ISOTOPIC EVIDENCE ON THE AGE OF THE TRYSIL PORPHYRIES AND GRANITES IN EASTERN HEDMARK, NORWAY

by

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Abstract.

Rocks from the (sub-Jotnian) acidic plutonic and volcanic basement complexes in the Trysil area, eastern Hedmark, yield a Rb—Sr isochron age of 1541 ± 69 million years. This agrees within the limits of error with the isochrom age of 1590 ± 65 million years determined for the Dala porphyries and granites in Dalarna, Sweden, which are the continuation of the acidic igneous complexes in the Trysil area. The sub-Jotnian acidic magmatism in the eastern Hedmark—Dalarna region can thus be dated at 1570 ± 40 million years ago, i.e. some 100 million years younger than the termination of the Svecofennian orogeny. (Ages computed with $\lambda = 1.47 \times 10^{-11}$ yr^{-1}; errors with 95 % confidence level). Chemically, this magmatism is characterized by a granitic to alkali granitic and alkali syenitic composition.

The Trysil area has also been affected by a tectonothermal event in Sveconorwegian time, about 925 million years ago, as evidenced by the Rb—Sr and K—Ar ages of separated biotites.

Introduction.

Studies on the geology of the Trysil area in eastern Hedmark have been published by Schiøtz (1903), Reusch (1914), Holmsen (1915), Holtedahl (1921), Dons (1960) and Holmsen et al. (1966). The Quaternary deposits were mapped by Holmsen (1958, 1960). A geological sketch map of the area is shown in Fig. 1 (mainly after the Geologisk Kart over Norge, 1960).

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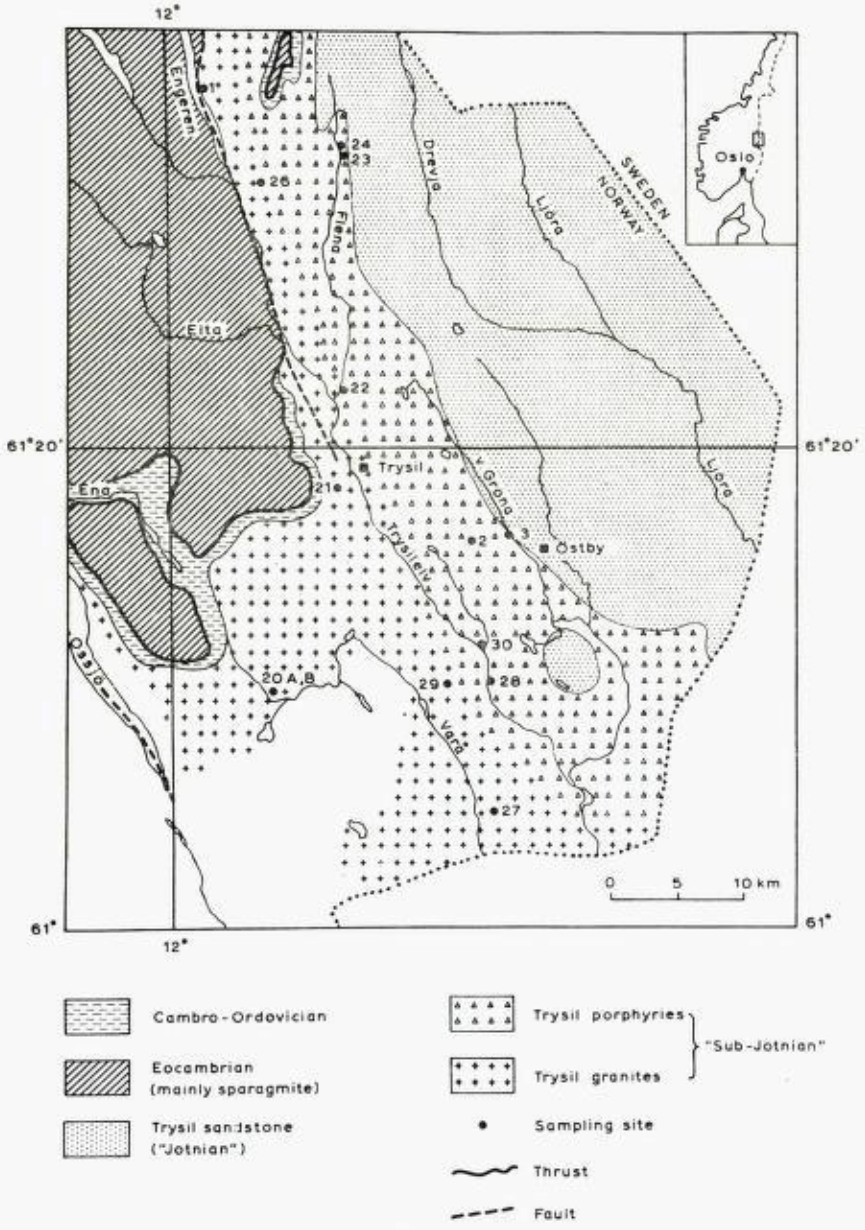

