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A Rb-Sr isochron from a single biotite crystal

MINERAL constituents of a single rock sample can be used to date its crystallization, or recrystallization, i.e. 'the internal isochron method'. These authors wondered if there could be enough variation in Rb and Sr in a single biotite crystal to enable Rb-Sr isochron calculations. Therefore a biotite megacryst from an undeformed granite pegmatite near Burås in the Proterozoic Bamble Sector, South Norway (e.g. Verschure, 1985), was investigated.

The Burås pegmatite is emplaced in a discordant metagabbro of supposedly Sveconorwegian (Grenvillian) age in Sveconorwegian upper amphibolite facies setting about 5 km outside the orthopyroxene-in isograde (Starmer, 1985*a*,*b*; Theulings, 1988; de Haas *et al.*, 1992; Nijland *et al.*, 1993). In the Bamble Sector similar pegmatites are widespread and probably cogenetic, e.g. the Gloserheia (Baadsgaard *et al.*, 1984) and the Auselmyra pegmatites (Neumann, 1960), respectively 1 km S and 14 km NE of the Burås occurrence.

The biotite megacryst measures 40 × 25 × 10 cm. Petrographical observation of the biotite showed no traces of chloritization or intercalations of Ca-bearing silicates (e.g. epidote, prehnite, pumpellyite, hydrogarnet). However, some thin quartz intercalations, tiny ilmenite flakes or symplectitic quartz-ilmenite intergrowths do occur.

A prism measuring 3 × 3 × 10 cm was sawn from the crystal and split into 7 slices, each approximately 1.4 cm thick. The slices 91 Bam $108A_1$ through $108A_7$ were powdered and subjected to standard techniques for the analysis of Rb and Sr and major elements (Verschure *et al.*, 1987). The analytical accuracy is considered to be within 0.5% for isotope dilution of Rb and Sr and 0.005% for $^{87}Sr/^{86}Sr$. The errors quoted for the isochron ages and intercepts are 2σ inclusive a correction for the MSWD. The ages are based upon the IUGS decay constant of ^{87}Rb ($\lambda^{87}Rb = 1.42 \times 10^{-10}a^{-1}$).

The variation in the analysed major elements of the biotite crystal is restricted (Table 1) and does not show any relationship with the vertical outlines. The variation in Rb and in Sr however, showing no relationship with the vertical outlines of the biotite crystal, was enough to warrant isotope analyses for a possible isochron calculation. The average K/Rb ratio of 105 excludes severe Rb depletion.

The results of the Rb–Sr determinations are given in Table 2 and presented in Fig. 1. Regression of the Rb-Sr data of all slices yields an errorchron (MSWD = 2.9) of 987 ± 62 Ma with initial $^{87}Sr/^{86}Sr$ = 1.00 ± 0.513. If slice A_1 is omitted, the data of the remaining slices define an isochron (MSWD = 1.1) of 976 ± 37 Ma with initial $^{87}Sr/^{86}Sr$ = 1.141 ± 0.312. These ages are

Table 1. Chemistry of the Buràs biotite megacryst.

Oxides [Wt %]	Average	Minimum	Maximum
SiO_2	34.50	33.93	35.11
TiO_2	3.96	3.85	4.03
Al_2O_3	14.06	13.75	14.22
FeO	27.81	27.50	28.28
MnO	0.29	0.28	0.30
MgO	5.57	5.39	5.69
CaO	0.03	0.01	0.05
BaO	0.11	0.11	0.13
Na_2O	0.19	0.17	0.21
K_2O	8.92	8.74	9.06
Total	95.44	93.73	97.08
Elements [ppm Wt]	**Average**	**Minimum**	**Maximum**
Rb	706.1	674.9	736.6
Sr	6.420	5.142	7.545
Ratio	**Average**	**Minimum**	**Maximum**
K/Rb	105	101	109

Table 2. Rb-Sr data of the Buràs biotite megacryst slices.

Sample numbers	Rb [ppmWt]	Sr [ppm Wt]	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$
91 Bam 108-A1	736.6	7.039	527.4	8.23073 ± 6
91 Bam 108-A2	705.2	6.980	508.1	8.19247 ± 6
91 Bam 108-A3	721.1	7.545	449.6	7.42668 ± 7
91 Bam 108-A4	688.0	6.349	632.4	10.08280 ± 8
91 Bam 108-A5	707.9	5.233	821.0	12.45338 ± 12
91 Bam 108-A6	709.1	6.651	556.8	8.86876 ± 9
91 Bam 108-A7	674.9	5.142	834.5	12.85007 ± 14

younger than that of approximately 1060 Ma given by Baadsgaard *et al.* (1984) for the emplacement age of the Gloserheia pegmatite and that of approximately 1090 Ma assigned to the Auselmyra pegmatite (Neumann, 1960). The age quoted by Baadsgaard *et al.* is based on: (i) the 11 points Rb-Sr isochron age of 1062 ± 11 Ma, ($Sr_{(i)} = 0.7023 \pm 0.0002$, MSWD = 90) Baadsgaard *et al.* gave for suites of essentially unaltered K-feldspars. (The error of ±11 Ma is an expanded error = 1 $\sigma \times \sqrt{\text{MSWD}}$); (ii) the Pb–Pb isochron age of 1085 ± 28 Ma (MSWD = 2.39) of the same K-feldspars with the least radiogenic leads; and (iii) the U–Pb concordia intersection age of 1060 +8/−6 Ma (MSWD 35) for xenotime and euxenite.

