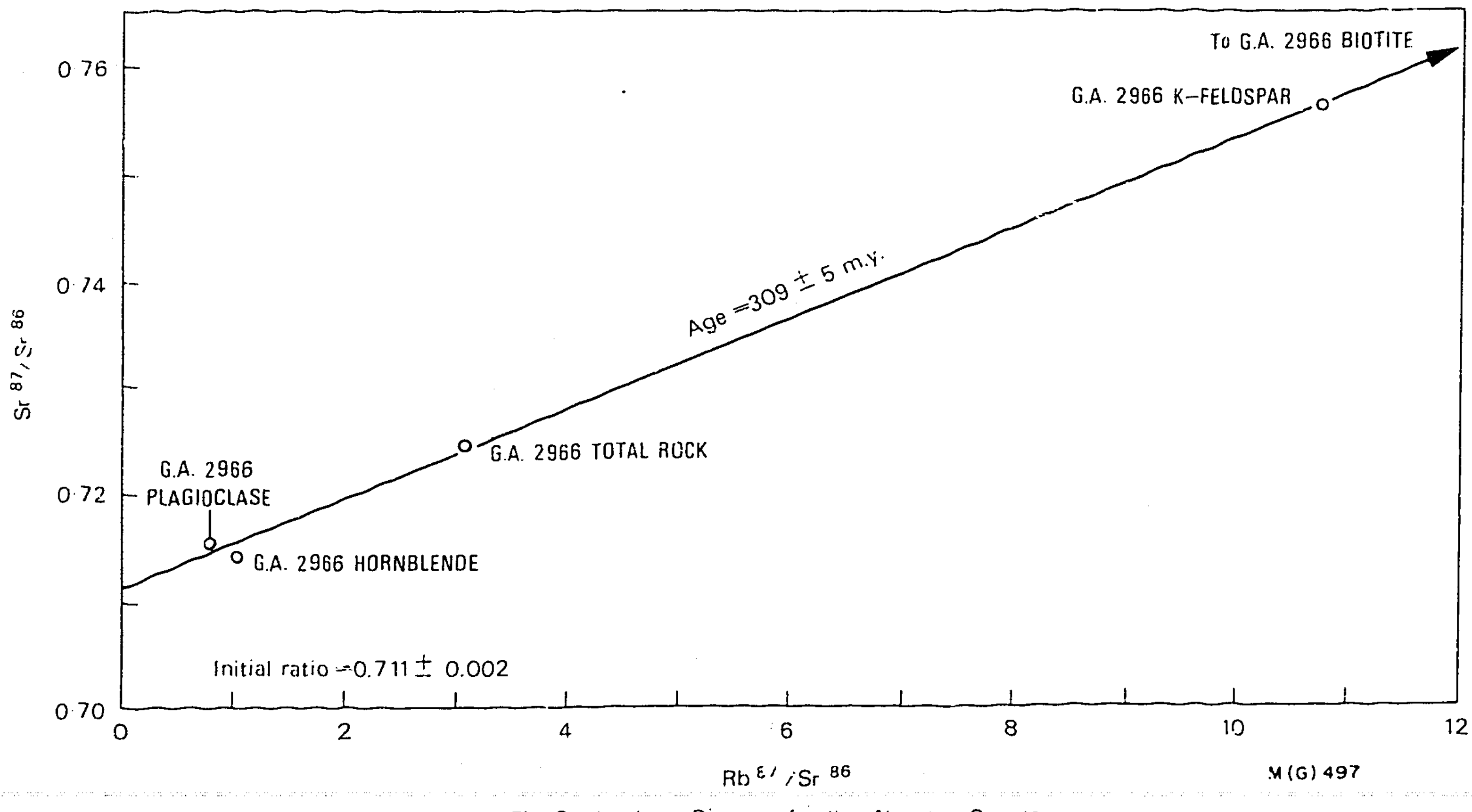

Fig 8 Isochron Diagram for the Almaden Granite

trending belt between Almaden and the Walsh River. It is typically a medium-grained, grey, biotite-bearing hornblende granodiorite which is sometimes porphyritic. Basic xenoliths are common and rather uniformly distributed throughout the granite.

The Almaden Granite is thought to intrude the Nychum Volcanics (de Keyser & Wolff, 1964; Branch, 1966), and on the basis of plant fossils within the volcanics was originally assigned a Late Permian age (de Keyser & Wolff, op. cit.). However, subsequent work by Black et al. (1972) has shown two distinct ages within the Nychum Volcanics, and that the younger limit of Late Permian for the Almaden Granite is no longer applicable.

The K-Ar mineral ages by Richards et al. (1966) on the Almaden Granite yield ages between 284 and 302 m.y. So far no meaningful Rb-Sr age for the granite has been published (see Black & Richards, 1972a).

<u>New isotopic data</u> (Fig. 8 and Table 5)

In the present study three total-rock analyses were added to the previous analyses of Black & Richards (1972a), and a new regression has been obtained. The resulting 'age' (363 $\pm$ 33 m.y.) is considerably younger than the previous 'age' estimate (475 $\pm$ 50 m.y.) but still older than the expected value, for de Keyser & Wolff (1964) believed that this granite is probably younger than the Herbert River Granite. It would appear that these anomalously high ages result from the grouping of a suite of samples in which there is an approximate correlation of initial Sr^{87}/Sr^{86} ratio with Rb^{87}/Sr^{86}. The isochron approach has failed because the selected samples were apparently not initially in isotopic equilibrium. This problem can be overcome by two procedures. First, ages which are virtually independent of initial ratio assumptions can be derived from biotite concentrates. Alternatively, internal mineral isochrons, which delineate initial ratios on a local scale, can be used.

TABLE 5. ISOTOPIC DATA FOR THE ALMADEN GRANITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
G.A. 433 Biotite	1.5 km W of Almaden	606.3	4.879	2.5159	422.3	307	This work
68590053 Biotite	6.5 km SE of Almaden	1084.1	12.582	1.9092	278.0	310	"
G.A. 2953	3 km NE of Chillagoe	169.9	175.0	0.72290	2.812		Black & Richards (1972a)
G.A. 2966	1.5 km SE of Almaden	171.90	159.61	0.72472	3.114		"
G.A. 2966 Plagioclase	"	24.41	85.34	0.71594	0.8264		This work
G.A. 2966 K-feldspar	"	529.5	142.39	0.75594	10.788		"
G.A. 2966 Hornblende	"	8.236	22.42	0.71468	1.0616		"
G.A. 2966 Biotite	"	669.9	2.711	5.086	1019.09		"
G.A. 2971	6 km ESE of Almaden	178.0	172.3	0.72350	2.989		Black & Richards (1972a)
G.A. 2972	1.5 km SE of Almaden	156.4	166.3	0.72180	2.720		"
70571283A	3 km SW of Almaden	179.46	196.52	0.72136	2.640		This work
70571283B	"	200.2	162.18	0.72475	3.570		"
70571285	3 km N of Almaden	97.56	289.0	0.71249	0.9752		"

Biotite ages have been determined on samples G.A. 443 and 68590063 (considered by Richards et al. (1966) to be a Herbert River Granite/Almaden Granite 'hybrid') from the intrusion around Almaden, yielding ages of 307 and 310 m.y. respectively. These are essentially the same as the biotite ages derived from the Herbert River Granite.

An internal mineral isochron, developed from a phase of the Almaden Granite within this same intrusion, yields the same age. The isochron, regressed through total rock, plagioclase, K-feldspar, hornblende, and biotite points, yields an age of 309 $\pm$ 5 m.y.; the initial ratio is 0.711 $\pm$ .002 (Fig. 8). Even within the restricted area of this sampling site there is evidence of geological perturbation. The MSWD of 13 indicates a substantial geological effect which the computer-selected model ascribes to a lack of initial isotopic equilibrium between minerals.

The concordant biotite ages and internal mineral isochron indicate that the Almaden Granite was emplaced contemporaneously with the Herbert River Granite about 309 $\pm$ 5 m.y. ago.

<u>Ixe Microgranodiorite</u> (Table 6)

The Ixe Microgranodiorite, with a total outcrop of 50 km^2, occurs in two areas to the north of Fossilbrook homestead in the southwest corner of the Atherton Sheet area. Best (1962) refered to it as 'monzonite'. However, Branch (1966) and de Keyser & Lucas (1968) have classified it as biotite microgranodiorite with rare hornblende. Locally the rock grades into adamellite.

The Ixe Microgranodiorite, which is intruded by the Elizabeth Creek Granite, is considered by Branch (1966) to be the same age as the Herbert River Granite. A single K-Ar analysis by Richards et al. (1966) on a biotite separate indicates an age of 300 m.y.

TABLE 6. ISOTOPIC DATA FOR THE IXE MICROGRANODIORITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
68590076 Biotite	8 km SW of Bullock Creek Siding	700.7	20.17	1.18851	105.03	327	This work

New isotopic data

The same biotite concentrate analysed by Richards et al. (op. cit.) gives a Rb-Sr age of 327 m.y. This apparently correlates with the event which formed much of the Elizabeth Creek Granite in the eastern part of the Atherton 1:250 000 Sheet area. The Ixe Microgranodiorite is, then, older than the Herbert River Granite currently dated, with the exception of the possible occurrence at the True Blue fluorite mine.

Diorite at Petford (Table 7)

An unnamed orthoclase diorite, which has been described by de Keyser & Wolff (1964) and Black (1969), crops out around the town of Petford immediately to the south of the Featherbed Volcanics. It is shown as Almaden Granite on the Atherton 1:250 000 Sheet despite its somewhat basic composition. The diorite has a colour index of about 35 and contains plagioclase (labradorite to andesine), K-feldspar, quartz, biotite, orthopyroxene and clinopyroxene, and pale-coloured hornblende. This unit was not dated during the earlier isotopic studies.

New isotopic data

A series of four total-rock analyses were made in an unsuccessful attempt to define an isochron: the points scattered too widely to estimate an age. However, a biotite separate from sample G.A. 2963 was found to be sufficiently enriched in Sr^{87}/Sr^{86} to yield a relatively precise age of 308 m.y. This is not distinguishable from the Almaden and Herbert River Granite ages. It is possible to explain the scatter of the total rock points about the isochron by a variation in initial Sr^{87}/Sr^{86} ratio from 0.708 to 0.711.

TABLE 7. ISOTOPIC DATA FOR THE DIORITE AT PETFORD.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
70571018	2 km N of Petford	134.61	225.6	0.71594	1.7243		This work
70571288	1 km W of Petford	110.45	242.7	0.71610	1.3152		"
70571290	2.5 km NE of Petford	145.02	208.6	0.71937	2.010		"
G.A. 2963	2 km E of Petford	142.9	217.9	0.71631	1.895		Black & Richards (1973a)
G.A. 2963 Biotite	2 km E of Petford	894.6	6.772	2.6620	454.4	308	This work

Mareeba Granite (Fig. 9)

Descriptions of the Mareeba Granite are found in Best (1962), Branch (1966), and de Keyser & Lucas (1968). The granite intrudes a basement high in the southern part of the Hodgkinson Basin as several large intrusions and a number of smaller stocks. Total area of outcrop is about 1700 km^2. This rock type consists mainly of adamellite. However, granodioritic and granitic variants also occur. The Mareeba Granite resembles the Herbert River Granite in chemical composition and only differs from it petrographically by the presence of muscovite (though it is less abundant than biotite), which is only rarely present in the Herbert River Granite. Branch (1966) considered that both these granites had a common genesis.

Best (1962) recorded that the Mareeba Granite intrudes the Barron River Metamorphics and the Hodgkinson Formation, and is unconformably overlain by the Cainozoic Atherton Basalt.

Richards et al. (1966), using K-Ar mineral analyses, demonstrated that the Mareeba Granite was formed during a single episode at 264 $\pm$ 2 m.y., which is distinct from the emplacement age of the Elizabeth Creek and Herbert River Granites.

New isotopic data (Table 8)

In the present study an initial regression was attempted on nine total-rock samples ranging 150 km northwards from Atherton to China Camp. It is quite evident from the large MSWD of 148 (indicated age = 287 $\pm$ 21 m.y.) that not all the analytical points fulfil the isochron requirements. The model II fit of the points to the isochron suggests that this is due to age differences between the samples. A refined age of 288 $\pm$ 9 m.y., with initial ratio 0.710 $\pm$ .003, is obtained by rejecting the two most divergent points, sample 68590087, a pegmatitic rather than granitic phase, and the most northern sample (68590042) which also