Fig. 1. Geological sketch map of the Trysil area, eastern Hedmark (mainly after the Geologisk Kart over Norge, 1960), showing the locations of the samples investigated. The numbers 1—30 correspond to the sample numbers 67 Hed 1 — 68 Hed 30 (see also Table 1).

The sub-Jotnian basement is made of acidic volcanic and plutonic rocks, i.e. the «Trysil porphyries» in the eastern part and the «Trysil granites» in the western part of the map area. All basement rocks have been tectonized, occasionally showing a gneissic appearance. The boundary between porphyries and granites is of tectonic origin (strike N-S, with steep dips); the porphyry series has moved downwards with regard to the granites (Holtedahl, 1921). Reusch (1914) already suggested a co-magmatic origin for the plutonic and volcanic complexes.

Towards the Swedish border, the porphyries are overlain by the Jotnian Trysil sandstone (mostly eastward dipping, with increasing deformation to the West). In the western part of the map area thick series of «Eocambrian» rocks (mainly sparagmites) and Cambro-Ordovician deposits occur.

The Trysil granites, porphyries and sandstone continue into Dalarna, Sweden, where they are designated as Dala granites, porphyries and sandstone, respectively. According to Hjelmqvist (1966), the Dala granites range in composition from true granitic and granodioritic rocks to quartz syenites, while the Dala porphyries mostly have an ignimbritic character. For these plutonic and volcanic rocks likewise a co-magmatic origin was postulated (Rutten, 1966).

The present study reports the results of a Rb–Sr isochron study of 14 whole-rock samples from the Trysil area (seven granites and syenites, one aplitic vein and six porphyries). Also, biotites separated from two granites were dated according to the Rb–Sr and K–Ar methods. The sampling sites are shown in Fig. 1 and listed in Table 1.

Plutonic and volcanic rocks investigated.

The plutonic rocks are coarse-grained, usually with reddish or greenish colours. Occasionally, aplitic veins can be observed. The volcanic rocks are fine-grained and mostly porphyric, usually in greyish, greenish or reddish colours. Major element compositions of the samples investigated have been analyzed by X-ray fluorescence spectrometry, using G-2 as external reference standard (Table 2). The chemistry points to a magmatism of granitic to alkali granitic and alkali syenitic composition.

With the exception of 68 Hed 29, all rocks contain quartz, microcline-perthite and albite as main components. These minerals also make up the phenocrysts in the porphyric volcanics. The granite 68 Hed 29 bears oligoclase (An_{18}) instead of albite. The plagioclase feldspars are