Baadsgaard *et al.* (op. cit.) also investigated suites of biotite, muscovite and plagioclase from the Gloserheia Pegmatite. According to Baadsgaard *et al.* these minerals yield strontium variation plots with different approximate dates and data points scattered outside the limits of analytical variation about straight lines. To Baadsgaard *et al.* these results were not unexpected since petrographic examination showed that almost all plagioclases were strongly sericitized and the biotites bent and sometimes chloritized. The muscovites of the Gloserheia Pegmatite however, were apparently unaltered. Therefore, Baadsgaard *et al.* (op. cit.) envisaged mild thermal post-emplacement hydration at 830–900 Ma of the Gloserheia Pegmatite.

The temperature–time path of the Bamble Sector (Nijland, 1993) discloses regional temperatures of the order of ~650 °C at 1060 m.y. ago (the time of emplacement of the Gloserheia pegmatite). This temperature was high enough to sustain formation of pegmatites. By 980 Ma ago the region had cooled according to Nijland's temperature–time curve to about 400 °C in the vicinity of the closure temperature of biotite (Verschure *et al.*, 1980). The apparent 'monocryst isochron' age therefore probably represents the closure of the Rb–Sr isotopic system of the biotite megacryst at about 400 °C and not later thermal

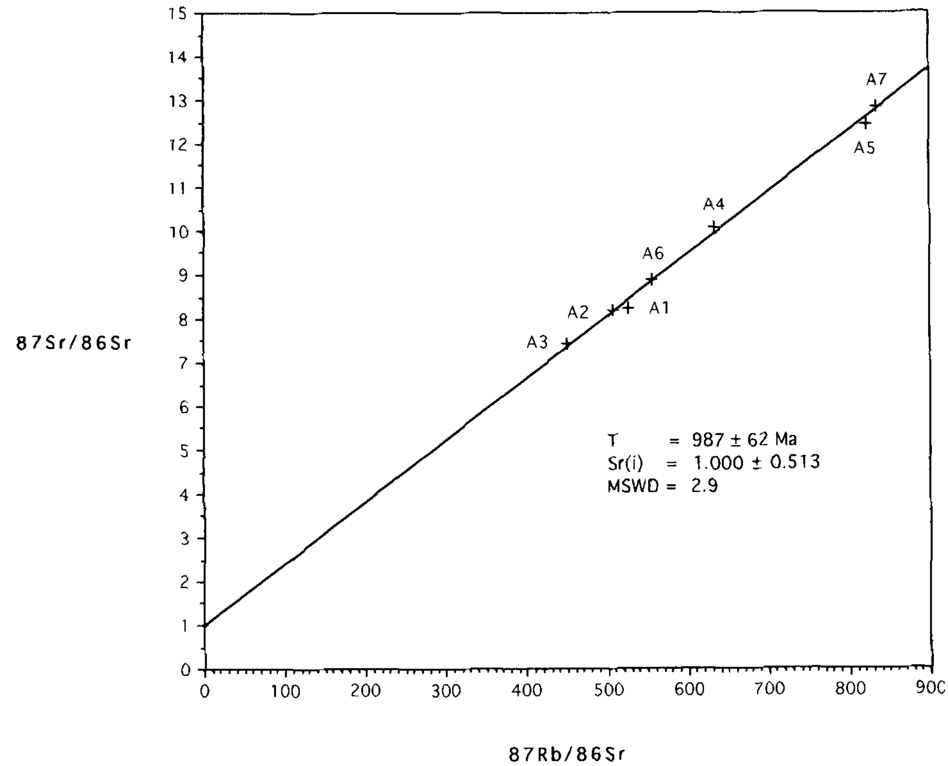

FIG. 1. Rb–Sr isochron plot of the Burås biotite monocryst.

hydration. The Rb–Sr isotope system of the biotite must have remained open during the period of about 1060–980 Ma ago. Speculation about the calculated very high $^{87}Sr/^{86}Sr$ initial ratio of the Burås biotite megacryst are not meaningful because of its immense uncertainty. The observed alteration of some minerals observed by Baadsgaard *et al.* (1984) is probably due to deuteric processes during late phases of the pegmatite crystallization. It is difficult to comprehend why the K-feldspar suite could remain isotopically closed for Rb–Sr during regional cooling—K-feldspar being notorious for its open system behaviour—whereas the biotite, muscovite and plagioclase suites were not. Our results indicate that large-sized crystals may be isotopically inhomogeneous enough to enable Rb–Sr isochron dating.

The use of other decay systems, e.g. Sm–Nd, which are less susceptible to possible isotopic open-system behaviour after initial crystallization, might give igneous emplacement ages.

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