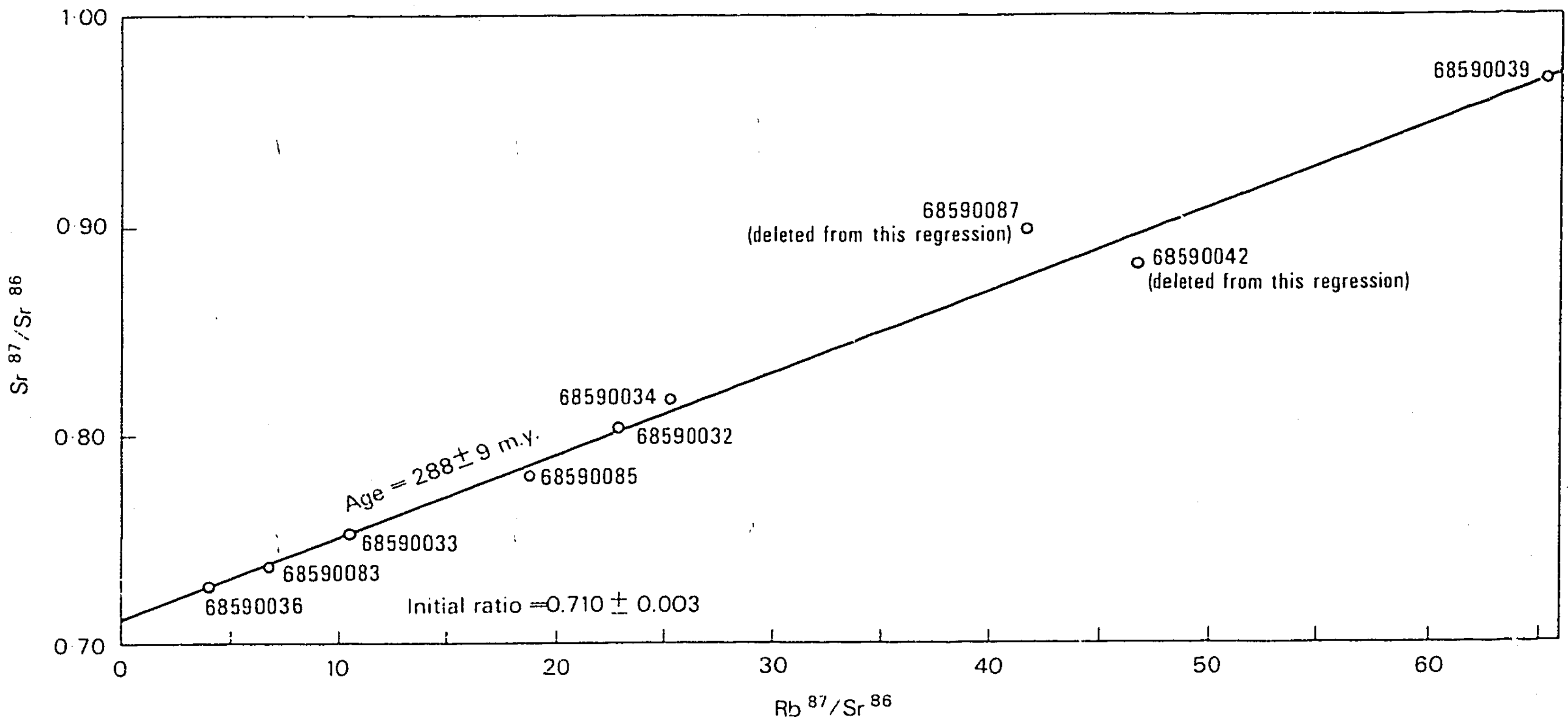

Fig 9 Isochron Diagram for the Mareeba Granite

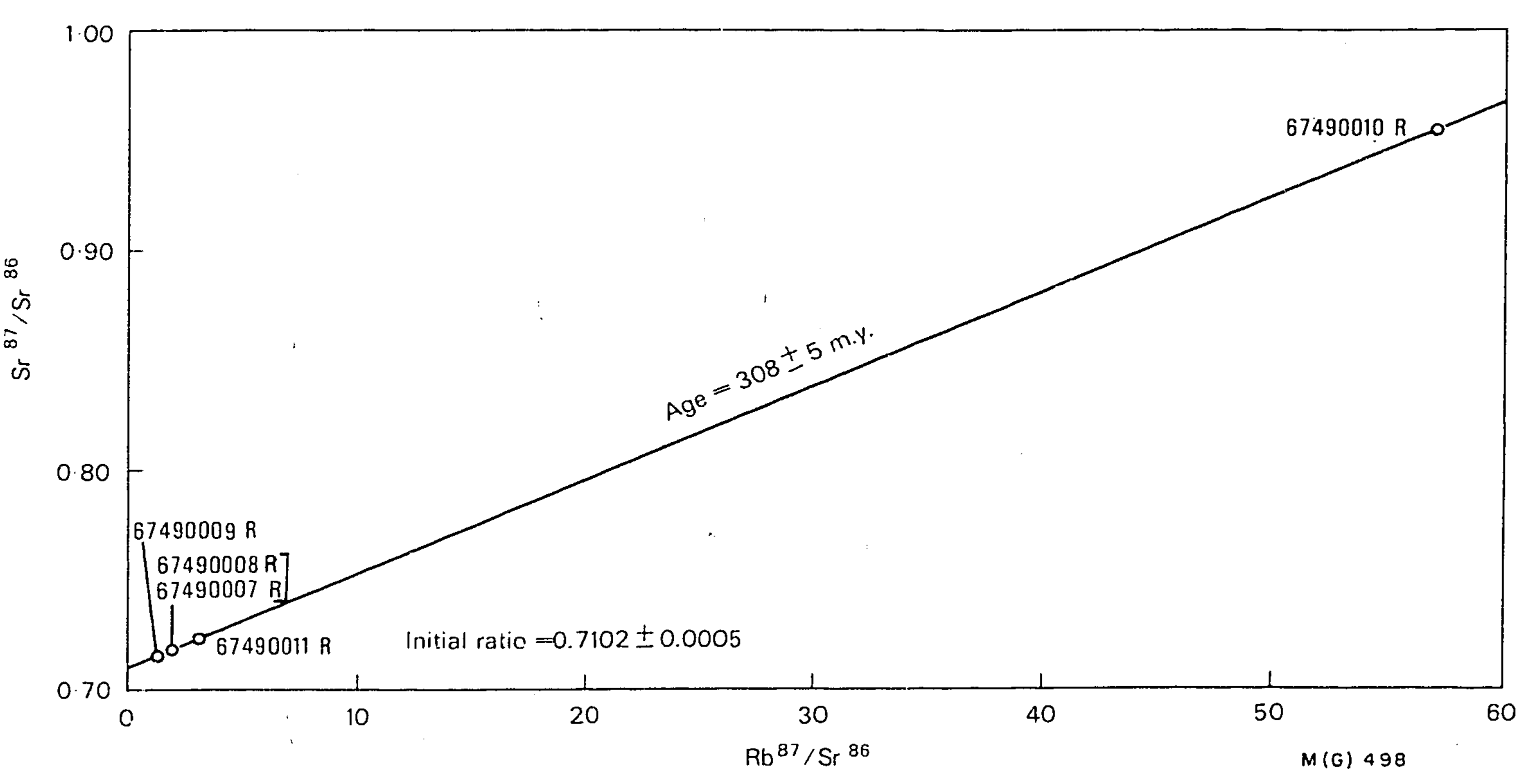

Fig 10 Isochron Diagram for the Bakerville Granodiorite

TABLE 8. ISOTOPIC DATA FOR THE MAREEBA GRANITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
68590032	1 km S of "Southedge"	357.0	45.54	0.80358	22.84		This work
68590032 Biotite	"	1467.6	6.358	4.2633	898.3	285	"
68590032 Muscovite	"	1240.5	6.058	3.7382	766.5	284	"
68590033	5 km W of Rumula on Mt Lewis forestry road	266.6	73.30	0.75183	10.545		"
68590034	Lighthouse Mtn, 11 km W of Molloy	358.8	40.99	0.81563	25.54		"
68590036	26 km along track to Mt Spurgeon from Mulligan Hway	175.6	120.84	0.72827	4.204		"
68590039	1.6 km E of "Spring Hill"	464.7	21.08	0.97115	63.30		"
68590042	1.6 km NE of China Camp	430.5	27.11	0.88279	46.65		"
68590083	Gillies Hway, 11 km W of Little Musgrave R crossing	242.5	101.53	0.73734	6.916		"
68590083 Biotite	"	1130.9	28.02	1.19912	122.12	288	"
68590083 Muscovite	"	1052.4	16.143	1.51919	203.17	287	"
68590085	2 km from Tinaroo Dam on N shore road	316.5	48.79	0.78297	18.863		"
68590087	Quarry at Tinaroo Dam	604.2	42.76	0.89791	41.56		"

yielded the youngest K-Ar age (Richards et al., 1966). In this instance the computer selected model (III) indicates that the reduced MSWD (38) probably results from the attempted correlation of samples with somewhat different initial ratios.

It appears that the pegmatitic sample (68590087) had an initial ratio as high as 0.73. This probably resulted from the leaching of radiogenic strontium from country rock by the fluid-rich magma. A tentative age estimate of 266 m.y. can be made for the Mareeba Granite at China Camp. This is subject to a possible error of 7 m.y. for each increment of 0.005 in Sr^{87}/Sr^{86} ratio beyond the assumed value of 0.710. The value 266 m.y. is consistent with that calculated by a 6% upwards correction of the biotite K-Ar age to adjust for half-life discrepancy and errors in spike calibration.

Four mica ages are now available to complement the total-rock data. A muscovite-biotite pair of sample 68590083, which was collected 25 km east of Atherton, gives ages of 288 and 286 m.y. A further mica pair (68590032), from 25 km northwest of Mareeba, yields ages of 284 and 285 m.y.

The mica ages quite clearly reinforce that derived from the total-rock isochron, so that the time of emplacement for much of the Mareeba Granite can be confidently taken to fall in the range 288 $\pm$ 9 m.y.; the mica data suggest that the true age may be slightly on the young side of the total-rock mean age. These Rb-Sr data further justify the statement of Richards et al. that the Mareeba Granite is younger than both the Elizabeth Creek and Herbert River Granites. The intrusion at China Camp appears to postdate the bulk of the Mareeba Granite by about 20 m.y. The indicated initial Sr^{87}/Sr^{86} ratio of 0.710 for much of the Mareeba Granite is identical with that found for the Herbert River Granite, suggesting a common genesis, as was proposed by Branch (1966).

Bakerville Granodiorite (Table 9 and Fig. 10)

The Bakerville Granodiorite was originally mapped as Herbert River Granite (Best, 1962), but reclassified and described by Blake (1972). It crops out at Bakerville, 13 km west of Herberton, over an area of 8 km^2. The predominant rock type is even-grained dark grey, medium to fine-grained hornblende-biotite granodiorite which contains small mafic xenoliths. It is thus petrographically very similar to the Almaden Granite.

Blake considered that the Bakerville Granodiorite is younger than the Elizabeth Creek and Watsonville Granites, though closely similar to the latter in age (i.e. Early Permian - Richards et al., 1966).

New isotopic data

Two ages have been derived for the Bakerville Granodiorite in the current study. The first, from the total-rock isochron, is 308 $\pm$ 5 m.y. This age is essentially controlled by the aplitic sample (67490010R), which is markedly enriched in Sr^{87} with respect to the other four samples. The analytical points yield a model III isochron (i.e. slightly different initial ratios for the regressed samples) with MSWD of 5.7. The initial ratio indicated by the total rock system is 0.7102 $\pm$ .0005.

A concordant biotite age of 304 m.y., determined on sample 67490008R, testifies to the authenticity of the total-rock result; apparently the aplitic phase was formed essentially contemporaneously with the granodioritic phases. Thus, the Bakerville Granodiorite is similar in age and initial isotopic composition to several other intrusives in the area; for example, the petrographically similar Almaden Granite, the Elizabeth Creek Granite at Petford, and the Herbert River Granite.

TABLE 9. ISOTOPIC DATA FOR THE BAKERVILLE GRANODIORITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
7490007R	1.2 km E of "Bakerville"	128.89	202.8	0.71788	1.8508		This work
7490008R	0.4 km SW of "Bakerville"	116.39	193.15	0.71780	1.7415		"
7490008R Biotite	"	556.2	5.509	2.1118	331.53	304	"
67490009R	"	118.47	219.5	0.71672	1.5597		"
67490010R	1.5 km SW of "Bakerville"	507.4	26.30	0.95452	57.06		"
69490011R	"	176.27	158.77	0.72430	3.210		

Kalunga Granodiorite (Table 10)

The Kalunga Granodiorite crops out over 50 km^2 to the south of Herberton. It was originally regarded as Herbert River Granite (Best, 1962), but has since been reclassified by Blake (1972). Blake considered that, because of its considerable range in texture and composition, the Kalunga Granodiorite may not represent a single intrusion. It is most typically a grey medium and even-grained hornblende-biotite granodiorite which grades into a hornblende-free adamellite in places. Mafic xenoliths are common.

Blake reported that the granodiorite intrudes the Hodgkinson Formation, and probably also the Glen Gordon Volcanics. It is intruded by the Elizabeth Creek Granite and minor acid intrusions which are thought to correlate with the Slaughter Yard Creek Volcanics. Blake predicted a Carboniferous age for this intrusive.

New isotopic data (Fig. 11)

The age of the Kalunga Granodiorite is somewhat problematical; a completely unequivocal result must await further sampling. The difficulties arise from a lack of consistency between calculated ages. Regression through the eight total-rock points yields a model IV isochron with MSWD of 21.5; indicated age and initial ratio are 273 $\pm$ 14 m.y. and 0.7116 $\pm$ .0013. The model IV interpretation combines the assumptions of models II and III (see McIntyre et al., 1966).

A biotite age of 282 m.y. on sample 67490027R, which conforms with that of the total-rock isochron, probably indicates the age of much of the Kalunga Granodiorite. However, duplicate age determinations on a biotite separate from sample 67490061R (Table 9) indicate a clearly older age of about 300 m.y. As sample 67490061R occurs near Kalunga, unlike the other samples,

TABLE 10. ISOTOPIC DATA FOR THE KALUNGA GRANODIORITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
67490025R	2 km W of Stella mine	274.0	128.19	0.73576	6.189		This work
67490026R	1.3 km W of Stella mine	248.4	104.12	0.73739	6.910		"
67490027R	1 km W of Stella mine	174.38	131.49	0.72648	3.836		"
67490027 Biotite	"	945.2	4.662	3.6825	755.8	282	"
67490061 R	0.5 km NNW of Kalunga	231.1	144.65	0.72906	4.622		"
67490061) Biotite)	"	679.0	5.377	2.5163	429.1	302)	"
67490061 R) Biotite) (repeat))	"	710.1	6.592	2.2451	370.7	298)	"
67490062 R	2.4 km SW of Stella mine	336.6	52.21	0.78584	18.757		"
67490063	2.8 km WSW of Stella mine	314.5	115.12	0.74102	7.914		"
67490064 R	1.6 km W of Stella mine	267.2	93.09	0.74243	8.315		"
67490064 R1	"	300.5	24.35	0.84739	36.13		"