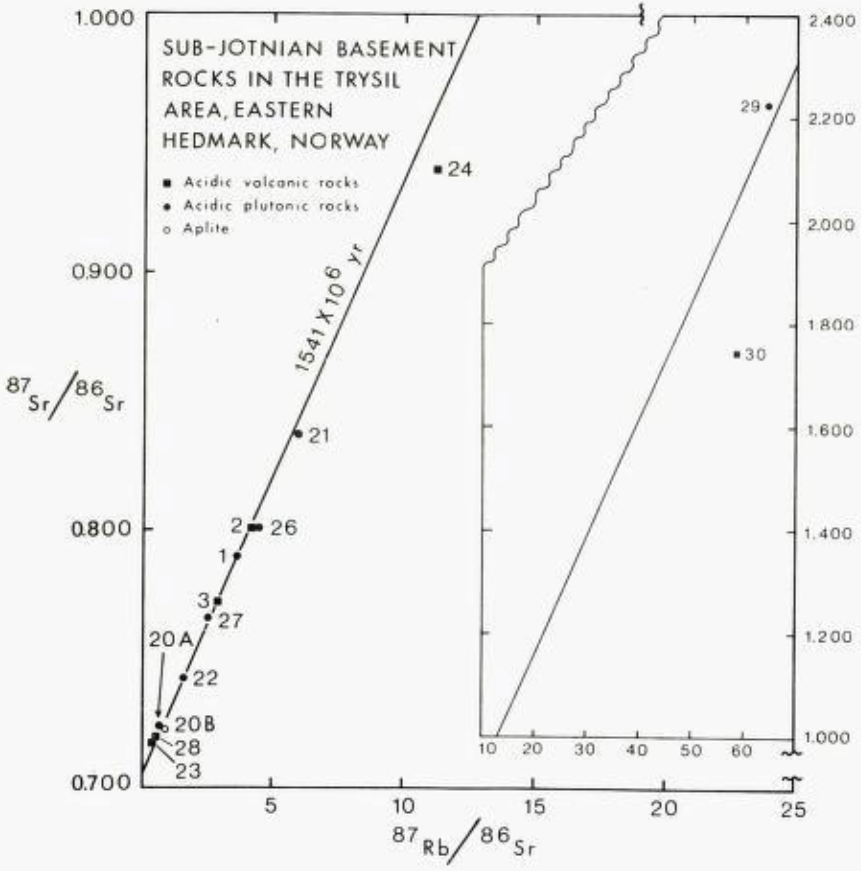

Fig. 2. $^{87}Sr/^{86}Sr$ *versus* $^{87}Rb/^{86}Sr$ *plot of the whole-rock samples from the Trysil area. The numbers 1—30 correspond to the sample numbers 67 Hed 1 — 68 Hed 30. Data points 24 and 30 were omitted from the isochron calculation.*

often filled with sericite and epidote. Biotite (partly chloritized) and colourless mica occur in varying amounts in all samples. Ferrohastingsite and actinolitic hornblende are major constituents in the granite 68 Hed 21 and the trachyandesite 68 Hed 23, respectively. Stilpnomelane is present in varying amounts in the samples 68 Hed 21, 22, 26 and 29; the occurrence of this mineral seems to be restricted to zones of shearing and mylonitization. Wide-spread accessories are titanite, zircon, apatite, fluorite, orthite, calcite, hematite and opaque ore. Especially in the plutonic rocks titanite often occurs in conspicuous crystals, easily re-

cognizable in hand specimen, while the zircon likewise forms fairly large crystals (up to 0.15 mm in length).

Effects of shearing and mylonitization are shown by four samples, three (68 Hed 22, 26 and 29) from the boundary zone between the plutonic and volcanic complexes, and sample 68 Hed 21 probably from a NNW–SSE trending fault zone. Stilpnomelane has exclusively been found in these rocks.

Experimental procedures.

Splits of crushed and pulverized whole-rock samples were analyzed for their Rb and Sr contents by X-ray fluorescence spectrometry; five rocks have also been measured by stable isotope dilution. Separated biotites were analyzed by stable isotope dilution only. The isotope dilution measurements were made with spikes enriched in ^{87}Rb and ^{84}Sr, respectively. For the isotope measurements a 20 cm, 60° mass-spectrometer with digital output was used, utilizing thermal ionization and multiplier detection. A single Ta filament source was employed for all measurements. Except for the biotites, $^{87}Sr/^{86}Sr$ ratios were measured directly on unspiked strontium; whenever isotope dilution analyses were made, the $^{87}Sr/^{86}Sr$ ratio was also calculated from the isotope dilution run. Correction for effects of isotope fractionation and mass discrimination was made by normalizing to $^{88}Sr/^{86}Sr = 8.3752$.