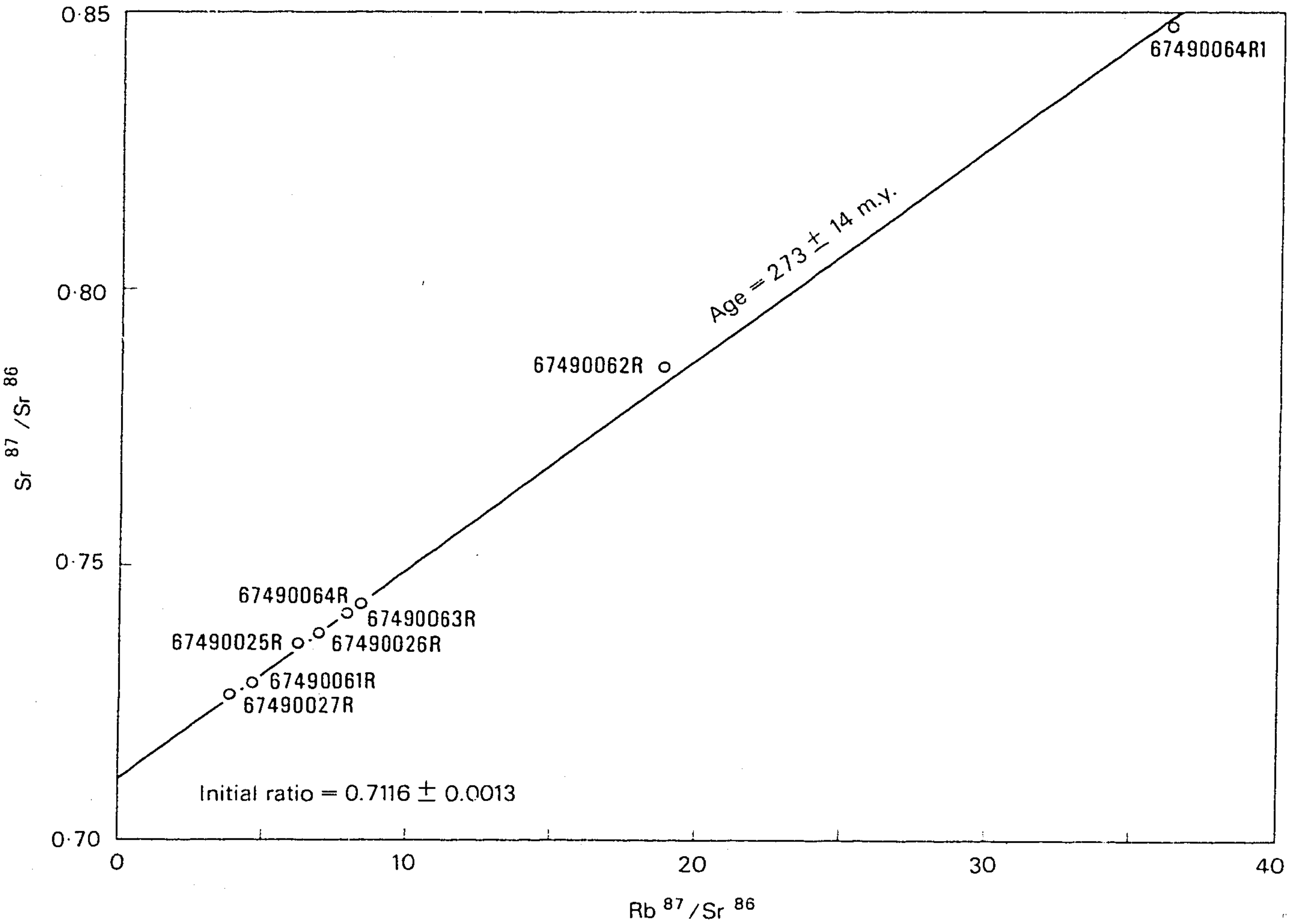

Fig 11 Isochron Diagram for the Kalunga Granodiorite

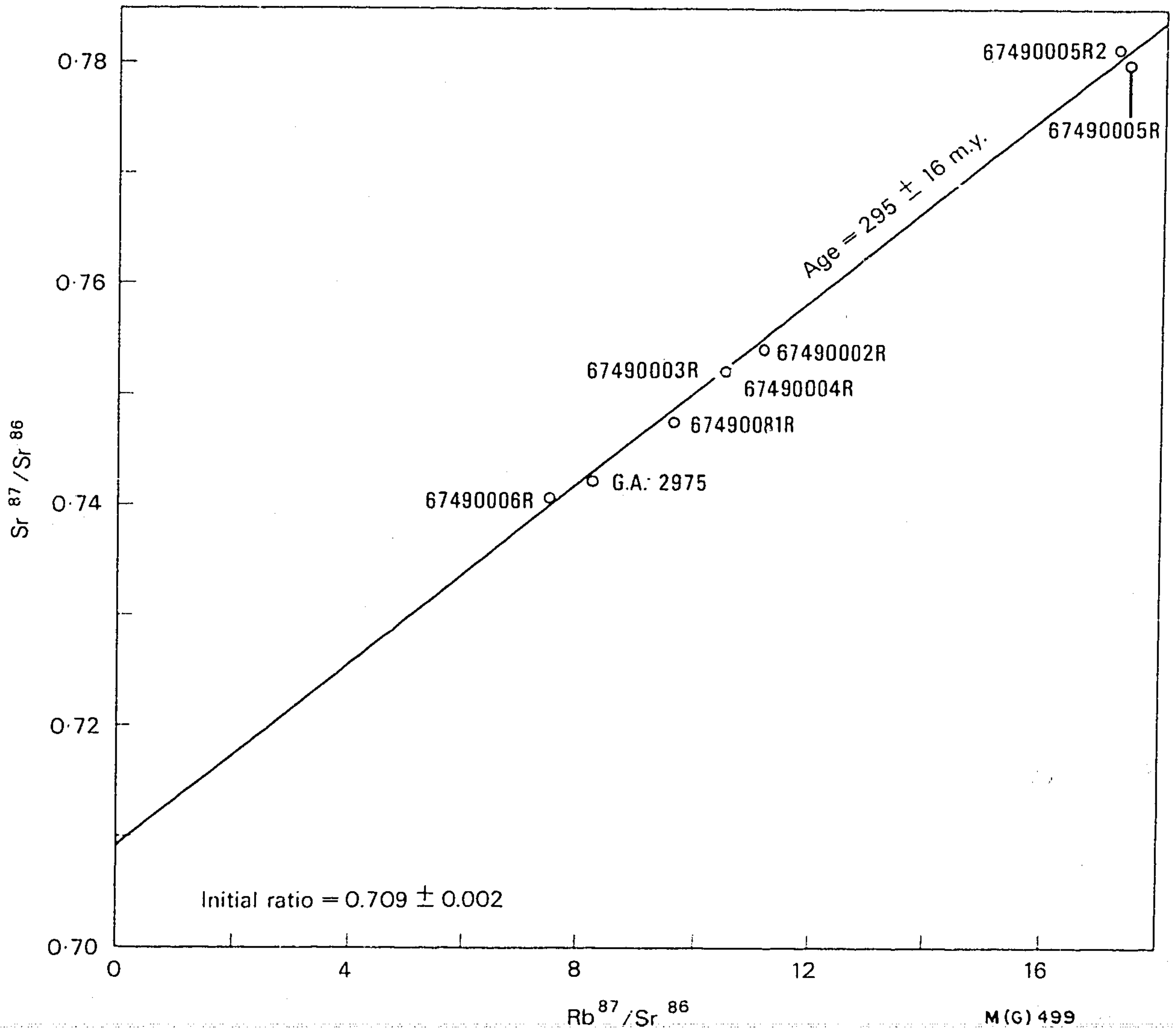

Fig 12 Isochron Diagram for the Watsonville Granite

which were collected 6 km to the west-northwest, it seems that the Kalunga Granodiorite represents a composite intrusion. That part near the settlement of Kalunga may antedate by 20 m.y. the granite of the same name to the west. Deletion of sample 67490061R from the total-rock isochron produces parameters (273 $\pm$ 16 m.y.; 0.711 $\pm$ .002) in agreement with those of the original regression. Thus, it appears that the Kalunga Granodiorite near Kalunga itself may be the same age as the Herbert River Granite with which it was originally mapped. It is recommended that statements regarding the field relations and age of the Kalunga Granodiorite be deferred until the question of composite intrusions is fully resolved.

Watsonville Granite (Fig. 12)

The Watsonville Granite was originally mapped as Herbert River Granite (Best, 1962), but has been described and reclassified by Blake (1972). It crops out over 130 km^2 to the north of the township of Watsonville, 6 km west of Herberton. This unit is a homogeneous, pink or grey, medium to coarse-grained biotite adamellite which commonly contains orthoclase microperthite phenocrysts. Mafic xenoliths are widespread although nowhere abundant.

Blake (op. cit.) reported that the Watsonville Granite intrudes the Hodgkinson Formation, Elizabeth Creek Granite, Walsh Bluff Volcanics, and Slaughter Yard Creek Volcanics, and is itself intruded by the Bakerville Granodiorite. Richards et al. (1966) derived a K-Ar biotite age of 267 m.y. for this unit, making it comparable in age to the petrographically similar Mareeba Granite.

TABLE 11. ISOTOPIC DATA FOR THE WATSONVILLE GRANITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
G.A. 2975	1 km W of Watsonville	244.9	86.40	0.74272	8.232		Black (1969)
67490002R	3.5 km W of Watsonville	266.0	69.44	0.75460	11.113		This work
67490003R	1.5 km W of Watsonville	234.1	65.28	0.75218	10.397		"
67490004R	Watsonville	237.2	66.02	0.75226	10.418		"
67490005R	3 km N of Watsonville	252.1	42.19	0.78010	17.377		"
67490005R2	"	357.6	60.50	0.78116	17.191		"
67490006R	"	254.3	97.89	0.74133	7.525		"
67490081	2 kn NNW of Watsonville	262.0	79.11	0.74810	9.598		"
67490081) Biotite))	"	955.5	6.367	2.7712	520.8	285)))	"
67490081) Biotite) (repeat))	"	967.4	6.308	2.8521	535.7	288))	"

New isotopic data (Table 11)

In the present study a Rb-Sr total-rock age of 295 ± 16 m.y. has been derived from an eight-point isochron with MSWD of 11; initial ratio is 0.709 ± .002. The analytical scatter about the isochron is best explained by model IV conditions, i.e. some combination of initial ratio differences and either age difference between the samples or a redistribution of isotopes since the original closure of the system. The total-rock result is supported by a relatively precise biotite age estimate of 287 m.y. for sample 67490081.

The Rb-Sr age of the Watsonville Granite is, then, concordant with that of the Mareeba Granite, as was expected from the K-Ar results. From this evidence it would appear to postdate both the Elizabeth Creek Granite and Bakerville Granodiorite (cf. Blake's conclusions reported above).

Nymbool Granite (Fig. 13)

The Nymbool Granite crops out over 10 km^2 at Nymbool, 9 km west-northwest of Mount Garnet township. It was originally mapped as Herbert River Granite (Zimmerman et al., 1963), but has since been reclassified by Blake (1972). Blake described this unit as a medium to coarse-grained adamellite with up to 10 percent biotite and containing many small biotite-rich xenoliths; small cross-cutting veins of aplite are common.

To date Blake (op. cit.) has been unable to determine any unambiguous field relations for this granite, apart from the observation that it definitely intrudes the Hodgkinson Formation. He tentatively assumed it to be younger than the Elizabeth Creek Granite, and of Early Permian age.

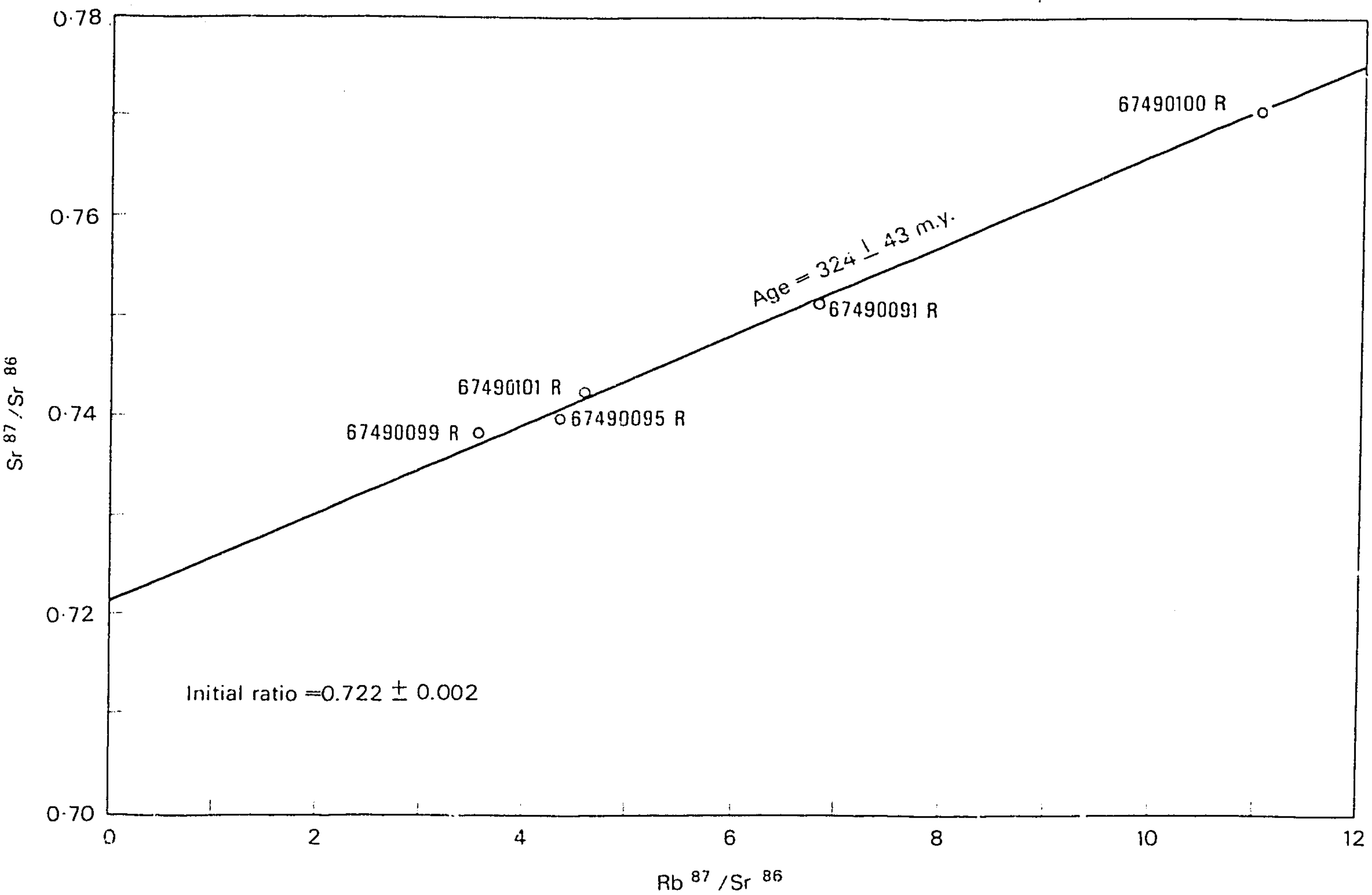

Fig 13 Isochron Diagram for the Nymbool Granite

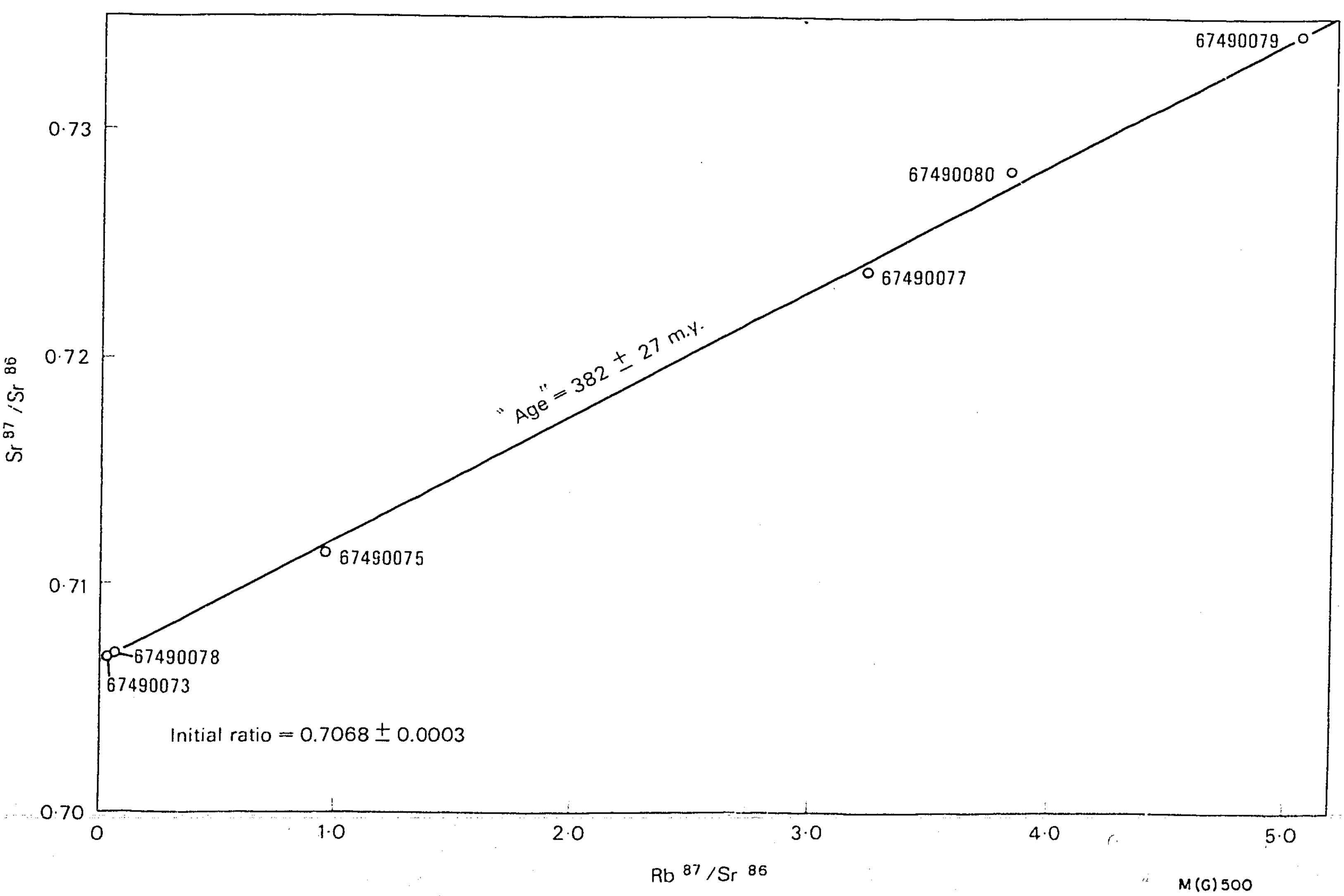

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Fig 14 Isochron Diagram for the Gurrumba Ring Complex

TABLE 12. ISOTOPIC DATA FOR THE NYMBOOL GRANITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.722 (m.y.)	Reference
67490091 R	1.7 km W of Nymbool	198.96	85.00	0.75134	6.788		This work
67490095 R	2 km WNW of Nymbool	192.25	129.00	0.73996	4.316		"
67490099 R	3.5 km N of Nymbool	175.32	145.32	0.73851	3.494		"
67490100 R	3 km N of Nymbool	248.8	65.65	0.77175	11.011		"
67490101	2.5 km N of Nymbool	197.44	126.52	0.74251	4.521		"
67490101 R Biotite	"	898.9	6.321	2.9681	501.5	322	"

New isotopic data (Table 12)

Five total-rock samples have been analysed in the present study. When regressed, these yield an age of 324 ± 43 m.y. and initial ratio 0.722 ± .004. The high MSWD (59) indicates that the large uncertainty results from dispersion of the analytical points about the isochron. The model III interpretation suggests that this dispersion results from the correlation of samples with different initial isotopic composition.

A more precise age estimate is available from the biotite concentrated from sample 67490101 R. This gives an age of 322 m.y. for an assumed initial ratio of 0.722 (indicated by the total-rock isochron). Any change of 0.005 in assumed initial rock would change this age by only 1 m.y. This precise biotite age, which conforms so closely to the mean total-rock age, indicates that the Nymbool Granite is roughly the same age as the nearby Elizabeth Creek Granite.

Hammonds Creek Granodiorite

The Hammonds Creek Granodiorite, which crops out over 30 km^2 to the west of Mount Garnet township, was originally mapped as Herbert River Granite (Zimmerman et al., 1963). Blake (1972) has since renamed and described it. It is normally a medium-grained hornblende-biotite granodiorite, but adamellite and quartz diorite variants also occur. Small dark xenoliths and thin veins of aplite are associated with it. The Hammonds Creek Granodiorite is distinguished from the Nymbool Granodiorite to the north by a higher plagioclase to alkali feldspar ratio, and by the presence of hornblende. The Hammonds Creek Granodiorite intrudes the Hodgkinson Formation and is tentatively considered by Blake (1972) on the basis of outcrop shape and the fact that it is unmineralized, to postdate the Elizabeth Creek Granite.

TABLE 13. ISOTOPIC DATA FOR THE HAMMONDS CREEK GRANODIORITE.

Sample No.	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.710 (m.y.)	Reference
67490082 Biotite	4 km WSW of Mt Garnet	360.3	15.865	0.99020	67.39	299	This work
67490083 R	6 km WSW of Mt Garnet	75.97	300.5	0.73034	0.71463		"
67490083 R1	"	70.32	326.5	0.71345	0.6223		"
67490084	"	69.62	331.2	0.71271	0.6073		"
67490087	7 km WNW of Mt Garnet	66.52	351.3	0.71144	0.5470		"
68490015 G	8 km WSW of Mt Garnet	97.90	311.6	0.71435	0.9076		"
68490016 G	8.5 km WSW of Mt Garnet	150.37	233.4	0.71742	1.8622		"

New isotopic data (Table 13)

It was not possible, in the present study, to determine a total-rock age for the Hammonds Creek Granodiorite, as the six analytical points show considerable scatter on the conventional isochron diagram. However, an age estimate has been made from a biotite concentrate from sample 67490082 by assuming an initial ratio of 0.710. The resultant value of 299 m.y. varies by 5 m.y. for any change of 0.005 in assumed initial ratio.

Thus, the Hammonds Creek granodiorite appears to be approximately contemporaneous with some of the other granites of the area, e.g. the Herbert River, Almaden, and some phases of the Elizabeth Creek Granite. It is, however, about 20 m.y. younger than the neighbouring Elizabeth Creek and Nymbool Granites.

Gurrumba Ring Complex (Fig. 14)

The Gurrumba Ring Complex, which was originally known as the Gurrumba Volcanic Neck, was considered to be a roof pendant within the Elizabeth Creek Granite (Branch, 1966). More recently, Blake (1972) has convincingly argued against this hypothesis and reinterpreted the structure as a ring complex.

The Gurrumba Ring Complex crops out 19 km northwest of Mount Garnet over an elliptical area measuring 5 x 2.8 km. Its outer margin is a ring dyke composed of granophyre, olivine gabbro, and hybrid rocks of mostly quartz dioritic composition. The basic and intermediate rocks occur as inclusions within the granophyre, forming a net-veined complex over much of the outcrop area. Blake attributed the net-veining to the commingling of acid and basic magmas. The outer ring surrounds a zone containing sandstone, siltstone, and quartz conglomerate of the Hodgkinson Formation. Within this, at the centre of the complex, are two bodies of auto-brecciated and flow-banded acid lava, and a small mass of quartz diorite. A comprehensive description of the petrography of the igneous rocks is given by Blake (op. cit.). The Gurrumba Ring Complex has approximately vertical contacts with, and clearly intrudes, the Elizabeth Creek Granite. Blake considered that the complex may be of Permian age. No attempt has been made to date the complex isotopically in previous studies.

New isotopic data (Table 14)

The slope generated from a regression through six total-rock samples of the Gurrumba Ring Complex yields an 'age' of 382 ± 27 m.y. with indicated initial rock ratios equal to 0.7068 ± .003; the MSWD of this model II 'isochron' is 15. This result conflicts with the stratigraphical evidence of Blake (op. cit.), as the ring complex should be younger than the surrounding granite, which has been dated at about 320 m.y. A possible explanation for this discrepancy can be found in the work of Black et al. (1972), who postulated incomplete mixing of isotopically unrelated magmas to explain erroneous age results for the Nychum Volcanics of north Queensland. Such an explanation could reconcile the isotopic data with the field relations observed by Blake (1972) for the Gurrumba Ring Complex, and noted above.

If a mixing relation between acidic and olivine-gabbro magma should apply, yielding a range of hybrid intermediate rocks, the individual rock types will be characterized by different initial Sr^{87}/Sr^{86} ratios. Then, one of the fundamental assumptions underlying the isochron method would be inapplicable: an incorrect slope (and age) would be produced from the total-rock isochron. The rocks of the Gurrumba Ring Complex would be particularly susceptible to a process of this kind as they have low Sr^{87}/Sr^{86} values (maximum enrichment is only 0.734 - see Table 13). However, under these circumstances it should still be possible to determine a valid age from an internal mineral isochron, as it seems reasonable to expect initial isotopic equilibrium over the scale of a hand specimen. Furthermore, because of their enrichment in Rb with respect to Sr, mica separates should produce an age relatively independent of initial ratio. Consequently, a biotite from the gabbro sample 67490073 R

TABLE 14. ISOTOPIC DATA FOR THE GURRUMBA RING COMPLEX.

Sample No.	Rock type	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age assuming I.R. = 0.707 (m.y.)	Reference
67490073 R	Gabbro	7.078	424.2	0.7070	0.0482		Black (1969)
67490073 R Biotite		372.7	14.892	1.03267	74.55	314	This work
67490075	Granophyre	100.06	298.6	0.71159	0.9679		"
67490077	Diorite	181.20	162.15	0.72371	3.231		"
67490078	Gabbro	7.962	390.9	0.70716	0.0588		"
67490079	Rhyolite	173.68	8.576	0.73419	5.045		"
67490080	Granophyre	196.48	148.19	0.72834	3.836		"

was separated and analysed (Table 13). The separate yielded an age of 314 m.y. for an assumed initial ratio of 0.707 (calculated from the total rock sample).

The biotite age, then, is completely compatible with the field observations of Blake (1972) and the isotopic age derived for the surrounding Elizabeth Creek Granite. It is comparable with, though possibly slightly older than, those of several other rock types in the area, notably with the Herbert River and Almaden Granites, the Bakerville Granodiorite, and the diorite and Elizabeth Creek Granite near Petford.

Featherbed Volcanics

Comprehensive descriptions of the Featherbed Volcanics are given in de Keyser & Wolff (1964), Branch (1966), de Keyser & Lucas (1968), and Blake (1972). The volcanics occur just outside the northeastern margin of the Georgetown Inlier. Branch (op. cit.) stated that they occupy a cauldron subsidence area measuring 100 by 30 km. The volcanics occupy about 800 km^3 over an area of about 2400 km^2; maximum thickness is 600 m. They are predominantly of rhyodacitic composition, though rhyolite is fairly common at the base of the sequence. Dacite and intermediate rock types are rare. One of the most noticeable features of the rhyodacite welded tuffs is the high proportion (20-80%) of phenocrysts. Although welded tuffs predominate, normal lava flows and pyroclastic accumulates can also be found. In the area northeast of Chillagoe, and also northwest of Petford, a series of puys up to 200 m high of flow-banded pink rhyolite crop out along the marginal fault.

The Tennyson Ring Dyke is a large composite dyke, 1.2 km wide and 25 km long, which forms the boundary of the Featherbed Cauldron between Almaden and Petford. The ring dyke is mainly composed of fluidized porphyritic rhyodacite (Branch, 1966) cut by pipes filled with tuff and volcanic breccia-agglomerate. Spilled-over flows are still preserved west of Lappa (de Keyser & Wolff, 1964), suggesting that the Tennyson Ring Dyke is probably the feeder for some of the Featherbed Volcanics.

The Featherbed Volcanics unconformably overlie the Almaden Granite (Best, 1962; Branch, 1966) and the Hodgkinson Formation. Blake (1972) listed several localities where breccia or conglomerate beds at the base of the Featherbed Volcanics contain rock fragments derived from the Hodgkinson Formation. Branch (1966) and Blake (1968) cited examples where the Elizabeth Creek Granite intrudes the volcanics and concluded that this is the general case. Later, in view of the results of Black (1969), Blake (1972) discussed the possibilities of more than one age for both the Elizabeth Creek Granite and the Featherbed Volcanics. Previously, de Keyser & Wolff (1964 - quoted in de Keyser & Lucas, 1968) had considered the Featherbed Volcanics to the south-west of Emu Creek to be a separate unit from those to the west. The idea of more than one age for the volcanics was originally introduced much earlier (e.g. Whitehouse, 1930; Jensen, 1941).

In his study, Branch correlated the Featherbed Volcanics at least approximately in time with most outcrops of acid volcanics on and east of the Georgetown Inlier. Blake (1972) considered that the Featherbed Volcanics are probably Middle to Upper Carboniferous and of comparable age to the Glen Gordon and Nanyeta Volcanics.

On the basis of a single Rb-Sr analysis and a K-Ar result on a nearby granitic sample, Richards et al. (1966) derived an age of about 280 m.y. for the Featherbed Volcanics. Further isotopic work by Black and Richards (1972a) yielded a Rb-Sr age for the volcanics of 299 ± 13 m.y. This age was corroborated by later U^{238}-Pb^{206} and Th^{232}-Pb^{208} ages (Black & Richards, 1972b) which were 314 ± 27 m.y. and 312 ± 37 m.y.

New isotopic data (Table 15)

A marked scatter, which obviously reflects a complex history, is apparent when all analytical points for the Featherbed Volcanics are simultaneously considered on the isochron diagram. This scatter can be resolved into several distinct trends with geographical significance. Recent field investigations by A.D. Lawrence of Latrobe University (unpublished thesis) confirm the reality of these subdivisions. Hence, discussion of the new Rb-Sr data will be on an areal basis.

Southeastern area (Fig. 15) The oldest isotopic group comprises samples from the southeastern part of the Featherbed Volcanics. This unit extends at least as far west as sample 67490032 R, which crops out in Emu Creek 10 km southeast of Petford.

Of the 14 samples from this area, only one (67490042 R) is markedly displaced from the isochron. According to A.D. Lawrence (pers. comm.) it may represent part of a still older formation at the extreme southeastern margin of the volcanics. No other samples from the older unit were available for this study. The remaining 13 samples, when regressed, yield a model III age of 318 $\pm$ 16 m.y. with initial ratio 0.7112 + .0014. The MSWD for the regression is 16.

A more precise age can be derived from the analyses of several biotite concentrates. Samples 67490030 R and 67490031 R both yield an age of 317 m.y.; that given by sample 67490035 R is 320 m.y. The excellent agreement with the total-rock mean age strongly suggests that this phase of the Featherbed Volcanics was formed at about 318 m.y.