The X-ray fluorescence data were obtained on a semi-automatic X-ray spectrometer equipped with a 2 kW Mo X-ray tube and a (200) LiF crystal for the analysis of Rb, Sr, Fe, Ti, Ca and K, a 2 kW Cr X-ray tube and a PE crystal for the analysis of Si and Al, or a 2 kW Cr X-ray tube and a KAP crystal for the analysis of Mg and Na. Mass-absorption corrections for Rb and Sr (both for external standard and sample) were made by measurement of the intensity of the Compton scattering of the Mo $K\alpha$ primary beam. Matrix corrections for the major element analyses were calculated from tables of mass-absorption coefficients (Dewey et al., 1969). Assuming, initially, that there are no differences in mass-absorption between standard (G-2) and sample, an approximate composition of the sample is calculated by direct reference to the standard. From this approximate composition the total mass-absorption coefficient of the sample is determined for each operational wavelength. The original chemical composition is then corrected by the ratio of the calculated total mass-absorption coefficients of sample and standard, respectively. In turn, this corrected chemical composition is used to

provide a yet more accurate value for the total mass-absorption coefficient at each wavelength. The process is repeated until a self-consistent analysis results.

Rb–Sr isochrons were computed as the best-fitted straight lines through the $^{87}Sr/^{86}Sr - {}^{87}Rb/^{86}Sr$ data points, following the computation method of York (1966, 1967) and Williamson (1968). To each pair of coordinates the relative weight was assigned based upon estimated relative standard errors of 0.6 % and 2.0 % for the measured $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios, respectively. The errors for the isochron ages and the initial $^{87}Sr/^{86}Sr$ ratios are quoted with 95% confidence limits as calculated from the analytical data.

Potassium determinations were made by flame-photometry with a lithium internal standard and a CsAl buffer. Argon was extracted in a bakeable glass vacuum apparatus and determined by standard isotope dilution techniques (using ^{38}Ar as tracer) in a Reynolds-type glass mass-spectrometer; the measurements were made by the static method.

Constants used.

All calculations were made using the following constants:

$$^{87}Rb: \lambda\beta = 1.47 \times 10^{-11} \text{ yr}^{-1};$$
$$^{40}K: \lambda e = 5.85 \times 10^{-11} \text{ yr}^{-1},$$
$$\lambda\beta = 4.72 \times 10^{-10} \text{ yr}^{-1}, \text{ and}$$
$$\text{abundance } ^{40}K = 0.0118 \text{ atom \% total K.}$$

Rb–Sr ages of the Dala porphyries and granites published by Welin et al. (1966) and Welin & Lundqvist (1970) are based upon a ^{87}Rb decay constant of 1.39×10^{-11} yr^{-1}. These ages have to be multiplied by 0.946 in order to make them comparable with the Rb–Sr ages of the present study.

Results and discussion.

The whole-rock Rb–Sr data are listed in Table 3, whilst Fig. 2 shows an isochron plot of the data points. In Table 4, the Rb–Sr and K–Ar data of the separated biotites are given.

The K–Ar ages of both biotites and the Rb–Sr age of biotite 68 Hed 27 are concordant at about 925 million years. Evidently, this date reflects the imprint of a tectonothermal event, causing resetting of the K–Ar and Rb–Sr clocks. This 925 million years old event can be placed

within the Sveconorwegian (Dalslandian) orogenic period, the youngest Precambrian period of igneous and metamorphic activities wide-spread in southern and south-western Scandinavia (e.g., Broch, 1964; Welin, 1966). Biotite 68 Hed 29 has a somewhat lower Rb–Sr age; possibly, this phenomenon may be connected with its high degree of chloritization. (The concentrate still contains much chlorite, which is also reflected in its low potassium content).