Central area (Fig. 16) This grouping essentially comprises samples of the Featherbed Volcanics cropping out between Wolfram Camp and Petford. The included area is bounded by longitudes 144°50' and 144°58'. Also included on this isochron is a sample

TABLE 15. ISOTOPIC DATA FOR THE FEATHERBED VOLCANICS

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Isochron	Age assuming I.R. = 0.711 (m.y.)	Reference
68590073	Porphyritic rhyodacite welded tuff	5 km NW of Petford	212.0	133.40	0.72856	4.597	B		This work
G.A. 301	Rhyodacite welded tuff	16 km ENE of Chillagoe	267	51.8	0.7694	14.91	C		Richards et al (1966)
G.A. 2961	Dacite	7.5 km NNE of Petford	100.1	202.5	0.7164	1.4828	B		Black & Richards (1972a)
G.A. 2962	Rhyodacite welded tuff	11.5 km N of Petford	144.2	200.3	0.7183	2.081	B		"
G.A. 2964	Rhyodacite	10 km SW of Petford	231.7	77.02	0.7475	8.720	B		"
G.A. 2970	Rhyodacite welded tuff	1.5 km W of Stannary Hills			0.73716	5.657	A		"
G.A. 2973	Rhyodacite	6 km NW of Petford	211.5	97.14	0.7370	6.303	B		"
G.A. 2974	Porphyritic rhyolite	Walsh River, 8 km S of Wolfram Camp	260.7	47.07	0.7786	16.10	B		"
67490030R) Biotite))	Porphyritic rhyodacite welded tuff	8.5 km NW of Emuford	458.9	14.474	1.13248	95.33	A	317)))	This work
67490030) (repeat)	"	"	458.9	14.493	1.13251	95.22	A	318)	"
67490034R	Porphyritic rhyodacite	"	221.2	114.17	0.73551	5.610	A		"
67490035R	"	4.5 km N of Emuford	199.91	131.47	0.73161	4.401	A		"
67490035R Biotite	"	"	527.6	20.63	1.05138	76.31	A	320	"

TABLE 15 (Continued)

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Isochron	Age assuming I.R. = 0.711 (m.y.)	Reference
67490042R	Porphyritic rhyodacite welded tuff	8 km ENE of Emuford	199.57	89.13	0.74638	6.489	?		"
68490018B	Rhyodacite	9 km N of Emuford	245.8	86.32	0.74770	8.253	A		"
68490175A	Porphyritic rhyodacite welded tuff	2.5 km NW of Stannary Hills	168.29	129.32	0.72754	3.765	A		"
68490175B	"	"	211.4	117.02	0.73402	5.229	A		"
68490175C	Porphyritic rhyodacite	"	293.7	145.30	0.73831	5.853	A		"
68490175D	"	"	231.4	89.18	0.74495	7.518	A		"
68490175E	Porphyritic rhyodacite welded tuff	"	270.8	84.00	0.75225	9.348	A		"
67490031R) Biotite)	"	8.5 km NW of Emuford	454.1	13.744	1.14949	99.52	A	316)	"
67490031R) Biotite) (repeat))	"	"	450.5	13.526	1.15512	100.36	A	318)	"
67490032R	"	"	168.62	151.29	0.72450	3.223	A		"
68490019	Porphyritic rhyodacite	19 km NW of Irvinebank	224.1	88.56	0.74300	7.332	A		"
70571000	Porphyritic rhyodacite welded tuff	1 km N of Wolfram Camp	295.1	100.06	0.75477	8.555	?		"

TABLE 15 (Continued)

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Isochron	Age assuming I.R. = 0.711 (m.y.)	Reference
70571001	"	"	297.8	102.34	0.74506	8.441	?		"
70571006	Porphyritic rhyodacite	9 km SSW of Wolfram Camp	207.2	91.66	0.73829	6.546	B		"
70571007	Porphyritic rhyolite	10 km SSW of Wolfram Camp	263.6	50.28	0.77262	15.233	C		"
70571019	Porphyritic rhyodacite welded tuff	6 km SW of Stannary Hills	206.5	175.22	0.72673	3.410	A		"
70571020	Porphyritic rhyodacite	6.5 km SW of Stannary Hills	215.7	113.12	0.73564	5.521	A		"
70571026	Porphyritic rhyolite welded tuff	16 km ENE of Chillagoe	214.9	41.78	0.77140	14.947	C		"
70571027	Porphyritic rhyolite	"	324.2	21.73	0.87370	43.79	C		"
70571028	"	"	319.2	23.32	0.86660	40.14	C		"
70571029	Porphyritic rhyodacite	"	241.6	104.16	0.74017	6.719	C		"
70571030	"	"	209.6	90.92	0.73946	6.677	C		"
162.1*	Rhyodacite welded	20 km NNW of Petford	211.0	80.54	0.74192	7.589	C		"

* Sample supplied by A.D. Lawrence of Latrobe University

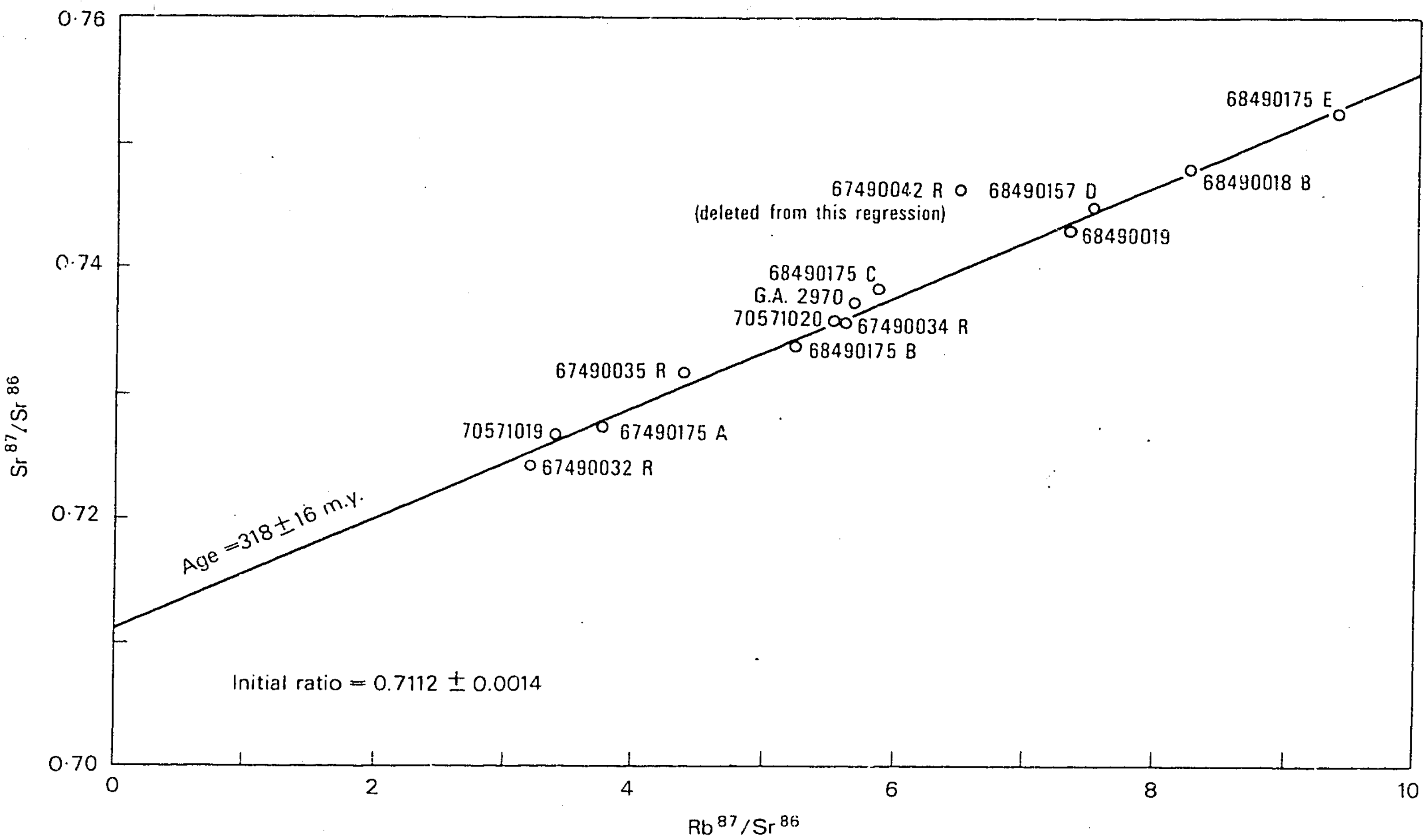

Fig 15 Isochron Diagram for the Southeastern Area of the Featherbed Volcanics

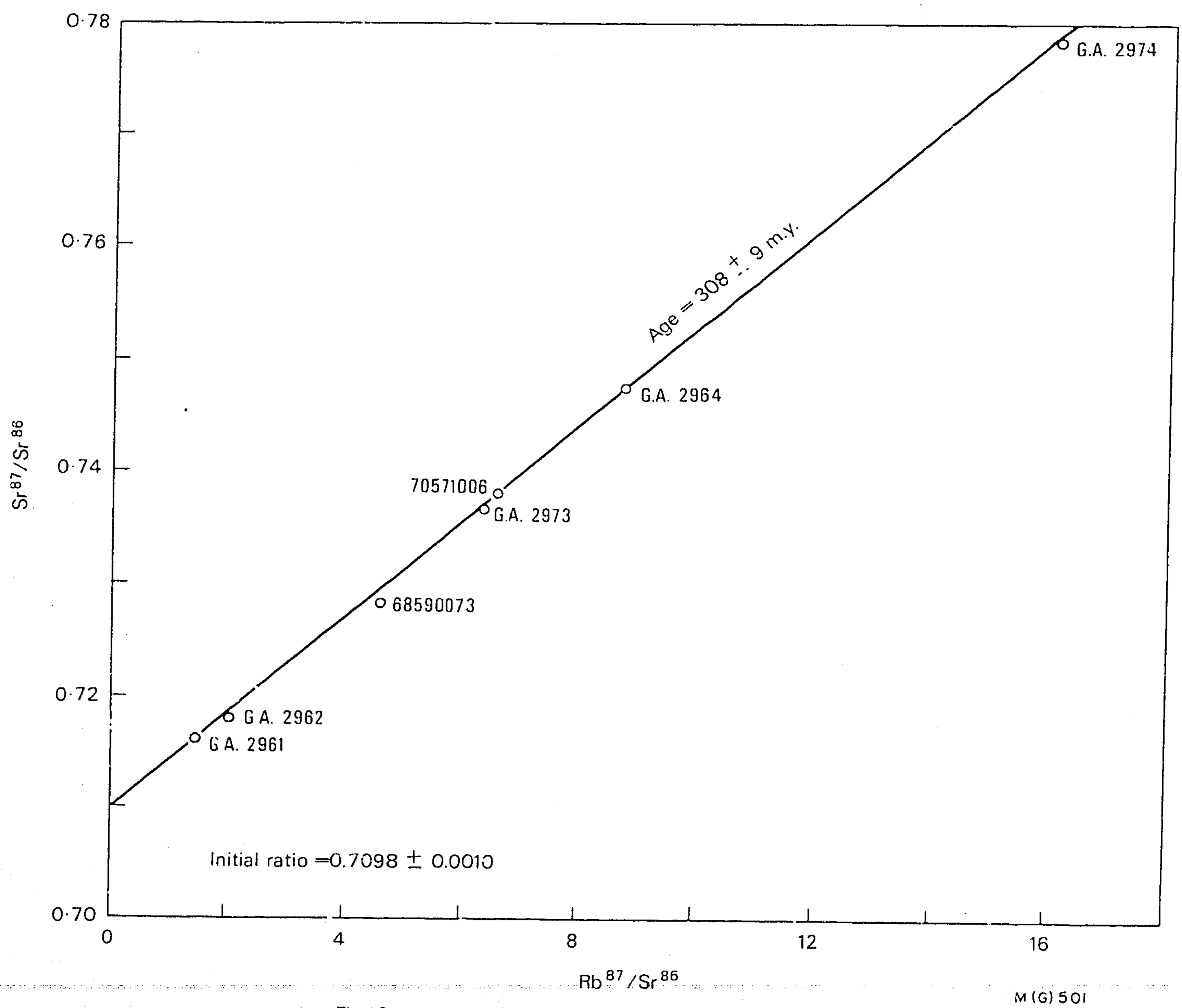

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Fig 16 Isochron Diagram for the Central Area of the Featherbed Volcanics

(G.A. 2964) of the Tennyson Ring Dyke which, according to de Keyser & Wolff (see above), is continuous with the volcanics. In all, a total of seven points are regressed. These yield an age of 308 ± 9 m.y. and initial ratio of 0.7098 ± .0010 according to the assumption of a model III regression; MSWD is 17.

Application of the Student's t test indicates that the initial ratios of the southeastern and central areas of the Featherbed Volcanics are not significantly different from each other. However, the mean biotite age of the southeastern area is significantly different at the 95% confidence level from the age developed for the central volcanics.

The indicated age for the central area of Featherbed Volcanics is completely consistent with the limitations imposed by the intruding granites at Bamford Hill (297 ± 4 m.y.).

Western area (Fig. 17) A suite of six samples has been collected from Fisherman Waterhole, 14 km north-northeast of Chillagoe; one of then, G.A. 301, has been previously reported in Richards et al. (1966). When all six samples are regressed, a model III isochron with age of 267 ± 11 m.y. and initial ratio 0.7150 ± .0016 is obtained. The MSWD of 12.4 is significantly greater than unity. However, this value can be reduced to 2.69, a value not significantly greater than unity for this number of samples, by the deletion of sample 70571027. The new regression yields the similar parameters of 273 ± 5 m.y. and 0.7144 ± .0006. According to A.D. Lawrence (pers. comm.), two samples collected much farther east are also part of this unit. The addition of these two samples (70571007 and 162.1) produces values of 273 ± 7 m.y. and 0.7139 ± .0015 for the age and initial ratio: the MSWD of this model III isochron is 14. Thus, the computer-selected model suggests that the increased MSWD results from initial ratio differences and that the two additional samples are indeed contemporaneous with the original ones at about 273 m.y.

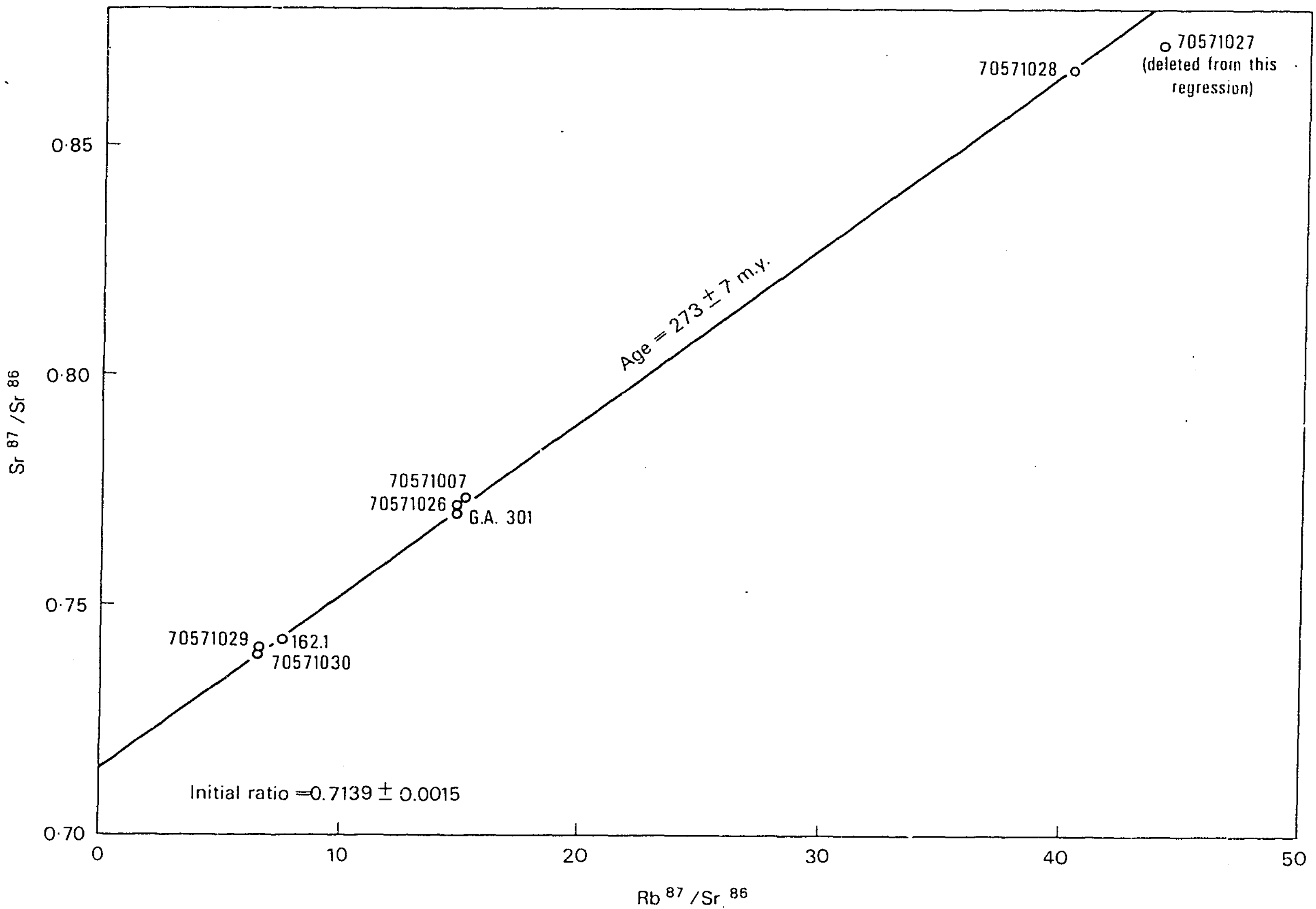

Fig 17 Isochron Diagram for the [W]estern Area of the Featherbed Volcanics

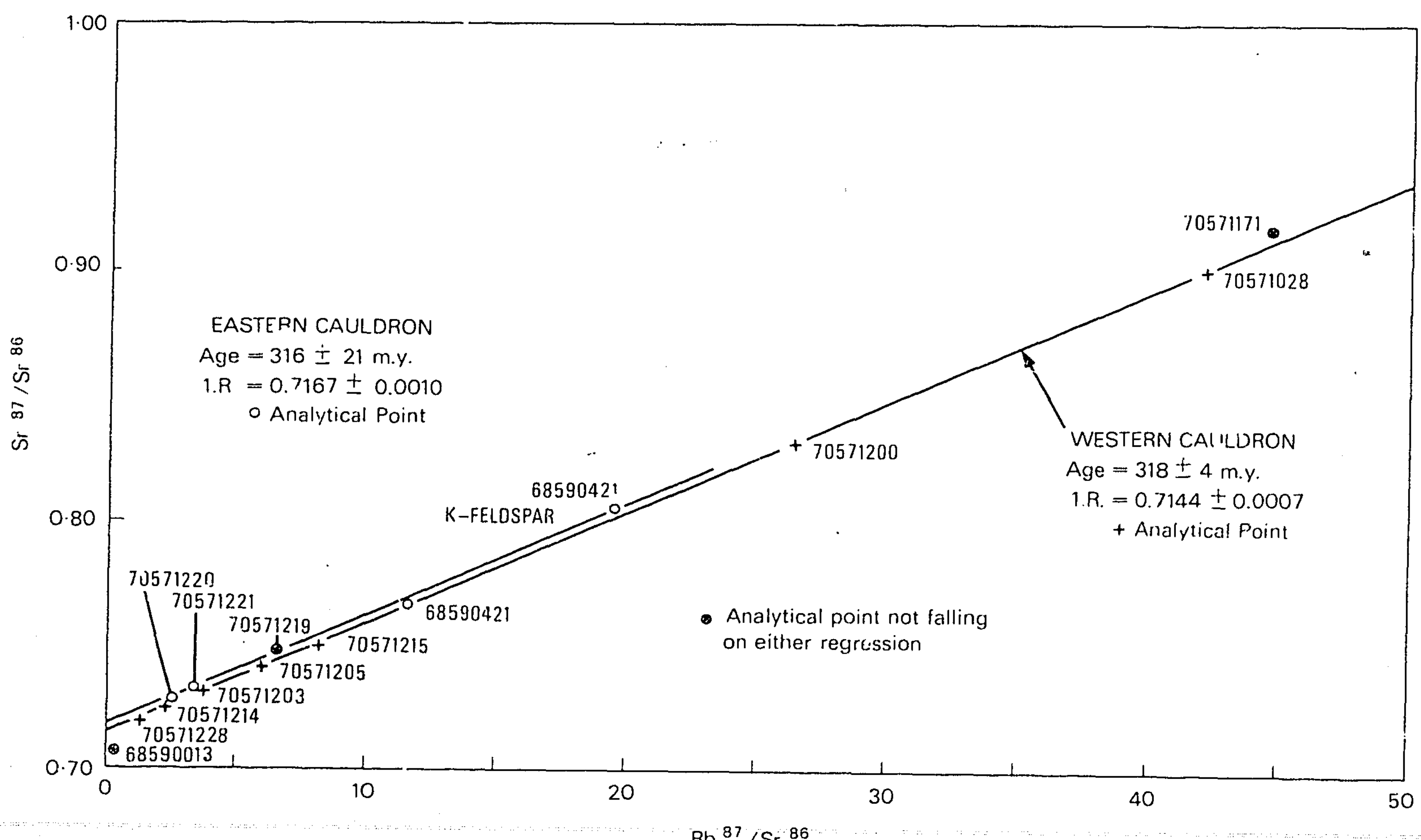

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Fig 18 Isochron Diagram for the Newcastle Range Volcanics

Hence, the Featherbed Volcanics of the western area are approximately 35 m.y. younger, and significantly more enriched in initial radiogenic strontium, than those occurring immediately to the east. Isotopic calculations indicate that the volcanic rocks of the western area could have been derived from rocks of similar age and isotopic makeup to the earlier Featherbed Volcanics.

On the basis of photo-interpretation A.D. Lawrence (pers. comm.) believes that still younger rocks may form the extreme northwest end of the Featherbed Range. Currently, no samples from this area are available for isotopic dating.

Two samples (70571000 and 70571001) of volcanics from the Wolfram Camp area are isotopically distinct, with the lone exception of 67490042R, from other Featherbed Volcanic samples. The line generated by these points, if meaningful, indicates a similar age to, though distinctly higher initial ratio than, the oldest Featherbed Volcanic isochron. This interpretation must be treated with caution, as the two localities are 40 km apart.

Newcastle Range Volcanics (Fig. 18)

Details of the geology of the Newcastle Range Volcanics are given by Branch (1966). The volcanics crop out over 2000 km^2 at the centre of the Georgetown Inlier. They occur in two flanking structures, a western cauldron and a subsidiary related structure designated the Eastern Newcastle Range Cauldron Subsidence Area. Similar lithological successions occur in both cauldrons. Rhyodacite welded tuff units predominate. In addition, true intermediate rocks in the form of four small andesite flows occur at the northern end of the main cauldron. A series of glassy acid dykes averaging 12 [illegible] which occur southwest of Eveleigh homestead, may represen [illegible] feeder fissures for the welded tuff sheets within the cauldrons. Both cauldrons of the Newcastle Range Volcanics are intruded by the Elizabeth Creek Granite.

The isotopic study of Richards et al. (1966) did not yield an unambiguous age for the volcanics, but suggested values of either about 377 or about 333 m.y. The former, which was accepted by Richards et al. as probably correct, was derived from a two-point total-rock isochron, whereas the latter was derived from a regression through a total-rock and a K-feldspar analytical point. Recently, Black (1973) obtained a Rb-Sr age of 318 $\pm$ 5 m.y. for the Newcastle Range Volcanics.

New isotopic data (Table 16)

A more thorough appraisal of the recent analytical data of Black (1973) reveals that the two cauldrons of the Newcastle Range Volcanics are isotopically distinct. Regression through the seven analytical points representing the western cauldron yields an age of 318 $\pm$ 4 m.y. and initial Sr^{87}/Sr^{86} ratio of 0.7144 $\pm$ .0007. The MSWD of this model III isochron is 10.8. Regression through the four points of the eastern cauldron yields a model I isochron (MSWD = 3.5) with an age of 316 $\pm$ 21 m.y. and an initial ratio of 0.7167 $\pm$ .0010. By assuming original isotopic equilibrium and subsequent chemical closure the uncertainty limits of both the age and initial ratio are approximately halved. Thus, the ages of the two cauldrons are not statistically distinguishable. However, the indicated initial ratios are statistically distinct at the 95% confidence level, even without the lowered uncertainty limits deduced for the eastern cauldron.

Two additional analyses for the Newcastle Range Volcanics plot above these isochrons. Sample number 70571171 was collected from the western cauldron in a location 30 km south-southeast of the other samples and separated from them by an area obscured by flat-lying Mesozoic sediments. Sample 70571219 is a representative of the acid dykes southwest of Eveleigh homestead. A line through these two data points would yield, perhaps fortuitously, a similar age to that of the other volcanics, and an initial ratio of approximately 0.72.

The andesite sample (68590013) previously analysed by Richards et al. (1966) plots below the Newcastle Range Volcanics isochron; it appears to have been characterized by an initial ratio of approximately 0.707. It was the correlation of this sample with the isotopically distinct rhyodacite (68590421) which led Richards et al. (op. cit.) to deduce the erroneous Devonian age for the volcanics. The present isotopic evidence indicates that, even though the Newcastle Range Volcanics appear to have been characterized by a range of initial Sr^{87}/Sr^{86} ratios, they were probably extruded during a sharply-defined event in the Late Carboniferous about 318 m.y. ago.

Glen Gordon Volcanics

The Glen Gordon Volcanics are a major volcanic unit to the southeast of the Featherbed Volcanics at the eastern margin of the Georgetown Inlier. They were the subject of an isotopic study by J.A. Cooper whilst he was an officer of the BMR. The results of this study have not yet been published.

Slaughter Yard Creek Volcanics

The Slaughter Yard Creek Volcanics, which were formerly mapped as part of the Glen Gordon Volcanics by Best (1962) and Branch (1966), have been renamed and described by Blake (1972). They crop out over 15 km^2 between the towns of Herberton and Watsonville. Pale grey acid lava crops out in the north; to the south the volcanics are composed of intrusive rocks which are considered contemporaneous and occur in the form of dykes, inclined sheets, and irregular bodies.

TABLE 16. ISOTOPIC DATA FOR THE NEWCASTLE RANGE VOLCANICS.

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Reference
70571171	Porphyritic rhyolite welded tuff	15 km NE of Wirra Wirra	221.1	14.701	0.91778	44.30	This work
70571200	Porphyritic rhyolite	13.5 km E of George-town	230.3	25.58	0.83114	26.31	Black (1973)
70571203	Rhyodacite welded tuff	17 km E of Georgetown	137.14	107.87	0.73147	3.680	"
70571205	Porphyritic rhyodacite welded tuff	17.5 km E of George-town	148.99	74.11	0.73987	5.823	"
70571208	Porphyritic rhyolite	20 km E of Georgetown	257.5	18.057	0.90050	41.95	"
70571214	Banded rhyolite	25 km E of Georgetown	51.40	62.60	0.72520	2.375	"
70571215	Porphyritic rhyodacite	"	173.64	61.97	0.74973	8.122	"
70571219	Rhyodacite	13 km SW of "Eveleigh"	216.8	96.36	0.74937	6.523	This work
70571220	Porphyritic rhyodacite welded tuff	6.5 km SW of "Eveleigh"	134.53	149.53	0.72829	2.603	Black (1973)
70571221	"	"	150.67	123.73	0.73194	3.524	"
70571228	Rhyodacite	Near Mt Fisher gold mine	116.90	236.5	0.72059	1.4289	"
68590013	Andesite	32 km NW of "Talaroo"	320	39.7	0.709	0.3569	Richards et al. (1966)
68590421	Rhyodacite	13 km N of Einasleigh	156	39.4	0.7667	11.47	"
68590421 K-feldspar	"	"	338	50.0	0.8048	19.67	"

The Slaughter Yard Creek Volcanics intrude the Hodgkinson Formation and Elizabeth Creek Granite. Blake (1972) believed that the volcanics are younger than the Kalunga Granodiorite on the evidence of cross-cutting dykes which are thought to relate to the volcanics. He also considered that the volcanics antedate the Watsonville Granite. On the basis of these field relations he provisionally assigned an earliest Permian age to the volcanics.

New isotopic data (Table 17 and Fig. 19)

Regression through the eight total-rock analyses listed in Table 17 yields an ambiguous result. It is not possible, from the nature of the analytical scatter, to chose between the model II age of 286 ± 15 m.y. and the 280 ± 6 m.y. of the model III regression. One can, however, markedly reduce the MSWD of the isochron from 35 to 4.2 by the omission of only one analytical point (67490065R). The new regression yields an age of 281 ± 3 m.y., and an initial ratio of 0.7073 ± .0006 from a model III isochron. This date, consistent with the model III interpretation of the initial regression, probably represents the true age of the volcanics. Thus, the Slaughter Yard Creek Volcanics appear to postdate the Elizabeth Creek Granite, as was suggested by Blake (1972). The indicated age of the volcanics, however, appears to be younger than the biotite age for the Watsonville Granite, contrary to the view expressed by Blake.

Walsh Bluff Volcanics

The Walsh Bluff Volcanics are described by Best (1962), Branch (1966), de Keyser & Lucas (1968), and Blake (1972). They crop out to the west of Atherton in a triangular area largely bounded on its eastern and western margins by faults. Total outcrop area is 220 km^2. The volcanics are composed of subaerial acid lava flows, welded tuff sheets, and minor agglomerate and tuff. Blake (op. cit.) reported that the volcanics, which are

TABLE 17. ISOTOPIC DATA FOR THE SLAUGHTER YARD CREEK VOLCANICS.

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Reference
67490055 R	Porphyritic rhyolite	4.5 km W of Herberton	245.1	26.40	0.81306	27.09	This work
67490056 R	Rhyolite	"	278.0	35.81	0.79605	22.61	"
67490057 R	Porphyritic rhyodacite	"	230.2	101.93	0.73282	6.536	"
67490058 R	"	"	253.6	98.83	0.73599	7.430	"
67490059 R	"	"	221.9	105.38	0.73084	6.093	"
67490060 R	Spherulitic rhyolite	"	318.9	9.925	1.08313	96.23	"
67490065 R	Porphyritic rhyolite welded tuff	6 km SW of Herberton	220.4	38.31	0.77797	16.728	"
67490066 R	Rhyodacite	"	193.60	88.75	0.73255	6.314	"

mostly flat-lying, have a maximum thickness probably in excess of 600 m. According to Branch, these rocks possibly contain units equivalent to those in the Glen Gordon Volcanics.

Best (1962) correlated the Walsh Bluff Volcanics with the Featherbed and Newcastle Range Volcanics. Blake (1972) stated that the Walsh Bluff Volcanics unconformably overlie the Elizabeth Creek Granite, and are intruded by the Watsonville Granite. Earlier, Branch had claimed that the volcanics are intruded by the Elizabeth Creek Granite. On the basis of these field interpretations the Walsh Bluff Volcanics have been designated as Middle to Upper Carboniferous by Branch (1966) and Lower Permian by Blake (1972).

New isotopic data (Fig. 20 and Table 18)

The isotopic results presented here are not conclusive, as the analytical scatter about the isochron does not conform to any of the theoretical models. Moreover, the scatter cannot be attributed to any particular analytical point: it is rather uniformly spread between all the analyses. Hence, deletion of any individual analyses does not clarify the situation. The overall MSWD for the five analytical points is 30. A model II regression yields an age of 281 ± 23 m.y. and initial ratio of 0.708 ± .004, whereas the model III parameters are 288 ± 9 m.y. and 0.707 ± .003. Thus, it would appear that the Walsh Bluff Volcanics were formed in the Early Permian as was suggested by Blake (op. cit.); they are approximately contemporaneous with the Watsonville Granite and younger than most occurrences of Elizabeth Creek Granite.