When plotted in a diagram of $^{87}Sr/^{86}Sr$ versus $^{87}Rb/^{86}Sr$ (Fig. 2), it is evident that not all rocks follow the simple Rb–Sr systematics of a closed system. Twelve samples, i.e. all plutonic and volcanic rocks with lower Rb/Sr ratios and one granite sample (68 Hed 29) of higher Rb/Sr ratio, show an approximately linear arrangement. This confirms the allegedly co-magmatic origin of both rock types, as any time interval between eruption of the porphyries and intrusion of the granites and syenites must have been relatively short. However, two rhyolites of high Rb/Sr ratio (68 Hed 30 and, to a minor extent, 68 Hed 24) depart significantly to the right of the overall linear array of the other twelve samples.

All rocks in the area have experienced a tectonothermal event in Sveconorwegian time. Rocks of high Rb/Sr ratio (thus also of relatively high $^{87}Sr/^{86}Sr$ before metamorphism) are the most likely to have lost ^{87}Sr or exchanged strontium with less radiogenic strontium in surrounding rocks during the metamorphism. The two rocks falling significantly below the best-fitted straight line through the other twelve samples are both rhyolites of high Rb/Sr ratio. It is obvious that rocks belonging to a sequence of volcanic extrusions and eruptions, with many abrupt Rb/Sr discontinuities over relatively short distances, are the most vulnerable for modifications of strontium isotopic relationships between successive layers under conditions of metamorphism. An alternative explanation, that the lowering of the apparent Rb–Sr ages of the rhyolites 68 Hed 24 and 30 was entirely or mainly due to gain of rubidium, does not seem probable. For 68 Hed 30, such a process would have implied a doubling of the rubidium content in the rock system at the time of metamorphism, which is hardly feasible without assuming extensive metasomatism involving enrichment in potassium; no evidence whatsoever is available for such a process. Moreover, the two rhyolites of high Rb/Sr ratio are characteristically low in strontium and calcium, not high in rubidium and potassium.

If we omit the rhyolites 68 Hed 24 and 30, then the isochron age

computed for the twelve samples of plutonic and volcanic rocks is 1541 ± 63 million years with an intitial $^{87}Sr/^{86}Sr$ ratio of 0.7051 ± 0.0039. It may be noted that granite sample 68 Hed 29, being a much higher point than the other eleven data-points, has a disproportionally strong influence on the slope of this isochron. If this sample is omitted from the computations, then the slope of the isochron would correspond to an age of 1428 ± 124 million years and the intercept to an initial $^{87}Sr/^{86}Sr$ ratio of 0.7089 ± 0.0052.

As all rocks could have behaved to some degree as open systems with regard to strontium during the metamorphism 925 million years ago, the isochron age of 1541 ± 63 million years might be a minimum estimate of the true age. In our opinion, however, this age should approximate the true age of the magmatism. This view is supported by the Rb–Sr measurements on the Dala porphyries and granites in Sweden, which form the continuation of the Trysil porphyries and granites. Measurements on these rocks have been made by Welin et al. (1966), Priem et al. (1968) and Welin & Lundqvist (1970); in total, eleven rocks (ten porphyries and one granite) from that area have been analysed. It was shown by Welin & Lundqvist that nine porphyry samples and the granite define a fairly good isochron. The slope of the isochron is computed by the present authors as corresponding to an age of 1590 ± 65 million years with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7042 ± 0.0062. Of the eleven samples measured from the Dala porphyries and granite, there is also one rhyolite sample, likewise of high Rb/Sr ratio, that falls significantly below the 1590 million years isochron (see the discussion by Welin & Lundqvist).

Within the limits of error, the isochron ages of the sub-Jotnian plutonic and volcanic complexes in the Trysil area (excluding samples 68 Hed 24 and 30) and Dalarna (excluding one rhyolite sample) are identical. If we take all samples from the Trysil area and Dalarna together, excluding the three data-points which do not conform to the linear array, then the slope of the computed isochron corresponds to an age of 1569 ± 42 million years and the intercept to an initial $^{87}Sr/^{86}Sr$ ratio of 0.7047 ± 0.0030.

Conclusions.