Nanyeta Volcanics

Descriptions of the Nanyeta Volcanics are given by Best (1962), Branch (1966), de Keyser & Lucas (1968), and Blake (1972). The volcanics crop out over 60 km^2 trending north-northwest from Mount Garnet. Rock types, which are predominantly acidic, comprise welded tuffs, lava flows, airfall tuffs, and minor agglom-

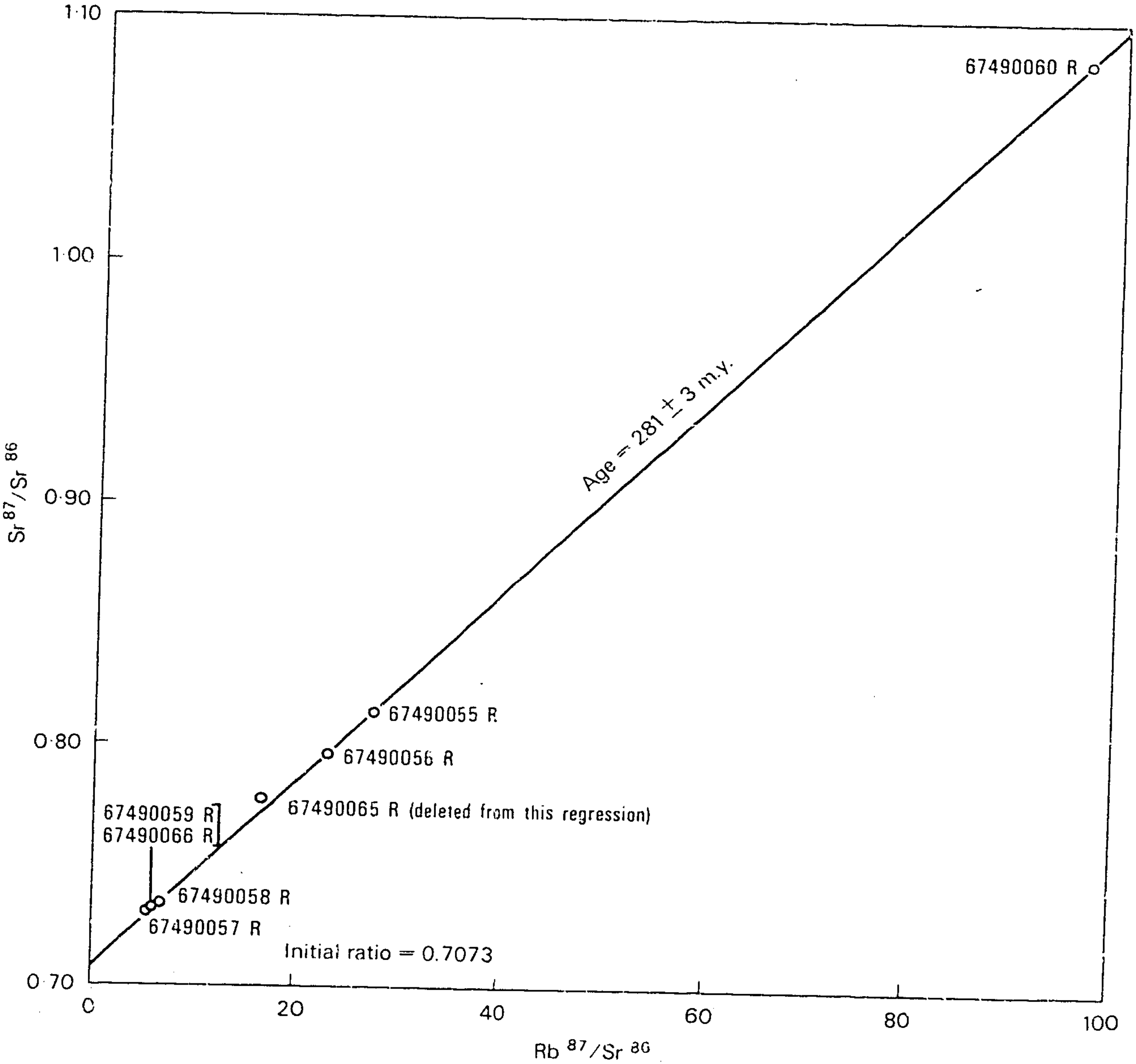

Fig 19 Isochron Diagram for the Slaughteryard Creek Volcanics

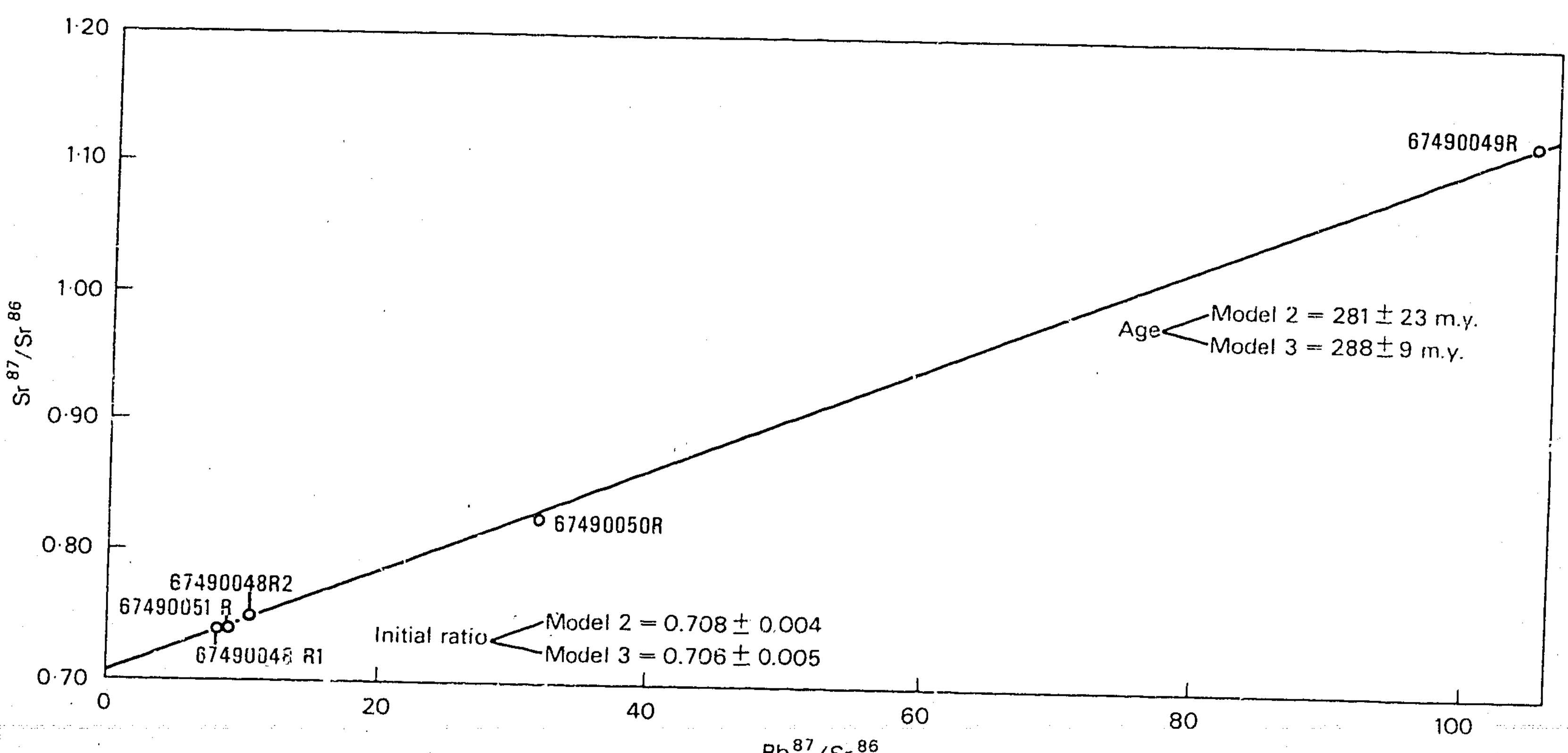

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Fig 20 Isochron Diagram for the Walsh Bluff Volcanics

TABLE 18. ISOTOPIC DATA FOR THE WALSH BLUFF VOLCANICS.

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Reference
67490048 R1	Porphyritic rhyodacite	14 km W of Atherton	219.6	77.55	0.74017	8.201	This work
67490048 R2	"	"	246.8	67.57	0.74770	10.589	"
67490049 R	Porphyritic rhyodacite welded tuff	"	336.3	9.676	1.1268	104.47	"
67490050 R	Rhyodacite	"	235.8	21.70	0.82926	31.76	"
67490051 R	"	"	257.8	84.81	0.74263	8.806	"

erate. Subordinate trachyandesite and andesite also occur. The volcanics have a maximum thickness of 170 m, and dip at 20^{o} to 50^{o} to the northeast.

The Nanyeta Volcanics unconformably overlie Precambrian metamorphics and the Hodgkinson Formation. According to Branch (1966) and Blake (1968), the volcanics are intruded by the Elizabeth Creek Granite, though Blake affirmed that no contacts between the two units could be found in the field. On the basis of lithology and structure, Branch correlated the Nanyeta Volcanics with his 'first volcanic episode'. He considered them to be Middle Carboniferous and older than the Glen Gordon Volcanics. However, Blake (op. cit.) believed that the Nanyeta Volcanics are Middle to Upper Carboniferous in common with both the Glen Gordon and Featherbed Volcanics.

New isotopic data (Fig. 21)

Regression through the six analytical points yields an isochron with an age of 295 $\pm$ 10 m.y. and initial ratio equal to 0.709 $\pm$ .001. The high MSWD of 22 indicates a substantial geological perturbation which apparently derives from lack of initial isotopic equilibrium between samples (model III conditions). On the basis of these data it appears that the volcanics are either earliest Permian or latest Carboniferous. The Nanyeta Volcanics are approximately contemporaneous with the younger phases of the Elizabeth Creek Granite, such as the masses at Wolfram Camp and at Bamford Hill.

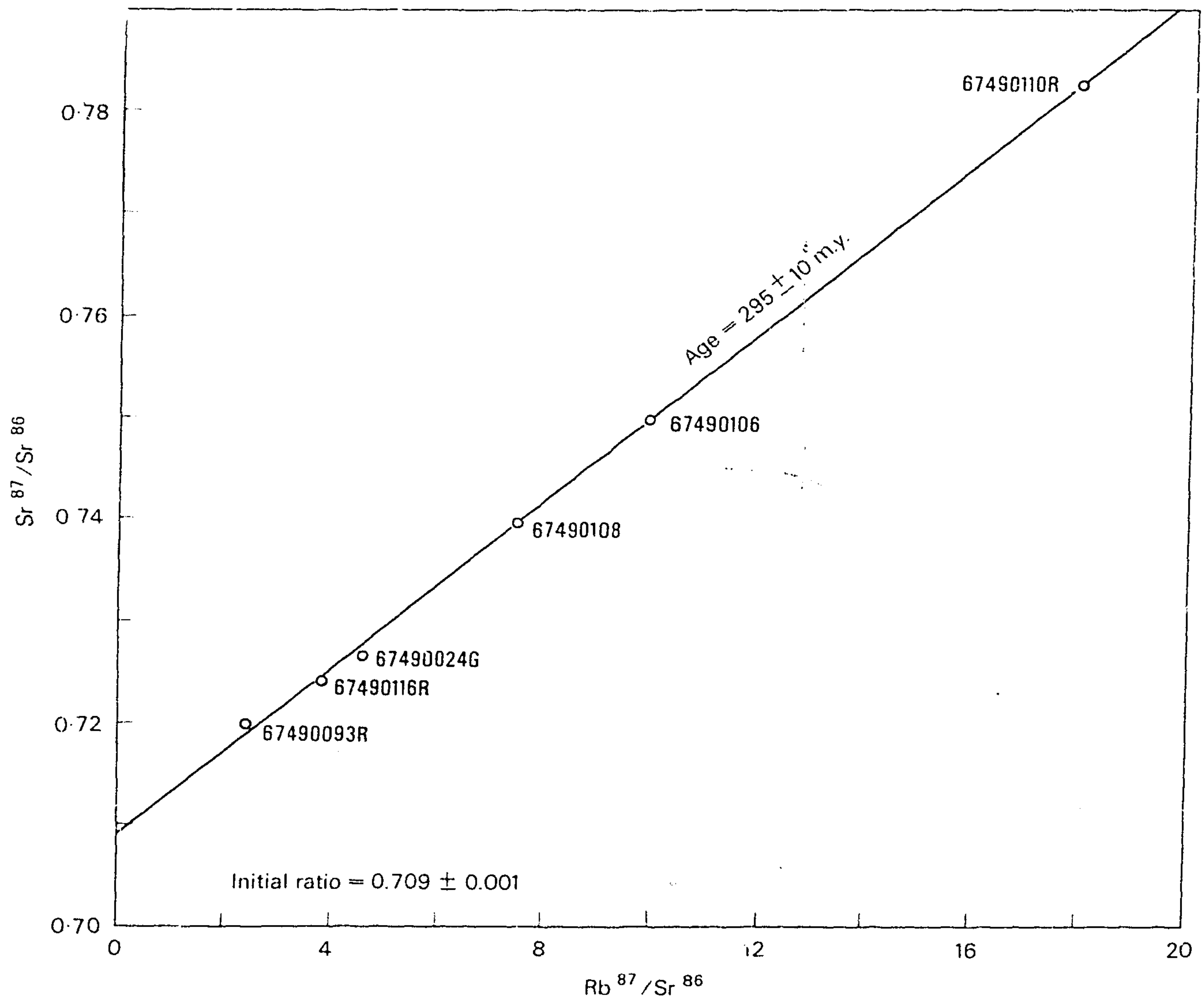

Fig 21 Isochron Diagram for the Nanyeta Volcanics

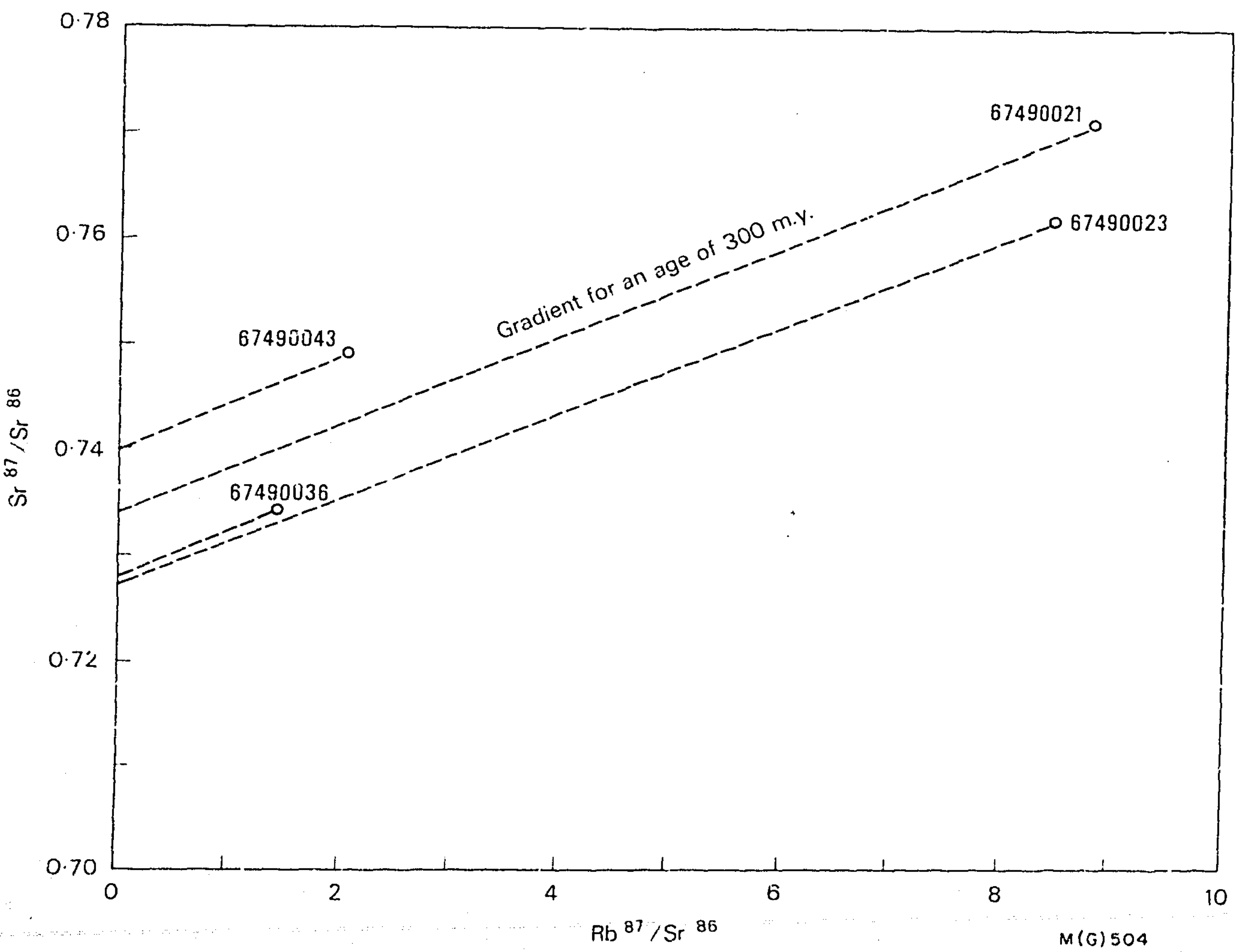

Fig22 Isotopic Data for the Hodginson Formation

TABLE 19. ISOTOPIC DATA FOR THE NANYETA VOLCANICS.