Rb–Sr isochron data of the sub-Jotnian plutonic and volcanic rocks in the Trysil area, eastern Hedmark, and in the adjoining Swedish province of Dalarna indicate an event of acidic magmatism 1570 ± 40

million years ago. However, contrary to Dalarna where intrusive and extrusive rocks are often closely associated, the plutonic and volcanic complexes in the Trysil area seem to be spatially separated; the volcanic rocks make up the eastern block which has been down-faulted with regard to the western block of plutonic rocks. It is obvious that the sub-Jotnian acidic basement complexes in the eastern Hedmark—Dalarna region represent magmas that were partly intruded at a high crustal level, and partly extruded at the Precambrian surface of the Earth.

This magmatism took place some 100 million years after the termination of the Svecofennian orogeny. The magmas range in composition from granitic to alkali granitic and alkali syenitic, in accordance with the alkaline affinities characteristic for most of the post-Svecofennian acidic magmatism in the Baltic Shield. It also reflects the anorogenic nature of the magmatic event, as syenitic and per-alkaline granitic magmatism are generally restricted to stable continental areas, characterized tectonically by simple fracturing.

The biotite Rb—Sr and K—Ar ages of around 925 million years reflect the imprint of a tectonothermal event in Sveconorwegian (Dalslandian) time. This younger event is probably also responsible for the migration of radiogenic strontium from some volcanic rocks.

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Table I

Investigated plutonic and volcanic rocks from the Trysil area (see Fig. 1).

Sample Nr.	Rock type	Sampling site
67 Hed 1	Albite granite	Storeneset, E side Engeren Lake.
67 Hed 2	Porphyric rhyolite	On road Nr. 25, 6 km E from Nybergsund.
67 Hed 3	Porphyric rhyolite	Grønli on road Nr. 25.
68 Hed 20-A	Quartz-rich alkali syenite	On road Nr. 25, 14.5 km SW from Nybergsund.
68 Hed 20-B	Aplitic vein	idem.
68 Hed 21	Slightly mylonitized, stilpnomelane-bearing ferrohastingsite granite	On road from Trysil to Gjevaldshaugen, 2.1 km SW from bridge at Trysil.
68 Hed 22	Mylonitized, stilpnomelane-bearing, quartz-rich alkali syenite	Flendalen, on road 7.8 km N from Trysil bridge.
68 Hed 23	Hornblende trachyte	Rundhöa, about 24 km N from Trysil.
68 Hed 24	Porphyric rhyolite	Rundhöa, about 1 km NNW from 68 Hed 23.
68 Hed 26	Slightly mylonitized, stilpnomelane-bearing biotite granite	Gammelsæterberget, about 24 km NNW from Trysil.
68 Hed 27	Biotite granite	On road Nr. 208, 20.5 km E from Midtskogberget.
68 Hed 28	Porphyric quartz-rich trachyte	Sagnfossen in Trysilelva.
68 Hed 29	Gneissose stilpnomelane-biotite granite	Vestsjöberget.
68 Hed 30	Rhyolite	Kolos, on road Nr. 26.

Table 2

Major element compositions of the investigated plutonic and volcanic rocks from the Trysil area (Wt. %).

Sample Nr.	G-2	Hed 1	Hed 2	Hed 3	Hed 20-A	Hed 20-B	Hed 21	Hed 22	Hed 23	Hed 24	Hed 26	Hed 27	Hed 28	Hed 29	Hed 30
SiO_2	69.19	71.15	69.86	73.37	63.50	73.58	71.57	64.01	62.01	74.17	72.67	70.92	67.19	75.66	75.88
TiO_2	0.53	0.46	0.33	0.27	0.58	0.16	0.40	0.62	0.82	0.24	0.27	0.46	0.36	0.11	0.22
Al_2O_3	15.35	13.65	14.73	13.57	17.30	13.71	13.61	16.89	16.53	12.80	13.63	13.82	16.14	12.44	11.33
Fe_2O_3*	2.77	2.83	3.03	2.20	3.52	1.39	2.79	4.05	5.83	1.89	2.01	2.80	3.34	1.41	3.21
MgO	0.78	0.43	0.54	0.51	0.79	0.25	0.24	0.79	1.61	0.10	0.28	0.42	0.89	0.05	0.08
CaO	1.99	1.28	1.36	1.30	2.80	1.25	0.81	2.09	3.61	0.72	1.09	1.12	2.83	0.48	0.11
Na_2O	4.16	3.73	4.02	2.75	4.56	4.03	4.09	4.09	4.51	3.11	3.87	4.16	4.87	4.61	3.68
K_2O	4.51	5.74	5.40	5.31	6.23	4.90	5.74	6.73	4.35	6.27	5.46	5.58	3.67	4.52	4.78