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Reference
68490024 G	Porphyritic rhyodacite	1.5 km NNE of Mt Garnet	181.07	116.57	0.72678	4.493	This work
67490093 R	"	4 km E of Nymbool	188.18	225.0	0.71985	2.418	"
67490106	Rhyodacite welded tuff	4 km N of Mt Garnet	243.2	71.30	0.74980	9.889	"
67490108	Porphyritic rhyodacite welded tuff	"	289.6	112.93	0.73991	7.428	"
67490110 R	Banded rhyolite	"	319.0	52.03	0.78255	17.830	"
67490116 R	Porphyritic rhyodacite welded tuff	6 km W of Brownville	168.69	129.68	0.72432	3.762	"

Hodgkinson Formation (Fig. 22 and Table 20)

A brief description of the rocks constituting the Hodgkinson Formation was presented on Page 2. Four isotopic analyses (Table 20) from this unit are included here in an attempt to define the source area of the Upper Palaeozoic igneous rocks. The Sr^{87}/Sr^{86} isotopic values of the four samples are 0.727, 0.728, 0.734, and 0.740, after correction for in situ decay of Rb^{87} to Sr^{87} during the past 300 m.y. On this evidence it seems most unlikely that the extensive Upper Palaeozoic igneous rocks, whose initial ratios range as high as 0.722 for only one rock type so far analysed (the Nymbool Granite), were derived from the Hodgkinson Formation sediments. It must be emphasized, however, that the analysed sedimentary specimens were collected south of the Featherbed Volcanics and cannot, therefore, be regarded as necessarily representing the Hodgkinson Basin as a whole. The isotopic evidence appears compatible with derivation of the Hodgkinson sediments from the Precambrian inlier for the results of Black (1969, 1973), and the table of Forsayth Granite analyses presented here (Table 21) indicates a variable but pronounced enrichment in radiogenic strontium for the rocks of the inlier during the Permo-Carboniferous.

GENERAL DISCUSSION OF THE ISOTOPIC RESULTS

With the exception of the Croydon Volcanics on the western edge of the Georgetown Inlier, the oldest volcanic age found for the area at present is the 318 m.y. determined for the Newcastle Range and eastern part of the Featherbed Volcanics. The next youngest documented volcanic event, about 10 m.y. later, produced the central area of the Featherbed Volcanics and possibly the Nychum Volcanics. This phase of volcanism was apparently characterized by relatively basic extrusives ranging to andesite and even basalt in the Nychum Volcanics. Later events formed the Nanyeta Volcanics at about 295 m.y., and the Slaughter

TABLE 20. ISOTOPIC DATA FOR THE HODGKINSON FORMATION.

Sample No.	Rock type	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Reference
67490021	Medium-grained feldspathic sandstone	Silver Valley	133.02	43.95	0.77094	8.792	This work
67490023	Bedded siltstone	Silver Valley	138.62	47.64	0.76180	8.446	"
67490036	Creywacke	N of Emuford	113.07	223.6	0.73426	1.4636	"
67490043	Greywacke	S of Montalbion	81.92	115.11	0.74904	2.063	"

Yard Creek Volcanics at approximately 281 m.y. It is currently not possible to discern whether the Walsh Bluff Volcanics correlate with either of these events or are intermediate in age. Upper Palaeozoic volcanic activity in the area ceased with the formation of the northwestern area of the Featherbed Volcanics.

The earliest clearly established plutonic activity after Siluro-Devonian time was marked by the intrusion of the Ixe Microgranodiorite, some areas of Elizabeth Creek Granite, and possibly the Nymbool Granite about 325 m.y. ago. Shortly after, at approximately 320 m.y., the bulk of the Elizabeth Creek Granite was emplaced. This was followed by further intrusion from 314 to 300 m.y., during which the majority of the more basic intrusives were emplaced. The Herbert River Granite, Almaden Granite, Petford Diorite, Bakerville Granodiorite, Gurrumba Gabbro, Hammonds Creek Granodiorite, and some phases of the Elizabeth Creek Granite were intruded at this time. The contemporaneous development of basic variants in the volcanic rocks is a persuasive argument for the cogenesis of volcanic and plutonic units.

The next intrusive event at about 290 m.y. is defined by the Mareeba and Watsonville Granites and some areas of Elizabeth Creek Granite on the southern edge of the Atherton 1:250 000 Sheet area. Finally, the tentative age of 266 m.y. for the Mareeba Granite at China Camp appears to correlate with that of the youngest phase of the Featherbed Volcanics. It is probably also the same age as the Finlayson and Trevethan Granites, which crop out on the coast between Mossman and Cooktown.

Thus, we find that volcanic and plutonic activity were essentially contemporaneous throughout the entire Late Palaeozoic history of the area. Indeed, this correlation will be even more marked should the earliest phase of the Featherbed volcanic activity be found to relate to the earliest Elizabeth Creek Granite in the vicinity, as seems probable . The overall duration of Late Palaeozoic magmatism was about 60 m.y.

TABLE 21. ISOTOPIC DATA FOR THE FORSAYTH GRANITE.

Sample No.		Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age (m.y.)	Reference
68590016		near "Forest Home"	159.18	593.3	0.71989	.7756		This work
68590016	BIOTITE	"	1284.1	17.530	6.6382	334.2		Black (1973)
68590019		16 km W of "Eveleigh"	80.47	832.9	0.70890	.2790		This work
68590019	BIOTITE	"	526.5	11.531	1.5314	142.45	414	Black (1973)
68590019	MUSCOVITE	"	515.6	168.45	0.84547	8.955	1085	"
68590020	BIOTITE	8 km E of Forsayth on the road to Einasleigh	850.8	7.077	4.71912	483.3	390	"
68590021		10 km along road to "Mt Turner" from Georgetown-Croydon road	311.6	109.14	0.89473	8.395		This work
68590021	BIOTITE	"	1426.7	8.551	7.4264	798.3	603	Black (1973)
68590021	MUSCOVITE	"	635.7	12.695	5.0527	206.0	1500	"
68590417		8 km E of Georgetown	72.12	953.2	0.70939	0.2185		This work
68590417	BIOTITE	"	775.7	14.238	1.7082	172.70	415	Black (1973)
68590103	BIOTITE	16 km NE of "Carpentaria Downs"	560.0	18.325	1.2436	92.86	412	"
G.A. 428	BIOTITE	11 km SW of Chillagoe	400.5	16.876	1.1689	71.61	434*	"
68590100		5 km N of Kidston on road to Einasleigh	98.30	1013.6	0.71322	.2802		This work
68590100	BIOTITE	"	382.4	54.43	0.8267	20.52	408	Black (1973)
G.A. 2954		11 km SW of Chillagoe	96.57	361.8	0.73270	0.7727		Black (1973)
G.A. 2954	PLAGIOCLASE	"	15.133	240.2	0.72910	0.1823		Black (1973)
G.A. 2954	K-FELDSPAR	"	281.8	392.3	0.74005	2.081		This work
G.A. 2954	BIOTITE	"	184.00	17.637	0.89002	30.66		Black (1973)
G.A. 2954	MUSCOVITE	"	349.2	48.99	.84640	20.86		"

* Using an assumed initial ratio of 0.729 as derived from the analysis of G.A. 2954 Plagioclase.

The geochronological relations established for some granite types present certain problems in formal nomenclature. For example, that part of the Elizabeth Creek Granite dated at 325 and 320 m.y. is older than many of the nearby rock units (e.g. the Herbert River Granite, Almaden Granite, and the diorite at Petford) which the youngest phases of the Elizabeth Creek Granite (approximately 290 m.y.) postdate. Samples of Elizabeth Creek Granite from the type area near Cumbana homestead have yet to be dated. However, the available evidence suggests they may correlate with the youngest grouping at about 290 m.y. If this should prove correct it may be necessary to rename the oldest phases of the Elizabeth Creek Granite, which have clearly different field relations. Alternatively, the total age spread of about 35 m.y. may present too fine an interval for practical subdivision.

AGE OF MINERALIZATION

The subject of economic mineralization in the Georgetown/Chillagoe/Herberton area has been discussed in previous publications, e.g. Best (1962), de Keyser & Wolff (1964), Blake (1972), and Black & Richards (1972a). More recently Sheraton & Black (1973) have discussed the matter in the light of geochemical studies and general isotopic results on the granitic rocks. Until now, however, there has been only one direct dating of an ore-bearing rock: Richards et al. (1966) determined a muscovite K-Ar age of 280 m.y. on a molybdenite-bearing vein within Elizabeth Creek Granite.

Five additional ages on ore-bearing material are presented in this section. These have all been determined by the Rb-Sr method on mica concentrates. The isotopic data are presented in Table 22. In each case the enrichment in Sr^{87}/Sr^{86} is such that the presented ages are virtually independent of initial ratio assumptions.

The results would appear to indicate that the formation of these gangue minerals, and presumably the tin and tungsten ore as well, began during the main pulse of Elizabeth Creek Granite emplacement (about 320 m.y. ago) and continued for at least the next 10 m.y. The data do not yet appear to be sufficient to indicate whether the indicated muscovite ages are indeed younger than those of the dark micas. Stratigraphical restrictions do not require a later time of formation for the tin and lead deposits in the Featherbed Volcanics around Bamford Hill. However, the near proximity of these deposits to granite dated at 297 $\pm$ 4 m.y. suggests a slightly later age. To the northeast, in the Hodgkinson Basin proper, the Mareeba Granite (with its associated tin, tungsten, and copper mineralization) has been dated at 288 m.y. This would seem to define a later mineralizing event which one could reasonably expect in the northeastern part of the Atherton 1:250 000 Sheet area. Indeed, the tin mineralization within the Nanyeta Volcanics (295 $\pm$ 10 m.y.) may be of this age. Alternatively, it could relate to the Bamford Hill deposits. This evidence for more than one mineralizing event may provide the explanation for the reversed zoning (see Blake, 1972) found in many of the mines in the Herberton/Mt Garnet district, as has been suggested by Black (1969). It would appear quite feasible for ore-channelways and depositional sites to be reactivated by successive mineralizations.

With the possible exception of Butlers Gully, the sampled mines are characterized by a greiseniferous gangue. In the Elizabeth Creek Granite section (see Table 2) two other greisen ages are tabled. Sample 67490121, from the Brownville area, yields an age of 326 m.y. That for sample G.A. 542 from Whitechalk homestead is 295 m.y. The overall indicated spread of 30 m.y. in greisen ages merits further isotopic and petrological investigation to determine whether or not economic mineralization was continuous throughout this period.

TABLE 22. ISOTOPIC DATA FOR MINERALIZED AREAS.

Mineral	Mine	Product	Location	Rb(ug/g)	Sr(ug/g)	Sr^{87}/Sr^{86}	Rb^{87}/Sr^{86}	Age(m.y.)
Biotite?	John Bull	W	1 km SW of Top Nettle Camp	3430	9.297	9.5426	1986.3	319
Lithium Mica?	Black Prince	Sn	19 km N of Mt Garnet	3067	5.666	22.136	4839	318
Lithium Mica?		W	Head of Butlers Gully, 3 km S of Coolgarra	3153	4.859	48.043	10551	322
Muscovite	Jimbilly	Sn	3 km SE of Glenlinedale	1788.9	9.440	3.8322	714.4	314
Muscovite	Treasure	W	1 km NE of Geebung Hill	1662.3	4.455	9.3712	1990.4	312

COMPARISON OF Rb-Sr WITH K-Ar RESULTS

An interesting anomaly is revealed by a comparison of the new Rb-Sr mineral data with the previous K-Ar results of Richards et al. (1966 - see Table 23). The average age difference of 8.5% between the two methods lies outside the value of 6% that one would expect from spike calibration and half-life considerations (see Black, 1969 pp. 133-4; Black & Richards, 1972a). It seems that the discrepancy is best explained by a preferential post-crystallization loss of Ar^{40} with respect to Sr^{87}. This effect probably results from continued thermal effects produced by the abundant igneous activity remaining in the critical temperature interval within which radiogenic strontium does not migrate whereas Ar^{40} is lost from the rock. If the discrepancy had been produced by an episodic rather than continuous process, one might expect the last-formed rocks in the area to demonstrate only the 6% age discrepancy. This is clearly not the case, as the average discrepancy for the Mareeba Granite samples at 8.5% is no different from the mean value for all samples.

TABLE 23. COMPARISON OF Rb-Sr WITH K-Ar RESULTS.

Sample No.	Rock type	Rb-Sr age (m.y.)	K-Ar age (m.y.)	% Difference
68590067 biotite	Elizabeth Creek Granite	288	260	10.8
68590107 biotite	"	293	270	8.5
G.A. 542 biotite	Griesen within Elizabeth Creek Granite	295	270	9.3
68590108 biotite	Elizabeth Creek Granite	294	270	8.9
68590068 biotite	"	322	300	7.3
68590071 biotite	"	328	295	11.2
G.A. 505 biotite	Herbert River Granite	296	280	5.7
68590074 biotite	"	328	295	11.2
68590078 biotite	"	309	290	6.6
G.A. 443 biotite	Almaden Granite	307	290	5.9
68590053 biotite	"	310	285	8.8
68590032 biotite	Mareeba Granite	285	260	9.6
" muscovite	"	284	265	7.2
68590083 biotite	"	288	260	10.8
" muscovite	"	287	270	6.3
		Average difference		8.5

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