* Total Fe as Fe_2O_3.

Table 3

Rb-Sr whole-rock data of the investigated plutonic and volcanic rocks from the Trysil area.

Sample Nr.	Rb ppm Wt.	Sr ppm Wt.	$^{87}Sr/^{86}Sr$	$^{87}Rb/^{86}Sr$
67 Hed 1	209 **	166 **	0.7902°°	3.70
	209 *	163 *	0.7881°	
67 Hed 2	285 **	196 **	0.8013°°	4.30
	286 *	192 *	0.8000°	
67 Hed 3	199 **	196 **	0.7718°°	2.99
	201 *	194 *	0.7701°	
68 Hed 20-A	131 *	545 *	0.7235°	0.70
			0.7260°	
68 Hed 20-B	99.1*	355 *	0.7231°	0.81
			0.7262°	
			0.7227°	
68 Hed 21	139 *	67.7*	0.8380°	6.02
			0.8360°	
			0.8372°	
68 Hed 22	181 *	329 *	0.7425°	1.60
			0.7424°	
			0.7427°	
68 Hed 23	98.3*	615 *	0.7175°	0.46
			0.7192°	
68 Hed 24	236 *	61.8*	0.9399°	11.31
			0.9402°	
			0.9420°	
68 Hed 26	221 *	144 *	0.8095°	4.48
			0.8116°	
			0.8109°	
68 Hed 27	136 *	154 *	0.7701°	2.57
			0.7654°	
			0.7641°	
			0.7652°	
68 Hed 28	127 *	737 *	0.7198°	0.50
			0.7200°	
68 Hed 29	314 **	16.1**	2.222 °°	64.5
		16.2**	2.226 °°	
	313 *	16.2*	2.224 °	
68 Hed 30	247 **	13.5**	1.748 °°	58.5
	244 *	13.3*	1.748 °	

** Isotope dilution analysis.
* X-ray fluorescence spectrometry.
°° Calculated from isotope dilution run.
° Direct measurement on unspiked sample.

Table 4

*Rb-Sr and K-Ar data of separated biotites from the granites 68 Hed 27 and 29**

Rb-Sr data

	Rb ppm Wt.	Sr ppm Wt.	$^{87}Sr/^{86}Sr$**	Radiogenic ^{87}Sr*** ppm Wt.	Age**** million years
68 Hed 27	893	23.1	2.560	3.50	928
	906	22.7	2.576	3.47	
68 Hed 29	1962	17.1	8.896	6.95	842
	1996	16.5	9.529	7.02	

K-Ar data

	K % Wt.	Radiogenic ^{40}Ar ppm Wt.	Atmospheric ^{40}Ar (% total ^{40}Ar)	Age**** million years
68 Hed 27	6.88	0.594	11.4	942
	6.88	0.594	10.0	
68 Hed 29	3.98	0.326	4.0	908
	4.01			

* 68 Hed 27: Green biotite, $n_y = 1.633$. The concentrate contains very little chlorite.
68 Hed 29: Dark, greenish brown lepidomelane, $n_y = 1.672$. The concentrate contains many impurities, mainly chlorite and some stilpnomelane.

** Calculated from isotope dilution runs.

*** The initial $^{87}Sr/^{86}Sr$ ratios were calculated as 0.730 and 1.425, respectively, using a graphical analysis according to Compston, Jeffery & Riley (1960).

**** Maximum analytical error estimated at ± 4 %.

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